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HELICOPTER DITCHING RESEARCH – EGRESS FROM SIDE-FLOATING HELICOPTERS

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HELICOPTER DITCHING RESEARCH – EGRESS FROM SIDE-FLOATING HELICOPTERS

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Foreword

The research reported in this paper was funded by the Safety Regulation Group of the UK Civil Aviation Authority and the UK Health and Safety Executive. The work was instigated at RGIT Limited in response to the conclusions and recommendations of earlier research performed for CAA by BMT Fluid Mechanics Limited. This earlier work was commissioned by CAA as part of its ongoing research programme on the stability of ditched helicopters in response to recommendations made in the HARP Report (Report of the Helicopter Airworthiness Review Panel - CAP 491), and was published as CAA Paper 97010 in December 1997.

The earlier research addressed the hyrodynamic aspects of providing a post capsize side-floating attitude. The work covered in this paper comprised an investigation of the human factors issues associated with escape from a side-floating helicopter. This was accomplished by comparing escape from both fully inverted and side-floating helicopters in a series of helicopter underwater escape trainer trials using 30 naïve subjects.

The CAA and HSE concur with the conclusions of the research, and consider the results to weigh heavily in favour of providing a post capsize side-floating attitude. Consequently, the CAA now plans to proceed with a design study to address the practical issues associated with the provision of the modified emergency flotation systems required. In view of the nature of these issues, the study will focus on a specific helicopter type.

Safety Regulation Group

27 June 2001

Management Summary

RGIT Limited were contracted by the Civil Aviation Authority (CAA) to develop an appropriate technique and associated training procedures for egress from side-floating helicopters, and determine the overall benefit/disbenefit of the scheme by comparison with egress from a fully inverted helicopter. This report describes the results of this work.

A review of accident reports and relevant research was undertaken to identify the main issues associated with helicopter underwater escape. Particular attention was paid to the Super Puma, due to it's high usage in the North Sea. An examination of an operational Super Puma was carried out in order that the risks of egress would be realistically assessed and to ensure that the helicopter simulator closely resembled its configuration in the trials.

Practical trials were carried out using a helicopter underwater escape trainer (HUET) as a simulator. The helicopter simulator was modified so that it came to rest at an angle of 150° after capsize. Buoyancy bags were fitted above the window exits on one side to simulate the proposed flotation system.

Initial work was performed using training staff as subjects who were able to use their knowledge and experience to determine best practice and develop new escape procedures. Carefully controlled feasibility trials were performed in which all possible means of escape from the side-floating helicopter simulator were explored. A risk assessment was then carried out to ensure that the risk of injury from such an escape would be kept to an acceptable, minimum level. From the feasibility trials, escape procedures were developed.

Thirty naïve subjects were recruited to evaluate escape from the side-floating helicopter simulator following capsize through an angle of either 150° or 210° and to compare it with escape from the fully inverted helicopter simulator following a capsize of 180°. Psychological and physiological measurements were taken at various intervals during the trials to measure the subjects' performance and levels of anxiety. Subjects also rated their perception of the difficulty associated with each escape. Each trial was filmed from inside the simulator and from the pool-side in order to measure escape times and assess ease of escape. The different escape procedures were compared in order to assess the relative advantages and disadvantages of each.

The results showed that 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, difficulty 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. These problems were not thought to outweigh the advantages of escape from a side-floating helicopter.

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1 INTRODUCTION

1.1 Background

In one year (1991) offshore helicopter operators in the UK sector of the North Sea flew over two million passengers on over 300,000 flights. Over the preceding seven year period, in excess of 2 million flights were made carrying nearly 15 million passengers. During this time there were two accidents resulting in passenger fatalities. In these accidents a total of 51 passengers were killed, 45 of these being in the Chinook accident in November 1986. It is obvious that the only satisfactory record is one in which no fatal accidents occur at all, however these figures do indicate that a high level of safety and passenger awareness exists (Bycroft, 1992). Between 1992 and 1999 there was one further fatal accident in the UK sector in which 11 died (AAIB, 1993).

As part of a Helicopter Underwater Escape Training (HUET) workshop in 1996, Shell UK Exploration and Production set some high safety targets for helicopter travel (Clark, 1996). By the year 2000 they hoped to have reduced the fatal accident rate to 5 per one million flying hours, with a further reduction to 2 per one million flying hours by the year 2005 (equivalent to the projected commuter airline standard at that time). Shell hoped to achieve these targets through a range of safety improvements and an aviation research programme, including flotation aids for helicopters. Currently, flotation systems are mounted low down and must be manually activated.

The capsize boundaries for the helicopter types which operate in the North Sea region lie in the range of Sea State 4-5. Studies of wave climate along six North Sea helicopter routes (BMT, 1997) have shown that if helicopters were to ditch in the winter months there is a significant risk of the sea state being greater than 6. Damage to the helicopter or malfunction could also lead to capsize in more moderate seas. Generally the worst case scenario can be assumed, as Ryack (1986) suggested by stating: *'When a helicopter crashes in the water, it almost always rolls over. The sea begins to rush in, and the cabin fills with turbid water, oil, fuel and debris. Within a minute – even in as few as 20 seconds – the helicopter will often begin to sink to a depth from which no one can survive'.*

The Helicopter Airworthiness Review Panel (HARP) Report, published in 1984, stated that: *'the frequency of forced landings is such that a high probability of survival of all occupants is essential. To achieve this, the helicopter must have adequate buoyancy, stability, practicable means of escape and effective life-raft equipment. Buoyancy needs to be assured in order to provide the pilot with ditching as an acceptable option, and there are strong arguments in favour of deployment of flotation bags before contact with the water. The need for stability is emphasised by the very limited practicability of escape from a capsized helicopter. The conditions on which the stability of the helicopter should be demonstrated must take account of realistic wind speeds accompanying severe sea states'.*

Recommendation 10 of the report (HARP, 1984) identified ditching stability as an area which required improvement. Helicopters have a limited range of stability due to their weight distribution. This means that in moderate to severe conditions the likely outcome is capsize, and without flotation, is often followed rapidly by sinking. In 1995, the CAA's Report of the Review of Helicopter Offshore Safety and Survival (RHOSS) emphasised the need for helicopters to remain afloat long enough for survivors to escape. Improved flotation systems were recommended.

The Civil Aviation Authority (CAA) is currently investigating options for improving the potential for escape from a ditched helicopter. The solutions entail the positioning of additional flotation devices high on the fuselage in the vicinity of the main rotor gearbox and engines. The aim of these flotation systems is to prevent total inversion of the helicopter following capsize and retain an air space within the cabin. The provision of an air space within the cabin would remove the time pressure of escape and ensure that some of the potential exits and escape routes remain above the water level, facilitating egress.

Model tests have been carried out (Jackson and Rowe, 1997) to investigate the different flotation systems and configurations. These systems were intended to prevent the total inversion of a ditched helicopter following capsize. The most efficient and stable flotation system proved to be an asymmetric configuration with a combination of a buoyant cowling panel and a single buoyancy unit placed along one side of the fuselage (Jackson and Rowe, 1997).

The model tests demonstrated that this asymmetric configuration resulted in the helicopter inverting to an attitude of 150° from the vertical, and remaining stable in that attitude. It may have rolled through an angle of 150° or 210°, depending upon whether the wave hit the helicopter model on the side with or without the buoyant unit. The asymmetric configuration removed the potential for a two stage capsize which would be possible with a symmetric system. Clearly this event is undesirable as it may occur while people are trying to make their escape after the first capsize.

The provision of a definite air gap in the cabin and a number of exits which are above the water surface, combined with appropriate egress training to cope with this flotation angle and scenario will, in theory, improve the individual's ability to successfully egress from a capsized helicopter. However, in order to properly assess the chances of survivors escaping from a helicopter after capsize, it was necessary to have extensive knowledge of the problems which they might encounter.

This being the case, a number of factors needed to be considered such as the jettisoning of exits and the position of windows in relation to seats. A helicopter on its side creates specific issues for consideration. The angle of flotation and degree of buoyancy have significant effects on both the position and angle of the seating. Release from the harness was also a potential problem.

Jackson and Rowe (1997) suggested that there is limited evidence in the literature to show whether occupants could escape from a side-floating helicopter. Rice and Greear (1973) suggested that when a helicopter sinks on its side, the escape hatches are beneath and above the occupants. Some survivors have actually dived down under the sinking aircraft because the opposite hatch was unreachable, approximately 8 feet up. The new EH101 helicopter (EH Industries) includes a rope ladder, built into the side window seal so that survivors can pull themselves up towards the window if necessary. However, following a ditching into the sea and capsize, it might still prove difficult to reach up and release the window and rope ladder. Escape from the windows may thus depend upon design, the size of the cabin, and the flotation angle of the helicopter. Issues like these help to illustrate the importance of assessing the feasibility of escape from a helicopter floating on its side.

1.2 Aims and Objectives

The overall aim of the project reported here was to study the human factor issues related to egress from a side-floating helicopter.

The main objectives of the study can be summarised as follows:

1. To develop an appropriate technique and associated training procedures for egress from side-floating helicopters;

2. To determine the overall benefit/disbenefit of the scheme by comparison with egress from fully inverted helicopters.

An important first step towards a feasible solution was to carry out a thorough review of all available information relating to the problems facing individuals having to effect an underwater escape from a helicopter. This was considered important in helping to ensure the success of the practical phase of the work. There were two parts to this review. The first part was to study Air Accident Investigation Branch reports; the second part complemented this by looking at papers in the literature on helicopter escape research.

The next step was to develop a generic procedure for egress from a side-floating helicopter which was as simple and safe as possible and achievable. It was considered important to assess the subjects' perceptions of the difficulty associated with escape from a side-floating helicopter in order to accomplish this.

A further objective was to ensure that any generic procedure developed would be appropriate to the wide range of helicopters currently in use offshore (there are currently 42 different configurations). Training for passengers thus needs to be representative of the 'norm' building up general knowledge and levels of confidence. The intent was to provide the helicopter passenger with the skills and ability to cope in a real ditching, whatever the helicopter configuration.

1.3 Review of Accident Reports and Research

1.3.1 *Overview*

The Accidents Investigation Branch (AIB), and later Air Accidents Investigation Branch (AAIB), reports and bulletins (1977 – 1999) on accidents involving helicopters landing in the sea with and without capsize were reviewed. Information relating to egress was extracted and analysed. Of particular interest were those accidents involving Super Puma helicopters since this is one of the most commonly used helicopters operating in the North Sea. (The underwater escape trainer used in the trials was also configured to represent a Super Puma – Sections 2 and 3 refer).

The following accidents were reviewed in detail:

- Sikorsky S.61N helicopter, G-BBHN, in the North Sea, North East Of Aberdeen, on 1 October 1977 (AIB, 1978)
- Bell 212 G-BIJF, in the North Sea, osuth east of the Dunlin Alpha platform, on 12 August 1981 (AAIB, 1982)
- Boeing Vertol (BV) 234 LR, G-BISO, in the East Shetland Basin of the North Sea, on 2 May 1984 (AIB, 1987)
- Bolkow BO 105D, G-AZOM, 5½ nm due east of Skegness, Lincolnshire, on 24 July 1984 (AIB, 1985)
- Bell 214 ST G-BKFN, in the North Sea 14 miles North East of Fraserburgh, Scotland, on 15 May 1986 (AAIB, 1987)
- Aerospatiale AS 332L, Super Puma G-BKZH, 35 nm east-north-east of Unst, Shetland Isles, on 20 May 1987 (AAIB, 1988)
- Sikorsky S-61N, G-BEID, 29 nm north east of Sumburgh, Shetland Isles, on 13 July 1988 (AAIB, 1990a)
- Sikorsky S61N, G-BDII, near Handa Island off the north-west coast of, Scotland on 17 October 1988 (AAIB, 1989)
- Sikorsky S61N, G-BDES, in the North Sea 90 nm north east of Aberdeen, on 10 November 1988 (AAIB, 1990b)
- Sikorsky S61N, G-BEWL, at Brent Spar, East Shetland Basin on 25 July 1990 (AAIB, 1991)
- AS 332L Super Puma, G-TIGH, near the Cormorant 'A' platform, East Shetland Basin, on 14 March 1992 (AAIB, 1993)
- AS 332L Super Puma, G-TIGK, in North Sea 6 nm South West of Brae Alpha Oil Platform on 19th January 1995 (AAIB, 1997)

Summaries of each of the above accidents, with particular reference to evacuation and escape, are given in Appendix 1.

As well as reviewing accident reports, efforts were made to interview witnesses from helicopter ditching accidents in order to gain a better understanding of the issues involved with evacuation and escape. One such witness report is contained in Appendix 2.

The results of the accident review were then related to the results from studies of helicopter escape, sourced from the scientific literature.

1.3.2 *Findings of Accident Review and Escape Research*

From the accident review it was possible to identify six critical stages which could determine the success of an individual's attempted egress from a helicopter when forced to land in the sea. The outcome of a particular stage may be influenced by a number of factors, including the outcome of the previous stages.

1.3.2.1 Stage One – Impact of Helicopter with the Sea

The force of impact of the landing is very important in terms of an occupant's chances of egress and is largely affected by the type of landing. In the report of the Review of Helicopter Offshore Safety and Survival (RHOSS; CAA, 1995) landings are classified as either a ditching or a crash. A ditching is used to describe the event when a helicopter makes a controlled descent, with some measure of warning, into a 'non-hostile' sea. A crash includes all uncontrolled or inadvertent impacts with the water, controlled descents into a hostile sea and the case of a helicopter falling off a helideck. These definitions are used for the remainder of this review.

As a general rule, the more controlled the landing, the more favourable the outcome for the occupants of the aircraft in terms of their chances of egress. A good example is the controlled landing of AS 332L Super Puma G-TIGK in the North Sea in January 1995 (AAIB, 1997). Despite heavy seas the landing was executed successfully and the helicopter remained upright enabling the passengers and crew to board a heliraft without injury.

The forced landing of Bolkow BO 105D G-AZOM in July 1984 (AIB, 1985) could not be controlled so effectively. The pilot had intended to ditch but lost control during the descent, resulting in the aircraft crashing into the water while still rotating. As a result, one of the floats detached and the aircraft rolled onto its side, which made it more difficult for the pilot to escape.

In the worst case scenario the accident occurs without warning, with the helicopter impacting the water with considerable force. On such occasions, helicopter passengers will not have time to prepare for the emergency. Analysis of military helicopter accidents clearly indicates that pre-crash warning could, at best, be measured in seconds (Haywood, 1993). The fact that helicopters are operating at such low altitudes means that the occupants must depend on the basic crashworthiness of the aircraft for survival (Shanahan and Shanahan, 1989).

An accident involving a crash happened to AS 332L Super Puma G-TIGH in the East Shetland Basin in March 1992 (AAIB, 1993). The commander allowed the aircraft to descend unnoticed until collision with the sea was inevitable. Five of the seventeen occupants were unable to escape from the helicopter before it capsized and sank, probably because they had so little time to react, even though post-mortems indicated that the impact would not have incapacitated them. In other accidents, such as that to Sikorsky S61N G-BEWL at Brent Spar in July 1990 (AAIB, 1991), the force of impact incapacitated some occupants to the degree that escape was virtually impossible. The AAIB report recommended that upper torso restraint should be installed in new and existing UK helicopters to help lessen impact injuries, thus providing an individual with a greater chance of escape.

Whilst the proposed new flotation system would not have any effect on the impact with the sea, the system would provide additional available buoyancy, allowing some redundancy. This would reduce the likelihood of the helicopter sinking on impact with the water.

1.3.2.2 Stage Two – Stability of Aircraft Upon Entering Water

The desired outcome is that a helicopter will remain afloat in an upright attitude long enough for the occupants to complete a successful evacuation. In reality it is likely that the helicopter will capsize and start to sink. Of the 11 accidents reviewed involving helicopters landing on the sea, seven aircraft capsized. Furthermore, six of these capsizes were very rapid, occurring within 1 or 2 minutes of impact with the sea. One of the aircraft sank almost immediately after capsize and another remained afloat for only 15 to 20 minutes.

From the evidence provided by accident reports the pattern which emerges is that the majority of helicopters will capsize very soon after striking the sea with the possibility of fairly rapid sinking. This is clearly influenced by how the helicopter impacts upon the sea and the subsequent damage to the hull. The commander had managed to execute a very controlled landing in three (AIB, 1987; AAIB, 1987; AAIB, 1990a) of the four accidents when a capsize did not take place (the other was a severe crash resulting in immediate sinking of the aircraft [AAIB, 1991]). In two of these three accidents the weather conditions were favourable, suggesting that this is another factor which influences whether a helicopter capsizes or not. Finally, the effectiveness of the flotation gear and whether the commander has time to deploy it will impact upon the stability of the helicopter in the water. Once again, the flotation gear is more likely to be deployed effectively and keep the helicopter upright if the pilot is able to carry out a successful controlled ditching.

The aim of the side-floating system is to mitigate the consequences of a capsize. This is achieved by providing a post-capsize floating attitude with at least one set of exits above the water surface, which should increase the time available for escape and increase the overall ease of escape.

1.3.2.3 Stage Three – Unfastening of Safety Belt

Once an aircraft has come to rest on the sea, if an individual has followed their training then their next task is to open their safety belt. There is evidence that this does not always happen easily and some may be unable to release their seat belts (Ryack et.al., 1976; Ryack et.al., 1986). An example of this occurred after the accident to Bell 212 G-BIJF in August 1981 (AIB, 1982). The accident involved collision with the sea followed by rapid capsize. One of the passengers had considerable difficulty in freeing himself from his safety belt, only managing to extend it enough so he could wriggle free. The effort of this took its toll on the man who was unable to help himself upon egress from the aircraft which caused him to drift away and drown. Subsequent examination of the safety belt in question showed it to be in working order. The report recommended that: *'the opening and adjustment mechanisms on safety belt release buckles be designed to avoid similarities in their operation'*. This measure might help to ensure that such buckles are always operated in the right direction at the first attempt, which is clearly crucial in an accident such as the one to G-BIJF. However, the CAA did not accept this recommendation. In the 'Follow-up action to accident reports' published subsequent to this accident (CAA, 1987a), the CAA point out that the great majority of seat belts are released by operating the mechanism from left to right but that in some cases this is not possible due to practical constraints.

