EASA
European Union Aviation Safety Agency

RESEARCH REPORT

Underwater Escape from Helicopters

An Agency of the European Union

REPORT NUMBER: Final report
REPORT CLASSIFICATION: UNCLASSIFIED
DATE: 11 November 2020
KNOWLEDGE AREA(S):
DESCRIPTOR(S): Helicopter; evacuation; escape; underwater; survival; ditching; water-impact; exit; drowning; cold water; training.
CUSTOMER: UK CAA
CONTRACT NUMBER: EASA.2019.LVP.102
OWNER: European Union Aviation Safety Agency
DISTRIBUTION: Public
CLASSIFICATION OF TITLE: **UNCLASSIFIED**

Author(s):
Dr Susan Coleshaw
Mr Dave Howson

RESEARCH REPORT

Underwater Escape from Helicopters

CAA International Limited

CAA International is the technical cooperation arm of the [UK Civil Aviation Authority (UK CAA)](). As part of the CAA's [International Group](), we are committed to supporting ICAO and EASA on international cooperation initiatives to help shape tomorrow's international aviation legislation, improving regulatory capacity and efficiency, and sustaining society's confidence in aviation.

Our primary focus is providing advisory, training, examination and licensing services to agencies, fellow National Aviation Authorities (NAAs) and industry. From 192 ICAO contracting States, we have provided our expertise in more than 140 countries.

As a registered Social Enterprise, a sustainable part of any profit we make is reinvested in the global aviation community through the International Group, with whom we share a simple vision: To raise the standards of aviation across the globe, to protect those who choose to fly and those who do not.

We foster strong and lasting relationships with aviation organisations internationally to lay the foundations for long-term collaboration on safety, security and environmental performance, and the progression of aviation strategies.

Aviation House | Gatwick Airport South | West Sussex | RH6 0YR Crawley | United Kingdom |
+44 (0) 330 0224401 | international@caa.co.uk | www.caainternational.com

CONTENTS

Table Of Figures

SUMMARY

Problem area

The evidence available from potentially survivable helicopter water impact accidents indicates that drowning is the primary cause of death in those who do not survive. Capsize is virtually inevitable in helicopter water impacts, requiring those who survive the impact to perform an underwater escape. Capsize can also occur following a controlled ditching due, for example, to wave action.

Fatalities can be divided into those who fail to escape from the inverted cabin and those who do escape but then drown while awaiting rescue and recovery. The main focus of this research is underwater escape where many factors may contribute to the failure to survive but, overall, the issue is a mismatch between breath hold time and escape time. In cold water, the inability to breath-hold for sufficient time to complete an underwater escape is well documented. Issues that increase escape time may include seat harness release, the difficulties of locating and opening exits underwater and the size of the exit. While changes in helicopter design and improvements to personal safety equipment over the years have reduced the level of risk associated with underwater escape, some issues remain to be adequately addressed.

Description of work

The literature review reported in this document forms the initial phase of the work commissioned to improve the understanding of the survivability issues associated with helicopter underwater escape. The review consisted of a search for scientific papers, technical reports from the industry, accident investigation reports and other documents relating to helicopter underwater escape. Research undertaken to evaluate the underwater escape process has been broken down to allow an assessment of the different factors that may impede escape up to the point of reaching a place of relative safety (normally by boarding a life raft). Human morphology and both physiological and psychological responses have been considered as they will also have a major impact on the likelihood of survival. Helicopter underwater escape training research has been included, providing useful data relating to the underwater escape process.

Results and application

The literature review aims to provide a comprehensive overview of the problems experienced in performing an underwater escape and the research undertaken to both understand the issues and identify areas where safety improvements can be made. The results of the review are then analysed, with the aim of identifying any gaps in the understanding of the problems faced by survivors. Finally, recommendations for future research are outlined.

ABBREVIATIONS

ACRONYM	DESCRIPTION
AAIB	Air Accident Investigation Branch (UK)
AIB	Accident Investigation Board/Bureau
AMC	Acceptable means of compliance
BFU	German Federal Bureau of Aircraft Accident Investigation
CAA	Civil Aviation Authority (UK)
CAP	Civil aviation publication
CAT	Commercial air transport
DSB	Dutch Safety Board
EASA	European Union Aviation Safety Agency
EBS	Emergency breathing system
ECG	Electrocardiogram
EFS	Emergency flotation system
FAA	Federal Aviation Administration
FSIR	Flight Safety Investigation Report
HEELS	Helicopter emergency egress lighting system
HUET	Helicopter underwater escape training
ICAO	International Civil Aviation Organization
IDE	Instruments, data and equipment
NOGEPA	Netherlands Oil and Gas Exploration and Production Association
NPA	Notice of proposed amendments
OHSI	Offshore Helicopter Safety Inquiry

ACRONYM	DESCRIPTION
PLB	Personal locator beacon
SAR	Search and rescue
SWET	Shallow water escape trainer
TSB	Transport Safety Board

GLOSSARY

Term	DESCRIPTION
Arrhythmia	A condition in which the heart beats with an irregular or abnormal rhythm.
Cold shock	Physiological responses of the body caused by sudden cooling of the skin, characterised by an increase in heart rate and blood pressure and an inability to control breathing.
Ditching	An emergency landing on water, deliberately executed in accordance with flight manual procedures, with the intent of abandoning the helicopter as soon as practicable.
Diving reflex	Physiological responses of the body to submersion which include a temporary cessation of breathing, a decrease in heart rate and constriction of peripheral blood vessels.
Drowning	The process of experiencing respiratory impairment due to submersion or immersion in liquid.
Emergency exit	An exit to be used in an emergency as described in CS 27/29.805 and 27/29.807[1].
Emergency flotation system	A system of floats and any associated parts that is designed and installed on a helicopter to provide buoyancy and flotation stability.
Escape	Leaving the helicopter by the quickest means possible, often using underwater emergency exits.
Evacuation	Leaving the helicopter via the emergency exits, in a controlled manner.
Hostile sea area	Open sea areas north of 45N and south of 45S designated by the authority of the State concerned[2].
Survivable water impact	A water impact with a reasonable expectancy of no incapacitating injuries to a significant proportion of persons inside the helicopter, and where the cabin and cockpit remain essentially intact.
Syncope (Fainting)	A temporary loss of consciousness usually related to insufficient blood flow to the brain. It most often occurs when blood pressure is too low (hypotension) and the heart doesn't pump enough oxygen to the brain.
Underwater	An emergency exit designed and installed to facilitate rapid occupant escape from a

[1] Certification Specifications and Acceptable Means of Compliance for Small/Large Rotorcraft (EASA, 2020b; 2020c)
[2] See EU (2012) for full definition of hostile

Term	DESCRIPTION
emergency exit	capsized and flooded helicopter (also commonly referred to as emergency exits and push-out windows in the literature).
Water impact	Unintentional contact with water or exceeding the ditching capability of the helicopter for water entry.

1. Introduction

1.1 Background

The research presented in this report addresses Safety recommendation 2016-016 from the UK Air Accident Investigation Branch (UK AAIB) report AAR 1/2016, relating to the accident to helicopter G-WNSB on approach to Sumburgh, UK, on 23 August 2013. Safety Recommendation 2016-016 states: "*It is recommended that the European Aviation Safety Agency instigates a research programme to provide realistic data to better support regulations relating to evacuation and survivability of occupants in commercial helicopters operating offshore. This programme should better quantify the characteristics of helicopter underwater evacuation and include conditions representative of actual offshore operations and passenger demographics*".

In the accident in question (AAIB, 2016) twelve passengers escaped from the helicopter and survived while four did not survive. When considering some of the problems experienced during underwater escape, the report confirms that one passenger died as a result of being unable to successfully escape from the cabin. Those passengers who escaped from the cabin used the escape windows as exits. A number of escape windows were displaced during the initial impact; others were removed by the passengers. The majority of passengers who removed windows to escape reported that "*this was not easy and was significantly harder than they experienced during training*". Few reported having time to take a breath before becoming submerged, and none of the survivors used their emergency breathing system (EBS). Problems due to darkness and poor visibility were also reported, with one passenger describing finding the exit window by feel alone. While some passengers used their nearest exit, others crossed the cabin to find an exit. The two crew members were both injured but survived. Both had problems locating the door emergency jettison handle and had to resort to using the normal handle to open the doors and escape.

After due consideration of the safety recommendation EASA responded "*EASA agrees that generation of safety data as suggested by this recommendation, and the related discussion text in the accident report, could provide valuable input to future rulemaking decisions related to underwater evacuation of rotorcraft. EASA will perform an initial review into the nature of the research that could be envisaged.*"

AAR 1/2016 (AAIB, 2016) states that underwater evacuation studies carried out over the last 25 years, for the most part, used simulated fuselages and seats and have been conducted in warm, still water conditions. This is quite correctly attributed to cost, safety and ethical reasons. They then go on to state that research trials have tended to centre on one aspect of the evacuation, rather than researching the whole evacuation process from start to finish under realistic conditions. The limitations already cited may prevent this from being achieved. A review of the literature is therefore needed to identify the work that has been undertaken to date relating to helicopter evacuation, underwater escape and survivability.

1.2 Overall Aims and Objectives

The overall aim of this research is to address the initial review referred to in EASA's response to the Safety Recommendation 2016-016. The objectives are:

- to provide an up-to-date review of information currently available on helicopter evacuation and underwater escape;
- to investigate why some occupants fail to escape while others succeed;
- to identify gaps in the knowledge;
- to determine what further research is needed to fill those gaps and improve the likelihood of successful escape in future accidents;
- to provide information that will help in future rule-making tasks undertaken by EASA.

1.3 Scope

Chapter 3 of this report presents the results of the literature review relating to helicopter evacuation and underwater escape. When reviewing helicopter accidents, emphasis has been placed on more recent accidents where current helicopter designs are involved and where the problems experienced are more relevant to current equipment, rules and training. Survivability issues not directly related to underwater escape (e.g. issues with life rafts) are also included for completeness. The review of helicopter underwater escape research is intended to be more comprehensive as the results tend to be more generic and research undertaken in the past is often still relevant today.

Chapter 4 describes the gaps in research that have been identified. An analysis has been undertaken of the shortfalls in the evidence for each key task and component involved in the process of underwater escape and survival, identifying areas where research is lacking, of poor quality or out-of-date.

Chapter 5 provides recommendations for future research. An outline of each project is provided as well as an estimation of the costs of high potential benefit projects.

2. Analysis of Information

2.1 Literature

An extensive literature review was undertaken to source as much information as possible relating to helicopter underwater escape, covering the experience of passengers and crew in accidents as well as research conducted into helicopter underwater escape. This includes procedures, equipment, evacuation and escape routes, training and survivability. The following data sources were used:

- Personal library of scientific/research papers, technical reports, accident investigation reports and fatal accident inquiry reports gathered over 30 years working in the area, including industry reports from before the year 2000 which are not available in electronic format.
- Accident reports, accessed from the website of organisations such as the Air Accident Investigation Branch (AAIB), AIB Norway, AIB Nigeria, Transport Safety Board (TSB) Canada, National TSB (US), Australian TSB and the Dutch Safety Board.
- Review of key documents generated by aviation safety regulators such as NPA 2016-01 (EASA, 2016a) and CAA CAP 1145 (CAA, 2014).
- Access to a range of ergonomics journals including 'Ergonomics' and 'Applied Ergonomics' and the Research Gateway through membership of the Chartered Institute of Ergonomics and Human Factors.
- Online search engines such as Google Scholar.
- Mendeley: a cloud-based data repository.
- ScienceDirect: access to Elsevier journal papers within the ergonomics field.
- PubMed: access to literature from MEDLINE, life science journals.

Keywords used in the search for reports, papers and articles included terms such as: helicopter, evacuation, escape, underwater, survivability, exit, cabin, cockpit, disorientation, ditching and impact. Authors known to work in this area were also targeted.

Information was collated and organised based on its content and the nature of the information provided. The main literature review was supported by a Bibliography (Annex A) which provides a brief summary of each accident report and research document referenced (regulations, specifications and equipment standards are not included in the Annex). The research papers and reports were rated on the basis of publication type; peer reviewed science journal papers were given the highest rating while conference papers and unpublished industry reports were given the lowest rating.

Where possible, research documents were sought that are freely accessible. However, some of the key research undertaken in the past has been commissioned by industry. In a number of cases, industry reports have been written which are unpublished and therefore not freely accessible via the internet. These were awarded a lower grading than peer reviewed published papers that are freely accessible.

2.2 Witness Evidence

Efforts were made to identify all sources of information including, where possible, access to individuals involved in the G-WNSB Sumburgh accident as well as discussion with the accident investigators.

A meeting was held with the Air Accident Investigation Branch (AAIB) with the aim of fully understanding their concerns arising from the investigation. Their report, AAR 1/2016, states that "*survivors from this accident repeatedly commented that their experience of escaping from the helicopter cabin was very different from that simulated in training*". The testimonial evidence from survivors could not be disclosed, but the problems experienced were discussed in general terms with the AAIB Senior Inspector of Air Accidents to gain further understanding of the reported findings. There was a desire to understand why some individuals survive while others do not, and how passenger demographics affect survival. The AAIB's concern about a lack of research undertaken in helicopter underwater escape was also discussed along with access to unpublished work and reports that have not been made available electronically. There was also concern that accident report recommendations were often not acted upon and lessons were not being learned. With regard to training, there was concern that this was not regulated by EASA, with a dependence upon the offshore industry to define minimum requirements. This feedback will be used when performing the analysis of the literature.

3. Literature Review

3.1 Review of Accident Reports

3.1.1 General

As this literature review focuses on helicopter underwater escape, the main emphasis of the accident review is on water impact accidents which almost always result in immediate capsize. One notable exception was the water impact accident to G-REDU (AAIB, 2011) which did not capsize, primarily due to the automatic deployment of the emergency flotation system (EFS) following impact with the water. This led to a recommendation to EASA to require a means of automatically inflating emergency flotation equipment following water entry.

Some of the high impact accidents were non-survivable, meaning that there is little or no knowledge to be gained with regard to escape. These have not been included in the review.

Ditching accidents have been included where lessons can be learned; there are a number of cases where the aircraft has capsized following successful evacuation of the occupants (AIB Norway, 1998; AIB Nigeria, 2016). Capsize is a less frequent occurrence following a ditching accident, occurring either due to lack of, damage to, or non-deployment of the emergency flotation system (EFS) or due to severe weather conditions (e.g. AAIB, 1990).

In the past, accident reports have concentrated upon the cause of accident, but in recent years, much more emphasis has also been placed on survivability aspects, providing strong pointers to the problems experienced by the occupants in escaping from the helicopter.

3.1.2 Failure to escape

When passengers or crew fail to escape from the aircraft they are often found in their seat, with the harness still secured (AAIB, 1993; TSB Canada, 2010; AAIB, 2016). In many cases, this is due either to loss of consciousness, other impact injuries, or drowning without evidence of significant impact injuries.

Five passengers failed to escape from G-TIGH in the 1992 accident near the Cormorant Alpha platform (AAIB, 1993). All five passengers who failed to escape from the cabin had managed to release their seat belts and "*appeared to be in the process of escaping*". One was still inside the cabin, lying across the rear bench seat next to a small sized escape window; the investigators considered that his stature was such that he could have passed through the aperture. One was found partially through an escape window, one was lying across an exit door and one was just outside the aircraft. The remaining non-survivor who did not escape from the cabin was found to be trapped by a headset cord around his neck.

In the 2013 G-WNSB accident (AAIB, 2016; 2020), a head injury was sustained by the one passenger who was found still secured by the seat harness. A second passenger had released their seat harness but did not escape from the cabin. This person was recovered from the water, outside of the helicopter, after the fuselage had broken open due to wave action and contact with the shore. The evidence suggested that the passenger had drowned while still in the helicopter.

In the 2009 C-GZCH water impact accident east of St. John's, Newfoundland and Labrador (TSB Canada, 2010), seven of the non-survivors had no significant injuries, while the injuries that were incurred were to the lower rather than upper limbs. The accident report states that the seat belt mechanisms were operational suggesting that, in this case, it was the debilitating effects of cold shock which resulted in drowning before the non-survivors were able to locate and release their seat belts.

3.1.3 Seating, harnesses and crash attenuation

In a 1990 North Sea accident to G-BDES (AAIB, 1991) which occurred before the introduction of energy absorbing seats, the force of impact with the sea, coupled with the collapse of passenger seats, was considered to have contributed to injury and incapacitation and may have been a direct cause of death of some of the occupants. The collapse of the seats would certainly have hampered escape. Lap belts were still being used at this time; it was reported that three of the passengers had some difficulty in releasing their lap strap buckle. The accident report recommended that seat requirements should be reviewed and newly manufactured aircraft should have an effective upper torso restraint installed.

The report of the C-GZCH accident in 2009 (TSB Canada, 2010) is one of the few to provide information about the energy absorbing seating used. This report stated that the helicopter "*impacted with the water with an estimated force in the magnitude of 20g to 25g. Much of the impact force was absorbed by the fuselage, the attenuating seats, and four-point harness system. The g-force experienced by each individual differed depending on the force applied to the fuselage in the area where they were seated. Except for the four passenger seats that bottomed out, the occupants were generally subjected to inertia load factors between at least 5.3g and 8.6g in the direction of the vertical seat axis. In addition, the helicopter struck the surface with a forward velocity of approximately 55 to 60 knots which would have introduced a horizontal force on the occupants of approximately 5g to 8g*". As stated above, most of the resultant injuries were to the lower limbs. The report states that all of the seat harness systems were examined after the accident and were found to be functional.

3.1.4 Exit route used

While most helicopter underwater escape training (HUET) courses require participants to escape from a seat next to their exit, passengers may not be sitting next to an emergency escape window in the real environment. These passengers may have to select an exit route after overcoming the stress of the impact and disorientation following inversion.

In the G-TIGH accident (AAIB, 1993) it was reported that none of the passengers recalled seeing the exit lighting. There was no evidence to suggest that it was not working, and the investigators thought that they may have escaped before the lights were activated.

In the 2009 water impact accident to G-REDU near the ETAP platform (AAIB, 2011), a number of issues were highlighted in relation to the evacuation and survivability of occupants. Not all passengers used the Type IV exits to evacuate directly into the life raft. Contrary to their training, five of the passengers used three of the escape windows to leave the cabin. The co-pilot evacuated via his exit and entered the water before boarding the life raft from the water. The commander's door jettison was obstructed by the forward EFS flotation unit. This was thought to be due to loss of the helicopter's tail which resulted in a nose-down floating attitude.

The G-WNSB accident (AAIB, 2016) demonstrated that the exit routes used are not always those that might be expected. While some passengers sitting next to a window escaped through that window, others did not. For example, Passenger 'F' was sitting next to exit R2, and was close to R1 (through which two other passengers escaped) but escaped through exit L2 after crossing the cabin. In all, four passengers were known to have undertaken what would be termed a cross-cabin escape when this was not the shortest route to an exit. Four emergency exit windows were opened by passengers; two passengers escaped through window R1, three passengers escaped through window R5, two passengers escaped through window R6 and three passengers escaped through window L2. Problems due to darkness and poor visibility were also reported, one passenger describing finding the exit window by feel.

3.1.5 Release of exits

There are a number of accidents from the last 30 years where the release of exits has prevented or made escape much more difficult. There are also cases where the impact resulted in dislodgement of the exits, potentially making escape easier for the occupants.

In the water impact accident to G-BEWL at the Brent Spar platform (AAIB, 1991), most of the cabin windows were either broken or dislodged cleanly by the distortion of the airframe or the force of the water. This clearly aided egress for those who were not incapacitated by the impact. In the case of the C-GZCH accident in Canada in 2009, both sides of the fuselage fractured horizontally along the passenger window frames and exits; all of the passenger escape windows had separated from the fuselage during the impact and none were recovered (TSB Canada, 2011).

A ditching accident to G-BDES in 1988 (AAIB, 1990) took place in rough seas, resulting in an immediate roll to the side followed by capsize. After capsize, neither pilot was able to locate the jettison handle for their emergency exit from an inverted position under water. One pilot proceeded aft to the cargo door which he was not able to open. On the point of drowning the pilot managed to escape by punching out a passenger window. The second pilot had slid open his side window through which he escaped after failing to find the jettison handle for his emergency exit.

The Canadian Air Force accident on the approach to HMCS Athabaskan, east of Aalborg, Denmark, in 2008 (FSIR, 2008a) again provided evidence of the difficulties that can be experienced when attempting to escape from an inverted helicopter, exacerbated by almost complete darkness in this case. Four of the five crew members had problems locating and operating the various exit release handles, with three using their EBS to give them enough time to make a successful escape. One of the occupants recalled that "*the HEELS lit up the doorframe well, but did not show the position of the emergency release handle*" for the upper personnel door.

The evacuation of G-REDU (AAIB, 2011) was hindered by the D-ring, used to jettison the right cabin door, being obscured by a passenger seat. The passenger briefing had shown how to jettison the doors and windows, but had not made it clear that the release mechanism was not readily accessible from the door area. As a result, the right cabin door was opened normally (i.e. it was slid forward), which resulted in two of the escape windows being obstructed.

In the October 2012 ditching of G-CHCN southwest of Shetland, UK (AAIB, 2014), after the crew had deployed the life rafts, one crew member entered the cabin and opened the left door rather than jettisoning it as he thought jettison of the door would damage the life raft. The commander went back to the cockpit and operated the jettison handle for the cockpit doors (in case of capsize), but did not appear to realise that the doors needed to be pushed to fully jettison them.

In the G-WNSB accident (AAIB, 2016), neither pilot could locate the emergency jettison handle for their respective door and were forced to use the normal door handle. In the passenger cabin a number of the underwater escape windows were displaced by the water impact, while others were removed by passengers. The majority of passengers who removed escape windows reported that this was not easy and was "*significantly harder than they experienced during training*".

3.1.6 Non-survivors recovered from the surface

There are a number of survivable accidents where occupants appear to have released their harness and escaped from the helicopter but have then failed to survive. In most cases evidence suggests that the cause of death was drowning, sometimes exacerbated by cold exposure. In some cases the lifejacket had been successfully inflated (AAIB, 2016) following escape. In others, the lifejacket had not been inflated (TSB Canada, 2015), was only partially inflated (AAIB, 1993; TSB Canada, 2015) or a lifejacket was not worn (BFU, 2014).

In the G-TIGH accident (AAIB, 1993), one of the survivors attempted to help another occupant into the life raft, but the attempt failed and the individual drifted away. Of the other non-survivors who reached the water surface, the report suggests that some were initially conscious, while there was at least one case of a passenger who had apparently died at an early stage, possibly drowning before reaching the surface. The co-pilot survived for a considerable time, helping others, but is then thought to have succumbed to hypothermia and subsequently drowned. Another was still alive when grab lines were thrown to him, but drowned before he could be rescued, presumed due to swamping by waves.

There are other cases where an occupant has successfully escaped from the helicopter but has then died prior to rescue. In the C-GZCH accident (TSB Canada, 2010), one passenger managed to escape from the helicopter but drowned either before or shortly after reaching the water surface. She was observed face-down in the water 17 minutes after the impact. In the 2013 G-WNSB accident (AAIB, 2016), one passenger was thought to have suffered heart failure after being helped onto the fuselage and then into a life raft. In this accident, another passenger was recovered from the sea; this individual had released their harness, escaped from the helicopter and inflated their life jacket. Death was therefore attributed to drowning despite a minor head injury.

3.1.7 Personal safety equipment problems

While the design of personal safety equipment has improved over the years, issues relating to design and performance are still regularly identified in accident reports.

The G-WNSB accident (AAIB, 2016; AAIB, 2020) is one of the few survivable water impact accidents involving capsize where passengers were carrying a hybrid rebreather EBS. All but one were still in the stowed position when checked after the accident. The stored air had been released into the EBS counterlung (due to automatic activation on contact with the water). The accident report suggests that the passenger survivors "*were unaware that the hybrid LAP Plus jacket had an automatically released air supply. They believed that the EBS would only be of assistance if they inflated it manually with an expelled breath*". It should be noted that the training provided to offshore workers at this time did cover the gas cylinder and release of gas on water entry, but this gas release was not experienced during practical training exercises. In the case of one non-survivor, damage to the air bladder was found, sufficient to result in loss of air or entry of water into the EBS, although it cannot be determined when this happened. The crew were not equipped with EBS.

Compressed air EBS were carried by the crew of the Canadian military SAR aircraft, in the accident over Chedabucto Bay in 2008 (FSIR, 2008b). One crew member had tried to use his EBS but could not locate it (it had become separated from his life preserver); a second had no recollection of using his EBS; another had not had any formal training in EBS operation and did not attempt to use it. The EBS assemblies carried for the two flight engineers, both non-survivors, were found with the cylinders empty. Of the EBS assemblies carried for the SAR technicians, one was found empty with the pressure gauge cracked and the other was not found.

Problems were experienced with the lifejackets used at the time of the 1992 G-TIGH accident in the North Sea (AAIB, 1993), with the buoyancy chambers riding up the body, while survivors also reported problems deploying the sprayhood. Of the non-survivors two were supported by their lifejackets, one was floating face-down with the lifejacket deflated due to damage, while the lifejacket had ridden up the bodies of the other two non-survivors to the point where their faces were underwater. The survivors reported that waves were breaking over their heads, with no protection provided by the sprayhoods due to a failure to deploy them. Only one of the immersion suits, worn by a non-survivor, was found to have leaked significantly, although the suit was partially unzipped when the body was recovered.

Immersion suit seals have improved over the years, reducing problems due to leakage, but there are still some reports where water has leaked into the suit (e.g. DSB, 2010). The DSB report suggests that despite the level of leakage being within requirements it had an adverse effect on the occupants' mental state. A much more serious leakage problem was identified in the Canadian Coast Guard C-GCFU accident in the M'Clure Strait in 2013 (TSB Canada, 2015). In this fatal accident, in water temperatures of -0.6 °C, all three occupants had escaped from the helicopter but drowned before recovery. The zip of the suit worn by the pilot was only done up to mid-sternum level and the suit was consequently full of water. He had donned a lifejacket before departure but was not wearing it when found. The pilot was thus thought to have drowned due to the combined effects of cold and a lack of buoyancy to keep the head above water. The suits of the two non-HUET-trained passengers were both full of water, and they had both failed to don the hood and gloves. The level of insulation in their suits was half that which would be expected for an approved helicopter suit. One had a partially inflated lifejacket and was floating on his side. The other was wearing an uninflated life jacket and was found floating face-down. Both passengers were also therefore assumed to have drowned due to the combined effects of cold and lack of support from their lifejackets. In the G-REDW ditching (AAIB, 2014), both crew members were wearing immersion suits with a split neck seal, which were worn with the zip partly undone to improve comfort. While the co-pilot was able to do up his zip to prepare for the ditching, the commander was not. If the helicopter had capsized before evacuation was complete his suit would have filled with water (the sea surface temperature was 8 °C; sea state was slight to moderate).

Following a ditching of G-CHCN in 2012 (AAIB, 2014), a number of problems with the personal safety equipment worn by occupants were identified. Passengers donned the neoprene gloves of their immersion suits in preparation for the ditching, resulting in loss of manual dexterity, which may have contributed to problems experienced in locating and removing the cover of the EBS. Neither pilot was wearing an immersion suit. The sea surface temperature was reported as being 11 °C, with a moderate sea state and swell of somewhere between 1 and 2 m. Fortunately, both pilots were able to enter the life rafts directly without entering the water. If they had been forced to enter the water they would have been at risk of experiencing cold shock and body cooling. A similar situation occurred in the G-WNSB accident (AAIB, 2016) when neither pilot was wearing an immersion suit due to high cockpit temperatures. None of the survivors "*mentioned feeling cold initially, or suffering cold shock when first submerged in the water*". One suit filled with water over time, with the wearer feeling cold as time passed. Four other passengers reported some water ingress. In the Canadian SAR accident in 2008 (FSIR, 2008b), neither the three pilots, who survived, nor the two flight engineers who did not survive, were wearing an immersion suit. The two SAR technicians were wearing flotation coveralls with positive buoyancy and life preservers, which had not been inflated; one survived and one died. Cause of death of the non-survivors was given as drowning. Sea water temperature was about 10°C. The two occupants of the ditching accident in the Baltic Sea in 2012 (BFU, 2014) were found some distance from the aircraft, with cause of death attributed to hypothermia in combination with drowning. In this case, sea water temperature was about 4°C. No protective clothing or lifejackets were worn by the two crew members.

Gloves are not normally donned pre-ditching as they may make it more difficult to carry out actions such as releasing the seat harness. However, dexterity may be lost very quickly in cold water. Following the G-JSAR ditching into the North Sea near Den Helder in 2006 (DSB, 2010) the passengers reported having difficulties in donning their gloves while in the water and in poor light. Breaking waves also made it difficult for the passengers to don the hood, with some receiving assistance from others. Most of the crew were either not wearing gloves or not carrying them. Peripheral cooling and loss of dexterity may explain why the co-pilot was unable to fire the emergency flares. The one survivor from the Canadian C-GZCH accident in 2009 reported that, on reaching the water surface, he was "*unable to don his gloves or raise his spray hood*" due to all feeling in his hands having been lost (TSB Canada, 2010). Similarly, in the Canadian Air Force accident in Denmark in 2008 (FSIR, 2008a) one crew member had difficulty releasing his EBS from its Velcro strap, the survivors struggled to use their strobe lights once on the water surface, and only one of the five crew members was able to operate his back-pack life raft. This was all attributed to loss of dexterity caused by the exposure to water at 2°C.

Once in the life raft, a loss of manual dexterity due to cold would mean that survivors would find it difficult to grasp and use the survival equipment provided within the raft. Survivors may need to carry out actions such as operating painter lines, deploying the sea anchor and firing flares. Although these actions are difficult to complete with cold hands, they will also be difficult to perform with gloved hands. In the G-REDU accident (AAIB, 2011), some passengers had problems retrieving seasickness tablets from sodden packaging resulting in Safety Recommendation 2011-070 that all emergency equipment should be capable of being easily accessed and utilised with gloved hands.

Following the C-GZCH accident in Canada (TSB Canada, 2010), no signals were detected from either the emergency locator transmitter or the personal locator beacons worn by the occupants of the helicopter.

3.1.8 Value of passenger briefings and training

A number of recent accidents have highlighted both benefits and concerns about training that have affected procedures followed by the crew and passengers.

In the ditching incident east of Aberdeen (G-REDW) in May 2012 (AAIB, 2014), the passengers were reported to have carried out pre-ditching drills recalled from their safety training, fitting their survival hoods, preparing their rebreather EBS and locating their nearest exits. Both crew and passengers appear to have correctly followed evacuation procedures according to their training. As an example, both life rafts were deployed by the crew. The passengers jettisoned the main cabin doors, presumably in response to the pre-flight briefing and training.

Following the ditching of G-CHCN in October 2012 (AAIB, 2014), it was reported that some passengers experienced difficulty in locating and opening the EBS mouthpiece cover. They had donned their gloves first and it was considered that this may have contributed to the difficulty in opening the cover. The AAIB also reported that they considered the donning of gloves would have made it difficult to operate the jettison mechanism on the cabin windows. It is not stated whether prior training or the pre-flight briefing provided any instruction about when to don the gloves. This demonstrates how a small detail such as when to deploy gloves can prevent equipment from being used effectively under emergency conditions.

Also during the evacuation of G-CHCN (AAIB, 2014) the co-pilot took the decision to open rather than jettison the cabin door due to concern that the liferaft would be damaged if the door was jettisoned. The action of opening the door blocked two escape windows, making them unavailable for escape had the aircraft capsized. Problems with liferaft deployment also meant that individuals had to use their initiative to make it work. This demonstrates how the dynamic situation of a real accident can differ from the set scenario taught during training.

Issues relating to passenger briefing were found during a non-standard flight operation when G-JSAR ditched near Den Helder in 2006 (DSB, 2010). In this case a search and rescue helicopter was being used to transfer passengers to shore. A series of problems were experienced during the evacuation of the helicopter. As this was not a standard flight, the passenger briefing was not as detailed as usual, with no video being provided. No warning was given to the passengers of the impending ditching and there was no 'brace for impact' command, removing the opportunity to prepare for the event. Not all of the passengers heard the briefing to follow instructions from the crew in the emergency. As a result, some started to evacuate the cabin before instructed with the rotors still turning. Due to the severe sea conditions, the crew believed that the helicopter was in imminent danger of capsizing, although it remained upright for a further 8 hours. It was fortunate that no one was injured during the evacuation.

One further training issue identified from the G-JSAR accident (DSB, 2010) related to the use of personal safety equipment. As reported previously, the passengers experienced problems donning their gloves and were unable to don their hoods. Donning of hood and gloves was reported to have not been covered during HUET training.

In an accident involving a Canadian military SAR aircraft (FSIR, 2008b) where compressed air EBS was carried by the crew, one crew member had not had any formal training in EBS use and did not attempt to use it. It was suggested that this might be due to the fact that EBS use was "*not an ingrained part of his egress skills*". In the case of the G-WNSB accident (AAIB, 2016), passengers were carrying EBS but only a few attempted to use it, without success. They later reported that they were unaware of the automatically released air supply inherent in the design, even though this had been covered in their EBS training, suggesting that the detail of the training had been forgotten.

In the Canadian Coastguard C-GCFU accident (TSB Canada, 2015), neither of the two passengers were thought to have undertaken HUET training and it was thought that this may have contributed to their non-survival. All of the passengers in the 2009 C-GZCH accident (TSB Canada, 2010) had received HUET training, but the Offshore Helicopter Safety Inquiry which followed (Wells, 2010) placed great emphasis on the level of training fidelity offered by the different training organisations involved.

These issues demonstrate the importance to helicopter crew and passengers of both helicopter safety and HUET training and pre-flight briefings.

3.2 Review of Helicopter Underwater Escape Research

3.2.1 Brace position

In those ditching and water impact accidents where there is advance warning of impact, passengers are trained to adopt a brace position to limit any injuries that might be sustained due to the high accelerations experienced and flailing of limbs. Since the widespread use of shoulder harnesses has been implemented, an upright brace position has been adopted for helicopter passengers, although the specific position recommended may vary.

Over 30 years ago Brooks (1989) noted that brace positions advocated for helicopter crew members and passengers had been transferred directly from those used for fixed wing aircraft, in his words "*with little consideration for the fact that the majority of impacts have strong vertical force components with a high chance of contact injuries*", and no account taken of the effects of in-rushing water and disorientation in the event of immediate inversion. He made recommendations for passengers using a lap strap only. For a pilot not flying the helicopter, using a four-point harness and a seat with headrest he recommended that the feet be placed 10-15 cm apart, knees together, arms folded across each other and hands grasping the clothing collar and, if possible, the shoulder harness to protect the face.

At the current time, ICAO (2018) provide detailed information on bracing positions for aircraft passengers, but they go on to state that their guidance is "*not suitable for helicopter operations as crash dynamics differ significantly between fixed-wing aircraft and helicopters*".

In Canada, an Advisory Circular was released in 2016 requiring offshore passengers to assume a brace position with knees together and arms folded across the chest and fingers under the straps (Transport Canada, 2016). They go on to advise that "*after impact, the hand closest to the exit should lower to reach for the seat edge in order to landmark the exit. The occupant should then reach for the exit door/window frame with the hand closest to the exit and keep that hand on the exit while the opposite hand releases the shoulder harness*". They go on to acknowledge that *"Although in general, passengers and crew members are advised not to hold on to the restraint system as it can introduce slack into the system, for offshore helicopter occupants in a seat with a shoulder harness, TCCA recommends maintaining a positive grip on the restraint* *system with the fingers (thumbs should be facing up) in order to assist the occupant with egress upon impact. By maintaining a grip on the restraint system, the occupant need only slide his/her hand down the harness to unfasten their safety belt. Doing this may save time and reduce or limit the effects of disorientation caused by a helicopter sinking and rolling."* Disorientation is a known added problem when underwater, but the Canadian guidance does not explain why they recommend grasping the harness rather than the seat edge, despite then suggesting that after impact, one hand should be lowered to the seat edge to landmark the exit. Nor do they explain why this different procedure should "*assist the occupant with egress*". Anecdotally, the advice to grip the restraint system has caused concern within the offshore industry in recent years, as this could prevent effective recoil restraint.

In the US, the FAA (2016) have recommended a brace for impact position for helicopters that includes an instruction that "*arms and hands should be positioned in their laps or holding onto the side of their seats, but should not be holding onto their restraint systems*". The research was focussed on passengers and flight attendants, and makes no reference to the differences between onshore and offshore operations. A previous Interagency Aviation Safety Alert (US Department of the Interior, 2013) emphasised the importance of head positioning and the need to not grasp the restraint harness.

It is understood that in Europe, there is no mandated brace position for commercial helicopters, with variations depending upon aircraft type, harness type, whether seats are forward or aft facing and other seating configuration issues. Brace position is the responsibility of the helicopter operator. The generic brace position used for passenger training is therefore not necessarily exactly the same as that described in the briefing and safety card for a particular helicopter. Options used include placing hands on the front edge of the seat or holding onto the immersion suit at the knees to avoid flailing of the arms. In any aircraft with stroking seats, feet need to be slightly forward of the seat to avoid injury.

It is recognised that in a helicopter crash, and particularly a water impact, the dynamics are different to a fixed-wing aircraft impact, with higher vertical accelerations and reduced forward components in many cases (Barthelmess, 1988; Transport Canada, 2016). Barthelmess also pointed out that the brace position may not reduce serious injuries in accidents where the impact results in very high vertical accelerations and that inertial reactions of the head or of internal organs cannot be effectively controlled by bracing, although energy absorbing restraint systems will help. Despite this, no research papers have been found which specifically investigate the optimum brace position for a helicopter water impact.

While not having a direct influence on underwater escape other than helping to minimise injury, brace position may affect the ease of undertaking the initial steps in an underwater escape procedure. After impact, when the brace position is released, the helicopter occupant must be able to locate their harness release mechanism, locate and deploy the EBS if worn, and establish a reference point in relation to the best escape route, before jettisoning the exit, if seated next to an exit, and then releasing the harness. The ability to adopt any given brace position may also be influenced by the body size of the individual.

During a cross-cabin escape test following training, Mills and Muir (1998) found that one participant forgot to adopt the brace position. This is unlikely in a ditching when the crew giving the command to brace provide a prompt. The more likely situation is the water impact case where the majority of occupants may be unaware and will not have braced for impact. Injuries are much more likely to be sustained in this situation although the use of shoulder harnesses and energy absorbing seating go some way to mitigate this.

3.2.2 Seating

If a helicopter occupant is to have a chance of successfully undertaking underwater escape then the initial water impact must be survived, ideally with minimal or no injuries. Crash attenuating (energy absorbing) seats have been developed as one means of reducing acceleration injuries, along with crashworthy designs, delethalisation of structures and body restraint harness systems (see Shanahan, 2005). Such seats are particularly important in mitigating vertical acceleration loading. Early designs were based on a fixed load (Desjardins, 2006; Heimenz et al, 2007) designed for a 50th percentile seat occupant meaning that lighter occupants were exposed to higher accelerations than heavier occupants, while heavier occupants used more stroke, i.e. the seat moved to a lower position. Variable-load energy absorbers were then developed to allow for occupants with different mass, reducing the risk of the seat 'bottoming out'. According to Taber (2013), the crash attenuating seats used in the Sikorsky S-92 helicopter are designed for a standard mass of 77 kg, which is below the average mass of a member of the offshore workforce in Europe and North America (see section 3.2.17). This example seat moves through approximately 18 cm to achieve the maximum 'stroked' position.

When undertaking either training or research trials, the fidelity of equipment such as the seating within helicopter simulators has been questioned. In the past, low fidelity seating has been used, with low seat backs and two-point lap strap harnesses. More modern designs of helicopter simulator tend to have higher fidelity seating with slightly higher seat backs and four or five-point seat harnesses. Some also have stroking seats.

Helicopter underwater escape trainers (HUET) in Canada now have seats which can be used both in the normal position, and in a lower position which simulates the so called 'stroked' position. The C-GZCH accident report (TSB Canada, 2010) shows a high fidelity HUET seat used for training in Halifax, Canada (reproduced at Fig 1). Fig 2 shows a training seat in the low (stroked) position, with the knees of the trainee bent as a result. The body position which results from this change in seat position means that the person has to reach further to push out the window, from where it may be more difficult to apply force to eject the window. It may also be more difficult to find the harness release due to the more crouched body position.

Taber (2013) compared escape times from a helicopter simulator set up to be representative of an S-92 and found that escape from three different seats that were fixed in a stroked position (lower by about 24 cm) took significantly longer (21.4 ± 6.2 s; n = 28) than escape from the same seats in their normal position (18.9 ± 4.7 s; n = 53). Subjects also found it to be more difficult to escape from the stroked seat position than the seat in its normal position; location and deployment of the seat harness being more difficult. This study was undertaken with one design of compressed air EBS. The author noted that space limitations could limit deployment of other EBS designs when in the stroked position. However, this could also be true of other compressed air EBS dependent upon the location of the EBS on the suit system. A later study (Taber et al, 2015) using trained staff showed no difference in the success rate for harness release between a normal seat position and the stroked position, suggesting that training and experience of releasing the buckles underwater could reduce the incidence of problems with release. In this study there was just one case out of nine where the participant found it difficult to locate the harness buckle from the stroked seat position.

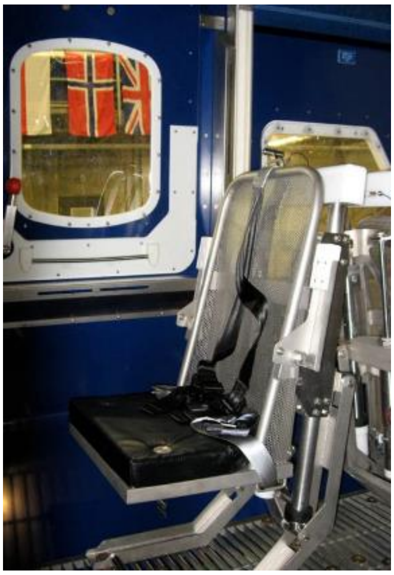

Figure 1 - Energy absorbing seat for training (Taken from TSB Canada, 2010)

Figure 2 - Energy absorbing seat for training in a stroked position

3.2.3 Seat harness release

Seat harness release is a key component in the process that occupants must follow when attempting to escape from a submerged helicopter. In 1973, Rice and Greear recommended HUET training, suggesting the "*trainees should be so well drilled in the procedure to be followed in unstrapping that he can perform instinctively in a panic type situation*". They also advocated the development of an automatic, water-activated, time-controlled release mechanism for seat harnesses. While such systems have now been developed, they pose the problem that early release of the harness could impair rather than improve the likelihood of a successful escape, particularly if it occurred before or during the exit removal operation. In the meantime, harness mechanisms have been improved in relation to ease of release, and the majority of civilian commercial helicopters now utilise a four-point harness with waist straps, dual inertia reel shoulder straps and a rotary buckle.

