Development of a Technical Standard for Emergency Breathing Systems

CAP 1034

Safety Regulation Group

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Foreword

1. This paper reports on the experimental work performed in support of the development of a technical standard for helicopter emergency breathing systems (EBS), and also contains the resulting technical standard. The work was commissioned by the UK Civil Aviation Authority (CAA) and was funded by the CAA, the UK Health and Safety Executive and Shell Aircraft International. The project formed part of the joint-industry Helicopter Safety Research Management Committee (HSRMC) programme of work and was performed by Dr Susan Coleshaw, an acknowledged expert in the field of offshore safety and survival. The work follows on from the review of EBS implementation and use reported in CAA Paper 2003/13, also performed by Dr Coleshaw.

2. EBS is considered to have the potential to mitigate the safety risk associated with water impact/post ditching capsize in the short to medium term pending availability of the side-floating emergency floatation systems (see CAA Papers 97010, 2001/02, 2001/10 and 2005/06), and in the long term if and where retrofit of the side-floating scheme is judged to be impractical. The CAA concluded from the review of EBS reported in CAA Paper 2003/13 that, given the benefits and potential issues with EBS, there is no compelling case to either mandate or ban the use of EBS. If EBS is to be used, however, care must be taken to ensure that the equipment and associated training are designed and implemented in a manner that will truly provide a net safety benefit; compatibility with other safety and survival equipment and systems is particularly important. The equipment should also be fit for purpose and the its limitations should be made clear to users. It is for this reason that the CAA believes that a technical standard is needed, and that any EBS deployed should meet the technical standard.

3. The technical standard contained in this paper is offered for voluntary adoption as best practice and application by industry. The technical standard is deliberately objective and includes two levels of performance depending on the needs of the end user. In the absence of any formal requirement for EBS, it is for the end user to determine what standard of EBS (Category A or B) is appropriate for their operation. The following guidance is, however, offered to assist the process:

- The main consideration in deciding which Category of EBS (A or B) to deploy is what scenario is to be mitigated, i.e. ditching or water impact. In the case of ditching, it is considered to be reasonable to assume that sufficient notice will be available to allow the EBS to be deployed prior to submersion which would be compatible with Category B. In the case of water impact, experience suggests that minimal or no notice may reasonably be expected and that the need for an underwater deployment capability, commensurate with likely breath-hold time in the water temperatures to be expected should be assumed, i.e. Category A.
- As regards the ditching scenario, a further factor to be considered is the standard of emergency floatation system (EFS) fitted to the helicopter in relation to the wave climate in the area of operation. If the EFS has been demonstrated to be capable of maintaining the helicopter in a upright attitude for the worst case conditions likely to be encountered then there may be no need for any EBS. However, due account should be taken of the possibility that the EFS may not deploy correctly or that the helicopter capsizes for some other reason such as imperfect alighting on the water in sea conditions approaching the limit of the capability of the aircraft.
- For the water impact case, due account should be taken of the increased possibility of the helicopter sinking and, therefore, the depth at which the EBS will need to be capable of operating at.
- If the EFS fitted to the helicopter has a reversionary side-floating mode, this could be considered sufficient mitigation for both the ditching and water impact scenarios on the basis that, due to the provision of an air pocket in the cabin, submersion time is likely to be less than breath-hold time. In this event, there may be no need for any EBS but the possibility that the EFS does not operate correctly should still be considered.

4. The subject of EBS is to be disucussed during the forthcoming EASA review of the regulations and advisory material on ditching and water impact under Rulemaking Task RMT.0120 (27&29.008). In the event that EBS is adopted, the technical standard may be used to form the basis of an ETSO for EBS. Although it is recognised that some, mostly editorial, changes will be required to convert the technical standard from its present form to that of an ETSO, it is considered that the basic technical content will likely remain unchanged.