In the accident to Sikorsky S61N G-BDES in November 1988 (AAIB, 1990b) three passengers reported some difficulty releasing their lap strap buckle although they were able to escape without serious injury.

Clearly any problems and delay in releasing a safety belt may seriously diminish the chances of an individual escaping from an aircraft. This will be affected by familiarisation with and ease of use of the buckle, the condition of the buckle and possibly the orientation of the wearer. This has possible implications for the side-floating configuration, where the victim may be strapped into the seat at an angle of about 150° to the vertical following capsize.

It should also be noted that in the accident to Super Puma G-TIGH in 1992 (AAIB, 1993) one passenger's escape was impeded by the cord of his headset becoming wrapped around his neck. The benefit of cordless headsets is suggested in the RHOSS report (CAA, 1995).

1.3.2.4 Stage Four – Reaching an Exit

The next critical stage is to reach an exit. It should be remembered that the chances of survival at this point have already been affected by the extent of injury and incapacitation from the helicopter's impact with the sea, the orientation of the helicopter and the ease and speed of release from the safety belt. In particular, heavy impact or a rapid capsize may have moved or damaged some of the cabin fittings, turning them into obstacles.

This happened in the accident to Sikorsky S61N G-BBHN in October 1977 (AIB, 1978) when cabin floorboards and baggage compartment doors became detached. It was recommended that: *'the cargo door on S.61N helicopters should be modified so that it can be locked in the open position to facilitate an emergency evacuation'. A further recommendation was that: 'under floor baggage locker doors, floor covering and panels should be tightly secured to prevent their becoming detached after a capsize'.*

In the report on the accident to Boeing Vertol 234 LR G-BISO in May 1984 (AIB, 1987) underwater escape was discussed. Based on interviews with helicopter ditching survivors, a US Army report (see AIB, 1987) found that reaching and operating exits, disorientation and dark, were major factors in escape. Underwater escape tests completed by the Royal Navy suggested that the maximum number of trained personnel likely to escape from one hatch was four. In addition, tests conducted by the Royal Air Force Institute of Aviation Medicine showed that the minimum dimensions of an aperture through which a 95th percentile male could escape, while wearing standard survival clothing used by North Sea passengers, was 17 inches by 14 inches. The AIB (1987) suggested that consideration should be given to the possibility of modifying some windows to provide additional exits of such minimum dimensions. It was recommended that the Civil Aviation Authority conduct a review of the number and type of exits required for all public transport helicopters. The CAA' s response to this was to require that all suitable openings in the passenger compartment which are 17' by 14' or larger be designated as an escape route and capable of being opened. In addition, that larger persons do not occupy seats adjacent to windows smaller than approximately 19' by 17' down to the minimum acceptable size of 17' by 14' (CAA, 1987b).

From this, it is clear that the number of escape exits available and exit size, will have a direct affect on an individual's chances of escape. Seat position was identified by Bohemier and Morton (1996) as another factor which might improve or impede egress. The RHOSS report (CAA, 1995) considered it to be important that each passenger should have easy access to one clearly identified exit and noted worthwhile efforts to alter cabin design and seating configuration in order to optimise this.

The ditching of Sikorsky S-61N, G-BEID in July 1988 (AAIB, 1990a) was caused by fire in both engines which led to the cabin filling with noxious thick smoke. Clearly this made it more difficult for occupants to find an exit and slowed egress. In this case passengers and crew were able to evacuate successfully but had they less time, the effects of the smoke may have been more crucial in terms of their chances of survival.

The rapid inrush of water is another factor which might severely hamper an individual's attempts to reach an exit. This has been identified by a US army report (see AIB, 1987) as the major difficulty encountered when trying to escape from a helicopter landing in the sea and is supported by several authors (Ryack et.al., 1976; Ryack et.al., 1986; Rice & Greear, 1973; Muir, 1996). There is also evidence from the AAIB reports that this is indeed one of the most crucial factors determining chances of escape. The accident to AS 332L Super Puma G-TIGH in 1992 (AAIB, 1993) provides a stark illustration of this. The helicopter crashed into the sea causing rapid water ingress into the cabin. It is likely that four of the five passengers who did not escape from the helicopter before it sank were in some way overcome by this rush of water before they were able to make their escape. Breath holding time possible in the conditions was estimated at less than 20 seconds.

Another example is provided by the accident to Sikorsky S61N G-BDII in October 1988 (AAIB, 1989) involving capsize. The winch operator was considerably hampered by the inrush of water through the open starboard cargo door although he managed to escape. The winchman, who had been sitting halfway down the fuselage, was washed by a succession of waves, emanating from the open forward exits, towards the rear of the aircraft. He was eventually trapped in a small air pocket in the tail section of the inverted aircraft, from where his attempts to reach one of the jettison mechanisms for the rear port emergency exit were frustrated by his own natural buoyancy and the air trapped in his immersion suit. This latter point constitutes another problem which may hamper attempts to reach an exit in an inverted helicopter full of water. The winchman was eventually rescued by the commander who opened the rear port door from outside the aircraft.

Some of the perceived benefits of the side-floating helicopter are that one set of exits will be above the water surface after capsize, and, that a large air gap will be maintained within the cabin. This will allow the victim to surface within the cabin air gap and reduce the need for the individual to make an immediate escape following capsize. Once the head is above the water surface, the individual can take a breath, overcome any disorientation, locate the nearest exit and then make an escape.

1.3.2.5 Stage Five – Opening an Exit

Upon reaching an exit it will probably be necessary for the individual to jettison the potential escape exit. This will usually have to be done by touch rather than sight due to poor visibility. This final challenge may be too much for those who are at the limit of their breath holding ability or who have been injured in the accident. According to Brooks et al (1994), these individuals will form part of the 25-35% mortality rate associated with helicopter ditching accidents, suggested by military helicopter accident statistics.

Exits may already have been jettisoned if the crew are able to initiate an automatic unlatching control. This will depend on whether the crew have enough time to react or if they remember under the stress of bringing a helicopter to land in rough seas. This added responsibility upon crew members was noted by Hognestad (1993) and is certainly another factor which may affect egress. As an example, in the accident to Sikorsky S-61N G-BEID in 1988 (AAIB, 1990a) the crew did not manage to activate the automatic control for one of the exits which slowed egress from the aircraft, although everyone eventually escaped unharmed.

It may also be the case that the helicopter's impact with the sea has broken or dislodged some exits due to the distortion of the airframe. In this case occupants may be able to make use of the exits without having to open them.

Assuming exits have still to be opened, there are a number of problems which may face those trying to do so. If the helicopter is upside down this will present particular difficulties for anyone trapped inside. The jettison mechanism may be difficult to locate due to the fact it will almost certainly be underwater. This was the case in the accident to Sikorsky S-61N G-BDII in October 1988 (AAIB, 1989) when the winchman had great difficulty in getting to the jettison mechanism for the rear port door. Not only did his buoyancy make it difficult to progress under the water but upon reaching the exit, the mechanism was visually obscured by a curtain of bubbles illuminated by the emergency lights. Poor visibility can often prevent people from even finding escape hatches and egress routes (Ryack et al, 1976; Ryack et al, 1986; Bohemier & Morton, 1996).

A further problem with locating and operating an exit after the inversion of a helicopter is caused by disorientation (Ryack et al, 1976; Ryack et al, 1986; Rice & Greear, 1973). The problem of disorientation was highlighted in the accident to Sikorsky S61N G-BDES in November 1988 (AAIB, 1990b). The commander was forced to execute an immediate landing into a fairly hostile sea which was followed by rapid capsize. After capsize, neither pilot was able to locate the jettison handle for their emergency exit from an inverted position under water. One factor which probably contributed to this was identified from research into disorientation of subjects inverted under water. Tests were carried out in an intact S61 cockpit to establish why neither pilot could locate the operating handle for his emergency exit. Results indicated that when a pilot in the left hand seat reaches for the side escape exit operating handle his hand would naturally fall between the collective lever and his seat. This raises the possibility that the collective lever would obstruct the attempts of a pilot to reach the emergency exit operating handle. This problem may be exacerbated by the weight of the inverted pilot raising him from his seat. The effect of raising the pilot two inches from his seat is to put the emergency handle near the limit of normal reach. Research into disorientation of subjects inverted under water had demonstrated that their perception of the vertical could be seriously in error. Any one or a combination of these factors probably explain why neither pilot was able to locate their emergency exit operating handle. This being the case, it is possible that crew of an aircraft who are inverted under water may reach to the wrong place for a jettison handle, or find that the lever is beyond their normal reach.

A design issue raised by the RHOSS report (CAA, 1995) concerns the lack of standardisation in the operation of emergency exits. Although there is little evidence from the accident reports that this has hampered egress, research has shown that operating controls for escape hatches may be problematic. In controlled simulated training, trained subjects failed to correctly operate controls for escape hatches and required assistance to egress in 3.5% of escapes (Brooks et al, 1994). Jettison levers may appear to operate in the 'right direction' and be ergonomically well designed in terms of size, shape and location for emergency ground egress. However, their operation may become much more difficult in an inverted position underwater due to a person's disorientation and inherent buoyancy. Brooks et al also found that due to poor depth perception and magnification effects underwater, combined with disorientation, individuals required great eye-hand co-ordination to execute physical actions more than 25cm ahead of their finger tips when they were seated with the elbows flexed.

Lack of uniformity in the placement and operation of the levers is a potential problem. Theriault found that of 35 helicopter types, there were 23 different mechanisms positioned in many different places relative to the seated pilot or passenger (Theriault, 1998). As Brooks et al (1994) stated, solutions require both standardisation and improvement to design since the inconsistency can only serve to increase the difficulty of escape.

It has been identified that the design of an emergency exit may inhibit it being opened after a helicopter has landed in the sea. As early as 1987, the crew of AS 332L Super Puma G-BKZH (AAIB, 1988) elected not to ditch after technical failure because they were aware that the Super Puma cabin doors cannot be jettisoned when the aircraft is inverted. British International Helicopters confirmed this when they undertook practical tests in 1990 which showed that the Super Puma sliding doors are very unlikely to jettison if the aircraft is other than upright (Bailey, 1990). This is due to the fact that the design of the emergency release mechanism for these doors relies on gravity to release a portion of the sliding door track. The AAIB report (1988) relating to the accident to G-BKZH in 1987 recommended that the door design of the Super Puma should be reviewed, which the CAA agreed to undertake in its reply. However, the same design was involved when Super Puma G-TIGH (AAIB, 1993) crashed into the sea in 1992.

In the report on the accident to the aforementioned Super Puma (AAIB, 1993) the issue of this aircraft's cabin door jettison was discussed. The report concludes that the inability of the cabin doors to jettison unless the aircraft is in a near vertical position cannot be viewed as acceptable for the wide range of impacts where the helicopter is likely to remain erect for a very short period. It is also suggested that the benefit of opening a relatively large aperture, for personnel escape and perhaps life-raft deployment should not be ignored.

Somewhat contrary to this, the RHOSS report (CAA, 1995) found it difficult to envisage circumstances in which it would be practicable to use a main exit when the fuselage is not upright and therefore did not consider there to be any need for the CAA to reconsider the operating parameters for cabin door release mechanisms. However, there is evidence of instances when a helicopter capsized but did not sink immediately in which attempts were made to open a cabin door (AIB, 1978; AAIB, 1989; AAIB, 1990b). From this, it seems there are situations when it may be beneficial for cabin doors to open when a helicopter is not upright.

Further vindication of this point comes from the accident to Super Puma G-TIGK in 1995 (AAIB, 1997). The aircraft was upright but rolling in the sea and the inherent buoyancy of one of the doors prevented it from falling vertically, causing the upper locating arm to fail. It was thought that the fractured end of the floating door punctured the lower chamber of one of the helirafts. In conclusion, it appears that the need to open a cabin door in a non upright helicopter is not unlikely and could be beneficial. As such, the design of cabin doors perhaps requires further attention.

Once open it is preferable that the door remains open (see AIB, 1978). All non-jettisonable doors of emergency exits must now have a means of securing them in the open position (Document BCAR 29.809[i]; see CAA, 1992) and a provision has been made to deal with the issue of properly securing items which, if unsecured, might obstruct escape in the event of a helicopter ditching (CAA, 1987b).

Other factors which may prevent or hamper the successful opening of an exit include an obstacle on the outside of the door or part of an individuals clothing inhibiting the mobility they require to open the exit. An example of the former was observed in the accident to Bolkow BO 105D G-AZOM in 1984 (AIB, 1985) when the aircraft rolled onto its side and a detached flotation bag lay beneath the commander's door making it impossible to open. The latter was illustrated after the accident to Sikorsky S61N G-BDES in November 1988 (AAIB, 1990b) when one passenger reported he could not grip the fabric tag attached to the window rip-out beading until he had removed a survival glove. The AAIB (1990b) recommended that the CAA give further consideration to the problems of escape from inverted helicopters when approving helicopters for offshore operations, given the likelihood of rapid capsize following ditching. The CAA fully accepted this recommendation (CAA, 1990) and undertook to consider what further action could be taken in determining future escape facility standards.

When the side-floating configuration is considered, one set of exits will be above the water, allowing time to operate the release mechanism without undue panic.

1.3.2.6 Stage Six – Using an Open Exit to Make a Safe Escape

Having successfully reached and opened an escape exit there is a reasonably good chance that egress from the helicopter to the sea will be achieved. In this critical final stage, it is important that an individual's personal safety equipment is not so bulky or buoyant as to impede progress, and is designed to present the least possible risk of snagging (CAA, 1995). Also, a few incidents have been noted in this review which emphasise the fact that nothing should be taken for granted at this stage of escape.

In the accident to Bell 214 ST G-BKFN in 1986 (AAIB, 1987) the aircraft was forced to ditch but remained upright and all passengers and crew were eventually rescued safely. However, one of the passengers entered the sea inadvertently as a result of slipping off a flotation bag, and subsequently found himself drifting towards the still turning tail rotor. The individual was able to arrest the situation but clearly this final stage of egress was far from ideal. The AAIB report suggests that the addition of a non slip surface to the float bag could have prevented this from occurring.

The accident to AS 332L Super Puma G-TIGK in January 1995 (AAIB, 1997) highlighted a situation whereby an open exit could not be used. The aircraft had alighted on the sea and remained upright with both cabin doors being ejected and a heliraft being deployed from each. Passengers on the left side of the aircraft were having difficulty since the heliraft was blowing up against the open door on this side, making boarding very difficult. Fortunately the heliraft on the right side of the helicopter was available for all to board but this situation clearly slowed egress.

Finally, the rapid inrush of water is probably the most important factor which might prevent egress through an open exit. This has been reported by survivors of helicopter crashes at sea and was emphasised during the accident to Sikorsky S61N G-BDII in October 1988 (AAIB, 1989) when the winch-man was washed away from the open starboard cargo door and the winch operator had considerable difficulty overcoming the water as it entered the cabin.

In-rushing water should not be a problem with the side-floating helicopter. On-coming waves may be a concern, but this situation is little different to the upright-floating helicopter. The design of the new flotation system should aim to ensure that the top of the inverted exits are close to the water surface, allowing an easy escape to the sea. The victim should not have to climb up to the exit. If a flotation unit is fitted along the outside of the cabin, the victim may have to clamber over the unit, but this poses little risk of injury or difficulty.

1.3.3 *Life-rafts*

Life-raft evacuation from a ditched helicopter has been very problematic for survivors as a result of heavy sea states and the condition of the ditched helicopter. Problems which have been encountered include; total loss of the raft because the helicopter rolled on top of it; puncture through friction on the fuselage or tail rotor strike; the raft being blown on to its side against the fuselage and impossible to right; survivors having difficulty in boarding; the line or painter securing it to the helicopter cut by a sharp edge; and a liferaft which is difficult or impossible to launch (Brooks et al, 1997; Brooks et al, 1998).

Although not directly a recommendation of the HARP report (CAA, 1984), the launching of a life-raft and life-raft evacuation was suggested for further research. Following these suggestions, offshore helicopter operators performed a number of actions to improve life-raft deployment and reliability. Bailey (1990) stated that *'the sharp edges and projections which in the past had punctured life-rafts were covered or reprofiled. A new life-raft, the RFD heliraft was developed. This was very much tougher than previous rafts and thus puncture resistant. A drawback was that the canopy was difficult to erect in a rough sea or strong wind. Nevertheless, it was and is a great advance on earlier models'.* A number of operators took the step of mounting life-rafts externally on the Super Puma. The possible puncture of liferafts by damaged structure or sharp projections was again highlighted in 1997 (AAIB, 1997), when the AAIB recommended that action be taken to prevent door mounting arm failures.

Whilst work has been done to examine the options for life-raft evacuation from a ditched but non-inverted surface floating helicopter, (see Brooks et al 1997), the issue of life-raft deployment from a capsized helicopter appears to be absent from the research and only features in two of the AAIB reports reviewed for this study. In the accident to G-BBHN in 1977 (AIB, 1978), after capsize the co-pilot experienced difficulty moving the stowed life-raft towards the cargo door due to obstacles in his way. With the water level rising it became more important for the co-pilot to concentrate on opening the cargo door, which he managed with assistance, but only when neck deep in water with little breathing space above. In the accident to G-BDII near Handa Island (AAIB, 1989), the commander, who had already escaped from the aircraft, opened the rear port exit which allowed the winchman to escape from an air pocket in the tail section. The winchman had already removed the life-raft from this exit in his efforts to escape and was then able to retrieve it for use.

These cases illustrate the impracticability of deploying a life-raft from a capsized helicopter when an individual may only have a matter of seconds to make their escape. In the accident to G-BBHN in 1977 (AIB, 1978), the co-pilot was forced to abandon his attempt to deploy the life-raft in order to make his escape. In the accident to G-BDII (AAIB, 1989) the life-raft was deployed, but only because it could be accessed from outside the aircraft.