Various research projects have highlighted problems related to harness release. Work commissioned by the UK CAA to investigate escape from a partially inverted helicopter (Jamieson et al, 2000; Jamieson, Armstrong & Coleshaw, 2001), known as the 'side-floating' concept (see 3.2.11), demonstrated that subjects had some difficulty releasing the seat harness when seated on the upper side of the simulator, when the body was held partially above the water surface. This was thought to place an uneven load on the harness release mechanism. Two participants (out of 30) were completely unable to release the harness without assistance. Fortunately, under the conditions of the simulation, with the helicopter at an angle of either 150° or 210° from upright, video footage showed that participants were able to place their heads clear of the water, within the air gap, before releasing the harness. The project report (Jamieson et al, 2001) recommended that more work be undertaken to investigate uneven loading on a four-point harness release mechanism.

Harness functionality was investigated by Taber et al (2015), who found some issues with the release mechanism. In trials undertaken in dry conditions there was one case where the harness release mechanism did not fully disengage on the first attempt; in this case the shoulder harness had not been tightened in a central position. In a further three cases, the straps did not symmetrically release when the harness was loose or when a manikin was used and legs influenced release. In trials conducted underwater, there were four cases where not all straps released simultaneously, all with the harness fully tightened. In one of these, the participant needed three attempts to release the harness. No other problems were reported, although it should be noted that these trials were conducted using either a manikin or trained instructors. Offshore passengers will have much less experience of releasing the rotary buckle underwater and are more likely to panic during an underwater escape. Taber (2013) had previously reported that trial participants found it was more difficult to locate and operate the seat harness from the cramped stroked seat position than from the normal seat position.

Compatibility issues between the seat harness and emergency breathing systems, worn on either the lifejacket or immersion suit chest area, were identified by Coleshaw (2013). When the EBS was deployed in air there were some cases where the harness was overlaying the EBS, impairing deployment of the EBS. There were also a number of occasions where the EBS was found to be sitting just above the harness buckle, causing concern that buckle release could be compromised. On a number of occasions, on attempting to release the buckle during underwater escape the shoulder strap furthest from the escape window failed to release from the buckle. This created resistance when the participants attempted to move towards their escape window, hindering escape. In each case, however, the participant was able to pull free and successfully escape from the helicopter simulator.

These studies tend to show that seat harnesses are generally functioning correctly, but that there are some cases where release may be hampered, thereby potentially slowing the escape process.

3.2.4 Size of underwater exits

Surprisingly little work had been undertaken until very recently regarding the minimum size requirements for underwater emergency exits, i.e. escape windows. A key piece of work was undertaken by the RAF Institute of Aviation Medicine (RAF IAM) (Allan and Ward, 1986), which used an adjustable escape exit to investigate the smallest acceptable size. Only five subjects were used for this study, with bi-deltoid breadths (shoulder widths) ranging from 465 mm up to 512 mm. This represented the 50th up to the 99th percentile of the Royal Air Force population in 1971. It must be assumed that these subjects were young and physically fit, being military airmen. They wore a range of different uninsulated helicopter immersion suit and lifejacket combinations over underclothing, which is likely to have been less bulky than the clothing and equipment worn by civilian helicopter occupants in recent years. Subjects performed repeated escape exercises in different body orientations. During initial trials, a similar technique was observed to be used by all four participants, with one hand grasping the exit, the other arm, shoulder and head passing through the exit followed by the second shoulder, trunk then legs. After varying the exit size, the authors concluded that escape exits down to a size measuring 432 mm (17") by 356 mm (14") were compatible with escape for all but very large individuals. It was also shown that four individuals could escape through an exit of this size in a period of 24 s. It should be noted that the exit in this study was oriented such that it was 432 mm wide, with the smaller dimension of 356 mm being the height. It is not likely that the orientation would have affected the minimum size determined, but it should be noted that helicopter escape windows are generally taller than they are wide, which may add some additional escape difficulty as the individual must orientate themselves correctly to escape though a minimum size of exit. The minimum acceptable escape window size determined by this study was then used by the UK CAA in guidance (Leaflet 11-18[3], Helicopter emergency escape facilities) included in their Civil Aircraft Airworthiness Information and Procedures (CAA, 2006).

No further work was performed on helicopter underwater escape window sizing until the mismatch between underwater escape window size and passenger body size was highlighted by the UK CAA's offshore helicopter safety review, CAP 1145 (CAA, 2014), published following the G-WNSB accident in 2013 (AAIB, 2016). Research into body size for the offshore industry (Stewart et al, 2016) was underway at the Robert Gordon University at the time, directed at setting design standards for offshore installations, e.g. width of corridors, size of hatches. This included a consideration of helicopter exit sizing. The study investigated the ability of differently sized individuals to pass a frame over the body, sized to replicate the previously recommended minimum escape window dimensions (432 mm x 356 mm). The participants in this study were members of the UK offshore workforce. The body size of participants was measured using a 3-D scanner, with each dressed in a helicopter immersion suit and lifejacket with hybrid rebreather, as worn by the UK offshore workforce at that time. The authors concluded that body morphology could explain up to 75% of the likelihood of successfully escaping through a small window, with the best three variables (weight, bi-deltoid and maximum chest depth) predicting egress outcome with a 70% accuracy.

[3] Later amended as CAP 562, Leaflet 44-30.

Working with Step Change in Safety[4], the CAA developed a scheme for establishing the minimum exit size. Based primarily on the RAF IAM research (Allan and Ward, 1986), the minimum exit width was related to thorax depth and the minimum exit diagonal measurement was linked to bi-deltoid breadth. This scheme was validated by the results of the research at Robert Gordon University (Stewart et al, 2016) and agreed with the industry. The minimum dimensions were set based on window sizes of the existing fleet and anthropometric data gathered in the UK and took account of the type of clothing and equipment currently worn by the European offshore workforce. It would not have been practical to set the minimum exit size large enough for the largest occupant; hence, a scheme entailing the 'grading' of the offshore workforce was established. The minimum width was set to 14 inches and the minimum diagonal to 22 inches; non-rectangular exits were required to be capable of admitting an ellipse of 14 inches by 22 inches. Under the scheme, members of the offshore workforce exceeding these dimensions were to be graded as 'extra broad' (XBR) and seated next to the larger main aircraft exits having a minimum width of 19 inches and a minimum height of 26 inches (Type IV exit, or ellipse of 19 inches by 26 inches), i.e. large enough for any foreseeable occupant. Based on the data available, it was estimated that there would be sufficient seats next to these exits on all current helicopter types to accommodate the proportion of XBR passengers expected. The scheme was mandated in the UK in 2014 under a Safety Directive issued by the CAA (CAA, 2015c) in response to an action in the CAA's offshore review (CAA, 2014). The scheme was subsequently incorporated into the EASA air operating rules for Helicopter Offshore Flight Operations (HOFO) (EASA, 2016b) in hostile environments, which came into effect in 2018 in the form of new Acceptable Means of Compliance (AMC1 SPA.HOFO.165(h)).

Anthropometric data available from the Stewart et al (2016) research confirmed that, as thorax depth and bideltoid breadth are correlated, it was not necessary to measure thorax depth, only bi-deltoid breadth (shoulder width) this being the easier of the two parameters to measure. Step Change in Safety undertook a campaign during 2014 and into 2015 to measure the shoulder width of all UK offshore workers (see CAA, 2015a; 2016); by April 2015 they had measured 40,000 individuals, representing 100% of the core workforce and 50% of those who travelled less frequently. Of all the individuals measured, a little fewer than 3% had a shoulder breadth exceeding the minimum window diagonal, i.e. XBR passengers.

The issue of passenger size versus underwater escape window size was also addressed by the European rule-making task group RMT.0120, as part of an initiative to enhance the aircraft design specifications in relation to helicopter ditching and water impact occupant survivability (EASA, 2016a). As from 2018, the minimum size for all underwater exits on new helicopter designs is Type IV (i.e. 19 inches wide by 26 inches high) for CS 29 rotorcraft (EASA, 2018a), and of a size and shape capable of admitting an ellipse of 19 inches by 26 inches for CS 27 rotorcraft (EASA, 2018b).

---

[4] Step Change in Safety is a not for profit tripartite organisation representing the UK offshore workforce, regulators and employers.

3.2.5 Escape through underwater emergency exits

The ability to escape through a particular exit is affected by a number of different factors other than exit size.

Following the RAF IAM escape trials conducted in 1986, Allan and Ward recommended that hand-holds be provided to allow passengers to pull themselves towards an escape exit. This was thought to be particularly important when the buoyancy of an immersion suit tends to float the individual away from the exit. Brooks et al (1994) similarly called for a grab bar around the periphery of an exit.

The effort needed to remove an exit was explored by Bohemier et al (1991), who found that the time taken to remove an exit reduced escape success rates when compared to escape with exits missing. For a push out window, they identified the now well understood issue that participants found that their body floated away from the window as they pushed against them. The authors state that bracing the body against the seat back aided exit removal. They also found that an exit with a pull strip required dexterity to grasp the pull tab.

The Bohemier study looked at two exits with mechanical release mechanisms, and two types of push-out window (one with a seal). Brooks et al (1994) raised concern about the number of different exit jettison mechanisms and the fact that release mechanisms were not always intuitive. While this study focussed on helicopters used by the Canadian Air Force at that time, they observed that what appeared to be relatively simple release mechanisms when upright on dry land became much more difficult when inverted underwater, with the occupant breath-holding and buoyant due to the immersion suit. A further study in 1997 (Brooks and Bohemier, 1997) of both military and civilian helicopters found a similar lack of standardisation, with little progress made since the previous report. This paper identified many problems with the exit mechanisms used and also reviewed a number of different tab and lever emergency window mechanisms. It identified the issue that, at that time, there was no regulatory requirement for a push-out type window (although there were requirements for Type IV exits, but these did not specify what the operating mechanism should be). Barker and Bellenkes (1996) confirmed the prevalence of problems opening and jettisoning exits in their review of cockpit egress problems reported by US Navy pilots. In an attempt to resolve some of these problems Brooks et al (1999a) developed their own universal exit mechanism, incorporating an "*easy to locate and grasp*" bar jettison mechanism with a surround to hold and aid actuation and strobe lighting. They reported a 2 s advantage for time to escape compared to jettison of a standard push-out window, although the new system was slower than a simple rotary lever exit mechanism.

Mills and Muir (1998) also found that the time taken to operate and remove exits was critical to the overall time taken to escape. Escape window removal was the most common factor reported to impede escape, with some failing to operate the (simulated) exit, although this was primarily a problem for those who had not received training in exit removal. The force required to remove the exit was a key issue. The authors concluded that "*it is essential that HUET trainees have experience of operating representative exits, underwater during training*" to ensure transfer of training to the operational environment.

It is generally accepted that if a helicopter occupant needs to remove an exit or escape window, then it is highly desirable to do this with the seat harness still secured, enabling the individual to apply force effectively. This was confirmed by Mills and Muir (1998, 1999a); a number of their study participants had released their seat belt before operating the exit, making operation of the exit either difficult or impossible.

The forces needed to jettison an exit have come under much greater scrutiny in recent years. In the first of a series of studies Taber and Sweeney (2014), using training staff, measured the maximum voluntary forces needed to jettison a push-out force plate designed to replicate a helicopter simulator push-out window based on the S-92 (as used during helicopter underwater egress training in Canada). Significantly higher forces were needed to jettison the exit when pressure was applied to the centre of the force-plate compared to the outer corners. Overall, individual maximal voluntary jettison forces varied from as little as 15 kg force up to 63 kg force, with a mean value of 29 kg force across all conditions. In this study, there was no significant difference in the forces generated by the male (n=7) and female (n=3) participants.

King et al (2018) compared different methods of jettisoning a simulated push-out window in both dry and wet (underwater) conditions. Analysis of the data suggested that an elbow strike was highly successful when participants were inverted underwater. When attempting to jettison the simulated window by striking it with a hand as opposed to the elbow, the arm and fist moved through a long range of motion generating drag that was thought to oppose the movement, thus decreasing the load applied. This made it very difficult for participants to jettison the window using a hand in the wet condition. A smaller range of movement when striking the window was thought to improve the jettison success rate. A 2017 study (Taber et al, 2017a) explored other factors that influence the ability of a passenger to successfully jettison an S92 helicopter push-out window under simulated conditions. In this paper, based on trial results, they suggested that the mass and functional reach of occupants be considered when selecting individuals to sit next to push-out windows requiring high forces to jettison the exit.

Taber et al (2017b) gained access to the push-out windows of a number of operational S-92 helicopters. They used a re-designed force plate to measure jettison forces, described as '*dynamic strike values*'. (It is of note that the authors state that these windows are designed to be struck rather than pushed out). Using three different helicopters, a total of 17 trials were completed on eight windows, with force applied to the window corners in all but one case. Four out of seven static force trials were successful, requiring a mean force of 119 kg to jettison the window. In dynamic force trials, four out of ten were successful, requiring a mean force of 117 kg to jettison the window. A finite element analysis (FEA) model predicted that 115 kg force would need to be applied to a corner to achieve jettison. Interestingly, the figures presented show that the maximum dynamic forces applied to the real windows averaged 123 kg when jettison was not achieved. Taber et al commented on intra- and inter-aircraft variability which was considered to be due to a number of factors. The main seal was secured with an adhesive during painting, while a small amount of oil or grease had permeated into the space between the seal and window's outer surface in some other cases. This was thought to have either increased or decreased the amount of friction between the two components. The higher friction forces could account for some of the failures despite higher mean loads being applied.

Conversely, Taber et al (2017b) comment on the anecdotal claim that windows sometimes fall out when someone leans against them. Due to this potential variability, Taber et al warn against training for maximal loads to avoid too many trainees failing to complete the task. Taber et al (2017a) suggested that, for training, "*one window in the simulator could be used to demonstrate the more realistic loads while the others could remain at the current lower jettison load requirements*".

Following their 2014 study, Taber and Sweeney stated "*the fact that this is the only known study of its kind, indicates that there are thousands of individuals being transported to and from offshore installation around the world every week in helicopters that have not had exit jettison force tests carried out*". In their later study, Taber et al (2017b) concluded that "*at present, there is no way of truly knowing if the person sitting next to an exit is physically capable of opening it in the event of a survivable water impact*", going on to suggest that further testing should be carried out on existing and future helicopter designs.

Once an occupant has removed the escape window, they are faced with the task of egressing through the opening. The size of helicopter occupants is addressed at 3.2.17. The relationship between exit size and body size is considered at 3.2.4.

The equipment worn by a helicopter occupant must also be taken into account when considering underwater escape. The bulk of an immersion suit, uninflated lifejacket and EBS add to body size (Kozey et al, 2009; Stewart et al, 2016) and may therefore influence the ability to escape. The buoyancy of an immersion suits will affect ease of escape; those with higher inherent buoyancy make it more difficult for an occupant to control their position and pull themselves down to an exit when inverted (Brooks, 1988; Stewart et al, 2017b). The bulk may cause snagging or may check the progress of the individual, requiring the individual to adjust their position to progress through the exit (Coleshaw, 2013). Allan and Ward (1986) found that snagging, during escape through an underwater exit, was most likely to be caused by protrusions over the back rather than those over the abdomen. They recommended that careful consideration be given to the compatibility of added safety equipment to ensure that it does not pose a snagging hazard. Benham and Haywood (1996) established that a very bulky item such as a personal survival pack (carried by military aircrew) slowed down escape, while body orientation when passing through the exit influenced the level of snagging experienced. Furthermore, high levels of snagging had an effect on the aircrew's confidence in their ability to escape, while enhanced training helped to counteract this, increasing levels of confidence.

A study of offshore survival training programs (Taber and McGarr, 2013) found that a higher percentage of female trainees required assistance when opening the exits compared to male trainees, although no gender difference was found in the earlier Taber and Sweeney study (Taber and Sweeney, 2014).

3.2.6 Disorientation

Disorientation is a common problem experienced by individuals when exposed to submersion and inversion as would occur in a helicopter capsize. Under normal circumstances, orientation is achieved by integrating information from the visual (eyes), vestibular (ears) and other parts of the somatosensory system; the conscious perception of sensations such as touch, pressure, pain, temperature, position, movement and vibration which arise from the muscles, joints, skin, and fascia.

When a person is submerged underwater, important visual cues are generally lost due to low light levels and the effects of water on visual acuity (see 3.2.7). At the same time inversion results in confused stimuli from the vestibular system, particularly when the motion of the helicopter suddenly changes. Sensory cues can be misinterpreted by the brain resulting in a loss of sense of direction and an inability to determine true body position and orientation.

In an early study of underwater escape from helicopters, Rice and Greear (1973) found that in-rushing water was the most significant problem for those attempting to escape from a helicopter following water impact, and that this was associated with confusion, disorientation and problems reaching the exits. As a result, they suggested that participants in underwater escape training should wait for the simulator movement to stop and the bubbles clear before attempting to orientate themselves, and only then release their harness. This is now the standard training procedure.

The Mills and Muir (1998) study found that 61% of participants experienced disorientation during a test inversion following training. A majority described this as a sensation of losing their sense of direction and feeling confused about the direction of escape. Some reported a degree of panic, and others of feeling dizzy and confused. Rather surprisingly, only a small number reported that disorientation had impeded their escape. These individuals had to re-orientate themselves and this took more time. A lower percentage reported disorientation during a second cross-cabin escape test, although this lower incidence could be due to the increased experience of an additional run and habituation to the environment. In this case, 9% of participants went in the wrong direction due to the disorientation.

In their 1991 study, Bohemier et al found that disorientation decreased with experience in the helicopter. They also speculated that occupants needing to turn their bodies to locate the exit experienced greater disorientation than those who were facing the direction of egress.

In an attempt to quantify the degree of disorientation induced by a helicopter capsize Cheung et al (2000) compared the relative degree of underwater disorientation induced by a METS™ helicopter simulator and a shallow water escape trainer (SWET). The SWET is a device consisting of a metal frame and seat, which floats on the water surface when upright. It allows an individual to experience inversion in very controlled conditions, the SWET generally being turned by two instructors. Changes in perception of the gravitational vertical, indicated by pointing, were used as a measure of disorientation. A majority of the subjects pointed in a direction parallel to the frontal plane in each seating condition (SWET, METS™ window seat and METS™ aisle seat). Angular deviations from the gravitational vertical primarily ranged between 0° and 90° in the SWET, compared to a much wider range of 0° to 180° in the METS™. Subjective responses confirmed a significantly higher degree of disorientation in the full helicopter simulator. It was concluded that the METS™ provided higher fidelity with respect to disorientation.

Lower levels of disorientation were reported by participants escaping from a helicopter in a side-floating (150°) attitude (Jamieson et al, 2000; 2001) compared to a similar 180° inversion (see 3.2.11).

Leach (2016) made the important point that valuable time must be expended in reorienting a cognitive map even when there was no change in the relative positions of the person and the exit. This mental map is needed to allow the helicopter occupant to locate their exit in poor visibility conditions with very limited visual reference points. The increased time needed to locate the exit was supported by the findings of Cheung et al (2000) who reported that egress from the helicopter simulator took significantly longer than that from the SWET seat, despite use of a similar exit.

3.2.7 Vision underwater

In his 1989 review of helicopter underwater escape Brooks referred to a degradation of vision when underwater and suggested the benefits of wearing swimming goggles. Luria and Kinney (1969) found a 90% decrement in visual acuity when subjects were immersed in water without a face mask compared to in air. In their study of escape through underwater exits, Allan and Ward (1986) found that swimming goggles greatly helped the vision of their participants. The training situation shows that some individuals will close their eyes while underwater and attempt to escape by feel only. Mills and Muir (1998) commented on one subject who did not open his eyes, and who failed to escape. When undertaking a cross-cabin escape test some reported that although they had opened their eyes, it had not helped as they were unable to see the exit. In trials undertaken in 4°C water, Mallam and MacKinnon (2011) found that escape tasks, including deployment of EBS, jettison of an exit and harness release, took significantly longer in the dark than in light conditions. Anecdotally, it is also recognised that the large number of bubbles created by the capsize of a helicopter greatly reduces underwater visibility during the first few minutes following inversion.

A limited number of studies have looked at the effects of low light levels. Early work by Ryack et al (1977) evaluated the effectiveness of escape hatch lighting in day and night conditions, finding that more rapid egress was achieved when exits were illuminated. A further study (Ryack et al, 1984) found that electroluminescent lighting for escape hatches was visible to light-adapted subjects in turbid water. Luria et al (1984) investigated the optimal arrangement of lights around helicopter escape exits, the range of intensities required, effects of viewing angle and dimensions of lights on visibility. In 2004, O'Neil et al similarly investigated the underwater detectability of a lighting system on a helicopter escape exit. They found that at a distance of 1.5 m, the lighting system was detectible in less than 1.5 s by all subjects in both clear and turbid water and in both dark and light conditions. Performance deteriorated somewhat at 3 m, but was not reliably detected in turbid water under light conditions at this distance. While exit lighting systems have been developed to improve the ease of escape, no more recent published work has been found covering this issue. It should be noted that night-time flying accounts for approximately 8% of total annual flying hours in the North Sea (Nascimento, 2012; Nascimento, 2014), while night-time accident rates are much higher than day-time rates (Ross and Gibb, 2008).

3.2.8 Cross-cabin escape

In 1999, Bohemier et al made the important point that "a *seat beside an open exit provides the greatest probability of survival. Chances of survival decrease with increased distance between seat and exit*." Whilst this is well recognised, during training subjects are usually placed in a seat next to a window, primarily for safety reasons. Anecdotally, in the past, injuries during training have been caused by participants seated in aisle seats being unwilling to wait for the person in the exit seat to escape. However, a number of different research studies using helicopter simulators have included cross-cabin underwater escape exercises.

The Shell study (Mills and Muir, 1998) included a cross-cabin escape exercise, but without the use of escape windows. Participants took a mean time of 17 - 18 s to escape from the simulator having crossed to an exit on the opposite side of the simulator to their seat. Only slight variations in the mean time to escape were observed with the different training regimes used. In the cross-cabin test the most common factor which impeded escape was seat belt release, with 54% of participants reporting this problem. Disorientation and confusion about the direction they had to travel to escape was reported by 38% of participants. This, and the motion of the water within the helicopter simulator, meant that participants had to 'fight' to swim across the cabin. Many pulled themselves hand-over-hand across the cabin.

Bohemier et al (1990) investigated ease of underwater escape from three different seat positions in a helicopter simulator. Escape from a seat across the aisle from the designated exit took a mean time of 49 s, compared to 60 s and 62 s to escape following a route that either required the participant to turn to an exit behind the seat, or to move down the fuselage to an exit on the opposite side, i.e. the escape route required longitudinal movement inside the cabin. These authors later found that the provision of either an overhead guide bar or a guide bar mounted on the side of the cabin improved escape success rates (Bohemier et al, 1991), whereas use of seat backs along the aisle as handholds resulted in little or no improvement.

Disorientation and difficulty finding exits were the two factors found to give the highest ratings of difficulty when escaping from a fully inverted helicopter simulator (Jamieson et al, 2001). This was especially true when subjects were required to make their way across the cabin to escape, when finding the exit was much more difficult without any direct physical contact with the exit used for escape and with poor visibility due to the underwater environment and bubbles. In this case, 50% of participants failed to escape correctly. Of those who failed, 67% surfaced in the small air gap maintained in the simulator for safety reasons, while the other 33% escaped through their nearest exit instead of crossing the cabin. If this exit had been blocked in a real accident, this option would not have been available and there would be very little chance of finding an air gap in a fully inverted cabin.

3.2.9 Success and egress time

Various studies that have measured the time taken by individual subjects to escape from a helicopter simulator have found it to vary from about 15 seconds up to 25 seconds dependent upon conditions (Bohemier, Chandler and Gill, 1990; Mills and Muir, 1998; Coleshaw and Howson, 1999; Taber, 2013). Longer escape times for those who are last to leave the cabin have been found when a full cabin of passengers is simulated (see 3.2.10).

Bohemier et al (1990) provided some evidence to suggest that the probability of making a successful escape improved over a sequence of seven exercises when no EBS was used. When EBS was used, success rates were higher, masking any improvement due to repetition. They went on to find that egress success rates were dependent upon the exit route taken (Bohemier et al, 1991), attributing this to disorientation and the distance travelled to reach the exit. They demonstrated that the probability of successfully reaching the exit improved over a sequence of five to seven exercises, but commented that reaching the exit did not necessarily equate to a successful escape due to a lack of a reference handhold next to the exit and movement of the door release handle when operated in the inverted position (in this sequence of tests an 'emergency escape door' was used).

Mills and Muir (1998) demonstrated an improvement in success of escape and overall escape time as the level of training was increased. A group of subjects who only undertook dry training took 23.1 ± 3.9 s to escape, whereas those who had received training in water, that included one inversion and removal of exits, took 15.7 ± 2.0 s to escape. This latter group showed a 100% success rate for escape, compared to success rates ranging from 11 to 87 % in other training groups. In the three groups of subjects who undertook at least one inversion during training, significantly more participants escaped successfully compared to those who had not experienced inversion, indicating the importance of experiencing at least one capsize during training. Those who covered only parts of the full escape process in their practical training were slower and less successful than the group whose practical training included all aspects (inversion and exit removal).

Taber (2013) found that subjects took significantly longer to escape from an inverted helicopter simulator when lights were dimmed and the angle of inversion was changed from 180° to either 160° or 200°. However, it is not possible to determine whether it was the reduced light levels, the offset to the inversion angle or both which caused the longer escape time.

3.2.10 Full underwater escape trials

The authors of Air Accident Report 1/2016 (AAIB, 2016) commented that research trials "*have tended to centre on one aspect of the participant's evacuation experience; for example, use of survival equipment, rather than researching the whole evacuation process from start to finish under realistic conditions*".

While there is some truth in this statement (leaving aside the issue of realistic conditions), one of the reasons is that the scientific process involves testing a hypothesis that can be clearly defined and controlled. When multiple factors are considered it is much more difficult to come to clear conclusions about cause and effect. A number of research studies have been undertaken where multiple variables are considered (e.g. Taber, 2013), but this makes it much more difficult to determine the cause of a particular finding. In Taber's paper (2013), the finding about escape times from stroked and normal seats is confounded by the fact that some trials were conducted with full inversion in the light and some were conducted in reduced light and an offset angle; it is impossible to determine whether and how this affected the primary finding.

Only a limited number of research trials are believed to have been undertaken with a realistic number of people in the cabin. A series of trials were commissioned by Shell, with the helicopter simulator configured to replicate a range of helicopter types in service in the 1990s (Clark, 1996). These were conducted with a small number of subjects initially, but then built up progressively to half the expected number of occupants (see Brooks et al, 2001). This study focussed on the ability of participants to follow the manufacturer's or operators recommended escape routing, the operation of underwater emergency exits and re-routing to alternative exits if a chosen route was blocked. Capsizes were undertaken with a predictable roll rate in either direction, with the cabin completely flooded. Problems varied, dependent upon the aircraft type simulated, but included factors such as:

- a lack of space and leg-room between the seating;
- the brace position required for lap belts causing disorientation;
- problems of disorientation and means of establishing reference points for escape;
- a lack of hand-holds;
- those in aisle seats having to wait for others to make their escape before they could proceed;
- seats unexpectedly folding forwards;
- seats with no direct access to an exit;
- problems operating multiple action exits.

These findings led to some significant changes in the layout of the helicopters in service at that time, as well as a range of other design and equipment changes. Cabin configuration changes included enlarged and push-out windows, seating aligned with the exits, high-backed seats with upper torso-restraint, and guide bars added to bench seats.

The only known study to use a full complement of passengers was an investigation aimed at establishing the time needed to evacuate a Super Puma (Brooks et al, 1999b; 2001). The helicopter simulator used was configured to seat either 15 or 18 passengers. With the 18-seat configuration and a slow 180° inversion, participants took between 43 s and 109 s to escape, timed from the point when the simulator hit the water; the participants were underwater for between 27 s and 92 s for the last person out. With an immediate inversion, escape times ranged from 17 s for first person out to 36 s for the last person out, with the last person breath-holding for 33 s. Escape times following an immediate inversion were a little slower in the dark, with the last person out taking 43 s to escape, representing a 38 s breath-hold. The authors report that EBS were used by a number of the participants in different exercises, although it is not reported at what time the subjects resorted to it (EBS were provided in case subjects could not breath-hold for sufficient time to complete their escape). When considering problems encountered, some participants reported difficulty opening exits and difficulty due to exits not being aligned with seats, although there were few problems locating exits. A number found that their bulky (insulated) immersion suit impeded their escape, mostly due to the suit's inherent buoyancy. In one trial conducted in dark conditions it is stated that "*there were five reports of subjects feeling their escape had been impeded by other subjects or by the dark*". Unfortunately, it is not possible to separate the impact of these two factors, although there are no similar comments about other subjects impeding escape in the earlier trials in the light. The exit being blocked by another subject was the second least reported problem. However, in the discussion it is reported that, although not commented on in the questionnaire, some of the participants remarked afterwards that use of EBS allowed them to stay calm while waiting for others to clear their exit route. Darkness was reported to have increased anxiety, disorientation and the ability to see exits.

One further variable investigated by Brooks et al (2001) was a 90° roll to simulate a 15-seat helicopter floating on its side. None of the participants attempted to escape from the underwater exits. All climbed out of their seats to egress via the exits "*facing the surface of the water*". It would appear that these exits were underwater as breath-hold times extended to 52 s for the last person out and again, some participants used their EBS. The bulky wet immersion suits impeded egress.

There were a number of limitations to the Brooks et al (2001) study. All the trials were conducted with the same group of subjects and appear to have been conducted on the same day, meaning that both learning and increasing fatigue may have had an effect on the results. All of the trial subjects were either professional instructors and divers from a HUET training centre or were trained naval clearance divers, this being to reduce the likelihood of drowning or injury during the trials and for ethical reasons. All were therefore comfortable underwater and skilled at escaping from confined spaces. Greater problems and longer escape times are likely to have been found with naïve subjects, and the authors acknowledged this issue. This factor may also have influenced the fact that there were surprisingly few formal comments about escape routes being blocked by other participants, and the need to wait to egress through an exit. It is also acknowledged in the paper that the highly trained professional participants were less likely to report anxiety and difficulties than an average helicopter passenger.

Overall, Brooks et al (2001) concluded that breath-hold times were too long for the last occupants to escape from the fully occupied helicopter simulator without having to use an EBS (in spite of the fact that participants of the trial were highly trained and experienced). The authors called for new helicopters to be designed to accommodate a total underwater evacuation time of within 20 seconds. If this could not be achieved, passengers should be provided with some form of air supply, or the helicopter should be modified to stay afloat with an air space in the cabin (i.e. side-floating, see 3.2.11).

It should be noted that the first (internal) report of these trials (Brooks et al, 1999b) referred to the study as "*an initial investigation*", inferring that further work was originally intended. The original intention was to carry out a follow-up study with naïve subjects, but this was prevented by a lack of funding (Dr Brooks, personal communication).

3.2.11 Effects of capsize angle

While helicopter underwater escape training always assumes that an inverted helicopter will have rolled through 180°, this is not the case in all helicopter water impact accidents. Different orientations can result from uneven deployment of a helicopter's emergency flotation system, e.g. due to damage sustained to the flotation during the impact. Damage to one or more of the flotation bags could result in the helicopter floating on the surface but either on its side, nose down, or something in-between. Evacuation or escape from such an angle may be easier than a fully inverted aircraft, but may pose different challenges to the occupants for which they have not been specifically trained.

Rice and Greear (1973) commented that when a helicopter sinks on its side, the escape exits are either below or above the occupants. They reported cases where survivors have had to dive down under the sinking aircraft because the opposite exit above them was unreachable, highlighting some of the problems that might be experienced by occupants in this situation. According to the Wells Report (Wells, 2010a, p52) investigating offshore helicopter safety following the C-GZCH accident in Canada in 2009, the helicopter sank very quickly on its port side, with the one survivor escaping through a starboard exit before floating up to the surface. This report of the events suggests that the starboard underwater emergency exits were pushed out by water pressure.

More recently the 'side-floating' concept has been promoted by the UK Civil Aviation Authority (CAA), with the aim of preventing total inversion of the helicopter, thereby allowing some exits to remain above the water once a stable position is achieved (CAA, 2005a; Howson, 2006). Model tests were initially undertaken to prove the concept and determine the most efficient and stable flotation system (Jackson and Rowe, 1997). This study found an asymmetric configuration to be the most effective, with a combination of a buoyant cowling panel and a single buoyancy unit placed along one side of the fuselage, high up on the cabin wall. The flotation was designed to provide a floating level and attitude that would provide a significant air gap in the helicopter cabin, and also ensure that the exits were above the water surface and accessible to the occupants. The model tests demonstrated that this could be achieved with the asymmetric configuration, the helicopter model floating at an attitude of 150° from the vertical. The helicopter remained stable in that attitude whether it rolled through an angle of 150° or 210°.

A human factors study followed (Coleshaw and Howson, 1999; Jamieson et al, 2000; Jamieson et al, 2001), which established that participants found escape from the side-floating helicopter simulator to be significantly easier than escape from a fully inverted position. In this configuration, those in a seat with their head below the water surface were able to surface into the air gap on releasing their seat belt. Those seated on the upper side dropped down into the water when they released their seat belts. The main benefit was the greatly reduced risk of being unable to maintain a breath-hold for sufficient time to make an escape.

Once in the air gap the participants had time to decide on their best route of escape, generally from an above-water exit. A significant difference was noted in the difficulty of cross-cabin escapes, where 57% of subjects carrying out the fully inverted capsize found 'disorientation' to be very difficult, compared to 20% of the subjects when carrying out the side-floating (150°) capsize. Mean submersion times were reduced from 20.0 s (fully inverted) to 9.5 s (side-floating), the latter being achievable within an average breath-hold in cold water. Similarly, 57% of subjects found 'finding the exit' to be very difficult in the cross-cabin escape from a fully inverted helicopter simulator, while only 3% (one person) found this to be very difficult in the side-floating capsize. The provision of a hand-hold next to emergency exits was recommended by the authors, to assist in the location of the exit and to provide a leverage or reaction point for anyone trying to operate a push-out window. One of the few problems found with the side-floating capsize related to release of the harness, thought to be due to uneven loading on the release mechanism, with further work recommended. Overall, 90% of participants preferred escaping from the side-floating helicopter simulator and found this easier than the fully inverted scenario.

As a result of the side-floating trials, there was some concern raised by a risk analysis looking at a fully loaded helicopter (Jamieson et al, 2001), which considered the issue of occupants seated on the upper side of the helicopter falling down onto occupants seated on the lower, underwater, side of the helicopter. While this was seen as a potential problem for trials and training, it was not considered that it would significantly increase risk in a real capsize, which would likely be chaotic for many reasons. The potential benefits of having an air gap were believed to outweigh any additional risk. Similarly, wave action will have a different impact on a side-floating helicopter compared to a fully inverted helicopter. In the former case, occupants may have to cope with oncoming waves while making an escape. However, they would already be in the air gap and able to breathe at this point, which was considered to be much lower risk than an underwater escape. Brooks (1994) highlighted the greater difficulty of locating, opening and using exits that are underwater. Jamieson et al (2001) concluded that "*consideration should be given to the appropriate training programme for helicopter passengers who may find themselves fully inverted or on their side in the event of an aircraft capsizing*". One issue, however, is that OPITO Helicopter Underwater Escape Training (OPITO, 2020) currently only addresses removal of exits when above the water in a fully upright attitude (evacuation scenario) and when partially submerged but upright (underwater escape) and does not cover any other flotation attitudes during practical training sessions.

3.2.12 Cardiac responses to underwater escape

When considering why some individuals do not survive an emergency situation such as underwater escape, one of the causes of death other than or associated with drowning is a cardiac event. Sudden death in cold water is attributed to drowning in some cases where they may in fact have been caused by an electrical disturbance of the heart (Tipton, 2003).

Swimming can involve exertion, voluntary breath-holding and cold water face immersion, which results in increased sympathetic and parasympathetic nervous system activity through activation of what is known as the 'dive reflex' (Marsh et al, 1995). Swimming is also known to trigger cardiac events caused by arrhythmias, which can lead to drowning deaths in certain individuals, with a proposed genetic basis (Choi et al, 2004).

A 2010 study (Tipton et al) specifically investigated the incidence of cardiac arrhythmias during HUET. In total, 32 cardiac arrhythmias were identified during 130 runs in 22 different participants. All but 6 of the arrhythmias occurred just after submersion. Higher levels of aerobic fitness were associated with an absence of arrhythmias, meaning that those who were less fit were more likely to experience the arrhythmias. The participants in this study were young (< 40 years old) and healthy. The arrhythmias observed were "*asymptomatic and probably of little clinical significance*".

A later review paper by Shattock and Tipton (2012) investigated the conflict between the 'cold shock' response which drives an increase in heart rate via the sympathetic nervous system and the 'diving' response which causes a decrease in heart rate (bradycardia) via the parasympathetic nervous system. They propose that these two strong and antagonistic responses lead to the cardiac arrhythmias seen following a period of submersion and breath-holding. The authors report that arrhythmias initiated by the combination of cold water submersion and release of a breath-hold occurs in 62% to 82% of young, fit and healthy research participants.

While there are anecdotal reports of the very occasional cardiac event attributed to HUET training, only one case has been found in the medical literature (Kaur et al, 2016). They describe the case of an otherwise fit and healthy 32-year-old presenting with palpitations caused by atrial fibrillation. Five years on, following further HUET, the patient presented with identical symptoms. The authors proposed that the sustained arrhythmia secondary to cold water submersion may have been provoked by the autonomic conflict proposed by Shattock and Tipton (2012).

Incidence of arrhythmias has not been ascertained in older, nonathletic individuals undertaking HUET. Data obtained during HUET training (Harris, Coleshaw and Mackenzie, 1996), covering a broad demographic of offshore workers showed a significant increase in heart rate during the submersion and capsize exercises over and above that thought to be caused by anxiety during the training briefing. This was particularly marked in those undertaking basic training, which is generally the first time that participants undertake an underwater escape exercise. No age-related differences in heart rate due to the HUET training were found. This study included some preliminary measurements (unpublished) of ambulatory ECG (electrocardiographs), with the authors recommending further work in this area. The Tipton et al study (2010) also showed an increase in heart rate during HUET. They demonstrated that the heart rate response to HUET habituated over five repeat exercises. Helicopter underwater escape training is undertaken in relatively warm water temperatures, meaning that these responses are likely to be due to a combination of anxiety and physical activity and not due to any cold shock which is also likely to be experienced during underwater escape in the real emergency environment.

It is quite possible that, in cases where an individual has successfully escaped from the helicopter but then suffered a cardiac event (e.g. AAIB, 2016), this autonomic conflict and resultant arrhythmias may have contributed to the cause of death. This will be more likely in individuals who are already suffering from ischaemic heart disease where cold water immersion places additional demands on the heart. The use of an immersion suit will mitigate the cold shock response. However, it is interesting that Shattock and Tipton (2012) suggest that, whereas the cold shock response is normally dominant, a factor that may ameliorate this response, such as clothing, may allow the autonomic conflict to take effect.

3.2.13 Drowning during escape

Drowning has long been recognised as the primary cause of death in helicopter water impact accidents (Chen et al, 1993; CAA 1995; Clifford, 1996). Helicopters invert and/or sink in a high proportion of water impact accidents (Rice & Greear, 1973; Brooks, 1989; Clifford, 1996) and occupants have to make an underwater escape. Both a high impact velocity and rough sea states with breaking waves increase the risk of capsize.

The effect of water temperature on the initial respiratory responses to immersion (Tipton et al, 1991) is a significant factor when considering the survivability of a helicopter water impact accident. Brooks (1989) reported the cases of two US coastguard helicopter accidents in water temperatures of 13˚C and 14˚C respectively. Only 3 of the 9 crewmen successfully escaped from the inverted aircraft. The effects of cold on breath-hold capability were implicated as a possible cause of drowning.

When immersed in cold water the 'cold shock' response (Tipton & Vincent, 1989; Tipton et al, 1995; Tipton et al, 1997) greatly reduces the ability of individuals to control ventilation. It follows that if submerged, it becomes very difficult to breath-hold. Breath-hold duration following sudden immersion decreases linearly with a reduction in water temperature (Hayward et al, 1984). At water temperatures below 15˚C, the breath-hold times of individuals not protected by a suit decrease to 25–50 % of pre-submersion values, to less than 30 seconds.

Under simulated conditions, the time spent underwater escaping from the cabin can take 25 s for one individual sat next to an exit (Bohemier et al, 1990; Coleshaw and Howson, 1999) and up to 92 s for the last person to escape from a fully occupied cabin (Brooks, Muir & Gibbs, 1999; 2001). This is the time that an occupant must be able to breath-hold if not using an EBS. A median breath-holding time of 40 ± 21 s has been shown in 228 offshore oil workers immersed in 25°C water (Cheung et al, 2001). Only 3% of these individuals were able to maintain a breath-hold for the 92 s it might take to escape. These values were measured in relatively warm water. In cold water (5-10˚C), mean breath-hold time measured in small groups of subjects has been found to be close to 20 seconds, but may be as low as 10 seconds in some individuals (Tipton & Vincent, 1989; Tipton et al, 1995). There is therefore a mismatch between breath-hold time and the time needed to escape from an inverted and possibly sinking helicopter. When escape time exceeds the individual's breath-hold time drowning will result. This mismatch between breath-hold time and escape time led to the development of helicopter EBS (see 3.2.15).

3.2.14 Drowning following escape

Once a helicopter occupant has successfully escaped from the helicopter and reached the water surface the individual is still at risk from drowning. The immediate need is to achieve a stable face-up orientation and inflate any lifejacket or inflatable component of the helicopter immersion suit to help achieve this. Such protective equipment is designed to achieve a minimum freeboard (distance of the mouth and nose above the water), and maintain the individual in a stable face-up position in the water to reduce the risk of drowning by submersion of the face. For helicopters operating offshore, EU Regulations (EU, 2016) ensure that a lifejacket (or equivalent buoyancy) is worn by all occupants at all times. Aviation lifejackets are operated manually to avoid automatic deployment within the submerged helicopter which would prevent escape. The lifejacket or additional buoyancy must therefore be inflated after escaping from the helicopter. For this to be achieved the occupant must be conscious and free from injuries that might prevent the individual from locating and operating the inflation system. The only other option is that another person in the water could operate the inflation mechanism. This would only be possible if survivors were close together and sea conditions allowed.

