Safety Regulation Group

Civil Aviation Authority

CAA PAPER 2003/13

Preliminary Study of the Implementation and use of Emergency Breathing Systems

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Foreword

This preliminary study of the implementation and use of various forms of emergency breathing systems (EBS) was commissioned by the UK Civil Aviation Authority (CAA) on behalf of the Joint Aviation Authorities' Helicopter Offshore Safety and Survival (HOSS) working group following a workshop on EBS held at Billingham, UK in October 2000, and was performed by Dr Susan Coleshaw. The work was funded by the Safety Regulation Group of the UK CAA and the Offshore Safety Division of the UK Health and Safety Executive as part of an ongoing programme of research into the mitigation of helicopter ditchings and water impacts. The research in this area was originally instigated in response to recommendations made in the HARP Report (Report of the Helicopter Airworthiness Review Panel - CAP 491, Recommendations 7, 9 and 10) and the RHOSS Report (Review of Helicopter Offshore Safety and Survival - CAP 641, Recommendation 14.2(g)).

Following completion of the research reported in this paper, CAA conducted a review of its policy in relation to EBS and concluded that there was no compelling case to either mandate or ban the use of EBS. CAA also decided not to produce a formal design specification largely because it is not normal practice to do so for non-mandated equipment. A draft example technical standard is included as an appendix to the report however, which is considered to provide a good basis for any future specification. It should be noted that the draft standard is incomplete in some respects, and contains some provisional design parameters that will require confirmation. All areas of the draft standard in need of further attention are appropriately annotated.

Safety Regulation Group

22 August 2003

Summary

The primary aim of this study was to establish the extent of knowledge and testing performed on various forms of emergency breathing system (EBS). Issues and concerns were reviewed, highlighting gaps in the current knowledge.

Published data on helicopter water impact accidents was analysed to determine the frequency of different impact conditions and the incidence of drowning. The high incidence of drowning is largely due to cold shock, which greatly reduces breath-hold time and thus limits the time available for escape. EBS are designed to help overcome cold shock by allowing individuals to breathe underwater for a short time, thus extending underwater survival time. In this way EBS can provide a means of bridging the gap between maximum breath-hold time and escape time, and thus reduce the incidence of drowning.

Consideration of the different types of helicopter accident has led to the conclusion that emphasis should be placed on the deployment of EBS after landing on water, but before submersion. Underwater deployment should only be attempted if escape would otherwise be impossible.

Whilst it was considered that reliance on EBS for escape should be minimised, it has been shown that successful use of EBS can reduce the levels of stress experienced during helicopter escape under simulated conditions. That said, satisfactory performance of EBS is dependent upon good design, reliability of the equipment, ease of use and performance on demand. Other key factors include human individual capabilities, training, environmental conditions, helicopter design and the features of the helicopter accident.

In order to maximise the benefits of EBS and minimise the risk of human error during deployment and operation, training is required. Such training should include both classroom and practical sessions (dry and wet), with a progressive development of knowledge leading to competence and confidence in the use of EBS. It was also considered important that competence be maintained to prevent any potential failure of deployment.

When reviewing current knowledge on EBS equipment, particular attention was given to the testing and development of two products, one being a re-breather and one a compressed gas system. The background and rationale behind their selection are discussed. Established performance criteria and problems encountered during the development of these and other products provide a basis for the approval and selection of future products.

Based on this knowledge, an example technical standard for emergency breathing systems has been drafted. The draft example standard identifies minimum performance requirements to ensure that equipment is manufactured to consistent and satisfactory standards, and that basic health and safety requirements are met.

Glossary

AIB	Accidents Investigation Branch (UK)
AAIB	Air Accidents Investigation Branch (UK)
APP	Air Pocket Plus
CAA	Civil Aviation Authority (UK)
CEN	Comité Européen de Normalisation
DCIEM	Defence and Civil Institute of Environmental Medicine (Canada)
EBS	Emergency breathing system
HABD	Helicopter aircrew breathing device
HEBE	Helicopter emergency breathing equipment
HEED	Helicopter emergency egress device
HUET	Helicopter underwater escape trainer
METS	Modular egress training simulator
MoD	Ministry of Defence
MTC	Maritiem Trainingscentrum
NHC	National Hyperbaric Centre
NPD	Norwegian Petroleum Directorate
NTP	Normal temperature and pressure
OPITO	Offshore Petroleum Industry Training Organisation
pCO_2	Partial pressure of carbon dioxide
pO_2	Partial pressure of oxygen
PPE	Personal protective equipment
P-STASS	Passenger STASS (see STASS)
SEA	Survival egress air
STASS	Short term air supply system
SWET	Shallow water escape trainer
UEM	Underwater escape module
UER	Underwater escape re-breather
UKOOA	UK Offshore Operators Association
VC	Vital capacity

Definitions

Crash	A high velocity impact with significant or total loss of control. (Crashes are sub-divided into vertical descents with limited control, fly-ins and uncontrolled impacts).
Ditching	A 'controlled alighting on water', assuming pre-meditation and warning of contact with the water.
Hyperventilation	A voluntary or involuntary increase in the ventilation of the lungs produced by an increase in the depth and/or rate of breathing.
Minute volume	The volume of gas exhaled from the lungs in a minute.
Tidal volume	The volume of gas exhaled from the lungs per breath.
Forced vital capacity	The total volume of gas that can be voluntarily moved in one breath, from full inspiration to maximum expiration.

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The author would like to thank the many representatives of the offshore industry who have willingly discussed their experiences with the implementation and use of EBS. Particular thanks are due to the following people who have provided documents and reports, and filled in some of the knowledge gaps which could not be obtained from published data:

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Tom Maddern - Shark Group

Justin Stafford - MoD Abbey Wood

Mike Tipton - University of Portsmouth

Part A Objectives and Approach

1 Introduction

Recent research has confirmed a disparity between the time required to make a successful escape from a capsized helicopter and the time available for underwater escape. The time available for escape is limited by the breath-hold time of the individual. Emergency breathing systems (EBS) have been developed to increase the chances of making a successful escape by increasing the underwater survival time.

Helicopter emergency breathing systems are now being carried by passengers flying offshore in the North Sea, but they are not mandated or approved by the Civil Aviation Authority (CAA). It is understood that many of the devices, currently available in Europe, do not carry a CE mark which would demonstrate that they have been assessed against the basic health and safety requirements of the PPE Directive (89/686/EEC). When considering use by the offshore work-force, the PPE 'Use' Directive (89/656/EEC) states that, under the employers' obligations, all personal protective equipment should be appropriate for the risks involved without leading to any increased risk. Greater knowledge and understanding of the equipment is needed to allow these risks to be adequately addressed.

2 Aims and Objectives

The aim of this study was thus to review the status of emergency breathing systems with the intention of establishing the benefits and risks associated with the carriage and use of such equipment.

The study addresses the following objectives:

a) Establish the extent of knowledge and testing performed on various forms of EBS.

b) Review the issues and concerns that exist in the context of current knowledge, highlighting any areas requiring further research.

c) Draft an objective performance specification.

3 Methodology and Approach

3.1 Literature search and review

Existing published work relating to re-breather, compressed air and hybrid emergency breathing systems was sought using library and Internet searches. Efforts were made to secure research reports from the manufacturers that may not have been published and, therefore, were not in the public domain. Recognition was given to the confidentiality and commercially sensitive nature of this information.

A range of both civilian and military operators of EBS were contacted to determine the background and rationale behind the selection of their own EBS equipment. Manufacturers, such as the Shark Group, were contacted with a view to obtaining any available independent research reports relating to their own products. The OPITO (Offshore Petroleum Industry Training Organisation) Training Providers Advisory Group and Training Standards Committee were contacted to determine their views relating to training. This group is currently reviewing training requirements for EBS. (The OPITO Training Standards Committee reports to the UKOOA Aircraft Committee). Gaps in current knowledge and areas requiring further research were identified.

3.2 Analysis

The results of the literature search and review were analysed, applying the knowledge gained to the implementation and use of EBS in civilian helicopter operations. The analysis included:

- potential benefits of use;
- potential adverse effects on escape;
- required performance and operational envelope (e.g. duration of use at given water temperatures, depth, orientation);
- ease of use (e.g. operation, accessibility, purging and breathing resistance);
- potential for misuse (e.g. failure to operate, incorrect operation);
- compatibility with other equipment;
- ergonomic issues;
- potential effects of anxiety on performance (positive and negative);
- potential injury and medical risk;
- training (potential benefits and hazards).

3.3 Performance specification

The results of the literature review and analysis were used to develop an example draft performance standard for EBS, suitable for development into a Joint Technical Standard Order. The draft standard used objective measures where possible, keeping subjective assessments to a minimum. Where appropriate, recognised and validated test methods were recommended. Any areas of uncertainty were identified and cross-referenced to the knowledge gaps highlighted previously.

Part B Review

1 Background

1.1 Helicopter accidents

The outcome of a helicopter accident in the North Sea will depend upon its nature and causes, the weather and sea conditions at the time and the behaviour of the individuals involved. It is recognised that an uncontrolled crash into water is likely to result in serious injury to the crew and passengers and serious damage to the helicopter structure, whereas a ditching is much more likely to have a favourable outcome.

Evidence from accident reports has demonstrated that in about 60% of all water impacts, the helicopter inverted or sank immediately or after a short delay (Rice and Greear, 1973; Hayes, 1991; Brooks, 1989; Clifford, 1996). Capsize often occurred before evacuation was completed, requiring the occupants to make an underwater escape. Clifford's (1996) review of world civil helicopter water impacts showed that capsize and/or sinking was equally likely in both controlled ditchings and crash landings on water (69% of controlled ditchings, 56% of vertical descents with limited control, 65% of fly-ins and 68% of uncontrolled impacts). Risk of capsize was increased by high impact speed and rough sea conditions.

Time to capsize varied greatly. In some cases capsize was immediate (less than 30 seconds), in many it was rapid (one to two minutes after impact), while in other cases it was delayed, occurring 20 minutes or more after the water impact (Jamieson et al, 2001). The accident reports illustrate the many problems experienced, depending upon the varying events which follow impact.

Examples include the accident in which an S61N ditched north east of Aberdeen (AIB, 1978). Capsize was almost immediate (within 30 seconds) when the helicopter descended into a wave trough and the rotor blades struck the water. Occupants evacuated from the partially flooded aircraft, *"neck-deep in water"*. In the accident to BO 105D east of Skegness (AIB, 1985), a controlled ditching was attempted due to heavy vibration, but the helicopter then rotated into the sea when yaw control was lost. The aircraft immediately rolled onto it's side due to damage to one flotation bag. The occupants were thought to have made their escape within a period of about 30 seconds, after which time the helicopter capsized fully. In 1988, 11 passengers and 2 crew experienced serious problems when escaping from an S61N which capsized almost immediately after a controlled ditching onto the sea (AAIB, 1990). After capsize, both crew had problems locating the jettison handle for their emergency exit from an inverted position underwater. One then moved aft to the cargo door, which he was unable to open, and finally managed to escape by pushing out a passenger window, after a considerable time underwater. The other crew member managed to escape through his emergency exit, but had problems due to several projections which were thought to have snagged clothing and equipment. Three of the eleven passengers (who all eventually escaped) reported some difficulty when attempting to release their lap belt seat harnesses. One reported problems gripping the rip-tag for the push-out window and had to remove a glove to complete the action, while a further passenger broke a bone in his hand while attempting to push out a window. In 1992, an AS332L crashed into the sea near the Cormorant Alpha Platform (AAIB, 1993). The helicopter initially rolled onto one side, and reportedly took one to two minutes to fully capsize and sink. Five passengers failed to make an escape. These examples demonstrate the range of capsize scenarios, some of the problems experienced, and the range of different outcomes in relation to occupant survival.

Research has shown that the upper practical limit for a helicopter’s capsize boundary is around Sea State 6 (Jackson and Rowe, 1997). Helicopters are inherently unstable in water due to their weight distribution and resulting high centre of gravity. Thus, there is a significant risk of the helicopter capsizing in heavy seas. Other factors that may lead to capsize in more moderate seas include malfunctioning flotation equipment, rotor strike or imperfect alighting onto the sea. The HARP (Helicopter Airworthiness Review Panel) Report (CAA, 1984) made reference to the frequency of forced landings and identified the consequent need for adequate buoyancy, stability and practicable means of escape from a helicopter.

If a helicopter does capsize it will generally invert to a position where all the exits are submerged, meaning that those who survive the water impact must make an underwater escape. Survivors must cope with the in-rushing water, cold shock, the severe disorientation caused by inversion, the difficulties of releasing their seat belts, and then locating and opening exits.

Not surprisingly, the high incidence of capsize is associated with a high incidence of drowning. Rice and Greer (1973) reviewed 78 US Navy helicopter accidents. Of 63 lives lost, 16% were due to impact injuries, 40% were attributed to drowning, and the remainder (44%) were lost at sea. Clifford's (1996) review of UK military accidents (survivable) from 1971 to 1992 shows that 83% of the fatalities were due to drowning whilst 17% were due to impact injuries. His review of world civil water impact accidents (survivable) demonstrated a lower ratio, with 54% of fatalities (where cause of death had been identified) attributed to drowning (Table 1). (N.B. The exclusion of non-survivable accidents may influence the ratios cited. More information about cause of death tends to be recorded for military compared to civil accidents.)

Table 1 shows that in controlled ditchings, there were only four fatalities, all of which were attributed to drowning. Known cases of drowning significantly exceeded known cases of fatal impact injury for both fly-in accidents and vertical descents with limited control, whereas fatal impact injuries predominated in the uncontrolled impact accidents. These figures thus show a high proportion of fatalities where drowning was the primary cause. Probable causes of drowning which were cited included incapacitation due to injury, disorientation leading to an inability to escape, entrapment, and jammed or obstructed exits. These figures represent worldwide helicopter accidents, covering a wide range of helicopter designs, occupant groups (with different levels of training), and perhaps of most importance, water temperature at the time of the accident.

The hazard of an accident in the North Sea is potentially more serious than that of an accident in more temperate waters due to the higher risk of cold shock. In this sense, the North Sea area can be considered to be a relatively hostile environment. Flights for the oil and gas industry also differ from other civilian flights due to the fact that the passengers are all flying within their occupational role, they wear protective immersion suits and they receive training for survival in the event of an accident. Thus, whilst conditions may be more severe, the chances of making an escape are improved by the training and the level of personal protection provided to the individuals.

Table 1 Analysis of impact type and cause of fatality (survivable world civil impacts)

Impact type	No. Accidents	No. Occupants	Total fatalities	Fatalities where cause known		Serious injuries
			(%)	Drowning	Impact	
Controlled ditching	29	308	4 (1)	**4**	**0**	0
Vertical descent with limited control	25	181	47 (26)	**16**	**3**	18
Fly-in	17	138	78 (57)	**33**	**1**	7
Uncontrolled impact	25	248	198 (80)	**28**	**66**	18
Total	**96**	**875**	**327**	**81**	**70**	**43**

Data taken from Clifford (1996)

The RHOSS report (CAA, 1995) provided statistics for all UK registered multi-engine helicopters over the time period from 1976 to 1993. This report showed that there were 11 controlled ditchings (all non-fatal) compared to 7 survivable crashes at sea and 4 non-survivable crashes at sea. Ditchings exceeded survivable crashes by a factor of 1.6, demonstrating a much higher proportion of controlled ditchings to survivable crashes in the UK sector compared to the worldwide figures.

RHOSS cited some eight fatal accidents offshore in the same time period, with the loss of 85 lives. Of the four survivable accidents at sea, survival rates were 93%, 90%, 54% and 35% respectively. At that time, these figures represented a fatality rate of 3.86 per 100,000 flying hours. It should be noted that there has not been a fatal accident in the UK sector since 1992, with just one controlled ditching in 1995 (AAIB, 1997), and so this rate will by now have decreased.

RHOSS suggested that the total of 19 fatalities in the four survivable accidents *"represents a theoretical maximum number of lives that might possibly have been saved through the perfect functioning of the safety and survival system".* In the Brent Spar accident (AAIB, 1991), one of the six fatalities drowned despite being uninjured, while a second passenger with only minor injuries failed to release his harness and drowned. A further two crew and two passengers suffered fatal impact injuries. In the Cormorant Alpha accident (AAIB 1993), five passengers drowned after releasing their seat belts but failing to complete their escape from the helicopter. Cold shock and inadequate breath-holding time were thought to be limiting factors in the case of four of these victims. In both of these accidents, there was little or no warning, one accident being an uncontrolled crash and the other a fly-in type of impact.

In summary, the recent accident record shows a low incidence of helicopter water impacts in the North Sea. The overall figures for UK registered helicopters suggest that a controlled ditching is a more likely occurrence than a survivable crash (vertical descent, fly-in or uncontrolled impact). Whilst controlled ditchings are more common, the fatality rate is low, despite a large proportion of helicopters capsizing. This suggests that there was still time for individuals to adequately prepare for escape in the event that submersion or inversion occurred before evacuation was completed.