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Management summary

1. The Safety Regulation Group of the UK Civil Aviation Authority (UK CAA) commissioned SRK Coleshaw (Consultant) to develop a Technical Standard for helicopter emergency breathing systems (EBS). The work follows on from the development of an example draft technical standard published in 2003 (Coleshaw, CAA Paper 2003/13). Whilst a review of the literature suggested that little new information regarding EBS performance had been published since 2003, usage of EBS has increased and a number of new products have appeared on the market since then, reflecting the increasing interest in helicopter EBS.

2. Work has been undertaken to enable the gaps in the draft technical standard to be filled. Additional requirements have been added to the draft technical standard including design, compatibility, servicing, maintenance, marking and information for the user. Consideration has been given to the need for a mechanical strength test, whilst the content of the requirement for work of breathing has been reviewed and discussed with experts in the field. The draft technical standard has also been re-formatted and amended, separating requirements and test methods, and giving some consideration to the format of typical ETSOs (European Technical Standard Orders).

3. There was little or no published data regarding EBS performance in some areas, making it difficult to establish pass/fail criteria for parameters such as emergency deployment time and cold water performance. Trials have therefore been conducted on three generic designs of EBS in air and in water at two temperatures; in 25˚C (cool) and 12˚C (cold) water. The facilities of FalckNutec, Aberdeen were used to investigate deployment in air and water, underwater endurance, the effects of inversion, and performance during underwater escape exercises. These ergonomic performance trials were conducted by the author, Dr Susan Coleshaw with safety cover and support provided by FalckNutec staff. All of the in-water assessments were undertaken in water at a temperature of about 25˚C. Cold water performance trials were conducted at the University of Portsmouth, Department of Sport and Exercise Science, in water temperatures of 25˚C and 12˚C. These trials were led by Dr Martin Barwood (under the overall supervision of Prof Mike Tipton), with the majority observed by the author.

4. Following this work the draft technical standard was extensively amended (Appendix A), with more detailed procedures and both revised and additional requirements. Some concerns raised by the CAA were also accommodated when revising the standard. This improved technical standard was then issued for consultation to a wide range of stakeholders including regulators, manufacturers, end-user and training organisations and comments addressed, resulting in a final proposed technical standard.

Glossary

AAIB	Air Accidents Investigation Branch (UK)
Barotrauma	Injury caused by an excessive increase in pressure in cavities such as the lung or ear.
CA	Compressed air EBS
CAA	Civil Aviation Authority (UK)
CEN	European Committee for Standardisation
Counterlung	A variable volume chamber for the EBS user to exhale to and inhale from.
Dead space (mouthpiece)	The internal volume of the mouthpiece and any associated hose up to the point where the activation valve blocks off the counterlung.
Ditching	An emergency landing on the water, deliberately executed, with the intent of abandoning the helicopter as soon as practical. The helicopter is assumed to be intact prior to alighting on the water with all controls and essential systems, except engines, functioning properly.
Dyspnoea	Shortness of breath / subjective experience of breathing discomfort.
EBS	Emergency breathing system
ECG	Electrocardiogram
FEV1	Forced expiratory volume in 1 second
FVC	Forced vital capacity
H	Hybrid EBS
HUET	Helicopter underwater escape trainer
Hypercapnia	A high level of carbon dioxide in the blood.
Hypoxia	Deficiency in the amount of oxygen reaching body tissues.
MIRG	Maritime Incident Response Group

Non-survivable crash	An impact in which the forces transmitted to the occupants exceed the limits of human tolerance and in which the structure surrounding the occupants does not remain sufficiently intact to permit survival.
OLF	Norwegian Oil Industry Federation
PEF	Peak expiratory flow
PPE	Personal protective equipment
RB	Rebreather EBS
SD	Standard deviation
SWET	Shallow water escape trainer
TSB	Transportation Safety Board (Canada)
VAS	Visual-analogue scale
Water impact	Any contact with water that is not a ditching, i.e. a crash onto/into water.