Some buoyancy will also be provided by air trapped within an immersion suit, the amount depending upon the suit design and the thickness of any insulating layer. In general terms, the thicker the layer of insulation, the greater the level of buoyancy provided. Armstrong, Bennett-Smith and Coleshaw (1994) measured the performance of immersion suit and lifejacket combinations under real sea conditions, using an anthropometric marine manikin. They found that insulated immersion suits provided sufficient buoyancy to achieve good levels of mouth freeboard and airways protection. Lifejackets that did not channel water up to the face and those with buoyancy across the shoulders reduced the amount of water and wave splash that reached the nose and mouth, thereby reducing the risk of drowning.

Current rules for helicopter offshore operations (EU, 2016) define when survival suits must be worn, which includes: when sea temperatures are below 10°C; when the estimated rescue time exceeds the calculated survival time; when the flight is operated at night. The oil and gas industry dictates that the offshore workforce wear immersion suits for all flights, whereas crew may decide to not wear an immersion suit during summer months, primarily due to high cockpit temperatures. This means that once survivors reach the surface, passengers will always benefit from the inherent buoyancy of their immersion suit system, the amount varying depending upon the insulation of the suit and the amount and type of clothing worn underneath. For crew, only those wearing an immersion suit will benefit from the added buoyancy and improved protection from drowning.

Even when a lifejacket or equivalent buoyancy is worn, drowning can still be caused by waves; either by a wave breaking over the mouth, or by continual wave splash. Because the legs act as a sea anchor, waves tend to cause a turning moment that will turn an unconscious or relaxed survivor into a position facing the oncoming waves (Golden and Tipton, 2002). Water is then able to splash over the face, particularly with poor designs of buoyancy either allowing water to channel up to the face between double chest lobes, or where there is minimal buoyancy provided over the shoulder area. Repeated assault from the waves can interfere with normal breathing, and as the survivor fatigues it can become increasingly difficult to synchronise breathing with gaps in the wave splash. In such rough conditions, use of a spray hood will significantly improve airways protection (Armstrong, Bennett-Smith and Coleshaw, 1994) and reduce the risk of drowning. However, if helicopter occupants have not been exposed to waves during training they may not realise the importance of this accessory. In the past, spray hoods were criticised for steaming up, clinging too close to the face and obscuring vision. Spray hoods can also be difficult to deploy with cold or gloved hands. More modern designs have addressed some of these issues while the European equipment standards (EASA, 2006a, 2006b, 2006c) for lifejackets and immersion suits (ETSO-2C502, -2C503 and -2C504) are currently being revised with more specific requirements for spray hood deployment and performance.

3.2.15 Emergency breathing systems

When considering those occupants who do not manage to escape from the helicopter following a water impact and capsize, it has been established that the cause of death in survivable accidents is most likely to be drowning (3.2.13). While design improvements such as larger exits and improved seating layouts can facilitate escape, there will always be some occupants who, without breathing aids, do not have sufficient breath to escape from the aircraft and reach the surface. This may be because they did not take a large breath before submersion, or because their escape took too long. There is also a strong psychological component to the breath-hold such that anxiety can exacerbate the cold shock response and reduce breath-hold times (Leach, 2016), while psychological interventions including goal-setting, arousal regulation, mental imagery, and positive self-talk can be used to extend breath-hold times (Barwood et al, 2006). Other behaviours such as inaction are observed in an emergency which impair performance and affect the individual's ability to undertake the required survival actions (Leach, 2004; Robinson et al, 2008). Any of these factors could lead to an individual failing to complete the escape process. As a final intervention, the use of an EBS allows the breath-hold to be broken and gives the user time to overcome any of these problems before making their escape.

The mismatch between breath-hold time and escape time described in section 3.2.13 establishes a strong justification for providing helicopter occupants with a supplementary means of breathing during underwater escape. While this issue had been recognised, there was resistance to the introduction of underwater EBS in the UK during the 1990s. The UK military had successfully introduced compressed air EBS and recommended the development of rebreather technologies (Benham et al, 1995). Others had shown that use of EBS improves the probability of successfully escaping from a helicopter simulator (Bohemier et al, 1990). However, an assessment of breathing aids undertaken as part of the Review of Helicopter Offshore Safety and Survival (CAA, 1995) concluded that "*there was no clear advantage to be gained from the introduction of underwater breathing equipment and that, on the evidence currently available, the CAA would not be justified in pursuing this as a regulatory measure*". Instead, emphasis was placed on systematic improvements and measures to facilitate rapid escape i.e. reduce escape time.

Despite this influential recommendation, research progressed into the development of a simple rebreather (Tipton et al, 1995) as an alternative to compressed air breathing systems. A number of review documents have looked at the development of a range of different EBS, covering rebreathers, compressed air systems and hybrid devices (Brooks and Tipton, 2001; Coleshaw, 2003). While a compressed air system was shown to provide a slightly longer underwater duration (Tipton et al, 2007), the rebreather system provided a system with minimal risk of the pulmonary barotrauma that had been shown to be a possibility with compressed air systems (Benton et al, 1996). A rebreather was first brought into service for passengers flying offshore in the UK sector of the North Sea in 1996. This was later modified to include a small cylinder of supplemental air which discharged automatically on immersion in water. This 'hybrid' rebreather was introduced in 1999 and was adopted by all UK oil and gas operating companies within a few years. Norway later introduced a rebreather integrated into their offshore passenger suit system. This product was produced to a Norwegian Oil and Gas Association specification (Norwegian Oil and Gas, 2004) which, at that time, required the breathing system to be automatically activated on submersion, reducing the actions that must be remembered and undertaken by the user. At that time, there was no technical specification for EBS. The UK CAA therefore commissioned work to develop a technical standard. A preliminary study focussed on the development of EBS and concerns that existed in the context of current knowledge (Coleshaw 2003). Further work resulted in a proposed draft technical standard for EBS in CAA CAP 1034 (Coleshaw, 2013). This report included the results of ergonomic and cold water performance tests carried out on the three generic types of EBS (see also Barwood et al, 2010; Coleshaw, 2012). The information so gathered was used to inform the development of realistic performance requirements.

Following the 2013 G-WNSB accident (AAIB, 2016; 2020) where none of the survivors used the hybrid EBS that they carried, the UK CAA published an offshore helicopter safety review, published as CAP 1145 (CAA, 2014), which made a recommendation that required the use of Category A EBS if other actions were not met:

> "***Action A8***:
> *With effect from 01 June 2014, the CAA will prohibit the occupation of passenger seats not adjacent to push-out window emergency exits during offshore helicopter operations, except in response to an offshore*
> *emergency, unless the consequences of capsize are mitigated by at least one of the following:*
> *a) all passengers on offshore flights wearing Emergency Breathing Systems that meet Category 'A' of the specification detailed in CAP 1034 in order to increase underwater survival time;*
> *b) fitment of the side-floating helicopter scheme in order to remove the time pressure to escape*".

This was followed by two Safety Directives (CAA, 2015b; 2015c) mandating Action A8. In response, the UK offshore industry introduced a Category A EBS which met the requirements of the (then still draft) requirements for EBS in CAA CAP 1034 (Coleshaw, 2013). This involved a shift from using a hybrid EBS to use of a compressed air EBS, and the introduction of a new training programme. The intention was to provide helicopter passengers with an EBS that could be rapidly deployed underwater, where deployment would be simple and intuitive. While this was a significant step forward, issues relating to the application of the UK Health & Safety Executive Diving at Work Regulations have meant that training in the use of compressed air EBS in the UK and other countries undertaking OPITO training is currently restricted to classroom training and shallow water exercises with no exercises conducted in the helicopter simulator (OPITO, 2020). This fails to provide trainees with the opportunity to use the EBS under realistic conditions (Coleshaw, 2016). In Canada, compressed air EBS training using a helicopter simulator has been successfully introduced (Brooks et al, 2010). Training in the use of emergency underwater breathing apparatus (EUBA/EBS) became mandatory in Canada in 2015 (Transportation Safety Board of Canada, 2015).

Other studies have investigated EBS performance under different operational conditions. Taber and McCabe (2009) studied troops training to escape from a helicopter simulator configured to represent a military CH124, with seating along the side of the cabin and just two exits, an upper personnel door and a large cargo door. All of the military participants escaped from the inverted simulator when using EBS, whereas only 58% succeeded when escaping on a breath-hold. This helps to demonstrate the benefits of EBS use in a high fidelity training environment.

3.2.16 Protection from cold

The immersion suit provides protection from cold water during a helicopter accident involving submersion in a number of ways. During the underwater escape phase, the main role of the immersion suit is to prevent a sudden drop in skin temperature and help to limit the cold shock response (Tipton, 1989) that could otherwise lead to drowning (see 3.2.13). This is achieved by covering as much of the skin surface as is practicable and keeping the wearer dry. Following escape from the helicopter, the next challenge is to prevent peripheral cooling which leads to a loss of manual dexterity, grip strength and muscle strength (Vincent and Tipton, 1988; Geisbrecht et al, 1995), making it increasingly difficult to carry out survival tasks such as grasping a painter line, boarding a life raft or helping others in the water. Swimming failure can also be caused by peripheral muscle cooling (Tipton et al, 1999). As time in the water is extended, the insulation of the immersion suit and clothing worn under the suit acts to limit heat loss and prevent the development of hypothermia. Hypothermia should only be a high risk for those who are unable to board a life raft and who remain in the water. A helicopter immersion suit is also required to keep the wearer dry, with seals at the face/neck and wrists, to maintain the insulation of the suit and any clothing worn under the suit.

An interesting case study (McCallum et al, 1989) looked at two cases of accidental immersion hypothermia, both occurring during the same aircraft ditching. One victim survived while the other patient died despite identical immersion time and environmental conditions. The most important discriminating factor was skinfold thickness, reflecting the difference in body fat between the two individuals. Any advantage that body fat provides in protecting the individual from cold exposure must be balanced against the ease of escape from the helicopter. Body fat will tend to increase body size and increase buoyancy, decreasing the ease of escape but increasing the chance of survival once on the water surface.

In line with this thinking, a study investigating escape from submerged vehicles (McDonald and Giesbrecht, 2013) compared different clothing ensembles and their effect on exit time and difficulty in 20 °C and 8 °C water. They found that while a pre-inflated personal inflatable vest worn over a winter jacket created the most perceived exit impedance compared to controls, insulated flotation jackets and overalls did not increase exit time or impede exit during egress from the submerged vehicle but were beneficial in providing thermal protection and inherent buoyancy.

One further hazard related to cold water immersion is circum-rescue collapse, when an individual loses consciousness during the period of rescue and recovery. This condition accounts for some cases where an individual is apparently conscious in the water when rescuers arrived on scene, but who does not survive the recovery process (Golden et al, 1991). This is thought to be due to a number of factors including a sudden drop in blood pressure on being lifted from the water, as the hydrostatic pressure exerted by the water is lost (this effect is most prominent when an individual is lifted in a vertical posture) and an 'after-drop' in body temperature following prolonged immersion in cold water. This has led to SAR crew using double strops to achieve a more horizontal lifting position.

While a modern helicopter immersion suit, with an appropriate level of thermal insulation for the operational environment, will provide generally good levels of protection from cold shock, parts of the body remain exposed, at least during the underwater escape. The face is one area that always remains exposed. The rest of the head and the hands are protected by a hood and gloves, but these will not necessarily be worn during the underwater escape phase.

A recent study (Madu et al, 2020) investigated the influence of cold shock on the endurance times of a compressed air EBS by varying the amount of skin exposed to cold water. Overall, it was found that a lower water temperature and increased area of skin exposure reduced the predicted endurance time. The EBS, stated to have a capacity of ~40-55 L, was worn with a helicopter immersion suit and underclothing, gloves and hood. Subjects were instructed to breath-hold for as long as they could before then breathing from the EBS for 90 s. When exposed to cold water at 8°C the mean predicted endurance time (based on a maximum breath-hold plus 90 s breathing from the EBS) decreased from 2 min 39 s when the suit was worn zipped up with hood and mask donned, to 1 min 11 s when the suit was unzipped and the hood and face mask not worn. (N.B. Members of the Canadian offshore workforce are allowed to carry a diver's face mask, worn on the arm during flight, for use in the event of underwater escape). They pointed out that the corresponding reduction in mean breath-hold time, from over 50 s under control conditions down to 10 s under their worst case conditions, suggests that the cold shock response predominated over the opposing dive reflex (the dive reflex results in an increase in breath-hold time). The authors therefore stressed the benefits of wearing an immersion suit zipped up completely with the hood donned in the event of cold water exposure, while acknowledging that this is a problem for long flights in a warm helicopter.

Policies in different European countries still vary with regard to the question of whether an immersion suit should be fully zipped up during flight. This decision is influenced to some extent by the design of immersion suit worn and the level of insulation provided. The immersion suit ETSOs (EASA, 2006a; 2006b) require an EN ISO 15027 Class B immersion suit as a minimum. Passengers in Scandinavian countries are required to wear a helicopter suit with a higher level of insulation to take account of low sea water temperatures during winter months. Norwegian Oil and Gas (2004 as amended) now require an integrated immersion suit meeting EN ISO 15027:2002, Class A, with some further tightening of the requirement to include the effects of wind. They tend to prefer an immersion suit that can be worn with the zip undone to reduce the likelihood of thermal stress when cabin temperatures are warm. This presents the problem that a passenger may not have time to fully seal the immersion suit in the event of a water impact accident, which commonly occurs with little or no warning. In this event the immersion suit could quickly fill with water and compromise the thermal protection provided by the immersion suit. Passengers flying in the UK sector switched from an immersion suit that could be left with the zip partially open to one that remained fully sealed during flight following the G-TIGH Cormorant Alpha accident. The immersion suit of one non-survivor was found to have taken in a significant amount of water, while it was stated that most of the passengers had the central zip "*up to at least 3 inches from the top*" (AAIB, 1993); enough of a gap to allow a significant ingress of water into the suits. Follow-on work undertaken by the RAF Institute of Aviation Medicine and included in the RHOSS report (CAA, 1995) looked at the effect of leakage into immersion suits. They found that an unzipped immersion suit leaked 17 L water during a 20-minute test, compared to 0.5 L with the immersion suit zip fully closed.

It is well documented that water leakage reduces the insulation of clothing worn under an immersion suit (Allan et al, 1985; Light et al, 1987; Balmi and Tipton, 1996, Tipton, 1997). Allan et al (1985) showed that a leak of 500 g produced an average loss of 30% of the initial insulation of immersion-protection clothing, while 1000 g leakage resulted in a 40% loss of insulation. The location of a leak can have a significant effect on the consequent deep body response to cooling (Tipton and Balmi, 1996; Tipton, 1997), with a leak to the limbs being far less critical than a leak to the torso. Leakage due to an immersion suit not being fully zipped is likely to result in leakage over the torso, with a high risk of body cooling. The insulation of clothing worn under an immersion suit can also be reduced by dampening due to sweating (Light et al, 1987), although the advent of breathable immersion suit fabrics has provided a means of mitigation for this problem (Light et al, 1985).

One further point addressed in the RHOSS report (CAA, 1985) was the fact that crew would not have time to zip up while coping with an aircraft emergency. It is therefore more important that the crew fly with a fully sealed immersion suit.

The problem for designers and users remains, with a compromise to be made between a zipped-up immersion suit that will not leak and an immersion suit that can be left unzipped in warm cabin conditions. This issue could be greatly helped by the wider and more efficient use of air conditioning within helicopters (EASA, 2016a).

It is recognised that helicopter occupants, and in particular the crew, may experience a degree of thermal discomfort and stress during flights in the summer months (Gaul and Mekjavik, 1987; Faerevik et al, 2001; Faerevik and Reinertsen, 2003; Ducharme, 2006). The cabin of a helicopter does not suffer from the same degree of 'greenhouse' effect as the cockpit but can still reach values as high as 28°C ambient (Taber et al, 2011). Two studies have been conducted to investigate whether helicopter occupants who are warm due to wearing an immersion suit in flight are compromised in the event of an emergency and subsequent cold water immersion. Faerevik and Reinertsen (2012) found that, when wearing a dry suit, initially raised skin and core temperatures resulted in faster cooling rates during the first 10 min of immersion, but no difference in thermal responses compared to controls after 2 hours. Taber et al (2011) investigated the effect of two ambient temperatures (21 °C and 34 °C) on the performance of underwater escape skill sets. No impairment in performance was found, although it should be noted that mean core temperature fell slightly in the thermoneutral condition and only increased by 0.1°C in the hot condition. The authors commented that "*the thermal loading experienced by the participants of this study was related more to a perceived level of comfort than an actual increase in body core temperature that would influence performance*". They concluded that no decrement in escape performance should be expected during the first 90 min of a flight.

When considering the protection of the hands to maintain manual dexterity, helicopter immersion suits generally have gloves that are held in a pocket of the suit. They are provided to protect the hands in the event of an accident and consequent immersion in water. Occupants are unlikely to don the gloves before submersion, both due to a lack of time in many accidents and due to the problem that thick gloves will greatly reduce manual dexterity and could therefore hinder the escape process. This presents manufacturers with a challenge to design gloves that provide an adequate level of thermal protection, but which do not impair dexterity to the point where they will not be worn when needed. This generally results in a compromise situation, meaning that some tasks may still have to be completed without gloves worn.

Even the act of donning gloves is impaired by cold. Mallam and MacKinnon (2011) found a significant difference between donning times in warm (20°C) compared to cold (4°C) water, taking 46 s and 66 s respectively. Problems found included loss of grip strength and tactile senses, inability to get hands into the glove and difficulty using Velcro wrist straps. The almost 10% decrease in grip strength also resulted in slower times to complete bare-handed tasks including PLB activation, ancillary buoyancy deployment and donning of the sprayhood.

For those who do not reach a life raft and thus remain in the water, the helicopter immersion suit is required to provide thermal protection equivalent to 4 h when exposed to water with a temperature < 2 °C (ETSO-2C502, ETSO-2C503; EASA, 2006a; 2006b). Approval testing of an immersion suit means that it has been proved to meet this minimum requirement, when tested in calm water. In real emergency conditions, the sea water temperature may not be as low as 2 °C, but different environmental conditions such as wind and wave will reduce the effectiveness of the thermal insulation (Ducharme and Brooks, 1998; Power et al, 2015). This is another situation where a compromise has to be made between providing the best level of insulation for the expected conditions in the event of immersion, and designing an immersion suit that will not be too warm during flight. The immersion suit standards ETSO-2C502 and ETSO-2C503 (EASA, 2006a; 2006b) are currently being revised. The new requirements will allow four different levels of thermal protection, to provide more flexibility and allow crew in particular to select an appropriate level of thermal protection for their local environmental conditions.

It has previously been recognised that impact injuries frequently impair post-impact survivability (Muller and Bark, 1993). One factor may be a decrease in metabolism and reduced shivering following trauma, along with shock that can impair performance. An example is the badly injured survivor of the 2009 C-GZCH accident (TSB Canada, 2010), who cooled more than might be expected, despite the thermal protection provided by his immersion suit.

When considering whether HUET research trials are fully representative of the real situation, there are many cases where the clothing worn by test subjects differs from that worn by helicopter occupants, due to convenience, but also due to the water temperature of the pools where helicopter simulators are operated. This water temperature tends to be dictated by safety and comfort considerations relating to emergency response training. Immersion suits worn during such trials tend to be those in general use in the jurisdiction where the research has been undertaken. While fully insulated immersion suits are used in Scandinavia and Canada, for example, those used in the UK have tended to incorporate thermal liners that can be removed. Some reports detail the fact that the liner was worn (Coleshaw, 2013) whereas others make no mention of an insulation layer. In some cases standard offshore clothing has not been worn; in the case of the work undertaken for Shell (Mills & Muir, 1998b), boiler suits were worn under "*a typical survival suit*". Conversely, laboratory trials of, for example, thermoregulatory responses where the temperature of the water can be controlled, allow the investigators to use representative clothing under the immersion suit being worn by the trial participants (e.g. Barwood et al, 2010).

3.2.17 Occupant and test subject demographics

One area of concern voiced by the accident investigators involved with the 2013 G-WNSB accident on approach to Sumburgh (AAIB, 2016) was the influence of passenger demographics on successful egress from an inverted helicopter. In 2010 the Honourable Robert Wells, reporting on Phase 1 of the Canadian 'Offshore Helicopter Safety Inquiry' (Wells, 2010a) stated that in his view "*it would be an advantage in any such emergency to be physically fit*", and that this, together with mental preparation, would help to engender confidence in surviving a water impact accident. The sole survivor identified his age, fitness and good health among the factors that made a difference in his survival (TSB Canada, 2010).

The majority of passengers in civilian (commercial) helicopters are members of the offshore workforce. The first time that the UK offshore workforce is known to have been surveyed was in 1985, when Light and Dingwall measured the basic anthropometry of 419 male workers and found that they were heavier and had a higher percentage body fat than the equivalent onshore population. According to Light and Gibson (1986) 45% of the offshore population were overweight and 5% obese. Percentage body fat was found to increase with age (Light and Gibson, 1987) with those in their 20s having a mean body fat of 21% increasing to 30% for those in their 40s.

Helicopter operators use a standard passenger mass to estimate the helicopter's weight and balance. In 2005, a UK survey (CAA, 2005b) suggested that average mass for a male passenger, not wearing an immersion suit, had increased from an earlier figure of 79.4 kg up to 87.6 kg. Based on a 95% probability, the standard passenger mass for a helicopter carrying 10 to 19 passengers was increased to 98 kg (including 3 kg for the mass of an immersion suit and associated equipment) for males, and 77 kg for females. This increase in mass points towards the changing demographic of the offshore workforce.

A study of the size of the Atlantic Canada offshore workforce (Reilly et al, 2015) was conducted to address concerns about the correct sizing of immersion suits following the 2009 C-GZCH accident (TSB Canada, 2010; Wells, 2010). Measures were taken from just 42 participants although, unlike the previously mentioned studies, those taking part included both men and women. The dimensions of the participants demonstrated an increase with "*suit circumferences increased by as much as 246 mm, vertical measures (stature) increased by 14 mm to 41 mm, and horizontal measures (breadths) increased by 15 mm to 37 mm*". In this group, the 50th percentile body weight (38 male and 4 female subjects) was 85 kg, with the mean body weight for men only being just over 90 kg. Concerns remained about the sizing of immersion suits for smaller subjects.

Only one historic study of the anthropometry of helicopter pilots was identified (Light et al, 1988). The authors found that the sample data for the helicopter crew resembled data for sedentary onshore workers in terms of height, weight and body fat, although the pilots were on average older than the comparison group. When compared to UK offshore workers (Light and Gibson, 1986), a lower percentage of crew were overweight.

It was not until 2014 that a major survey (Ledingham et al, 2015) was undertaken which would update the data generated by Light et al in the 1980s (Light and Dingwall, 1985; Light and Gibson, 1986; 1987) for a European (UK) offshore workforce. As an example, the 50th percentile weight had increased from 76.1 kg (Light and Dingwall, 1985) to 89.6 kg (Ledingham et al, 2015). Members of the offshore population was again shown to be larger than their onshore counterparts, with mean bideltoid breadth and chest depths of 51.4 cm and 27.9 cm respectively, compared with 49.7 cm and 25.4 cm in the UK population as a whole (Stewart et al, 2015). A total of 404 male offshore workers were measured using the 3D scanning techniques by Stewart et al (2016). Body morphology explained up to three quarters of the likelihood of successful egress through the minimum sized escape window with the best predictors of egress success being weight, bideltoid breadth and maximum chest depth (see also 3.2.4). Differences in body flexibility and egress technique were thought to have explained some of the variance.

A paper by Stewart et al (2017a) has moved the thinking away from looking just at height and chest girth to defining a range of different somatotypes for offshore workers determined using whole-body scanning. They proposed that this body shape information could better inform immersion suit design and lead to better suits with less trapped air. Predicted buoyancy forces were shown to be greater for heavier subjects (Stewart et al, 2017b), which may impede their ability to escape from a submerged helicopter. This led the authors to state "*how buoyancy impacts underwater egress should be the focus of further research, because it is possible that some individuals may exceed the safe limit that must be overcome to enable escape from a submerged helicopter*".

Academic laboratory studies tend to use young, fit and healthy test subjects due to a combination of ethical and safety considerations, volunteer availability and a certain amount of subject self-selection, particularly when participation is likely to be physically demanding or stressful. That said, much of the research that has been undertaken to specifically investigate helicopter underwater escape is conducted at an emergency response/survival training facility with access to a helicopter simulator for underwater escape trials. In many cases, study participants have been drawn from members of the offshore workforce attending the training centre, meaning that the test subject group demographic is more likely to be representative of the helicopter user population. Even so, the same factors of safety and self-selection will remove some individuals from the participant mix, particularly those who are less physically fit.

A Taber and McGarr (2013) study found that female participants required significantly more assistance to open the exits during training exercises, in 5.8 % of cases, compared to males requiring assistance in less than 1 % of cases. No size or fitness data was collected from the trainees so it was not possible to confirm whether this difference was linked to factors such as strength or mass. Similarly, Mallam and MacKinnon (2011) reported that all four failures to jettison an exit related to female test subjects "*of generally smaller morphology*" in relation to other subjects. However, a 2014 study by Taber and Sweeney found there was no significant difference in the forces generated by the male (n=7) and female (n=3) participants. Again, it was not possible to relate this finding to body size or strength.

3.3 Life Rafts

3.3.1 Life raft issues in accidents

The review of accidents highlighted a number of issues relating to life raft performance.

One of the life rafts deployed in the G-TIGH accident (AAIB, 1993) suffered major damage but still provided some support for survivors, despite being only partially inflated and despite overturning several times. One survivor attempted to assist another passenger into the life raft but was unsuccessful. The other life raft (mounted inside the cabin) was not deployed.

Severe problems were experienced by the survivors of LN-OBP in the accident southwest of Sola (AIB Norway, 1998) when the life raft on the port side was blown under the tail rotor resulting in the puncture of one chamber. Several occupants fell overboard as a result and some chose to swim back to the helicopter. All occupants of the port life raft eventually returned to the helicopter cabin. The life raft on the starboard side was blown onto the roof of the helicopter hindering deployment and boarding. Three passengers eventually boarded the starboard raft with the pilot-in-command. All were rescued after one hour.

In the G-TIGK ditching southwest of the Brae Alpha platform in 1995 (AAIB, 1997), passengers on the port side of the aircraft had problems with the life raft blowing up against the open door, making boarding difficult. All boarded the starboard life raft. The lower chamber of the starboard life raft was punctured, apparently due to contact with the edge of a floating door.

Following the G-JSAR accident in 2006 (DSB, 2010), neither the flight crew nor the rear crew deployed the life rafts before ordering evacuation of the cabin, resulting in all of the passengers and crew evacuating into the water. It was only later that the winchman attempted to manually deploy a life raft from the sponson. He was unsuccessful and it was noted that his training had covered location of this handle but not operating it. As a result, all of the passengers and two of the crew remained in the water without the protection offered by a life raft. Water temperature was approximately 12 °C. Fortunately, they were rescued from the water after approximately one hour, with one passenger suffering from hypothermia. The accident investigators considered that if lessons from previous successful ditchings had been learned and passed on in crew training, the crew may not have decided to evacuate into the water. However, it was also recognised that the SAR crew were not sufficiently trained for a ditching with passengers.

Issues with the deployment of life rafts were experienced following the G-REDU evacuation in 2009 (AAIB, 2011). The port life raft was deployed from inside the cockpit by the co-pilot, but the pilot was unable to operate the starboard life raft deployment D-ring behind his seat as he was occupied in shutting down the aircraft and the rotor blades were still turning at this stage. Passengers thought that the port raft was slow to inflate, restricted by various lanyards, and therefore attempted to assist with its deployment. It was later realised that the lower chamber had not inflated due to damage caused by shattered and sharp carbon-fibre reinforced plastic fairings. Passengers attempted to deploy the starboard life raft using an external deployment handle but were not successful; the life raft was manually removed from its housing after which it inflated. Once in the life rafts the long retaining lines, designed to keep the life raft with the aircraft, were cut when the life rafts drifted to a position where they were at risk of being struck by the stationary rotor blades. The occupants found it difficult to find the knife needed to cut the retaining line due to the low light conditions. Despite training in its use, the occupants did not deploy the life rafts' sea anchors; it was thought that their use could have limited the drift of the life rafts caused by the rescue helicopter's downdraft.

In the May 2012 G-REDW ditching (AAIB, 2014) both life rafts were deployed by the crew. The passengers jettisoned the main cabin doors, presumably in response to the pre-flight briefing and training. All occupants evacuated through the starboard cabin door and boarded the starboard life raft, with those on the port side reacting to the perceived slow inflation of the port life raft. Once again, the long retaining line was cut due to the proximity of the life raft to a pitching main rotor blade, causing the life raft to drift away from the helicopter.

In the October 2012 ditching of G-CHCN (AAIB, 2014), the port life raft inflated on top of the sponson, restrained by tangled mooring and rescue lines which had to be untangled. This was another incident where one of the life rafts drifted, in this case under the tail rotor, causing concern about puncture and resulting in the long retaining line being cut.

In the G-WNSB accident (AAIB, 2016) both life rafts were deployed by the co-pilot, using the D-rings on the bottom of the sponsons. The co-pilot and a passenger attempted to manoeuvre one of the life rafts to some other passengers in the water, but were unable to reach them. Five passengers thus remained in the water until rescued. The life rafts were observed to be slow to inflate and painter lines were tangled.

3.3.2 Research into life raft use

Concerns have been raised over the years regarding the performance of helicopter life rafts (Anton, 1984; CAA, 1984; Kinker et al, 1998; Brooks and Potter, 1998). Problems identified include:

- difficulties in deploying a life raft stored within the cabin;
- life rafts blowing against the side of the aircraft, making it difficult to board;
- life rafts blowing away from the helicopter;
- puncture of the buoyancy chambers, by sharp objects or blade strike when tethered by a painter.

While some of these early reports relate to military equipment, the reports mirror findings from more recent civilian water impact accidents (section 3.3.1.).

Studies have shown that helicopter occupants find direct entry into the life raft ('dry-shod'), to be significantly less difficult than the process of entering the water, swimming to the life raft (attached by its long painter) and subsequent boarding (Brooks et al, 1997; Brooks et al, 1998). Brooks et al (1997, 1998) found an advantage for evacuation on the windward side of the helicopter, based on time and difficulty. To leeward there were problems of paddling or swimming away from the aircraft. On the windward side, the occupants did not have to swim away due to the drift of the helicopter. A comparison of two different designs of life raft (Brooks et al, 1998), those with either an inflating or non-inflatable canopy found that the inflatable canopy type had the disadvantage that it did not always inflate the correct way up, requiring one participant to undertake the difficult task of climbing onto the life raft and righting it. It should be noted that the righting of an inflatable canopy life raft may not be possible when it is attached by the short painter. Brooks et al (1998) also made the important point that painters needed to be relocated to allow the life raft to be hauled up tight to the fuselage without the boarding ramps being in the way.

Differences exist between the ability of men and women to board a life raft (Tikuisis et al, 2005). Men demonstrated an ~ 90% success rate in boarding a life raft over-the-side compared to an ~ 70% success rate for women. Less pronounced differences were found when using either a boarding ladder or ramp. A boarding ramp was found to be the easiest and quickest boarding method, with no gender differences for this measure. Greater strength and height were positive attributes for boarding the life raft using a ladder, with men found to board more quickly than women. Tikuisis et al also concluded that heavy layers of wet clothing or loss of muscle strength can easily compromise an individual's ability to board a life raft.

The stability of a life raft in strong winds depends on the number of occupants, with a fully occupied life raft being more stable than a partly occupied one (Birciu and Grabski, 2011). These authors also pointed out that, on boarding a life raft in strong winds, the survivors should occupy the windward side of the life raft first, to minimize the danger of capsizing. In a partially occupied life raft survivors should always occupy the windward side. The RHOSS Report (CAA, 1995) described events following the G-TIGH Cormorant Alpha accident (AAIB, 1993), when a damaged and partially inflated life raft was overturned on several occasions in heavy seas, tipping survivors back into the water. It describes how, after the life raft had been released from the helicopter, survivors "*spaced themselves evenly around its circumference*" and were then able to maintain it in a fairly stable state, enabling at least one survivor to climb on board.

3.4 HUET Training

3.4.1 Benefits of helicopter underwater escape training

An early study at the Naval Centre, Norfolk, USA investigated helicopter crashes into water from 1969 to 1975, involving more than 400 men (Ryack et al, 1986). Despite a lack of good fidelity in the 'Dilbert Dunker', they reported that "f*ewer than 8% of those who had received training in the Dilbert Dunker died in such crashes, compared to more than 20% who had not*". They considered that the training provided individuals with familiarity with the crash environment and confidence in their ability to cope with the emergency situation. The confidence provided by the training was considered to be paramount. HUET training for all navy helicopter crew members was recommended. Similarly, Rice and Greear (1973) commented that dunker training had markedly enhanced the chance of survival of helicopter occupants having to make an underwater escape. They considered that successful escape depended upon reflex actions which were best achieved when using a representative helicopter simulator, recommending that realistic underwater escape training should be implemented. Brooks and Tipton (2001) cite a 1978 study by Cunningham investigating military helicopter accidents from 1963 to 1975. Of those who had undertaken an underwater escape, there was a 91.5% success rate for those who had received training in escape techniques compared to only 66% of those without training.

Hytten (1989) interviewed five crew members from a rescue helicopter who survived a crash into a cold lake. One untrained crew member died. His colleagues observed that he had shown a panic reaction causing him to swallow fuel. This was put down to a lack of training. He was also a poor swimmer and was wearing inadequate clothing resulting in hypothermia. Of the five survivors four were reported to have received simulated helicopter accident training prior to the crash. It was considering that the training "*was of decisive moment in their escape and survival*". Benefits of training cited by the survivors included the development of reflex actions, an understanding of what to do, an ability to stay calm and not panic, and the development of a behaviour pattern that the individual could activate in the real situation. While it was found that none of the survivors had carried out the exact behaviours they had been taught in training and the real situation was very different from the simulator experience, training had provided self-confidence and the ability to cope with the real situation (Hytten, 1989).

In the early days of training civilian passengers to work offshore in the North Sea the ethos was to train for a controlled or nearly controlled ditching (Urquhart and Cross, 1980), making the training as realistic as possible to ensure that survival was not left to chance, but without terrifying the participants. Urquhart and Cross considered that training should be designed to build confidence and culminate in exercises that would improve the chance of escape in a real accident. In 1989, Brooks pointed out that helicopter escape training cannot be carried out in a classroom, commenting upon the fact that even experienced divers are surprised at the profound disorientation experienced when first undertaking an underwater escape following capsize in a helicopter simulator.

Two survivors from the Cormorant Alpha accident in 1992 considered that the HUET training they had previously undertaken had been good value and had contributed to their survival (CAA, 1995). In 1995, Benham et al stated that "*it is becoming accepted that the more realistic training is, the more beneficial it will be in a real situation*". Hognestad (1997) discussed the value of HUET as a powerful tool in the transfer of learning. All of this is dependent upon not only the fidelity of equipment but is also a question of whether the procedures being followed are representative of the real situation.

3.4.2 Fidelity of training

The fidelity of HUET training has received much attention over the years, with increasing emphasis placed on creating a realistic training experience which more accurately simulates the conditions that may be experienced in a real emergency. In recent years, demands to improve training fidelity have come from two major reviews of helicopter safety (Wells, 2010; CAA, 2014).

Following the 2009 fatal accident in Canada, Wells (2010a) reported how the one survivor considered that previous experience of sailing and being submerged in cold water helped him to survive, reducing his level of panic after the crash. Wells considered that that HUET and EBS training were necessary "*but should not be so rigorous as to pose safety risks*". However, he concluded that HUET and sea survival training should be conducted with greater fidelity, including more realistic sea conditions (N.B. Sea survival training is conducted in the sea in Canada, rather than in the more controlled pool facilities used in Europe). In 2014 the UK CAA (CAA, 2014) recommended that OPITO should "*review and enhance its safety and survival training standards with regard to the fidelity and frequency of training provided*". They also recommended that underwater escape training should be undertaken using 'worst case' exits.

The current OPITO emergency response training (BOSIET) (OPITO, 2020) is based on the principle of part-task training, building up skills so that trainees gain confidence as the tasks become more complex. Research into aviation training has suggested that whole-task training may result in maximal learning for expert pilots but that this is not necessarily the case for novice students (Noble, 2002). Part-task training is thought to be particularly beneficial to both novice (Noble, 2002) and low aptitude individuals (Wightman, 1983) who may not be able to overcome problems and who can become confused in whole-task training. In a high fidelity training simulator novice pilots became overwhelmed (Noble, 2002), performing better in a part-task simulator. Noble suggested that part-task training can build confidence in procedural knowledge while improving learning from mistakes. Wightman (1983) suggested that segmentation of a task allowed early proficiency to be gained and permitted errors to be corrected. Once tasks have been learnt, it is then highly desirable to bring all the components together in a training scenario that more closely represents the real emergency situation, whilst limiting the level of hazard to which trainees are exposed (e.g. underwater escape following capsize, with trainees deploying their EBS, releasing the seat harness, pushing out the exit window and making their escape). Achieving this takes time, and requires multiple exercises to be undertaken in the helicopter simulator. If additional features are added to improve fidelity, such as the use of crash-attenuating seats or the inclusion of different escape routes across the cabin, then more exercises are needed to ensure that confidence and required competence levels are achieved.

Abernethy (2005) compared algorithmic training (learning pre-defined step-by-step procedures) with heuristic training (learning concepts and then problem solving in the real environment). He discussed the merits of both approaches for HUET, but came down on the side of algorithmic training for those who do not have the benefit of supplemental air (EBS).

According to Salakari (2011), transfer of learning is not just dependent upon simulator fidelity; the success of simulator training depends upon well-designed scenarios, well defined training objectives and goals, and high motivation of trainees and instructors. Salas and Burke (2002) determined that "*the level of simulation fidelity needed should be driven by the cognitive and behavioural requirements of the task and the level needed to support learning*". They considered that there was a need to assess performance and provide feedback. Taber (2014) considered that varying the task requirements would benefit future performance, including escape from both sides of the cabin and from different locations.

A number of authors (Abernethy, 2005; Coleshaw, 2010, Mills and Muir, 1999b; Taber, 2016; Wells, 2010) have discussed the issue of higher fidelity helicopter underwater escape training and most concluded that this is easier to achieve where just one helicopter type is used by the trainee population, in which case aircraft-specific training can be provided. In Europe, most helicopter simulators are generic and do not simulate a specific helicopter type, although some have the facility to use specific exits if requested by a client. Generic training simulators will not fully address the different mechanisms for the operation and jettison of emergency exits in different helicopter designs and may also fail to reproduce seating layouts, with the distance from seating to exits differing between helicopters. Taber (2014) stated that the use of generic helicopter simulators was sub-optimal and that such training would not necessarily guarantee that individuals could generalise the knowledge gained in a low fidelity environment to a different situation in the real environment. Perhaps as a result of generic helicopter simulators, there is little evidence of research undertaken to investigate the effects of different layouts, seating and exits on training outcomes.

One exception is the work undertaken in Canada to investigate the fidelity of S-92 push-out windows used in HUET training (Taber and Sweeney, 2014; Taber et al, 2017a, 2017b). This has highlighted the high forces needed to jettison the exits (see 3.2.5). What is apparent is that the forces needed to jettison the windows from the helicopter simulator are much less than those needed to jettison the real escape windows in an S-92. It was pointed out (Taber et al, 2017b) that a balance was needed between designing simulator exits that provided a level of realism in terms of jettison forces, and the need to ensure that sufficient trainees were successful in their attempt to complete the training. The latter is needed to develop confidence and coping skills.

3.4.3 Development of coping skills

Successful escape from a capsized helicopter requires complex behaviours to be carried out (Robinson, 2016). Without training, in a capsize event the helicopter occupant would be responding to a series of novel situations in a highly stressful environment. Helicopter underwater escape training helps individuals to develop coping skills and behaviours that allow them to respond to the threat and undertake behaviours that increase their abilities to escape if faced with this emergency situation.

In early underwater escape trials conducted by Ryack et al (1986), anxiety was found to decrease as training progressed, suggesting an improvement in the level of coping, which they felt provided support for the effectiveness of underwater escape training.

Hognestad (1997) discussed the value of helicopter underwater escape training as a powerful tool in the transfer of learning. He commented on the ability to recreate potentially hazardous situations under controlled conditions, allowing skills to be practiced in a safe setting. Ideally, trainees were free to make errors that could result in failure in a real accident, and could thereby learn from them. He considered that real-life situations could be replicated and that desired skills and knowledge should be reinforced to achieve desired learning outcomes.

Research has shown that most individuals undertaking HUET training develop a positive expectancy for future coping (Hytten, Jensen & Vaernes; 1989; Harris et al, 1996), with the greatest effect seen after initial basic offshore emergency response training (Harris et al, 1996). Of the 78 participants in the Hytten et al (1989) study, 88% considered that they were in a better condition to cope with a helicopter water impact after completing the training. Coping skills were thought to have been developed through repetition and controlled action in this unusual situation. An increased confidence in flying was also reported by 78% of the subjects. In the Harris et al study (1996), 49% of trainees undergoing basic training stated that their confidence in helicopter transport was increased while 47% felt no change in confidence. Of those undertaking the further (refresher) training, the majority of trainees reported no difference in confidence in helicopter transport.

Similarly, Taber and McGarr (2013) suggested that individuals' self-rating of confidence was significantly increased after completing HUET skills training, while participant's rating of confidence in water was also significantly improved after completing practical training.

3.4.4 Stress due to training

A number of studies have investigated the levels of stress and anxiety induced by helicopter underwater escape training (Harris et al, 1996; Robinson et al, 2008).

A 1996 study compared the responses of those undertaking either basic or further (refresher) training (Harris et al, 1996). Lower levels of anxiety were associated with greater perceptions of coping, emphasising the need to develop coping skills and build up confidence in all delegates. While no age affect was found in participants undergoing basic training, lower levels of anxiety were found in the older participants undertaking further training, suggesting that repeated experience of the training may be beneficial in reducing stress due to training. However, the older individuals did find the training to be more demanding than they had expected.