The UK figures show that survivable crashes are less likely to occur, but that fatality, drowning in particular, is much more likely. Theoretically, more lives could therefore be saved in high energy crashes.

Following concerns raised by the CAA, a recent analysis of impact conditions and EBS deployment procedures (Coleshaw, Head and Muir, 2001) suggested that emphasis should be placed on the deployment of EBS after contact with the water. This recommendation took account of the higher probability of drowning following a crash onto water with little or no warning, and the risk of injury if EBS were to be deployed prior to a crash.

1.2 Escape times

Little information is available to assess the actual time needed to escape during a helicopter capsize accident. Tipton et al (1997) state that *"estimations from groups such as the Coast Guard, military, civilian operators and training establishments suggest that 40-60 seconds are required"* to make an escape in real conditions. This estimate is important for many of the arguments relating to the chances of making a successful escape.

When measured during trials in a standard helicopter underwater escape simulator, maximum escape times (without use of EBS) are of the order of 25 to 30 seconds (Bohemier, Chandler and Gill, 1990; Coleshaw and Howson, 1999). These escapes were made under controlled conditions in relatively warm water (20-25°C). Trials conducted with a full complement of passengers in a simulator configured to represent the Super Puma helicopter, demonstrated escape (underwater submersion) times ranging from 27 to 92 seconds, with 10 of the 18 subjects using EBS to complete their escape (Brooks, Muir and Gibbs, 1999).

In a real accident, conditions are likely to be much more severe and the water much colder. In the North Sea, water temperatures may be as low as 4°C, meaning that cold shock has a significant effect on the outcome of a ditching or crash.

1.3 Cold shock

Cold shock is probably the single most important factor limiting the escape of an uninjured victim from a capsized helicopter, particularly in the North Sea. Cold shock is caused by the sudden drop in skin temperature on immersion, and is characterised by a gasp reflex and uncontrolled breathing (Keatinge and Evans, 1961; Keatinge and Nadel, 1965; Hayward and French, 1989; Tipton, 1989). It is the involuntary nature of this reflex response which makes it so dangerous. In the event of submersion, cold shock greatly reduces the breath-hold time. The urge to breathe rapidly becomes overwhelming and, if still submerged, the individual will inhale water resulting in drowning.

Tipton, Stubbs and Elliot (1991) investigated the cold shock response, with head-out immersion of subjects wearing swimming trunks in water at 10°C. The gasp response was evoked in 2.3±0.7 seconds, the gasp itself having a duration of 2.7±0.3 seconds. During the first minute of immersion, minute ventilation was 76±23 litres per minute. The average tidal volume reached a maximum value of 1.9 litres after 30 to 40 seconds of immersion. Rate of ventilation was maximal after 20 seconds, with an average rate of about 60 breaths per minute. Responses to 5°C and 10°C water were similar, suggesting that a maximum respiratory drive had been evoked in both conditions. The authors concluded that, for head-out immersion, the threat was greatest during the first 20 to 30 seconds of immersion *"when the magnitudes of the responses are at their greatest, and subsides as the responses habituate during the first 2 minutes of immersion"*. When considering the case for breath-holding underwater then, it is obvious that the overall threat of drowning will not subside, even if there is habituation to the cold shock response.

Whilst recorded times differ somewhat depending upon the trial protocols, experimental evidence showed that in subjects wearing helicopter suits in water colder than 10°C mean maximum breath-hold time was less than 20 seconds and could be as little as 6 seconds (Tipton and Vincent, 1989, Tipton et al, 1995, Tipton et al, 1997). This would allow very little time for an individual to escape from a capsized helicopter. Maximum breath-hold time is therefore a limiting factor in the survival of the individual.

As previously reported, breath-holding time was thought to have been a limiting factor in the case of four of the victims who failed to escape from the submerged cabin in the Cormorant Alpha accident (AAIB, 1993).

1.4 The escape time problem

The results of both accident investigation and underwater escape research demonstrate that **breath-hold time in cold water may be much less than the time taken to complete an underwater escape from an inverted helicopter**.

As stated by Miles (2000), *"for the passengers to have a 'good prospect' of survival the breath hold time must exceed the escape time"*. Miles went on to emphasise the fact that this discrepancy was now moving into the public domain, and that Regulators were now obliged to act.

It has been recognised that the use of emergency breathing systems can provide a means of bridging the gap between breath-hold time and escape time, at least in the short term. In the long-term, other options may present themselves. One possibility is the introduction of side-floating helicopters with improved flotation, which may prevent the complete inversion of a helicopter following capsize (Jackson and Rowe, 1997; Coleshaw and Howson, 1999; Jamieson, Armstrong and Coleshaw, 2001).

1.5 Underwater breathing

Emergency underwater breathing systems aim to extend the underwater survival time for a period sufficient to allow escape to be completed. Endurance times of at least 60 seconds are generally specified. When designing underwater breathing equipment, a number of factors must be taken into account. The device must be simple and easy to operate if the user is to be able to deploy and breathe from the unit when suffering from cold shock, disorientation and high levels of anxiety.

Even in warm water, it is not easy to breathe in and out due to the hydrostatic pressure of water on the chest. Hayes (1990) uses the example of breathing from an upturned bucket to explain the problems of underwater breathing. *"Below the surface the volume of air rapidly shrinks as pressure increases and respiration rate increases in response to increased levels of carbon dioxide. It is difficult to pull the bucket of air below the surface because of its positive buoyancy. Greater activity requires larger volumes of gas to breathe. If all these problems are surmounted the underwater excursion will end as a result of hypoxia when the oxygen supply is depleted. The specification for the underwater escape apparatus will be a compromise between these factors; breathing gas requirements versus buoyancy, simplicity of operation versus complexity of purpose, available gas supplies versus physiological requirements and the physiological/biochemical problems of breathing in water versus what is convenient, comfortable and acceptable to the man".*

A number of different concepts have been developed to address these issues, with a variety of design compromises made dependent upon the particular needs of a given end-user. EBS devices can be divided into three broad categories, compressed air systems, re-breather systems and hybrids incorporating a re-breather bag with additional gas from a cylinder. The compressed air EBS have tended to be developed and used by the military for aircrew use. The end-users thus tend to be young and fit and undergo regular, thorough training. Re-breather systems have been developed primarily for the offshore workforce. The end-users come from a wide range of backgrounds, of all ages and levels of fitness, with varying requirements for training. A hybrid system was first used for helicopter underwater escape by the US Coastguard, which used a second bladder on the lifejacket, topped up by 100% oxygen from a gas cylinder. More recently, hybrid re-breather bags incorporating an additional cylinder of air have been developed for use by the offshore workforce.

The test programmes undertaken to develop and implement one type of re-breather (Air Pocket / Air Pocket Plus) and two types of compressed air system (STASS and P-STASS) are described in Sections 2 and 3 of this report respectively. These particular types of EBS were selected for review as it was known that a full programme of testing had been, or was currently being undertaken to ascertain the safe use of the equipment. Testing proceeded from unmanned tests using breathing machines to manned tests of increasing complexity, before progressing to simulated helicopter escape trials.

1.6 Accidents involving the use of EBS

Whilst there were some reported cases of compressed air systems being used in real accidents, the author was unaware of any cases where a re-breather system had been used during a helicopter escape.

The first reported helicopter accident involving the use of EBS (HEED2) took place in 1987 (McKinley, 1988; Bohemier, Chandler and Gill, 1990). A US Navy helicopter crashed into the Indian Ocean following a loss of power, with only about 5 seconds warning before impact. Two of the aircrew, one of whom was trapped in the cockpit, used their EBS to escape and described the calming effect gained from using the device. The other two members of crew escaped without the use of HEED2, using standard underwater escape techniques. One had attempted to use HEED2 but had been prevented by a broken jaw, sustained during the impact.

A similar comment on the calming effect of EBS was reported after a second accident involving the use of HEED2 (Negrette, 1988). In this case, a US Navy helicopter was on a night-time approach to land on a ship in the Mediterranean. The helicopter ditched close to the ship in thick fog (17°C water), and immediately capsized and inverted. One of the three crew members used HEED2 to escape after initially failing to push out a nearby window.

Brooks and Tipton (2001) cite a further case where the pilot described how he suffered facial injuries on impact. HEED was used during a problematic escape after the pilot had forgotten to release his seat harness.

It should be noted that all of these accidents are thought to have occurred in relatively temperate water temperatures. Whilst the crew members needed to use their EBS to provide them with enough time to escape, there is no mention of the effects of cold shock. Serious cold shock is likely to have increased the need for EBS, possibly at an earlier time. This could have made deployment more difficult. There is some suggestion of a delay of a number of seconds before the individuals remembered that they had an emergency breathing system which could aid their escape.

In a further incident in the late 1980's (Hayes, 1990), again involving HEED2, a crew member who had successfully escaped from a sinking helicopter, attempted to use his EBS to dive down and rescue a trapped colleague. The unit failed to work. It was thought possible that the on/off knob on the unit had been accidentally and progressively knocked when sited in the clothing assembly, allowing the gas to slowly leak and discharge the unit. (This problem has since been addressed by the use of a contents gauge and regular checks and maintenance). In addition, Hayes reports that the US Navy measured the breathing resistance of three HEED2 units and found them to be high. They suggested that HEED2 should not be used at depths in excess of 30 feet.

The first use of EBS by a Royal Navy pilot occurred in 1993 when a Sea King helicopter ditched off the west coast of Scotland; both crewmen used their STASS. The survival of one of the crew, who experienced snagging problems during escape, was attributed to the use of the EBS. The pilot described the feeling of relief when he deployed the EBS, reducing the level of panic (Brooks and Tipton, 2001). Despite the pilot trying to control his breathing to conserve air, the gas bottle was empty when he reached the surface. Whilst the water temperature is not known, it was likely to have been relatively cold (<15°C).

Two further cases are reported by Brooks and Tipton (2001). In one, STASS was used by two US Coastguard crew in 1995. The other case involved the pilot of a helicopter en route from Puerto Rico to US Virgin Islands.

1.7 **Barotrauma**

One of the risks involved in the use of any compressed air system is barotrauma. Barotrauma is an injury caused by a change in pressure. Pulmonary (lung) barotrauma will occur if a diver holds his/her breath, or breathes out too slowly during ascent, after breathing compressed air at depth. This results in over-inflation and damage to the lining of the lungs, allowing small bubbles of air (emboli) to escape, either into the bloodstream or into the chest compartment. Middle ear barotrauma occurs on descent, usually when the Eustachian tube is blocked. The increase in pressure with depth causes a partial vacuum in the middle ear, causing damage to the mucosal lining, rupture of small blood vessels, exudates and possible perforation of the tympanic membrane. Whilst helicopter underwater escape training is undertaken in shallow water (usually less than 4m depth), barotrauma is possible, in particular if the user breath-holds on ascent.

Benton et al (1996) describe a case of arterial gas embolism in a 45-year-old military helicopter pilot following initial training in the use of STASS. The individual had used the device in water at a maximum depth of 1m. His symptoms included loss of short-term memory, being unsteady on his feet, discomfort in his right arm, tingling fingers and some visual disturbance. Full recovery was made after a series of three hyperbaric oxygen therapies.

Risberg (1997) described a case of pulmonary barotrauma which occurred during helicopter escape training using a compressed air emergency breathing system. The 28-year-old military crew member suffered chest pain and vertigo 15 minutes after completing three simulated helicopter ditching procedures. After undergoing hyperbaric oxygen therapy, a chest X-ray demonstrated air in the middle of the chest (resulting from damage to the lining of the lungs).

Several incidents of middle ear barotrauma associated with helicopter escape training were also reported (Risberg, 1997), occurring over a 6-year period. Risberg considered that these injuries were caused by a lack of middle ear equalisation during the rapid rotation of the helicopter. These injuries were not associated with the use of emergency breathing equipment.

Risberg (1997) stated that the probability of serious damage from barotrauma was *"very small and identical to that experienced by any snorkel diver training for other purpose in pool or open water"*. Whilst excluding persons with current airway infection, he felt that improved selection criteria would probably not decrease illness or injury significantly.

Whilst insufficient data exist to assess the risk of training with emergency breathing systems, some indicators can be drawn from data on sports diving accidents. A quantitative risk assessment of SCUBA diving incidents, drawing largely upon the sports diving fraternity, reported a total risk of fatality of approximately 1/5,000 divers per year (Paras, 1997). This figure was considered to be *" … typical for 'adventure sports'."* The British Sub-Aqua Club statistics used for this study indicated that only 4% of the UK fatalities were due to air embolism (1/125,000 divers per year), linked to rapid ascent and breath-holding. Non-fatal cases of air embolism were not specifically reported. Figures from the United States showed a higher proportion of diver fatalities due to air embolism, which the authors attributed to differing training standards, with lower levels of training in the US where the diving environment may be perceived as being more benign. Given the short periods of exposure and shallow depths, lower levels of risk can be expected for EBS pool training, as long as adequate care is taken and thorough and progressive training procedures are used.

A number of conclusions can be drawn:

- End users and trainers should be aware of the small risk of air embolism.
- Training should emphasise the importance of **not** breath-holding during ascent when compressed air is breathed.
- Hyperbaric facilities should be available to the training establishment in case treatment is required.
- Medical screening before training should take account of the risk of air embolism and the prevalence of airways infections.

Whilst the risk of barotrauma should be given due consideration, the level of risk is probably very low, and is only relevant to the training situation. In the event of a real accident, the risk of air embolism is insignificant compared to the potential benefits of being able to breathe underwater.

2 Development of a Re-breather System

2.1 Background to Shell's work

In the early 1980s, Shell recognised the need to protect helicopter passengers from the potential effects of accidental immersion in cold water. The first step was to introduce immersion suits, including a partial coverage wet suit known as the 'shuttle jacket'. Whilst the 'shuttle jacket' provided improved thermal protection against the risk of hypothermia compared to standard clothing, it was shown that it *"provided little or no greater protection against the initial responses to cold water immersion than [the] cotton overall assembly"* (Tipton and Vincent, 1989). A full dry immersion suit provided significantly greater protection, but subjects still demonstrated a cold-induced reduction in breath-hold time (ranging from 9 to 23 seconds in cold water), followed by hyperventilation, an increase in respiratory frequency, heart rate and oxygen consumption. It was therefore considered that the immersion suit did not provide adequate protection against cold shock. This formed the basis for the 'Survival in the Sea Project'.

A number of helicopter accidents in the North Sea, involving Shell personnel, gave added impetus to the development of an emergency breathing system. The accident to the Chinook in 1986 was followed by the Brent Spar accident in 1990 and the Cormorant Alpha accident in 1992. Sixty two lives were lost. A later review of fatality distribution in 1993 showed that, at that time, flying in contracted aircraft resulted in more fatalities within Shell world-wide than for any other reason with the exception of road transportation (Clark, 2000). It has been Shell's policy to set strategic targets for helicopter safety, rejecting specific aircraft types or applying conditions of use if the fatal accident rate for a type is significantly higher than these figures.

The concept of the 'Survival in the Sea Project', started in 1989, was to develop an integrated survival system which included an immersion suit, lifejacket and re-breather unit. Shell were concerned about the risk of cold shock, suffered by helicopter occupants in the event of a forced landing on the sea followed by capsize. A key specification for the re-breathing system was that it should significantly extend the underwater survival time of individuals compared to their own maximum breath-hold times. This recognised the variability between subjects. A 'duration of use' performance specification e.g. of 60 seconds (equal to the estimated escape time), was not used as it was considered that duration would be highly influenced by factors such as depth, water temperature and clothing. It was also considered important that the re-breather unit should be deployed prior to submersion, protecting the individual from the onset of the cold shock response.

2.2 'Air Pocket' development

2.2.1 Summary

Shell opted to develop an emergency breathing system which was simple to use, and which *"when used as recommended, can only be of assistance in significantly extending the underwater survival time of the user"* (Tipton, 1992). For Shell, this ruled out the use of a compressed air device due to the perceived potential risk of a lung over-pressure injury (see Section 1.7).

The concept was to introduce a simple system which would extend survival time during helicopter underwater escape, *"without introducing any additional dangers, great expense, or lengthy training requirements"* (Tipton et al, 1995). The re-breather bag concept allowed some respiratory movement, enabling the user to tolerate greater degrees of hypoxia and hypercapnia than would occur at the break point of a normal isovolumetric breath-hold. It was known that subjects could re-breathe for 2 to 4 times as long as they could hold their breath (see Tipton et al, 1995).

A progressive research and development programme was initiated, as summarised below (greater detail is given in Sections 2.2.2 to 2.2.7 and 2.3):

- Phase I - feasibility trial.
- Phase II and III - unmanned physical tests.
- Phase IV - manned tests to determine optimum procedure in air, at rest and with exercise.
- Phase V - manned tests at rest in warm and cold water; EBS integrated into immersion suit.
- Phase VI - simulated simple helicopter underwater escape, in warm and cold water.
- Phase VII - underwater escape from a helicopter simulator.
- Second generation system trials.