1.3.4 *Helicopter Escape: Fully Inverted Compared to Side-Floating*

From the review of helicopter accidents and related research it has been established that a helicopter which has been forced to land on the sea in high sea states, is likely to capsize and then sink. This fact makes it extremely important to establish which floating position after capsize gives the best chance of escape.

Common sense suggests that if a helicopter is floating on its side, this would be easier to escape from than a fully inverted aircraft due to the fact that the exits on one side of the helicopter would be above the water. There is also likely to be a larger air pocket within the cabin. Despite this, there may also be disadvantages of the side-floating position. One such disadvantage may be the release of the harness at an angle of about 150°. Such an angle is likely to create an uneven load on the harness buckle, which might make it more difficult to release. This is not a problem specific to the side-floating position, but one which may be exacerbated by the proposed flotation angle. Harness release has caused problems in at least one accident (AIB, 1982) and such problems are not uncommon during helicopter underwater escape training. Evidence from the review indicates that in many respects, escape from a side-floating helicopter would probably be easier than escape from a fully inverted one.

The review has shown that problems trying to reach exits are a major factor in escape. While waves could still provide a problem, 'inrushing' water will not affect exits which are above the water surface. The problems of underwater escape, particularly in poor visibility are well known, with speed and ease of escape being critical. Military research has shown that a maximum of only four people are likely to escape from any one exit. It is easy to see why this would be the case if occupants are trapped underwater and must rely on holding their breath to locate an exit, escape and reach the surface. However, if a helicopter is on its side, breath-hold time is likely to be less critical and passengers can wait their turn in the air pocket, before using an above water exit. The problems of locating an underwater exit can be avoided, increasing the chances of escape. The accessibility of the exits above the water will depend upon the angle of flotation and the flotation depth.

Substantial evidence has been presented which shows that the operation of an exit jettison mechanism presents a considerable barrier to an individual attempting to escape from a fully inverted helicopter. If a helicopter came to rest on its side after capsize in a stable flotation position, the problem of operating exit jettison mechanisms may be much less severe. Occupants would have more time and could better orientate themselves, making it more likely that they could release the exit.

The external mounting of a life-raft may be the only realistic way that it can be used following the capsize of a helicopter to the fully inverted position. However, if a helicopter rests on its side after a capsize, the resulting air pocket may allow more time for a life-raft to be located and deployed. Rice and Greear (1973) have suggested that when a helicopter floats on its side, the escape hatches above the occupants may be unreachable, approximately 8 feet up. If this was the case it would be extremely difficult for a life-raft to be taken to the outside but, again, this could depend upon flotation angle and depth.

It may be concluded that many of the potentially life-threatening problems associated with reaching and opening exits in a fully inverted helicopter would be less severe if the aircraft was floating on its side. It is also probable that life-raft deployment may be more feasible from a side-floating helicopter.

1.3.5 *Helicopter Underwater Escape Training*

At the time of this report, the United Kingdom Offshore Operators Association (UKOOA) are responsible for developing and reviewing the guidelines for emergency training provided to offshore workers. It is then the role of the Offshore Petroleum Industry Training Organisation (OPITO) to develop training standards to meet the requirements of the UKOOA guidelines (Ramsay, 1996). The training providers are accredited by OPITO to provide courses which meet these standards. Although helicopter underwater escape training (HUET) is not mandatory for all aircrew and passengers involved in flying over water in helicopters, the offshore industry does impose HUET training on its workforce.

Helicopter underwater escape training has been emphasised repeatedly in the literature as important for preparing occupants of helicopters on what actions to take in the event of a ditching. As Haywood (1993) states: *'the importance of timely emergency egress post crash, whether on land or at sea, is equally important. The hazards in each crash scenario, whilst obviously different (fire, water), nevertheless necessitate early egress from the wreckage to facilitate survival. In both scenarios survival beyond two minutes, post crash, is unlikely. The importance, therefore, of adequate safety or survival training (including briefing) cannot be over emphasised'.*

In a real ditching, noise, poor light conditions, inrushing of water, oil, petrol and debris, may all cause confusion and hamper escape. Training is carried out under safe and calm conditions. Hognestad (1993) stated that: *'simulators play a powerful role in the transfer of learning. Recreating potentially hazardous situations in a controlled environment offers the participant the ability to practice skills in a safe setting, free to make what would otherwise be tragic errors. By creating an environment as closely as possible to what could actually be expected to present in a given situation, the desired skills and knowledge can be reinforced through drill and practice.'*

The military believe that it is imperative that personnel are trained to cope with the physical, physiological and psychological stress of helicopter emergency egress in order to maximise what little time is available in the event of an accident (Haywood, 1993). Both Haywood (1993) and Hytten (1989b) believe that the training develops a positive response outcome, nurtures the survival instinct or will to survive and improves the individual's ability to cope with the stress of an emergency situation. The practical involvement provides clarification and confirmation of specific briefing points but, much more importantly, the physical experience will generate confidence. Coping is developed through repetition of controlled action in the training. Such a high level of training is not thought to be appropriate for the offshore workforce who may range in age from 18 to 70 years, who may not be physically fit and generally, only use helicopters to travel to work.

Research has shown that close physical fidelity (i.e. faithfulness to the real condition) is not necessarily required for the effective transfer of training from the helicopter simulator to the real situation (Summers, 1996). Task analysis should be performed to identify what skills and knowledge must be transferred to ensure effective learning and positive outcomes in the event of a real incident. Summers (1996) states that: *'skill learning does not require complete physical correspondence between the simulator and operational environments. What is needed is psychological or operational simulation rather than purely physical simulation'.*

There is evidence to support the philosophy that HUET training improves the survival chances of those who ditch in a helicopter. As far back as 1973, Rice and Greear stated that: *'many of the individuals who have egressed from underwater helicopters indicated that helicopter simulator training markedly enhanced their chances of survival. Successful escape from a submerged, inverted aircraft may depend largely upon reflexive action, which can best be learned in a realistic underwater egress trainer'.*

Statistics presented by Ryack et al (1986) showed that fewer than 8% of those who had received underwater escape training died in ditchings with capsizes, compared to more than 20% who had not received such training. This led him to believe that proper training would markedly reduce the number of such fatalities. A study of survivors of a Norwegian Army helicopter crash in the winter of 1988/89 (Hytten, 1989) highlighted the important role that helicopter simulator training had played for all survivors. It was reported that training had been decisive for successful escape, in particular helping to keep survivors calm and causing reflex conditioned behaviour. More recent studies have re-emphasised the critical role that training can have in preparing both crew and passengers for an emergency ditching (Bohemier & Morton, 1996; Haywood, 1996).

One disadvantage of HUET training is that it may cause anxiety. However, studies of offshore workers undergoing HUET training showed that repeated training reduced feelings of anxiety. Heart rates of trainees undergoing their first, basic HUET were relatively higher than those undergoing refresher training (Harris, Coleshaw and MacKenzie, 1996). The heart rates which were elicited during the HUET exercises were found to be comparable, if not lower, than those that might be expected during moderate manual external work offshore.

2 FEASIBILITY TRIALS

2.1 Method

2.1.1 *Preparation of the helicopter simulator*

The helicopter simulator was customised to represent a Super Puma. Changes were made to make the escape process as realistic as possible, allowing comparison with escape from a real helicopter.

A visit was made to Bristow Helicopters Limited in Aberdeen, where measurements were taken from an operational Super Puma. These measurements included window dimensions and distances to exits. Following the visit it was possible to confirm that the seating arrangement in the helicopter simulator matched the rear and forward seats in a Super Puma cabin and that the distances from the seats to the exits were similar in both (Appendix 3).

In addition, aluminium window frames were fitted to the helicopter simulator which were of the same or very similar dimensions to Super Puma windows. Perspex push-out windows were fitted so that subjects would have to complete the action of pushing out a window during escape. Velcro rip-cords were attached to the window frames to simulate the rip cord on a real helicopter window, again allowing the subjects to carry out an action required during a real escape.

Yacht fenders were used to simulate the proposed helicopter flotation system in order to assess their effect on the difficulty of escape. Two fenders of the appropriate size were attached securely to the port side of the helicopter simulator, one above each window.

A practical method was needed to ensure that the helicopter simulator would reliably come to rest at the desired side-floating position following capsize. The required capsize angle was achieved by application of the drum brake. A block was attached at the appropriate point on the drum rail so that the helicopter simulator would reliably come to rest at the same desired angle on each capsize. This angle was 150° from the vertical. The depth of submersion of the helicopter simulator was controlled by the operator.

To enable simulation of a reverse capsize, the block on the drum rail was moved, allowing a controlled capsize through 210°.

2.1.2 *Protocol*

The helicopter simulator was set up prior to the feasibility trials, with the flotation bags and window frames attached. The helicopter simulator was then capsized with no personnel on board to check that the correct angle could be achieved. Once the helicopter simulator was in the side-floating position at around 150°

from the vertical, training staff boarded the cabin to observe the angle of seats and predict the effect this would have on occupants who were strapped inside. They were allowed to explore the possibilities of escape and potential difficulties. Appendix 4 shows a view inside the cabin at 150°. Sources of potential risk of injury to someone escaping were also noted at this stage. The training staff were encouraged to identify any aspects of the escape which could cause problems.

Training Officers were used for the feasibility trial for safety reasons. All were qualified divers and so were comfortable inside the helicopter simulator and able to assess the potential problems. An escape route was agreed before each capsize for the training staff to test. The possible escape scenarios which were tested are listed in Table 1.

Table 1 – Possible escape procedures tested in the feasibility trials

Seat position	Angle of roll	Escape route
Starboard	150°	Underwater escape through starboard exit
Starboard	150°	Rise to air pocket then underwater through starboard exit
Starboard	150°	Rise to air pocket then out through port exit (above water)
Port	150°	Rise to air pocket then underwater through starboard exit
Port	150°	Rise to air pocket then out through port exit (above water)
Starboard	210°	Underwater escape through starboard exit
Starboard	210°	Rise to air pocket then underwater through starboard exit
Starboard	210°	Rise to air pocket then out through port exit (above water)
Port	210°	Rise to air pocket then underwater through starboard exit
Port	210°	Rise to air pocket then out through port exit (above water)

Information was gathered in the form of comments from the training staff as well as photographs and video recordings. The findings were used for two purposes. Firstly, a risk assessment was constructed to identify any part of the escape procedure which carried an unacceptable risk of injury. The modifications to the helicopter simulator, i.e. the window frames and flotation bags, were taken into account when assessing the safety requirements. A work assessment record was completed which included the scoring of hazards on a matrix to produce a quantitative measure of risk. This was used to determine whether the level of risk was acceptable. Any procedure which was thought to carry excessive risk was either amended to make it safer or completely discarded. Secondly, the results from the feasibility trials were used to help select a number of escape procedures which could be tested against corresponding escapes from a fully inverted helicopter.

On completion of the feasibility trials, escape procedures were agreed and protocols were drawn up. In helicopter underwater escape training it is considered important for trainees to build up a clear mental picture of egress, where the different actions form a pattern. Emphasis was therefore placed upon the development of 'generic' procedures which could be broken down into a series of simple steps performed in a particular order. This was taken into account when developing procedures for escape from a side-floating helicopter.

2.2 Results

In total, 7 different subjects provided feedback from 5 different trial sessions in which escape from the side-floating helicopter simulator was tested. All subjects were experienced RGIT staff. Table 2 shows the most commonly identified issues and the number of subjects who raised them.

Table 2 – Most common issues identified from feasibility trials

Problem issues	Number of reports
Difficulty locating exit due to a person's angle in the seat	2
Release problem with harness due to uneven weight distribution	3
Shoulder strap of harness twisting around neck area	2
Fall with force from upper seat	6
Which escape route to take when on lower side of helicopter simulator?	3
Difficulty going from air pocket to underwater exit	2
Difficulty getting foot purchase to pull through window on upper side	3
Better to exit window backwards	3
Disorientation worst in 210° roll	2
Bumping head	1
Escapee kicking to assist escape, presenting hazard	2

The major immediate concern for the trials was that when an occupant in an upper seat released their harness, their legs fell with considerable force toward the person in the lower seat on the opposite side of the cabin. It was concluded that individuals coming up from the lower seats would be at serious risk of injury from the forceful leg swing of people releasing from the upper seats. Furthermore, it was felt that someone might kick their legs to help them pull through an upper window which might injure occupants behind them. (This latter point was also true of current underwater escape procedures). Whilst this was a potential problem for the trials and future training, it was not thought likely to have any impact in the outcome of a real accident.

The issue of which escape route to take from an underwater seat was also raised. It was suggested that, in such a position, an individual might be inclined to make an immediate underwater escape from the exit next to them instead of first going to the air pocket. Going to the air pocket and then making an underwater escape was found to be problematic due to inherent buoyancy.

The four point harness caused two concerns. Firstly, it was predicted that an uneven load on the buckle might make it more difficult to release than normal. This was confirmed in practice on three occasions. Secondly, it was observed that once the harness had been released, a shoulder strap had the tendency to get caught around the neck of someone twisting to get clear of the harness and rise to the air gap. This was found to be due in part to the method of retracting the harness on release; the retraction system used in the simulator exerted less force than the system used in operational helicopters.

The issue of hand and footholds was raised. It was felt that handholds might be useful for maintaining contact with an exit whilst at an angle, and that footholds would be useful for an individual to push themselves through an exit on the upper side of the aircraft. On the subject of exiting from the upper side, it was noted that the safest method of leaving the exit would be to sit on the window ledge and then push backwards into the water. This method allowed the subject to present their back to any potential oncoming waves, and keep the face pointing upwards, reducing the potential risk of drowning from further head immersion.

As a final point, it was reported by two subjects that the 210° capsize caused the greatest disorientation of any of the side-floating exercises. The subjects said that this was because of the extra roll, which came unexpectedly after the helicopter simulator had gone through 180°, increasing the sense of disorientation.

2.3 Discussion

The results of the feasibility trial were used to develop the procedures and protocols for the comparison trials using naïve subjects.

The risk assessment resulted in a restriction to the number of naïve subjects who would be allowed to escape from the helicopter simulator at any one time. It was decided to restrict this number to two, both sitting on either the starboard or port side of the helicopter simulator. This would ensure that a subject in an upper seat would not fall down onto a subject in an underwater seat, risking injury.

Issues relating to the harness caused some concern. These were given due consideration during the naïve subject trials to assess whether harness release affected the reported ease of escape. Further work is needed to determine the best system of buckle release for a side-floating helicopter.

Hand and footholds close to windows and exits deserve consideration for future designs of helicopter. They are likely to ease the process of escape, particularly in real situations in which the occupant has released the seat harness before reaching a window or exit. In such cases, the individual would need some leverage to push out a window. Hand and footholds could help to provide leverage.

The additional disorientation identified by the trained staff during the 210° capsize may be explained by the experience of the staff who were habituated to the more normal 180° roll by repeated regular exposure. The degree of roll was likely to be much less obvious to a naïve subject.

2.4 Development of capsize scenarios

The escape procedures following capsize which were chosen for the side-floating trial were those in which subjects would take advantage of the perceived benefits of escape from a side-floating helicopter, namely the air pocket and the fact that exits are above the water on one side. As a result, it was decided that in escapes from the side-floating helicopter simulator, subjects should always rise to the air pocket before escaping from an above water exit, irrespective of where they were sitting.

A series of exercises was developed which would allow side-floating escape to be compared to conventional fully inverted escape. The first exercise simulated a surface ditching, allowing all occupants to evacuate through the cabin door into a heliraft. The second exercise was a slow immersion without capsize when the helicopter simulator slowly sank and occupants escaped from the underwater windows and door. The capsize exercises were developed to include escape from seats on each side of the helicopter simulator. In each case, subjects were required to exit through a port side window. They also included a reverse roll capsize, with subjects escaping from the nearby port window. This was thought to provide a representative coverage of the possible escape scenarios.

The first capsize selected was subjects sitting on the starboard side followed by a 150° roll and then escape through one of the above-water port windows. This was known as a 'cross-cabin escape'. Subjects would have to release from their harnesses, surface in the air gap and then escape through the opposite above-water exit. The second capsize was the same except that subjects sat on the port side, labelled the 'same-side escape'. This would involve the subjects having to release from a seat which rested mostly above water after the capsize, falling down from the air gap into the flooded cabin and then escaping by the above-water exit next to their seat. The third and final capsize chosen was subjects sitting on the port side, a reverse 210° roll capsize and then escape through the nearby above-water port exit. This was included to simulate a wave striking the side of the aircraft which does not have the added buoyancy and was called 'reverse capsize escape'. It should be noted that, in this case, the helicopter still came to rest at 150° but had to roll through 210° to get there.

Each of the side-floating escape procedures was matched to a corresponding fully inverted escape procedure in terms of using the same seat, the same direction of roll and the same target exit for escape. By controlling these factors, it was more valid to attribute any differences between the escapes to the floating angle of the helicopter simulator and the corresponding escape procedure. The capsizes were ordered so that they had a small increase in difficulty each time, in a way that would build up the confidence of a subject. The procedures were incorporated into a draft lesson plan and multi-media briefing. The lesson plan was reviewed to assess its suitability for use by naïve passengers and amended accordingly before implementation within the naïve subject trials.

3 NAÏVE SUBJECT TRIALS

3.1 Method

3.1.1 *Overview*

To assess the benefits or disbenefits of escape from the side-floating helicopter, trials were carried out using naïve subjects who had no pre-conceived views or experience of helicopter escape. Thirty subjects were recruited, each subject completing two trials. In one, three escapes were carried out from a fully inverted helicopter following a 180° capsize. In the other, the subjects carried out three escapes from a side-floating helicopter following capsizes of either 150° or 210°. Ethical approval for the study was obtained from Grampian Research Ethics Committee.

It was considered desirable to record objective as well as subjective measures of performance during the trials. Subjects were required to complete a questionnaire before and after each trial, which asked them to rate their perception of the difficulty associated with each escape.