Mills and Muir (1998) compared the effects of different levels of training on stress and anxiety. They found that higher fidelity training, including inversion plus either the removal of exits or a cross cabin escape, appeared to reduce stress and anxiety when a test escape was subsequently undertaken, compared to low fidelity training with only dry training or partial submersion. However, the high-fidelity training induced more inherent stress and anxiety during the training process. Regardless of type of training, subjective stress levels were lower after a repeat test escape, again suggesting that stress levels decrease with repeated exposure.

Robinson et al (2008) investigated the effects of HUET training on state anxiety, working memory and salivary cortisol levels. She found that working memory performance was preserved during anticipation of HUET training (the acute stressor), but impairments were observed immediately after exposure to the stress. Significantly higher state anxiety levels were reported prior to training, showing an anticipation response, and following training. Significant elevations in cortisol levels were observed 25 min after exposure to stress, but were not observed either before or immediately after exposure to the stressor. This closely reproduces the findings of Harris et al (1996).

A further study in 2018 (Robinson, 2018) used a simulated helicopter water impact to explore the effect of a neurotic personality on cognitive processing under pressure. She discussed the fact that neuroticism is characterised by anxiety, negative mood and proneness to distress while very neurotic people have been found to cope poorly in acute stress situations. Participants undertook between four and seven HUET exercises with at least two submersions and two capsizes. The results showed that although exposure to HUET did have an effect on cognition, the decline in performance was only seen one hour after the HUET exercise. Thus, while this may have repercussions for rescue services managing victims following an emergency, it is unlikely to affect cognitive performance during underwater escape.

Other studies have shown that aerobic fitness may moderate perceived stress and improve an individual's capacity to cope with stress (Ritvanen et al, 2007).

Brooks et al (2007) describe a systematic desensitization programme used to help a pilot with a fear of undertaking the underwater escape training. The pilot reported how his confidence increased and anxiety reduced as the difficulty of the escape exercises increased. This supports the practice of part-task training, which builds up skills and confidence and reduces anxiety in a progressive sequence of exercises.

3.4.5 Retention of training skills

Only a limited amount of research has been undertaken into the retention of helicopter underwater escape training (HUET) skills. In Europe, most members of the offshore workforce only undertake repeat 'further/refresher' training every 3 to 4 years. Retraining periods may be shorter for crew members, the military and aircrew involved in SAR operations or medical evacuation. The frequency of training and the level of skill decay and performance decrements that may occur between training sessions is therefore of concern.

In 1996, an anticipated removal of regulations which had, up to then, prescribed HUET training every two years, caused the Industrial Foundation for Accident Prevention in Western Australia to investigate an optimum training strategy. They wished to address a concern that refresher periods were based on general industry practice rather than being informed by empirical knowledge. As a result a study was commissioned to look at skills decay and optimal retraining strategies (Summers 1996). Summers pointed out that declarative knowledge of a given skill area will not necessarily result in procedural skill or the ability to perform the given task. Procedural skills involve decisions about the correct actions to take and the order in which these actions should be made; it was stated that such skills are easily forgotten if not reinforced.

Study participants were 158 offshore workers plus 16 military trainees. At the start of the trial session, those with previous training experience showed higher skills knowledge than novices, suggesting that some knowledge had been retained from their previous HUET training. Both novices and those who were re-training showed a significant degree of learning at the end of the trial training session. This suggests that there had been some decay in skill knowledge in the experienced trainees since their last training. The degree of learning was significantly higher in the novices, resulting in no significant difference between the groups at the end of the training day. For the experienced trainees, those who had last completed training outside the statutory 2-year period learned more than those whose last training had been completed less than 2 years previously, suggesting a relationship between retraining period and skills decay. However, the number of times an experienced participant had undertaken HUET training did not affect test scores, supporting the need to provide refresher training. Unfortunately, this study examined skill knowledge but did not look at the ability to perform the skills in question. Summers concluded that a two-year training interval was too long.

She also commented that it was quite possible that skill decay could have occurred within 6 to 12 months and considered that this was an issue worthy of further research.

Mills and Muir (1999a) also attempted to investigate optimum retraining periods and skills retention over different time periods, studying the complete HUET training course. Six groups of participants (52 in all), all members of the UK offshore workforce, were asked to undergo a test escape exercise either 6, 12, 18, 24, 36 or 48 months after having complete standard HUET training at an approved training centre. They were then requested to complete a questionnaire used to evaluate their knowledge of the emergency procedures and any difficulties encountered during escape. Some limitations of the study were acknowledged; only those who were relatively comfortable with HUET volunteered for the study, while the type and fidelity of the previous training varied considerably, resulting in different levels of competency. It was considered that the differences in initial competency may have masked any influence of time elapsed since the last training session on escape test performance; they were not able to identify the optimum point of retraining.

A large proportion of the participants, regardless of time since last trained, failed to perform the correct actions for escape in the correct order. Many forgot to brace, forgot to locate the exit or released their seat belt before removing the exit. The number of previous training sessions did not significantly affect performance, although there was a trend for the number of correct actions to increase with repeat training. Those who had received prior training including the removal of representative exits reported fewer difficulties operating the exit than those whose previous training did not involve exit removal, independent of the time interval since their last training session. The authors emphasized the need for refresher training to prevent the skills and knowledge decay observed and recommended a longitudinal study[5] to assess the optimal retraining period for HUET skills (Mills and Muir, 1999a, b). They also concluded that the quality and fidelity of training provided was more important than the recency of the training.

In 2006, Kozey et al confirmed that if sufficient training in a task is given, the learning will be retained for at least 6 months. They demonstrated an improvement in inverted underwater escape performance 6 months after initial training, achieved by increasing the number of inversion exercises undertaken during that training (one exercise without a window and four with an escape window in place). Those who had no experience of pushing out escape windows during the initial training had a 54% success rate in the test HUET escape. Participants who had experienced use of push-out windows once during training had a success rate of 81%, while the group who undertook four HUET inversions using push-out windows during training demonstrated a success rate of 96% when carrying out the test HUET escape after 6 months. This research supported the view that more exercises conducted during training, with greater fidelity (push-out windows) will produce greater levels of learning and skill acquisition.

A more recent study of skills retention focussing on the adoption of a correct brace position and correct heat escape lessening posture (HELP) during basic offshore safety and emergency response training (Hussin et al,

[5] A research design that involves repeated observations of particular individuals over prolonged periods of time.

2015). Based on 38 participants, it was found that the average skills test score had dropped to 83% after 2 months, and to 76% after 6 months. When the data was extrapolated, the authors predicted that the skills level would be at 50% by the end of 3 years. The authors commented that the offshore industry did not have a skills competence benchmark, but that they considered 50% retention after 3 years to be acceptable.

Sanli and Carnahan (2018) questioned whether a 50% decrement in skills by the time further training is undertaken (i.e. Hussin et al, 2015) was acceptable or safe. These authors also cautioned against generalising findings relating to retention of single skills to learning from a multi-day training course such as emergency response training including HUET. They also commented on the approach used by Kozey et al (2006), commenting that "*a greater number of participants that had completed practice of the more difficult versions of the task passed the retention test, however the influence of practice task difficulty could not be disentangled from the influences of more practice trials and similarity between practice and testing contexts*". This demonstrates the difficulties placed on researchers attempting to investigate the many different aspects of a complex task such as helicopter underwater escape. After reviewing literature relating to retention of skills for a number of complex tasks involving movement skills, Sanli and Carnahan (2018) concluded that it was only possible to "*expect retention of skills for 6 months at best*".

When preferred retraining intervals and competencies were self-assessed by members of the Royal Netherlands Air Force (Bottenheft et al, 2019), all considered that the interval between courses should increase dependent upon the number of refresher courses undertaken. The maritime crew, who were used to a 12-month training interval, preferred an initial interval of 11 months, increasing up to 22 months between their third and fourth refresher courses. The regular flight crew, who were used to a 36-month training interval, preferred an initial interval of 22 months, increasing up to 33 months between their third and fourth refresher courses. The maritime crew thus felt that as experience was gained, the training interval could increase, whereas the regular flight crew preferred a shorter training interval than they were used to. For flight crew in particular, with lower levels of maintained competence the self-assessment on the retention of skills varied widely. Competence levels were perceived to be higher and showed low variance for the maritime crew, presumably due to their short retraining interval. The authors concluded that (for air force crew) the HUET course interval should be made adaptive and tailored to individual's needs.

Bottenheft et al (2019) also noted that for aircrew, ease of escape may depend upon the aircraft type flown and on the crew role. It was recognised that crew sitting in the back behind bulkheads may find it relatively more difficult to escape from an aircraft compared to pilots escaping from the cockpit. They considered that this needed to be taken into account when determining the retraining period.

4. Analysis and Shortfalls

4.1 Brace position

While brace position is not a component of underwater escape and bracing is rarely mentioned in the helicopter accident reports, the body position adopted will influence the likely occurrence of limb and neck injuries. It is also an important starting point for the escape process following water impact and capsize.

The literature review suggests that no generic brace position has been mandated for offshore helicopter operations. There are regulations relating to seating and harnesses. The CS-27/29 acceptable means of compliance for ditching, AMC 27/29.801 (EASA, 2018a; 2018b), states that "*attention should be given to the avoidance of injuries due to arm/leg flailing, as these can be a significant impediment to occupant egress and subsequent survivability*". This relates to the design of new helicopters, with suggestions including energy-absorbing padding and no sharp edges. In the air operation regulations (EU, 2012), CAT.IDE.H.205, relating to seats, safety belts and restraint systems, states that helicopters shall be equipped with a seat belt with upper body restraint for use on each passenger seat (for helicopters first issued with an individual certificate of airworthiness on or after 1 August 1999). Each flight crew seat is required to have "*a seat belt with upper torso restraint system incorporating a device that will automatically restrain the occupant's torso in the event of rapid deceleration*".

The review of the research demonstrated that brace positions have been recommended for helicopter passengers (Barthelmess, 1988; Brooks, 1989; FAA, 2016; Transport Canada, 2016), which anecdotally roughly match the brace positions recommended by operators and training establishments. High backed seats with upper body restraint harnesses determine the upright position of the body torso, in line with the various recommendations. In all cases, the feet must be placed in front of the seat edge to prevent leg injuries due to energy absorbing ('stroking') seats. As regards head position, for forward facing seats the head should be tucked down as far as possible (chin on sternum), for rear facing seats the head should be placed firmly against the head rest (Barthelmess, 1988; Transport Canada, 2016). However, there appears to be some uncertainty and recent controversy over the position of the hands. The Canadian Advisory Circular (Transport Canada, 2016) recommended maintaining a positive grip on the restraint system with the fingers, so that the occupant was able to slide their hand down to the harness release when required. Concern has been raised that occupants should not be grasping the harness as this could affect harness performance. In Europe, the general advice given is to place the hands under the knees or to grasp the material of the immersion suit legs. No publication could be found which explored the impact of the Canadian alternative brace position.

Further research is therefore recommended to investigate two aspects of the brace position:

1. Whether grasping the upper torso harness impairs the performance of the harness.
2. The effects of hand position on ease of accessing and releasing the harness and ease of EBS deployment.

Proposed future research: see 5.3.1.

4.2 Seating

The report of the G-BDES accident (AAIB, 1991) concluded that the collapse of passenger seats contributed to the injuries and incapacitation of occupants. This accident occurred before the introduction of energy absorbing (crash attenuating) seating.

Due to the potentially high vertical accelerations experienced in a helicopter water impact, seats are now provided with energy absorption systems to attenuate the accelerations that may be experienced by the occupants, designed to reduce spinal compression loads and thereby reduce the risk of spinal injury. Moradi et al (2012) state that due to the limited stroke available in seat designs, "*the design of the energy absorber becomes a trade-off problem between minimizing the stroke and maximizing the energy absorption*". Fixed load energy-absorbing systems were designed for the of 50th-percentile occupant (with respect to effective mass), to ensure a tolerable stroke for the majority of occupants while not exceeding the stroke limitations of the seats (Desjardins, 2006; Moradi et al, 2012). This means that heavier occupants use more of the stroke (and are more likely to bottom out) resulting in lower deceleration, whereas lighter occupants use less of the stroke but will experience higher levels of deceleration.

In the Canadian C-GZCH accident (TSB Canada, 2010), which occurred after the introduction of energy absorbing seats, four of the passenger seats were reported to have bottomed out. According to Taber (2013), the crash attenuating seats used in C-GZCH were designed for a standard passenger mass of 77 kg. Current European certification requirements (EASA, 2020b; 2020c) state at CS 27/29.562(a) that "*the rotorcraft, …. must be designed to reasonably protect each occupant when: (1) The occupant properly uses the seats, safety belts, and shoulder harnesses provided in the design*" and when exposed to loads equivalent to those resulting from defined conditions. The defined tests are required to be undertaken with an occupant simulated by a 77 kg anthropomorphic test dummy, sitting in the normal upright position. An occupant mass of at least 77 kg is also used in the requirements at CS 27/29.785(f) where "*each seat and its supporting structure must be designed for an occupant weight of at least 77 kg (170 pounds) considering the maximum load factors, inertial forces, and reactions between the occupant, seat, and safety belt or harness corresponding with the applicable flight and ground load conditions, including the emergency landing conditions of CS 29.561(b)*".

Research reported at 3.2.17 (CAA, 2005b) described a mean mass of 98 kg for male passengers and a mean mass of 77 kg for female passengers (both values are inclusive of 3 kg for the mass of an immersion suit and associated equipment). A Canadian study (Reilly et al, 2015) described a 50th percentile body mass (38 male and 4 female subjects) of 85 kg, with the mean body mass for men only being just over 90 kg. The occupant weight of at least 77 kg used for certification purposes could therefore be below the average mass of a member of the offshore workforce in Europe and North America. It can be concluded that, with fixed load energy absorption systems, a proportion of the seats occupied by heavier passengers and crew are likely to 'bottom out' in a high impact accident, as was found in the C-GZCH accident (TSB Canada, 2010). This has implications with respect to underwater escape.

The research undertaken by Taber and co-workers (Taber, 2013; Taber et al, 2015) suggested that helicopter underwater escape from a stroked seat takes longer than escape from a seat in the normal position, but that this may be influenced by practice; in the 2015 study, training staff had fewer problems than were experienced by the test subjects in the 2013 study. Causes of difficulty included the ability to reach the exit, as well as the cramped position making it difficult to locate and release the harness. It was recognised that deployment of some designs of EBS could also be made more difficult by the cramped position. Taber (2013) recommended that offshore personnel be trained to overcome the influence of attenuating seats.

As a proportion of helicopter occupants in a water impact are likely to have to escape from a seat with a more stroked position, it is important to fully understand the extent of the problem relating to stroking seats. In the accident scenario, it is the heavier occupants who are more likely to have to escape from the lowest position. Lighter occupants may not experience the fully stroked position, but those with short stature may still experience problems reaching the exit from a partially stroked seat. In the Taber studies, subjects escaped from both a stroked position and from a normal seat position. Only one helicopter type was simulated and only one immersion suit system and EBS combination was worn by the subjects during the trials.

Further research is therefore needed to assess the effects of body mass and height on ease of escape from stroking seats and further investigate the problems caused by the different seat positions. It is recommended that this research should also consider the effects of the stroked seat position on the ease of EBS deployment, given that successful deployment could provide the time needed to overcome any difficulties due to escape from the stroked seat.

Proposed future research: see 5.3.2.

4.3 Seat harness release

Evidence from the review of accidents shows that some occupants who failed to escape in survivable accidents were found still in their seat, with the harness secured. It is not possible to determine whether non-survivors had problems when attempting to release the harness. Little evidence was found of harness failure in these cases. In the C-GZCH accident (TSB Canada, 2010), seat belt mechanisms were tested and found to be operational. This suggests that the occupants drowned before they were able to release the harness (no EBS was carried by the occupants at this time).

Some problems were reported with the release of lap belts in the 1990 G-BDES accident (AAIB, 1991). Lap belts have now largely been replaced by four-point harnesses with a dual direction rotary buckle and inertia reel functions on the shoulder straps.

Some potential problems relating to harness functionality have been identified during helicopter underwater escape research (see 3.2.3). Jamieson et al (2000, 2001) found problems with harness release during trials where capsize angle was varied, thought to be due to uneven loading on the harness release mechanism. While this study was looking at a potential flotation system that would prevent full inversion (the side-floating concept), uneven seat harness loading could also occur in a helicopter which partially capsized due to flotation system damage on one side of the helicopter. Anecdotally, occasional problems with harness release are also experienced during routine helicopter underwater escape training when the trainee fails to release the harness. Other research projects have highlighted cases where the four points of the harness fail to release simultaneously, or one point failed to release (Coleshaw, 2013; Taber, 2015). Taber (2013) raised concerns that individuals in fully stroked seat positions found it more difficult to locate and operate the harness buckle. Compatibility issues were also demonstrated by Coleshaw (2013) where interference was observed between an EBS system and the harness straps and buckle, with the potential to impair the performance of either one or both items of equipment. While this research has been undertaken in helicopter simulators, it is considered that the harness systems used are sufficiently realistic and representative of the equipment used operationally to raise some concern about harness performance in the operational environment.

Air Operation Regulation CAT.IDE.H.205 relating to seats, safety belts and restraint systems (EU, 2012) states that helicopters shall be equipped with a seat belt with upper body restraint for use on each passenger seat (for helicopters first issued with an individual certificate of airworthiness on or after 1 August 1999). According to CAT.IDE.A.205 each flight crew seat is required to have "*a seat belt with upper torso restraint system incorporating a device that will automatically restrain the occupant's torso in the event of rapid deceleration*". Further, seat belts with upper torso restraint shall "*have a single point release*". No guidance is provided in relation to harness release. Following a rule-making task covering helicopter ditching and water impact occupant survivability (RMT.0120), it was recommended (EASA, 2016a) that "*ETSO-C22g and ETSO-C114 should be modified to: (a) require testing of the release mechanism for correct operation under all foreseeable loading conditions, including uneven loading; all of the harness straps must be correctly loaded, based on a passenger mass that is consistent with current anthropometric data and other ETSOs, such as those for life rafts*".

It is therefore recommended that more work be undertaken to investigate both harness release under varying conditions, and uneven loading on a four-point harness release mechanism. This would help to inform any amendments made to the relevant technical standards (EASA, 2003a; 2003b).

Proposed future research: see 5.3.3.

4.4 Underwater emergency exits

4.4.1 General

The research described in 3.2.4 and 3.2.5 demonstrated that escape through underwater emergency exits is affected by a number of factors including exit size in relation to body size, the ease of operation of the exit release mechanism and the equipment worn by the helicopter occupants.

4.4.2 Exit size

Prior to 2018, there was no regulated size for an underwater escape window (see 3.2.4). The work of Allan and Ward (1986) was the only research found prior to 2014 which attempted to investigate a minimum aperture size for underwater escape based on occupant size and ease of escape. Their data was thought to have been used to inform the UK CAA guidance which followed (e.g. CAA, 2006). The G-WNSB accident in 2014 stimulated a further review of the issue as part of the UK CAA offshore helicopter safety review (CAA, 2014), informed by the anthropometry data generated by the Stewart et al study (2016) of offshore worker body size. As described in 3.2.4, as a result, a new seating scheme was mandated in the UK in 2014 (CAA, 2015c) aimed at ensuring that passengers had easy access to an underwater emergency exit that matched their body size.

The scheme was subsequently incorporated into the EASA air operating rules for Helicopter Offshore Flight Operations (HOFO) in hostile environments, which came into effect in July 2018 in the form of new Acceptable Means of Compliance to SPA.HOFO.165(h) (ED Decision 2016/022/R; EASA, 2016b; EASA, 2019). SPA.HOFO.165(h) states that "*all emergency exits, including crew emergency exits, and any door, window or other opening suitable to be used for the purpose of underwater escape shall be equipped so as to be operable in an emergency*". AMC1 SPA.HOFO.165(h) (EASA, 2016b; EASA, 2019) provides details of the criteria to be met, matching passenger shoulder widths with the size of openings used for underwater escape. Further, GM1 SPA.HOFO.165(h) states that "*the identification and seating of the larger passengers might be achieved through the use of patterned and/or colour-coded armbands and matching seat headrests*".

In the case of new helicopters, 29.807 'Passenger emergency exits' (d) (EASA, 2018b) now states that if a helicopter is certified for ditching, one underwater emergency exit must be provided "*in each side of the rotorcraft, meeting at least the dimensions of a Type IV exit for each unit (or part of a unit) of four passenger seats. However, the passenger seat-to-exit ratio may be increased for exits large enough to permit the simultaneous egress of two passengers side by side*". CS 27 contains a similar requirement except that, instead of a Type IV exit, one underwater emergency exit "*that will admit a 0.48 m by 0.66 m (19 inch by 26 inch) ellipse*" is specified (EASA, 2018a) in each side of the rotorcraft for each unit (or part of a unit) of four passenger seats.

Of the new rules and specification described, one change that has not been verified is the simultaneous egress of two occupants, side-by-side, through an exit large enough to admit two 0.48 m by 0.66 m (19 inch by 26 inch) ellipses (see AMC 29.807(d); EASA 2018b). It is therefore proposed that this be addressed by further research into underwater escape from a helicopter cabin with multiple occupants.

Proposed future research: see 5.2.2.

4.4.3 Hand-holds

A number of research papers recommended that hand-holds be provided in the cabin and close to exits to allow the passengers to pull themselves to and through the exit (Allan and Ward, 1986; Brooks et al 1994).

The benefits of having a hand-hold adjacent to an underwater emergency exit were recognised by the EASA rule-making task group RMT.0120 (EASA, 2016a). In 2018, a requirement was added to the Certification Specifications and Acceptable Means of Compliance for both Small and Large Rotorcraft, CS 27.807 (d)(3) and CS 29.809 (j)(3) (EASA, 2018a; 2018b), stating that each underwater emergency exit in a helicopter certified for ditching must be provided with "*a suitable handhold, or handholds, adjacently located inside the cabin to assist occupants/passengers in locating and operating the exit, as well as in egressing from the exit.*" This requirement applies only to new (post 2018) helicopter designs.

It would be useful to validate the potential benefits provided by the addition of hand-hold(s) located close to the underwater emergency exits.

Proposed future research: see 5.2.1 and 5.2.2.

4.4.4 Release of exits

The review of accidents provided evidence that in some cases, the force of the impact causes distortion or fracture of the airframe, resulting in the dislodgement of the exits (AAIB, 1991; TSB Canada, 2011). While this reduces or removes the need for occupants to have to jettison an exit, it is only likely to occur in accidents where impact forces are high.

In most accidents involving capsize of the helicopter, the crew and passengers must remove underwater emergency exits before they can make their escape. There is evidence of crew having difficulty locating and releasing the jettison handle of their underwater emergency exit (AAIB, 1990; FSIR, 2008a; AAIB, 2016). In one of these cases (FSIR, 2008a) crew were equipped with EBS that provided them with more time to overcome the problems.

Only one accident provided direct evidence of helicopter passengers having difficulty or being unable to release push-out style underwater emergency exits (AAIB, 2016). In this accident, the majority of passengers who removed escape windows reported that this "*was not easy and was significantly harder than they experienced during training*". In the case of survivable accidents where some occupants did not survive, it is not possible to determine whether failure to remove an exit contributed to the non-survival of those individuals. That said, it is known (see 3.2.5) that the time taken to remove an exit increases the time taken to escape (Muir and Mills, 1998) and reduces escape success rates (Bohemier et al, 1991).

While other emergency exit mechanisms are becoming more standardised with time, some problems are still being experienced, such as a cabin door jettison handle not being found as it was obscured by a passenger seat (AAIB, 2011). This case resulted in the door being slid open rather than being jettisoned, thereby blocking two underwater emergency exits. This would have reduced the options for underwater escape if the accident had occurred in rough sea conditions and the helicopter had capsized during the evacuation. Further problems with the jettison of exits were found in the G-CHCN accident (AAIB, 2016; see 3.1.5) over issues which may or may not have been covered by training, and where the required action was not clear to the crew in the accident scenario.

The research conducted by Taber et al (2014, 2017a, 2017b) and King et al (2018), described at 3.2.5, demonstrated that high forces are required to remove an underwater emergency exit representing one of the helicopter designs currently operated by the offshore industry. No published research has been undertaken to date on other designs of helicopter being operated. Serious concerns (Taber and Sweeney, 2014; Taber et al, 2017b) were raised regarding the ability of helicopter occupants to jettison such exits in the event of a survivable water impact.

N.B. The research which has been undertaken to date has often involved more than one variable being studied; making it at times difficult separate the causal factors and gain a clear interpretation of the results.

The certification specifications at CS 27.807 and CS 29.809 (EASA, 2020b; 2020c) state that "*the means of opening each emergency exit must be simple and obvious and may not require exceptional effort*". AMC 29.809 (b)(3) iii and AMC 27.807 (d)(b)(8) iii (EASA, 2017a; 2019) state that underwater emergency exits are considered to be non-compliant if the exit does not meet the opening effort limitations set by FAA AC 29.809 (FAA, 2008). This Advisory Circular in turn states at (b)(1) that "*If the effort required to open the exit is in the range of 40 to 50 pounds, it is recommended that a person of slight stature, such as a female in the 90 to 110 pound weight range, be used for the exit opening demonstration/test. In any case, the average load required to operate the exit release mechanism and open the exit should not exceed 50 pounds, and the maximum individual load of a test series should not exceed 55 pounds*".

The origin of the maximum loads in the FAA Advisory Circular (FAA, 2008) is not known. However, a historic study undertaken by the FAA's Civil Aviation Research Laboratory (McFadden et al, 1959) investigated the magnitude and direction of forces that can be exerted when operating fixed-wing aircraft emergency exits, to provide criteria for the establishment of recommended practices and design standards as related to structural reliability and operation of exits. They were also reported to be interested in establishing "*a crude range of the subject's force capability*" when operating exits. They measured the maximum forces applied to D-ring handles. When seated, pulling a rubber-covered D-ring with a 5 s muscular contraction, female subjects exerted mean forces of 53 lb (left hand) and 69 lb (right hand). Higher forces were applied when standing, demonstrating that the forces that can be achieved are dependent upon the position of the person and their ability to apply load in that position. Higher forces were also achieved when using a jerk action when standing, suggesting that higher loads were achieved with a dynamic action. Maximum jerk forces were thought to be limited by grip strength. An earlier study (McFadden et al, 1958) found that the variation in forces exerted between individuals was not only due to muscular strength but also differences in limb length when lifting a handle at a fixed distance from the floor.

Research to date suggests that this 24.95 kg (55 lb) maximum force required to jettison a standard over-wing exit, in air, is much lower than the forces required to jettison some helicopter underwater emergency exits. More importantly, it is not known whether the 24.95 kg (55 lb) maximum force is appropriate for occupants inside a flooded and inverted cabin attempting to operate a push-out style underwater emergency exit, or whether this is assessed when a helicopter is certified for ditching. Work is therefore recommended to define an acceptable maximum jettison force for underwater emergency exits.

Proposed future research: see 5.2.1.

4.5 Disorientation

Numerous research studies have demonstrated that disorientation is experienced by a majority of individuals exposed to submersion and capsize within a helicopter (Bohemier et al, 1998; Cheung et al, 2000; Jamieson et al, 2001; Mills and Muir, 1998; Rice and Greear, 1973). These studies suggest that the main problem relates to locating the nearest exit to achieve a rapid escape, with severe disorientation causing confusion, panic and a loss of direction.

When considering how to reduce disorientation, any measure that prevents or delays complete inversion is likely to have the most significant impact. The certification specifications for new helicopter designs at CS 27/29.801(e) and CS 27/29.802(c) (EASA, 2018a; EASA, 2018b) now invoke scale model testing in irregular waves as an acceptable means of demonstrating post-ditching flotation stability, and require a limitation corresponding to the demonstrated sea-keeping performance to be included in the rotorcraft flight manual. This is expected to improve the capsize resistance in waves, delaying or reducing the probability capsize. If escape could be achieved prior to capsize the problem of disorientation would be largely removed. Disorientation was also found to be greatly reduced (Jamieson et al, 2000; 2001) by the side-floating concept described in 3.2.11. With their heads above water the occupants had time to orientate themselves before making an escape.

In the absence of these measures, some of the other measures taken to improve safety may reduce the problems caused by disorientation following capsize:

- the successful use of EBS should provide occupants with more time to orientate themselves and plan a route to their nearest exit;
- provision of continuous visual and tactile cues to guide occupants to an exit;
- the provision of hand-holds (see 4.4.3) may reduce the impact of disorientation.

It is concluded that no further research into disorientation is required.

4.6 Vision underwater

The ability to see properly underwater is a significant factor in making an underwater escape from a submerged helicopter.

In the G-TIGH accident (AAIB, 1993) it was reported that none of the passengers recalled seeing the exit lighting. There was no evidence to suggest that it was not working, and the investigators thought that they may have escaped before the lights were activated. Most survivors had difficulty with the poor visibility under the water in the G-WNSB accident (2016), with one passenger describing finding the exit window by feel alone.

The research described in 3.2.7 demonstrates that there are a number of factors which reduce vision underwater and increase the difficulty of escape, including visual acuity underwater (Luria and Kinney, 1969), dark conditions (Mallam and McKinnon, 2011) and bubbles. Other work has evaluated the effectiveness of exit lighting systems (Ryack et al, 1977; Ryack et al 1984) and recommended optimum lighting arrangements. More recent work by O'Neil et al demonstrated that current exit lighting systems can be detected at 1.5 m in dark and in turbid conditions, with deterioration at 3 m.

SPA.HOFO.160 Equipment requirements (EU, 2016) state that "*all emergency exits, including crew emergency exits, and any door, window or other opening that is suitable for emergency egress, and the means for opening them shall be clearly marked for the guidance of occupants using them in daylight or in the dark. Such markings shall be designed to remain visible if the helicopter is capsized or the cabin is submerged*".

In practice, numerous Helicopter Emergency Egress Lighting (HEEL) systems are available on the market for this purpose.

One of the other means to potentially improve vision underwater is the provision of swimming goggles or a diving mask (Allan and Ward, 1986; Brooks, 1989; Luria and Kinney, 1969). In Canada, all passengers flying offshore carry diving masks. The masks are stowed under the seat while not in use, but most passengers, after adjusting it for fit, wear the mask on their sleeve during transit, ready for use. Potential problems include the need for one size to fit all, which would be difficult to achieve if the mask is to fit well, and issues around clearing the mask if deployed underwater. Swimming goggles, if used, would have to be deployed prior to submersion.

This issue was considered by the rule-making task group RMT.0120 (EASA, 2016a) but no further action was taken by the RMT due to uncertainty over the ability of helicopter occupants to be able to don the mask or goggles before submersion. It is considered that this topic deserves further research, given the low cost of implementation and the safety improvement that might be gained if occupants had improved vision underwater, making it easier to locate the exits.

Proposed future research: see 5.3.4.

4.7 Escape routes and cross-cabin escape

The review of accidents demonstrated that occupants do not necessarily escape through their nearest exit, in many cases using other options.

In the G-WNSB water impact accident (AAIB, 2016) a wide range of underwater escape routes were reported by the survivors. Where the escape route was known (in 11 cases) only four passengers were sitting next to an exit and escaped through that exit. Four passengers undertook a 'cross-cabin' escape when this was not their shortest route to an exit. Some individual underwater emergency exits were used by up to three passengers, meaning that the second and third person escaping would presumably have had to wait for individuals in front of them to escape before following them through the exit. It is of note that current helicopter underwater escape training (OPITO, 2020) is all undertaken with the trainee sitting in a seat next to an exit window, and is instructed how to escape through that exit. No cross-cabin exercises are included (see 4.14 for further analysis of training issues).

It would be interesting to understand the decision process used to select an exit. In water impact accidents, it is not known if any of those who followed others out through an exit did so because they were unable to remove their nearest exit. In the Inquiry that followed the C-GZCH accident (Wells, 2010b) Taber commented that "*an obstruction such as an auxiliary fuel tank placed between the individual and an exit may impede egress*". Disorientation and low visibility may also influence the escape route followed.

A number of research projects have shown that disorientation and confusion about the direction of travel to reach an exit result in difficulty locating exits when the individual is required to cross the cabin or move to an exit in front or behind their designated seat (Bohemier et al, 1999; Jamieson et al, 2001; Mills and Muir, 1998).

The certification specifications for new helicopter designs at CS 27.807(d)(1) and CS 29.813(d)(1) now require passenger seats to be located relative to underwater escape exits in a way that best facilitates escape with the helicopter capsized and flooded (EASA, 2018a; 2018b). Means to assist cross-cabin escape following capsize are considered in CS 29.813(d)(2) and in AMC 29.813 (EASA, 2018b), with the statement that "*the means provided to facilitate cross-cabin egress should be accessible to occupants floating freely in the cabin, should be easy to locate and should, as far as practicable, provide continuous visual and tactile cues to guide occupants to an exit*". The AMC also aims to ensure that "*no occupant should need to wait for more than one other person to escape before being able to make their own escape*".

While these specifications help to address the problem in new helicopters, the issues still exist in current designs. It is also the case that while a design improvement may help, the evidence from the accidents reported suggests that occupants are still likely to take unexpected routes to underwater emergency exits when suffering from extreme disorientation. It would therefore be of value to undertake further research looking into the decision-making that influences choice of escape route.

The problems experienced when an occupant is not sat next to an exit also need to be addressed by helicopter underwater escape training (HUET). If further knowledge could be gained about the decisions made when selecting an exit, this would help to inform the arguments to be made regarding higher fidelity training. This is discussed further in section 4.14.

Proposed future research: see 5.2.2. ; 5.2.3

4.8 Time to escape

The majority of the helicopter underwater escape research undertaken involves either individuals or small numbers of subjects escaping from a helicopter simulator at any one time. This makes it much easier to monitor the performance of each trial subject, and allows a high level of safety to be achieved. As the number of trial subjects within the helicopter at any one time is increased, it becomes more difficult to control the risks. This needs to be taken into account by the investigators when applying for ethical approval to undertake underwater escape trials.

As a result, research undertaken to date investigating the time taken to escape has been biased towards the time taken by an individual to complete the escape process, which generally varies from about 15 to 25 s. Only one study was identified which investigated the time taken for all occupants to escape from a simulated Super Puma cabin (Brooks et al, 1999b; 2001). With an 18-seat configuration and a slow 180° inversion, participants took between 43 s and 109 s to escape, with the last person out being underwater for 92 s (see 3.2.10). These trials were all conducted using highly trained rather than naïve subjects. It is not known how long it would take for all occupants to escape with modern seating configurations, and representative exits.

If these times are representative of the real situation, then those occupants who are last out must successfully deploy and use EBS if they are to survive. As previously discussed (3.2.13), breath-hold times are greatly reduced when a person is immersed in cold water due to the cold shock response. It is highly unlikely that anyone would be able to breath-hold for 90 seconds in cold water, in a highly stressful environment.

The air operations rules relating to underwater escape are based on the expectation of an underwater survival time of 60 seconds in the event of capsize (AMC1 SPA.HOFO.165(h) Additional procedures and equipment for operations in a hostile environment (EASA, 2017a; EASA 2019)). Based on the Brooks et al (1999b, 2001) study, it is not clear that the full evacuation of a passenger cabin, with seating for 19 passengers, could be achieved within 60 seconds.

This proposal is supported by the authors of Air Accident Report 1/2016 (AAIB, 2016), who called for research into the whole evacuation process from start to finish, under realistic conditions.

It is therefore proposed that further research is needed to better quantify the underwater escape process, using a full complement of subjects in the helicopter simulator, in light and dark conditions, and thereby establish whether a 60 second escape time is achievable under a range of conditions. It is proposed that the trials would also be used to investigate the different possible seat configurations specified in CS 27/29.807 'Passenger emergency exits' (d) (EASA, 2018a; 2018b), investigating ease of escape from groups of four passenger seats and the possibility of two passengers escaping side by side through a large exit. No evidence has been found which demonstrates that this latter design option has been tested.

Proposed future research: see 5.2.2.

4.9 Effects of capsize angle

Research undertaken to date to investigate the side-floating concept (CAA, 2005a; Howson, 2006; Jackson and Rowe, 1997; Jamieson et al, 2000; 2001) has demonstrated the safety benefits of achieving a helicopter flotation attitude following capsize where one set of exits are above the water surface and an air gap is maintained within the cabin. Further research (Delorme et al, 2009; Denante et al, 2008) proved the concept of locating additional flotation devices high on the fuselage in the vicinity of the main rotor gearbox, with the benefits of an air gap and flotation redundancy, although some technical issues were also identified in this feasibility study.

A research project is currently in progress (EASA, 2020d) investigating enhanced emergency flotation systems for helicopters. The overall objective of this study is to establish the feasibility of providing a step change in occupant survivability through the side-floating concept.

It is concluded that no further research into the side-floating concept is required at this time.

4.10 Cardiac responses to underwater escape

While the accident review only provided evidence of one individual suffering a heart attack shortly after escaping from the helicopter (AAIB, 2016), there is a growing body of evidence showing cardiac irregularities associated with cold immersion, and more specifically with helicopter underwater escape (Tipton et al, 2010). The autonomic conflict described by Shattock and Tipton (2012) and the potential incidence of arrhythmias during HUET is of most relevance to training organisations, given the high numbers of individuals exposed to the HUET every year. It may be a good reason for not undertaking HUET training in cold water, despite the fact that this would make the training more 'realistic'.

While arrhythmias leading to a cardiac event may be one reason why some occupants fail to escape, and while further research would be useful to identify any risks associated with higher fidelity training, such work would not provide information that will help in future rule-making tasks undertaken by EASA.

It is concluded that further research by EASA into cardiac responses is not required.

4.11 Personal safety equipment

In the case of accidents where an occupant has successfully escaped from the helicopter but has then not survived (AAIB, 1993; AAIB, 2016; BFU, 2014; TSB Canada, 2010; TSB Canada, 2015), it is often not possible to determine whether they drowned during the escape process or after reaching the water surface (3.1.6). EBS are provided to reduce the risk of drowning during escape. Once on the water surface, both the immersion suit and the lifejacket worn will provide buoyancy and protection from drowning as well. In addition, the immersion suit importantly provides protection from the initial cold shock responses as well as providing insulation to reduce body cooling.

Without the use of EBS, occupants may not be able to breath-hold for sufficient time to complete all of the actions required to escape and then reach the water surface. The mismatch between breath-hold time and underwater escape time is well documented (see 3.2.13). This is likely to have contributed to the non-survival of at least one individual in the G-TIGH (AAIB, 1993) and G-WNSB (AAIB, 2016) accidents.

The use of EBS for offshore operations has increased over the last 20 years, but the type of EBS used has varied, and until recently, passengers have often carried EBS while the crew have not. While there was one example of military crew members successfully using compressed air EBS (FSIR, 2008a), some problems were experienced in another accident (FSIR, 2008b), but no published cases were found of passengers successfully using EBS when flying offshore. This may in the most part be due to the small number of survivable water impact accidents that have occurred since the introduction of EBS for offshore operations in hostile sea areas. However, the fact that the hybrid EBS was not successfully used in the G-WNSB raises a number of important points:

1) Was the fidelity and frequency of training sufficient to allow the passengers to use the EBS in an emergency situation?
2) Was the design of the EBS sufficiently intuitive for use in an emergency situation?
3) Personal safety equipment is provided for use when all other safety mitigation measures have failed and reliance should not be placed on the individual to use the equipment correctly in an emergency.

The carriage of EBS was not mandated in the European Union until 2016 (EU, 2016), with a regulation stating that "*all persons on board shall carry and be instructed in the use of emergency breathing systems*". EASA qualified this rule in AMC1 SPA.HOFO.165(c) (EASA, 2017a; EASA 2019) by stating that the EBS carried should be capable of rapid underwater deployment. This followed a 2015 mandate for passengers to carry Category A EBS in the UK (CAA, 2015b; CAA, 2015c), and for all occupants including flight crew from January 2016, with an exemption if the helicopter was fitted with additional flotation to provide an air gap in the cabin (the side-floating concept). For the previous 15 to 20 years, passengers flying offshore in Europe had carried either a rebreather EBS or hybrid rebreather system, following offshore industry initiatives to improve safety. In the UK, the change from a hybrid to a compressed air EBS occurred following the 2013 G-WNSB accident and in response to the UK CAA's offshore helicopter safety review, CAP 1145 (CAA, 2014) which recommended use of Category 'A' EBS meeting the requirements of the draft technical standard in CAP 1034 (Coleshaw, 2013) (see 3.2.15). It is not mandatory for Category 'A' EBS to be compressed air, but only compressed air systems have so far been assessed by the UK CAA which meet Category 'A'.

In Canada, both the provision of EUBA (EBS), for passengers and crew, and training in the use of EBS was mandated in 2015 (TSB Canada, 2015; CAR 602.66). The Canadian offshore industry had started training and introduced compressed air EBS for offshore operations in 2009 following the C-GZCH accident (Brooks et al, 2010).

Until recently, there was no published technical standard for EBS. The need for a technical standard was recommended by Coleshaw (2003), to ensure that minimum acceptable levels of performance were achieved and health and safety standards could be met by products on the market. This led to the further research described in 3.2.15, and the publication of the proposed technical standard in CAP 1034 (Coleshaw, 2013).

The draft technical standard was adopted by the standards body ASD-STAN and after further refinement, a full standard was eventually published as EN 4856 in 2018 (CEN, 2018) and republished by EASA in ETSO-2C519 (EASA, 2020a). Rather than focussing on the design of products and whether an EBS uses compressed air or rebreather technology, this standard provides minimum performance requirements for the equipment. Two categories of EBS are currently defined to cover all products currently in use. A 'Category A' EBS is defined as having "*the capability to be rapidly deployed and used both in air and underwater. These designs of EBS are suitable for use when capsize and/or sinking occurs immediately after the helicopter makes contact with the water*". A 'Category B' EBS is defined as having "*the capability to be deployed in air and used both in air and underwater. These designs of EBS are suitable for use where there is sufficient time to deploy the equipment prior to any subsequent submersion. They will have limited capability in water impact accidents as capsize and/or sinking is likely to occur immediately after the helicopter makes contact with the water*". As a result, Category A EBS are more likely to be selected for use in hostile sea areas.