Overall, it was concluded by Shell that the re-breather *"can enhance safety to an extent which may be life-saving for a proportion of passengers"* Elliot (1993).

Shell prepared a specification and test criteria for emergency underwater breathing devices. Further documents covered the fixing of the re-breather in garments other than the integrated suit system, the validation of the re-breather for use with lifejackets and other immersion suits, training requirements and maintenance. Whilst there was no requirement for CAA approval at this time, the option of a new CEN (European) standard was considered.

A number of helicopter immersion suits, with 'Air Pocket' integrated into the suit, were re-assessed against CAA Specification 19 on a *'no hazard, no credit'* basis, i.e. the suits were approved for use in combination with the EBS *"on the basis of having no adverse affect on mandatory performance requirements of CAA Specification 19", and that "no credit [was] given or implied to functionality and operational performance"*. N.B. Similar approvals were later obtained for suits used in combination with 'Air Pocket Plus'.

Before adoption by Shell, a period of consultation took place when some parts of the company had to be convinced of the justification for the additional costs of maintenance and training. Those who were sceptical were convinced after seeing video footage of a member of Shell staff in difficulty during standard helicopter escape training.

As 'Air Pocket' was adopted by Shell world-wide, some equipment compatibility problems became apparent. In warmer climates, immersion suits are not worn and it became necessary to develop an 'Air Pocket' which could be used as an independent unit. As a separate unit, and with a method to determine whether the unit had been deployed, it was also possible to increase the servicing period to 5 years, thus reducing costs.

In 1999, the UK Ministry of Defence (MoD) evaluated a number of helicopter passenger emergency breathing devices for ease of use (see Section 3.4). In responding to this tender, the manufacturer of 'Air Pocket', the Shark Group, produced a second-generation, hybrid version of their EBS, known as 'Air Pocket Plus'. This unit had a small cylinder of gas attached to the re-breather unit which delivered a charge of clean air when required, thereby increasing the duration of use of the equipment. The additional charge of air provided a further benefit. If the user failed to take a breath prior to submersion, then it would still be possible to breathe from the bag. The hybrid unit developed for the MoD also incorporated a mouthpiece designed for underwater deployment of the unit.

At this time, Shell re-assessed the risks of using a hybrid unit with the additional charge of air. It was considered that the added benefits outweighed the risks of overpressure and, as a result, a version of 'Air Pocket Plus' was adopted by Shell.

In 1999, Cranfield University evaluated the ease of use of 'Air Pocket Plus' whilst escaping from an inverted helicopter simulator. They also assessed the effects of introducing 'Air Pocket Plus' on the current safety equipment used by passengers. They concluded that 'Air Pocket Plus' can enhance the survival chances by increasing individuals' underwater survival time, and that the unit was compatible with any orientation of the body. Automatic (water activated) deployment of the air charge was preferred to manual deployment of the additional gas. Whilst subjects reported feeling buoyant when the additional air was discharged, this did not prevent them from escaping. It was recommended that further work be carried out on the design of the mouthpiece (due to one experienced subject who preferred the original mouthpiece to the new underwater deployment mouthpiece). As a result, Shark reverted to the original mouthpiece requiring deployment prior to submersion. Also, it was considered that *"serious thought must be given to the provision of training for Air Pocket Plus"*.

2.2.2 Phase 1 - feasibility trials on prototype re-breather

Manned trials on a number of prototype re-breather systems were first carried out at the National Hyperbaric Centre (NHC) in Aberdeen (Elliot, 1993; Hayes, 1991). Shell were interested in an underwater breathing duration of at least 60 seconds, in cold water and to a depth of 4.5m. Whilst it was accepted that re-breathing systems could impose a significant hydrostatic work factor when attempting to breathe underwater, it was considered that a volume of expired gas of 6 to 11 litres could provide a breathing time of 60 seconds whilst working hard in cold water.

Feasibility trials were carried out using trained divers. When wearing immersion dry suits, a mean maximum breath-hold time of 26 seconds was obtained in water at 4°C (n=5). Mean breath-hold times of 32 to 36 seconds were recorded in water at 10°C and 12°C. Thus, breath-hold time in cold water had been shown to be less than the estimated underwater escape time of 60 seconds. Trials were then conducted in water at 10°C, using a prototype re-breather bag with a volume of 12-15 litres. With one vital capacity of expired air placed in the prototype bag before use, two divers were able to exercise underwater for periods of 54 and 59 seconds respectively. With two vital capacities of air in the bag, five divers exercised underwater for a mean breathing time of 70 seconds.

Hayes (1991) also considered the issue of buoyancy. It was recognised that an increase in buoyancy would increase the work of escape, and that too much buoyancy could lead to entrapment. Tests had been conducted in Canada (see Brooks, 1989) after which it had been recommended that helicopter immersion suits should have a maximum allowable inherent buoyancy (including trapped air) of 146N (15 kg force). The suits themselves had a buoyancy of about 100N (10 kg force). Compressed air breathing systems available at that time had a buoyancy of 7.8N (800g force), whilst the prototype re-breathers under consideration had a buoyancy of 40-100N (4-10 kg force). The total buoyancy of the suit and re-breather bag with two vital capacities of gas was *"considered to be on average about 20 kgf (195N)"*. The point was made that propulsion during escape is achieved by gripping various fixtures en route to the exit rather than the action of swimming, thus reducing the influence of buoyancy. It should be noted that this would only be possible if sufficient hand-holds were available en-route to the exit and in addition, if EBS could be used hands-free.

It was also recognised that the difficulty of breathing would be affected by the orientation of the person. Hayes stated that a re-breather bag system will *"result in hydrostatic imbalance between the pressure in the lungs (usually measured at the lung centroid) and that in the bag. Pressures fluctuate in response to relative volumes (in and out of the lungs) and the position of the man in the water"*. Hydrostatic imbalance was noted during the trials and was said to be *"obvious and marked"*. Some parts of the re-breather bag were closed off by the pressure, and gas was *"squeezed"* from the area around the mouthpiece. It was recognised that improvements could be made to the bag design and the bag position on the body, thereby reducing the work of breathing and reducing any distress experienced during the initial period of uncontrolled breathing in cold water.

The task of releasing a seat belt harness was considered to be a further potential hazard. Reference was made to the need to prevent snagging, and the importance of the integration of survival equipment. It was noted that the individual must maintain access to the harness release.

Overall, it was concluded that re-breathing times of approximately 60 seconds could be achieved during exercise in cold water, despite the hydrostatic imbalance (N.B. later work showed that it was not necessary, or desirable, to prime the bag with expired air). In addition, Hayes (1991) commented that breathing from expired air re-breather bags was sometimes found to be uncomfortable and difficult, but, that *"60 seconds discomfort is a welcome alternative to drowning"*.

2.2.3 Phases II and III – unmanned tests

Phases II and III involved unmanned tests on the prototype re-breather bag (Air Pocket), conducted using a breathing machine. These early tests included:

a) Optimisation of the shape, size and position of the bag on the body.

b) Measurement of static and dynamic hydrostatic and breathing resistances, and the work of breathing, to ensure that they were within acceptable physiological limits.

c) A method for retrieving air no matter where it had migrated to on expiration.

Three designs of re-breather bag were rejected at this stage due to high hydrostatic pressures, high breathing resistance or excess buoyancy (Elliot, 1993). Two designs demonstrated *"tolerable hydrostatic loads and low flow resistance"* but, at low inflation volumes, 'shut off' was observed in some orientations when opposing sides of the bag came together, blocking the movement of air from that region of the bag.

It was recommended that the hydrostatic characteristics of the bag should be improved and that bags with a 7 to 10 litre capacity, of various shapes and with different hose configurations, should be tested.

Further trials with a 6 litre and a 10 litre triangular re-breather bag demonstrated the importance of the position of the bag and its attachments. A bag held close to the torso but without compressing it, provided the best results, leading to a repeated recommendation that the bag should be built into the immersion suit.

The revised design was fitted with *"an internal distribution system"* which allowed the bag to be breathed down to empty in any orientation without 'shut-off' occurring at low internal volumes. The bag was fitted with a protective cover to prevent accidental damage. The tube to the mouthpiece was smooth, with an outer diameter of 22 mm (which gave the same resistance as a 32 mm diameter corrugated hose), keeping the bulk of the unit as low as possible. A valve arrangement had been developed to permit the user to switch from breathing ambient air to re-breathing from the bag.

A breathing machine was used to measure work of breathing and breathing resistance (Shark, 1991), using a respiratory minute volume of 62.5 litres per minute, over a range of manikin orientations at angles of 45, 90, 135, 180, 225, 270 and 315 degrees and two rotation planes. Despite an increase in resistance due to the air distribution system, the Norwegian Petroleum Directorate (NPD; 1991) recommended limits were exceeded only when the torso was rotated in the horizontal plane with 6 litres of inflation. At the lower inflation levels, values were within NPD limits at all angles and in both of the axes used. It was recognised that the hydrostatic pressures were only measured with one size of suit with a fairly tight fit. Breathing performance was considered to be satisfactory. The re-breather bag and tube were patented by Shell at this time.

2.2.4 Phase IV – manned tests in air

The objective of Phase IV (manned) was to determine the optimum procedure for the use of the re-breather. The re-breather bag was *"fitted with a two-way valve which permitted a rapid change from breathing ambient air to rebreathing from the bag"* (Tipton and Balmi, 1992). Tests were carried out at rest and with steady state exercise, either with the subject taking a deep breath, holding the breath to break-point and then re-breathing up to the break-point, or taking a maximal breath in and then re-breathing immediately up to the break-point.

The results showed that exercise significantly ($P < 0.01$) reduced breath-hold time and total breathing times (Tipton and Balmi, 1992). Total breathing time using the bag was 175 seconds at rest, compared to 80 seconds when exercising at a rate of 1.0 litres per minute (n=6). On ceasing re-breathing, break-point oxygen concentrations tended to be just below 5%, whilst break-point carbon dioxide concentrations exceeded 8%, both values being close to tolerance limits.

The total duration of breathing was not significantly different between conditions. It was therefore decided to opt for the procedure where the user first breath-held before re-breathing from the bag. The results led to a clear recommendation relating to the procedure for use of the re-breather:

> *"It is recommended that individuals are told to hold their breath for as long as possible before using air pocket. This will ensure that air pocket can only be an advantage to those who use it (these individuals will have otherwise drowned). It also means that individuals can continue to do what they would already do: hold their breath for as long as possible".*

Trials were then carried out to assess the potential benefits of priming the re-breather bag with expired air. The increase in breathing duration was found to be small and it was therefore recommended that the re-breather bag should be un-primed prior to use, removing the risks of a pulmonary over-pressure accident and the necessity for recompression facilities during subsequent in-water trials or training. This decision also led to a simplified operating procedure.

Further tests were carried out in warm water, demonstrating that subjects could breathe from the unit in any orientation and with no 'shut off' (due to an internal manifold which ensured better distribution and enhanced emptying of the re-breather bag). The least preferred orientation was found to be an anterior turn to 180°, caused mainly by water ingress into the nose. It was concluded that the hydrostatic pressure imbalances encountered should remain within physiological tolerance limits.

Balmi and Tipton (1992) described further trials conducted at this time to investigate the minimum optimum volume for a re-breather bag, taking into account the fact that an individual may take a large breath in before the breath-hold and submersion. Data was gathered from measurements made on 14 subjects, and information gained from a number of published sources. It was recommended that the re-breather bag should have a minimum volume of 5.5 litres.

2.2.5 Phase V - evaluation in warm and cold water (upright, seated submersion)

During Phase V, the re-breather bag was fitted into an integrated suit and lifejacket system for trials in both warm and cold water. Eight subjects were seated in a chair which was lowered into the water (Tipton, 1992a). Subjects were instructed to take a larger than normal breath and switch the valve from ambient air to bag breathing before submersion, but to then breath-hold for as long as possible before re-breathing.

In water at 25°C, all of the subjects completed a 70 second underwater breathing time (four subjects did not feel the need to use the re-breather).

In water at 10°C, the re-breather significantly extended the submersion time (breath-hold plus re-breathing time) of subjects at rest. Whilst mean maximum breath-hold time was 30.4 seconds, seven out of the eight subjects achieving an underwater breathing time of 70 seconds (the ethical limit) when using the re-breather. The one subject who did not achieve the 70 second limit did extend his underwater breathing time to 3.7 times his breath-hold time.

Tipton (1992a) was surprised how long it took to train the test subjects in the use of the re-breather. The need for formal training was emphasised and it was concluded that training in air and in water would be most effective. It was recommended that users be trained to *"attempt to escape from the helicopter whilst breath holding but use Air Pocket when they need to" rather than "breath hold for as long as possible before using Air Pocket"*.

2.2.6 Phase VI - simulated simple helicopter underwater escape in cold water

Phase VI involved the introduction of exercise, with subjects completing a simulated helicopter escape procedure, in both warm (22°C) and cold (10°C) water (Tipton, 1992a).

When ready, the subjects took a slightly larger than normal breath, and switched the valve from breathing ambient air to re-breathing from the counter-lung before submersion. Subjects were seated in a chair which was rotated forwards from the pool-side, through 180°, causing the subjects to be inverted. The subjects then located a ladder on the floor of the pool (at a depth of 1.5m), released the seat belt and then pulled themselves hand-over-hand along the ladder. Subjects were instructed to continue at a steady rate for as long as they could up to a maximum of 60 seconds. They were also asked to indicate when they took their first breath after their maximal breath-hold.

In water at 25°C, all subjects completed the 60 second test with the help of the re-breather (mean breath-hold time was 27 seconds; no subjects breath-held for 60 seconds when carrying out this activity).

In water at 10°C, five of the eight subjects completed the 60 second test with the help of the re-breather (mean breath-hold time was 17 seconds). One of the subjects who surfaced before 60 seconds complained of shortness of breath. Those subjects who did not complete the 60 second test demonstrated an extended underwater time (> 2 times maximum breath-hold time) when using the re-breather.

Maximum breath-hold times when carrying out the escape activity were less than for the seated submersions of Phase V, at each water temperature. Exercise as well as cold thus appears to influence maximum breath-hold time underwater. Average breath-hold time carrying out the underwater escape test in cold water (10°C) was only 17.2 seconds. This is close to the average time to escape from a helicopter simulator during training in warm water (Coleshaw and Howson, 1999), and much less than the estimated time to escape from a helicopter in a real accident.

Tipton (1992a) provides graphical representations which show the potential estimated 'survival benefit' provided by the re-breather for any given egress time requirement. With these eight subjects, the lowest recorded value for maximum breath-hold time was 9 seconds, whereas the lowest recorded value for time underwater when using the re-breather was 34 seconds, a significant improvement. Tipton stated that ***"if the time required to make such an escape is 20 seconds, 12.5% of subjects (1 in 8) should be able to do this by breath holding alone whereas 100% (8 out of 8) should manage this time when using Air Pocket"***. It can be seen that several of the subjects were close to 20 seconds and would probably have managed a time of 20 seconds in a real situation if close to the surface. If escape were to take 30 seconds, then the results do suggest a low rate of successful escape if the individual was dependent upon breath-holding alone.

Finally, the author emphasised the fact that the results were achieved with the re-breather fitted into an integrated survival system and that assumptions should not be made regarding performance in other circumstances.

2.2.7 Phase VII - helicopter underwater escape

The final set of trials, Phase VII, assessed any adverse effects of the re-breather on manoeuvrability and the ability to escape from a helicopter simulator (Tipton 1992b). Six experienced instructors and six naïve subjects received training in the use of 'Air Pocket' using a shallow water egress trainer (SWET) and the deployment procedures developed in Phases V and VI. Trials of increasing complexity were then carried out in a modular egress training simulator (METS) configured to simulate an S61 helicopter, using a number of different seats.

During the METS trials, one commented that *"in water, AP had a calming effect"*. One subject reported that he had not taken a large enough breath in and *"therefore sucked bag down"*. Two of the experienced subjects reported that they were getting short of breath by the end of the most complex escape (taking 55 and 48 seconds).

Many of the observations made by the naïve subjects related to general problems of escape, disorientation and buoyancy of the suit being worn. One of the naïve subjects, after the first of the METS escape tests, commented that they needed more training to fully understand how to operate the re-breather. One subject was observed to use the re-breather when exit problems were encountered. A further subject who became disorientated and had problems with suit buoyancy commented that the re-breather was *"useful"*. Only one minor snagging problem was reported, when the hose of the re-breather snagged on the door frame during escape. Finally, one subject forgot to use the nose-clip, resulting in an aborted run.

Whilst the calming effect of the re-breather was noted, some problems were experienced which led to a conclusion that users would require incremental and comprehensive training for the full benefits of the re-breather to be realised. Tipton concluded that *"individuals will require incremental and comprehensive training in the use of [Air Pocket] if it is to provide significant assistance during a ditching"*. This was supported by the instructors involved in running the trials. The instructors reported their view that *"the higher the number of physical aids [that individuals] depend on, the lower the chance of survival"*.