Physiological and psychological measurements were taken at various intervals during the trials to assess the subjects' levels of anxiety. Cortisol production has been shown to increase in response to demanding and stressful situations (Bohnen et al, 1991; Harris et al, 1996; Selye, 1980). Cortisol in saliva provides an acute measure of stress, an increase in cortisol concentration reflecting physiological activation within the previous 20 to 90 minutes. Samples of saliva were collected at intervals throughout each trial. Cortisol levels in urine provide a chronic measure of stress and the psychological status of the subject. Samples of urine were collected early in the morning (overnight sample) on the day of each trial.

Anxiety levels were measured using Spielberger et al's (1983) State/Trait Anxiety Inventory (STAI) to provide an indicator of subjectively experienced stress. The STAI was chosen due to its wide recognition in the scientific literature and its applicability over a wide range of stressors (see Harris, 1995; Harris et al, 1996).

It is well established that heart rate is related to the metabolic requirements of the body (Anastasiades & Johnston, 1990). There is also evidence of a relationship between heart rate and stressful situations, heart rate increasing with anxiety (Fuller, 1992; Hodges & Spielberger, 1966). Subjects were fitted with heart rate monitors (Polar), providing a continuous record of heart rate throughout each trial. Data was later down-loaded onto computer. In order to separate the effects on heart rate of physical effort and anxiety, activity records were completed for each subject, providing precise times when subjects were carrying out activities such as sitting, walking or swimming.

Each trial was filmed from the pool-side to allow escape time to be measured accurately by stopwatch. Underwater cameras were used to record the escapes and provide evidence of any problems experienced by the subjects.

3.1.2 *Subject recruitment*

A total of 30 subjects were recruited from 3 age ranges (18 – 29, 30 – 39, 40 – 49 years) with ten subjects from each category. An upper age limit of 50 years was set for medical ethics reasons. The subjects were to be predominantly male and cover a range of body heights and builds. This was intended to represent the profile of the offshore population as far as possible. Recruitment took the form of distributing a poster to advertise the need for volunteers and spreading information about the study verbally. The recruitment criteria were that subjects had to be reasonable swimmers and not have any previous experience of helicopter underwater escape training. Potential volunteers were issued with written information describing the study and had a chance to discuss the study with one of the research team. If they were happy to take part they were required to provide written, witnessed consent and fill in a medical screening form.

3.1.3 *Experimental trial programme*

Each subject completed one trial with egress from the capsized and fully inverted helicopter simulator using current training procedures (the control condition) and one trial with egress from the side-floating helicopter simulator using the new procedures. Only two subjects at a time were allowed in the helicopter simulator for a side-floating capsize, seated one at each end, to reduce the risk of injury. Consequently, in order to make valid comparisons, only two subjects were in the helicopter simulator at any one time for capsize to the fully inverted position.

The order of carrying out the trials was randomised so that half of the group used the fully inverted (control) procedures first, and the other half used the new side-floating procedures first. This was done to remove any order or training effects which might affect subjects' preferences and perceptions of difficulty. The two trials were separated by at least a week but by no more than a month. All trials were started at roughly the same time of day.

An initial briefing was completed at least a day before the trial itself. Subjects were provided with written information about the trials and asked questions before filling in a consent form. They also completed Spielberger's state and trait anxiety questionnaires (Spielberger et al, 1983) and supplied a saliva sample to provide control measures of their anxiety. They were also given a sample bottle in order to take a urine sample on the morning before their first trial.

When subjects arrived for a trial they were seated in a warm room and checks were made that they had received written information, given consent, and had completed and passed a medical screening procedure. The trial programme was then explained.

Subjects provided the first saliva sample after washing out their mouth with water. Next, 'Polar' heart rate monitors were fitted. This involved subjects putting on a chest band transmitter and a wrist watch monitor to receive and store the signal. Subjects were instructed to start their monitors in synchronisation with each other. At the same time a member of the research team started a stopwatch and recorded the time. This enabled heart rate recordings to be linked to events in time recorded on activity sheets. The final part of the initial session was for subjects to complete a pre-trial evaluation questionnaire assessing how each individual thought they would perform during the trials, i.e. their perceived efficacy. Before their first trial they were also asked to fill in some background information such as swimming ability and physical fitness.

Subjects were then transferred to a classroom for a multi-media briefing to train them in the helicopter escape techniques which they were due to undertake. After the briefing, a second saliva sample was taken. Subjects were then taken to the RGIT Environmental Tank where they donned a helicopter immersion suit and a lifejacket over jeans, shirt, jumper and socks. Training shoes were worn over the immersion suit and subjects wore a safety helmet. Finally, just before starting the HUET exercises, subjects gave a pre-trial saliva sample and completed a pre-trial state anxiety questionnaire.

The escape procedures tested in the naïve subject trials are shown in Table 3. They are displayed in the order in which they were undertaken in the trial, i.e. with a small increase in difficulty each time. It should be noted that it was the corresponding capsizes in terms of position of seating, direction of roll and target exit that were compared.

Table 3 – Escape procedures tested in naïve subject trials

Escape procedures after 180° capsizes to fully inverted position	**Escape procedures after 150°/210° capsizes to side-floating position**
1. Surface evacuation	1. Surface evacuation
2. Partial submersion, port seats leaving by port windows	2. Partial submersion, port seats leaving by port windows
3. *Same-side Escape* – 180° fast capsize, port seats leaving by port windows	3. *Cross-cabin Escape* – 150° fast capsize, starboard seats leaving by port windows
4. *Escape After Reverse roll* – 180° reverse fast capsize, port seats leaving by port windows	4. *Same-side Escape* – 150° fast capsize, port seats leaving by port windows
5. *Cross-cabin Escape* – 180° fast capsize, starboard seats leaving by port windows	5. *Escape After Reverse roll* – 210° reverse fast capsize, port seats leaving by port windows

During the trials, the timing of events was carefully recorded. This included making notes on escape success and recording escape time. This was supplemented by a video record of the exercises from the pool-side and from two underwater cameras mounted inside the helicopter simulator. Both underwater cameras were mounted on the starboard side, one at roof level and one at floor level.

Once all escapes had been completed the subjects left the pool and provided another saliva sample as well as completing the post-trial state anxiety questionnaire. They then showered and changed before proceeding back to the classroom. In the final part of the trial, subjects were required to complete a post-trial evaluation questionnaire, rating each capsize in terms of the difficulty to escape. Subjects were also asked questions about their confidence before and after the trials and how satisfied they were with the way they had coped in the exercises. After this, subjects gave the final saliva sample of the trial and removed the heart rate monitor which signalled the end of a trial.

3.1.4 *Management and analysis of data*

3.1.4.1 Heart rate

After each trial, the heart rate data stored by the wristwatch receiver was downloaded onto computer via an interface. Data was transferred into a software package where it was saved as a file. The software package provided several options for analysing the heart rate data. Heart rates were plotted over the course of each trial. The sampling rate was once every 5 seconds.

Heart rate averages were calculated for particular periods of time. Of interest in this study was the level of heart rate before each trial, during the exercises and after a trial had finished. A pre-trial average was taken over a 5 minute period before subjects went to the pool-side. This was selected by visual inspection of each heart rate graph and by identifying a 5 minute period of steady state resting heart rate. An average heart rate was also taken for the critical phase of each partial submersion exercise and each capsize exercise. The start of these sampling periods was marked at 10 seconds before the helicopter simulator started its descent, running until the subject's head was clear of the water. The time period thus varied between subjects but covered the same activities. Once subjects had completed the trial, a resting post-trial average was taken using the same rationale employed for the pre-trial average.

Statistical comparisons were made between average heart rates in the side-floating and fully inverted exercises. Paired sample t-tests were used to test if there were any differences in subjects' heart rates before, during and after the escape exercises, depending on the type of trial, and any differences between trials. Heart rate was tested for any effects of age using a one way analysis of variance (ANOVA).

3.1.4.2 Urinary and salivary cortisol

Urine samples were brought to each trial by the subjects, who had taken them on that morning. The samples were immediately placed in a freezer. As described in 3.1.3, a control saliva sample was taken a day before the first trial. Further samples were taken on the day of each trial; on arrival, after the briefing, immediately before entering the pool, immediately after leaving the pool and at the end of proceedings. Saliva samples were frozen directly after each trial. All samples were given a unique identifier which included the subject number, whether it was their first or second trial, the type of trial, the time the sample was taken and the date.

After the trials had been completed, it was necessary to decide which of the saliva samples that subjects provided over the course of a single trial should be analysed to provide the most meaningful results. To this end, all the serial saliva samples from three subjects were analysed and the results were plotted in graph form. This indicated that the biggest difference in cortisol was between the first saliva sample of the trial (on arrival) and the one taken immediately on leaving the pool after the subject had completed the escape exercise.

Consequently, it was decided that the samples taken at these two times would be analysed for all subjects in both trials as well as the control sample taken at least a day before the first trial. This meant that five saliva samples were analysed for each subject as well as their two early morning urine samples.

Samples were sent to a qualified professional for analysis using a standardised immunoassay kit *(DRG Instruments)*, providing a quantitative measurement of cortisol (Haeckel, 1990). This biochemist was not told the code used to identify individual samples and was therefore blind to the timing, and relevance, of each sample.

The values of salivary cortisol were compared using paired sample t-tests to determine if the level of cortisol before and after the escape exercises was significantly altered depending on the trial. The same test was used to compare the control samples and those taken during the trials. In addition, the levels of cortisol found in this study were compared to those reported from other populations.

3.1.4.3 State / trait anxiety questionnaires

Subjects completed the Spielberger (1983) state and trait anxiety questionnaire during the initial briefing. They then repeated the state questionnaire before and after the escape exercises in each trial. The questionnaires were scored according to a template. This provided one trait anxiety score and five state anxiety scores for each subject.

The state anxiety scores from the side-floating trial were statistically compared to those from the fully inverted trial. The state anxiety scores from before and after each pool session were assessed using paired sample t-tests to assess whether subjects' were significantly more anxious in one trial compared to the other. The same test was used to compare the control scores with those from during the trials. Levels of state and trait anxiety taken from this study were compared to those reported elsewhere in the literature.

3.1.4.4 Perceptions of difficulty, confidence and coping

These were measured by way of pre-trial (perceived efficacy) and post-trial evaluation questionnaires which each subject completed. Before the first trial subjects were asked about their general confidence in helicopter transport. Before each trial subjects were asked to rate how confident they were about escape in the exercises. After each trial they were asked to re-assess their level of confidence, to rate how satisfied they were with the way they coped in the session and to rate how they felt they would cope in a real helicopter ditching.

Subjects were also asked about the general difficulty of each capsize escape and to rate 10 factors in terms of how difficult they were. These included disorientation, releasing the harness, finding the exit and getting snagged. Each answer was given a score along an ordinal scale which made it possible to statistically compare the perceptions from the side-floating trials with those from the fully inverted trials. Copies of first and second trial questionnaires are given in Appendix 5.

A Wilcoxon Matched-Pairs Signed-Ranks test was used to compare the difficulty scores given to the side-floating escapes with those given to the corresponding fully inverted escapes. Similarly, this test was used to compare the confidence and coping scores from each trial.

3.1.4.5 Escape and submersion times

Escape times were always taken from when the floor of the helicopter simulator made contact with the water to when subjects surfaced outside the simulator with their mouth clear of the water. This time was recorded by stopwatch and checked using the video footage.

Submersion times were taken from the video footage of the trials. This came from a pool-side camera and two underwater cameras inside the helicopter simulator. The separate footage was edited so that the three different synchronised views could be seen at the same time on one screen. This made it possible to accurately judge the time from when a subject took a breath to when they surfaced.

For submersion time in the partial submersions, the time was taken from when subjects took a breath before being submerged to when they surfaced outside the helicopter simulator with their mouth clear of the water. The same was true for the fully inverted capsizes. In the side-floating capsizes, submersion time was taken from when subjects took a breath before submersion to when they rose to the air pocket inside the side-floating helicopter simulator with the mouth clear of the water.

Even when the time a breath was taken was unclear, e.g. when subjects were sat on the same-side of the simulator as the underwater cameras, there was still enough information in the video to allow a good estimation of the submersion time to be made.

Escape and submersion times from each trial were compared using statistical analysis. The escape and submersion times from the fully inverted trial were compared to those from the side-floating trial, using paired sample t-tests to determine any significant differences. Additional testing was carried out on the ratings from the cross-cabin exercises. This was because only 15 out of 30 subjects made a cross-cabin escape, as instructed, from the fully inverted helicopter simulator. As a result, an independent samples t-test was used to compare the submersion times of the subjects who made a 'successful' escape from this scenario with the ratings from the subjects who did not.

3.1.4.6 Statistical significance

For all statistical comparisons, a probability of $P<0.05$ was taken to be significant.

3.2 **Results**

3.2.1 *Background*

A total of 30 naïve subjects, aged 18 to 49 years, completed the side-floating and the fully inverted trials. Subjects were naïve in that none had experienced HUET training before. Fifteen took part in the side-floating trial first and the other 15 went through the fully inverted trial first. This was to control for any order effect. Table 4 shows the average height and weight of the subjects, demonstrating a wide range of body morphologies.

Table 4 – Average height and weight of subjects

	Height (cm)	Weight (kg)
Mean	175.6	82.4
Standard deviation	6.9	14.1
Maximum	187.5	111.2
Minimum	162.5	57.0

It can be seen from Table 5 that the majority of subjects rated themselves as being moderately fit, moderately good swimmers, moderately confident about helicopter transport and had no previous knowledge of helicopter underwater escape.

Table 5 – Subjects' background

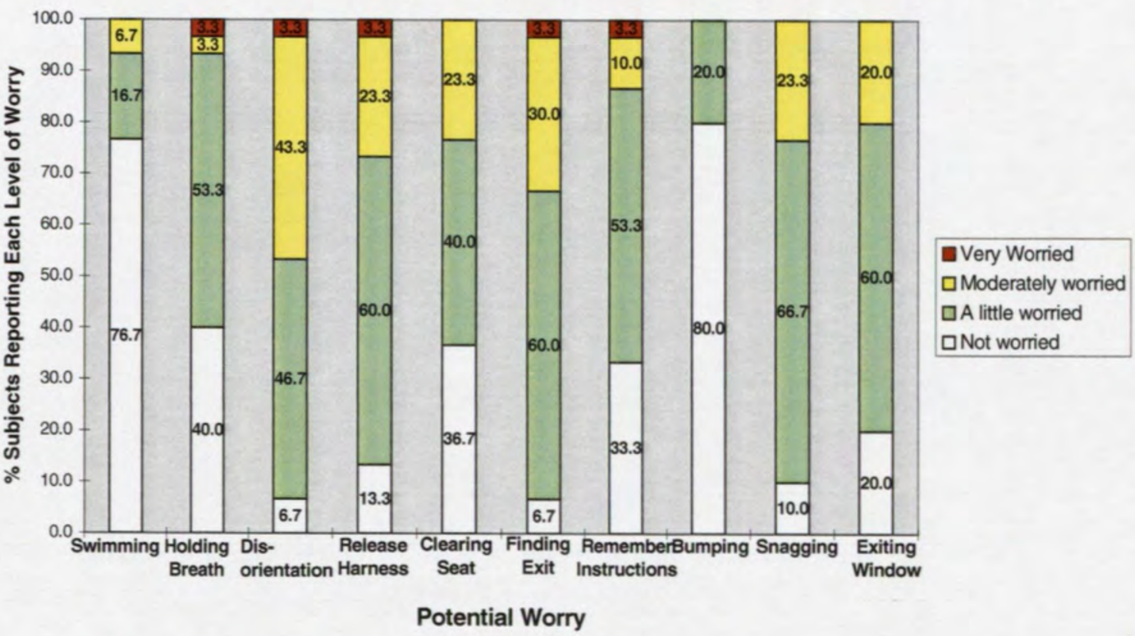
Variable	Responses %			
Physical fitness	*Unfit* 6.7	*Moderately unfit* 23.3	*Moderately fit* 70.0	*Very fit* 0.0
Swimming ability	*Non-swimmer* 3.3	*Basic* 10.0	*Moderately good* 63.3	*Very good* 23.3
Confidence in helicopter transport	*None* 0.0	*Low* 0.0	*Moderate* 63.3	*High* 36.7
Previous knowledge of HUET	*No* 93.3	*Yes* 6.7		

3.2.2 *Perceived worry*

Before each trial, subjects were asked to rate 10 factors in terms of how worried they were that the factor might affect their escape (perceived efficacy).

Figure 1 shows that the factor causing most concern before the first trial was disorientation, with 43.3% of subjects moderately worried about it. Finding the exit was also reported to be an issue with 30% expressing moderate worry in relation to this factor. Figure 1 indicates that, overall, for all factors, the majority of subjects were either not worried or only a little worried.

Figure 1 - Perceived Worry Before First Trial



3.2.3 *Difficulty ratings after the trials*

3.2.3.1 Overall difficulty

Table 6 provides information about how difficult subjects found each capsize. It is clear that the fully inverted cross-cabin capsize was found much more difficult than the side-floating equivalent. In the former, 89% found escape moderately or very difficult compared to only 29% in the latter. This difference was significant at the P = 0.0001 level.

Table 6 – Subjects' rating of capsize difficulty

	RATING (%)			
CAPSIZE	**No difficulty**	**A little difficult**	**Moderately difficult**	**Very difficult**
Fully inverted cross-cabin	0	10	46	43
Side-floating cross-cabin*	23	46	23	6
Fully inverted same-side	16	40	36	6
Side-floating same-side	26	53	13	6
Reverse fully inverted	23	36	36	3
Reverse side- floating	20	43	30	6

**Side-floating exercise significantly less difficult than fully inverted exercise (P=0.0001)*

In the escape from the same-side exit following the fully inverted capsize, less people had no or little difficulty and more people had moderate difficulty compared to the equivalent side-floating exercise. The difficulty ratings for the reverse capsizes were closely matched.

3.2.3.2 Cross-Cabin Capsizes

Figures 2 and 3 allow comparison to be made between the difficulty of specific factors in the fully inverted cross-cabin capsize and the side-floating cross-cabin capsize.

Of particular note when comparing the cross-cabin capsizes is the fact that 15 subjects (50%) failed to complete this escape correctly when the helicopter simulator was fully inverted. Ten of these subjects were forced to rise to the air pocket inside the helicopter simulator and the other 5 escaped through their nearest exit instead of crossing the cabin. In the side-floating trial, everyone successfully completed the cross-cabin escape.