This means that EBS manufacturers now have a process to follow for their products to be approved, while meeting minimum performance requirements. For successful underwater escape in cold water, the ability of users to rapidly deploy the EBS is considered critical, whether that is achieved before submersion or when already underwater. Compliance with the requirements of the technical standard should help to ensure that this can be achieved in future accidents. The other factor which will influence correct use is effective training (4.14). If an occupant is able to successfully deploy EBS, under most conditions they should have sufficient time breathing from the EBS to allow them to complete the actions needed to escape and reach the water surface. The technical standard (CEN, 2018; EASA, 2020a) uses 60 s as the minimum performance requirement for duration of use.

Once an occupant reaches the water surface, survival will in many cases be dependent upon the sea surface conditions and the availability of a life raft. If a life raft is not immediately available for boarding, the immersion suit and lifejacket system worn will help to protect the individual from drowning. Both the immersion suit and the lifejacket worn will provide buoyancy. The lifejacket (integrated or worn separately) should also help turn and maintain the individual in a face-up position with the mouth and nose clear of the water surface. The sprayhood will provide protection from wave action, if deployed. All of these factors will reduce the risk of drowning when floating on the water surface. Conversely, factors that will increase the likelihood of drowning include waves splashing or washing over the face of the individual whose airways are not being protected by an effective sprayhood and a lack or loss of buoyancy which results in the mouth and nose being too low in the water (low freeboard) or the failure to self-right an unconscious or exhausted survivor.

Lifejackets were worn by helicopter occupants in all but one of the accidents reviewed. The one exception (BFU, 2014) was a flight that should not have followed a route over open water. In this one case, the lack of a lifejacket or any protective clothing worn by the occupants was thought to have been a significant factor leading to non-survival.

In the Canadian SAR accident (TSB Canada, 2015), where lifejackets were carried, all three of the occupants were found floating in a position where their mouth and nose were not clear of the water surface, which would have increased the likelihood of drowning:

- The pilot had donned a lifejacket prior to departure, but it appeared that he had removed the lifejacket after escaping from the aircraft (the lifejacket was found in the water in the inflated state).
- One occupant was found face-down in the water with his lifejacket uninflated. It is not known if this individual drowned during the escape, before reaching the surface, or if he reached the surface but was then unable to inflate the jacket. The accident report suggests that he may have been incapacitated by the effects of cold immersion.
- One occupant was wearing a partially inflated lifejacket and was found floating on his side; full inflation of both sides of the lifejacket would have been needed to turn the individual face-up. The accident report records the fact that there had been issues identified with the packing of the lifejacket, which could have affected inflation performance, although it could not be determined if this had been the cause of the partial inflation.

It is of note that in this accident (TSB Canada, 2015), the life raft carried on the helicopter was not deployed and was found within the recovered cabin. The survival of these three occupants, in water at -0.6 °C, was therefore dependent upon adequate performance of their personal safety equipment, which was not achieved.

While only a limited amount of research work has been published with regard to lifejacket performance (3.2.14), a significant amount of knowledge has been gained by the industry from lifejacket testing conducted over the years, while designs have been improved in response to the findings of accident reports.

In accordance with Commission Regulation (EU) No 965/2012 as amended (EU, 2012), approved lifejackets are required to be worn at all times by all persons on board a helicopter unless integrated survival suits that meet the combined requirement of the survival suit and life jacket are worn (see CAT.IDE.H.310, EU, 2012;

SPA.HOFO.165, EU, 2016). Since 2006, the minimum standard of design and performance for a helicopter constant-wear lifejacket has been prescribed by the EASA standard 'Helicopter constant-wear lifejackets for operations to or from helidecks located in a hostile sea area', ETSO-2C504 (EASA, 2006c). The standard covers issues such as means to prevent the lifejacket riding up the body, mouth freeboard, ability to right an unconscious person and spray hood performance. ETSO-2C504 is currently under a major revision process, which aims to update the requirements in line with current knowledge and good practice.

As described in 3.2.16, immersion suits provide protection from hypothermia due to immersion in cold water, but also play an important role in protecting the wearer and reducing the risk of drowning due to the cold shock response. The accident review demonstrates some problems with suits that leak (DSB, 2010), although this appeared to have been caused by the suit not being fully zipped up (AAIB, 2014; TSB Canada, 2015) rather than leaking seals.

The findings of the C-GCFU accident report (TSB Canada, 2015) also emphasised the need for occupants to select a suit with the correct level of thermal insulation for the water temperature conditions that might be experienced in the event of an accident. There were also a number of accidents in the North Sea where crew members were either not wearing an immersion suit (AAIB, 2016) or were wearing their suits with the zip down at the time of the accident (AAIB, 2014).

In accordance with Commission Regulation (EU) No 965/2012 as amended (EU, 2012), helicopter passengers and crew flying over water when the sea temperature will be less than plus 10 °C during the flight are required to wear an approved survival [immersion] suit (see CAT.IDE.H.310, EU, 2012; SPA.HOFO.110, EU, 2016; and SPA.HOFO.165, EU, 2016). The minimum standard of design and performance for a helicopter crew and passenger immersion suits is prescribed in two technical standards: ETSO-2C503 covers immersion suits designed to be used with a separate approved lifejacket and ETSO-2C502 covers integrated immersion suits which incorporate the functionality of a lifejacket. These standards include requirements for thermal protection, water ingress, buoyancy and floating position and helicopter escape. Only one level of thermal insulation is specific in the current standard, meaning that crew have the option, when sea water temperatures are 10°C or higher, of either not wearing an immersion suit, or wearing a suit with a relatively high level of thermal insulation. Immersion suits were not worn by the crew in the G-WNSB accident (AAIB, 2016) due to high temperature in the cockpit on the day of the accident. RMT.0120 (EASA, 2016a) recommended that "*requirements for the wearing of survival suits as a function of sea temperature should be revised, with staged limits versus immersion suit insulation levels*".

The two immersion suit technical standards (EASA, 2006a; 2006b) are currently being revised and replaced with a single standard. Issues such as the appropriate level of thermal insulation required by different user groups, the ability of users to turn or be turned to a face-up floating position and the ability to complete tasks with gloved hands are all being addressed by the revision. The revised technical standard will allow the approval of an uninsulated suit as well as versions with three different levels of thermal insulation.

Gloves have also proved to be an issue in accidents, either due to difficulties donning the gloves with already cold hands, or due to the problem of attempting to undertake manual tasks with gloved hands. This issue will be addressed by both of the new technical standards for lifejackets and immersion suits.

It is concluded that further research by EASA into personal safety equipment is not required.

4.12 Occupant and test subject demographics

Following the G-WNSB accident (AAIB, 2016) the accident investigators raised concern about the influence of passenger demographics on successful egress from an inverted helicopter. Further, the UK CAA's review of offshore helicopter safety (CAA, 2014) had identified the fact that escape time can be affected by exit size in relation to passenger body size (including survival equipment). They were concerned about the adequacy of the minimum size of push-out windows in the context of increases in both passenger size and the bulk of personal safety equipment. At the time of the accident, data relating to the demographic of the UK offshore work force was almost 30 years out-of-date (3.2.17).

The review of research demonstrates that some significant work (Ledingham et al, 2015; Stewart et al, 2016) has been undertaken in recent years to update anthropometric information about the offshore workforce in the UK. Some of this work was already underway at the time of the accident, but it provided an opportunity to address some of the question pertaining to the relationship between body size and shape and underwater emergency exit size. This data was then used to inform the work undertaken by the UK CAA and EASA (3.2.4) to amend the air operation rules for offshore helicopters and the certification specifications for new helicopters.

While this research has gone a long way to address the issues relating to body size, one further factor that is likely to influence ease of escape is the flexibility of the body. This is likely to vary greatly between individuals and between age groups. It is proposed that this could be investigated as part of the proposed further research into underwater escape from the passenger cabin with a full complement of passengers.

Proposed future research: see 5.2.2.

4.13 Life Rafts

Life rafts are provided to give the passengers and crew the best chance of survival following evacuation or escape from the helicopter. Following an underwater escape, the survivor must swim to and board the life raft which requires a huge amount of effort in many cases, and which can be especially difficult if the individual is injured or fatigued. If the survivor fails to board a life raft they will remain at risk of drowning in heavy seas and breaking waves and will be in danger developing hypothermia if rescue services are not close to hand.

In a ditching, a life raft that can be boarded directly from the helicopter will greatly reduce the need for occupants to enter cold water and avoid the difficulties of boarding. The greatest challenges for a survivor in the water have been shown to be the ability to reach the life raft, and then board it. Rapid life raft boarding is also important for maintaining the body temperatures of survivors, with body cooling on the raft being roughly half that observed during cold water immersion (Hall, 1972).

Some of the issues raised by the accidents reviewed include:

- Problems with deployment.
- Problems boarding the life raft.
- Once inflated, the life raft was blown against the side of the helicopter, in one instance blocking the passenger door.
- Life raft inflated on top of the sponson, restrained by tangled retaining lines.
- Life raft drifted under the tail rotor risking puncture damage.
- Life raft drifted away from the survivors.
- Life raft overturned in high sea states.
- Failure to deploy sea anchors.
- Occupants unable to locate knife due to low light levels.

Many of these issues have previously been identified in other studies assessing life raft performance (Anton, 1984; CAA, 1984; Kinker et al, 1998; Brooks and Potter, 1998), suggesting that measures are needed to address the problems.

Recent changes have been made to the certification specifications following a number of recommendations relating to life rafts made by RMT.0120 (EASA, 2016a):
"*(a) The effect that damaged carbon fibre/carbon-reinforced plastic may have on the integrity of the life raft should be considered when designing life raft containers.*
(b) AMC on the location of externally mounted life rafts should be developed with particular emphasis on protection from impact loads and damage.
(c) There should be three means of life raft release.
(d) There should be clear indicator markings showing the location of external deployment handles".

For new helicopters, a number of the identified issues are now covered by AMC 27/29.1415 Ditching equipment (EASA, 2020b; 2020c):

- It should be verified that the length of the long retaining line will not result in the life raft taking up a position which could create a potential puncture risk or hazard to the occupants, such as directly under the tail boom, tail rotor or main rotor disc.
- Life raft activation should be provided for each life raft "*(A) primary activation: manual activation control(s), readily accessible to each pilot on the flight deck whilst seated; (B) secondary activation: activation control(s) accessible from the passenger cabin with the rotorcraft in the upright or capsized position; if any control is located within the cabin, it should be protected from inadvertent operation;*

and (C) tertiary activation: activation control(s) accessible to a person in the water, with the rotorcraft in any foreseeable floating attitude, including capsized".

- Successful deployment of life raft installations should be demonstrated in all representative conditions, including underwater deployment, if applicable. Consideration should be given to all reasonably foreseeable rotorcraft floating attitudes, including upright, with and without loss of the critical emergency flotation system (EFS) compartment, and capsized.
- Projections likely to cause damage to a deployed life raft should be avoided by design, or suitably protected to minimise the likelihood of their causing damage to a deployed life raft.

The certification specifications for new helicopter designs at CS 29.803 (EASA, 2018b) state that: "*(c) If certification with ditching provisions is requested by the applicant: (1) ditching emergency exits must be provided such that following a ditching, in all sea conditions for which ditching capability is requested by the applicant, passengers are able to evacuate the rotorcraft and step directly into any of the required life rafts*". At AMC 29.803 Emergency evacuation (EASA, 2018b) provision is made with regard to life raft entry: "*It should also be substantiated that the life rafts can be restrained in a position that allows passengers to step directly from the cabin into the life rafts. This is expected to require provisions to enable a cabin occupant to pull the deployed life raft to the exit, using the retaining line, and maintain it in that position while others board*". These provisions also apply to small multi-engine rotorcraft certificated as Category A by meeting the requirements of CS 27 Appendix C (EASA, 2018a).

The technical standard for life rafts (ETSO-2C505, EASA, 2006d) is currently being revised. Issues being addressed include inflation systems, deployment, length of retaining lines, boarding facilities and resistance to puncture.

It is concluded that further research by EASA into life raft performance is not required.

4.14 Training

The review of accidents (3.1.8) provided evidence of the benefits of helicopter safety training, but also highlighted areas where training was either inadequate or had been forgotten. Experience from ditching accidents such as G-REDW (AAIB, 2014) shows the benefits of training when procedures are correctly followed. While a ditching is an emergency situation, levels of stress will be much lower than those found in a water impact and there is much more time available to execute a controlled evacuation of the cabin.

The survivors of the G-WNSB accident highlighted the significance of helicopter underwater escape training to their successful evacuation from the helicopter (AAIB, 2016), but they were also reported to have "*repeatedly commented that their experience of escaping from the helicopter cabin was very different from that simulated in training*". The accident report suggests that the passengers "*were unaware that the hybrid LAP Plus jacket had an automatically released air supply. They believed that the EBS would only be of assistance if they inflated it manually with an expelled breath*". It should be noted that the training provided to offshore workers at this time did cover the gas cylinder and release of gas on water entry, but this gas release was not experienced during practical training exercises. This suggests that some details of their training had been forgotten, with a significant impact on their survival experience. Further, the majority of passengers who removed windows to escape reported that "*this was not easy and was significantly harder than they experienced during training*". This raises concerns over the physical fidelity of HUET.

There is currently no mandate for helicopter underwater escape training (HUET). Underwater escape training for crew is an option covered by AMC1 ORO.FC.230(a)(2)(iii)(F) Recurrent training and checking, ED Decision 2016/019/R (see EASA, 2019). HUET is mentioned as a component of water survival training, but greater emphasis is given to the use of life rafts and lifejackets. It states that:

"*Training should include the use of all survival equipment carried on board life-rafts and any additional survival equipment carried separately on board the aircraft;*
— consideration should be given to the provision of further specialist training such as underwater escape training. Where operations are predominately conducted offshore, operators should conduct 3-yearly helicopter underwater escape training at an appropriate facility;
— wet practice drill should always be given in initial training unless the crew member concerned has received similar training provided by another operator".
No detail is provided with regard to minimum requirements for the underwater escape training.

Given the lack of any mandate for HUET, the investigators of the G-WNSB accident raised concerns that "*there is no common minimum standard specified by the regulator for the provision of such training, nor any regulatory requirement to have undertaken training prior to travelling offshore*". Despite the fact that EASA state that they do not have the remit to directly regulate passengers (AAIB, 2016) the investigators recommended that EASA "*amends the operational requirements for commercial offshore helicopter operations, to require operators to demonstrate that all passengers and crew travelling offshore on their helicopters have undertaken helicopter underwater escape training at an approved training facility, to a minimum standard defined by the EASA*".

Passenger training is currently undertaken following industry standards established by organisations such as OPITO, NOGEPA and the Norwegian Oil and Gas Association (e.g. OPITO, 2020). Passengers are required to undergo further/refresher training within 4 years.

When considering the retention of training skills (see 3.4.5) the Mills and Muir (1999a, b) research into training concluded that the quality and fidelity of training provided was more important than the recency of the training. They were unable to identify the optimum point of retraining but did observe skills and knowledge decay in some individuals regardless of the length of training interval (from 6 to 48 months). They recommended a longitudinal study to assess the optimal retraining period for HUET skills. Others have shown significant decrements in skills and HUET performance over periods of much less than 4 years. Summers (1986) concluded that a two-year training interval was too long and suggested that skill decay could have occurred within 6 to 12 months. Kozey et al (2006) concluded that skills could be retained for 6 months so long as sufficient training in the task is given in the first place.

As there is likely to be significant resistance from the oil and gas industry and the offshore workforce to any increase in training frequency (reduction of the training interval), there is a need to further investigate both the retention of HUET skills over time and means to improve skills retention. Consideration should be given to the adequacy of initial (basic) training, and any measures that could be taken to reinforce the learning between practical training courses.

The fidelity of training has repeatedly been challenged in research reports (see 3.4.2), with a significant body of work being undertaken by Taber's group in Canada investigating issues such as the use of representative exits in training and stroking seats (e.g. Taber, 2014; Taber and Sweeney, 2014; Taber et al, 2017a).

In 2014, the UK CAA (CAA, 2014) made a recommendation to the UK oil and gas industry to review and enhance its safety and survival training standards with regard to the fidelity and frequency of training provided. The potential improvements suggested included escapes through 'worst case' exits, cross-cabin escapes, and exposure of trainees to representative examples, in role and type, of real helicopters.

A number of significant gaps in the fidelity of training have been identified in this report. At the present time, all underwater escape exercises in the OPITO basic and further training course (OPITO, 2020) are undertaken from a seat next to the exit, allowing the individual to directly locate and remove the exit with the harness still fastened, before then releasing the harness and escaping through the exit. No cross-cabin exercises are included within the HUET courses, meaning that the trainees never experience the problem of having to locate an exit from an aisle seat. Trainees do not have to wait for another occupant to escape before using the exit either. In the past, training included escape with two trainees sitting side-by side, but this resulted in injuries when trainees competed to use a single exit. However, other methods could be used to train for escape from an aisle seat. Another gap relates to current EBS training in the UK, caused by the additional medical requirements required for trainees to use compressed air EBS in the helicopter simulator (see 3.2.15). While trainees learn to use the EBS in shallow water they are given no experience of deploying the equipment, seated in the helicopter simulator, as part of an escape sequence where the order of completing tasks is an important factor. There is little doubt that the inclusion of such tasks and experience into the training would provide safety benefits in the event of an accident.

The current basic helicopter safety training (OPITO, 2020) only includes one capsize exercise and only two opportunities to operate a push-out window underwater.

No passenger training is currently undertaken in reduced light conditions. This alters the underwater experience, but there may be few training benefits from completing exercises under reduced light conditions.

Further work is therefore needed in terms of frequency and fidelity to determine how training could be improved while taking account of the potential additional risks imposed by the training and without adding undue stress to the training.

A study of the relationship between the fidelity and frequency of HUET training is therefore recommended, to improve the survival outcome in future accidents.

Proposed future research: see 5.2.3.

5. Recommendations for Further Research

5.1 General

The gaps and shortfalls in knowledge identified in section 4.0 have been reviewed and priority areas for future research activities proposed.

High potential benefit projects are:

- Establishment of a maximum operating/jettison force for underwater emergency exits.
- Study of underwater escape from the passenger cabin with a full complement of passengers.
- Fidelity and frequency of passenger training.

The above projects are considered to provide the greatest safety benefits, giving consideration to both the survivability of occupants in water impact accidents and the provision of a robust evidence base for the rule-making process.

Other identified projects are:

- Bracing position for helicopter passengers.
- Attenuating seats.
- Harness release.
- Underwater vision.

5.2 High potential benefit projects

5.2.1 Forces required to jettison push-out underwater emergency exits

Applicable Regulations, related acceptable means of compliance and guidance material:

Commission Regulation (EU) No 965/2012 of 5 October 2012 (EU, 2012); CAT.IDE.H.310 Additional requirements for helicopters conducting offshore operations in a hostile sea area amended by COMMISSION REGULATION (EU) 2016/1199 of 22 July 2016 (EU, 2016); SPA.HOFO.165 (h) states that for emergency exits and escape hatches "*All emergency exits, including crew emergency exits, and any door, window or other opening suitable to be used for the purpose of underwater escape shall be equipped so as to be operable in an emergency*".

The certification specifications at CS 27.807 and CS 29.809 (EASA, 2020b; 2020c) state that "*the means of opening each emergency exit must be simple and obvious and may not require exceptional effort*". AMC to CS 29/27, at AMC 29.809 (b)(3) iii and AMC 27.807 (d)(b)(8) iii (EASA, 2017a; 2019) make further reference to the effort required to open an exit.

Background:

In the G-WNSB accident (AAIB, 2016), the majority of passengers who removed escape windows reported that this "*was not easy and was significantly harder than they experienced during training*".

Some research work has been undertaken using an underwater emergency exit representing a single helicopter type (Taber and Sweeney, 2014; Taber et al, 2017a; Taber et al, 2017b; King et al, 2018). This has demonstrated that high forces are required to remove this type of exit, raising serious concerns regarding the ability of helicopter occupants to jettison exits when required. No research on other helicopter types has been published. The research which has been undertaken to date has often involved more than one variable being studied, making it difficult to achieve a clear interpretation of the results.

AMC to CS-29 and CS-27, at AMC 29.809 (b)(3) iii and AMC 27.807 (d)(b)(8) iii, state that underwater emergency exits are considered to be non-compliant if the exit does not meet the opening effort limitations set by FAA AC 29.809 (FAA, 2008). This Advisory Circular in turn states at (b)(1) that "*If the effort required to open the exit is in the range of 40 to 50 pounds, it is recommended that a person of slight stature, such as a female in the 90 to 110 pound weight range, be used for the exit opening demonstration/test. In any case, the average load required to operate the exit release mechanism and open the exit should not exceed 50 pounds, and the maximum individual load of a test series should not exceed 55 pounds*".

The above research suggests that the 24.95 kg (55 lb) maximum force required to jettison a standard over-wing exit in air, is much lower than the forces required to jettison certain helicopter underwater emergency exits. In addition, it is not known whether the 24.95 kg (55 lb) maximum force is appropriate for occupants inside a flooded and inverted cabin. Work is therefore needed to define an acceptable maximum jettison force for underwater emergency exits.

Overall aim:

To determine the forces that human tests subjects (representatives of offshore helicopter occupants) are capable of applying to jettison an underwater emergency exit and establish an appropriate maximum operating/jettison force. This work will serve to underpin/validate the regulations introduced under Amendment 5 to CS 27 and 29.

Objectives:

- Determine the optimum point of impact for jettison of a generic push-out underwater emergency exit. This point to be used in following trials.
- Determine the maximum jettison force for a generic push-out underwater emergency exit using a hand push jettison technique (i.e. increase jettison force until failure to jettison occurs with any test subject) to include:
    - the effect of seat position by comparing the normal seated position with the stroked position;
    - the ability to jettison the exit when not seated, both with and without a single hand hold.
- Determine the maximum jettison force for a generic push-out underwater emergency exit using a hand strike jettison technique (i.e. increase jettison force until failure to jettison occurs with any test subject) to include:
    - the effect of seat position by comparing the normal seated position with the stroked position;
    - the ability to jettison the exit when not seated, both with and without a single hand hold.
- Determine the maximum jettison force for a generic push-out underwater emergency exit using an elbow strike jettison technique (i.e. increase jettison force until failure to jettison occurs with any test subject) to include:
    - the effect of seat position by comparing the normal seated position with the stroked position;
    - the ability to jettison the exit when not seated, both with and without a single hand hold.
- Determine the maximum safe jettison force for a lever operated exit for both the normal seated and the stroked position.

Project guidelines:

- Trial subjects should be representative of helicopter occupants flying offshore, including females and male subjects with lower levels of upper body strength.
- Underwater emergency exits used should be representative in terms of operation of those found in helicopters used in the European fleet for offshore operations.
- The size of the exits should be as defined by SPA HOFO or type IV.
- The optimum point of impact to achieve exit jettison should be defined and standardised across all experiments.
- If hand-holds are provided close to the exit, they should be used in all cases to prevent a further variable from confounding the results.

Estimate of project cost: **€334,300**

5.2.2 Underwater escape from the passenger cabin with a full complement of passengers

Applicable Regulations, related acceptable means of compliance and guidance material:

AMC1 SPA.HOFO.165(h) (a) (EASA, 2017a; EASA 2019) refers to an expectation that all passengers shall be able to escape from the helicopter within an underwater survival time of 60 s in the event of capsize.

Background:

The accident investigators for the G-WNSB accident (AAIB, 2016) considered that helicopter underwater escape research undertaken to-date had been too specific, tending to concentrate on one aspect of the evacuation experience, with no research undertaken which studied the whole process under realistic conditions. Safety Recommendation 2016-016 (AAR 1/2016) stated: "*This programme should better quantify the characteristics of helicopter underwater evacuation and include conditions representative of actual offshore operations and passenger demographics*". The only study known, which investigated the simulated evacuation of a full passenger cabin, was undertaken by Brooks, Muir and Gibbs (1999b; 2001), in which a helicopter simulator was configured for 15 and 18 passengers. With the 18-seat configuration and a slow 180° capsize, participants took between 43 s and 109 s to escape, with the last person out being underwater for 92 s. Faster escapes were found following a rapid capsize, conducted under light and dark conditions. These trials were all conducted using highly trained rather than naïve test subjects. It is not known how long it would take for all occupants to escape with modern seating configurations, and representative exits.

There is a mismatch between the 92 s escape time measured in the study (Brooks, Muir and Gibbs, 1999b; 2001) for the last person out of a fully occupied helicopter cabin and the 60 s escape time criterion being used in the rules and standards. It is therefore considered important to validate the escape time used as a basis for regulations and ensure that valid assumptions are being made when specifying design and operating rules.

Overall aim:

To better quantify the underwater escape process using a full complement of test subjects in a helicopter simulator, in light and dark conditions, and thereby establish whether a 60 s escape time is achievable under a range of conditions. The trials would also investigate different possible seat configurations. This work will serve to underpin/validate the regulations introduced under Amendment 5 to CS 27 and 29.

Objectives:

- Measure escape time from a capsized helicopter simulator, for a full complement of occupants.
- Validate the performance of EBS - the 60 s assumption.
- Effects of seating arrangement and handholds.
- Validate whether two occupants can escape through a large exit at one time.
- Consider whether the orientation of a large exit ('portrait' versus 'landscape' orientation) influences ease of escape.
- Use of trial subjects representative of the demographic of the European offshore population.
- Determine escape routes and exits used.

- Assess difficulty of escape and levels of anxiety.
- Determine the effects of age, body build and flexibility of the test subjects on ability to escape.
- Option to increase complexity by blocking some exits.
- Determine whether any changes to passenger training and guidance are needed.

Project guidelines:

- Underwater emergency exits used should be representative of those found in particular helicopters used in the European fleet for offshore operations. (This would be dependent upon the findings of the exit jettison force study).
- The size of the underwater emergency exits used in the simulator should match the sizes defined in AMC1 SPA.HOFO.165(h)(b).
- Trials should build up to full cabin escape, starting with two window seats in a single row, increasing up to four seats, and then a double facing row (with a large exit), before a full cabin trial. There is an option to also look at the effects of a blocked exit.
- Personal safety equipment should be representative of that used by the offshore workforce, including an immersion suit / lifejacket / Category A EBS combination. The impact of wearing a more heavily insulated integrated immersion suit should also be evaluated.
- As ethical approval may limit what can be undertaken, it is suggested that test subjects could be members of the offshore workforce who have already completed basic and further helicopter underwater escape training. Otherwise, training staff or divers might have to be used.
- Category A EBS should be provided for use by all trial subjects.

Estimate of project cost: **€220,000**

5.2.3 Passenger Training Fidelity and Frequency

Applicable Regulations, related acceptable means of compliance and guidance material:

There is currently no mandate for helicopter underwater escape training (HUET). HUET for crew is an option covered by AMC1 ORO.FC.230 Recurrent training and checking, ED Decision 2016/019/R (EASA, 2017b). The AMC simply states that consideration should be given to underwater escape training, without any minimum requirements.

Background:

The effectiveness of helicopter safety training, including fidelity and frequency, has repeatedly been challenged in research reports. While the benefits of training are often cited in accident reports, the survivors of the G-WNSB accident (AAIB, 2016) stated that escape was significantly harder than that experienced during training. Survivors also demonstrated that they had forgotten aspects of their training relating to the emergency breathing system used. As a result, the accident investigators recommended that EASA amend the operational requirements for commercial offshore helicopter operations "*to require operators to demonstrate that all passengers and crew travelling offshore on their helicopters have undertaken helicopter underwater escape training at an approved training facility, to a minimum standard defined by the EASA*".

Training is undertaken following industry standards, with passengers having to repeat helicopter safety training within 4 years. While the fidelity of training has improved somewhat over the years, there are still calls to improve the fidelity of the equipment used by training establishments. One example is the work undertaken into the fidelity of emergency exits (e.g. Taber et al, 2014; 2017a). Mills and Muir (1998, 1999a, 1999b) undertook research into training fidelity and optimum retraining periods. They concluded that the quality and fidelity of training provided was more important than the recency of the training. They were unable to identify the optimum point of retraining but recommended a longitudinal study to assess the optimal retraining period for HUET skills. Others have shown significant decrements in skills and HUET performance over a period of as little as 6 months (Hussin et al, 2015; Kozey, 2006; Mills and Muir, 1999a; 1999b). There is therefore a need to improve knowledge and skills retention and determine how this can be best achieved.

It is therefore proposed that further work be undertaken to assess the relationship between training fidelity and training frequency to allow minimum requirements to be established. The results of this work could be promoted to the organisations responsible for setting the training standards, or could be used by aviation authorities to set appropriate standards if and when they determine to mandate training.

Overall aims:

To study both the fidelity and frequency of helicopter safety training, to establish minimum requirements for HUET and thus improve the survival outcome in future accidents.

Objectives:

- Conduct of a longitudinal study to assess level of skill and knowledge loss over time.

- Consider the benefits of increased fidelity in initial/basic HUET training.
- Compare the effectiveness of current basic training with higher fidelity training, with a high-fidelity test conducted after 6 months. Assess skills and knowledge retention 6 months after basic training.
- Consider the role of virtual training to maintain knowledge and understanding during the retraining period.
- Establish minimum requirements for helicopter safety training.

Project guidelines:

- Assess the retention of HUET skills and knowledge at intervals of 6 months, for up to 48 months, in a cohort of trainees. Practical tests of HUET after 12 or 24 months.
- For the fidelity study, consideration should be given to the optimum level of training required for initial/basic training, to enhance skill retention between basic training and further refresher training. Issues to be addressed include:
    - exits which require a jettison force representative of current helicopter types;
    - use of representative exit sizes;
    - cross-cabin escape;
    - use of a seat in a stroked position;
    - reduced light levels.
- Test HUET exercises should be conducted using a high-fidelity helicopter simulator, with realistic procedures followed. Measurements made to include escape success rates, correct actions taken in correct order and difficulty of escape.
- Consideration to be given to stress levels experienced in fidelity study.
- Ethical approval would be required.

Estimate of project cost: €301,500

5.3 Other Identified Projects

5.3.1 Brace position

Applicable Regulations, related acceptable means of compliance and guidance material:

CAT.IDE.H.205 (EU, 2012) states that helicopters shall be equipped with a seat belt with upper body restraint for use on each passenger seat (for helicopters first issued with an individual certificate of airworthiness on or after 1 August 1999). Each flight crew seat is required to have "*a seat belt with upper torso restraint system incorporating a device that will automatically restrain the occupant's torso in the event of rapid deceleration*". No generic brace position has been mandated for offshore helicopter operations.

Background:

Brace positions have been recommended for helicopter passengers (Barthelmess, 1988; Brooks, 1989; FAA, 2016; Transport Canada, 2016). Where high backed seats with upper body restraint harnesses are used the body position is largely defined, and the feet must be placed in front of the seat edge to prevent leg injuries from the operation of energy absorbing ('stroking') seats. As regards head position, for forward facing seats the head should be tucked down as far as possible (chin on sternum), for rear facing seats the head should be placed firmly against the head rest. However, there has been some recent controversy over the position of the hands. The Canadian Advisory Circular (Transport Canada, 2016) recommended maintaining a positive grip on the restraint system with the fingers, so that the occupant was able to slide their hand down to the harness release when required. Concern has been raised that occupants should not be grasping the harness as this could affect harness performance. In Europe, the general advice given is to place the hands under the knees or to grasp the material of the immersion suit legs. No publication could be found which explored the impact of the alternative brace position recommended by Transport Canada. It is proposed that research be conducted to explore this issue.

Overall aim:

To investigate the best position for the hands in the brace position recommended for passengers in helicopters operating offshore for immediate promulgation and use.

Objectives:

- To determine whether grasping the upper torso harness impairs the performance of the harness.
- To determine the effects of hand position (hands under the knees compared to hands holding the harness) on ease of accessing and releasing the harness and ease of EBS deployment during the underwater escape process.

Project guidelines:

- Harness used to be representative of those found in particular helicopters used in the European offshore fleet.
- Brace position (other than hands) to follow that advised by the Canadian Advisory Circular (Transport Canada, 2016).

5.3.2 Attenuating seats

Applicable Regulations, related acceptable means of compliance and guidance material:

The use of energy absorbing/attenuating seats is not currently mandated for offshore helicopter operations.

Background:

In the Canadian C-GZCH accident (TSB Canada, 2010) four of the seats were reported to have 'bottomed out'. Research has shown that escape from a seat in the stroked position may increase the difficulty of escape and escape time (Taber, 2013; Taber et al, 2015). According to Taber (2013), the crash attenuating seats used in the helicopter were designed for a standard mass of 77 kg. The occupant mass used in the design of these seats matches that used in the CS-27 and CS-29 requirements for seat design and crashworthiness (see CS 27.562; EASA, 2020b and CS 29.562; EASA, 2020c). This value is below the average mass of a member of the offshore workforce in Europe and North America, increasing the likely frequency of seats 'bottoming out' on impact due to high body mass.

Limited research has been undertaken to-date to assess ease of escape from the normal and stroked seat positions, showing longer escape times from a fully stroked seat. Consideration should be given to both the mass and stature of helicopter occupants, and the likely movement of the seating due to different accelerations. Further, it is not known if the stroked seat position affects ease of EBS deployment. Consideration should also be given to the potential safety benefits of using variable load energy absorbing seats.

Overall aim:

To assess the effect of body mass and stature on the time taken to escape from a stroked seat position, using test subjects representative of the offshore workforce and establish whether attenuating seats provide a net safety benefit, regardless of average passenger mass.

Objectives:

- To assess the effects of body mass on time to escape from a fully and partially stroked seat.
- To assess the effects of body stature on time to escape from a fully and partially stroked seat.
- To further examine the factors that affect ease of escape from a stroked seat.
- To assess the effect of seat position on EBS deployment times.
- To assess the impact of an average passenger mass of 98 kg on a stroking seat designed for 77 kg.

Project guidelines:

- Test subjects to be selected who are representative of the offshore workforce.
- Particular focus should be placed on individuals with high body mass and short stature.
- Sledge testing would be required.

5.3.3 Harness release

Applicable Regulations, related acceptable means of compliance and guidance material:

Air Operation Regulation CAT.IDE.H.205 relating to seats, safety belts and restraint systems (EU, 2012) states that helicopters shall be equipped with a seat belt with upper body restraint for use on each passenger seat (for helicopters first issued with an individual certificate of airworthiness on or after 1 August 1999). According to CAT.IDE.A.205 each flight crew seat is required to have "*a seat belt with upper torso restraint system incorporating a device that will automatically restrain the occupant's torso in the event of rapid deceleration*". Further, seat belts with upper torso restraint shall "*have a single point release*". Similarly, CS 27/29.785 Seats, berths, safety belts, and harnesses (EASA, 2018a; 2018b) states that:

"(b) *Each occupant must be protected from serious head injury by a safety belt plus a shoulder harness that will prevent the head from contacting any injurious object except as provided for in CS 29.562(c)(5). A shoulder harness (upper torso restraint), in combination with the safety belt, constitutes a torso restraint system as described in ETSO-C114.*

(c) Each occupant's seat must have a combined safety belt and shoulder harness with a single-point release".

Background:

Research projects have identified some potential problems with the release of the seat harness during underwater escape (Coleshaw, 2013; Taber et al, 2015) and more specifically when the harness was under uneven loading (Jamieson et al, 2000; 2001) or when the seat was in the stroked position (Taber, 2013). These have tended to be observations only. Few reports of harness problems were found in the review of accidents, but this may be due to the fact that those experiencing problems locating or operating the release mechanism did not survive.

It is therefore proposed that research be undertaken to specifically study harness release when inverted underwater, with the uneven loading that might be experienced with different capsize angles, and looking at harness release in 'stroked' attenuating seats.

Overall aim:

To investigate the performance of seat harness release systems under a range of conditions with a view to establishing whether any changes to the regulations are required.

Objectives:

- Investigate harness loading and release for a range of capsize angles under water.
- Investigate harness release from the stroked seating position, with occupants wearing representative immersion suits (with different lifejacket, immersion suit and EBS currently in use).

Project guidelines:

- The seat harness, including upper torso restraint and recoil systems used, should be representative and as close as possible in design to operational harness systems.

5.3.4 Underwater vision

Applicable Regulations, related acceptable means of compliance and guidance material:

SPA.HOFO.160 (b) (EU, 2016) requires that *"All emergency exits, including crew emergency exits, and any door, window or other opening that is suitable for emergency egress, and the means for opening them shall be clearly marked for the guidance of occupants using them in daylight or in the dark. Such markings shall be designed to remain visible if the helicopter is capsized or the cabin is submerged."*

In addition, CS 27.805(c), AMC 27.805(c)(b)(6), CS27.807(d)(2)&(4); CS 29.809(j), CS 29.811(h)(1), and CS 29.812(a)(1), AMC 29.809(b)(2), AMC 29.811(h)(b) address emergency exit lighting (EASA, 2020b; 2020c).

Background:

In the G-WNSB accident (AAIB, 2016) problems due to darkness and poor visibility were reported; one passenger describing finding the exit window by feel. In the Canadian Air Force accident in 2008 (FSIR, 2008a) escape was exacerbated by darkness. One of the occupants recalled that "*the HEELS lit up the doorframe well, but did not show the position of the emergency release handle*" for the upper personnel door. Mallam and MacKinnon (2011) found that escape tasks, including deployment of EBS, jettison of an exit and harness release, took significantly longer in the dark than in light conditions. In addition, there is anecdotal evidence that the large number of bubbles created by the capsize of a helicopter greatly reduces underwater visibility during the first few minutes following inversion. Underlying these issues is the reduction in visual acuity when underwater (Luria and Kinney, 1969).

Issues of darkness are mitigated by various helicopter emergency egress lighting systems (HEELS), with research conducted to determine detectability of lighting systems at different distances.

While the effects of reduced visibility have been identified and researched, little work has been undertaken to improve visual acuity underwater. Some early work demonstrated the benefits of swimming goggles (Allan & Ward, 1986), but concerns have been raised that goggles would have to be deployed before submersion as they could not be cleared underwater. Members of the Canadian workforce carry diving masks, which potentially can be cleared underwater. However, little work has been undertaken to determine the effects of mask deployment time on escape time, or the ability of users to clear the masks underwater. If a dive mask could be deployed successfully in a water impact accident, either before or following submersion, it could provide a significant benefit for helicopter occupants who would otherwise find it difficult to see their escape route and the underwater emergency exits in dark or turbid conditions.

Overall aim:

To study the potential benefits and disbenefits of using a dive mask during underwater escape and determine whether the mask can be used effectively without any significant decrement in escape time. This is aimed at establishing whether dive masks should be mandated, allowed (and, if so, under what conditions) or banned.

Objectives:

- Measure dive mask deployment time both before and following submersion, while completing an underwater escape from a helicopter simulator.
- Investigate the ease of clearing water from the dive mask following underwater deployment.
- Assess compatibility of dive mask deployment with the other part-tasks undertaken during the underwater escape process, including EBS deployment.
- Compare visual acuity with and without the dive mask when underwater within the helicopter simulator.

Project guidelines:

- Consider dive mask fit for a wide range of face shapes and sizes and how this will affect mask performance.
- The need to clear the mask effectively dictates the use of Category A EBS.

6. Conclusions

A comprehensive literature review has been performed on the subject of helicopter underwater escape, focussing primarily on accident investigation reports, research reports and papers. The review of survivable helicopter water impact accidents has identified issues affecting the likelihood of survival of the occupants. A systematic review of the research undertaken in relation to helicopter underwater escape has revealed a wide range of studies conducted over a period of 40 years. Research sources have ranged from peer reviewed academic journals to industry reports and conference papers, resulting in some variation in the quality.

The results of the literature review have been analysed to identify gaps and shortfalls in the understanding of the issues. The review has confirmed that much of the research undertaken focusses on specific aspects of the underwater escape process or equipment used by helicopter occupants, with only one study simulating the underwater evacuation of a fully occupied helicopter cabin. While the research results allow the characteristics of helicopter underwater escape to be described, some areas are better defined than others. As an example, recent research has been undertaken to define the forces needed to jettison an underwater emergency exit, but has only been investigated in relation to one aircraft type so far and does not inform the setting of a maximum exit operating force. There are also apparent shortfalls in the research undertaken to optimise the fidelity and frequency of training.

Outline proposals have been produced for further work aimed at filling the knowledge gaps in relation to helicopter underwater escape. The proposals have been designed to address regulatory aspects as well as enhancing the general knowledge base.

The following three high potential benefit projects have been identified:

- Establishment of a maximum operating/jettison force for underwater emergency exits.
- Study of underwater escape from the passenger cabin with a full complement of passengers.
- Fidelity and frequency of training.

Four other projects have been identified as follows:

- Bracing position for helicopter passengers.
- Attenuating seats.
- Harness release.
- Underwater vision.

References

Accident Reports

AAIB (1990) Report on the accident to the Sikorsky S61N helicopter G-BDES in the North Sea, 90 nm north-east of Aberdeen on 10 November 1988. AAR 1/90. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

AAIB (1991) Report on the accident to Sikorsky S61N G-BEWL, at Brent Spar, East Shetland Basin, on 25 July 1990. AAR 2/91. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

AAIB (1993) Report on the accident to as 332L Super Puma, G-TIGH, near the Cormorant 'A' platform, east Shetland Basin, on 14 March 1992. AAR 2/93. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

AAIB (1997) Report on the accident to AS 332L Super Puma G-TIGK, in North Sea 6 NM south west of Brae Alpha oil platform, on 19 January 1995. AAR 2/97. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

AAIB (2011) Report on the accident to Eurocopter EC225 LP Super Puma, G-REDU near the Eastern Trough Area Project (ETAP) Central Production Facility Platform in the North Sea on 18 February 2009. AAR 1/2011. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

AAIB (2014) Report on the accidents to Eurocopter EC225 LP Super Puma G-REDW 34 nm east of Aberdeen, Scotland on 10 May 2012 and G-CHCN 32 nm southwest of Sumburgh, Shetland Islands on 22 October 2012 AAR 2/2014. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

AAIB (2016) Report on the accident to AS332 L2 Super Puma helicopter, G-WNSB on approach to Sumburgh Airport on 23 August 2013. AAR 1/2016. Aldershot, Hampshire, UK: Air Accidents Investigation Branch.

AAIB (2020) Formal Report Addendum to AAR 1/2016 - G-WNSB. AAIB Bulletin: 9/2020, EW/C2013/08/03.

AIB Nigeria (2016) Preliminary report on accident involving Sikorsky S-76c++ helicopter belonging to Bristow Helicopters Nigeria Limited with registration 5N-BQJ which occurred at about 75 nm to Lagos in the Atlantic Ocean on the 3rd of February, 2016.