The need to consider the possibility of deploying 'Air Pocket' if it was not placed in the mouth before submersion was also identified.

2.3 Human factors evaluation of 'Air Pocket Plus'

During 1999, the performance of a second-generation re-breather was assessed (Mills and Muir, 1999). 'Air Pocket Plus' (APP) is similar to 'Air Pocket', but incorporates a small cylinder of gas delivering an additional charge of clean air to the re-breather bag. Automatic and manual systems of deployment of the gas cylinder were compared. The mouthpiece used for these trials had been developed to meet a military specification, allowing underwater deployment.

The twenty eight naïve subjects who completed the trials were trained in helicopter escape and received classroom training in the use of APP. During the helicopter escape tests, subjects were simply asked to use APP during their escape, and not 'for as long as possible'. Two types of helicopter passenger suit and two types of CAA-approved lifejacket were worn.

2.3.1 Deployment

All of the participants were able to open the APP packaging and use the nose clip during a partial submersion exercise. Most managed to twist the mouthpiece, allowing them to re-breathe from the bag, although a few felt that there was a lack of positive feedback, so that the subjects were unsure whether the unit was operational. The description of APP deployment demonstrates that many of the subjects developed their own strategy for deploying the unit, with some having to use both hands to switch breathing to the re-breather bag as a result. This sometimes resulted in them losing their point of contact for location when the helicopter submerged. Similar comments were recorded following an inversion exercise. One subject who had taken part in earlier assessments of the original 'Air Pocket' preferred the original design of mouthpiece.

2.3.2 Additional charge of compressed air

Subjects tended to prefer the automatic deployment of the additional air. This meant that the air was in the bag when needed and that users did not have to overcome any opening resistance on first exhaling into the bag. During the helicopter inversion trials, most subjects were unaware of the additional charge entering the bag.

2.3.3 Escape time

Mean escape times following upright submersion of the helicopter simulator were close to 30 seconds (timed from the start of breathing with Air Pocket Plus to when the subject reached the surface). These times were longer than the times recorded by others for escape from a simulator without EBS, suggesting that the EBS allowed the subjects to take a little more time. The authors state that *"many commented that using Air Pocket had aided their escape by providing them more time during which they were able to think calmly about the actions they were required to take"*.

Three subjects (with automatic deployment of additional air) forgot or failed to turn the mouthpiece fully, meaning that they were unable to breathe from APP. One further subject who failed to escape *"undid their seat belt when they felt buoyant and the Air Pocket was beginning to float towards their face"*. All of the subjects in the manual deployment test escaped successfully from the simulator, despite the extra actions required.

In the helicopter inversion trials, all subjects made a successful escape in an average time of about 18 seconds. The calming effect of APP was again commented on. This time is similar to the time recorded by others for escape from a simulator without EBS, providing some evidence that APP does not necessarily slow down the overall escape time. As in previous studies of helicopter underwater escape (Jamieson, Armstrong and Coleshaw; 2001), the time taken to escape following an inversion was less than the time taken to escape following upright submersion. This difference may be due to the increased stress associated with capsize and inversion.

In every case in the submersion trial, the re-breather bag floated up towards the mouthpiece, but this did not impede vision or influence escape. This was not reported in the inversion trials, when the re-breather bag remained close to the lung centroid.

Ten subjects reported feeling more buoyant in the submersion trial, particularly with the extra air in the bag, making manoeuvring within the cabin a little more difficult.

The main criticism of APP reported by the participants related to the number of actions which had to be remembered in order to make an escape. However, their ability to do so was reported to improve with practical wet training. Repeated use of APP was reported to help individuals who did not find it natural to place their head underwater and breathe simultaneously.

2.3.4 Compatibility with harness

Whilst some of the subjects reported that the APP 'got in the way', all were able to make a successful escape from the submerged helicopter. Many reported difficulty with the operation of the three-point harness itself, APP having no impact. When having problems releasing the harness, the APP appears to have been of benefit to several subjects: *"the fact that they were able to re-breathe actually kept them calm and allowed them to have several attempts at operating the equipment"*.

2.3.5 Compatibility with immersion suit and lifejacket

Neither the type of suit nor the type of lifejacket influenced escape time. After a jump into water from 3 meters APP remained in place and did not impair the inflation of an aviation lifejacket. Nor did APP cause any problems during the boarding of a liferaft.

2.3.6 Training

The authors reported that *"all of the participants who were asked about the type of training required for Air Pocket Plus felt that they would have benefited from some training in the water. One participant reported that they had to make a conscious effort to remember to breathe, something which had become easier with practice in the swimming pool"*.

2.3.7 Conclusions

The authors' conclusions included the following:

- APP was *"relatively simple to use"*, but that *"further investigation into the best mouthpiece was urgently required"* (N.B. Shark later reverted to supplying the old mouthpiece with APP).
- APP *"can enhance survival chances by increasing individuals escape time"* (considered to mean that the individual can survive underwater for a longer period of time).
- APP was found to be *"compatible with any orientation"*.
- Automatic deployment of the additional charge of air was preferable.
- APP was compatible with two passenger suits and two approved aviation lifejackets.
- APP did not hinder subjects when jumping from 3m, swimming to and boarding a liferaft.
- Some buoyancy problems were observed, requiring further investigation;
- *"Serious thought must be given to the provision of training for Air Pocket Plus"*.

3 Development of Compressed Air Systems

3.1 History

In the 1950's, the aviation industry had been concerned about escape from aircraft which had flown into the sea (Hayes, 1991). Closed and semi-closed-circuit oxygen sets were developed and provided, but were abandoned on the development and introduction of ejector seats. The first helicopter emergency breathing equipment (HEBE) was developed in 1975. This was a low-pressure system with the gas cylinder mounted beneath the seat. This early system was thought to have been abandoned for reasons of policy (Hayes, 1991).

A number of US Coastguard accidents in the 1970s, with fatalities during cold water escape from an upturned boat and from two inverted helicopters, prompted the development of an underwater escape re-breather vest (UER), similar to a diver's adjustable buoyancy lifejacket. An additional mini cylinder of gas attached to the lifejacket provided emergency breathing gas. The UER (referred to by some authors as HEED1) provided 12 litres of oxygen from one half of a double-bladder lifejacket. This system was reported to be able to provide a submersion time of 120 seconds (Hayes, 1991) although it is not stated if this was achieved in warm or cold water. UER was introduced into service by the US Coastguard in 1984.

There was some concern expressed by Hayes that pure oxygen was not an acceptable breathing gas due to the lack of stimulus to respiration from a lowered level of oxygen (hypoxic drive). This could lead to a long breath-hold time and an unacceptable build up of carbon dioxide (severe hypercapnia), meaning that a subject might remain submerged but unable to perform safely. A gas composition of 40% oxygen in nitrogen was recommended by Hayes (1991) as the optimum stored gas mixture. Hayes presumed that the US Coastguard decided to use 100% oxygen because the time to reach potentially dangerous carbon dioxide levels was longer than the required 2 minutes, and because it was difficult to prepare and recharge cylinders carrying unusual gas mixtures. Hayes (1991) described some initial problems encountered with UER when used in the water, with gas leakage out of, and water leakage into, the gas bladder. He further reported collapse of the bag over the hose entry point, with certain positions in the water worse than others. The author also pointed out that it was oxygen consumption and carbon dioxide production that limited re-breathing time and not hyperventilation, minute volume, tidal volume or breathing rate.

During the period when UER was in service with the US Coastguard a number of problems were encountered (personal communication). The unit had no demand valve, which meant the entire oxygen contents of the bladder could be lost if the mouthpiece was knocked out of the mouth of the user. Further problems were encountered during helicopter escape training, due to the oxygen bladder of the UER having a buoyancy of 28 lbs (12.7 kg). Whilst escape was feasible if the user was able to move hand over hand out of the aircraft, maintaining contact at all times, difficulty was experienced if a hand-hold was lost. This was not helped by the size of the inflated yoke around the neck. (The US Navy rejected UER/HEED1 due to this buoyancy problem). In addition, the US Coastguard were concerned about the safety of using pure oxygen in situations where the user might surface in a fire or fuel slick. (The US Coastguard have since adopted a compressed air device, HEED3 – Section 3.3 refers)

Another concept from the diving industry started development and trials in Canada and the US in the early 1980's as a possible alternative emergency breathing system. Submersible Systems Incorporated (SSI) had developed 'Spare Air', a self-contained mini SCUBA set complete with regulator and mouthpiece. This unit was relatively simple to use by a trained diver, required one turn to activate, but did need to be purged of water from the mouthpiece and regulator. Following simultaneous trials by the Canadian Defence and Civil Institute of Environmental Medicine (DCIEM) and the US Naval Air Development Centre, both the Canadian Forces and the US Navy helicopter squadrons adopted the SSI system. As a result of the trials, the Canadian Forces had requested a modification to allow the cylinder to be stored in a survival back-pack, with a length of hose connecting the cylinder to the single stage regulator and mouthpiece. On completion of testing in 1986, the accepted Submersible Systems Incorporated unit was redesignated HEED2.

The US Navy specification included the following requirements:

- 2 minutes underwater breathing time;
- capable of working at 6 m (20 feet);
- functional at a water temperature of 13°C (55°C).

'Spare Air' / HEED2 held approximately 50 litres of air stored at 123 bar (1800psi) in a bottle with a volume of 0.4 litres.

Brooks and Tipton (2001) cite a US Naval Safety Centre report which concluded that HEED2 had facilitated underwater escape, with 25 individuals reporting that they could not have survived without EBS. Two minor injuries were noted, due to the unit not being properly secured to the lifejacket pre-flight. The design was modified so that the compressed gas bottle was an integral part of the lifejacket. An air hose was added so that only the mouthpiece and regulator had to be located and deployed when required.

However, Hayes states that by the time of his report in 1991 there was growing concern in the US Navy that HEED2 had been brought into service too quickly and too early, and that what had been intended as an interim measure had been adopted as a standard. In the early 1990's, the US Navy took a decision to update their EBS. Several designs were rejected due to respiratory pressures in excess of 4 kiloPascal. The US Divers Inc. Helicopter Aircrew Breathing Device (HABD) SRU-40P was selected, despite some concerns that the regulator could be inadvertently unscrewed while activating the bottle (Brooks and Tipton, 2001). This small risk was addressed by being pointed out in maintenance and training sessions.

The Canadian Air Force commenced steps to replace HEED2 in 1994 after several complaints about poor regulator performance and low operator confidence. Different designs of equipment were assessed for ease of use and compatibility with other aircrew equipment. One of the preferred items was dropped because it could not be fitted on the back of the lifejacket. They finally opted for the same system as the US Navy, due to good breathing performance and simple one-handed operation (Brooks and Tipton, 2001).

3.2 Performance of HEED2

3.2.1 Unmanned tests of HEED2 - breathing resistance

Three trials on HEED2 with a single stage demand regulator were conducted at the National Hyperbaric Centre in the UK (Hayes, 1991). The results showed that:

- extreme inspiratory flutter was observed which would result in difficult inspiration;
- peak to peak differences in pressure (maximum inhalation to maximum exhalation) ranged from 55 to 65 cm water (5.5 to 6.5 kiloPascal) - considered to be quite high;
- the overall work of breathing (0.33 to 0.42 Joules per litre) was considered acceptable for short-term emergency use.

(During testing, a poppet valve in one of the units became stuck which, if it had occurred when being used by a person, would have allowed a damaging pressure of 60 kiloPascal to be delivered to the lungs (Hayes, 1991)).

3.2.2 Manned tests of HEED2

Testing of HEED2 was undertaken by DCIEM in Canada and the UK Institute of Aviation Medicine (for Hynes, 1983 see Hayes, 1991).

Table 2 Duration of use of HEED2

<table>
<tr><th>Condition</th><th>Mean Breathing Times</th><th>Authors</th></tr>
<tr><td>3m water</td><td>96 seconds</td><td>Hynes, 1983</td></tr>
<tr><td>10m water</td><td>78 seconds</td><td>Hynes, 1983</td></tr>
<tr><td>2m, hand-pulling along a pipe in water at 32-34°C</td><td>137 seconds</td><td>Sowood and Higenbottam (1989)</td></tr>
<tr><td>2m, hand-pulling along a pipe in water at 11°C</td><td rowspan="2">43 seconds

(range <30 to 78 seconds)</td><td rowspan="2">Sowood and Higenbottam (1989)</td></tr>
<tr><td>2m, hand-pulling along a pipe in water at 5°C</td></tr>
</table>

Table 2 shows that duration of use was limited by an increase in depth and a decrease in water temperature.

3.3 UK military systems - STASS

The Royal Navy first considered the need for an emergency breathing system in 1975 (see Brooks and Tipton, 2001). Whilst it is not thought that HEBE was introduced into service, a report of early trials with the Helicopter Emergency Breathing Equipment (HEBE) supported the introduction of such equipment to allow aircrew to assist passengers. The trials suggested that a facemask was essential if survivors were to escape from a submerged helicopter, but that deployment took 5 to 10 seconds to achieve. More disorientation was produced when a facemask was not worn.

Reader (1990; cited by Brooks and Tipton, 2001) concluded that the provision of an EBS could have saved 50% of the fatalities (n=55) in military helicopter ditching accidents between 1972 and 1988. Of the 28 who might have been saved, 8 were aircrew.

The UK MOD started the procurement process for a Short-Term Air Supply System (STASS) in 1989. In the event of a forced landing on water, STASS was required to assist trained military aircrew in their escape from the helicopter. The initial specification included the following requirements:

- compressed air system (similar to HEED2);
- to be mounted on the lifejacket;
- first-breath activation;
- capacity ≥ 50 litres at 207 bar;
- capable of being purged in any orientation;
- contents gauge;
- able to withstand the forces of ditching and remain fully functional.

Information relating to the selection, testing and development of STASS was not available to the author at the time of writing this report.

The equipment that was selected, HEED 3 (Submersible Systems Inc), was renamed STASS by the UK MoD. STASS/HEED3 has a higher operating pressure allowing a shorter compressed air cylinder compared to HEED2. (STASS/HEED 3 has a gas cylinder rated to 3000psi while HEED2 had a cylinder rated to 1800 psi). STASS is a single-stage breathing device with regulator and mouthpiece, weighing approximately 1.5 lb (0.7 kg). The EBS is stored in a pocket on the right chest area of the lifejacket. A lanyard links the EBS to the lifejacket. Air is instantly available with STASS, there being no on/off switch. A red/green (Go/No Go) contents gauge acts as a safety feature, allowing the user to check that the unit is fully charged and ready for use. A purge button is provided to remove water from the mouthpiece when deploying the unit underwater.

Training was commenced, and STASS introduced during 1992. In the following year, the decision was taken to identify equipment considered suitable for use by ordinary passengers, due to the loss of a number of passengers in uncontrolled water impacts during the previous five year period.

3.4 UK military systems - Passenger STASS

3.4.1 Specification

The specification for an emergency breathing device for helicopter escape by passengers required the unit to be able to be easily deployed and instantly activated by a user suffering a degree of shock. The specification included a target duration of as near to 2 minutes as possible, at a water temperature of 55°F/12.8°C and a working depth of up to 5 metres. In order to facilitate deployment of the system underwater, the EBS would ideally incorporate an occlusion system, so that the user would not have to purge or clear water from the mouthpiece, allowing the user to breathe immediately. It was considered that a nose clip or barrier should be incorporated to reduce discomfort and the potential inhalation of water via the nose. The unit should provide air even if the passenger had no breath. Maintenance should be minimal.

Due to the size, nature and geographic distribution of the possible passenger population, it was considered that in-water training was generally impractical. The aim was to provide an EBS which was easy to use and intuitive, such that the training of passengers could be limited to a briefing prior to making a flight. Equipment designed for use in an uncontrolled water impact, at night and inverted was specified.

3.4.2 **Selection process**

In late 1999, a number of different designs of EBS were evaluated against the requirements of the MoD. The emergency breathing systems submitted for testing included open circuit, semi-closed circuit and closed circuit re-breathers. Evaluation of the equipment covered unmanned measurement of breathing performance (work of breathing and respiratory pressure) plus a more subjective manned assessment made by three members of training staff, all being experienced divers.

The unmanned evaluation of breathing performance showed that, in most cases, the emergency breathing equipment did not meet the NPD/DEn (1991) guidelines (specifying performance requirements for breathing apparatus for underwater operations). Each EBS was immersed in water at 7°C, at simulated depths of 0 metres and 5 metres and, where applicable, at supply pressures of 50 and 150 bar. Breathing performance was measured at ventilation rates up to 90 litres per minute. Poor performance was found in particular at the higher ventilation rates. It was felt that this was in part due to the water occlusion devices within the mouthpieces. Higher levels of performance were observed with designs where the water occluder remained open once the equipment was put into operation. These devices had the disadvantage that they would not re-seal if the mouthpiece was lost from the mouth. (N.B. Whilst every effort should be made to maximise breathing performance, users of these devices are only likely to breathe from the equipment for 1 to 2 minutes in an emergency situation. Higher breathing resistances may be tolerated, though it is important to determine that users can breathe with relative ease in all orientations whilst performing exercise and panic breathing).