Bearing this in mind, it is understandable that the most striking differences between Figures 2 and 3 are the difficulty ratings for 'disorientation' and for 'finding the exit', in that both were found significantly more difficult ($P = 0.005$ and $P = 0.0001$ respectively) in the fully inverted cross-cabin escape. In the fully inverted trial, disorientation made cross-cabin escape 'very difficult' for 56.7% of the sample with the same percentage reporting that finding the exit was very difficult. In the side-floating cross-cabin escape, the corresponding figures were 20% and 3.3% respectively.

Another factor which was found significantly more difficult in the fully inverted cross-cabin exercise was 'exiting through the window' with 26.7% finding it 'very difficult' compared to no one finding it 'very difficult' in the side-floating cross-cabin escape. This difference was significant ($P = 0.0051$) and is hardly surprising considering the fact that 50% of subjects failed to even get to the required exit in the fully inverted cross-cabin exercise.

Finally, there was a significant difference ($P = 0.041$) between the levels of difficulty with swimming in the trials, with subjects rating it as more difficult in the fully inverted cross-cabin escape, in which they had to swim underwater. This was not even a feature of the side-floating equivalent. Linked to this was the fact that breath holding was rated as more difficult in the fully inverted cross-cabin escape, although the difference was not significant.

It was something of a surprise that the ratings of breath holding difficulty were not significantly different for the cross-cabin escapes given that one required substantial breath holding and the other a breath hold of only a few seconds. As a result, this issue was looked at in more detail. Due to the fact that 15 subjects did not complete the escape from the fully inverted helicopter simulator as intended, it was decided that these subjects should be treated as a separate group. This group's breath hold ratings were compared to the ratings from the other 15 subjects who did successfully complete this escape. It was found that the former rated breath holding as significantly more difficult than the latter at the $P = 0.02$ level of significance.

Figure 2 - : Subjects' rating of difficulty factors in the FULLY INVERTED cross cabin capsize

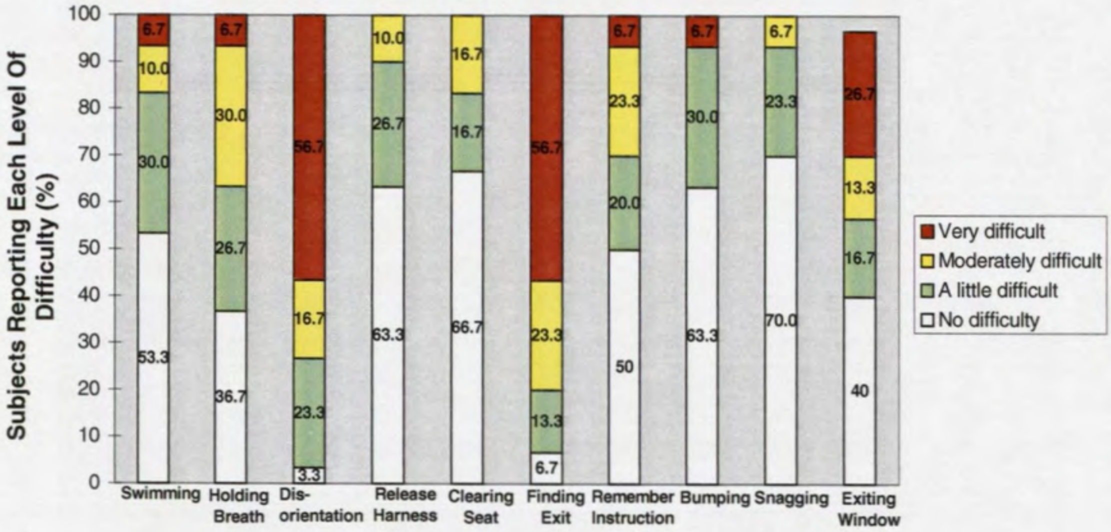
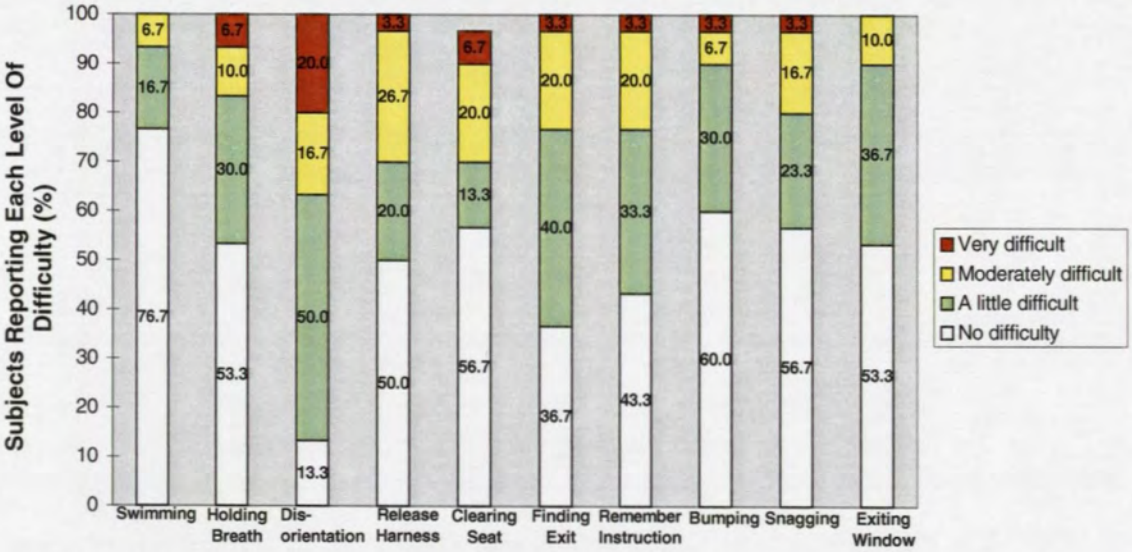


Figure 3 - : Subjects' rating of difficulty factors in the SIDE-FLOATING cross cabin capsize



Further comparisons were made in order to investigate if there was any difference between the sub-group's cross-cabin breath hold ratings depending on whether the trial was fully inverted or side-floating. No significant difference was found between the fully inverted and side-floating cross-cabin breath hold ratings reported by those who were successful in the fully inverted trial. It was hypothesised that those who failed the fully inverted cross-cabin would rate breath hold as being significantly easier in the side-floating cross-cabin escape. In fact, no significant difference was found. The higher level of difficulty in both exercises suggests that these subjects found breath holding to be difficult per se.

It should be noted that in the fully inverted trials, subjects who rose into the safety air gap 'opted out' rather than continue to hold their breath and make an escape.

3.2.3.3 Sit/escape same-side capsizes

Figures 4 and 5 show how much difficulty was caused by the specific factors in the escapes from the fully inverted and side-floating capsizes when subjects were seated on the same-side as the exit window.

Differences between the difficulty ratings are less marked than those for the cross-cabin capsizes. However, a similar trend was found in that 40% of subjects found disorientation to be moderately or very difficult in the fully inverted same-side escape, compared to only 20% in the side-floating equivalent, although this difference was not significant. Subjects did rate holding their breath as being more difficult in the fully inverted same-side escape than in the corresponding side-floating exercise and this was significant ($P = 0.043$). This trend was also noted in the cross-cabin escapes and can be accounted for by subjects using the air pocket in the side-floating exercises and not needing to hold their breath for long.

3.2.3.4 Reverse Capsizes

Figures 6 and 7 show the levels of difficulty reported from the escapes after the reverse capsizes. Contrary to the findings so far, these figures show that disorientation caused more difficulty in the side-floating exercise. This can be explained by the fact that the roll was 210° in this capsize, the longer turn causing added disorientation. Also, this was the last fully inverted capsize with no added difficulty, which may have influenced this comparison.

Perhaps as a result of the added disorientation, subjects rated locating the exit as being significantly more difficult in the side-floating reverse capsize ($P = 0.03$), although the fact that they were in the air pocket allowed them time to orientate themselves. Subjects also reported more difficulty releasing their harness in this exercise ($P = 0.05$), which had also been observed in the feasibility trials and was thought to be because of the uneven load on the buckle with the body also out of the water.

Figure 4 - : Subjects' rating of difficulty factors in the FULLY INVERTED same side capsize

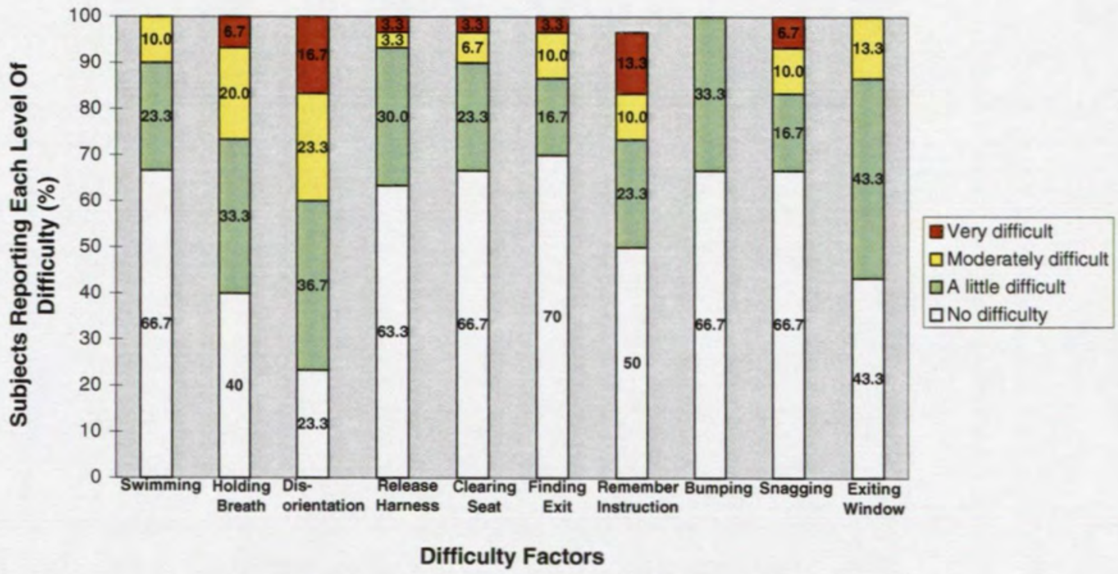


Figure 5 - : Subjects' rating of difficulty factors in the SIDE-FLOATING same side capsize

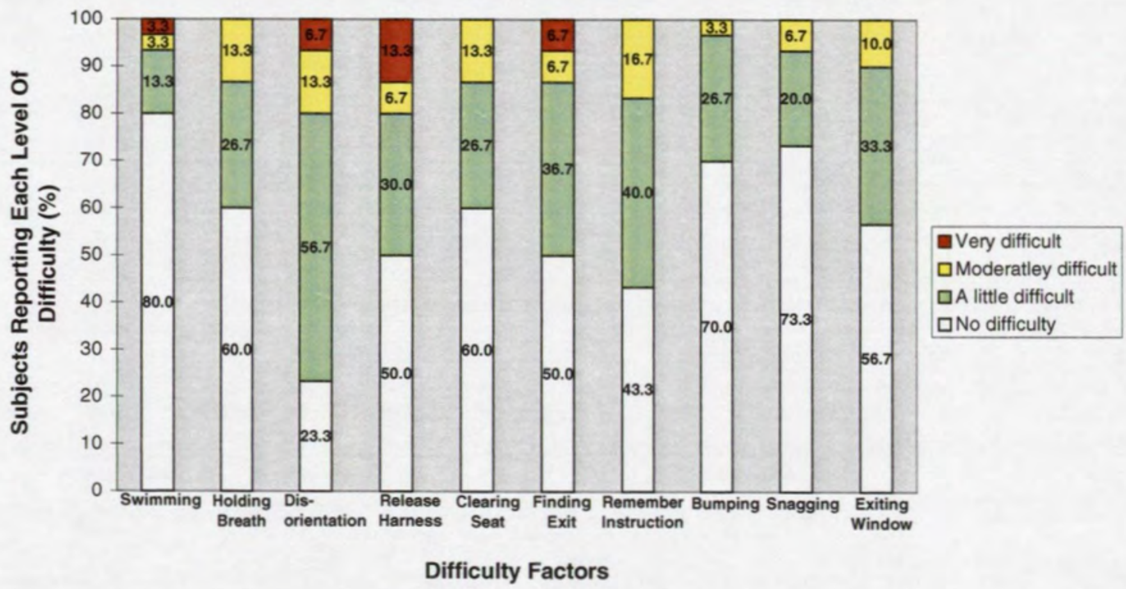


Figure 6 - : Subjects' rating of difficulty factors in the FULLY INVERTED reverse capsize

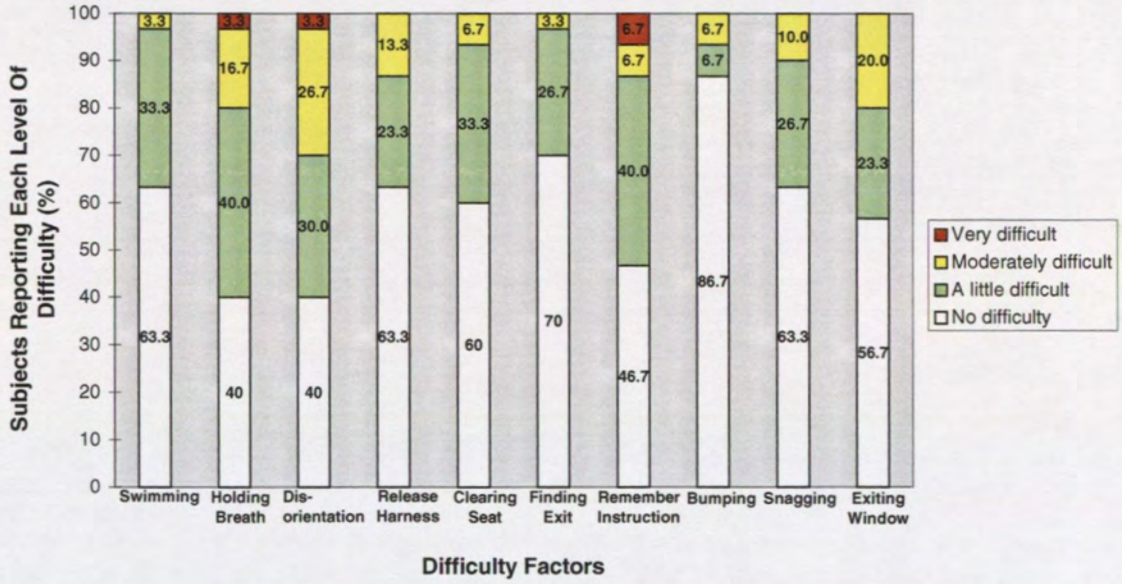
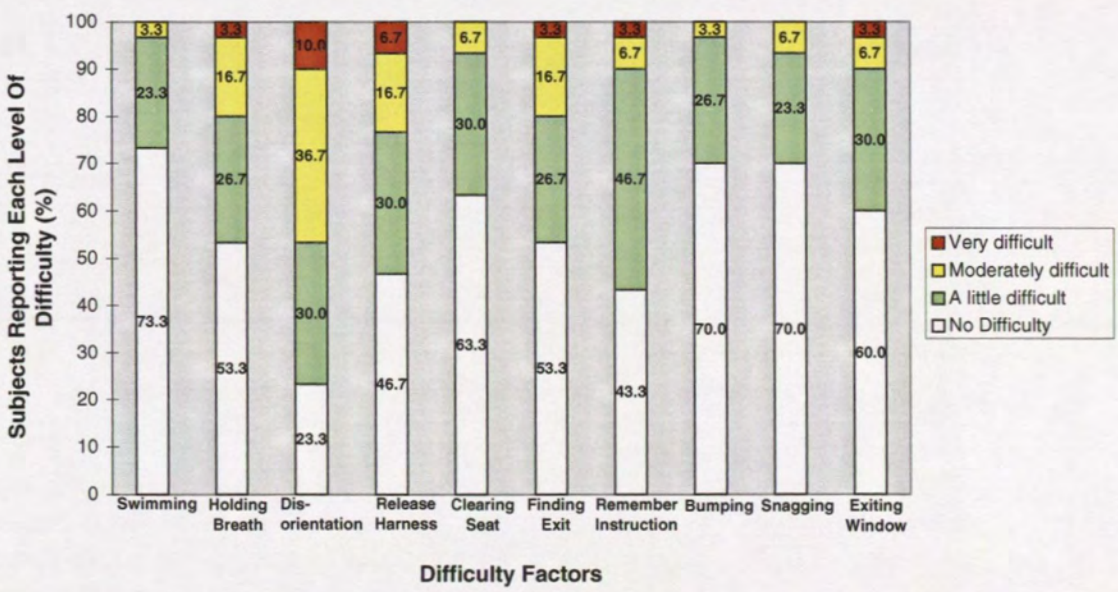


Figure 7 - : Subjects' rating of difficulty factors in the SIDE-FLOATING reverse capsize



3.2.3.5 Summary of results

Table 7 provides a summary of the significant differences which were found when statistical comparisons were made between the difficulty ratings for the corresponding fully inverted and side-floating capsizes.

Table 7 – Significant differences between difficulty ratings

Capsizes	Significant Differences	'P' Value
Cross-cabin	Fully inverted rated as overall more difficult than side-floating	0.0001
	Locating exit rated as being more difficult in fully inverted	0.0001
	Disorientation rated as causing more difficulty in fully inverted	0.005
	Exiting window rated as being more difficult in fully inverted	0.005
	Swimming rated as causing more difficulty in fully inverted	0.04
Same-side	Holding breath rated as being more difficult in fully inverted	0.04
Reverse	Locating exit rated as being more difficult in side-floating	0.03
	Releasing harness rated as being more difficult in side-floating	0.05

3.2.4 *Post trial evaluations*

When subjects were asked which trial they preferred in terms of ease of escape, 90% opted for the side-floating escape. This gives an indication of the lower levels of difficulty which subjects experienced during escape from the side-floating helicopter simulator compared to underwater escape.