SECTION 1

Introduction

Background

1.1 The Safety Regulation Group of the UK Civil Aviation Authority (with joint funding from the Health and Safety Executive and Shell Aircraft International) commissioned the study to develop a Technical Standard for helicopter emergency breathing systems (EBS) covered in this report. An earlier study of the implementation and use of EBS (Coleshaw, 2003; CAA Paper 2003/13) reviewed the development of a number of designs of EBS. The benefits and disbenefits of use were considered and a qualitative risk assessment undertaken. It was concluded that a technical standard was needed to ensure that minimum acceptable levels of performance and safety were met. An 'example draft technical standard' was therefore developed and included as an Appendix to the report, but knowledge gaps prevented the development of a complete performance standard. When the example draft technical standard was written there was limited information available about generic EBS performance, covering areas such as deployment times under realistic emergency conditions and performance in cold water. There were also some gaps and areas of uncertainty where further research was needed before appropriate requirements and tests could be recommended. The objectives of the current study were developed to address these knowledge gaps.

The problem

1.2 Drowning is the primary cause of death in helicopter water impact accidents. It is a well documented fact that a helicopter will capsize and/or sink in a high proportion of water impact accidents (e.g. Rice & Greear, 1973; Brooks, 1989; Clifford, 1996). The risk of capsize has been shown to be equally prevalent in controlled ditchings and water impacts (Clifford, 1996), but is increased by both high impact velocity and rough sea states (breaking waves in particular). In the event that the helicopter does capsize or sink, the occupants must make an underwater escape. If capsize follows a ditching, it is anticipated that the helicopter flotation system will keep the helicopter at the water surface, giving the occupants a reasonable chance of making an escape. In the event of a crash, there is a high likelihood that the floats will either be damaged or will not be deployed. This means that the helicopter is much more likely to quickly sink, greatly reducing the chances of making a successful escape and increasing the likelihood of drowning.

1.3 To make a successful escape, the occupant must be conscious, mobile, and be familiar with escape procedures and escape routes. The risk of drowning is very high due to the fact that there is a mismatch between the time needed to escape from the inverted and possibly sinking helicopter and the time that individuals can hold their breath underwater (Cheung et al, 2001). The level of risk is much higher in cold water due to the 'cold shock' response (Tipton & Vincent, 1989; Tipton et al, 1995; Tipton et al, 1997). Cold shock greatly reduces the ability of individuals to control ventilation and breath-hold, such that they may not be able to hold a breath for long enough to make an underwater escape. In temperate (25˚C) water temperatures, the mean breath-hold time of a large group of offshore workers was found to be 40 ± 21 seconds (mean ± SD). In cold water (5-10˚C), mean breath-hold time measured in small groups of subjects has been found to be close to 20 seconds, but may be as low as 10 seconds in some individuals. This is less than the estimated time to escape from a helicopter cabin. Under simulated conditions, underwater escape can take 25 to 30 seconds (Bohemier et al, 1990; Coleshaw and Howson, 1999). It has been estimated that it could take 45-60 seconds to escape from an inverted helicopter (Tipton et al, 1995), but it could take much longer if escape routes were to be blocked or other problems were to be experienced.

1.4 A number of factors other than cold will also increase the risk of drowning. Disorientation, particularly if the helicopter is inverted and it is dark, will slow down escape and increase the risk of drowning. Injuries and pain will incapacitate the individual, causing delayed reactions, possibly preventing release of the seat harness or greatly impairing mobility. Exits may be jammed or obstructed requiring an alternative escape route. All of these factors will increase the time spent underwater attempting to make an escape.

1.5 Whilst there are few reported cases of drowning in controlled ditchings, drowning is thought to account for more than 50% of the fatalities in water impact accidents, exceeding the number of fatalities attributed to impact injuries in survivable or partially survivable accidents. Clifford's (1996) review of world civil helicopter water impacts (covering ditching and crash landings) shows that, of 151 fatalities where cause of death was known, 81 (54%) were due to drowning and 70 (46%) were due to impact injuries. Loss of life was low in controlled ditching cases, but fatalities were all due to drowning, where the cause was known. Accidents involving a controlled flight into water, characterised by a lack of warning and in-rushing water, resulted in a relatively high loss of life with almost all fatalities due to drowning. In vertical descent with limited control accidents, again the majority of fatalities were due to drowning. Highest fatality rates occurred in uncontrolled impacts, many being 'non-survivable'. Where cause of death was known, two thirds of the fatalities were due to impact injuries and a third due to drowning.