A theoretical assessment of gas endurance showed durations of the compressed air units ranging from 45 to 91 seconds. An increase in cylinder capacity was recommended to meet the 2 minute endurance requirement. Concern was raised regarding the possible build-up of CO_2 in the re-breather systems over a 2 minute period, although a fully validated estimation method was not developed.

Overall, it was concluded that no emergency breathing system evaluated could be recommended over any other in relation to unmanned breathing performance.

In the manned trials, a range of questions were asked with regard to performance:

- whether water entered the mouth with the first breath;
- whether it was possible to panic breathe and still get the volume of air required;
- whether the unit could be operated with one hand;
- how easy it was to use the equipment;
- how easy it was to apply the nose-clip and whether the nose-clip was effective;
- whether the equipment could be used when inverted;
- whether it was considered that an **un**trained person could use the equipment.

Five of the eight systems assessed were not considered to adequately meet the requirements defined. Three systems were considered to be partially successful and recommendations were made to improve their performance.

Problems encountered during the initial assessment included the following factors:

- bulky;
- inflexible high pressure hose;
- no nose clip or poor performance of nose clip;
- poor fit of face-mask;
- difficulty locating mouthpiece when underwater;
- two hands needed to deploy equipment;
- difficulty gripping mouthpiece with teeth;
- trickle of water entering the mouthpiece;
- failure of water excluder, often sticking in the open position;
- heavy resistance to breathing, making panic breathing difficult;
- no gas to breathe when inverted;
- problems with CO_2 absorber;
- free-flow of gas around face made it difficult to see.

3.4.3 **Development and testing of P-STASS**

3.4.3.1 Design

Following both unmanned and manned trials, one system was selected for further development and testing (P-STASS – MSI Defence Systems). This was an open-circuit compressed air system. Modifications were made to this equipment to improve breathing performance before it was re-evaluated. The mouthpiece orifice was enlarged, allowing a larger area for inhale and exhale valves to achieve water exclusion.

3.4.3.2 Unmanned tests

Breathing performance tests were, again, carried out in water at a temperature of 7°C, at simulated depths of 0 and 5 metres and with supply pressures of 50 and 150 bar. With the modified unit, values for work of breathing and respiratory pressure fell within the maximum limits of the NPD guidelines (1991). Theoretical gas endurance was estimated using working and minimum supply pressures, cylinder capacity, ventilation rate and absolute pressure. The theoretical gas endurance of 89 seconds estimated for P-STASS was still below the required 2 minutes and it was recommended that this issue should be addressed before the equipment went into service.

Further physical tests were carried out to assess resistance to vibration, shock or a drop onto a hard surface, salt spray, temperature cycling, sand and dust, and immersion at a depth of 10 metres for 2 hours. The equipment was reported to be functional after each of these tests.

3.4.3.3 Manned tests

Work was carried out by the manufacturer to determine the best location for P-STASS on two military lifejackets. Assessments were made by a limited number of trained civilian divers. A position on the right-hand side of the lifejacket was approved. It was recommended that a protective pouch be fitted to the first stage of the regulator to prevent the inadvertent operation of the purge button. Further assessments were then made by a single diver to identify any snagging or other problems during escape from a helicopter simulator. No problems were encountered during egress. The subject was then able to inflate his lifejacket without the EBS impairing the performance of the lifejacket.

Ease of use trials were carried out by six navy divers in water at 25 to 30°C. The divers wore swimwear, the EBS being hand-held rather than integrated into a lifejacket. Four of the six divers found the modified mouthpiece to be too big. The enlarged size of the mouthpiece prevented a good seal from being made and allowed water to seep into the mouthpiece, even after purging. While the divers were able to cope with the water in the mouth it was considered that untrained naïve users could experience problems. This finding demonstrates that the change in design of the mouthpiece had a positive effect on breathing performance but a negative effect on ease of use.

One of the divers found the nose clip very uncomfortable, expressing the need for softer rubber, whilst another diver found the nose-clip difficult to put on whilst underwater and inverted. One diver found that the hose tended to pull the mouthpiece away from the mouth. Overall, unit controls were found to be easy to locate and operate. Further trials at 5 metres depth produced similar results regarding the mouthpiece and nose-clip.

Endurance times measured when three of the experienced navy divers were using the breathing equipment whilst swimming underwater (close to the surface) ranged from 2 min 17 seconds to 3 min 10 seconds. This time is much longer than the theoretical estimate of gas endurance (see 3.4.3.2). Naïve subject trials have not yet been reported. It should be noted that endurance times achievable by naïve subjects may be less than those achieved by trained divers who are experienced in the use of breathing equipment.

Recommendations made following the trials included looking at the softness of the material used for the nose-clip, and investigating the rigidity of the hose when integrating the unit into a lifejacket. A further recommendation was made to progress to trials with naïve subjects. At the time of preparing this report, the naïve subject trials had not taken place.

4 Review of User Performance Trials

4.1 Comparison of a compressed air unit with a re-breather unit

Tipton et al (1997) conducted a study to compare the performance of two types of EBS, a re-breather (Air Pocket) and a compressed air system (STASS). Six subjects undertook tests at a water temperature of 15°C and six at a water temperature of 5°C, performing a simulated helicopter escape. A SWET chair was inverted into the water. The subject had to escape from the chair and then pull himself along a ladder using hand-over-hand techniques. Subjects performed a maximal expiration followed by a large inspiration, then began breath-holding and inserted the mouthpiece of either the 'Air Pocket' or the STASS. The SWET was then lowered and rotated into the water. Subjects breath-held for as long as possible, and then used the EBS for as long as they felt comfortable or until 1 minute had elapsed. Five of the original eight subjects had to be replaced, three because they were unable to use EBS while in cold water. Four subjects were unable to use STASS without a nose-clip.

Five of the six subjects (Subjects 1,4,6,7,8) completed 1 minute underwater using STASS in water at 5°C, while Subject 2 used STASS underwater for times of 41 and 39 seconds. Three of the six subjects (Subjects 1,4,6) completed 1 minute using 'Air

Pocket'. Subjects 2, 7 and 8 used 'Air Pocket' for average times of 32 seconds, 41 seconds and 59 seconds respectively. All subjects preferred STASS under these conditions, citing ease of use, comfort and confidence in using the EBS.

The average pO_2 recorded at the end of the 'Air Pocket' runs at 5°C was 9.8 kiloPascal, with the lowest value being 4.9 kiloPascal. The average pCO_2 was 6.25 kiloPascal, whilst the highest value measured was 7.4 kiloPascal. The minimum oxygen concentrations and maximum carbon dioxide concentrations measured were close to safe operating limits, and would have limited the re-breathing endurance times of the subjects in question. (Values of pO_2 below 4 kiloPascal or pCO_2 above 8 kiloPascal are likely to lead to loss of consciousness).

The authors reported that the performance of both devices improved with in-water training, allowing the users to get accustomed to the *"combined stresses of using a new piece of equipment and performing a helicopter underwater escape"*. It was found to be easier to train people with 'Air Pocket' than with STASS. Some initially found it difficult to breathe underwater using STASS.

In a full report of the trials, Tipton and Franks (1996) recommended *"that the current practice of training aircrew not to go onto STASS until they are submerged is reconsidered. Knowledge that breath hold times may be much reduced in cold water, particularly if individuals are poorly protected or have immersion suits which leak, leads to the conclusion that it would be safer to have any EUBA in situ prior to ditching"*. The medical support team for this study were concerned about the dangers of the subjects gasping (the cold shock response) on initial immersion in water at 5°C. As a result, the deployment of STASS following submersion was precluded, subjects being instructed to insert the mouthpiece before putting the head underwater.

4.2 Examination of EBS for use in Canadian offshore oil operations

4.2.1 Ease of use

The aim of this study (Brooks, 2001) was to review EBS equipment currently available, to enable the Canadian offshore industry to introduce a system for helicopter crew and passengers.

Subjective assessments of the ease of use of six compressed air systems were carried out by seven trained divers. Three naïve subjects assessed the mouthpieces of the compressed air units after training with just one type. Further limited assessments of a hybrid re-breather system were carried out by three divers and one naïve subject. It should be noted that the majority of the assessments were thus carried out by trained divers familiar with using underwater breathing apparatus. It is not stated whether the compressed air systems were deployed prior to submersion or deployed underwater.

No problems were experienced when charging the cylinders. Whilst all of the compressed units had a contents gauge, some were easier to read than others. A semi-circular display was recommended, with 'full' marked on one side (also marked e.g. 3000 psi) and 'empty' marked on the other (also marked 0 psi), with two thirds of the area coloured green to denote 'safe to use' and a third coloured red to denote the 'need for re-charging'.

The on/off operation varied between systems; one had to be turned against the regulator, three systems were ready to go once charged (no on/off knob), one had a knob with positive feel, and one had a spring-loaded sleeve fitted over the knob to prevent inadvertent operation (designed for military use, to be operated on and off before and after a flight). The units without an on/off switch were preferred by the subjects.

When the divers assessed ease of purging in the upright, inverted, left side down and right side down positions, no problems were experienced. No more than two presses of the purge button were needed to clear the regulators. Ease of purging by a naïve subject does not appear to have been evaluated.

Five of the six systems had a hose connecting the regulator to the gas cylinder. It was thus possible to use these systems hands-free following deployment. One unit, which did not have a hose, could be used hands-free by the divers, but this was not achieved by the naïve subjects.

Perceived resistance to breathing was reported to be low. An objective physical test of breathing resistance was not carried out.

When assessing the comfort of the different mouthpieces, the regular diving mouthpieces were preferred. Two systems had been designed to prevent water entry into the regulator on immersion. Both required the mouth to be opened wider, letting water in and negating the original objective of the design. One of these units caused problems as the user had difficulty biting the plastic sleeve to open the port in the mouthpiece.

One of the systems was fitted with a nose occluder, which successfully blocked the nose in SWET and pool trials. A second device had an integral nose clip which only provided a good seal in half of the subjects. It was felt that a stronger spring was required.

Endurance swims were conducted with four of the divers, in water at 24°C and 8°C, and at depths of both 2 feet and 10 feet, to assess the comfort and fit of the mouthpiece and resistance to breathing under different conditions. It is not clear from the report whether the times include the initial responses to immersion, and thus the cold shock effect in the 8°C exercises. If the swims did not include the initial immersion period, then endurance times in water at 8°C would be expected to be less when including a period of cold shock and hyperventilation at the start of the test. Mean endurance times are presented in Table 3.

Table 3 Duration of use when swimming with different compressed air systems (n=4)

Water temperature **Depth**	**24°C** **2 feet**	**24°C** **10 feet**	**8°C** **2 feet**	**8°C** **10 feet**
	Time (min : seconds)			
HABD (Aqua Lung)	2:36 ±1:03	1:57 ± 0.30	2:11 ± 0:50	1:39 ± 0:41
SEA (Aqua Lung)	1:56 ± 0:37	1:12 ± 0.18	1:32 ± 0:37	1:21 ± 0:45
STASS (Submersible Systems)	2:04 ± 0:36	1:28 ± 0.20	1:44 ± 0:52	1:44 ± 0:52
UEM (Mercury Products South)	3:16 ± 1:23	2:34 ± 0.24	3:12 ± 2:07[1]	2:37 ± 1:59[1]
Heloscape (Meggit Avionics)	2:04 ± 0:44	1:24 ± 0.38	1:39 ± 1:01	1:15 ± 0:27
P-STASS (MSI Defence Systems)	3:38 ± 1:33[1]	2:46 ± 1.09	2:31 ± 1:25	1:32 ± 0:41
Average	**2:36**	**1:54**	**2:08**	**1:41**

Data taken from Brooks (2001)

1. One subject with time of > 5 minutes

Large differences were observed between the four divers. Under these circumstances, the minimum endurance time was 53 seconds (SEA, 8°C, 10 feet) whilst the maximum duration was 6 minutes 18 seconds (UEM, 8°C, 2 feet). The mean results confirm that endurance time was reduced by an increase in depth and by a decrease in water temperature.

The author commented on how difficult it was to determine an endurance time for any given unit, given the many different factors which will affect performance (water temperature, depth, size of subject, work rate underwater, level of fatigue, with or without face-mask, charge of bottle). Whilst this is true, when considering the development of a technical standard there is, nevertheless, a need to specify minimum performance to give adequate protection to the individual, even if associated with a set of defined conditions.

The assessment of the hybrid re-breather (Air Pocket Plus) covered some of the areas addressed for the other systems. The contents gauge was found to be clear to read, while the disposable gas cylinder was easy to change. The system was always in the ready mode once a new cylinder and auto-inflation device had been fitted. The system tested was designed with the intention that it should be deployed prior to submersion, thus purging was not an issue.

No breathing resistance problems were reported, although all the subjects (n=4) experienced some light-headedness on surfacing after breathing from the unit for more than 1 minute. Brooks (2001) commented that this demonstrated the need to train users in water, to accustom them to this effect.

4.2.2 Compatibility

The units were tested in combination with a number of different immersion suits and lifejackets. Only one of the lifejackets had been designed to hold an EBS and, even then, the fit was very tight making it difficult to remove. Two units had external bandoliers to hold the EBS and attach the system to the lifejacket.

5 Training Issues

5.1 OPITO Training Standards

In April 2001, a working group was set up by OPITO, to explore the possibility of developing a competence-based training standard for re-breather systems. The need to consider an industry standard was stimulated by the growth in re-breather training, with different operators requesting different levels of training. At the time of writing this report it was proposed that such training should be separate from the other OPITO courses. This was to some extent due to the fact that a majority, but not all, operators had adopted the use of a re-breather. It was also due to the fact that it was considered that several hours of training would be required to ensure competence in water. In future it may be pertinent to incorporate the standards into the basic and further helicopter training courses. Whilst OPITO training standards do not specify the design of personal protective equipment used, it was thought that only one item of EBS equipment (APP) would be adopted by the UK offshore industry, due to the desire for uniformity.

The building up of confidence was considered to be a key issue within the training process. Breathing underwater was thought to be alien to many individuals, meaning that initial training would be needed to overcome the instinctive impulse not to breathe. Provision of a re-breather was considered to be a benefit which would give individuals time to overcome panic and think logically, and time to overcome problems such as a jammed four-point harness. On the negative side, there was concern that additional tasks would be added into underwater training. Concern was expressed regarding the time of deployment of EBS. A benefit of deployment before water contact was considered to be that there would be no actions taken at a critical time, whereas if deployed after water contact, additional actions would be required at a critical time. (N.B. This view was based on a controlled ditching when there would be some warning of water contact).

Any OPITO training standard developed is likely to include knowledge requirements in addition to both dry and wet competence requirements. Training criteria will specify required outcomes.

5.2 Review of best practice

The review of EBS performance and operation has demonstrated that best practice for training involves a progressive stepwise process, which builds up the confidence of the EBS user. Classroom briefings are followed by practical sessions. Trainees first learn to deploy the unit in air, then in water at the poolside, where basic underwater breathing techniques can be developed in both upright and inverted positions. A shallow water escape trainer (SWET) is often used to produce inversion under well-controlled and supervised conditions, before gradually building up to more complex escape tasks using a helicopter underwater escape simulator (HUET). HUET exercises are considered essential if trainees are to learn and become competent in the full process of EBS deployment, integrated into the standard bracing for impact, harness release and escape procedures. Ideally, sufficient time should be provided to ensure that all users are competent in the operation of the EBS and confident in its use on completion of training.

Training staff will generally be trained divers, who receive additional training in the EBS system being operated, and in basic diving medicine. This latter area should cover the causes, recognition and first aid treatment of dysbaric disorders and, in particular, arterial gas embolism. Having experienced a dysbaric injury in a trainee, the UK Royal Navy underwater escape training unit have a medical officer on-site, on immediate standby throughout STASS training operations. It is more commonly accepted that, where training incorporates the use of compressed air whilst breathing underwater, then a recompression chamber must be available for use in the event of a problem.

Medical screening, carried out before training, should include consideration of the use of compressed air.

5.3 Breathing techniques

Experience has shown that most people must be taught to breathe underwater, as it is not a natural action. Individuals must also learn to overcome the hydrostatic pressures experienced at depth, this being a particular problem of re-breathers.

It is general practice for re-breather users to be taught to breath-hold initially, so that re-breathing, when the individual feels the need to breathe, becomes an added benefit. This places emphasis on the need for the user to still take a breath before submersion. This practice should also help to discourage individuals from forgetting to take a breath in their efforts to use the EBS.

In contrast, when breathing on compressed gas systems, users must exhale during ascent to reduce the risk of lung over-pressure. Thus, with any compressed air system it must be stressed that, once the individual has started to breathe from the system they must **not** breath-hold.