Before the subjects had been through either trial they were asked how confident they were about helicopter transport. They were then asked how confident they were about helicopter transport after each trial. Table 8 shows that confidence in helicopter transport was almost exclusively moderate or high throughout the whole study period. The confidence level before the trials was compared to confidence after each trial and no significant differences were found. Confidence in helicopter transport after the fully inverted trial was then compared with confidence in helicopter transport after the side-floating trial and again there was no significant difference.

Table 8 – Subjects' confidence in helicopter transport

Level of confidence in helicopter transport	Before study	After fully inverted capsizes	After side-floating capsizes
High	37%	37%	30%
Moderate	63%	60%	70%
Low	0%	3%	0%
None	0%	0%	0%

As well as general confidence, subjects were asked specifically before each trial how confident they were about escaping from the helicopter simulator. Irrespective of which trial was undertaken first, there was no significant difference between the confidence levels before the trials.

After each trial, subjects were asked how satisfied they were with the way they had coped with the helicopter escape. Table 9 shows that subjects were more satisfied with their coping in the side-floating capsizes than they were in the fully inverted capsizes. In the side-floating trial, 96% of people were either satisfied or very satisfied with how they had coped. This compares to only 76% in the fully inverted trial, with 10% being undecided and 13% being dissatisfied with their coping in this trial. Statistical analysis showed that this difference was significant ($P = 0.019$).

Table 9 – Subjects' satisfaction with coping in the trials

Level of satisfaction with coping	Fully inverted capsizes	Side-floating capsizes
Very satisfied	23%	33%
Satisfied	53%	63%
Undecided	10%	0%
Dissatisfied	13%	3%

After each trial, subjects were also asked how much more confident they felt of coping with a real helicopter ditching compared to before the session. Table 10 shows that 46% of subjects felt much more confident of coping with a real ditching after the fully inverted trial compared to only 36% after the side-floating trial. It is speculated that this may reflect a greater feeling of achievement after the underwater escapes. Overall, a higher percentage reported improved confidence and a lower percentage had less confidence following the side-floating trial.

Table 10 – Subjects' confidence to cope with a real helicopter ditching after each trial

Confidence to cope with a real helicopter ditching	After fully inverted capsizes	After side-floating capsizes
Much more	46%	36%
More	23%	43%
About the same	16%	16%
Less	10%	3%
Much less	3%	0%

3.2.5 *Physiological correlates of stress*

3.2.5.1 Heart rate

Heart rate traces showed a large degree of noise. However, most traces showed peaks in heart rate as the subject swam across the pool, followed by a peak of similar amplitude which could be time matched to the period spent preparing for ditching and escaping from the helicopter simulator. Appendix 6 shows a typical heart rate trace.

Table 11 – Mean heart rates before, during and after the trials

Trial	Sampling period	Mean heart rate	Standard deviation
Fully inverted	Pre-trial / resting	71	10.2
Side-floating	Pre-trial / resting	73	10.7
Fully inverted	During partial submersion	120	23.8
Side-floating	During partial submersion	124	23.0
Fully inverted	During 1st capsize: sit/escape same-side	120	22.4
Side-floating	During 1st capsize: cross-cabin escape	122	17.1
Fully inverted	During 2nd capsize: reverse roll	121	19.3
Side-floating	During 2nd capsize: sit/escape same-side	122	18.1
Fully inverted	During 3rd capsize: cross-cabin escape	124	18.9
Side-floating	During 3rd capsize: reverse roll 210°	122	23.6
Fully inverted	Post-trial	91	13.7
Side-floating	Post-trial	87	15.3

Table 11 shows the average heart rates recorded before, during and after each trial. The average heart rate for each escape was calculated. It can be seen that there was very little difference between heart rate in each trial suggesting that the type of escape did not influence the level of heart rate.

Using statistical analysis, pre-trial heart rate was compared between the different age groups and no significant differences were found. Also, the average heart rates during the exercises were compared between trials and no significant differences were found. It can be concluded from this that the type of escape had no influence on the level of heart rate in these trials.

3.2.5.2 Cortisol

The average salivary cortisol values are shown in Table 12. A high degree of variability in cortisol levels was observed. Statistical analysis showed no significant differences either within or between trials. None of the values were significantly different from the average control value.

Table 12 – Mean salivary cortisol values

Trial	Sample	Mean cortisol value (nmol/litre)	Standard deviation
	Control	15.3	10.17
Fully inverted	Pre- trial	12.5	18.11
Fully inverted	Post-exercises	16.0	11.41
Side-floating	Pre-trial	15.3	26.44
Side-floating	Post-exercises	16.3	9.03

The average urinary cortisol, expressed as a ratio against creatinine concentration (see Harris, 1995 for rationale), recorded before each trial is shown in Table 13. It can be seen that the average values were similar before both trials. No significant differences were found between urinary cortisol values depending on either the escape procedure to be followed in the trial or which trial was undertaken first. Again, the variability was high for these values as suggested by the standard deviation.

Table 13 – Mean urinary cortisol values

Sample	Mean cortisol/creatinine (nmol/mmol)	Standard deviation
Pre fully inverted trial	105.78	58.3
Pre side-floating trial	110.05	60.5

3.2.6 **Psychological stress**

Table 14 shows the average state/trait anxiety inventory (STAI) scores which were recorded from these trials. It can be seen that anxiety levels were highest before each trial but had returned to around the control level immediately after completion of the exercises. Statistical analysis showed that the pre-trial anxiety ratings were significantly higher than post trial ratings (P = 0.0005 in each case) and were significantly higher than the control ratings (P = 0.0005 in each case). No significant difference was found when the anxiety in the standard trial was compared to anxiety in the side-floating trial.

Table 14 – Mean STAI scores

Time period	Mean trait score (standard deviation)	Mean state score (standard deviation)
Control	33 (6.6)	30 (7.2)
Pre- fully inverted exercises	-	39 (9.7)
Post- fully inverted exercises	-	31 (8.2)
Pre- side-floating exercises	-	41 (10.8)
Post- side-floating exercises	-	30 (8.6)

3.2.7 *Escape and submersion times*

Escape and submersion times were recorded for each trial. These were taken from video footage recorded from inside the helicopter simulator and from the pool-side.

Table 15 shows that mean escape times were much longer in the side-floating capsizes. This was due to the fact that subjects were able to use the air pocket inside the helicopter simulator and breath normally before assessing the situation and making their way to the outside. This extra time could be vital in allowing occupants of a capsized helicopter to orientate themselves and carry out the vital actions necessary to make an escape.

The average submersion time for each exercise is shown in Table 16. It should be noted that these calculated means only include times when the escape was achieved using the set down procedure. If subjects used the safety air pocket or wrong exit, or were unable to escape without assistance, then the submersion times from these escapes were not included in the mean. As a result, each average value can be firmly attached to a specific escape scenario. In a few cases, it was not possible to calculate the submersion time because underwater footage was not available.

Table 15 – Mean escape times from the trials

Exercise	Mean escape time (seconds)	Standard deviation	No. escapes included in calculation
Partial submersion	39.1	3.8	60
Fully inverted sit/escape same-side	15.0	3.1	29
Fully inverted reverse	13.7	2.9	30
Fully inverted cross-cabin	22.0	3.2	15
Side-floating sit/escape same-side	26.1	6.5	30
Side-floating reverse	24.6	5.3	30
Side-floating cross-cabin	27.7	5.1	30

Table 16 – Mean submersion times

Escape	Mean submersion time (seconds)	Standard deviation	No. escapes included in calculation
Partial submersion	12.1	3.0	53
Fully inverted sit/escape same-side	13.0	3.1	29
Fully inverted reverse	11.7	2.9	30
Fully inverted cross-cabin	20.0	3.2	15
Side-floating sit/escape same-side	9.4	2.1	26
Side-floating reverse	10.2	2.2	25
Side-floating cross-cabin	9.5	3.0	26

Table 16 shows that the mean submersion times for the side-floating exercises were shorter than those for the corresponding fully inverted capsizes. Statistical analysis showed that subjects' submersion time was significantly less in the side-floating cross-cabin and sit/escape same-side than in the equivalent fully inverted exercises ($P = 0.0001$ in both cases). The most striking difference was between the submersion times for the cross-cabin exercises. Nearly twice as many subjects successfully completed the side-floating cross-cabin escape and on average they had to hold their breath for only half as long. The large air pocket inside the side-floating helicopter simulator allowed shorter submersion times than was possible after the fully inverted capsizes, when a full underwater escape had to be completed on one breath.

3.3 **Discussion**

3.3.1 *Overall preference*

The vast majority of subjects (90%) indicated that they found the escapes from the side-floating helicopter simulator easier and that they preferred these to the escapes from the fully inverted helicopter simulator.

This overall preference was reported despite the fact that subjects were given the same briefing for each trial without bias. All 3 subjects who preferred the fully inverted escapes carried out this trial after the side-floating trial, so that an order and training effect could have influenced their decision. They were also among those who successfully completed the fully inverted cross-cabin exercise. It is possible that they preferred escape from the fully inverted capsizes due to a sense of achievement, feeling good after successfully completing all exercises. This may have outweighed any perceptions relating to ease of escape.

The overall preference for the partial 150° capsize was probably strengthened by the fact that subjects were significantly more satisfied with their coping in the side-floating trials. This difference came about despite subjects reporting difficulties in both trials and is perhaps an indication that, although subjects had a few problems in the side-floating helicopter such as with releasing the harness, they did not regard these as having a detrimental effect on their overall performance. The large air pocket and above water exits allowed them to cope better with these difficulties. This is important since building the confidence to cope is an important aim of helicopter underwater escape training (see Haywood, 1993). Problems during an underwater escape are much more likely to have serious consequences.

3.3.2 *Comparison of escape difficulty*

The reasons for subjects finding escape from the side-floating helicopter simulator easier than when it was fully inverted seem reasonably clear. Time spent underwater was much shorter, and subjects had time to assess the situation and plan their route out once they had reached the air pocket within the helicopter.

Disorientation and difficulty locating the exit were important factors, particularly in the fully inverted cross-cabin exercise. This escape required the most underwater swimming of any exercise. It seems that having the presence of mind to swim in the right direction across the cabin proved too much for many subjects. For those who did, their inherent buoyancy probably made the task harder. Greater disorientation was almost certainly caused by subjects having to look for an exit with which they had no direct contact, in poor visibility. This seemed to have a knock-on effect in that the exit was harder to find and, in the case of those who failed to complete this escape successfully, impossible to use. These findings are consistent with Ryack (1976 and 1986), Bohemier (1996), Brooks (1994), Rice and Greear (1973), and AAIB (1989); and are symptomatic of escape from a fully inverted helicopter.

This is in stark contrast to the situation in which subjects found themselves in the side-floating cross-cabin escape. They were able to come to the air pocket before proceeding and, as a result, the subsequent actions were found to be easier. It was demonstrated that a cross-cabin escape is much easier from a side-floating helicopter than from a fully inverted one. This is an important finding since such an escape may be necessary after a real capsize if the exit next to an individual is obstructed in any way. In the real situation, individuals sitting in central seats will also have a better chance of escape as they will not necessarily have to wait for those in outer seats to escape before they can themselves egress. Wherever seated, individuals must simply reach the air gap and take a breath, before assessing the best route out.

The only factor causing some concern in the side-floating helicopter was the release from the harness. Subjects were suspended from their seats when seated on the upper side of the helicopter, placing an uneven load on the harness and buckle. Whilst there was a tendency for the subjects to report greater difficulty in releasing the harness during side-floating capsizes, this only just reached significance in reverse capsize. The results suggest that the subjects did not themselves perceive harness release as a problem. This issue requires further work to investigate the best harness system for side-floating helicopters and ensure that escape will not be impaired by such potential problems. (N.B. It was observed from video footage that when seated on the upper side, subjects were able to get their head clear of the water without releasing the harness.)

Disorientation and finding the exit were slightly worse after the 210° roll, presumably due to the greater distance turned, but the consequences would be mitigated by the presence of the air gap and the shorter breath-hold time in the side-floating helicopter.

3.3.3 *Breath holding and escape times*

In general, breath holding was found to be less difficult in escapes from the side-floating helicopter simulator compared to when it was fully inverted. The cross-cabin exercises were looked at closely to assess breath-holding difficulty. It was hypothesised that those who failed the fully inverted cross-cabin escape would find breath holding easier in the side-floating equivalent. This was not the case but, instead, it was found that those who found breath-holding a problem did so in all circumstances. It can be concluded that those individuals who find breath holding difficult will experience greater benefit, and will have a greater chance of escape, from a side-floating helicopter with an air pocket, than from a fully inverted aircraft.

Further evidence for this comes from the fact that subjects spent less time with their head under the water in the side-floating exercises, despite the fact that they took longer to escape from the cabin. The time to escape was not related to difficulty in the side-floating situation. The extra time may be crucial in a real helicopter ditching, for example, in allowing an individual time to push out a window. This compares to the fully capsized helicopter where the window must be pushed out underwater whilst attempting to hold the breath.

The primary advantage of the side-floating helicopter is thus the air gap. Occupants need only remain underwater long enough to release their harness and surface within the helicopter cabin. In the current study the highest mean submersion time in any of the three side-floating exercises was 10.2 seconds. In a real incident, even in very cold water, this should be enough time for occupants to rise to the air pocket. They would then have time to orientate themselves before removing a door or window and making an escape, hopefully from an exit above the water surface.

The time available to escape in a real capsize will be greatly constrained by cold shock, which is a major factor affecting an individual's chances of survival if a helicopter should capsize in the North Sea, where water temperatures may be as low as 4°C in the winter. In water temperatures of 10°C, breath hold time can be as low as 10 seconds in some subjects (Tipton et al, 1995). When exercising underwater, average breath-hold time has been shown to be as little as 17 seconds (Tipton et al, 1995). For the majority of occupants to escape from a capsized helicopter, it is therefore desirable for them to be able to take a breath of air in a time of not much more than 10 seconds. Without breathing aids this may be very difficult since, in a real accident, an occupant may require more time than this to remove an exit. The side-floating configuration thus provides a means of limiting the consequences of cold shock .

3.3.4 *Stress*

No meaningful differences in the physical indicators of stress were found within or between the trials. Heart rates were significantly higher during the escape exercises compared to pre- and post-trial, but this rate was no higher than when subjects were swimming across the pool. No significant differences were found in either the salivary or urinary cortisol measurements. All but one of the average salivary cortisol values found in this study were slightly lower than a reference value of 14.3 ± 9.1 nmol/L taken from a study on 662 healthy adults (Kirschbaum and Hellhammer, 1989), although not markedly so.

A difference in psychological stress was found within the trials but not between trials. Pre-trial anxiety scores were significantly higher than corresponding post trial scores. The mean pre-trial scores of 39 and 41 were very similar to previous averages observed by Harris et al (1996) of 38.5 and 42.26 among groups of a similar size before HUET training. Indeed, the subjects in this study seem to have a relatively low level of anxiety which is suggested by a mean control score of 30 compared to a mean value of 35 which Spielberger et al (1983) recorded from over 1300 American working males.

It might have been expected that there would be less measurable stress in the side-floating trial, but stress is largely associated with perceived difficulty and problems prior to an event. As pre-conceptions were likely to be the same before each trial it is perhaps not surprising that similar pre-trial levels of stress were observed. Post trial evaluations clearly showed differences in perceived levels of difficulty in the trials, even though this did not influence the measured levels of stress.

3.3.5 *Confidence*

It is fair to say that the confidence levels which were elicited in this study were not greatly affected by either of the trials. Subjects' confidence about escaping was, on average, moderate to high before each trial irrespective of the order in which they were undertaken. Their confidence in helicopter transport was at similar levels and had not significantly deviated from this after either trial.

Confidence to cope with a real helicopter ditching showed a greater overall improvement following the side-floating capsizes compared to the fully inverted capsizes, suggesting a greater perception of benefit and chance of successful escape if a helicopter comes to rest on its side.

Responses following the fully inverted capsizes were more extreme, with more subjects who were 'much more' confident, but also more subjects who were 'less' or 'much less' confident. This can be attributed to people's performance in the fully inverted, underwater cross-cabin capsize. If people were successful in this escape this probably gave them a boost of confidence, whereas if they failed the opposite would happen. Overall, the side-floating scenario was better for the confidence of a greater number of people.

Although using naïve subjects helped to more accurately assess the merits of escape from a side-floating helicopter, it should be recognised that the a certain amount of self-selection will have taken place. This is demonstrated by the fact that the majority of subjects rated themselves as being moderately fit, good swimmers and confident about helicopter transport. In addition, when subjects were asked to rate their level of worry about what might affect their escape in the trials, the majority were either not worried or only a little worried about the 10 potential difficulties. These results suggest that the subjects in this study were fairly confident and self-assured people. This may not be representative of the offshore population.

3.3.6 *Problems of escape from a side-floating helicopter*

Whilst the benefits of escape from a side-floating helicopter were clear, the 150° flotation angle did cause some concerns.

Some problems were observed when subjects tried to release the harness buckle under an uneven load, requiring the application of more force to open it. This was observed when subjects were suspended mostly out of the water on the upper side of the helicopter simulator after capsize. In two cases, subjects were completely unable to release the harness without the assistance of the Training Officer. This problem is not specific to the side-floating situation, with similar problems occasionally being encountered during standard training in the inverted helicopter simulator. Given the uneven loading on the harness, and the higher incidence of problems, it is suggested that further investigation is needed in this area. It is expected that the harness system could be modified relatively easily to remove this problem.

A second concern related to the risk of injury from passengers in upper seats falling down into the air gap with some force. Occupants on the opposite side of the cabin were mostly underwater, and had to surface up into the air gap. Risk analysis suggested a high risk of injury to those surfacing from the lower side of a helicopter from individuals on the upper side falling on top of them. While this is a potential problem for trials and training, it is not seen as a life threatening problem in the real situation. It must be considered that in a real capsize there is probably a similar risk even if the helicopter comes to rest fully inverted. At any capsize angle, it is likely that some occupants may have released their harness before the capsize which would put them in danger of colliding with others. There is also likely to be as much flailing of limbs in the aftermath of a capsize irrespective of the final resting angle of the helicopter. This being the case, the benefits of the air gap in a side-floating helicopter are felt to be greater than the disadvantage of people falling onto each other.