AIB Norway (1998) Air accident involving Eurocopter Super Puma 332L, LN-OBP, in the North Sea on 18 January 1996, approx. 40 NM south-west of Sola, Norway. Report 02/98.

BFU (2014) Report on the accident to Eurocopter AS 350BA, Neustadt Bay, Baltic Sea, Germany on 05 December 2012. CX024-12/2014. German Federal Bureau of Aircraft Accident Investigation.

DSB (2010) Emergency landing Bristow AS332L2 search and rescue helicopter. North Sea, near Den Helder, 21 November 2006. Project number M2006LV1121-07. The Hague, Netherlands: Dutch Safety Board.

FSIR (2008a) Canadian Forces Flight Safety Investigation Report; 1010-12438 (DFS 2-2), relating to the accident on approach to HMCS Athabaskan (30 NM E Aalborg, Denmark, on 02 February 2006.

FSIR (2008b) Canadian Forces Flight Safety Investigation Report; 1010-149914 (DFS 2-3); relating to the accident over Chedabucto Bay, Nova Scotia on 22 January 2008.

TSB Canada (2010) Main Gearbox Malfunction/Collision with Water; Cougar Helicopters Inc. Sikorsky S-92A, C-GZCH; St. John's, Newfoundland and Labrador, 35 Nm E; 12 March 2009. Aviation Investigation Report Number A09A0016. Gatineau, Quebec: Transportation Safety Board.

TSB Canada (2015) Collision with water. Government of Canada, Department of Transport, MBB BO 105 S CDN-BS-4 (Helicopter) C-GCFU, M'Clure Strait, Northwest Territories, 09 September 2013. Aviation Investigation Report A13H0002. Gatineau, Quebec: Transportation Safety Board.

Research

Abernethy, B (2005) The appropriate roles for algorithmic and heuristic methods in helicopter underwater egress training: how to maximize aircrew and passenger survivability. *Paper presented at:* The International Association of Safety and Survival Training.

Allan JR and Ward FRC (1986) Emergency exits for underwater escape from rotorcraft. RAF Institute of Aviation Medicine, Aircrew Equipment Group Report No. 528.

Allan JR, Higenbottam C, Redman PJ (1985) The effect of leakage on the insulation provided by immersion-protection clothing. Aviat Space Environ Med, 56: 1107–1109.

Anton DJ (1984) A review of UK registered helicopter ditchings in the North Sea. Int J Aviation Safety, 2: 55-63.

Armstrong IJ, Bennett-Smith SC, Coleshaw SRK (1994) Performance of immersion suit and lifejacket combinations at sea. OTH 94 428. Sudbury: Health and Safety Executive.

Barker C and Bellenkes A (1996) U.S. Naval Helicopter Mishaps: Cockpit Egress Problems. Aviat Space Environ Med, 67(5): 480-485.

Barthelmess S (1988) Positions brace passengers for impact to reduce injuries. Flight Safety Foundation Cabin Crew Safety, 23(1): 1-6.

Balmi PJ and Tipton MJ (1996) The effect of water leakage on the results obtained from human and thermal manikin tests of immersion protective clothing. Eur J Appl Physiol, 72: 394–400.

Barwood MJ, Dalzell J, Datta AK, Thelwell R C, Tipton MJ (2006) Breath-hold performance during cold water immersion: effects of psychological skills training. Aviat Space Environ Med; 77 (11): 1136-1142.

Barwood MJ, Corbett J, Coleshaw S, Long G and Tipton MJ (2010) Performance of emergency underwater breathing systems in cool (25°C) and cold (12°C) water. Aviat Space Environ Med, 81: 1002-1007.

Benham JA and Haywood P (1996) A review of the snagging problems said to occur during underwater escape with current back and seat-mounted PSPs. Report No. DRA/CHS/PHS/WP96/004. Farnborough, UK: Defence Research Agency.

Benham JA, Redman PJ, Hayward P (1995) An interim report on the developments of safe underwater escape from helicopters. Report No. DRA/CHS/PHYS/WP95/017. Farnborough, UK: Defence Research Agency.

Benton PJ, Woodfine JD, Westwood PJ (1996) Arterial gas embolism following a 1-metre ascent during helicopter escape training: a case report. Aviat Space Environ Med, 67: 63-64.

Birciu Z and Grabski F (2011) The experimental and theoretical study of life raft safety under strong wind. Reliability Engineering and System Safety, 96: 1456-1461.

Bohemier A, Chandler P, Gill S (1990) Emergency breathing systems as an aid to egress from a downed flooded helicopter. Technical Report 108. Ottawa, Canada: Canada Oil and Gas Lands Administration.

Bohemier A, Chandler P, Gill S (1991) Factors affecting egress from downed flooded helicopter. Technical Report 109. Ottawa, Canada: Canada Oil and Gas Lands Administration.

Bohemier A, Brooks CJ, Morton JS, Swain JH (1999) High fidelity survival training for ditched aircrew and passengers. *Paper presented at:* RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", San Diego, USA, 19-21 October 1998. Published in: RTO MP-19. Neuilly-sur-Seine, France: NATO.

Bottenheft C, Oprins EAPB, Houben MMJ, Meeuwsen T, Valk PJL (2019) Self-assessed preferred retraining intervals of helicopter underwater egress training (HUET). Aerospace Medicine and Human Performance, 90(9): 800-806.

Brooks CJ (1988) Maximum acceptable inherent buoyancy limit for aircrew/ passenger helicopter immersion suit systems. Applied Ergonomics, 19: 266–270.

Brooks C (1989) The Human Factors Relating to Escape and Survival from Helicopters Ditching in Water. AGARD-AG-305(E). Neuilly-sur-Seine, France: NATO.

Brooks CJ and Bohemier AP (1997) Helicopter door and window jettison mechanisms for underwater escape: Ergonomic confusion! Aviat Space Environ Med, 68(9): 844-57.

Brooks C and Potter P (1998) The abysmal performance of the inflatable liferaft in helicopter ditchings. *Paper presented at*: RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", San Diego, USA, 19-21 October 1998. *Published in:* RTO MP-19. Neuilly-sur-Seine, France: NATO.

Brooks CJ and Tipton M (2001) The requirements for an emergency breathing system (EBS) in over-water helicopter and fixed wing aircraft operations. RTO AGARDograph 341. Neuilly-sur-Seine, France: NATO. Human Factors and Medicine Panel.

Brooks CJ, Bohemier AP, Snelling GR (1994) The ergonomics of jettisoning escape hatches in a ditched helicopter. Aviat Space Environ Med, 65(5): 387-95.

Brooks CJ, Potter PL, Hognestad B, Baranski J (1997) Liferaft evacuation from a ditched helicopter: dry shod vs. swim away method. Aviat Space Environ Med, 68(1): 35-40.

Brooks CJ, Potter PL, De Lange D, Baranski JV, Anderson J (1998) Options for liferaft entry after helicopter ditching. Aviat Space Environ Med, 69 (3): 743-749.

Brooks CJ, Miller L, Morton S, Baranski J (1999a) Evaluation of a new universal jettison mechanism for helicopter underwater escape. Aviat Space Environ Med, 70(8): 752-758.

Brooks CJ, Muir HC, Gibbs PN (1999b) An initial investigation of passenger evacuation from the Super Puma helicopter. Survival Systems Limited Report. Dartmouth, Canada: Survival Systems Limited.

Brooks CJ, Muir HC, Gibbs PN (2001) The basis for the development of a fuselage evacuation time for a ditched helicopter. Aviat Space Environ Med, 72(6): 553-561.

Brooks CJ, Gibbs PN, Jenkins JL, McLeod S (2007) Desensitizing a pilot with a phobic response to required helicopter underwater escape training. Aviat Space Environ Med, 78: 618–623.

Brooks CJ, Macdonald CV, Carroll J, Gibbs PNG (2010) Introduction of a compressed air breathing apparatus for the offshore oil and gas industry. Aviat Space Environ Med, 81: 683-687.

CAA (1984) Report of the Helicopter Airworthiness Review Panel (HARP) of the Airworthiness Requirements Board. Report No. CAP 491. London: Civil Aviation Authority.

CAA (1995) Report of the Review of Helicopter Offshore Safety and Survival (RHOSS). CAP 641. London: Civil Aviation Authority.

CAA (2005a) Summary Report on Helicopter Ditching and Crashworthiness Research. CAA Paper 2005/06. London: Civil Aviation Authority.

CAA (2005b) Standard weights for passengers carried on flights in connection with oil and gas exploitation. Safety Regulation Group Flight Operations Department Communication (FODCOM) 27/2005.

CAA (2014) Safety review of offshore public transport helicopter operations in support of the exploitation of oil and gas. CAP 1145. London: Civil Aviation Authority.

CAA (2015a) Safety review of offshore public transport helicopter operations in support of the exploitation of oil and gas. Progress Report CAP 1243. London: Civil Aviation Authority.

CAA (2016) Safety review of offshore public transport helicopter operations in support of the exploitation of oil and gas. Progress Report - 2016 CAP 1386. London: Civil Aviation Authority.

Chen C, Muller M, Fogarty K (1993) Rotorcraft ditchings and water related impacts that occurred from 1982 to 1989 – Phase I. DOT/FAA/CT-92/13. Springfield, Virginia: Federal Aviation Administration.

Cheung B, Hofer K, Brooks C J, Gibbs P (2000) Underwater disorientation as induced by two helicopter ditching devices. Aviat Space Environ Med, 71 (9): 879-888.

Cheung SS, D'Eon NJ, Brooks CJ (2001) Breath-holding ability of offshore workers inadequate to ensure escape from a ditched helicopter. Aviat Space Environ Med, 72: 912-918.

Choi G, Kopplin LJ, Tester DJ, Will ML, Haglund CM, Ackerman MJ (2004) Spectrum and frequency of cardiac channel defects in swimming-triggered arrhythmia syndromes. Circulation, 2010: 2119-2124.

Clark SE (1996) Standards of Cabin Safety for Offshore Helicopter Operations. *Paper presented at:* International Conference on health, Safety & Environment, New Orleans, Louisiana, 9-12 June 1996. Society of Petroleum Engineers, SPE 35942.

Clifford WS (1996) Helicopter crashworthiness. Study I. A review of UK military and world civil helicopter water impacts over the period 1971-1992. CAA Paper 96005. London: Civil Aviation Authority.

Coleshaw SRK (2003) Preliminary study of the implementation and use of emergency breathing systems. CAA Paper 2003/13. London: Civil Aviation Authority.

Coleshaw SRK (2010) Surviving a helicopter crash in water – the way forward? Journal of Ocean Technology, 5(4): 86-88.

Coleshaw SRK (2012) Minimum performance requirements for helicopter emergency breathing systems. Journal of Ocean Technology, Extreme Survival, 7(3): 60-73.

Coleshaw SRK (2013) Development of a technical standard for emergency breathing systems. CAP 1034. London: Civil Aviation Authority.

Coleshaw SRK (2016) Helicopter emergency breathing systems. *In:* M Taber ed. Handbook of Offshore Helicopter Transport Safety. Amsterdam: Elsevier, pp 151-174.

Coleshaw SRK and Howson D (1999) Escape from side-floating helicopters. *In:* Proceedings of the Second International Helicopter Escape Seminar/Workshop", Nutec, Billingham, UK, 21-22 October 1999.

Delorme L, Denante M, Santucci P, Gelas AD (2009) Study on floatation devices to avoid helicopters' total inversion after capsize. *Paper presented at:* 35th European Rotorcraft Forum 2009.

Denante M, Antomarchi P, Couant A, Delorme L (2008). Study on helicopter ditching and crashworthiness. European Aviation Safety Agency, Report EASA.2007.C16.

Desjardins SP (2006) The evolution of energy absorption systems for crashworthy helicopter seats. Journal of the American Helicopter Society, 51 (2): 150-163.

Ducharme MB (2006) Heat stress of helicopter aircrew wearing immersion suit. Industrial Health, 44: 433-440.

Ducharme MB and Brooks CJ (1998) The effect of wave motion on dry suit insulation and the responses to cold water immersion. Aviat Space Environ Med, 69(10): 957-64.

EASA (2016a) Notice of Proposed Amendment 2016-01. Helicopter ditching and water impact occupant survivability, RMT.0120 (27&29.008) - 23.3.2016.

FAA (2016) Brace for impact positions. Air Carrier Operations Bulletin 1-94-17.

Færevik H and Reinertsen RE (2003) Effects of wearing aircrew protective clothing on physiological and cognitive responses under various ambient conditions. Ergonomics, 46(8): 780 – 799.

Færevik H and Reinertsen RE (2012) Initial heat stress on subsequent responses to cold water immersion while wearing protective clothing. Aviat Space Environ Med, 83: 746 – 50.

Færevik H, Markussen D, Øglænd G, Reinertsen RE (2001) The thermoneutral zone when wearing aircrew protective clothing. Journal of Thermal Biology, 26: 419–425.

Gaul CA and Mekjavic IB (1987) Helicopter pilot suits for offshore application: a survey of thermal comfort and ergonomic design. Appl Ergonomics 18(2): 153-158.

Giesbrecht GG, Wu MP, White MD, Johnston CE, Bristow GK (1995) Isolated effects of peripheral arm and central body cooling on arm performance. Aviat Space Environ Med, 66(10): 968-975.

Golden F and Tipton M (2002) Essentials of Sea Survival. Champaign, Illinois: Human Kinetics, pp 108-113.

Golden FSC, Hervey G, Tipton M (1991) Circum-rescue collapse: collapse, sometimes fatal, associated with rescue of immersion victims. J R Nav Med Serv, 77: 139-49.

Hall JF (1972) Prediction of tolerance in cold water and life raft exposures. Aerospace Med, 43(3): 281-286.

Harris RA, Coleshaw SRK, MacKenzie IG (1996) Analysing stress in offshore survival course trainees. OTH 94 446. Sudbury: HSE Books.

Hayward JS, Hay C, Matthews BR, Overweel CH, Radford, DD (1984) Temperature effect on the human dive response in relation to cold water near-drowning. J Appl Physiol, 56(1): 202–206.

Heimenz GJ, Choi Y-T, Wereley NM (2007) Semi-active control of vertical stroking helicopter crew seat for enhanced crashworthiness. J Aircraft 44 (3): 1031-1033.

Hognestad B (1997) Helicopter evacuation training course considerations. *Paper presented at:* Helicopter Escape Seminar/Workshop; Nutec Centre for Safety, Billingham, UK; 6-7 November 1997.

Howson DA (2006) Research initiatives for improving the safety of offshore helicopter operations. The Aeronautical Journal, 110(1113): 723-7.

Hussin MFB, Wang B, Subahir S, Ismail NN, Hipnie R (2015) Skills Retention in Basic Offshore Safety and Emergency Training (B.O.S.E.T). *In:* R Hashim, AB Abdul Majeed, eds. *Proceedings of the Colloquium on Administrative Science and Technology.* Singapore: Springer, pp 383-390.

Hytten K (1989) Helicopter crash in water: effects of simulator escape training. Acta psychiatry Scand Suppl 355: 73-78.

Hytten K, Jensen A, Vaernes R (1989) Effects of underwater escape training - a psycho-physiological study. Aviat Space Environ Med, 60: 460-466.

Jackson GE and Rowe SJ (1997) Devices to prevent helicopter total inversion following a ditching. CAA Paper 97010. London: Civil Aviation Authority.

Jamieson DW, Coleshaw SRK, Armstrong IJ, Sellar C, Howson D (2000) Human factors associated with escape from side-floating helicopters. *In:* PT McCabe, MA Hanson, SA Robertson, Eds. Contemporary Ergonomics 2000. London: HMSO.

Jamieson DW, Armstrong IJ, Coleshaw SRK (2001) Helicopter ditching research - Egress from side-floating helicopters. CAA Paper 2001/10. London: Civil Aviation Authority.

Kaur PP, Drummond SE, Furyk J (2016) Arrhythmia secondary to cold water submersion during helicopter underwater escape training. Prehosp Disaster Med, 31(1): 108–110.

King TS, MacKinnon SN, Taber MJ (2018) How does load and impulse influence the success of jettisoning a simulated S-92 push-out window? International Journal of Industrial Ergonomics 68: 205–210.

Kinker LE, Loeslein GF, O'Rourke CR (1998) U.S. Naval and Marine Corps Helicopter Mishap Trends: Over Water Mishaps (1985 -1997). *Paper presented at:* RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", San Diego, USA, 19-21 October 1998. *Published in:* RTO MP-19. Neuilly-sur-Seine, France: NATO.

Kozey, J, McCabe J, Jenkins J (2006) The effect of different training methods on egress performance from the modular egress training simulator. *Published in:* Proceedings of the 44th Annual SAFE Symposium, Reno Nevada.

Kozey JW, Brooks C, Dewey SL, Brown RC, Howard KA, Drover D, MacKinnon S, McCabe J (2009) Effects of human anthropometry and personal protective equipment on space requirements. Occupational Ergonomics, 8(2,3): 67-79.

Leach J (2004) Why people freeze in an emergency: temporal and cognitive constraints on survival responses. Aviat Space Environ Med, 75(6): 539-542.

Leach J (2016) Psychological factors in underwater egress and survival. *In:* M Taber ed. Handbook of Offshore Helicopter Transport Safety. Amsterdam: Elsevier, pp 41-62.

Ledingham R, Furnace G, Lamb M, Stewart A (2015) Size and shape of the UK offshore workforce 2014. Data from 3D scanning survey. Robert Gordon University Report.

Light IM and Dingwall RHM (1985) Basic anthropometry of 419 offshore workers (1984). Offshore Survival Centre, Robert Gordon's Institute of Technology, Aberdeen, UK.

Light IM and Gibson M (1986) Percentage body fat and prevalence of obesity in a UK offshore population. Br J Nutr, 56: 97-104.

Light IM and Gibson M (1987) Application of weight-height relations for assessing adiposity in a United Kingdom offshore workforce. Br J Industrial Med, 44: 201-205.

Light IM, Gibson MG, Avery A (1985) Sweat evaporation and thermal comfort wearing helicopter passenger immersion suits. Ergonomics, 30: 793-803.

Light IM, Avery A, Grieve AM. (1987) Immersion suit insulation: the effect of dampening on survival estimates. Aviat Space Environ Med, 58(10): 964-969.

Light IM, Masson J, Ross H (1988) Anthropometry of North Sea helicopter pilots. Ergonomics, 31(6): 905-913.

Luria SM and Kinney JAS (1969) Visual acuity under water without a face mask. Report Number 581. Groton, Connecticut: US Naval Submarine Medical Centre.

Luria SM, Ryack BL, Neri DF (1984) Desirable characteristics of underwater lights for helicopter escape hatches. Report Number 990. Groton, Connecticut: Naval Submarine Medical Research Laboratory.

Madu VC, Carnahan H, Brown R, Ennis K-A, Tymko KS, Hurrie DMG, McDonald GK, Cornish SM, Giesbrecht GG (2020) Skin cooling on breath-hold duration and predicted emergency air supply duration during immersion. Aerosp Med Hum Perform, 91, 7: 578-585.

Mallam SC and MacKinnon SN (2011) The effect of hand immersion in 4°C water on the performance of helicopter evacuation and survival tasks. *Paper presented at:* Ergoship 2011, 1st Conference on Maritime Human Factors, Göteborg, Sweden, September 14-16, 2011.

Marsh N, Askew D, Beer K, Gerke M, Muller D, Reichman C (1995) Relative contributions of voluntary apnoea, exposure to cold and face immersion in water to diving bradycardia in humans. Clin Exp Pharmacol Physiol, 22: 886–887.

McCallum AL, McLellan BA, Reid SR, Courtade W (1989) Two cases of accidental immersion hypothermia with different outcomes under identical conditions. Aviat Space Environ Med, 60(2): 162-165.

McDonald GK and Giesbrecht GG (2013) Escape from a submersible vehicle simulator wearing different thermoprotective flotation clothing. Aviat Space Environ Med, 84: 708-15.

McFadden EB, Swearingen JJ, Wheelwright CD (1959) The magnitude and direction of forces that man can exert in operating aircraft emergency exits. Human Factors 1(4): 16-27.

Mills AM and Muir H (1998) Development of a training standard for underwater survival. Stage Two - Experimental testing. Cranfield University research report commissioned by Shell Aircraft Limited.

Mills A and Muir H (1999a) Development of a training standard for underwater survival. Stage Four - Refresher training. Cranfield University research report commissioned by Shell Aircraft Limited.

Mills A and Muir H (1999b) Executive Summary Final Report: Development of a Training Standard for Underwater Survival. Cranfield University research report commissioned by Shell Aircraft Limited.

Moradi R, Beheshti HK. Lankarani HM (2012) Lumbar load attenuation for rotorcraft occupants using a design methodology for the seat impact energy-absorbing system. Cent Eur J Eng, 2(4): 562-577.

Muller M and Bark LW (1993) Rotorcraft Ditchings and Water Related Impacts that Occurred from 1982 to 1989, Phase II, Final Report. DOT/FAA/CT-92/14, October 1993.

Nascimento FAC, Majumdar A, Ochieng WY (2013) Nighttime offshore helicopter operations - identification of contextual factors relevant to pilot performance. *In:* Advances in Human Aspects of Aviation Medicine. SJ Landry Ed. Boca Taton, Florida: Taylor & Francis.

Nascimento FAC, Majumdar A, Ochieng WY (2014) Helicopter accident analysis. Journal of Navigation, 67: 145-161.

Noble C (2002) The relationship between fidelity and learning in aviation training and assessment. Journal of Air Transportation, 7(3): 33-54.

O'Neil BD, Kozey JW, Brooks CJ (2004) Underwater detectability of a lighting system on a helicopter escape exit. Aviat Space Environ Med, 75: 526-530.

Power J, Ré A, Barwood M, Tikuisis P, Tipton M (2015) Reduction in predicted survival times in cold water due to wind and waves. Applied Ergonomics, 49: 18-24.

Reilly T, Kozey J, Brooks C (2015) Structural anthropometric measurement of Atlantic offshore workers. Occupational Ergonomics, 5(2): 111-120.

Rice EV, Greear JF (1973) Underwater escape from helicopters. *In:* Proceedings of the Eleventh Annual Symposium, Phoenix, AZ. Survival and Flight Equipment Association, pp 59-60.

Ritvanen T, Louhevaara V, Helin P, Halonen T, Hänninen O (2007) Effect of aerobic fitness on the physiological stress responses at work. Int J Occup Med Environ Health, 20: 1-8.

Robinson SJ (2016) Physiological and cognitive changes during helicopter underwater egress training. *In:* M Taber ed. Handbook of Offshore Helicopter Transport Safety. Amsterdam: Elsevier, pp 99-123.

Robinson SJ (2018) How can psychology inform disaster research? Procedia Engineering 212: 1083–1090.

Robinson SJ, Sünram-Lea SI, Leach J, Owen-Lynch PJ (2008) The effects of exposure to an acute naturalistic stressor on working memory, state anxiety and salivary cortisol concentrations. Stress, 11: 115-124.

Ross C and Gibb G (2008) A risk management approach to helicopter night offshore operations. Australian Society of Air Safety Investigators, 2008 Regional Seminar.

Ryack BL, Smith PF, Champlin SM, Noddin EM (1977) The effectiveness of escape hatch illumination as an aid to egress from a submerged helicopter: Final Report. Report Number 857. Groton, Connecticut: Naval Submarine Medical Research Laboratory.

Ryack BL, Luria SM, Robbins V (1984) A test of electroluminescence panels for a helicopter emergency escape lighting system. Report Number 1018. Groton, Connecticut: Naval Submarine Medical Research Laboratory.

Ryack BL, Luria SM, Smith PF (1986) Surviving helicopter crashes at sea: a review of studies of underwater egress from helicopters. Aviat Space Environ Med, 57(6): 603-609.

Salakari H (2011) A realistic appraisal of the practices and the delimitations of simulation-based training: what skills and toward what ends? In: Innovations for Competence Management, Conference proceedings. Eds. I Torniainen, S Mahlamäki-Kultanen, P Nokelainen & P Ilsley. Lahti: Lahti University of Applied Sciences.

Salas E and Burke CS (2002) Simulation for training is effective when …. Quality and Safety in Heath Care, 11: 119-120.

Sanli EA and Carnahan H (2018) Long-term retention of skills in multi-day training contexts: A review of the literature. International Journal of Industrial Ergonomics, 66: 10-17.

Shanahan DF (2005) Basic principles of crashworthiness. *In:* Pathological Aspects and Associated Biodynamics in Aircraft Accident Investigation. RTO-EN-HFM-113. RTO Educational Notes.

Shattock MJ and Tipton MJ (2012) ‘Autonomic conflict’: a different way to die during cold water immersion? J Physiol, 590.14: 3219–3230.

Stewart A, Ledingham R, Furnace G, Nevill A (2015) Body size and ability to pass through a restricted space: Observations from 3D scanning of 210 male UK offshore workers. Applied Ergonomics, 51: 358-362.

Stewart A, Ledingham R, Furnace G, Schranz N, Nevill A (2016) The ability of UK offshore workers of different body size and shape to egress through a restricted window space. Applied Ergonomics, 55: 226-233.

Stewart A, Ledingham R, Williams H (2017a) Variability in body size and shape of UK offshore workers: A cluster analysis approach. Applied Ergonomics, 58: 265-272.

Stewart A, Ledingham R, Furnace G, Williams H, Coleshaw S (2017b) Survival suit volume reduction associated with immersion: implications for buoyancy estimation in offshore workers of different size. Ergonomics, 60(6): 844-850.

Summers F (1996) Procedural skill decay and optimal retraining periods for helicopter underwater escape training. IFAP Technical Report. Willetton, Western Australia: Industrial Foundation for Accident Prevention.

Taber MJ (2013) Crash attenuating seats: Effects on helicopter underwater escape performance. Safety Science, 57: 179-186.

Taber MJ (2014) Simulation fidelity and contextual interference in helicopter underwater egress training: An analysis of training and retention of egress skills. Safety Science, 62: 271–278.

Taber MJ (2016) Use and implications of fidelity in helicopter underwater egress training. *In*: M Taber ed. handbook of Offshore Helicopter Transport Safety. Amsterdam: Elsevier, 125-150.

Taber M and McCabe J (2009) The effect of emergency breathing systems during helicopter underwater escape training for land force troops. Safety Science, 47: 1129-1138.

Taber M and McGarr GW (2013) Confidence in future helicopter underwater egress performance: An examination of training standards. Safety Science, 60: 169-175.

Taber MJ and Sweeny D (2014) Forces required to jettison a simulated S92 passenger exit: Optimal helicopter underwater egress training techniques. International Journal of Industrial Ergonomics, 44: 544-550.

Taber MJ, Dies NF, Cheung SS (2011) The effect of transportation suit induced heat stress on helicopter underwater escape preparation and task performance. Applied Ergonomics, 42: 883-889.

Taber MJ, Sanchez D, McMillan DH (2015) Operational functionality test of offshore helicopter seat harness in wet and dry conditions. Int J Human Factors and Ergonomics, 3 (3/4): 363-375.

Taber MJ, Sweeny D, Bishop N, Boute R (2017a) Factor effecting the capability to jettison an S92 push-out window. International Journal of Industrial Ergonomics, 58: 79-89.

Taber MJ, Sweeny D, Bishop N (2017b) Test methods to record the forces required to jettison a Sikorsky S92 in-cabin push-out window. International Journal of Industrial Ergonomics, 59: 1-7.

Tikuisis P, Bell DG, Keefe AA, Pope J (2005) Life raft entry from water: effect of strength, tallness, and weight burden in men and women. Aviat Space Environ Med, 76: 2-10.

Tipton M (1989) The initial responses to cold-water immersion in man. Clin Sci, 77: 581–588.

Tipton M (1997) The effect of water leakage on the protection provided by immersion protective clothing worn by man. OTH 432. Sudbury: HSE Books.

Tipton MJ (2003) Cold water immersion: sudden death and prolonged survival. Lancet, 362: S12-13.

Tipton MJ and Vincent MJ (1989) Protection provided against the initial responses to cold immersion by a partial coverage wet suit. Aviat Space Environ Med, 60: 769-773.

Tipton MJ, Stubbs DA, Elliot DH (1991) Human initial responses to immersion in cold water at three temperatures and after hyperventilation. J Appl Physiol, 70(1): 317-322.

Tipton MJ, Balmi PJ, Bramham E, Maddern TA, Elliot DH (1995) A simple emergency underwater breathing aid for helicopter escape. Aviat Space Environ Med, 66: 206-211.

Tipton MJ, Franks CM, Sage BA, Redman PJ (1997) An examination of two emergency breathing aids for use during helicopter underwater escape. Aviat Space Environ Med, 68(10): 907-14.

Tipton M, Eglin CM, Gennser M, Golden FSC (1999) Immersion deaths and deterioration in swimming performance in cold water. Lancet, 354: 626-9.

Tipton MJ, Gibbs P, Brooks C, Roiz de Sa D, Reilly TJ (2010) ECG during helicopter underwater escape training. Aviat Space Environ Med, 81: 399–404.

Transport Canada (2016) Brace for impact positions for all aircraft occupants. Advisory Circular AC 700-036, Issue 01, 2016-09-30.

Urquhart AE, Cross JH (1980) helicopter underwater escape trainer (H.U.E.T.). *Paper presented at:* Oceanology International 80. Brighton, Sussex, pp 40-44.

US Department of the Interior (2013) Helicopter Brace For Impact Positions. Interagency Aviation Safety Alert No. IA SA 13-01.

Vincent MJ and Tipton MJ (1988) The effects of cold immersion and hand protection on grip strength. Aviation Space Environ Med, 59: 738-41.

Wells R (2010a) Canada-Newfoundland and Labrador Offshore Helicopter Safety Inquiry. Phase 1, Volume 1, Report and Recommendations. St John's, NL: Canada-Newfoundland and Labrador Offshore Petroleum Board.

Wells R (2010b) Canada-Newfoundland and Labrador Offshore Helicopter Safety Inquiry. Phase 1, Volume 2, Expert and Survey Reports. St John's, NL: Canada-Newfoundland and Labrador Offshore Petroleum Board.

Wightman DC (1983) Part-task training strategies in simulated carrier landing final approach training. Technical Report NAVTRAEQUIPCEN IH-347.

Regulations and Standards

CAA (2006) Leaflet 11-18. Helicopter emergency escape facilities. In: Civil Aircraft Airworthiness Information and Procedures. CAP 562, Part 11, p3.

CAA (2015b) Safety Directive, Number: SD–2015/004, Offshore Helicopter Operations, Issued: 30 November 2015. London: Civil Aviation Authority.

CAA (2015c) Safety Directive, Number: SD–2015/005, Offshore Helicopter Operations, Issued: 8 December 2015. London: Civil Aviation Authority.

Government of Canada (2020) Canadian Aviation Regulations SOR/96-433. Part VI — General Operating and Flight Rules; Subpart 2 — Operating and Flight Rules; Division II — Operational and Emergency Equipment Requirements; Emergency Underwater Breathing Apparatus (EUBA) 602.66.

CEN (2018) EN 4856:2018, Rotorcraft - Emergency Breathing Systems (EBS) - Requirements, testing and marking.

EASA (2003a) Torso Restraint Systems, ETSO-C114.

EASA (2003b) Seat Belts, ETSO-C22g.

EASA (2006a) Helicopter Crew and Passenger Integrated Immersion Suits, ETSO-2C502.

EASA (2006b) Helicopter Crew and Passenger Immersion Suits for Operations to or from Helidecks Located in a Hostile Sea Area, ETSO-2C503.

EASA (2006c) Helicopter Constant-Wear Lifejackets for Operations to or from Helidecks Located in a Hostile Sea Area, ETSO-2C504.

EASA (2006d) Helicopter Liferafts for Operations to or from Helidecks Located in a Hostile Sea Area, ETSO-2C505.

EASA (2016b) Helicopter Offshore Operations (HOFO). Annex V to ED Decision 2016/022/R 'AMC and GM to Annex V (Part-SPA) — Amendment 4'.

EASA (2017a) Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex V Specific approvals [Part SPA] of Commission Regulation (EU) 965/2012 on air operations. Consolidated version including Issue 1, Amendment 5. March 2017.

EASA (2017b) Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Annex III Organisation requirements for air operations [Part-ORO] of Commission Regulation (EU) 965/2012 on air operations. Consolidated version including Issue 2, Amendment 12. December 2017

EASA (2018a) Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft CS-27, Amendment 5, 14 June 2018.

EASA (2018b) Certification Specifications and Acceptable Means of Compliance for Large Rotorcraft CS-29, Amendment 5, 14 June 2018.

EASA (2019) Easy Access Rules for Air Operations (Regulation (EU) No 965/2012).

EASA (2020a) Emergency Breathing Systems (EBSs), ETSO-2C519. CS-ETSO - Amendment 16, pp 870-871.

EASA (2020b) Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft CS-27, Amendment 7, 24 June 2020.

EASA (2020c) Certification Specifications and Acceptable Means of Compliance for Large Rotorcraft CS-29, Amendment 8, 24 June 2020.

EASA (2020d) Agency Research Agenda 2020-2022.

EU (2012) Commission Regulation (EU) No 965/2012 of 5 October 2012 laying down technical requirements and administrative procedures related to air operations pursuant to Regulation (EC) No 216/2008 of the European Parliament and of the Council.

EU (2016) Commission Regulation (EU) 2016/1199 of 22 July 2016 amending Regulation (EU) No 965/2012 as regards operational approval of performance-based navigation, certification and oversight of data services providers and helicopter offshore operations, and correcting that Regulation.

FAA (2008) Certification of transport category rotorcraft. Advisory Circular AC 29-2C Change 3; 30 September 2008.

ICAO (2018) Manual on Information and Instructions for Passenger Safety. Doc 10086, First Edition, 2018. Montreal: ICAO.

Norwegian Oil and Gas (2004) Recommended guidelines relating to requirement specifications for survival suits for use on the Norwegian continental shelf. Stavanger, Norway: Norwegian Oil and Gas Association.

OPITO (2020) Basic Offshore Safety Induction and Emergency Training (with Compressed Air Emergency Breathing System), Helicopter Underwater Escape Training (with Compressed Air Emergency Breathing System) Further Offshore Emergency Training (with Compressed Air Emergency Breathing System). Revision 0, Amendment 9 (January 2020). Portlethen, UK: OPITO.

Transportation Safety Board of Canada (2015) Reassessment of the response to Aviation Safety Recommendation A11-04, Emergency underwater breathing apparatus.

Annex A - Bibliography

Table 1 Accident Reports

Authors/Year	Report Title	Survival Issues Identified
AAIB, 1990	AAR 1/90. Report on the accident to the Sikorsky S61N helicopter G-BDES in the North Sea, 90 nm north-east of Aberdeen on 10 November 1988.	Ditching in rough seas (15 ft waves, 40 kt wind, 10°C sea temperatures). Aircraft immediately rolled to right and capsized. The crew and passengers were uninjured; all managed to escape from the inverted aircraft with varying degrees of difficulty. From an inverted position under water after the capsize, neither pilot was able to locate the jettison handle for their emergency exit. One pilot proceeded aft to the cargo door which he was not able to open. "*On the point of drowning*" the pilot managed to escape by punching out a passenger window. After failing to find the jettison handle for his emergency exit the second pilot slid open his side window through which he escaped. The edges of the opening presented several projections which could have snagged clothing or safety equipment during egress. All eleven passengers escaped; some encountering minor difficulty. One used the left hand escape exit and the others used push out windows. Three passengers reported some difficulty in releasing their lap strap buckle. One passenger reported that he could not grip the fabric tag attached to the window rip-out beading until he had removed a survival glove. One passenger sustained a broken bone in his hand while punching out a window. Most immersion suits leaked to some degree, with one passenger treated for hypothermia.
AAIB, 1991	AAR 2/91. Report on the accident to Sikorsky S61N G-BEWL, at Brent Spar, East Shetland Basin, on 25 July 1990.	Water impact accident which occurred when the helicopter was manoeuvring to land on the Brent Spar platform. The tips of the tail rotor blades struck part of the crane frame after which the helicopter crashed onto the helideck and almost immediately fell over the side of the deck and into the sea. Seven survivors

Authors/Year	Report Title	Survival Issues Identified
		were rescued from the sea having escaped from the rapidly sinking helicopter. Six occupants including the crew perished. Evidence from the surviving passengers indicated that, following the impact, the passenger cabin rapidly filled with water and the survivors escaped through the nearest window to their seat. Most of the cabin windows were either broken or dislodged cleanly by the distortion of the airframe or the force of the water. This aided egress for those who were not incapacitated by the impact. The collapse of passenger seats coupled with impact forces with the sea, contributed to injury and incapacitation. It was considered that may have been a direct cause of death and would certainly have hampered egress. Three of the passengers had some difficulty in releasing their lap strap buckle. It was recommended that seat requirements should be reviewed and that newly manufactured aircraft should have effective upper torso restraints installed.
AAIB, 1993	AAR 2/93. Report on the accident to as 332L Super Puma, G-TIGH, near the Cormorant 'A' platform, east Shetland Basin, on 14 March 1992.	This water impact accident occurred at night, in severe weather conditions, during a shuttle of personnel from an oil production platform to a nearby accommodation 'flotel'. The helicopter was equipped with emergency flotation equipment but the crew did not have time to activate it manually before the helicopter struck the surface. The helicopter remained at the surface, rolling onto its side before capsizing and sinking after an estimated one to two minutes. Among the 17 occupants there were 11 fatalities, all as a result of drowning (no significant injuries). Five failed to escape, 6 escaped but did not survive, while 6 survived. All five passengers who failed to escape from the cabin had managed to release their seat belts and "*appeared to be in the process of escaping*". One was still inside the cabin, lying across the rear bench seat next to a small aperture escape window. One was found partially through an escape window, one was lying across an exit door and one was just outside the aircraft. The remaining non-survivor who did not escape from the cabin was found with a headset cord around his neck.

Authors/Year	Report Title	Survival Issues Identified
		Water entry into the cabin was rapid and not all of the survivors reported having time to take a breath. One of the survivors attempted to help another occupant into the life raft, but the attempt failed and the individual drifted away (a non-survivor). Of the other non-survivors who reached the water surface, the report suggests that some were initially conscious, while there is at least one case of a passenger who had apparently died at an early stage, possibly drowning before reaching the surface. The co-pilot survived for a considerable time, helping others, but is then thought to have succumbed to hypothermia before subsequently drowning. Another was still alive when grab lines were thrown to him, but drowned before he could be rescued, presumed due to swamping by waves. The right life raft suffered major damage but still provided some support for survivors, despite overturning several times. Problems were experienced with the lifejackets used at the time, with the buoyancy chambers riding up the body. Of the non-survivors, two were supported by their lifejackets, one was floating face-down with the lifejacket deflated due to damage, while the lifejacket had ridden up the bodies of the other two to the point where their faces were underwater. The survivors reported that waves were breaking over their heads, with no protection provided by the sprayhoods which they did not manage to deploy. Only one of the immersion suits, worn by a non-survivor, was found to have leaked significantly, although the suit was partially unzipped when the body was recovered.
AAIB, 1997	AAR 2/97. Report on the accident to AS 332L Super Puma G-TIGK, in North Sea 6 NM south west of Brae Alpha oil platform, on 19 January 1995.	Ditching following a lightning strike. Despite 6 to 7 m waves and a 30 kt wind the helicopter remained upright enabling the passengers and crew to board a heliraft from which they were subsequently rescued without injury. Passengers on the port side of the aircraft had problems with the life raft blowing up against the open door, making boarding difficult. All boarded the starboard life raft. The lower chamber of the starboard life raft was punctured, apparently due to contact with the edge of a floating door. The passengers acknowledged the value of their training.

Authors/Year	Report Title	Survival Issues Identified
AAIB, 2011	AAR 1/2011. Report on the accident to Eurocopter EC225 LP Super Puma, G-REDU near the Eastern Trough Area Project (ETAP) Central Production Facility Platform in the North Sea on 18 February 2009.	This water impact occurred in low visibility conditions. The aircraft remained upright, primarily due to the automatic deployment of the emergency flotation system (EFS). Passengers were only aware of the impact when the cabin started to fill with water following a heavy "*landing*". Passengers started to evacuate immediately, through the exit doors, but also through escape windows. Most of the passengers did not experience any problems with the exits. However, those who were sitting beside the right cabin door were unable to locate that door's jettison handle. They opened the cabin door using the normal method and, in so doing, blocked the right forward cabin window exits. Issues were experienced with PLBs and with deployment of the life rafts. The port life raft was deployed from inside the cockpit. Its inflation was slow, restricted by lanyards, while the lower chamber was damaged. Passengers attempted to deploy the starboard life raft using an external deployment handle but were not successful; the life raft was manually removed from its housing after which it inflated. Once in the life rafts the long retaining lines were cut when the life rafts drifted to a position where they were at risk of being struck by the stationary rotor blades.
AAIB, 2014	AAR 2/2014. Report on the accidents to Eurocopter EC225 LP Super Puma G-REDW 34 nm east of Aberdeen, Scotland on 10 May 2012 and G-CHCN 32 nm southwest of Sumburgh, Shetland Islands on 22 October 2012.	Report of two ditching accidents which occurred in May and October 2012. No reported serious injuries to the crew or passengers, but lessons to be learned. <u>G-REDW:</u> With 7 min to prepare, "*passengers carried out their personal pre-ditching drills, which they recalled from their safety training. They fitted their survival hoods, prepared their rebreathers and located their nearest exit*." The passengers jettisoned the emergency exit doors. All passengers evacuated into the starboard life raft as it achieved full inflation before the other. Crew boarded the same life raft by climbing along the side of the fuselage. The port raft was unused but fully inflated. The long mooring line was cut due to concern over proximity of a rotor blade tip. None of the occupants inflated their lifejackets at any time. <u>G-CHCN:</u>

Authors/Year	Report Title	Survival Issues Identified
		In preparation for the ditching, the passengers donned their gloves and neoprene hoods stored in their immersion suits and opened their rebreather mouthpiece covers. Some passengers reported finding it difficult to locate or physically open the mouthpiece cover. They also reported the loss of manual dexterity once they donned the gloves; this may have contributed to their difficulty in opening their rebreather covers. The passengers considered it would have also made it difficult to operate the cabin window jettison mechanism had they needed to do so. "*The co-pilot climbed into the cabin to oversee the passenger evacuation and slid open the left cabin door. This allowed water to enter the cabin to a depth of about 20 cm. He reported that he opened, rather than jettisoned, this door as he was concerned that it might fall onto, and damage, the liferaft. In opening the door, it now blocked one of the cabin windows, so it could not have been used as an exit had the helicopter subsequently capsized or sunk*". The left liferaft was fully inflated, but it was being constrained on the sponson by tangled mooring and rescue pack lines. About a quarter of the raft was resting on the sponson. The crew evacuated to the life rafts via the cabin doors. Neither were wearing an immersion suit (sea water temperature 11°C, air temperature 9°C). The long mooring line was again cut due to proximity of a rotor blade and concern that helicopter might capsize. Five passengers reported wet feet, due to minor leaks into their suits.
AAIB, 2016	Aircraft Accident Report 1/2016 Report on the accident to AS332 L2 Super Puma helicopter, G-WNSB on approach to Sumburgh Airport on 23 August 2013.	This water impact accident occurred on the approach to Sumburgh Airport, resulting in four fatalities and 14 survivors. The sea surface temperature was 13°C; sea state was reported as slight to moderate. The aircraft was affected by wave refraction around the Garth Ness headland and ended up in the surf break zone. Crew were not wearing immersion suits due to high cockpit temperatures. The pilot suffered a back injury on impact; the co-pilot suffered a head injury.