Hybrid units have been developed to extend the performance and duration of use of simple re-breathers. Ideally, users should still be encouraged to take a deep breath so that they do not become over-reliant on the availability of EBS. Once the user starts to breathe from the unit it is again important that the individual does not breath-hold due to the additional volume of compressed gas made available.

By adding a cylinder of compressed gas to the re-breather unit, the risk of barotrauma is the same as that of other compressed air systems. Hybrid systems have the advantage that they can be used during in-water training in re-breather mode only. Whilst trainees would not experience the full effect of the system underwater, breathing in a real situation would be easier than that experienced during training. The cost of training (cylinders and maintenance) would also be reduced. If wanted, the charge of gas could be operated under dry surface conditions, without danger, as the user is then not exposed to any change in pressure.

Hayes (1990) reports that the US Navy provide trainees with simple explanations of the physiology and mechanics of pulmonary barotrauma. Training takes place in shallow water using a SWET chair, with the head to mid-thorax level no more than 3 feet (0.9m) below the water surface. They are trained to purge water from the mouthpiece prior to inspiration and to exhale on ascent.

The US Coast Guard does not use a helicopter underwater escape trainer for their hybrid compressed oxygen re-breather training, due to the possible risk of barotrauma from breathing the compressed gas. Students are first trained to breathe underwater without a nose clip but using a snorkel, to open their eyes underwater and continue breathing. They are then taught to clear the mouthpiece and breathe normally from the unit, and to exhale on ascent. They then go on to a progressive series of escapes using the SWET.

Nose clips are not normally provided for the USCG personnel, as it is considered that nose clips add to the complexity of operation. However, it is also recognised that some individuals fail to operate the device successfully during training. If the only way a student can successfully complete the training is by using a nose clip, then this is allowed. (The review of other work provides further evidence that a proportion of the population are unable to cope with underwater breathing without the aid of a nose-clip).

Survival Systems (in Canada) start their aircrew training with basic in-water procedures. The students then demonstrate their ability to purge the unit and subsequently breathe from the EBS for 1 to 1½ minutes. In the SWET they learn to egress using the EBS, while jettisoning an exit, also simulating a failed EBS and a jammed exit. Extensive training then follows in the helicopter simulator.

In the UK, 'Air Pocket / Plus' training concentrates on deployment prior to or immediately following impact, as the current versions of the equipment were designed for the controlled ditching scenario. Military STASS training concentrates on underwater deployment. The latter training is likely to involve higher levels of stress in naïve individuals. Tipton and Franks (1996) recommended against underwater deployment due to the risks of water inhalation during the 'gasp' phase of the cold shock response.

5.4 Buoyancy effects

US Coastguard experience using a re-breather vest with 40 lb (18 kg) buoyancy, demonstrated that there was no significant difficulty escaping from a helicopter simulator using hand-over-hand techniques (Brooks and Tipton, 2001). If reference points were lost users would float up but, with 2 minutes breathing supply, it was possible to re-establish the reference points and pull out of the aircraft.

The US Coastguard re-breather was designed to supplement proven standard egress procedures, and not to interfere with or replace egress standards. They include a warning in their training manual:

> *"Failure to maintain a handhold on a reference point until clear of the aircraft could result in disorientation.*
>
> *Anti-exposure coveralls, wet suits, and inflated life vests all exhibit positive buoyancy which may inhibit egress, but may be overcome by use of standard hand-over-hand egress techniques".*

They also stress that the re-breather vest is not a SCUBA or a salvage device and that users should not attempt to re-enter the aircraft once they have successfully escaped.

5.5 **Competence and confidence levels**

The primary aim of training in the use of EBS is to ensure that the potential end-user is competent in its use and will stand a high chance of deploying the unit correctly in the event of a forced landing on water followed by capsize of the helicopter. Whilst correct deployment will undoubtedly benefit the user and increase the chance of survival, incorrect use could increase the level of risk and reduce the chance of survival. It is therefore important that potential users achieve an acceptable level of competence, which is maintained at an adequate level thereafter.

Consideration must be given to the possibility that some individuals will not become competent in the use of EBS. The UK military have had experience of a small percentage of students who do not successfully complete training with their compressed air system. There is evidence that some individuals find it hard to breathe underwater, or use a system without a nose clip. Brooks (2001) commented that *"when the offshore oil industry decides to introduce an EBS into service, they must establish policies on (a) course training standards, (b) recertification requirements and (c) for those who are initially medically unfit, those who cannot pass the course in spite of their best effort and those who simply refuse to attend"*. Difficult decisions will thus have to be made about how to treat an offshore worker who has successfully completed standard survival training but who cannot cope with EBS.

At present, individuals are flying offshore carrying 'Air Pocket', but with varying levels of training in the use of the re-breather. The UK Royal Navy initially only issued STASS to personnel who had successfully completed training. However, as the proportion of aircrew with training increased, it was decided to install the equipment in the lifejackets, thereby making it available to a wider group of personnel including maintenance, medical and photographic staff. These personnel had not necessarily had training in STASS, but it was considered that, even without training, the equipment could potentially save lives. STASS was not made available to ordinary passengers.

Many of those involved in the training of offshore (and military) personnel consider that the other single most important aspect of training is that the EBS user gains confidence in the equipment, in helicopter underwater escape training and in flying in helicopters. Many offshore workers find helicopter flights to be one of the more stressful parts of their job. Helicopter underwater escape training is also known to cause relatively high levels of anxiety in a proportion of the workforce (Harris, Coleshaw and MacKenzie, 1994), with a potential negative effect on performance during the period leading up to emergency response training. Long-term health benefits can therefore be gained from reducing anxiety due to training and to flying offshore. There is some concern that any increase in the complexity of training may increase levels of anxiety. This can be counter-acted by providing sufficient time for all trainees to gain confidence in the equipment. Careful thought should be given to any change which would make training more difficult and complex, and therefore more stressful.

Experience gained by the Royal Navy suggested that the duration of training was too short for aircrew who lacked confidence or who had a basic fear of water. To address this issue, the instructor/student ratio was increased, as was the time devoted to practical in-water training. Levels of confidence increased as a result, with positive feedback from the trainees.

At the MTC training centre in Holland, a full day is allowed for training. Special attention is given to any students having problems. Longer familiarisation periods are provided whilst additional exercises will be provided if required. On completion, delegates are debriefed to ensure that trainees leave with a positive outcome.

5.6 Training interval

In the UK military, dry briefings on the equipment operation and procedures are conducted every 6 months. Full dry and wet training sessions, including SWET and HUET training, are completed every 2 years. Similar regimes are followed by other military groups.

The military training intervals recognise the complexity of EBS equipment and procedures, and the potential to lose skills which are not practised on a regular basis. In an investigation of retraining periods for helicopter underwater escape Summers (1996) describes the rapid and significant loss of procedural skills. High complexity tasks involving a large number of sub-tasks were more subject to decay than simple tasks involving few steps. Summers cites evidence that high levels of learning can be retained for periods up to 2 years if the original level of learning involves over-practice, over-practice being defined as *"the amount of practise that an individual is given after correct performance has been achieved"*. When levels of learning were tested before and after helicopter underwater escape training, the number of times individuals had carried out training did not effect retention but the time elapsed since the last HUET training session had a significant effect on the level of learning. A longer interval since the last training session was associated with a higher level of learning when further training was given. By inference, this suggested a lower level of information retention from the last training session (Summers, 1996).

Careful consideration thus needs to be given to the interval between EBS training for the offshore workforce. If an OPITO training standard is adopted it will be necessary for a training interval to be set down to establish the frequency of further training. It is likely that wet training with EBS will be tied in with helicopter underwater escape (HUET) training, and hence, a further training interval of 4 years seems likely in any future OPITO training standard. Given the issues regarding training interval, there are likely to be benefits from providing wet or, if wet is not practicable, dry training with EBS at shorter intervals, to ensure that users remain familiar with the deployment of the equipment. It would also be necessary to include a demonstration of EBS deployment in the pre-flight briefings to provide a consistent approach to personal protective equipment. It should be borne in mind, however, that there is already concern regarding the length of pre-flight briefings. Content should therefore be confined to key information.

6 Operator Viewpoint

6.1 Implementation

It is believed that the majority of UK oil and gas operators (estimated 80%) have now implemented or committed themselves to the use of a re-breather for helicopter escape. Some have consulted their work force and have either decided against implementation (one operator) or have not yet made a final decision. At the time of writing, one company was planning further trials to re-evaluate whether or not to adopt EBS. They expressed concerns about the repeatability of performance of the equipment. Their Safety Committee considered that further development of the equipment might still be needed.

Several companies commented that peer pressure and economic considerations relating to helicopter sharing had influenced the decision-making process. One company was known to have carried out a formal risk assessment as part of their decision-making process and were unwilling to implement use of EBS until this had been completed. There still appears to be a 'patchwork' of views, and a general feeling that different companies have a number of different stand-points. The Unions were reported to be *"vociferous that the industry aren't getting their act together"*. Different devices were coming onto the market and, without a technical specification, it was thought that this could raise further problems.

Whilst it was felt that there was a need to take an industry view, it would not be possible to have an industry mandate. A view was expressed that this would have to come from the CAA. This view was mainly influenced by the problem of companies working not just in UK or European waters, but also world-wide.

6.2 Harmonisation

Overall, there was a strong desire to harmonise equipment and procedures, allowing individuals to move between companies without the need to re-train on different designs of equipment. As a result, all those adopting EBS have selected 'Air Pocket' or 'Air Pocket Plus', despite some companies preferring other options.

The sharing of helicopters was currently an issue affected by the implementation of EBS. At least one company who was already carrying EBS was not willing to share with any company not using EBS and, thus, sharing had not taken place to date.

6.3 Ease of use

6.3.1 Time of deployment

It was accepted by all that re-breathers were introduced to reduce the risks of cold shock on ditching. Views were expressed that, if suffering from cold shock, it would be better to have the mouthpiece in place prior to submersion. It was felt that underwater deployment could cause problems with the confidence of the potential users. Also, the view was expressed that underwater deployment could slow down escape.

Several companies felt that they were now getting conflicting advice regarding the accepted time of deployment, i.e. whether before or after impact. Some thought that the risk of injury on impact was outweighed by the possible benefits of early deployment before a ditching. Their aim was to make passengers more comfortable when flying, and reduce levels of anxiety and panic. They felt that in an uncontrolled crash, passengers were likely to just try and get out of the nearest exit and were likely to forget the re-breather.

6.3.2 Bracing position / harness compatibility

Two of the major oil companies have recently identified problems relating to deployment of the re-breather when in the brace position. The problem related to two helicopter types, both having seats fitted with lap-belt harnesses. Members of the work force had tried to adopt the brace position but been unable to get the chin in the right position to deploy the mouthpiece.

On investigating the problem, the issue had been resolved for one helicopter type. Further trials have been conducted in the second helicopter type. Use of the re-breather on this latter helicopter is still suspended at the time of writing this report, pending a final decision on the safety of the brace position. This is not an issue if EBS is deployed after water impact.

6.3.3 **Confidence in ability to escape**

One company stated that, having introduced re-breathers, they *"couldn't take them away from the work force"*. Re-breathers were adopted by this company following a Union statement that *"whilst it [the re-breather] may not be the answer to all the problems it is incumbent on operators who do not use it to show good reason why not"* (Energy News, July 1998). The company in question decided to get the work force involved and carried out pool trials, using a helicopter underwater escape training simulator (HUET). Initial concerns included the question of whether they wanted to carry and use another piece of personal protective equipment. This was balanced against the problems of cold shock, the gasping reflex and the need to address this problem. It was thought that panic would also reduce breath-hold time. The company were also keen to address issues of fear and panic associated with HUET training. They had previously had problems with people completing the standard training without getting the benefit of increased confidence. Those involved received additional training with the re-breather, with a positive outcome, gaining in confidence. The overall response was good and endorsed the adoption of EBS equipment.

6.4 **Training**

Several companies only offered dry training at the time of writing. In one case, this was due to the logistical problems of having operations in many different countries. Most of those contacted supported the need for realistic wet training and thought that this should be implemented in the future. Those who had undertaken to carry out wet training had found it to be beneficial. One individual felt that the use of a re-breather would allow more realistic training to be carried out, without adding to the stress of training. However, another individual was concerned that harder training would introduce more fear. These two factors need to be balanced.

Several operators expressed the view that they would like to see EBS training as part of the helicopter underwater escape training process, ensuring a single standard of training. Different operating companies following different training policies could lead to problems with the records of individuals moving between companies. This was a particular problem when considering the management of contractors.

It was accepted that wet training would add to the overall cost of training. Further costs would be incurred due to maintenance, the disinfecting of equipment, and the replacement of gas cylinders where appropriate.

One offshore operator was reported to have adopted EBS, but was giving no training as they did not feel that there was any overall benefit of using EBS.

Kent Fire Brigade, who use helicopters to fly out to fires on vessels in the English Channel, have opted to use a compressed air device due to the fact that all of their personnel were already trained in using compressed air breathing apparatus. This was therefore the obvious choice to make in such circumstances.

7 Gaps in Current Knowledge

From the review of EBS development and operation, a number of knowledge gaps have been identified:

- Underwater deployment of EBS, in both the upright and inverted positions.
- Underwater deployment of EBS in cold water (<12°C), to demonstrate the influence of cold shock on ease and duration of use. (Experience has shown that it may be difficult to obtain ethical approval for such work).
- Consideration of EBS deployment time, to enable an appropriate time limit to be placed in the draft technical specification. It has been suggested that the maximum time allowed for deployment should be linked to the shortest maximum breath-hold times in cold water, to cover the worst case of underwater deployment. Further work would also be needed to increase the amount of available data relating to cold water breath-hold times.
- Use and reliability of nose-clips/nose occluders - it is has been shown that a proportion of the population are unable to use EBS without the aid of a nose clip. However, consideration needs to be given to the design of nose-clips/nose occluders to ensure a good fit on all users in addition to rapid and simple deployment.
- Values for buoyancy of EBS currently on the market.
- Success/failure rate - a measure of the reliability of EBS when deployed by relatively naïve subjects.

Part C Analysis

1 Benefits and Disadvantages of Using EBS

1.1 Helicopter water impacts and incidence of drowning

The brief review and analysis of accident data given in Part B Section 1.1 demonstrates some of the problems in drawing conclusions from accident data. Accidents have occurred under a wide range of conditions which can greatly affect the outcome, whilst the severity of the accident has a large influence on the problems experienced. That said, it is possible to draw some general conclusions from the data.

Clifford's (1996) review of world civil helicopter accidents demonstrated the large differences in the survival rates from different types of water impact, ranging from 99% survival in controlled ditchings, to 20% survival in uncontrolled impacts.

Drowning was the primary cause of death in fly-ins and vertical descents with limited control, whereas uncontrolled impacts were associated with a high incidence of fatalities due to both drowning and impact injuries.

The overall accident rate for the UK North Sea is relatively low, with only one fatal accident in the last 10 years. North Sea statistics also show that in the event of an accident, a controlled ditching is more likely to occur than a survivable crash. As referred to in the RHOSS report (CAA, 1995) the term ditching *"presupposes some measure of warning and a relatively benign sea state …"*. As described in Part B Section 1.1, whilst a large proportion of ditched helicopters have capsized, the fatality rate is low. In some cases, the occupants have completed an evacuation before capsize, whilst in others the occupants have made a successful underwater escape. Controlled ditchings are thus of relatively high probability but lower consequence than crashes. However, the offshore industry are still concerned by the high incidence of capsize and are looking for means both to reduce the risk associated with, and increase confidence in helicopter transport. The importance of confidence in flying should not be underestimated given its potential effects with regard to the health of the offshore worker.

In contrast, survivable crashes are less probable, but the chances of survival are lower. 'Fly-in' and 'vertical descent with limited control' accidents are the most likely event where lives could be saved, taking account of the high incidence of drowning and relatively low incidence of impact injuries. In the Brent Spar (AAIB, 1991) and Cormorant Alpha (AAIB, 1993) accidents, seven passengers with no or only minor injuries failed to escape. These lives could potentially have been saved by the use of EBS.

1.2 Human factors and ergonomics of escape

1.2.1 Cold shock, breath-hold and escape time

The water temperature of the North Sea can be as cold as 4°C at certain times of the year. On initial immersion, the risk of drowning is increased by the responses to cold shock. Cold shock develops within the first few seconds of exposure to cold, with the maximum threat during the first 20 to 30 seconds of immersion. The body then habituates over a period of 2 to 3 minutes. Due to the effects of cold shock, breath-hold time in cold water whilst at rest and under laboratory conditions can be as little as 6 seconds and is on average less than 20 seconds.

It has been estimated that in a real accident it may take 60 seconds to make an underwater escape from a helicopter. There is therefore a gap between mean breath-hold time and escape time which is likely to result in drowning. The primary consideration when specifying EBS is thus that it should be able to extend underwater survival time to at least equate with escape time. Required performance durations of 1-2 minutes have therefore been set by the majority of user groups selecting EBS.