3.3.7 *Wave action*

The procedure which was developed for escape from a window above the water surface took into account the possible action of waves acting against the helicopter (given that capsize is more likely in high sea states). Further work is needed to determine the possible effects of wave action on a capsized helicopter, and any specific issues relating to a side-floating position.

It is likely that individuals will have a greater chance of locating, opening and using exits above the water, as it is well documented that these actions are much more difficult if exits are underwater (see Brooks, 1994).

3.3.8 *Life-raft deployment*

Life-raft deployment has not been included within the remit of this study. Further work would be needed to determine the advantages or disadvantages of deployment from a side-floating helicopter.

4 CONCLUSIONS

4.1 Overall preference

It can be concluded that the vast majority of subjects in this study found it easier to escape from a side-floating helicopter simulator than from a fully inverted one without finding it any more stressful. In the side-floating trial, more subjects were satisfied with how they coped and more were instilled with greater confidence in their ability to deal with a real helicopter ditching. These findings suggest there could be significant benefit in training people to escape from helicopters which were designed to float on their side after capsize.

4.2 Ease of escape

The results of this study indicate why subjects found the side-floating trial easier than the fully inverted one. The provision of an air-pocket and exits above the water were important factors in making escape easier. The air-pocket in particular helped to mitigate the consequences of disorientation and meant that subjects did not need to hold their breath for so long. This latter point is important considering that, in a real helicopter accident, occupants may have to overcome the effects of cold shock which has been shown to reduce breath hold time to as little as 10 seconds. The additional air pocket reduced the required breath-hold time by up to 50% compared to that required for escape from a fully inverted helicopter simulator. This difference may be even greater in a real capsize incident, where additional barriers to underwater escape may be present. This one factor could save a significant number of lives if side-floating buoyancy systems were introduced.

4.3 Above-water exits

The task of locating an exit should be easier in a side-floating helicopter due to the likelihood that exits will be above the water on one side of the aircraft. This means that occupants will be less hampered in their attempts to reach and jettison an exit by poor visibility and their inherent buoyancy. Even if subjects are slowed by initial disorientation or are struggling to open an escape route, the presence of an air pocket will provide them with extra time in which to make their escape.

Problems with liferaft deployment have previously been described. Given the different orientation following capsize, consideration needs to be given to the deployment of liferafts by individuals escaping from a side-floating helicopter.

4.4 Harness release

There were only two problems with escape from the side-floating helicopter simulator which caused some concern. The most serious problem identified was the potential for an occupant on the upper side to release their harness and fall with force onto someone rising to the air pocket from the lower side. This would not be seen as a major hazard in a real helicopter accident. Injuries are possible in any capsize, particularly if the harness has already been released prior to the capsize. The higher risk of injury during training does, however, require some attention.

The release of the harness caused some difficulty, possibly due to the uneven load on the buckle. Further investigation relating to harness release is needed.

4.5 Overall benefits

None of the problems with escape from a side-floating helicopter which were identified in this study are thought to be life-threatening. They do not outweigh the advantages that such a scenario has over escape from a fully inverted aircraft. On the contrary, the evidence suggests that the occupant of a side-floating helicopter has a much better chance of escape and survival than someone inside a fully inverted aircraft.

5 RECOMMENDATIONS

5.1 Flotation systems on helicopters should be improved by the incorporation of means to achieve a side-floating attitude in order to improve the chances of survival of the occupants in the event of a ditching and capsize.

5.2 The flotation system should be designed so that the cabin floats with the top of the inverted exits at water level, thereby ensuring ease of escape.

5.3 The carriage and release of liferafts from a side-floating helicopter needs further assessment.

5.4 More work is required in order to make firm conclusions about the effects of an uneven load on a 4-point harness buckle.

5.5 The provision of a hand-hold next to emergency exits would assist in the location of the exit and provide a leverage or reaction point for anyone trying to operate a push-out window.

5.6 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.

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Appendix 1 Review of helicopter accidents

1 REPORT ON THE ACCIDENT TO SIKORSKY S.61N HELICOPTER G-BBHN IN THE NORTH SEA, NORTH EAST OF ABERDEEN, ON 1 OCTOBER 1977 (AIB, 1978)

The accident occurred when the helicopter made an emergency landing in very rough seas, due to a technical problem. It capsized almost immediately after touchdown. All three occupants were rescued after 53 minutes immersion, uninjured but suffering from the effects of exposure.

Following the capsize the co-pilot experienced difficulty moving the stowed life-raft towards the cargo door as, with the aircraft inverted, the cabin floorboards had become detached and the baggage compartment doors were hanging down. With the water level rising he instead concentrated on opening the cargo door which he was unable to do at first due to the water pressure on the outside. The commander, who had meanwhile left the flight deck through the starboard sliding window, proceeded to the side of the upturned hull and assisted the co-pilot to prize the door open wide enough so that the two occupants could escape. Since there was no way of restraining the cargo door once it was open, it kept sliding shut under the action of the waves and the pitching hull. The co-pilot and passenger were neck deep in water with little breathing space overhead before they were able to leave the cabin.

2 REPORT ON THE ACCIDENT TO BELL 212 G-BIJF IN THE NORTH SEA, SOUTH EAST OF THE DUNLIN ALPHA PLATFORM, ON 12 AUGUST 1981 (AIB, 1982)

The accident occurred during a daytime flight between the Brent Field and the Dunlin platform. The commander had decided to return to the Brent Field after encountering an area of reduced visibility. During the turn, control of the helicopter was lost resulting in descent, collision with the sea and then rapid capsize. The single fatality and 13 survivors were retrieved by another helicopter and a rig support vessel after some 44 minutes.

Normal access to the passenger cabin was via very large sliding doors on each side of the cabin which, when open, provided access to almost the whole length of the cabin space. These doors are vulnerable to jamming in an accident and so emergency exits were provided in the form of four large windows, two in each door. The windows, by virtue of their size and ease of removal in emergency, were significantly superior to emergency exits commonly found in helicopters. Twelve of the thirteen passengers were able to use the exits effectively to achieve a relatively swift escape to the sea. The remaining passenger had considerable difficulty in freeing himself from his safety belt. This passenger never managed to unfasten the belt but extended it enough so that he could wriggle free. Clearly this effort took its toll and the man was unable to help himself on egress from the helicopter. Eventually fatigue prevented the other passengers from supporting the man who drifted away from the upturned wreck of the helicopter and drowned. Subsequent examination of the safety buckle in question showed it to be in working order.

3 **REPORT ON THE ACCIDENT TO BOEING VERTOL (BV) 234 LR G-BISO, IN THE EAST SHETLAND BASIN OF THE NORTH SEA, ON 2 MAY 1984 (AIB, 1987)**

The aircraft was engaged on a flight from the Magnus Field to Aberdeen carrying a full load of 44 passengers, one cabin attendant and two flight deck crew. Two separate flying control system malfunctions produced intermittent loss of collective control. Following a successful landing on water, the crew proceeded to water taxi towards the nearest rig. When the aircraft was found to be taking on water and sinking, an evacuation of the passengers commenced, followed by the crew. All crew and passengers were rescued, without injury.

The report concluded that, for this type of helicopter, there was no great difficulty in achieving a successful escape of a full passenger load through the designated exits, following a controlled ditching in which the aircraft remains upright on the water.

4 **BULLETIN ON THE ACCIDENT TO BOLKOW BO 105D G-AZOM, 5½ NM DUE EAST OF SKEGNESS, LINCOLNSHIRE, ON 24 JULY 1984 (AIB, 1985)**

The purpose of the flight was to ferry two charter passengers from Lincolnshire to Norfolk. When the aircraft was about 5nm off the coast of Skegness the commander heard a dull bang which caused him to descend and turn towards Skegness. During the descent he felt further vibrations and so decided to alight on the sea. As power was applied to arrest the rate of descent, all yaw control was lost and the helicopter performed two or three 360° turns before hitting the water.

As a result of rotating into the surface of the sea, one of the four floats detached and the aircraft immediately rolled onto its right side. The aircraft was now lying on its right side with the detached flotation bag beneath the commander's door, holding it closed. However, one of the passengers had acquainted himself with the jettison mechanism of his door and acted swiftly to make this the most convenient egress from the aircraft. The evacuation was accomplished in less than 30 seconds. Very shortly after that the aircraft capsized.

5 **REPORT ON THE ACCIDENT TO BELL 214 ST G-BKFN, IN THE NORTH SEA 14 MILES NORTH EAST OF FRASERBURGH, SCOTLAND, ON 15 MAY 1986 (AAIB, 1987)**

The accident occurred during a flight from Sumburgh to Aberdeen. A technical failure caused a partial loss of collective control which forced the helicopter to ditch. The crew and passengers were able to evacuate safely and were picked up by a fishing vessel.

The commander was forced to operate his emergency exit manually since the automatic jettison mechanism had seized, although this did not hinder his escape. Similarly the life-raft deployment had to be undertaken manually since the crew actuation handle was ineffective due to a technical failure of the aircraft.

Two human factors problems were experienced. Firstly, the secondary escape windows proved resistant when attempts were made to dislodge them, forcing the passengers to proceed to the primary escape windows to make their escape. Secondly, one of the passengers entered the sea inadvertently as a result of slipping off the flotation bag, and subsequently drifted towards the still turning tail rotor. The AAIB report suggests that the addition of a non-slip surface to the float bag material could have prevented the exposure of the passenger to this hazard.

6 REPORT ON THE ACCIDENT TO AEROSPATIALE AS 332L SUPER PUMA G-BKZH, 35 NM EAST-NORTH-EAST OF UNST, SHETLAND ISLES, ON 20 MAY 1987 (AAIB, 1988)

Although the above accident did not involve a helicopter having to land on water, it was included in this review since the aircraft involved was a Super Puma and underwater escape issues were considered.

The aircraft was in transit between Sumburgh and the East Shetland Basin when it suddenly began to vibrate severely. The crew managed to keep the aircraft under control and assessed the source of the vibration to be the tail rotor. They decided that the aircraft was controllable at reduced power and elected to go to Unst to make a 'run on' landing. This was accomplished successfully and the passengers and crew disembarked without any injuries.

The wind and sea-state appear to have been within the tested parameters for flotation, but the sea state was outside that demonstrated by scale models for a water landing. The crew believed that it was probable that the helicopter would capsize during a ditching with consequent severe egress problems for the passengers. Furthermore they were aware that the Super Puma cabin doors could not be jettisoned when the aircraft was inverted. Although the normal mode of opening the doors was theoretically available when the aircraft was inverted, experience from other ditching accidents had shown that the ensuing disorientation of occupants who find themselves inverted and submerged, escalates the difficulty of performing even the most simple of tasks. The AAIB report recommended that the lack of a facility to jettison the cabin doors on this type of aircraft in an inverted position should be reviewed.

7 REPORT ON THE ACCIDENT TO SIKORSKY S-61N G-BEID, 29NM NORTH EAST OF SUMBURGH, SHETLAND ISLES, ON 13 JULY 1988 (AAIB, 1990A)

Whilst operating a passenger flight from a North Sea rig to Sumburgh, a mechanical failure caused fire in both of the aircraft's engines. A controlled ditching was carried out onto an almost calm sea. By this time the cabin had filled with smoke. All 21 occupants evacuated successfully into life-rafts and were winched into a search and rescue helicopter. Much of the helicopter was consumed by fire which eventually broke up and sank.

The escape of several passengers appeared to have been slowed because neither of the crew initiated the automatic unlatching control for the rear life-hatch. As a result, the passengers were required to unlatch the life-hatch manually which they had difficulty with, probably due to the cabin being full of noxious thick smoke. The passengers had time to complete the operation and evacuate before being incapacitated. Had the passengers had less time to act it is probable that the factors which slowed escape may have reduced their chances of survival.

The AAIB report recommended that crew and passengers be provided with accessible means of respiratory and eye protection from the effects of smoke arising from an on-board fire. Also, that S-61N checklists include an instruction to arm the life-hatch unlatching circuit in a ditching or forced landing situation. Appropriate action was taken on life-hatch systems. The CAA agreed to review the case for smoke hoods once products which satisfy the Authority's specification have been developed.

8 REPORT ON THE ACCIDENT TO THE SIKORSKY S61N HELICOPTER G-BDII, NEAR HANDA ISLAND OFF THE NORTH-WEST COAST OF SCOTLAND, ON 17 OCTOBER 1988 (AAIB, 1989)

The accident occurred during a search and rescue (SAR) mission centred off the coast of Scotland. The SAR crew were called out from Stornoway to conduct a SAR flight for the two occupants of a small fishing boat, which had capsized somewhere in the area of Handa Island. Towards the end of the search while performing a hover manoeuvre, a crew member noticed that the aircraft was travelling backwards very fast. The commander was unable to arrest the situation, the aircraft struck the sea and immediately rolled over. All four crew members were able to escape and board the life-raft and were later rescued by a second SAR helicopter.

The commander, co-pilot and winch operator all managed to escape to the sea after the helicopter ditched, although the winch operator was considerably hampered by the inrush of water through the open starboard cargo door. The winch-man, who had been sitting halfway down the fuselage, was washed by a succession of waves coming from the open forward exits towards the rear of the aircraft. He was eventually trapped in a small air pocket in the extreme tail section of the inverted aircraft. His attempts to reach one of the jettison mechanisms for the rear port emergency exit were frustrated by his own natural buoyancy and the small amount of air trapped in his immersion suit. After being trapped for some 15 minutes, and on the point of losing his will to survive, the winch-man was eventually rescued by the commander who opened the rear port door from the outside upon realising the winch-man was trapped.

The report states that it is recorded that most uncontrolled ditchings of helicopters, in other than ideal conditions, have resulted in a capsize. It is therefore concluded that emergency exit jettison mechanisms, whether on doors or hatches, should be as accessible when an aircraft is inverted as they are when it is upright.

9 REPORT ON THE ACCIDENT TO SIKORSKY S61N G-BDES, IN THE NORTH SEA, 90 NM NORTH EAST OF ABERDEEN, ON 10 NOVEMBER 1988 (AAIB, 1990B)

The aircraft was tasked on a non-scheduled service from Aberdeen to three oil installations in the North Sea. On the return flight the crew and passengers became aware of an unusual buzzing noise followed by increasing vibration. The commander attempted to reach a suitably equipped platform to land but was forced to execute an immediate ditching. The aircraft capsized almost immediately. The crew and passengers managed to evacuate the aircraft and were rescued without serious injury.

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 edges of the opening were not smooth and presented several projections which could snag 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.

10 REPORT ON THE ACCIDENT TO SIKORSKY S61N G-BEWL, AT BRENT SPAR, EAST SHETLAND BASIN, ON 25 JULY 1990 (AAIB, 1991)

The accident occurred whilst the helicopter was manoeuvring to land on the Brent Spar semi-submersible offshore storage and tanker loading unit. After the helicopter had approached to a hovering position above the helideck, witnesses realised it was positioned dangerously close to a part of the installation's crane structure. 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 were rescued from the sea having escaped from the rapidly sinking helicopter. Six occupants including the crew perished.

Evidence of the surviving passengers indicated that, following the impact with the sea, 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 clearly 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, may have been a direct cause of death, and would certainly have hampered egress. The AAIB report recommended that seat requirements should be reviewed and newly manufactured aircraft should have an effective upper torso restraint installed. The CAA response (CAA, 1991) was to agree with this recommendation in principal and state that such a requirement was in a draft Joint Operational Requirement (European) which was to come into effect soon after September 1992.

11 REPORT ON THE ACCIDENT TO AS 332L SUPER PUMA, G-TIGH, NEAR THE CORMORANT 'A' PLATFORM, EAST SHETLAND BASIN, ON 14 MARCH 1992 (AAIB, 1993)

The accident occurred at night, in severe weather conditions, during a shuttle of personnel from an oil production platform to a nearby accommodation 'flotel'. Having left the platform helideck and turning towards the flotel the commander reduced power and raised the nose of the helicopter such that the airspeed reduced to zero and a rate of descent built up. Once the pilot was aware of the descent it was too late for him to avert a collision with the sea. The helicopter rolled onto it's right side before capsizing and sinking within a minute or two. All but five of the 17 occupants managed to escape from the helicopter before it sank. Of the twelve survivors in the sea, only six were recovered alive; the others perished in the hostile sea environment.

The commander escaped from the aircraft via the right flight deck door window and emerged close to the co-pilot whose method of egress could not be established. Water ingress into the cabin was rapid and although the survivors seated to the rear reported that they had time to take a deep breath, those at the front did not. This was probably a limiting factor for four of the five who did not exit the helicopter although not physically impeded or incapacitated. The predicted breath holding time in the conditions prevailing was stated to be less than 20 seconds. In addition, once the fuselage inverted, it was thought that those still in it would have had to overcome the extra buoyancy provided by air in their survival suits to be able to reach an exit. One of the passengers who did not manage to exit the helicopter appeared to have been impeded in his attempt to escape by the cord from his acoustic headset which had wrapped around his neck without disconnecting.

It was possible to establish that 6 of the 10 passengers who escaped to the sea had done so with little difficulty via an emergency exit window. Five of these individuals survived the accident. It was not possible to determine the escape routes of the other four passengers.

The AAIB report suggested that the cabin doors of a Super Puma should be able to jettison in an emergency, at any aircraft attitude, in order to aid egress. Also, that the whole question of survival must be assessed in the light of a complete system such that safety deficiencies should not be viewed independently. For example, predicted survival times based on the performance of a survival suit must take into account the ability of an individual to escape from an inverted helicopter cabin which may depend upon such factors as the effectiveness of emergency lighting and the operability of emergency exits.