Authors/Year	Report Title	Survival Issues Identified
		The passengers received no warning of the impact from the flight crew, although some became aware they were about to hit the water before impact. Only a few had time to take a breath before submersion. Some passengers reported being able to see underwater but others had difficulty and felt their way to an exit. A few of the passengers initially attempted to use their EBS but they were unable to locate the cover for the mouthpiece and so concentrated on escaping from the cabin instead. "*Of the three fatalities caused by drowning, one did not release their seat harness and was still secured in their seat when the wreckage was recovered (harness later found to be serviceable). A second person released their seat harness but did not escape from the cabin. Their body was released when the helicopter fuselage broke apart. There was some evidence to suggest that the third person escaped from the cabin, but subsequently drowned*". A fourth passenger was able to escape from the helicopter and was assisted by other survivors onto the inverted fuselage of the helicopter and then into the liferaft, but died from a cardiac event. Escape routes: - four emergency exit windows were opened by passengers. - four passengers were known to have left by an exit window next to their seat. - four passengers were known to have crossed the cabin to escape, at least one of whom was sitting next to an exit window. - two in aisle seats left by their nearest exit. - two passengers did not exit the helicopter; 2 passengers were found deceased on the surface (one thought to be due to cardiac arrest). "*Some passengers who had removed window panes reported experiencing difficulty pushing out the panes due to the amount of force necessary, and in some cases more than one attempt was required, delaying their exit from the submerged cabin*." Neither pilot could locate the emergency jettison handle for their respective door and were forced to use the normal door handle. Both life rafts were released by the co-pilot, using the D-rings on the bottom of the sponsons. The co-

Authors/Year	Report Title	Survival Issues Identified
		pilot and a passenger attempted to manoeuvre one life raft to some passengers in the water, but unable to reach them. Five passengers remained in water until rescued. Life rafts were slow to inflate and painter lines were tangled. Two lifejackets were damaged in a manner consistent with damage sustained during the impact or the evacuation and rescue. There were some problems deploying buddy lines. None of the survivors "*mentioned feeling cold initially, or suffering cold shock when first submerged in the water*". One immersion suit filled with water over time; the wearer felt cold as time passed. Four other passengers reported some water ingress. EBS were not carried by crew. Passengers had a 'LAPP' hybrid rebreather system. All but one were still in the stowed position when checked after the accident. In each case the stored air had been released into the EBS counterlung. The investigators suggest that the passenger survivors "*were unaware that the hybrid LAP Plus jacket had an automatically released air supply. They believed that the EBS would only be of assistance if they inflated it manually with an expelled breath*". Most passengers thus elected to not use the EBS to aid escape. N.B. Training did cover the gas cylinder and release of the supplemental air on water entry, but gas release was not experienced during practical exercises to reduce risk.
AAIB, 2020	Formal Report Addendum to AAR 1/2016 - G-WNSB. AAIB Bulletin: 9/2020, EW/C2013/08/03.	Additional information has been presented to the AAIB which was not made available during the original investigation. The initial investigation found that the Emergency Breathing System (EBS) of one of the passengers had been found in a condition which indicated that an attempt had been made to use the system during the accident. The new information confirmed that when the victim was recovered from the sea and taken to shore the EBS had been found stowed in its pouch on the passenger's life jacket. Before being received by the AAIB, the EBS was removed from its pouch and the valve operated; it was not

Authors/Year	Report Title	Survival Issues Identified
		possible to identify when this had occurred. As a result, the report has been amended to correct the information provided.
AIB Nigeria, 2016	Preliminary report on accident involving Sikorsky S-76c++ helicopter belonging to Bristow Helicopters Nigeria Limited with registration 5N-BQJ which occurred at about 75 nm to Lagos in the Atlantic Ocean on the 3rd of February, 2016.	This helicopter ditched with eleven crew and passengers on board, in good weather conditions. All successfully evacuated into two life rafts. The left life raft was slightly damaged during jettison of the left side door. The aircraft capsized sometime later, but remained submerged at water surface until recovered.
AIB Norway, 1998	Report 02/98. Air accident involving Eurocopter Super Puma 332L, LN-OBP, in the North Sea on 18 January 1996, approx. 40 NM south-west of Sola, Norway.	This ditching occurred in wave heights of 3-4 m. All crew and passengers evacuated the aircraft successfully. The helicopter capsized some hours later. Both life rafts were released from the cockpit. All passengers and the co-pilot boarded the port raft while the pilot-in-command attempted to free the starboard raft, which had blown up onto the roof of the helicopter. The port side life raft was blown under the tail rotor resulting in puncture of one chamber. Several occupants fell overboard and some chose to swim back to the helicopter. All eventually returned to the helicopter cabin. Three passengers later boarded the starboard raft with the pilot-in-command. All were rescued after 1 hour.
BFU, 2014	CX024-12/2014. Report on the accident to Eurocopter AS 350BA, Neustadt Bay, Baltic Sea, Germany on 05 December 2012. German Federal Bureau of Aircraft Accident Investigation.	Helicopter which went missing between Germany and Sweden after losing radio contact. After a search lasting for several days the helicopter and the bodies of the crew were found and recovered. When found, the fuselage was intact leading to the conclusion that a controlled ditching with little forward motion had been achieved. The two occupants, found some distance from the aircraft, were determined to have died from hypothermia in combination with drowning (no injuries). Contributing factors were a lack of any protective clothing or lifejackets (the flight should not have followed an over-water route). Sea

Authors/Year	Report Title	Survival Issues Identified
		temperature was about 4°C. Three life vests should have been carried on the helicopter; none were found.
DSB, 2010	Emergency landing Bristow AS 332L2 search and rescue helicopter North Sea, near Den Helder, 21 November 2006. The Hague: Dutch Safety Board.	When the G-JSAR ditched into the North Sea near Den Helder in 2006, the search and rescue helicopter was being used to transfer passengers to shore; four crew and 13 passengers were rescued out of the water after approximately 1 hr, with one passenger suffering from hypothermia. A series of problems were experienced during the evacuation of the helicopter. As this was not a standard flight, the passenger briefing was not as detailed as usual, with no video. No warning was given to the passengers of the impending ditching and there was no 'brace for impact' command, meaning they were unable to prepare for the event. Not all of the passengers heard the briefing to follow instructions from the crew in an emergency. As a result, some started to evacuate the cabin before instructed, with the rotors still turning. Due to the severe sea conditions, the crew believed that the helicopter was in imminent danger of capsizing, although it remained upright for a further 8 hrs. The crew did not use the cockpit life raft deployment mechanism, and nor did the rear crew deploy the life rafts before evacuating, meaning that all of the passengers and crew evacuated into the water. It was only later that the winchman attempted to manually deploy a life raft from the sponson. He did not manage to do this; training had covered location of this handle but not actually pulling the handle. As a result all the passengers and two crew remained in the water (approx. 12°C), without the protection offered by a life raft. The immersion suits were reported to have performed effectively although there was some leakage through the neck and wrist seals. Passengers had problems donning their gloves in the water, in darkness. Most of the crew were either not wearing gloves or not carrying them. Hoods were not donned - donning of hood and gloves was reported to have not been covered during HUET training. The pilot was not wearing a lifejacket in the water; it is thought she may have released the lifejacket buckle when releasing the seat harness, and that the lifejacket was lost during egress from the cockpit.

EASA
European Union Aviation Safety Agency

Authors/Year	Report Title	Survival Issues Identified
		The accident investigators considered that if lessons from previous successful ditchings had been learned and passed on in crew training, then the crew may have made a different decision than the one to evacuate into water. However, it was also recognised that the SAR crew were not sufficiently trained for a ditching with passengers.
FSIR (2008a)	Canadian Forces Flight Safety Investigation Report; 1010-12438 (DFS 2-2), relating to the accident on approach to HMCS Athabaskan (30 NM E Aalborg, Denmark, on 02 February 2006.	This military water impact accident occurred on approach to a ship when the helicopter's rear fuselage and tail rotor contacted the water. The helicopter impacted the water near level but then yawed right and rolled over. Aircraft remained afloat for one hour, before then sinking. Water temperature was 2°C. All five crew members escaped and were recovered within 15 min, one with minor injuries. Darkness greatly exacerbated difficulty of escape. The first crew member to escape did so as the helicopter started to roll, before water started rushing in. One crew member mistakenly unfastened his pack-back instead of his seat harness. On unbuckling he was swept forward by a surge of water. A third crew member floated into an air gap after failing to operate one exit. He then used his EBS and went back to attempt to release the exit but pulled the lower door lever rather than the upper door release handle. He recalled that "*the HEELS lit up the doorframe well, but did not show the position of the emergency release handle*" for the upper personnel door. He eventually managed to escape. The fourth crew member also used his EBS after having difficulty locating the exit release handle (having already released his lap belt). He had difficulty releasing the Velcro strap that held the EBS. He pushed out the escape window on his third attempt. The fifth crew member deployed his EBS as the aircraft rolled. He could not locate his exit release handle and experienced extreme difficulty escaping. Only one was able to operate his back-pack life raft.
FSIR (2008b)	Canadian Forces Flight Safety Investigation Report; 1010-149914 (DFS 2-3); relating to the accident over Chedabucto Bay, Nova Scotia on 22 January	This accident occurred during a SAR night training mission in association with a fishing vessel, with 7 crew members on board. As the helicopter was approaching the vessel the aircraft captain became concerned with the helicopter's decreasing altitude. During an attempted go-around, the helicopter contacted the water. Upon water contact, the forward fuselage area was destroyed and the rear cabin area immediately filled with water. The three pilots and a SAR technician team leader in the

Authors/Year	Report Title	Survival Issues Identified
	2008.	cabin received injuries ranging from serious to minor, but survived. Two flight engineers and a SAR technical team member died, with cause of death given as drowning. Neither the pilots nor the two flight engineers were wearing immersion suits (allowed by a 15 min rescue capability), but each was wearing an integrated life preserver (lifejacket) with a survival vest. In two cases, only one lobe of the life preserver inflated, but both surfaced and remained afloat. Problems linked to inflation in the cold were suspected. The SAR technicians were wearing flotation coveralls with positive buoyancy and life preservers, which had not been inflated. A compressed air EBS was carried by the crew. One crew member had tried to use his EBS but could not locate it (it had become separated from his life preserver); a second had no recollection of using his EBS; another had not had any formal training in EBS use and did not attempt to use it - "*its use was not an ingrained part of his egress skills*". The EBS assemblies carried for the two flight engineers were found with the cylinders empty. Of the EBS assemblies carried for the SAR technicians, one was found empty with the pressure gauge cracked and the other was not found. During the escape process, one of the flight crew took several attempts to release his seat harness before successfully egressing from the helicopter. The other two pilots had no recollection of releasing the harness. Water temperature was approximately 10°C.
TSB Canada (2010)	Main gearbox malfunction / collision with water; Cougar Helicopters Inc. Sikorsky S-92a, C-GZCH; St. John's, Newfoundland and Labrador, 35 Nm E 12 March 2009. Aviation Investigation Report A09A0016. Gatineau, Quebec: Transportation Safety Board.	During an attempted ditching the S-92A helicopter struck the water in a high rate of descent, with significant impact forces. One passenger survived with serious injuries; he was rescued approx. 1 hr 20 min after the accident. The other 17 occupants of the helicopter died of drowning, attributed to the effects of cold shock. All were thought to have survived the impact, many with lower limb fractures. Only one of the non-survivors reached the water surface. There were no signals detected from either the emergency locator transmitter or the personal locator beacons worn by the occupants of the helicopter.

Authors/Year	Report Title	Survival Issues Identified
		It was reported that, in all likelihood, the survivor escaped the wreckage at a depth between 20 to 30 feet. He was able to hold his breath, despite the cold water shock, long enough to reach the surface. The survivor testified that by the time he reached the water surface, the cold water had caused him to lose all feeling in his hands and he was therefore unable to don his gloves or raise his spray hood. The occupants wore insulated immersion suits with integrated life preserver but no EBS. The one survivor should have been wearing a medium sized suit but was wearing a large suit. He swallowed a significant amount of water (which would have contributed to body cooling). After 1 hr 20 min in water at 0.2°C his body temperature was reported to have dropped to 29.8 °C (but it is not reported how/where/when this was measured). The accident report considered basic survival training conducted in Canada at the time, identifying issues relating to some HUET training equipment and whether it was representative of the S-92. The survivor had completed his most recent helicopter underwater training just two months before the accident. "*In addition to noting that HUET was very controlled and covered a ditching without a lot of impact, he identified environmental issues such as salt water, water temperature, and wave action as being the most significant differences*".
TSB Canada, 2015	Collision with water Government of Canada, Department of Transport, MBB BO 105 S CDN-BS-4 (Helicopter) C-GCFU, M'Clure Strait, Northwest Territories, 09 September 2013. Aviation Investigation Report A13H0002.	Canadian Coast Guard helicopter flight with one pilot, one ship's master and a scientist on board. Contact was lost during the flight. The 3 occupants survived the impact, escaped from the helicopter before it sank to the sea floor, but all succumbed to drowning. Sea temperature was −0.6 °C. Both the master and the scientist were wearing a helicopter transport suit, but with half the required insulation. The suits were full of water when they were recovered. Neither passenger was wearing hood or gloves. The pilot was wearing a suit with the supplied insulated thermal lining. The suit was also full of water due to the zip only being done up to mid-sternum level. The master was wearing an uninflated life jacket and was found floating face-down. The scientist was wearing a partially inflated lifejacket and was floating on his side. Although the pilot had donned a PFD prior to departing on the flight, the fully inflated PFD was floating near the pilot and was recovered separately, inflated. It is thought he removed the zipped lifejacket. None of the 3

Authors/Year	Report Title	Survival Issues Identified
		occupants was supported in a manner to keep their mouth and nose above the water line. The pilot had undertaken HUET training 2 years previously. Neither passenger had undertaken HUET.

Table 2 Research papers and reports reviewed relating to Helicopter Underwater Escape, Survivability and Training (ratings relate to method of publication and likely peer review but do not necessarily relate to quality of work)

Key to Ratings:

1 = Peer reviewed science journal

2 = Accident investigation report

2 = Industry published report (may or may not have been peer reviewed)

2 = Contribution to a book

3 = Conference paper

3 = Unpublished industry report

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Abernethy, B (2005)	Paper presented to the International Association of Safety and Survival Training.	The appropriate roles for algorithmic and heuristic methods in helicopter underwater egress training: how to maximize aircrew and passenger survivability.	Commentary comparing algorithmic training (learning pre-defined step-by-step procedures) with heuristic training (learning concepts and then problem solving in the real environment). Concludes that the disagreement between the two approaches seems to be primarily an empirical trade-off that depends on the level of variation that the trainee will encounter in an actual emergency, and the trainee's ability to carry out heuristic problem-solving quickly and correctly in an actual emergency. Provides opinion that training involving problem solving should be reserved for those using supplemental air.	3
Allan JR and Ward FRC (1986)	RAF Institute of Aviation Medicine Aircrew Equipment Group Report No. 528.	Emergency exits for underwater escape from rotorcraft.	Study of escape using an adjustably sized exit to determine the smallest rectangular exit compatible with underwater escape by passengers in the upper range of shoulder widths. An exit of 17" x 14" (432 x 356 mm) was considered to be the smallest acceptable size. Identified problem of snagging if protrusions are over the back of the	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
			passenger. Observed benefit of swimming goggles and suggests that hand-holds would aid escape. Recommends larger number of smaller escape exits for ditching emergencies.	
Allan JR, Higenbottam C, Redman PJ (1985)	Aviat Space Environ Med, 56: 1107-1109.	The effect of leakage on the insulation provided by immersion-protection clothing.	The effect of controlled, incremental water leakage on the thermal insulation provided by three immersion-protection assemblies was measured using a thermal manikin. The results showed an average loss of 30% of the initial insulation for a leak of 500 g, 40% for a leak of 1000 g, and nearly 60% for a leak of 3000 g. Recommendation that the substantial loss of insulation even with small leaks makes it essential that tests of the water-excluding performance of immersion suits are undertaken in realistic conditions rather than in calm water.	1
Anton DJ (1984)	Int J Aviation Safety, 2: 55-63.	A review of UK registered helicopter ditchings in the North Sea.	Reviews the outcome of seven survivable water impact accidents in the North Sea, identifying problems experienced.	1
Armstrong IJ, Bennett-Smith SC, Coleshaw SRK (1994)	OTH 94 428. Sudbury: Health and Safety Executive.	Performance of immersion suit and lifejacket combinations at sea.	The performance of lifejackets and lifejacket/immersion suit combinations was measured under realistic conditions at sea, using an anthropometric marine manikin, to define good design characteristics and compatibility. The equipment was chosen to be representative of personal protective equipment in use at that time by UK offshore industry (aviation and marine). Higher buoyancy lifejackets provided improved airways protection from wave splash, as did use of a highly insulated immersion suit. The use of a spray hood significantly improved the performance of the life jacket.	2
Barker C and	Aviat Space Environ	U.S. Naval	Review of military helicopter accidents. Of the 210 survivable mishaps, 289	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Bellenkes A (1996)	Med, 67(5): 480-485.	Helicopter Mishaps: Cockpit Egress Problems.	egress problems were reported in 128 mishaps, 61% involved aircrew factors, 16% environmental factors, 12% were related to helicopter factors, and 11% to cockpit factors. Of the 128 mishaps, 67.5% occurred during daytime, 32.5% at night, 64% in overwater crashes, 26% over land, and 10% over flight decks. The most significant, but uncommon, injuries involved the "stroking seat."	
Barthelmess S (1988)	Flight Safety Foundation Cabin Crew Safety, 23(1): 1-6.	Positions brace passengers for impact to reduce injuries.	Short paper looking at optimal brace positions for given circumstances. Reviews work undertaken by the FAA using manikins and addresses misunderstandings.	2
Balmi PJ, Tipton MJ (1996)	Eur J Appl Physiol, 72: 394–400.	The effect of water leakage on the results obtained from human and thermal manikin tests of immersion protective clothing.	The effect of both the volume and location of water leakage on the protection provided by an uninsulated immersion suit. The human experimentation provided some support for a 200-ml limit to water leakage in tests of immersion suits. Rectal and aural temperatures remained significantly higher when a 500-ml leak was applied to the limbs rather than the torso; this was primarily due to greater heat flow through and from the torso during the immersions with torso wetting.	1
Barwood MJ, Dalzell J, Datta AK, Thelwell R C, Tipton MJ (2006)	Aviat Space Environ Med; 77 (11): 1136-1142.	Breath-Hold Performance During Cold Water Immersion: Effects of Psychological Skills Training.	Experiment to test the hypothesis that part of the variability in the cold shock response is due to psychological factors. Psychological skills intervention comprised of four interlinked training sessions covering goal-setting, arousal regulation, mental imagery, and positive self-talk. Concluded that psychological influences may account for a significant amount of the variability in the respiratory responses during cold water immersion, and may be a key factor in determining the chances of survival	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
			following accidental immersion.	
Barwood MJ, Corbett J, Coleshaw S, Long G, Tipton MJ (2010)	Aviat Space Environ Med 2010; 81: 1002-1007.	Performance of emergency underwater breathing systems in cool (25°C) and cold (12°C) water.	Performance of rebreather, compressed air and hybrid EBS in cold water - human subject trials. The data suggested that the compressed air and hybrid designs of EBS outperformed the rebreather EBS, but the hybrid device required longer to deploy.	1
Benham JA and Hayward P (1996)	Report No. DRA/ CHS/PHS/WP96/ 004. Farnborough, UK: Defence Research Agency.	A review of the snagging problems said to occur during underwater escape with current back and seat-mounted PSPs.	Review of military problems relating to escape associated with personal safety packs. Trials conducted measuring escape time, body orientation and snagging.	3
Benham JA, Redman PJ, Hayward P (1995)	Report No. DRA/ CHS/PHYS/WP95/ 017. Farnborough, UK: Defence Research Agency.	An interim report on the developments of safe underwater escape from helicopters.	Review of factors contributing to safe underwater escape from helicopters (based primarily on military experience).	3
Benton PJ, Woodfine JD, Westwood PJ (1996)	Aviat Space Environ Med, 67: 63-64.	Arterial gas embolism following a 1-metre ascent during helicopter escape training: a case report.	Case study of a trainee who experienced an arterial gas embolism following helicopter underwater escape training when using a compressed air EBS.	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Birciu Z and Grabski F (2011)	Reliability Engineering and System Safety, 96: 1456-1461.	The experimental and theoretical study of life raft safety under strong wind.	The reliability function for the life raft was developed on the basis of the results of experimental research on hydrodynamic and aerodynamic reaction forces for 6, 10 and 20-person life rafts with and without a drogue. Concluded that the reliability of a life raft depends on the number of occupants, with a fully occupied life raft being more reliable than a partly occupied one. On boarding a life raft in strong winds, the survivors should occupy the windward side of the life raft first, to minimize the danger of capsizing. In a partially occupied life raft survivors should always occupy the windward side.	1
Bohemier A, Chandler P, Gill S (1990)	Canada Oil and Gas Lands Administration Technical Report 108.	Emergency breathing systems as an aid to egress from a downed flooded helicopter.	Underwater escape trials involving 26 naïve subjects representative of offshore workforce. Subjects escaped from three different seat positions, with and without compressed air EBS. Without EBS, success of reaching exit improved over seven escape exercises. Higher success rate recorded when EBS used (which masked any improvement over time).	3
Bohemier A, Chandler P, Gill S (1991)	Technical Report 109. Ottawa, Canada: Canada Oil and Gas Lands Administration.	Factors affecting egress from downed flooded helicopter.	Assessed escape from a simulator set up as an S-61, using naïve subjects representative of offshore workforce. Phase 1 assessed escape from different seat positions (no EBS). Probability of making successful escape decreased with distance from exit. Overall, escape from a seat near an exit was most successful (90%), similar success rates were achieved from cross-cabin and moving forward in the cabin (81% and 82%), while orientating to move to an exit behind the seat was most problematic (59% success); latter case did not improve with practice. Less disorientation was found when subjects had to move forward down the cabin, then when crossing the cabin. Phase 2 assessed exit mechanisms with escape from a seat next to an exit and cross-cabin escape. For push out windows, subjects found their bodies	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
			floated away from the window as they attempted to push the window out. An exit with a pull strip required dexterity to grasp the pull tab. Success rates improved over a sequence of 7 exercises. (N.B. Very little statistical analysis provided.)	
Bohemier A, Brooks CJ, Morton JS, Swain JH (1999)	NATO AGARDograph RTO-MP-19 AC/323(HFM)TP/4, RTO meeting Procedings 19: Current aeromedical issues in rotary wing operations.	High fidelity survival training for ditched aircrew and passengers.	Conference paper which lists reasons for difficulty escaping from a helicopter. The benefits of training are reviewed. The authors comment that "*a seat beside an open exit provides the greatest probability of survival. Chances of survival decrease with increased distance between seat and exit*."	3
Bottenheft C, Oprins EAPB, Houben MMJ, Meeuwsen T, Valk PJL (2019)	Aerospace Medicine and Human Performance, 90(9): 800-806.	Self-assessed preferred retraining intervals of helicopter underwater egress training (HUET).	This study investigated aircrew refresher training. Retrospective questionnaires were completed by 132 helicopter aircrew. Maritime crew self-reported increasing competence levels with the number of refresher courses followed. Preferred training intervals for HUET increased from 11/22 months for the first refresher up to 22/33 months for the third to fourth retraining interval (maritime/regular flight crew).	1
Brooks CJ (1988)	Applied Ergonomics, 19: 266–270.	Maximum acceptable inherent buoyancy limit for aircrew/	Study undertaken to determine whether the maximum buoyancy of a helicopter suit could be increased from 137 N to 146 N to allow greater thermal protection. Twelve subjects safely escaped from a helicopter underwater escape trainer with 146N (33 lbf) of added buoyancy.	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
		passenger helicopter immersion suit systems.	However, subjects found that if they did not firmly anchor their legs around the seat, their legs tended to lift off the floor when the helicopter simulator was inverted, making it difficult for the subjects to control their position when the lap belt was released.	
Brooks CJ (1989)	AGARDograph No.305(E). Neuilly-sur-Seine, France: NATO Advisory Group for Aerospace Research & Development.	The human factors relating to escape and survival from helicopters ditching in water.	Paper concerning military and civilian over-water helicopter accidents. Comprehensive review of problems related to survival including pre-flight briefing, escape and rescue.	2
Brooks CJ and Bohemier AP (1997)	Aviat Space Environ Med, 68(9): 844-57.	Helicopter door and window jettison mechanisms for underwater escape: Ergonomic confusion!	Investigation relating to the lack of standardization of doors, exits, windows and escape routes with 23 different release mechanisms identified in 35 types of helicopters used for over-water operations.	1
Brooks CJ and Potter P (1998)	*Paper presented at*: RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", San Diego, USA, 19-	The abysmal performance of the inflatable liferaft in helicopter ditchings.	Literature review of life raft performance. Considers problems experienced in different accidents. Includes development of the Heliraft™. "*It is clear from the more recent civilian and military data that a modified inflatable marine raft has simply been fitted into the cockpit and/or fuselage of the helicopter as an after-thought following the design of the helicopter*". "*The data presented in this paper of 15 civilian helicopter accidents between*	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	21 October 1998. Published in RTO MP-19. Neuilly-sur-Seine, France: NATO		*1984 and 1996 shows that only one accident in which the liferafts worked as specified*".	
Brooks CJ and Tipton M (2001)	RTO AGARDograph 341. Neuilly-sur-Seine, France: NATO. Human Factors and Medicine Panel.	The requirements for an emergency breathing system (EBS) in over-water helicopter and fixed wing aircraft operations.	Review document. Discusses the problem of drowning in helicopter water impact and ditching accidents and the principal that the cause of drowning is due to inability to breath-hold long enough to make an escape. The provision of some form of EBS, whether a re-breather or compressed air unit, would extend the time underwater and hence improve survivability. The development of EBS is described, and current available units are included to aid NATO to review their choice. Also covers training issues.	2
Brooks CJ, Bohemier AP, Snelling GR (1994)	Aviat Space Environ Med, 65(5): 387-95.	The ergonomics of jettisoning escape hatches in a ditched helicopter.	Investigation of the problem of location, operation and jettison of escape windows following ditching. Looks at escape using a variety of escape routes and nine different types of escape exit. Unforeseen problems experienced. There was no standardization of exits and levers; there were problems with location and operation of the levers thought to be principally due to poor design. The authors recommended that underwater escape training with exits in position should be mandatory for all who fly off-shore or over water for a living, and further research should be conducted to design a better standard exit and jettison system.	1
Brooks CJ, Potter PL, Hognestad B, Baranski J (1997)	Aviat Space Environ Med, 68(1): 35-40.	Liferaft evacuation from a ditched helicopter: dry shod vs. swim away method.	Report of a series of evacuation trials conducted from a Super Puma simulator into a Heliraft™ in Bergen Fjord. The 'dry shod' method of evacuation was preferred. It was found to be possible to evacuate a full complement of 18 people into life raft, in open ocean but good weather conditions, in 2 min, and paddle to a safe area in 4 min.	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
			The 'swim away' method was found to be problematic. This took longer on the leeward side. The time for all to reach safety in the life raft took a mean of 4 mins for swim away compared to less than 2 minutes for dry shod. The authors recommend evacuation from the windward side.	
Brooks CJ, Potter PL, De Lange D, Baranski JV, Anderson J (1998)	Aviat Space Environ Med, 69 (3): 743-749.	Options for liferaft entry after helicopter ditching.	Dry and wet evacuations were conducted by 24 male and 19 female subjects using a Super Puma simulator and two different types of aviation liferaft. Dry evacuation on the windward side was the method of choice. The non-canopy raft was subjectively and objectively easier to enter both from the helicopter and the sea. It was concluded that the non-canopy raft was the raft of choice and that the canopy raft needed a redesign to ensure that it always inflates the correct way. They considered that both rafts needed a redesign of the painter anchor point.	1
Brooks CJ, Miller L, Morton S, Baranski J (1999a)	Aviat Space Environ Med, 70(8): 752-758.	Evaluation of a new universal jettison mechanism for helicopter underwater escape.	Study due to concerns that there was no standard jettison mechanism for doors, windows, or hatches in ditched helicopters. A new Universal Escape Exit (UEE) was invented and the performance compared with two in-service systems in a helicopter underwater escape trainer. The UEE reduced escape time by 2 s. In the majority of cases the UEE was preferred to a rotating lever or a straight push out system.	1
Brooks CJ, Muir HC, Gibbs PN (1999b)	Survival Systems Limited Report. Dartmouth, Canada: Survival Systems Limited.	An initial investigation of passenger evacuation from the Super Puma helicopter.	Original SST report, later published by Aviat Space Environ Med, 2001 (see Brooks et al, 2001).	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Brooks CJ, Muir HC, Gibbs PN (2001)	Aviat Space Environ Med, 72(6): 553-61.	The basis for the development of a fuselage evacuation time for a ditched helicopter.	Investigation of underwater escape from a fully loaded cabin. The 132 subjects were all highly experienced instructors or Navy clearance divers. Evaluations were conducted in daylight and darkness to measure escape times from a helicopter underwater escape trainer configured to the Super Puma, with seating for 15 or 18 passengers. Breath-holding for the last subject out ranged from 28 to 92 s. An emergency breathing system was used by a minimum of four subjects each time and a maximum of 11 subjects in one condition. The buoyancy of the survival suit was the principal component that hampered escape. Breath-holding times were too long for the later subjects to escape without resorting to an EBS, in spite of the fact that they were highly trained.	1
Brooks CJ, Gibbs PN, Jenkins JL, McLeod S (2007)	Aviat Space Environ Med, 78: 618-623.	Desensitizing a pilot with a phobic response to required helicopter underwater escape training.	Case study showing an increase in confidence and reduced anxiety levels achieved by part task training, building up the difficulty of escape exercises progressively.	1
Brooks CJ, Macdonald CV, Carroll J, Gibbs PNG (2010)	Aviat Space Environ Med, 81: 683-687.	Introduction of a compressed air breathing apparatus for the offshore oil and gas industry.	Review of first 1000 civilian personnel trained with compressed air EBS in Nova Scotia and Newfoundland, Canada. Identifies problems experienced during training.	1
Civil Aviation Authority (1984)	Report No. CAP 491. London: Civil	Review of helicopter airworthiness.	This historic report is a review of existing requirements for public transport helicopters, with recommendations for improved safety standards. The focus is on UK operations, but some of the recommendations are addressed	2

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	Aviation Authority.	Report of the Helicopter Airworthiness Review Panel (HARP) of the Airworthiness Requirements Board.	to a wider audience. The report discussed factors such as the need for buoyancy, stability, practicable means of escape and effective life raft equipment. It identified the need for review of aspects of life raft deployment and operation. Recommendations covered issues such as improved crashworthiness and requirements for ditching and stability.	
Civil Aviation Authority (1995)	Report No. CAP 641. London: Civil Aviation Authority.	Report of the Review of Helicopter Offshore Safety and Survival (RHOSS).	Review commissioned by UK CAA following recommendations made after the helicopter water impact close to the Cormorant Alpha platform in 1992 (AAIB, 1993). It addressed all aspects of offshore helicopter safety and survival in the context of an integrated system, with the intention of maximising the prospects of occupants surviving a helicopter accident at sea. It covers aspects of evacuation and escape including cabin layout, emergency exit operation and personal survival equipment. A proposal to provide EBS was considered "*impracticable*".	2
Civil Aviation Authority (2005a)	CAA Paper 2005/06. London: Civil Aviation Authority.	Summary Report on Helicopter Ditching and Crashworthiness Research.	Review of helicopter safety research funded by the UK CAA.	2
Civil Aviation Authority (2005b)	Safety Regulation Group Flight Operations Department Communication	Standard weights for passengers carried on flights in connection with oil and gas	The UK CAA conducted a survey of offshore passengers and reported that the average mass for a male passenger, not wearing an immersion suit, had increased from an earlier figure of 79.4 kg up to 87.6 kg. Based on a 95% probability, the standard passenger mass for a helicopter carrying 10 to 19 passengers was increased to 98 kg (including 3 kg for the mass of an	2

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	(FODCOM) 27/2005.	exploitation.	immersion suit and associated equipment) for males, and 77 kg for females.	
Civil Aviation Authority (2014)	CAP 1145. London: Civil Aviation Authority.	Safety review of offshore public transport helicopter operations in support of the exploitation of oil and gas.	Review conducted following the accident on the approach to Sumburgh (AAIB, 2016). Includes wide ranging recommendations relating to occupant survivability.	2
Civil Aviation Authority (2015a)	CAP 1243. London: Civil Aviation Authority.	Safety review of offshore public transport helicopter operations in support of the exploitation of oil and gas. Progress Report.	Update to CAA (2014) safety review.	2
Civil Aviation Authority (2016)	CAP 1386. London: Civil Aviation Authority.	Safety review of offshore public transport helicopter operations in support of the exploitation of oil and gas. Progress	Update to CAA (2014) safety review.	2

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
		Report - 2016		
Chen CCT, Muller M, Fogarty KM (1993)	U.S. Department of Transportation Federal Aviation Administration, Report No. DOT/FAA/CT-92/13.	Rotorcraft ditchings and water-related impacts that occurred from 1982 to 1989 - Phase I.	Investigation of ditchings and water-related impacts. Includes post-impact survivability and six case studies.	2
Cheung B, Hofer K, Brooks C J, Gibbs P (2000)	Aviat Space Environ Med, 71 (9): 879-888.	Underwater disorientation as induced by two helicopter ditching devices.	Research where disorientation was measured in a shallow water escape trainer (SWET) device and helicopter simulator (HUET). Greater disorientation was found in the HUET than when using SWET, but no difference was found between window and aisle seats. There were a greater number of failures to escape from aisle than from window seats.	1
Cheung B, D'Eon NJ, Brooks C J (2001)	Aviat Space Environ Med, 72: 912-918.	Breath-holding ability of offshore workers inadequate to ensure escape from ditched helicopters.	Study which measured breath-holding times in air and water. In water at 25 °C, the overall breath-hold time (BHTw) ranged from 6 to 120 s with a median of 37 s. Of the 228 subjects, 34% had a BHTw less than the 28 s required for the complete evacuation of a Super Puma helicopter under ideal conditions. It concludes that inability to breath-hold in emergency situations is a major contributor to low survival rates.	1
Choi G, Kopplin LJ, Tester DJ, Will ML, Haglund CM, Ackerman MJ	Circulation, 2010: 2119-2124.	Spectrum and frequency of cardiac channel defects in	Study of cardiac arrhythmias triggered by swimming which can lead to drowning deaths in certain individuals. A genetic basis is proposed.	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
(2004)		swimming-triggered arrhythmia syndromes.		
Clarke SE (1996)	*Paper presented at:* International Conference on Health, Safety & Environment, New Orleans, Louisiana, 9-12 June 1996. Society of Petroleum Engineers, SPE 35942.	Standards of Cabin Safety for Offshore Helicopter Operations	Paper describes a series of trials commissioned by Shell, covering a range of helicopter types in service at the time. The study focussed on the ability of participants to follow the manufacturer's or operator's recommended escape route, the operation of emergency exits and re-routing to alternative exits if a chosen route was blocked. Problems varied, dependent upon the aircraft type simulated. Cabin configuration changes were recommended including enlarged and push-out windows and changes to seating layouts.	3
Clifford WS (1996)	CAA Paper 96005. London: Civil Aviation Authority.	Helicopter crashworthiness. Study I. A review of UK military and world civil helicopter water impacts over the period 1971-1992.	Review of UK military and world civil helicopter water impacts, identifying those that sink or invert.	2
Coleshaw SRK (2003)	CAA Paper 2003/13. London: Civil Aviation Authority.	Preliminary study of the implementation and use of	The study was undertaken to establish the extent of knowledge and testing performed on various forms of emergency breathing system (EBS). It describes the development of different EBS products to aid escape. Issues and concerns were reviewed, training issues were considered and gaps in	2

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
		emergency breathing systems.	the current knowledge highlighting. It includes a review of risks and mitigation. An outline technical standard is included as an appendix to the report.	
Coleshaw SRK (2010)	Journal of Ocean Technology, 5(4): 86-88	Surviving a helicopter crash in water – the way forward?	Commentary on factors affecting helicopter underwater escape.	1
Coleshaw SRK (2012)	Journal of Ocean Technology, Extreme Survival, 7(3): 60-73	Minimum performance requirements for helicopter emergency breathing systems.	This paper describes some of the work undertaken to fill the knowledge gaps relating to EBS performance. Trials with three generic designs of EBS. Measures included emergency deployment time and duration of use as well as potential problems associated with helicopter underwater escape. Design issues were identified with the aim of limiting potential problems during emergency use.	1
Coleshaw SRK (2013)	CAP 1034. London: Civil Aviation Authority.	Development of a technical standard for emergency breathing systems.	Research undertaken to inform the development of a technical standard for EBS, including a comparison of the performance of three generic products; a rebreather system, a compressed air system and a hybrid device. Two categories of EBS were defined, a Category A EBS with the capability to be deployed both in air and underwater and a Category B EBS with the capability to be successfully deployed in air. A complete draft technical standard is included as an appendix to the report.	2
Coleshaw SRK (2016)	*In:* M Taber ed. Handbook of Offshore Helicopter Transport Safety.	Helicopter emergency breathing systems.	Book chapter covering all aspects of EBS use in helicopters. Defines the three types of EBS and discusses performance. training issues are identified.	2

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	Amsterdam: Elsevier, pp 151-174.			
Coleshaw SRK and Howson D (1999)	*In proceedings of:* The Second International Helicopter Escape Seminar/ Workshop, Nutec, Billingham, UK, 21-22 October 1999.	Escape from Side-Floating Helicopters.	Preliminary findings from human factors study investigating escape from a side-floating helicopter (see also Jamieson et al, 2001).	3
Desjardins SP (2006)	Journal of the American Helicopter Society, 51(2): 150-163.	The evolution of energy absorption systems for crashworthy helicopter seats.	Review of development history of the energy absorbing systems used on crashworthy helicopter seats (military and civilian).	1
Ducharme MB (2006)	Industrial Health, 44: 433-440.	Heat stress of helicopter aircrew wearing immersion suit.	Study to define the lowest ambient air and cabin temperatures at which aircrew wearing immersion suits are starting to experience thermal discomfort and heat stress during flights. At the end of exposures, skin temperature, rectal temperature and heart rates had increased significantly. It was concluded that aircrews wearing immersion suits during summer months might experience thermal discomfort and heat stress at ambient or cabin air temperatures as low as 18 °C.	1
Ducharme MB and Brooks CJ (1998)	Aviat Space Environ Med, 69(10): 957-64.	The effect of wave motion on dry suit insulation and the responses to cold	Study looking at the performance of a dry immersion suit in water at 16°C. Wave heights up to 70 cm reduced suit insulation by 14%, with the head and trunk most affected by wave motion.	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
		water immersion.		
EASA (2016a)	Notice of Proposed Amendment 2016-01. RMT.0120 (27&29.008) - 23.3.2016	Helicopter ditching and water impact occupant survivability.	Report covering the work undertaken by a Rule-making task group working on survivability following helicopter ditching and water impact accidents, taking a holistic approach which crossed airworthiness/operational boundaries. The NPA proposed changes to CS-27 and CS-29 to mitigate helicopter design-related risks to new helicopter types. Recommendations for safety improvements in other areas were made, including the need to mandate the provision of EBS.	2
FAA (2016)	Air Carrier Operations Bulletin 1-94-17.	Brace for impact positions.	Bulletin based on research and tests conducted by the Aeromedical Research Branch of the Civil Aeromedical Institute (CAMI), Protection and Survival Laboratory, establishing “brace for impact” positions for passengers and flight attendants. The bulleting considers different seating configurations, type of emergency and other factors, and covers brace positions for helicopter passengers.	2
Færevik H and Reinertsen RE (2003)	Ergonomics, 46(8): 780 – 799.	Effects of wearing aircrew protective clothing on physiological and cognitive responses under various ambient conditions.	This study investigated the effect of wearing protective clothing under various ambient conditions on physiological and cognitive performance. Rises in rectal temperature, skin temperature, heart rate and body water loss indicated a high level of heat stress in the 40°C ambient temperature condition in comparison with 0°C and 23°C. Impaired vigilance was reported, correlating to the increase in body temperature.	1
Færevik H and Reinertsen RE	Aviat Space Environ Med, 83: 746 – 50.	Initial heat stress on subsequent	Study investigating pre-warming prior to cold water immersion. Wearing a dry immersion suit eliminated long-term differences in core	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
(2012)		responses to cold water immersion while wearing protective clothing.	cooling between pre-warmed subjects and those kept in a normothermic state. When entering cold water with a raised rectal and skin temperature, different thermal responses were found during the first 10 min, but this did not alter long-term core cooling.	
Færevik H., Markussen, D, Øglænd, G and Reinertsen, R.E. (2001)	Journal of Thermal Biology, 26: 419–425.	The thermoneutral zone when wearing aircrew protective clothing.	Study to determine the thermoneutral zone (TNZ) in subjects wearing aircrew protective clothing. Wearing aircrew protective clothing caused a displacement of the TNZ to 10–14°C ambient temperature (Ta). Discomfort increased at ambient temperatures above this range, as a result of increases in metabolic rate, mean skin temperature (MST) and sweating.	1
Gaul CA and Mekjavic IB (1987)	Appl Ergonomics 18(2): 153-158.	Helicopter pilot suits for offshore application: a survey of thermal comfort and ergonomic design.	The objective of this study was to determine the existing problems associated with helicopter pilot survival suits currently in use. A survey was conducted of helicopter pilots from both Canadian commercial and military disciplines. Reduced thermal comfort as well as lack of ventilation were the two most common criticisms of the pilot suits. The 'greenhouse' effect, common to helicopter cockpits, results in hot working ambient temperatures both in summer and winter.	1
Giesbrecht GG, Wu MP, White MD, Johnston CE, Bristow GK (1995)	Aviat Space Environ Med, 66(10): 968-975.	Isolated effects of peripheral arm and central body cooling on arm performance.	In this study, six subjects were immersed to the clavicles in a tank (body tank) of water under three conditions: 1) cold body-cold arm; 2) warm body-cold arm; and 3) cold body-warm arm. The authors concluded that cooling of the body and/or the arm elicits large decrements in finger, hand and arm performance. The decrements were due almost entirely to the local effects of arm tissue cooling.	1
Golden F and	Champaign, Illinois:	Essentials of Sea	Book which covers all aspects of sea survival including the effects of wave	2