Trials of products currently on the market, suggest that a majority of users will be able to breathe for at least 60 seconds when using EBS whilst exercising in cold water. Shorter breathing times have been achieved by some subjects but, when measured, these times have been at least double the breath-hold time of that individual (e.g. a maximum breath-hold time of 9 seconds and a breathing time with EBS of 34 seconds). These factors need to be considered when specifying performance standards.

For EBS to provide maximum protection against the responses to submersion and cold shock, the equipment should ideally be deployed just before submersion. If there is insufficient time to deploy before submersion or capsize, as will likely be the case with fly-in and uncontrolled impacts, then the individual must first overcome the effects of in-rushing water, possible inversion and consequent disorientation. At this point, a decision must be made whether to escape as quickly as possible without aid, or whether EBS deployment is essential for the individual to make an escape. This action is likely to delay escape by 5 to 10 seconds, but could give the user additional time to release a harness, operate and push out an exit, cross the cabin, or overcome any problems due to the impact and damage to the helicopter structure. (It should be recognised that some individuals will be able to breath-hold for long enough to escape without the need to use EBS).

Individuals who are least likely to benefit from EBS in the event of a crash impact are those with very short breath-hold times in cold water, who may not survive the initial seconds after impact. However, these individuals are also the group who would benefit most if they could succeed in deploying the equipment underwater, as they would be unlikely to survive a capsize without such an aid. For this reason it is important to consider the relationship between breath-hold time in cold water and the time taken to deploy EBS in this worst case situation.

1.2.2 Anxiety

In addition to cold shock and disorientation, helicopter passengers are also likely to experience high levels of anxiety during any helicopter water impact. Experience has shown that EBS can have a calming effect on victims undertaking helicopter underwater escape, giving them time to think. The calming effect of a re-breather has also been reported when individuals have been trapped or have had difficulty releasing their seat harness. Some individuals may respond to the situation by failing to act (Muir, 1999; Coleshaw, 2000), delaying their own escape and potentially that of others. EBS could be of benefit in such a situation, again allowing the individuals time to overcome the effects of the accident.

Conversely, high levels of anxiety may result in reduced performance levels and make the task of deploying EBS more difficult. Equipment design should therefore be simple in order to increase the likelihood of successful deployment.

Individuals suffering excessive levels of anxiety are also most likely to rush the escape process and forget or fail to correctly carry out actions such as the release of a harness. EBS are likely to be of benefit in such situations, as long as the individual can succeed in deploying the EBS. This is another scenario where those most at risk have the most to gain from the equipment. Training should ensure that users are competent in the operation of the equipment.

1.2.3 **Escape blocked by another individual**

Some concern has been raised about the possibility that a passenger in a central seat, who wishes to escape as quickly as possible without EBS, may be hindered or blocked by a passenger in an outer seat who is taking time to deploy EBS. Whilst this is a possibility, several other points must be considered:

a) If EBS is deployed prior to submersion, then the actions of deployment will not hinder the underwater escape of the user or of others, although the calming effect may lead to a longer escape time.

b) Anyone who tries but fails to deploy the unit before submersion is less likely to try again once underwater.

c) Individuals are only likely to contemplate underwater deployment of EBS if they would not otherwise succeed in completing an escape.

It is this latter individual who could block the escape of another. This will only be a problem if the second party has decided to make an escape without the need for EBS deployment. This is less likely to be the case for someone sitting in a central seat, as there is plenty of anecdotal evidence that passengers who do not get a seat near an exit or escape window feel vulnerable about the time needed to make an escape.

1.2.4 **Jettisoning of exits**

Problems experienced in releasing an exit will slow down the escape of all individuals hoping to use that exit. The use of EBS under such circumstances would provide more time and a greater chance of making an escape.

1.3 **Physical performance and operational envelope**

1.3.1 **Cold water performance**

To assess personal protective equipment for use in the North Sea or similar hostile areas, it is necessary to ensure that the equipment will function when the user is immersed in water as cold as 10°C. Testing must be conducted to demonstrate that the equipment will function correctly in cold water, and to measure the duration of use in cold water from the moment of immersion to the tolerance time of the subject. This cold water test must include the initial period of immersion to incorporate the effects of the cold shock response.

Research has demonstrated that the metabolic demands of exercise will reduce the duration of use of EBS. In the case of compressed gas systems, the capacity is utilised more quickly due to an increase in respiratory minute volume. In the case of re-breathers, oxygen content will fall more rapidly and carbon dioxide content of the re-breather bags will increase more quickly. It is therefore recommended that the cold water performance test should incorporate some form of activity, with a controlled work load.

In developing a test for cold water performance, conditions such as water temperature, depth of immersion, orientation, level of clothing, level of activity and procedures must be clearly laid down to ensure consistent and repeatable results. EBS performance is greatly affected by the individual capabilities of the user, their breath-hold and personal endurance times. A larger than normal subject sample size will be needed to take account of the variability due to these physiological influences.

1.3.2 Depth

The are few reports relating to the performance of EBS at depths greater than 6 metres. Escape from greater depths will extend the escape time and thus the need for assistance with breathing. However, increasing depth may limit the performance of both re-breathers and compressed air systems. The increased pressure is likely to increase the resistance to, and work of breathing from a re-breather and will therefore limit the operational envelope. With compressed air systems, duration of use will decrease as the depth of use is increased.

It was considered important that EBS performance should be maximised to work at depths where victims have the greatest chance of making a successful escape. It is thus proposed that unmanned tests of breathing performance should be conducted at simulated depths of 0 to 4 m.

1.3.3 Orientation

Evidence shows that the work of breathing, breathing resistance and hence ease of use of EBS are influenced by the orientation of the user. The face-down horizontal position has been shown to cause the highest levels of resistance when using a re-breather.

In trials carried out by the UK MoD, problems were experienced when attempting to breathe in the inverted position with a number of re-breather, compressed air and hybrid systems. All of the systems under test were designed for underwater deployment. (The test subject expired fully, inserted the equipment into the mouth and then started to breathe in from the unit).

Measures should therefore be taken to ensure that equipment will function adequately when deployed or used in the inverted position. Tests should include physical tests of breathing resistance using a breathing machine. If satisfactory results are obtained from the unmanned tests, further manned trials should be carried out, with subjects using the equipment in face-down and inverted positions, and then carrying out escape from a submerged and a capsized helicopter simulator.

1.4 Ease of use and potential failure to operate

1.4.1 Deployment

Ease of deployment and operation of EBS are influenced both by the design of the equipment and by the capabilities of the user.

It is intuitive that ease of use will be maximised by simple design. Complexity will be increased in-line with the number of actions which need to be performed to deploy and operate the EBS. Equipment which can, if necessary, be deployed with one hand will be an advantage if the EBS has to be deployed at a critical time, or when underwater when the user should use the other hand to locate and maintain contact with the nearest exit.

Operating failures are generally related to the sequence of actions taken to fit the mouthpiece and nose-clip, and then either switch from breathing atmosphere to breathing into a bag or, with compressed air systems, purging a regulator. Whilst each action is relatively simple, training is generally required to ensure that the user can carry out the actions quickly and in the correct sequence.

Some individuals may never have fitted a mouthpiece before, and fail to position the flange between the lips and gums. This can lead to leakage problems around the mouthpiece and an inability to achieve a good seal. The user must then cope with water in the mouth. There are some cases where the size of the mouthpiece has been increased to reduce breathing resistance, with the result that users found the unit leaked and was uncomfortable. When designing the mouthpiece, compromises may have to be made between comfort and breathing performance.

The use of a mouthpiece can cause a subconscious change in breathing pattern, at least under training conditions, when the individual is very focused on the activity of breathing. Further, the hydrostatic pressure of water greatly increases breathing resistance and individuals may have to overcome some panic when this is first experienced. These latter two points can both be addressed by in-water training.

Some nose-clips are better than others, but few fit everyone due to the many different sizes and shapes of noses. If no nose-clip is provided, end-users will need special training to breathe under water without using the nose. Such training could take a considerable amount of time. Some individuals will not be able to cope without a nose-clip. Nose occluders may avoid the problem of different nose sizes and shapes which affect standard nose clips, deserving further investigation. By forming an integral part of the mouthpiece, the nose occluder does not require any additional actions on the part of the user during deployment and thus could improve ease of use.

Some reports of failure to use an EBS occurred when the mouthpiece had to be twisted to allow the subject to breathe from a counter-lung. This was either a sequence problem or, in a number of cases, the subject was not sure whether or not the action had been carried out due to a lack of sufficient positive feedback. This type of problem can be minimised by an improvement to the design or by training and familiarity with the equipment.

If underwater deployment is introduced, this may increase the complexity of the training and could increase the fear, both of helicopter escape training and of flying in helicopters. Great care must therefore be taken to match the extent of training to the needs of the individual.

1.4.2 Purging

Underwater deployment of EBS, particularly when inverted, carries the risk of admitting water into the mouthpiece, the volume of water involved depending upon the dead space of the unit in question. In order to cope with this water, it must either be possible to purge the unit, or the user must learn to swallow the water. Both options carry the risk of operator failure. This risk could be reduced by design and/or by training.

1.4.3 Buoyancy

Even without EBS, trapped buoyancy in an immersion suit will mean that the individual may float upwards if not holding on to location points whilst making an underwater escape. Thus, any actions which require two hands should ideally only be required before submersion or, if after submersion, be carried out using only one hand and prior to release of the harness. Following release of the harness, individuals must ideally be able to keep one hand in contact with part of the helicopter structure. Any loss of contact is likely to increase the time taken to escape. For this reason, it is important that EBS can be deployed using one hand and can be used hands-free once deployed, allowing the escapee to concentrate upon finding hand holds and making a quick escape. That said, if an individual does lose contact during escape and float away from the exit, EBS may be of benefit by extending the underwater breathing time and allowing the individual time to re-orientate themselves and work their way back to the chosen exit. In a real event, visibility is likely to be poor, and the individual may well have sustained injuries. Emphasis must therefore be focussed upon making all aspects of escape easier, without adding any factors which would hinder the overall escape process.

There are some reports of additional buoyancy with re-breathers making manoeuvring within the cabin more difficult. This emphasises the need to assess the functional buoyancy of the total system (immersion suit, clothing, un-inflated lifejacket and deployed EBS), the accepted limit being a total trapped buoyancy of 15 kg. In addition, a helicopter underwater escape test should be performed to determine whether the buoyancy of the EBS impairs or prevents escape.

In terms of training, students should be instructed in the need to maintain contact with location points after deploying EBS, and use hand-over-hand techniques to pull themselves towards an exit.

1.5 Compatibility with other equipment

1.5.1 Accessibility

In general, it is necessary for EBS to be close to hand to allow rapid deployment in an emergency. Hose length should be kept to a minimum to reduce the snagging hazard. It must be easy for the user to find and locate the EBS immediately. The user should be able to grab the EBS when in a hurry, without any confusion.

When considering where EBS should be stored, various options are possible. The early versions of 'Air Pocket' were incorporated into the immersion suit to provide an integrated system for North Sea use. Later models were incorporated into a separate pouch, fitting between the lobes of a lifejacket, so that the unit could be used world-wide, including areas where immersion suits might not be utilised. This also made maintenance of the units more cost effective.

At least one lifejacket is known to have been designed with a pocket to carry a compressed air cylinder. Other units may be carried on an immersion suit. If worn by the person, there are two options. Units without a hose will have to be removed from the pocket for use. The unit must be secure in the pocket, but not too tight to prevent rapid release when needed. Units with a hose may increase the snagging hazard, but the user will only need to release the mouthpiece and regulator, with the cylinder remaining in place. This type is likely to be easier to deploy one-handed and use hands free once deployed, with less weight in the mouth.

1.5.2 Compatibility during use

To function correctly, equipment compatibility and the innocuousness of EBS must be considered.

Compatibility problems have generally been considered at an early stage in the development of EBS. It has sometimes been reported that EBS *"got in the way"*, although there was little evidence of impairing helicopter escape. There are some reports of pockets to hold EBS being very tight, making it difficult to remove the cylinder. It is therefore important that suit and lifejacket compatibility are assessed during the approval process, with the lifejacket inflated following escape to ensure that function is not impaired by the EBS.

EBS must be compatible with the harness system and not hamper harness release. There is limited evidence that some pocket covers could impede harness release. This should also be assessed during approval of the system.

Recent experience reported by users suggested that there could be a problem utilising EBS in helicopters fitted with lap belts. When adopting the brace position, users experienced difficulty in deploying the mouthpiece. No such problems were found with the four-point harness brace position. Earlier research with the re-breather system resulted in a recommendation that users should not fold their arms across the re-breather bag as this could make inflation difficult. It can be concluded that the performance of a re-breather bag may be impaired if the bag is restricted in any way. Potential problems with the forward-bent bracing position have since been eliminated by instructing users to deploy the EBS after landing or impact with the water.

1.6 Potential injury and medical risk

The risks associated with using compressed gas, resulting in barotrauma, are covered in Part B Section 1.7 of this report. Whilst the risk is unlikely to have any significant consequence in a real accident, it does pose problems for training. If an offshore work force of 20-30,000 were to receive wet training using a compressed air unit, with each individual undergoing training every 4 years, then there is potential for a small number of cases to occur during training over a period of years. This small risk can be reduced by restricting the use of compressed gas underwater, by staff training to recognise any problems, and by the provision of recompression facilities.

There is also concern that soft tissue injuries to the face could present if EBS were to be deployed prior to impact. This risk can be avoided by instructing users not to deploy EBS before impact with the water.

1.7 Policy relating to health and safety requirements

When considering the legislation relating to personal protective equipment, then any equipment which is not covered by CAA or JAR regulations should meet the requirements of the Personal Protective Equipment Directive (89/686/EEC), thereby ensuring that the product is safe to use and fit for purpose. The basic health and safety requirements of the PPE Directive cover design and comfort, performance, innocuousness, compatibility and information for users. Requirements for EBS that meet these headings were summarised by Coleshaw (2000). These issues should ideally be incorporated into any draft technical standard for EBS.

1.8 Summary of benefits/disbenefits

1.8.1 Benefits

The primary benefit of EBS is obvious, enabling users to overcome the effects of cold shock and allow the user to breathe underwater. This provides the user with an extended underwater survival time, significantly longer than breath-hold time. EBS provides a means of bridging the gap between breath-hold time and escape time, thereby improving the prospect of survival.

The review of real accidents and equipment trials has demonstrated that many individuals find that, once competent in its use, EBS reduces anxiety and panic whilst performing helicopter underwater escape. This will increase the likelihood of a positive outcome from training and have the knock-on effect of increasing confidence in helicopter flights.

Successful deployment would allow the user additional time to complete a number of complex actions which must or may have to be undertaken in the process of escape:

- overcome panic and disorientation;
- release the seat harness - particularly if the harness jams or snags;
- locate an exit - allowing time to cross the cabin if the nearest exit route is blocked;
- jettison an exit - operate a handle, remove window rip cord, push out window;
- escape through exit - overcoming any snagging due to structural damage of the airframe;
- overcome impact injuries which would slow but not prevent escape.

For EBS to be of overall benefit to the end-users, it is essential that the advantages of EBS use significantly outweigh any potential disbenefits. The consequences of many of the potential disbenefits identified in Section 1.8.2 must be balanced against the additional underwater escape time provided by a correctly functioning EBS.

Cases of drowning have been shown to significantly exceed fatalities due to impact in all types of water impact except for survivable uncontrolled crashes e.g. Brent Spar (see Part B Section 1.1). Theoretically, those who have drowned in helicopter accidents without suffering serious injuries could have been saved by the successful use of EBS.

EBS are likely to be of little or no benefit to individuals who are seriously injured by impact with the water, particularly serious head and facial injuries or hand/arm injuries which would prevent deployment.

The benefits of EBS will be enhanced by approval testing to ensure that EBS equipment is simple to use, is capable of being deployed within a relatively short time period, and provides the required level of breathing performance.

Training should be designed to progressively build up competence and confidence in use, thereby reducing the risk of human error during operation. Maximum benefits will be achieved if training incorporates both dry and wet components, and the conduct of helicopter underwater escape exercises. One of the overall aims of training should be to increase confidence and reduce the fear of flying.

1.8.2 Disbenefits

When evaluating the potential problems or disbenefits of using EBS, it is difficult to develop a risk matrix due to the complexity of the helicopter escape scenario. Performance will be influenced by an *"interaction of training, equipment, helicopter design, individual capabilities, environmental condition … and more"* (Miles, 2000).

In Table 4, potential disadvantages have been listed in the sequence they might occur during a helicopter escape. The estimated ratings for the likelihood and severity of problems are estimated for a generic item of EBS. These estimates are purely qualitative as EBS have only been used in a small number military helicopter accidents. In order to provide quantitative assessments of risk, it would be necessary to set up a database, collating information from future accidents where EBS is utilised.