1.6 When considering the means of mitigating the risk of drowning, considerable effort has gone into improving both the crashworthiness of helicopters and the ability to keep helicopters afloat (see CAA, 2005 for review of research). When operated over water, helicopters are required to meet ditching requirements (EASA CS 27 and 29), including the need to remain afloat for long enough to allow occupants to exit the aircraft under reasonably probable water conditions (see CAA, 2005). However, current requirements stipulate only Sea State 4 and the practical limit for ditching stability is thought to be in the region of Sea State 5 (CAA, 2005). This limit is exceeded for a significant part of the year in many sea areas of offshore activity; at these times the risk of capsize will be high. Sinking results from damage to the flotation system or to the floats themselves, or because the flotation system was either not armed or was not activated (Rowe, Howson & Sparkes, 2002). Automatic arming and deployment is not currently stipulated by the airworthiness (ditching) requirements, but has proven to be effective (see AAIB, 2011).

1.7 A considerable volume of research has been undertaken to investigate means of preventing the complete inversion of a helicopter and thereby reducing the risk of drowning (CAA, 2005; Denante et al, 2008; Jackson & Rowe, 1997; Jamieson, Armstrong & Coleshaw, 2001). Additional emergency flotation systems have been proposed which retain an air gap within the helicopter cabin and maintain some exits above the water surface. Occupants are able to surface in the air gap, reducing the time spent underwater. Escape can then be achieved through the above water exits. The additional flotation would be provided high up on the helicopter structure providing redundancy, and located in a position where they would be less likely to be damaged in the event of a high impact crash. Whilst this concept is considered viable, it has not as yet been implemented. In the absence of such a system, fatalities due to water impact and drowning are still being reported (TSB Canada, 2011). There is therefore still a need to take steps to reduce the risk of drowning.

1.8 Emergency breathing systems (EBS) provide an alternative or additional means to mitigate the risk of drowning. They are designed to allow helicopter occupants to breathe underwater for at least 1 minute, overcoming the need to make a single breath last for the duration of the escape process. If deployed successfully, EBS use should therefore increase the likelihood of survival.

1.9 As a type of personal protective equipment, EBS must be seen as a last line of defence, when other systems have failed. Helicopter EBS are thus provided to protect the user from the risk of drowning when underwater escape is the only option for survival. Given all the difficulties associated with making an underwater escape, if EBS are to be deployed and used successfully they must be relatively simple to use. Due to the complexity of the function that they are required to perform they are not particularly simple in design, but procedures for use need to be intuitive, with few actions required on the part of the user. As there is currently no technical standard against which EBS can be assessed, different user groups must undertake their own risk assessment and from that specify required performance levels for their own particular application. The provision of a technical standard would establish minimum performance requirements, allowing user groups to focus upon any possible additional requirements specific to their particular application.

EBS designs

1.10 Helicopter emergency breathing systems fall into three design categories: rebreather systems; compressed air devices; and hybrid systems that incorporate a rebreather with additional compressed air. Each design type has different advantages and disadvantages.

1.11 Rebreather systems allow the user to rebreathe air from their lungs using a counterlung. At the break-point of a breath-hold there is a strong desire to ventilate the lungs. The counterlung allows the user to breathe in and out, the period of rebreathing being limited by a build up of carbon dioxide and reducing concentration of oxygen. As the volume of air being moved in and out of the lungs remains the same, the rebreather EBS has the advantage that it does not introduce any risk of barotrauma during training or increase the buoyancy of the user.