12 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 (AAIB, 1997)

The helicopter was conducting a charter flight from Aberdeen to the Brae oil field. The helicopter was struck by lightning which resulted in severe vibration and caused loss of tail rotor control, necessitating an immediate ditching in heavy seas. The ditching was executed successfully and the helicopter remained upright enabling the passengers and crew to board a heliraft from which they were subsequently rescued without injury. Despite 6 to 7 metre waves and a 30 knot southerly wind, the helicopter remained afloat for some three hours and thirty minutes.

After ditching, the crew released their cockpit doors and the commander operated the flight deck jettison handle for the right cabin door. The passengers had prepared for evacuation by pushing out most of the windows and releasing and deploying the life-rafts. Passengers on the left side of the aircraft were having difficulty since the heliraft was blowing up against the open door on this side, making boarding very difficult. The decision was therefore made for everyone to board the heliraft on the right side of the helicopter.

A feature which had the potential to affect egress in this accident concerned the ejection of the cabin doors. The fact that the aircraft was rolling in the sea seemed to have contributed to the doors not being able to eject cleanly. This is thought to be because when such doors are jettisoned in rough sea conditions with the aircraft rolling through a large angle, the inherent buoyancy of the doors can prevent them from falling vertically, thus preventing the upper rollers from disengaging freely from the locating rails. In this event the upper locating arms will fail and their fractured ends become a potential hazard if the door floats in the region of the heliraft.

In this accident it seemed likely that a sharp end from the starboard door punctured the lower buoyancy chamber of the heliraft which was used. It was recommended that the CAA survey jettisonable doors to determine if they are initially buoyant on jettison and, if so, to inspect the doors for dangerous projections. This was duly undertaken by the Authority in consultation with the relevant manufacturers to determine relevant action.

As well as damaging safety equipment, it seems that this shortcoming of door ejection may hamper egress or cause physical harm in a worst case scenario. This problem with the door jettison of a Super Puma had been noted in other air accident reports (AAIB 9/88 and AAIB 2/93). The AAIB report in this case recommended that the manufacturers of this type of aircraft should review the failure modes of the cabin door upper guide roller mounting arms which can occur during door jettison in rough sea conditions, and take action to prevent such mounting arm failures.

Appendix 2 Witness report

Date of interview: **18.2.99**
Interviewer: **Dr Susan Coleshaw**

Statement

The accident took place in 1964, during daylight hours, in calm conditions, in the Indian Ocean.

I was employed by the Royal Navy acting as a winch-man performing search and rescue duties. The helicopter being flown was a single engine Westland Whirlwind Mk 7. We were standing close in by an aircraft carrier while fixed-wing aircraft were taking off and landing, providing safety cover.

The engine failed, at a height of about 120 feet. On contact with the water, the emergency procedure followed by the pilot was to push the stick hard over to the left, to ditch the helicopter onto it's port side. This was achieved, the helicopter hitting the water with the starboard side up. The open main exit door was located on the starboard side.

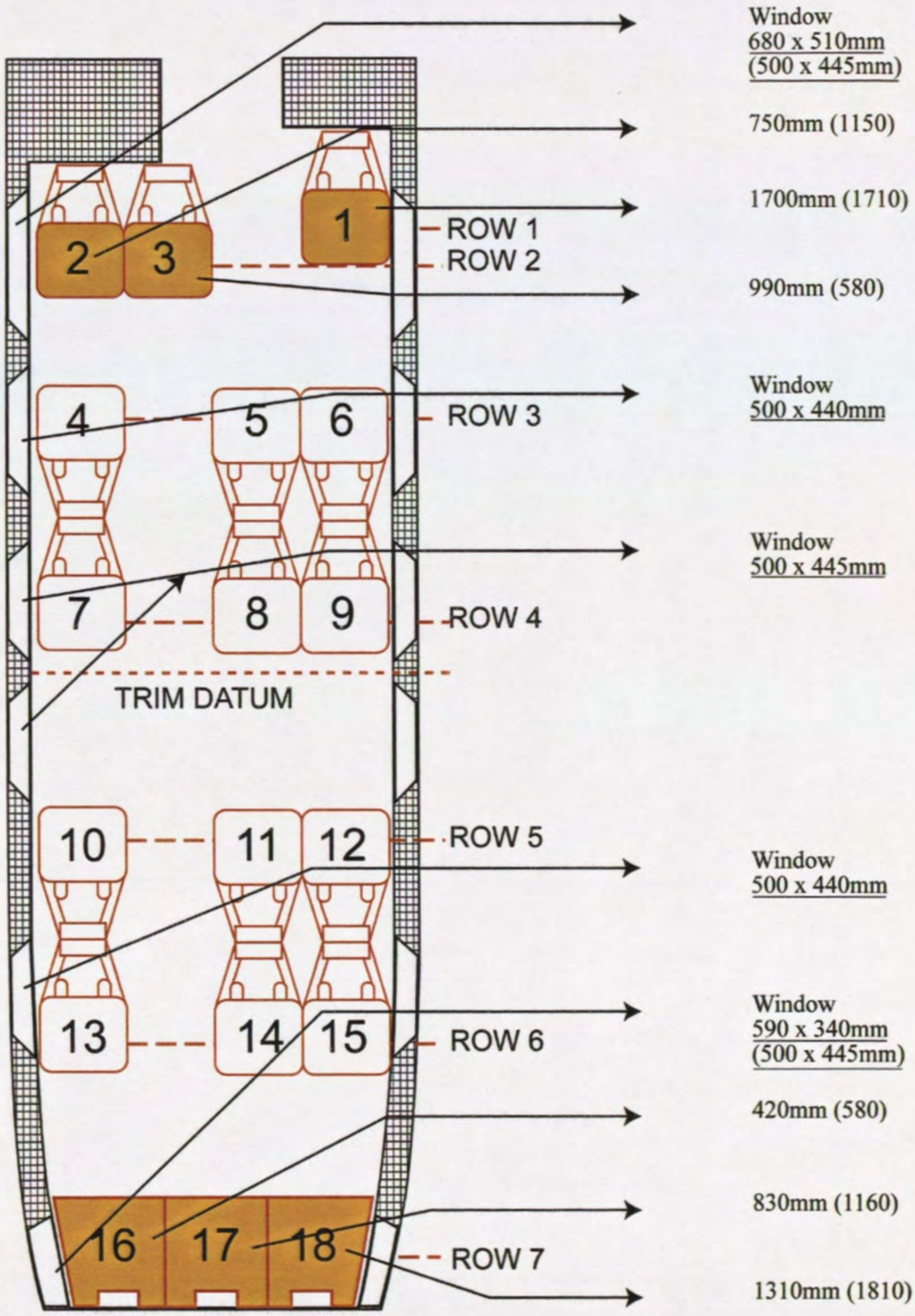
At the time of the incident I had been sitting in the open exit, with my feet on the step outside the aircraft. I found myself looking up at the sky, while hanging onto the rail at the top of the exit. As the helicopter sank, the water came up to support me. I took my feet back down into the cabin and was then able to swim out as the helicopter sank. I would estimate that it took 10 to 20 seconds from the time of hitting the water to the helicopter sinking.

There were three crew on board, including myself. The pilot was able to successfully escape through the starboard cabin window exit. The third crew member also escaped using the same procedure as myself.

The accident was filmed by personnel on the aircraft carrier (possibly held in MoD film archives). The footage showed that when the helicopter hit the water, the blades on striking the water, went around twice before stopping and in the process appeared to flex and curl upwards without breaking.

Appendix 3 Cabin configuration of Super Puma

Super Puma window dimensions and distances from seat centres to **port** windows measured at Bristows 23/11/98. **Shaded seats marked in orange indicate seats in Dunker, with dunker dimensions and distances in brackets.**



Appendix 4 View inside helicopter simulator at 150°

Appendix 5 Questionnaires

HELICOPTER ESCAPE RESEARCH

SUBJECT QUESTIONNAIRE

Subject Number ______________________

Trial Reference ______________________

Date ______________________

Instructions For Completing The Questionnaire

You will be given two separate parts of this questionnaire. Part One will be given to you *before* you take part in the helicopter escape. It will start with some background questions before asking about your feelings directly before these trials. Part Two is to be completed *after* you return from the pool session and will ask you how you felt during and after the ditchings. You should answer ALL the questions by ticking the appropriate box and writing comments in the spaces provided. Please record both positive and negative comments in as much detail as possible since this feedback is very important to our results.

PART ONE
Background Details

Question 1
How would you rate your physical fitness?

Very fit ☐ Moderately fit ☐ Marginally fit ☐ Unfit ☐

Question 2
How would you rate your swimming ability?

Very good ☐ Moderately good ☐ Basic ☐ Non-swimmer ☐

Question 3
Do you have any previous knowledge of helicopter underwater escape?

YES ☐ NO ☐

If YES please give details

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Question 4
How much confidence do you have in helicopter transport?

High confidence ☐ Moderate confidence ☐ Low confidence ☐ No confidence ☐

Feelings Before Helicopter Escape

Question 5
How much confidence do you have in your ability to escape after the capsizes in this trial?

High confidence ☐ Moderate confidence ☐ Low confidence ☐ No confidence ☐

Question 6

Using the following table, please indicate how worried you are about how the factors in the first column of the table might affect your escape, by placing a tick in the appropriate box.

	Very worried	Moderately worried	A little worried	Not worried
Swimming	☐	☐	☐	☐
Holding breath	☐	☐	☐	☐
Disorientation	☐	☐	☐	☐
Releasing harness	☐	☐	☐	☐
Getting clear of seat	☐	☐	☐	☐
Locating exit	☐	☐	☐	☐
Remembering instructions	☐	☐	☐	☐
Bumping part of the body	☐	☐	☐	☐
Getting snagged	☐	☐	☐	☐
Exiting through window	☐	☐	☐	☐

Any other comments:

PART TWO
Feelings During and After Helicopter Escape

Subject number ________________ Trial reference ________________

Question 7
How difficult did you find the first capsize, which was the 180° roll with your seat coming to rest on the lower side (underwater), followed by escape from an upper window?

Very difficult ☐ Moderately difficult ☐ A little difficult ☐ No difficulty ☐

Question 8
For the first capsize, could you please rate the factors in the first column of the table below in terms of how difficult they made the escape, by placing a tick in the appropriate box.

	Very difficult	Moderately difficult	A little difficult	No difficulty
Swimming	☐	☐	☐	☐
Holding breath	☐	☐	☐	☐
Disorientation	☐	☐	☐	☐
Releasing harness	☐	☐	☐	☐
Getting clear of seat	☐	☐	☐	☐
Locating exit	☐	☐	☐	☐
Remembering instructions	☐	☐	☐	☐
Bumping part of the body	☐	☐	☐	☐
Getting snagged	☐	☐	☐	☐
Exiting through window	☐	☐	☐	☐

Any other comments:

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Question 9

How difficult did you find the second capsize, which was the 180^0 roll with your seat coming to rest on the upper side (mostly out of water), followed by escape from an upper window?

Very difficult ☐ Moderately difficult ☐ A little difficult ☐ No difficulty ☐

Question 10

For the second capsize, could you please rate the factors in the first column of the table below in terms of how difficult they made the escape, by placing a tick in the appropriate box.

	Very difficult	Moderately difficult	A little difficult	No difficulty
Swimming	☐	☐	☐	☐
Holding breath	☐	☐	☐	☐
Disorientation	☐	☐	☐	☐
Releasing harness	☐	☐	☐	☐
Getting clear of seat	☐	☐	☐	☐
Locating exit	☐	☐	☐	☐
Remembering instructions	☐	☐	☐	☐
Bumping part of the body	☐	☐	☐	☐
Getting snagged	☐	☐	☐	☐
Exiting through window	☐	☐	☐	☐

Any other comments:

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Question 11

How difficult did you find the third capsize, which was the 180° roll with your seat coming to rest on the upper side (mostly out of water), followed by escape from an upper window?

Very difficult ☐ Moderately difficult ☐ A little difficult ☐ No difficulty ☐

Question 12

For the third capsize, could you please rate the factors in the first column of the table below in terms of how difficult they made the escape, by placing a tick in the appropriate box.

	Very difficult	Moderately difficult	A little difficult	No difficulty
Swimming	☐	☐	☐	☐
Holding breath	☐	☐	☐	☐
Disorientation	☐	☐	☐	☐
Releasing harness	☐	☐	☐	☐
Getting clear of seat	☐	☐	☐	☐
Locating exit	☐	☐	☐	☐
Remembering instructions	☐	☐	☐	☐
Bumping part of the body	☐	☐	☐	☐
Getting snagged	☐	☐	☐	☐
Exiting through window	☐	☐	☐	☐

Any other comments:

Question 13
How satisfied are you with the way you coped with the helicopter underwater escape training in this session?

Very satisfied ☐ Satisfied ☐ Undecided ☐ Dissatisfied ☐

Question 14
How much confidence do you now have in helicopter transport?

High confidence ☐ Moderate confidence ☐ Low confidence ☐ No confidence

Question 15
How much more confident do you now feel of coping with a real helicopter ditching than you did prior to this session?

Much more ☐ More ☐ About the same ☐ Less ☐ Much less ☐

You have now completed the questionnaire
THANK YOU FOR YOUR HELP

HELICOPTER ESCAPE RESEARCH

SUBJECT QUESTIONNAIRE

Subject Number ______________________

Trial Reference ______________________

Date ______________________

Instructions For Completing The Questionnaire
You will be given two separate parts of this questionnaire. Part One will be given to you *before* you take part in the helicopter escape and will ask you questions about your feelings directly before these trials. Part Two is to be completed *after* you return from the pool session and will ask you how you felt during and after the ditchings. You should answer ALL the questions by ticking the appropriate box and writing comments in the spaces provided. We ask that you record as much detail as possible since your opinions are very important to our results.

PART ONE
Feelings Before Helicopter Escape

Question 1

How much confidence do you have in your ability to escape after the capsizes in this trial?

High confidence ☐ Moderate confidence ☐ Low confidence ☐ No confidence ☐

Question 2

Using the following table, please indicate how worried you are about how the factors in the first column of the table might affect your escape, by placing a tick in the appropriate box.

	Very worried	Moderately worried	A little worried	Not worried
Swimming	☐	☐	☐	☐
Holding breath	☐	☐	☐	☐
Disorientation	☐	☐	☐	☐
Releasing harness	☐	☐	☐	☐
Getting clear of seat	☐	☐	☐	☐
Locating exit	☐	☐	☐	☐
Remembering instructions	☐	☐	☐	☐
Bumping part of the body	☐	☐	☐	☐
Getting snagged	☐	☐	☐	☐
Exiting through window	☐	☐	☐	☐

Any other comments:

PART TWO
Feelings During and After Helicopter Escape

Subject number ____________ Trial reference ____________

Question 3
How difficult did you find the first capsize, which was the 150° roll with your seat coming to rest on the lower side (underwater), followed by escape from an upper window?

Very difficult ☐ Moderately difficult ☐ A little difficult ☐ No difficulty ☐

Question 4
For the first capsize, could you please rate the factors in the first column of the table below in terms of how difficult they made the escape, by placing a tick in the appropriate box.

	Very difficult	Moderately difficult	A little difficult	No difficulty
Swimming	☐	☐	☐	☐
Holding breath	☐	☐	☐	☐
Disorientation	☐	☐	☐	☐
Releasing harness	☐	☐	☐	☐
Getting clear of seat	☐	☐	☐	☐
Locating exit	☐	☐	☐	☐
Remembering instructions	☐	☐	☐	☐
Bumping part of the body	☐	☐	☐	☐
Getting snagged	☐	☐	☐	☐
Exiting through window	☐	☐	☐	☐

Any other comments:

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Question 5

How difficult did you find the second capsize, which was the 150° roll with your seat coming to rest on the upper side (mostly out of water), followed by escape from an upper window?

Very difficult ☐ Moderately difficult ☐ A little difficult ☐ No difficulty ☐

Question 6

For the second capsize, could you please rate the factors in the first column of the table below in terms of how difficult they made the escape, by placing a tick in the appropriate box.

	Very difficult	Moderately difficult	A little difficult	No difficulty
Swimming	☐	☐	☐	☐
Holding breath	☐	☐	☐	☐
Disorientation	☐	☐	☐	☐
Releasing harness	☐	☐	☐	☐
Getting clear of seat	☐	☐	☐	☐
Locating exit	☐	☐	☐	☐
Remembering instructions	☐	☐	☐	☐
Bumping part of the body	☐	☐	☐	☐
Getting snagged	☐	☐	☐	☐
Exiting through window	☐	☐	☐	☐

Any other comments:

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Question 7
How difficult did you find the third capsize, which was the 210^0 roll with your seat coming to rest on the upper side (mostly out of water), followed by escape from an upper window?

Very difficult ☐ Moderately difficult ☐ A little difficult ☐ No difficulty ☐

Question 8
For the third capsize, could you please rate the factors in the first column of the table below in terms of how difficult they made the escape, by placing a tick in the appropriate box.

	Very difficult	Moderately difficult	A little difficult	No difficulty
Swimming	☐	☐	☐	☐
Holding breath	☐	☐	☐	☐
Disorientation	☐	☐	☐	☐
Releasing harness	☐	☐	☐	☐
Getting clear of seat	☐	☐	☐	☐
Locating exit	☐	☐	☐	☐
Remembering instructions	☐	☐	☐	☐
Bumping part of the body	☐	☐	☐	☐
Getting snagged	☐	☐	☐	☐
Exiting through window	☐	☐	☐	☐

Any other comments:

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Question 9
How satisfied are you with the way you coped with the helicopter underwater escape training in this session?

Very satisfied ☐ Satisfied ☐ Undecided ☐ Dissatisfied ☐

Question 10
How much confidence do you now have in helicopter transport?

High confidence ☐ Moderate confidence ☐ Low confidence ☐ No confidence

Question 11
How much more confident do you now feel of coping with a real helicopter ditching than you did prior to this session?

Much more ☐ More ☐ About the same ☐ Less ☐ Much less ☐

Question 12
Having now completed two exercises, one involving full capsize (180^0) and the other involving partial capsize (150^0 / 210^0), which did you prefer in terms of ease of escape?

Full capsize ☐ Partial capsize ☐

You have now completed the questionnaire
THANK YOU FOR YOUR HELP

Appendix 6 Example of heart rate trace