For any given item of EBS, the qualitative estimates of likelihood and severity will vary, dependent upon the design of the particular EBS equipment and levels of performance in the given area of concern. The level of risk will be reduced by good equipment design and performance, and use by individuals who have been trained to a level where they are competent and confident in the use of the equipment.

Great care should therefore be taken when interpreting the results of this analysis. The potential disbenefits of use detailed in Table 4 must be weighed against the potential benefits described in Section 1.8.1.

Table 4 Qualitative assessment of the potential disbenefits of using EBS (generic design)

Potential Disbenefits	Potential Consequences of Failure / Disbenefit	Likelihood*	Severity*	Actions / Possible Mitigation
Failure to deploy.	Time taken attempting to deploy EBS will delay possible escape.	D: Low C: Medium	D: Medium C: High	Testing: Assess ease of use. Ability of user to deploy repeatedly, without failure. Must be capable of being deployed within time limit; Training: Progressive training in dry and wet conditions, and performing helicopter underwater escape.
Risk of mouth injury if deployed prior to impact.	Possible inability to deploy EBS as direct effect of facial injury. Pain/stress of injury may reduce probability of making escape.	D: Low C: High	D: Low C: Medium	Testing: Sledge test to assess risk; Improve design of mouthpiece; Valid deployment procedures.
Inability to obtain good mouth seal and block off nose.	Leakage of air. Reduced performance and reduced benefit from EBS.	Low/Medium	Low/Medium	Design of mouthpiece and nose-clip/occluder; Testing: Ease of use; Training: Deployment of mouthpiece, underwater breathing.
Potential problems caused by added buoyancy.	Greater difficulty reaching and escaping through exit.	Low/Medium	Low	Testing: Limit maximum functional buoyancy; Training: Hand-over-hand escape techniques.
Hands used to deploy EBS may result in failure to keep contact with exit reference / location point.	Increase in time to escape or, failure to locate exit. (Unlikely to be a problem if deployed early, prior to submersion).	Medium/High	Medium/High	Design: Single-handed use; Training: Hand-over-hand escape techniques.
Possible high breathing resistance and work of breathing.	Limited advantage over taking normal breath-hold. Concentration on breathing rather than making escape.	Low/Medium	Low/Medium	Testing: EBS to meet breathing performance limits.

D = controlled ditching C = crash landing *Qualitative ratings only

Table 4 Qualitative assessment of the potential disbenefits of using EBS (generic design)

Potential Disbenefits	Potential Consequences of Failure / Disbenefit	Likelihood*	Severity*	Actions / Possible Mitigation
May be difficult to breathe from EBS when inverted.	Limited advantage over taking normal breath-hold. Concentration on breathing rather than making escape.	Medium	Medium	Testing: Ensure adequate performance of EBS in different orientations; Training: Breathing from EBS whilst inverted.
Individual having difficulty deploying EBS underwater may hinder escape of a 2nd individual.	Increase in time to escape. Could be critical if the second party is not using and getting benefit from their own EBS.	Low	Medium/High	Training: Ensure competence to rapidly deploy EBS following agreed procedures. (Second party may benefit from EBS use.)
Snagging hazard.	Increase in time to escape.	Low	Low/Medium	Testing: Ensure no snagging problems during helicopter escape.
Compatibility problems.	EBS impairs performance of other equipment.	Low/Medium	Low/Medium	Testing: Assess EBS with lifejacket, immersion suit, harness and any other associated equipment.
Increase in training demand.	Increase in the physical and psychological demands of training. Increased costs.	High	Low	Training: Ensure that training results in a positive outcome.
Small risk of barotrauma when training with compressed air systems.	Injury to the lungs, ears or nasal cavities.	Low	High	Training: No breath-hold at pressure/during ascent when breathing compressed gas; Ensure that trainers are aware of potential hazard and capable of recognising symptoms; Provide recompression facilities.

D = controlled ditching C = crash landing *Qualitative ratings only

2 Conclusions

a) EBS are capable of producing a significant extension to underwater survival time.

b) EBS can provide a means of bridging the gap between breath-hold time and escape time.

c) Emphasis should be placed on the deployment of EBS after landing on the water, but before submersion.

d) Reliance on EBS for escape should be minimised; in the event that underwater deployment is necessary, occupants should attempt to gain maximum benefit from the breath-hold time available and only use EBS if escape would otherwise be impossible.

e) Efforts should be made to reduce the risks of equipment failure.

f) Satisfactory performance of EBS is dependent upon an interaction between:

- good design;
- ease of use;
- performance on demand;
- human individual capabilities;
- training;
- environmental conditions;
- helicopter design;
- impact type.

g) A technical standard is needed to ensure that minimum acceptable levels of performance and health and safety standards are met. Any standard produced should incorporate clear pass/fail criteria for tests.

h) Adequate training should be provided, to maximise the benefits of EBS and minimise the risk of human error. Training should include:

- progressive development of knowledge, competence and confidence in use;
- dry and wet training.

i) It is recommended that further work be carried out to increase knowledge of EBS performance in the following areas:

- underwater deployment of EBS, in upright and inverted positions, and in cold water;
- deployment times under realistic conditions;
- nose occlusion;
- EBS buoyancy;
- EBS reliability in terms of success/failure rates.

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Appendix A Example Draft Technical Standard for Helicopter Emergency Breathing Systems

Foreword

The draft requirements and tests described in this document are provided to give an outline of the issues which should be covered by a technical standard.

When preparing such a standard, consideration needs to be given to the fact that the equipment in question is designed for emergency use only. This has several implications:

a) Individuals are only likely to breathe from the unit for a maximum of 2 to 3 minutes and in some cases for less than 1 minute. Higher breathing resistances and work of breathing can therefore be tolerated compared to a system designed for constant use of several hours. The final agreed requirements are therefore likely to differ from the figures given in current industry guidelines and international standards for underwater breathing apparatus.

b) Servicing and maintenance requirements will be influenced by the fact that the equipment will not normally be used.

c) The extent of the standard should be limited to the key safety and performance functions in this context (e.g. not include specific requirements relating to hoses).

That said, it is considered that reference should be made where possible to validated test procedures currently applied to breathing systems. Explanatory comments and areas of uncertainty requiring further work are placed within [square brackets].

For ease of reference, test methods are currently grouped with the relevant requirements. In a final document, a single section covering all of the test methods should be considered.

It is recommended that the technical standard should incorporate a section on pass/fail criteria for tests using human subjects.

1 Scope

This example technical standard applies to breathing systems for use by helicopter passengers and crew in the event of an emergency landing on water. The example standard is based upon deployment of the emergency breathing system following water contact but before submersion. Nevertheless, the emergency breathing system must still be capable of being deployed underwater.

The objective of this example standard is to ensure compliance with minimum health and safety requirements, to ensure that the equipment has no detrimental effects on other equipment, and to ensure that the equipment presents a minimal hazard in relation to escape from the helicopter.

[This draft document does not currently include any specific requirements or tests for cockpit compatibility. Nor does it include any requirement for servicing, maintenance and marking etc. Standard requirements to cover these areas will need to be added at a later date.]

2 Definitions

Emergency breathing system (EBS)

A system designed to significantly extend the survival time underwater, thereby improving the probability of successfully escaping from a submerged helicopter.

3 Test subjects for manned tests

Manned tests shall be carried out by naïve subjects with no previous experience of using breathing equipment.

At least 10 subjects* shall be used, with at least one subject in each of the following height and weight categories:

Height	Weight
1.4 m – 1.6 m	< 60 kg
	> 60 kg
1.6 m – 1.8 m	< 75 kg
	> 75 kg
1.8 m – 2.0 m	< 90 kg
	> 90 kg

*N.B. This number is higher than that used in other equipment standards as the performance of this type of equipment is highly dependent upon the individual responses of the user.

The subject group shall be representative of the user population in terms of age, gender and body build.

Each subject shall wear test clothing in accordance with Part B Section 6.3 and Appendix 2 of CAA Specification No.19, Issue 1, 1991. Each subject shall wear an approved helicopter immersion suit with hood, an approved aviation lifejacket and appropriate footwear.

4 Requirements and tests

4.1 General

Laboratory and practical performance tests are included for the assessment of compliance with the requirements. Not all of the requirements and/or tests will necessarily be appropriate for a given design of equipment.

Where applicable, the equipment shall be evaluated in combination with associated equipment such as an approved lifejacket and immersion suit. It shall be deployed in the same manner as it would be in a helicopter, and from the intended storage position.

All samples shall pass all objective tests to meet the requirements of this document. It shall be demonstrated that the equipment is reliable and will function on demand at all times.

4.2 Design

The equipment shall be of simple design, capable of being operated with one hand. The number of actions shall be minimised, ideally, with a single action for activation.

The equipment shall be as light in weight as possible without prejudice to the design strength and performance.

The emergency breathing system shall be compatible with other items of personal protective equipment being worn, such as a lifejacket and immersion suit, and shall not invalidate their aviation approval status.

Equipment may incorporate a re-breather bag and / or a compressed air cylinder.

Where a re-breather bag is incorporated into the system, the re-breather bag shall have sufficient capacity to prevent collapse during panic breathing in any orientation, unless demonstrated otherwise.

The equipment shall not have any protruding parts, corners or edges which may injure the user, during operation or during crash deceleration.

4.3 Materials

4.3.1 Requirements

The materials used shall have adequate mechanical strength and feature sufficient resistance to changes caused by the effect of temperature. This shall be tested according to 4.3.2.

Any outer fabric used to cover the EBS, shall be of low flammability. It shall not have a burn rate greater than 100 mm/min when tested in accordance with the horizontal test of JAR-25 Appendix F Part 1 or other equivalent method **[taken from HOSS, 2000: Draft JTSO, Issue 2]**.

Gas cylinders shall comply with the appropriate national or European specifications and shall be approved and tested with respect to the rated working pressure **[taken from CEN, 2000; BS EN 250]**.

4.3.2 Test

[Appropriate strength test required].

The EBS shall be alternately exposed to temperatures of +65°C and -30°C, demonstrated by testing in accordance with paragraph 3.9 of prEN ISO 15027-3:1999 **[taken from HOSS, 2000: Draft JTSO, Issue 2]**. Following temperature cycling, it shall be demonstrated that the EBS is functional.

4.4 Work of breathing

4.4.1 Requirements

The work of breathing shall not exceed [5.0 Joules/litre] (in accordance with the maximum limit in the Guidelines of the Norwegian Petroleum Directorate, 1991).

Respiratory pressure (differential pressure measured in the mouth during inhalation and exhalation) shall not exceed [5.0 kiloPascal] relative to the reference pressure.

Hydrostatic imbalance (the difference between a reference pressure in the mouth and lung centroid pressure) shall be between [+1.0] and [-2.0 kiloPascal] relative to lung centroid pressure, measured in the upright and face-down position.

[Awaiting further research data to confirm the acceptance of these values. Quoted figures represent recommended maximum values for someone carrying out longer duration, steady-state, underwater work, taken from Norwegian Petroleum Directorate, 1991).

4.4.2 Test

The test shall be conducted using breathing apparatus as described by the Norwegian Petroleum Directorate (1991).

Breathing performance of the EBS shall be measured at simulated depths of 0 and 4 metres, in water at a temperature of 10°C. A range of tidal volumes from 1.5 to 3 litres and breathing rates of 10 to 30 breaths per minute shall be used.

4.5 Safety devices

4.5.1 Requirements

Where appropriate, a contents gauge or equivalent shall be provided. Alternatively, it shall be possible to check that the EBS is ready for use.

The system shall be protected from inadvertent operation by the user.

4.6 Deployment

4.6.1 Requirements

The EBS shall be deployable both before and following submersion. Where a nose clip is provided, donning procedures shall encourage the user to fit the mouthpiece before the nose clip.

It shall be possible to deploy the EBS using one hand only in less than [10 seconds]. This shall be tested according to 4.6.2.

[Further work needed to confirm the acceptance of this value].

4.6.2 Test

Subjects, wearing a helicopter immersion suit and approved lifejacket, shall be seated, restrained by a harness. The method of deployment shall be demonstrated, following the manufacturer's instructions (but without any breath-hold).

This test shall be repeated with the subject immersed (upright, with the head submerged) in water at a temperature of 20°C to 25°C. In this case, the subject shall also demonstrate (where appropriate) their ability to purge any water from the mouthpiece.

The subject shall be timed from the signal to deploy the EBS, to the point when the subject is breathing effectively from the unit.

4.7 Manoeuvrability and helicopter escape

4.7.1 Requirements

Subjects shall be able to achieve a good seal at the mouth, and be able to block off the nose where applicable or if required. The subject shall demonstrate their ability to swim on the surface and manoeuvre at a depth of 3 m in different orientations (front and back). A record of subjective comments shall be made.

Each subject shall demonstrate their ability to deploy the EBS whilst successfully completing a simulated helicopter underwater escape. Any potential snagging hazards shall be reduced to a minimum. The system shall not cause injury to the user nor impair the performance of other equipment.

4.7.2 Test

Without further instruction, subjects shall deploy the EBS and demonstrate breathing underwater (water temperature: 20°C to 25°C). An observer shall determine whether the subject has achieved a good mouth seal by looking for leakage of air bubbles.

The subjects shall be instructed to swim on their backs and on their fronts, and pull themselves along a horizontal ladder at a depth of 3 m.

For the simulated helicopter underwater escape, the subject shall be seated next to an exit, with the harness fastened. The subject shall be instructed to deploy the EBS immediately before submersion, and then to escape, through an opening not greater than 0.43 m by 0.36 m, positioned with the top of the opening 0.9 m below the surface of the water. At least one of the subjects for this test shall have a bi-deltoid (shoulder) width measurement of at least 0.5 m.

Comments relating to ease of deployment and escape, plus any possible snagging hazards, shall be recorded.

4.8 Compatibility

4.8.1 Requirements

The EBS shall be designed to have no features which would be likely to have any detrimental effect on the performance or operation of other helicopter equipment. The EBS shall not impair the performance of a lifejacket or helicopter immersion suit. It shall not impair the performance of the seat harness nor prevent harness release. Following escape, it shall be possible to inflate the lifejacket.

4.8.2 Test

Test in accordance with 4.7.2. Compatibility shall be assessed by subjects whilst escaping from the helicopter simulator, and any problems experienced shall be reported.

4.9 Buoyancy

4.9.1 Requirement

The additional buoyancy of the deployed EBS shall be no more than [50 Newtons]. This shall be tested according to 4.9.2.

The combination of immersion suit, clothing and EBS shall meet the requirements of CAA Specification 19, Issue 1, 1991; Section 9.4.2.

[Further research is needed to confirm whether this is an acceptable buoyancy limit].

4.9.2 **Test**

The additional buoyancy of the EBS shall be determined by measuring the maximum underwater weight of the EBS when deployed. In the case of a simple re-breather, the unpacked unit, with covers, shall be evaluated. In the case of a hybrid compressed air / re-breather, the additional air shall be discharged into the bag prior to evaluation. In the case of a simple compressed air system, a unit with a fully charged cylinder will be evaluated. The EBS shall be placed in a net bag and immersed, using weights if necessary to fully submerge the equipment, taking care to remove any trapped air from the surfaces of the unit. The immersed weight shall be measured. The EBS shall then be removed, and the immersed weight of the test equipment measured. The additional buoyancy of the EBS shall be calculated from the difference in the two values of immersed weight.

4.10 **Cold water performance**

4.10.1 **Requirements**

Cold water performance shall be assessed following satisfactory completion of the swim and helicopter escape test (4.7).

Ninety per cent of subjects able to use the EBS equipment for 60 seconds in warm water (20-25°C) shall be able to use the equipment for 60 seconds in cold water (10°C) when tested in accordance with 4.10.2.

For re-breather systems, the partial pressure of O_2 in the re-breather bag after 60 seconds of use shall not be less than 5 kiloPascal. The partial pressure of CO_2 in the re-breather bag after 60 seconds of use shall not be greater than 8 kiloPascal.

4.10.2 **Test**

Ethical approval for this test shall be gained, and appropriate medical cover provided. Subjects shall be fully trained in the use of the EBS equipment in warm water before performing this cold water test.

Subjects shall be seated in a chair fitted with a 4-point harness, with a mock window or similar location point to one side. It shall be possible to lower the chair into water at 10°C, from a position just above the water surface. A ladder shall be fixed close to the chair, in a horizontal position, at a depth of 1.25 to 1.5 m.

Procedure:

The EBS shall be deployed following the manufacturer's instructions, immediately before immersion into the cold water. On completion of submersion, the subject shall grasp the end of the ladder, release the harness and then slowly move up and down the ladder, in a face-down position, using a hand-over-hand technique. The subject shall be instructed to surface on reaching their comfort tolerance limit underwater.

Duration of use shall be timed from the point of submersion to the point when the subject surfaces. The reason for surfacing shall be recorded. Any trial stopped for reasons which were not directly related to EBS performance shall be excluded and the trial repeated.