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Tipton M (2002)	Human Kinetics, pp 108-113.	Survival.	action on an immersion victim.	
Golden FSC, Hervey G, Tipton M (1991)	J R Nav Med Serv, 77: 139-49.	Circum-rescue collapse: collapse, sometimes fatal, associated with rescue of immersion victims.	This paper describes a syndrome when victims of accidental immersion collapse and die during the process of recovery or shortly afterwards. 'After-drop' in deep body temperature and a collapse of blood pressure due to loss of the hydrostatic support of water are considered. Removal from the water in a horizontal posture is recommended.	1
Hall JF (1972)	Aerospace Med, 43(3): 281-286.	Prediction of tolerance in cold water and life raft exposures.	Prediction model looking at tolerance time for clothed aircrew to attain body heat loss in cold water and life raft exposures at various temperatures.	1
Harris RA, Coleshaw SRK, MacKenzie IG (1996)	Offshore Technology Report: OTH 94 446. Sudbury: Health and Safety Executive Books	Analysing stress in offshore survival course trainees.	Research measuring stress/anxiety in offshore survival course trainees, including HUET, studying basic and refresher students. Most trainees were especially anxious at the start of a course due to pre-course apprehension, when HUET was perceived to be the most difficult exercise. Older refresher trainees were found to be less anxious than those with no previous experience. Low anxiety was associated with greater perceptions of coping.	2
Hayward JS, Hay C, Matthews BR, Overweel CH, Radford, DD (1984)	J Appl Physiol, 56(1): 202–206.	Temperature effect on the human dive response in relation to cold water near-drowning.	Maximum breath-hold duration (BHD) and diving bradycardia (decrease in heart rate), were measured in 160 subjects immersed in water between 0 and 35 °C. BHD was dependent upon water temperature. In water colder than 15 °C, BHD was greatly reduced, being 25-30% of the pre-submersion duration.	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Heimenz GJ, Choi Y-T, Wereley NM (2007)	J Aircraft, 44 (3): 1031-1033.	Semi-active control of vertical stroking helicopter crew seat for enhanced crashworthiness.	Paper looking at vertical stroking helicopter crew seats and means of accommodating occupants of varying weight.	1
Hognestad B (1997)	*Paper presented at:* Helicopter Escape Seminar Workshop; Nutec Centre for Safety, Billingham, UK; 6-7 November 1997.	Helicopter evacuation training course considerations.	Paper which discusses the value of HUET as a powerful tool in the transfer of learning.	3
Howson DA (2006)	The Aeronautical Journal, 110(1113): 723-7.	Research initiatives for improving the safety of offshore helicopter operations.	This paper outlines issues relating to helicopter escape in relation to the flotation attitude of the helicopter following water impact. It discusses the difficulty of escape when all escape routes are submerged. The need to improve the crashworthiness of emergency flotation systems is identified as a major factor in improving occupant survivability.	1
Hussin MF, Wang B, Subahir S, Ismail NN, Hipnie R (2015)	*In:* R Hashim, AB Abdul Majeed, eds. Proceedings of the Colloquium on Administrative Science and Technology. Singapore: Springer, pp 383-	Skills Retention in Basic Offshore Safety and Emergency Training (B.O.S.E.T)	This paper discusses a test based on assessment of trainees achieving correct brace positions and the heat escape lessening posture. The test was conducted over a period of 6 months with 38 offshore professionals. Analysis of the test data suggests that the skills level depreciated with time, reaching 76% at 6 months following initial training. An extrapolation of the data suggested that the skill set would have decreased to 50% after 3 years.	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	390.			
Hytten K (1989)	Acta psychiatr. Scand. Suppl. 355: 73-78.	Helicopter crash in water: effects of simulator escape training.	Findings from the interview of 5 crew members following a helicopter crash, four with previous HUET training and one with no training. One further untrained crew member died. Training was considered to have been decisive, reducing panic, providing confidence and thought control.	1
Hytten K, Jensen A, Vaernes R (1989)	Aviat Space Environ Med, 60(5): 460–464	Effects of underwater escape training - a psycho-physiological study.	This study analyzed the effect of underwater escape training (helicopter simulation) to determine the relationships between personality/background variables, anxiety, and perceived outcome. Most subjects, aged 22–48 yrs, were offshore workers. Perceived training effect was found to be inversely related to anxiety during training. Most subjects developed a positive response outcome expectancy.	1
Jackson GE and Rowe SJ (1997)	CAA Paper 97010. London: Civil Aviation Authority.	Devices to prevent helicopter total inversion following a ditching.	Paper describing model tests in a wave tank used to investigate different helicopter flotation schemes, to mitigate the effects of helicopter capsize and prevent total inversion. Additional flotation high up on the fuselage prevented total inversion, creating a floating position with an air gap in the cabin and one set of exits above the water surface.	2
Jamieson DW, Coleshaw SRK, Armstrong IJ, Sellar C, Howson D (2000)	*In:* PT McCabe, MA Hanson, SA Robertson, Eds. Contemporary Ergonomics 2000. London: HMSO.	Human factors associated with escape from side-floating helicopters.	Paper studying escape from a helicopter simulator capsized to 150° and 180° (see Jamieson et al 2001 also). Escape from the fully inverted helicopter was found to be much more difficult than from the side-floating equivalent. Greater confidence was gained about coping. No difference was found in physiological and psychological stress between the escape scenarios.	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Jamieson DW, Armstrong IJ, Coleshaw SRK (2001)	CAA Paper 2001/10. London: Civil Aviation	Helicopter Ditching Research - Egress from Side-Floating Helicopters.	Research looking at human factors of escaping from a helicopter following partial capsize. Thirty naïve subjects. Trials involved capsize through an angle of either 150° or 210°; this was compared to escape from the fully inverted helicopter simulator following a capsize of 180°. The majority of subjects preferred escape from the side-floating helicopter and found it to be easier. This was reflected by the fact that subjects were significantly more satisfied with how they coped with the side-floating escape. In escape from the fully inverted simulator, difficulties caused by disorientation, breath-holding, locating and using the exit were more prominent than was the case in the side-floating exercises. This was especially true when subjects were required to make their way across the cabin to escape. In the side-floating escapes, subjects had some difficulty releasing the harness when seated on the upper side of the simulator. This problem was not thought to outweigh the advantages of escape from a side-floating helicopter.	2
Kaur PP, Drummond SE, Furyk J (2016)	Prehosp Disaster Med. 31(1): 108–110.	Arrhythmia Secondary to Cold Water Submersion during Helicopter Underwater Escape Training.	Case study of a 32-year-old, fit and healthy male who presented with a less than 24-hour history of palpitations with the onset following participation in helicopter underwater escape training (HUET). The authors considered that 'autonomic conflict' may have provoked the cardiac arrhythmia.	1
King TS, MacKinnon SN, Taber MJ (2018)	International Journal of Industrial Ergonomics, 68:	How does load and impulse influence the success of jettisoning a	Study of escape window jettison using an elbow or a hand. Differences were found between the tasks when undertaken either in air or in water. A low success rate was recorded for female subjects.	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	205–210	simulated S-92 push-out window?		
Kinker LE, Loeslein GF, O'Rourke CR (1998)	*Paper presented at:* RTO HFM Symposium on "Current Aeromedical Issues in Rotary Wing Operations", San Diego, USA, 19-21 October 1998. Published in: RTO MP-19. Neuilly-sur-Seine, France: NATO.	U.S. Naval and Marine Corps Helicopter Mishap Trends: Over Water Mishaps (1985 - 1997).	Review of water impact accidents. 59% survival rate for all over-water accidents; 74% in survivable accidents. Found high incidence of passenger deaths, commenting that passengers received less survival training than crew. Refresher training was recommended at least once a year for aircrew, and METS training recommended for passengers. The paper also recommended incorporating crashworthy seats in all aircraft and improving seat restraints. Between 1985 through 1997, for the five helicopter designs studied, only 37 out of 217 (17%) over-water mishap survivors deployed life rafts. There were problems of deploying the life raft from within the helicopter resulting in a call for externally mounted life rafts.	2
Kozey J, McCabe J, Jenkins J (2007)	*Published in:* Proceedings of the 44th Annual SAFE Symposium, Reno, Nevada.	The effect of different training methods on egress performance from the Modular Egress Training Simulator.	Investigation of the effects of training fidelity and practice on egress performance six months following initial training. Success rate of training was found to be greater when more physical fidelity and practice was used in training.	3
Kozey JW, Brooks C, Dewey SL, Brown RC, Howard KA, Drover D, MacKinnon S,	Occupational Ergonomics, 8(2,3): 67-79.	Effects of human anthropometry and personal protective equipment on space	In this study, body mass, height and three selected anthropometric dimensions were measured with and without the presence of an immersion suit. The wearing of an immersion suit increased the physical size of each subject	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
McCabe J (2009)		requirements.	by substantial amounts. The magnitude of increase was related to the type of suit and whether there was external compression applied during the measurement.	
Leach J (2004)	Aviat Space Environ Med, 75(6), 539-542.	Why people freeze in an emergency: temporal and cognitive constraints on survival responses.	The aim of this paper was to identify the possible factors underpinning 'freezing' behaviour in emergency situations. "*Freezing' causes evacuation delays which increase the danger, establishing a closed loop process and further extending evacuation delays*". Concluded that cognitive limitations help to explain why survival training works and why there is a need to develop a survival culture.	1
Leach J (2016)	*In:* M Taber ed. handbook of Offshore Helicopter Transport Safety. Amsterdam: Elsevier, 41-62.	Psychological factors in underwater egress and survival.	Book chapter exploring the psychological factors that are involved in HUET and how the cognitive system creates a response to a threatening fast-moving situation, with behaviours determining survival.	2
Ledingham R, Furnace G, Lamb M, Stewart A (2015)	Robert Gordon University Report.	Size and shape of the UK offshore workforce 2014. Data from 3D scanning survey.	Report providing anthropometric data relating to a representative sample (n=588) of the UK offshore workforce. 3D scans were taken of individuals in form-fitting clothing and when wearing an immersion suit and lifejacket.	2
Light IM and Dingwall RHM (1985)	Offshore Survival Centre Report. Robert Gordon's Institute of Technology,	Basic anthropometry of 419 offshore workers (1984).	Report providing anthropometric measurements relating to a representative sample (n=419) of the UK offshore workforce.	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	Aberdeen, UK.			
Light IM and Gibson M (1986)	Br J Nutr, 56: 97-104.	Percentage body fat and prevalence of obesity in a UK offshore population.	Body weight, body height and skinfold measurement were taken in 419 adult males working in the UK offshore oil industry. Percentage body fat was estimated from skinfold thickness.	1
Light IM and Gibson M (1987)	Br J Industrial Med, 44: 201-205.	Application of weight-height relations for assessing adiposity in a United Kingdom offshore workforce.	Body weight, body height and skinfold thickness was measured in UK offshore workforce. A significant increase in percentage body fat (%BF) was found with increasing age. Suggestion that W/H^2 could readily be implemented during a routine medical, allowing comparison with other studies.	1
Light IM, Gibson MG, Avery A (1985)	Ergonomics, 30: 793-803.	Sweat evaporation and thermal comfort wearing helicopter passenger immersion suits.	Study looking at the performance of immersion suits in air at 21°C and 30°C. At the higher temperature the permeable suit performed significantly better. There was less body weight loss, less sweat uptake into the undergarments and a greater amount of sweat being evaporated. Rectal temperatures and thermal comfort were similar.	1
Light IM, Avery A, Grieve AM (1987)	Aviat Space Environ Med, 58(10): 964-969.	Immersion suit insulation: the effect of dampening on survival estimates.	Immersion suit leakage values were obtained from realistic testing of helicopter passenger immersion suits using eight subjects. The insulation of clothing worn under the immersion suits was reduced by dampening due to sweating.	1
Light IM, Masson J, Ross H (1988)	Ergonomics, 31(6): 905-913.	Anthropometry of North Sea helicopter pilots.	Measurements made on 244 North Sea pilots.	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Luria SM and Kinney JAS (1969)	Report Number 581. Groton, Connecticut: US Naval Submarine Medical Centre.	Visual acuity under water without a face mask.	Study which found that visual acuity underwater was extremely poor, similar to night vision.	3
Luria SM, Ryack BL, Neri DF (1984)	Report Number 990. Groton, Connecticut: Naval Submarine Medical Research Laboratory.	Desirable characteristics of underwater lights for helicopter escape hatches.	Study looking at optimal arrangement of lights around helicopter escape exits, the range of intensities required, the effects of viewing angle and the dimensions of lights on visibility.	2
Madu VC, Carnahan H, Brown R, Ennis K-A, Tymko KS, Hurrie DMG, McDonald GK, Cornish SM, Giesbrecht GG (2020)	Aerosp Med Hum Perform, 91, 7: 578-585.	Skin cooling on breath-hold duration and predicted emergency air supply duration during immersion.	Study which demonstrated that decreasing skin temperature and increasing skin exposure reduced breath-hold time. Authors stated that he most significant factor increasing breath-hold time and predicted survival time was zipping up the suit. Face masks and suit hoods increased thermal comfort. They concluded that "*wearing the suits zipped with hoods on and, if possible, donning the dive mask prior to crashing, may increase survivability*".	1
Mallam SC and MacKinnon SN (2011)	*Paper presented at*: Ergoship 2011, 1st Conference on Maritime Human Factors, Göteborg, Sweden, September 14-16, 2011.	The effect of hand immersion in 4°C water on the performance of helicopter evacuation and survival tasks.	Investigation of the amount of time subjects required to complete simulated helicopter escape and survival tasks. Tasks took longer under dark conditions. A significant difference was found between the times to don gloves in warm (20°C) compared to cold (4°C) water, taking 46 s and 66 s respectively. Problems found included loss of grip strength and tactile senses, inability to get hands into the glove and difficulty using Velcro wrist straps. The almost	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
			10% decrease in grip strength also resulted in slower times to complete bare-handed tasks including PLB activation, ancillary buoyancy deployment and donning of the sprayhood.	
Marsh N, Askew D, Beer K, Gerke M, Muller D, Reichman C (1995)	Clin Exp Pharmacol Physiol 22: 886–887.	Relative contributions of voluntary apnoea, exposure to cold and face immersion in water to diving bradycardia in humans.	Study where 18 subjects were exposed to voluntary apnoea, exposure to cold and face immersion in various combinations. Cold and apnoea caused significant reductions in heart rate. Cold exposure and voluntary apnoea applied simultaneously caused a summative effect but when tested with face immersion in water there was a synergistic response greater than the sum of individual responses.	1
McCallum AL, McLellan BA, Reid SR, Courtade W (1989)	Aviat Space Environ Med, 60(2): 162-165,	Two cases of accidental immersion hypothermia with different outcomes under identical conditions.	Two cases of accidental immersion hypothermia are presented, both occurring during the same aircraft ditching. One victim survived while the other patient died despite identical immersion time and environmental conditions. Pertinent literature is reviewed to attempt to explain the different patient outcomes. The most important discriminating factor appears to be skinfold thickness, which reflects body fat.	1
McDonald GK and Giesbrecht GG (2013)	Aviat Space Environ Med, 84: 708-15	Escape from a submersible vehicle simulator wearing different thermoprotective flotation clothing.	Study comparing different clothing ensembles and the effect on vehicle exit time and difficulty in 20°C and 8°C water. Flotation jackets and overalls did not increase exit time or impede exit during egress from the submerged vehicle while providing thermoprotection and buoyancy in 20°C and 8°C water. The inflated vest created the most perceived exit impedance in comparison to controls.	1
Mills A and Muir H	Cranfield University	Development of a	In this study, participants were split into groups provided with progressively	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
(1998)	research report commissioned by Shell Aircraft Limited, UK.	Training Standard for Underwater Survival. Stage Two - Experimental testing.	more complex training, from classroom training only up to wet training involving removal of exits or wet training with a cross-cabin escape. Part-task training was strongly supported by the authors, while multiple inversion exercises were also recommended. The need to provide training in exit removal was emphasised, plus the need for high fidelity exits requiring a representative force to operate them. Training using an early version of the 'Air Pocket' rebreather EBS was also investigated.	
Mills A and Muir H (1999a)	Cranfield University research report commissioned by Shell Aircraft Limited, UK.	Development of a Training Standard for Underwater Survival. Stage Four - Refresher training.	In this further phase of the Shell commissioned study, six groups of participants (52 in all) were asked to undergo a test escape exercise either 6, 12, 18, 24, 36 or 48 months after having complete standard HUET training at an approved training centre, and then complete a questionnaire used to evaluate their knowledge of the emergency procedures and any difficulties encountered during escape.	3
Mills A and Muir H (1999b)	Cranfield University research report commissioned by Shell Aircraft Limited, UK.	Executive Summary Final Report, Development of a training standard for underwater survival.	This report raised concern that survival training conducted at that time was not achieving competency in trainees. The authors recommended that students should complete all parts of the underwater escape exercises unaided, and that performance should be rated. They considered that representative exits should be used, requiring representative forces to operate. They also recommended that a second inversion exercise would be of benefit to trainees.	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Muller M and Bark LW (1993)	U.S. Department of Transportation, FAA. Report No. DOT/FAA/CT-92/14	Rotorcraft ditchings and water-related impacts that occurred from 1982 to 1989 - Phase II.	Examination of rotorcraft ditchings and water-related impacts for rotorcraft. Drowning and exposure were found to be the main post-impact hazards and other post-impact injuries were minor in severity. Structural failures of the rotorcraft are identified and discussed as they affected occupant injury. The performance and adequacy of rotorcraft flotation equipment is discussed. Means of alleviating occupant injury in rotorcraft water impacts are identified and discussed.	2
Nascimento FAC, Majumdar A, Ochieng WY (2013)	*In:* Advances in Human Aspects of Aviation, SJ Landry Ed. Boca Taton, Florida: Taylor & Francis, 2013, pp 224-233.	Nighttime offshore helicopter operations - Identification of contextual factors relevant to pilot performance.	Study which shows that fatal accidents are 15 times more frequent at night than in daytime. Numbers of fatalities in each night-time accident were significantly greater than in daylight.	2
Nascimento FAC, Majumdar A, Ochieng WY (2014)	Journal of Navigation, 67: 145-161.	Helicopter accident analysis.	Paper which refers to estimates of night-time flying hours, with 8·46% of North Sea's total annual flying hours occurring at night.	1
Noble C (2002)	Journal of Air Transportation, 7(3): 33-54.	The relationship between fidelity and learning in aviation training and assessment.	Paper which suggests that whole-task training may result in maximal learning for expert pilots but that this is not necessarily the case for novice students. The author comments that in a high fidelity training simulator novice pilots became overwhelmed. He suggests that part-task training can build confidence in procedural knowledge while improving learning from mistakes.	1
O'Neil BD, Kozey	Aviat Space Environ	Underwater	Paper looking at detectability of a lighting system on a helicopter escape exit	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
JW, Brooks CJ (2004)	Med, 75: 526-530.	detectability of a lighting system on a helicopter escape exit.	under varying conditions of ambient illumination, water turbidity and viewing distance. At 1.5 m, the lighting system was detectable in less than 1.5 s in both clear and turbid water and both bright and dark conditions. The exit could be detected at 3.1 m in clear and turbid water under dark conditions, but less reliably so in turbid water under bright conditions.	
Power J, Ré A, Barwood M, Tikuisis P, Tipton M (2015)	Applied Ergonomics, 49: 18-24.	Reduction in predicted survival times in cold water due to wind and waves.	Two immersion suit studies, one dry and the other with 500 mL of water underneath the suit, were conducted in cold water with 10-12 males in each to test body heat loss under three environmental conditions: calm and two combinations of wind plus waves to simulate conditions typically found offshore. In both studies mean skin heat loss was higher in wind and waves vs. calm. Deep body temperature and oxygen consumption were not different.	1
Reilly T, Kozey J, Brooks C (2015)	Occupational Ergonomics, 5(2): 111-120.	Structural anthropometric measurement of Atlantic offshore workers.	This study measured 42 Canadian offshore workers with and without immersion suits.	1
Rice EV and Greear JF (1973)	*In:* Eleventh Annual Symposium, Phoenix, AZ. Survival and Flight Equipment Association, pp 59-60.	Underwater escape from helicopters.	Early review of water impact accidents showing that twice as many occupants died from drowning than from injuries. Of those who drowned, 40% were still in the aircraft. For those who survived, in-rushing water was the main problem reported, coupled with disorientation and the inability to reach an exit. They reported that HUET training had markedly enhanced their chances for survival. Recommendations are made to improve chances of survival.	1
Ritvanen T,	Int J Occup Med	Effect of aerobic	This study examined the effects of aerobic fitness on physiological stress	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Louhevaara V, Helin P, Halonen T, Hänninen O (2007)	Environ Health, 20: 1-8.	fitness on the physiological stress responses at work.	responses experienced by teachers during working hours. The results suggest that a higher level of aerobic fitness may reduce muscle tension, HR and perceived work stress in teachers.	
Robinson SJ (2016)	In: M Taber ed. Handbook of Offshore Helicopter Transport Safety. Amsterdam: Elsevier, pp 99-123.	Physiological and cognitive changes during helicopter underwater egress training.	Book chapter which considers how an understanding of physiological and cognitive changes during helicopter underwater egress training can inform the training program.	2
Robinson SJ (2018)	Procedia Engineering 212: 1083–1090.	How can psychology inform disaster research?	This paper describes four studies covering preparedness, immediate response and long-term consequences of disaster. The first study used a questionnaire design to examine factors that influence evacuation behaviours. The second and third studies explored physiological and psychological responses to simulated disaster training. The fourth study explored the consequences of trauma exposure focusing specifically on predictors of post-traumatic stress disorder and post-traumatic growth.	1
Robinson SJ, Sünram-Lea SI, Leach J, Owen-Lynch PJ (2008)	Stress, 11: 115-124	The effects of exposure to an acute naturalistic stressor on working memory, state anxiety and salivary cortisol concentrations.	Two studies are reported, exploring the impact of exposure to an acute naturalistic stressor on state anxiety, working memory and HPA axis activation (salivary cortisol). In both experiments, ten healthy male participants were exposed to helicopter underwater evacuation training (HUET), and their physiological and behavioural responses before and after the stressor were compared to ten non-stressed controls. The results of both experiments showed that working memory performance was preserved during anticipation of an acute stressor, but impairments were observed immediately after stress exposure. Participants reported significantly higher state anxiety levels during anticipation and following stress exposure,	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
			whereas significant elevations in cortisol levels were only observed 25 min post exposure to stress, but not before or immediately after stress exposure. The results of both experiments demonstrated a dissociation between behavioural and biochemical measures and provided evidence for a dissociation of the effects of stress on cognitive and physiological measures depending on the time of testing, with cognitive impairments most evident following stress exposure.	
Ross C and Gibb G (2008)	*Presented at:* Australian Society of Air Safety Investigators, 2008 Regional Seminar.	A risk management approach to helicopter night offshore operations.	Paper presenting statistics relating to night-time flying operations. Reports 8.4 accidents/100K night hours. Disproportionately more night accidents/100K hours than daytime accidents (by factor of >5).	3
Ryack BL, Smith PF, Champlin SM, Noddin EM (1977)	Report Number 857, Groton, Connecticut: Naval Submarine Medical Research Laboratory.	The effectiveness of escape hatch illumination as an aid to egress from a submerged helicopter: Final Report.	Study which evaluated the effectiveness of escape hatch lighting in day and night conditions. More rapid egress was observed when exits were illuminated. An underwater breathing device was also evaluated. Instances were recorded when subjects became disorientated, lost, and/or entangled in the helicopter simulator; 15 cases when there was no lighting and only one with lighting. In eight cases, subjects relied on their breathing apparatus.	3
Ryack BL, Luria SM, Robbins V (1984)	Report Number 1018, Groton, Connecticut: Naval Submarine Medical Research	A test of electro-luminescence panels for a helicopter emergency escape	Study of the effectiveness of electroluminescence lighting for escape hatches. These were found to be visible to light-adapted subjects in turbid water.	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	Laboratory.	lighting system.		
Ryack BL, Luria SM, Smith PF (1986)	Aviat Space Environ Med, 57(6): 603-609.	Surviving helicopter crashes at sea: A review of studies of underwater egress from helicopters.	This paper discusses the problems of escaping from a submerged helicopter. The effectiveness of different types of escape hatch lighting was evaluated. The authors conclude that escape training, illuminating the emergency exits and providing EBS should increase the chances of survival in a crash at sea.	1
Salakari H (2011)	*In:* Innovations for Competence Management, Conference proceedings. Eds. I Torniainen, S Mahlamäki-Kultanen, P Nokelainen & P Ilsley. Lahti: Lahti University of Applied Sciences.	A realistic appraisal of the practices and the delimitations of simulation-based training: what skills and toward what ends?	Literature review which investigates the limits of simulation learning effectiveness, especially the learning of certain skills, the transfer of learning in simulated training, and how simulated learning environments correspond to learning in the real world. Presents view that the development of advanced psychomotor skills can be achieved from high-fidelity simulators. Well-defined goals, continuous evaluation, and selecting the suitable learning environment are important issues when striving for the desired learning outcome.	2
Salas E and Burke CS (2002)	Quality and Safety in Heath Care, 11: 119-120.	Simulation for training is effective when	Paper considering the effectiveness of simulator training: "*The level of simulation fidelity needed should be driven by the cognitive and behavioural requirements of the task and the level needed to support learning*". The author considers that training should assess performance and provide feedback.	1
Sanli EA and	International	Long-term	Literature review to determine the optimal training contexts and optimal	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
Carnahan H (2018)	Journal of Industrial Ergonomics, 66: 10-17.	retention of skills in multi-day training contexts: A review of the literature.	retraining period for skills included in multi-day training course. The review identifies task factors to consider including the influence of characteristics such as task difficulty, type of skill, and the specificity of training to the work domain. Factors related to the learner include the skill level attained during training, the amount a practice received and subsequent on-the-job exposure to specific skills. The authors state that there are also indications that for some tasks, retention of skills for 6 months at best can be expected.	
Shanahan DF (2005)	*In:* Pathological Aspects and Associated Biodynamics in Aircraft Accident Investigation. RTO-EN-HFM-113. RTO Educational Notes.	Basic principles of crashworthiness.	Review of factors influencing crashworthiness, including seating harnesses and energy absorbing seats.	2
Shattock MJ and Tipton MJ (2012)	J Physiol 590.14: 3219–3230	'Autonomic conflict': a different way to die during cold water immersion?	Review of cardiac arrhythmias due to cold water submersion and breath-holding. This paper discusses the conflict between the cold shock response and the diving response.	1
Stewart A, Ledingham R, Furnace G, Nevill A (2015)	Applied Ergonomics 51: 358-362	Body size and ability to pass through a restricted space: Observations from	This 3D scanning study found that mean bideltoid breadth and chest depth were 51.4 cm and 27.9 cm in the offshore workers, compared with 49.7 cm and 25.4 cm respectively in the UK population as a whole. Considering the probability of two randomly selected people passing within a restricted space of 100 cm and 80 cm, offshore workers were found to be 28% and	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
		3D scanning of 210 male UK offshore workers.	34% less likely to pass face-to-face and face-to-side respectively, as compared with UK adults, an effect which was exacerbated when wearing personal protective equipment.	
Stewart A, Ledingham R, Furnace G, Schranz N, Nevill A (2016)	Applied Ergonomics 55: 226-233	The ability of UK offshore workers of different body size and shape to egress through a restricted window space.	In this study, 404 male offshore workers aged 41.4 ± 10.7 yr underwent 3D body scanning and an egress task simulating the smallest helicopter window emergency exit size. The 198 who failed were older, taller and heavier than the 206 who passed. Best predictors were found to be weight, bideltoid breadth and maximum chest depth. The authors concluded that differences in flexibility and technique may explain the variance.	1
Stewart A, Ledingham R, Williams H (2017a)	Applied Ergonomics 58: 265-272.	Variability in body size and shape of UK offshore workers: A cluster analysis approach.	Study of 588 UK offshore workers. In this paper, the results of the 3D scans were characterised into 11 clusters, with four somatotypes expressed. These cluster centroids provide an evidence base for future clothing design and other applications where body size and proportions affect functional performance.	1
Stewart A, Ledingham R, Furnace G, Williams H, Coleshaw S (2017b)	Ergonomics, 60(6): 844-850	Survival suit volume reduction associated with immersion: implications for buoyancy estimation in offshore workers of different size.	This study predicted that buoyancy forces were greater for heavy subjects than light, when wearing helicopter immersion suits. The authors stated "... *how buoyancy impacts underwater egress should be the focus of further research, because it is possible that some individuals may exceed the safe limit that must be overcome to enable escape from a submerged helicopter*".	1
Summers F (1996)	IFAP Technical Report. Willetton,	Procedural skill decay and optimal	Study comprising a literature review looking at the rationale for HUET as well as procedural skill decay as it relates to HUET, and empirical research looking	2

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	Western Australia: Industrial Foundation for Accident Prevention.	retraining periods for helicopter underwater escape training.	at intervals between re-training. Study of 174 individuals, aged 21-57 yrs, undertaking HUET. The author suggests that a stressful environment places additional information processing demands on the individual. However, those skilled in a particular emergency procedure are more likely to be able to carry out that function under stressful conditions. It is suggested that overtraining can delay forgetting but cannot prevent it. The author concludes that procedural skills are highly susceptible to the effects of forgetting. Skills that are infrequently practiced are particularly likely to deteriorate, with skill decay occurring within 6-12 months. She considers that a 2-year training interval is too long.	
Taber MJ (2013)	Safety Science, 57: 179-186.	Crash attenuating seats: Effects on helicopter underwater escape performance.	Study investigating the effects of crash attenuating seats on helicopter underwater escape. The results demonstrated that escape from an inverted and flooded helicopter took significantly more time and was rated as being more difficult when the seat was in the fully attenuated (stroked) position. Trials were also undertaken with different capsize angles plus reduced lighting, which together increased mean egress time.	1
Taber MJ (2014)	Safety Science, 62: 271-278.	Simulation fidelity and contextual interference in helicopter underwater.	This paper discusses different aspects of training fidelity. Some accident data is presented to identify the tasks required in training, but it is not clear how this data influenced the thinking in regard to HUET training.	1
Taber MJ (2016)	*In*: M Taber ed. handbook of Offshore Helicopter	Use and implications of fidelity in	Review of how different types of fidelity influence the development of HUET skills.	2

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	Transport Safety. Amsterdam: Elsevier, 125-150.	helicopter underwater egress training.		
Taber M and McCabe J (2009)	Safety Science, 47: 1129-1138.	The effect of emergency breathing systems during helicopter underwater escape training for land force troops.	Study of helicopter escape with the simulator set up with a military seat configuration. Subjects escaped through either an upper personnel door or large cargo door, which allowed more than one person to escape at a time. The final three trials (of 22) involved 12 participants escaping the helicopter, simulating a full complement of occupants. In trial 20 (on a breath-hold), success rate was only 58%. In trials 21 and 22 with subjects using EBS, 100% of the subjects successfully escaped. (The many variables make it difficult to draw clear conclusions from the study findings).	1
Taber M and McGarr GW (2013)	Safety Science, 60: 169-175.	Confidence in future helicopter underwater egress performance: An examination of training standards.	An examination of success/pass rates and subjective HUET confidence ratings by individuals from different training centre programs. They found that there was an overall success rate greater than 99% across escape trials regardless of course training provider. Within a smaller dataset the results revealed that there were a total of 32 failed attempts across 648 individual egress exercises. Statement made that "*Women required help opening the exit 5.8% of the time and men required similar help <1% of the time*".	1
Taber MJ and Sweeny D (2014)	International Journal of Industrial Ergonomics, 44:	Forces required to jettison a simulated S92 passenger exit: Optimal helicopter	Investigation of the forces required to jettison a simulated S-92 exit as used in an underwater egress simulator. Higher forces were required in the centre of window.	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	544-550.	underwater egress training techniques.		
Taber M, Dies NF, Cheung SS (2011)	Applied Ergonomics, 42: 883-889.	The effect of transportation suit induced heat stress on helicopter underwater escape preparation and task performance.	In this study, 11 individuals completed underwater escape procedures in two ambient temperature conditions (21°C and 34°C). Mean skin and rectal temperatures were recorded throughout the trials, while situation awareness and thermal sensation/comfort were recorded on completion of trials. Results indicated that although mean skin and rectal temperatures were significantly higher at the end of both trials, escape procedures were not impaired.	1
Taber MJ, Sanchez D, McMillan DH (2015)	Int J Human Factors and Ergonomics, 3 (3/4): 363-375.	Operational functionality test of offshore helicopter seat harness in wet and dry conditions.	Testing of offshore helicopter seat harnesses for S76, S92, and AW 139. A weighted manikin (95.25 kg) was used in 24 dry trials, and 5 instructors completed 34 underwater egress trials. Uneven loading was investigated by assessing release at inversion angles of 70°, 90°, 120°, and 180°. Twenty five trials were completed with the seat in a normal position and nine were completed with the seat in a stroked position. Some cases were reported where the release mechanism did not disengage correctly or where the straps did not release symmetrically.	1
Taber MJ, Sweeny D, Bishop N, Boute R (2017a)	International Journal of Industrial Ergonomics, 58: 79-89.	Factor effecting the capability to jettison an S92 push-out window.	This study explored factors that influence the ability of a passenger to successfully jettison an S92 helicopter push-out window under simulated conditions. Comparisons were made of dry and wet conditions, arm reach, body mass and technique on exit jettison success rates. It was noted that the location at which the strike was applied significantly changed the force that could be applied. During wet testing, no participant successfully	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
			jettisoned the window with a dynamic strike in the upper corners. A dynamic strike to the lower corner produced success rates of 82% to 94%.	
Taber MJ, Sweeny D, Bishop N (2017b)	International Journal of Industrial Ergonomics, 59: 1-7.	Test methods to record the forces required to jettison a Sikorsky S92.	This paper describes the development of a purpose built force plate designed to record the forces necessary to jettison a Sikorsky S92 helicopter in-cabin push-out window. Jettison forces were measured in three different aircraft. The results suggested that there was significant inter/intra-aircraft variability in the amount of force required to jettison the push-out window. This variability was attributed to the seal system used to hold the window in place and was validated with an FEA model. Significant differences in required jettison forces were also associated with the type of impact (static push versus a dynamic strike) placed on the window.	1
Tikuisis P, Bell DG, Keefe AA, Pope J (2005)	Aviat Space Environ Med, 76: 2-10.	Life raft entry from water: effect of strength, tallness, and weight burden in men and women.	Study investigating over-the-side, ladder and ramp methods of boarding a life raft, with men and women. A boarding ramp was found to be the easiest and quickest boarding method. Gender differences were found in some cases. Strength and greater height were positive attributes for boarding the life raft using a ladder.	1
Tipton M (1989)	Clin Sci, 77: 581–588.	The initial responses to cold-water immersion in man.	This is an editorial review exploring the cold shock response, factors that may modify the response and interaction with the diving response.	1
Tipton M (1997)	OTH 432. Sudbury: HSE Books.	The effect of water leakage on the protection provided by	Study of the effects of water leakage into immersion suits. Measurements of clothing insulation were obtained both from human subjects and a thermal manikin. A leak to the limbs was found to be much less critical than a leak over the torso. (This could not be identified by manikin testing).	2

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
		immersion protective clothing worn by man.	The authors concluded that the 200 g leakage limit used in suit standards was reasonable.	
Tipton M (2003)	Lancet, 362: S12-13.	Cold water immersion: sudden death and prolonged survival.	This commentary looks at the different causes of sudden death on immersion in cold water. Factors such as cold shock and cardiac arrhythmias are discussed, as well as the effects of more prolonged cold exposure.	1
Tipton MJ and Vincent MJ (1989)	Aviat Space Environ Med, 60: 769-773.	Protection provided against the initial responses to cold immersion by a partial coverage wet suit.	This study looked at the effect of different levels of thermal protection on the initial responses to cold immersion, finding that a dry immersion suit provided more protection than wet suit or cotton overalls.	1
Tipton MJ, Stubbs DA, Elliot DH (1991)	J Applied Physiol, 70(1): 317-322.	Human initial responses to immersion in cold water at three temperatures and after hyperventilation.	In this study, eight naked subjects performed head-out immersions of 2-min duration in stirred water at 5, 10, and 15 °C and at 10 °C after 1 min of voluntary hyperventilation. it was found that the predominant effect of sudden immersion in cold water was an increase in rate rather than depth of breathing.	1
Tipton MJ, Balmi PJ, Bramham E, Maddern TA, Elliot DH (1995)	Aviat Space Environ Med, 66: 206-211.	A simple emergency underwater breathing aid for helicopter escape.	This study involved a series of submersions in water at 25 °C and 10 °C, with subjects breath-holding maximally. In the cold water, the mean maximum breath-hold time was 17.2 s. The study showed that use of a rebreather EBS could extend the time subjects could spend underwater.	1
Tipton MJ, Franks	Aviat Space Environ	An examination of	The performance of a rebreather EBS was compared with that of a	1

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
CM, Sage BA, Redman PJ (1997)	Med, 68(10): 907-14.	two emergency breathing aids for use during helicopter underwater escape.	compressed air EBS. Subjects were immersed in 15°C and 5°C water, before then traversing along an underwater ladder at a depth of 1.25 m. Both types of EBS significantly extended the time that could be spent underwater compared to their maximal breath-hold time, but it was considered that the 60 s submersion was more easily achieved when the compressed air EBS was used.	
Tipton M, Eglin CM, Gennser M, Golden FSC (1999)	Lancet, 354: 626-9.	Immersion deaths and deterioration in swimming performance in cold water.	Study which investigated changes in swimming capability in cold water. Ten subjects undertook three self-paced swims in a variable-speed swimming flume, in water at 25°C, 18°C, and 10°C, for a maximum of 90 min. All ten swimmers completed 90 min swims at 25°C, eight completed swims at 18°C, and five at 10°C. In the coldest water, swimming efficiency and stroke length decreased while stroke rate and swim angle increased.	1
Tipton MJ, Gibbs P, Brooks C, Roiz de Sa D, Reilly TJ (2010)	Aviat Space Environ Med, 81: 399–404.	ECG during helicopter underwater escape training.	In this study, asymptomatic cardiac arrhythmias were identified in participants undertaking HUET training. The heart rate response to HUET was reduced by the fourth run when compared to the first run.	1
Transport Canada (2016)	Advisory Circular AC 700-036, Issue 01, 2016-09-30.	Brace for impact positions for all aircraft occupants.	The purpose of this document was to provide operators with recommended procedures for use when establishing emergency procedures that include brace positions for impact. It details different seating configurations, with diagrams of recommended brace positions. Onshore and offshore helicopter brace positions are included.	2
Urquhart AE and Cross JH (1980)	*Paper presented at:* Oceanology International 80. Brighton, Sussex,	Helicopter underwater escape trainer (H.U.E.T.).	Paper which describes the early use of helicopter simulators for training. It presents their ethos of training for a controlled or nearly controlled ditching, making the training as realistic as possible to ensure that survival was not left to chance, but without terrifying the participants. The authors	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
	pp 40-44.		considered that training should be designed to build confidence and culminate in exercises that would improve the chance of escape in a real accident.	
US Department of the Interior (2013)	Interagency Aviation Safety Alert No. IA SA 13-01.	Helicopter Brace For Impact Positions.	Safety alert relating to helicopter operations. Includes statement that the restraint harness should not be grasped due to the effect on the inertial reels.	2
Vincent MJ and Tipton MJ (1988)	Aviation Space Environ Med, 59: 738-41.	The effects of cold immersion and hand protection on grip strength.	Examination of the maximal voluntary grip strength (MVGS) of male volunteers following a series of five intermittent 2 min cold water (5°C) immersions. Grip strength decreased following cold immersion.	1
Wells R (2010a)	Volume 1 Report and Recommendations. Canada-Newfoundland and Labrador Offshore Petroleum Board; St John's, Newfoundland	Offshore Helicopter Safety Inquiry.	Public Inquiry into the high impact accident of C-GZCH off Newfoundland in 2009. This wide-ranging inquiry covered many aspects relating to occupant survival, protective equipment and training. One survivor and one non-survivor reached the water surface. The survivor considered that training provided insufficient fidelity. He also stated that he thought his previous experience of exposure to cold water had helped him stay calm and not panic. Wells considered that that HUET and EBS training were necessary "*but should not be so rigorous as to pose safety risks*". He concluded that HUET and sea survival training should be conducted with greater fidelity.	2
Wightman DC (1983)	Technical Report NAVTRAEQUIPCEN IH-347.	Part-task training strategies in simulated carrier landing final	Study investigating part-task training. Part-task training was thought to be particularly beneficial to low aptitude individuals. The author suggested that segmentation of a task allowed early proficiency	3

AUTHORS/YEAR	REFERENCE	TITLE	SURVIVAL ISSUES IDENTIFIED	RATING
		approach training.	to be gained and permitted errors to be corrected.	

EASA
European Union Aviation Safety Agency

European Union Aviation Safety Agency

Konrad-Adenauer-Ufer 3
50668 Cologne
Germany

Tel. +49 221 89990- 000
Mail research@easa.europa.eu
Web www.easa.europa.eu

An Agency of the European Union