Helicopter rebreather EBS have been designed primarily to protect the occupant in the event of a controlled ditching. Most are designed with a valve which allows the user to breathe to the atmosphere when first deployed, with a switch that must be activated to allow the user to breathe to the counterlung. This allows the user to deploy the rebreather EBS in advance (either before or immediately after alighting on the water), and then only have to activate the switch immediately before submersion. In a controlled ditching, the EBS may be deployed in anticipation of capsize, but need only be activated if evacuation cannot be completed before capsize occurs. Some rebreathers are fitted with a water activation mechanism that removes the need for the user to manually activate the EBS. This will save time and remove the need for the subject to remember to switch to the counterlung if the helicopter submerges quickly, but means that such EBS are unlikely to be fully functional if deployed underwater as water could enter the system before the mouthpiece is inserted. Rebreather EBS have the disadvantage that they are less likely to be effective at depths of more than a few metres due to hydrostatic pressure acting on the counterlung, increasing breathing resistance. Even at shallow depths, hydrostatic imbalance (a difference in pressure between the lungs and the counterlung) may be experienced in certain orientations, making breathing uncomfortable. That said, Hayes (1991) commented that "60 seconds discomfort is a welcome alternative to drowning".

1.12 Compressed air EBS generally consist of a gas cylinder, regulator, demand valve and mouthpiece. Air is supplied on demand, so the user does not have to remember to take a breath before use. This design type is particularly suitable for underwater deployment, and can be used at depth. This will be a big advantage if the helicopter capsizes or submerges very quickly, with no warning and little time to prepare. Due to the ability to deploy compressed air EBS underwater, many military users train their aircrew to make a quick breath-hold escape, only deploying the EBS if needed, after submersion. This method of deployment creates its own problems as the EBS must be deployed within the duration of a breath-hold, which may be very short in cold water, and the user may be suffering from disorientation. The design thus needs to be very simple, allowing rapid deployment. With most designs, the EBS mouthpiece must also be purged of water. This places specific training demands upon the user with this type of EBS. If compressed air EBS are deployed before submersion there is a danger that the air supply will be used prematurely. The endurance depends upon the size of the gas cylinder provided, and the rate and depth of breathing of the user. With panic breathing the available air will be used much more quickly, reducing endurance times. The air supply will run out without warning so users must be made aware that this might happen. Larger cylinders carry more air but this must be balanced against the added volume of the cylinder.

1.13 Hybrid EBS designs consist of a rebreather system with a small cylinder of gas providing additional air. The gas cylinder supplies air to the counterlung equivalent to a single breath, allowing the user to breathe from the counterlung even if they were unable to take a deep breath before submersion. The additional volume of air in the counterlung will make breathing more comfortable and extend the time that can be spent underwater compared to a pure rebreather; the concentration of carbon dioxide in the expired air will be diluted, while the concentration of oxygen will remain within acceptable limits for a longer period of time. As with the rebreather, the hybrid EBS is designed primarily for use in ditching incidents, being deployed after alighting on the water but before submersion. A further potential advantage of the additional air is that it should allow the hybrid EBS to be deployed underwater even if the user has not taken a deep breath before submersion. The additional air ensures that the user still has sufficient air to breathe back in. As with compressed air devices, the requirements for purging the mouthpiece must be considered. Similar to the rebreather EBS, a hybrid EBS is less likely to be effective at depths of more than a few metres.

1.14 One disadvantage of the additional air provided with a hybrid EBS is that it will increase the overall buoyancy of the user. Current standards (e.g. ETSO-2C503; EASA, 2006b) allow only 150 N of additional buoyancy due to air trapped in a helicopter suit and recommended clothing. Consideration must therefore be given to the effect the added buoyancy may have on ease of escape from the helicopter, and the types of helicopter suit that are likely to be compatible with hybrid EBS (see further discussion in ‘Buoyancy’ on page 33 and page 97).

1.15 Both compressed air EBS and hybrid EBS carry a small risk of barotrauma during use (Benton et al, 1996; Coleshaw, 2006a; Risberg, 1997; Tipton, 2006). This risk can be considered negligible in a real accident, but must be taken into account when considering training. There are some cases of injury reported during ascents from depths of only 1m and a few cases of barotrauma injuries during EBS training. This has implications for training providers and end users and may result in restrictions to training procedures, such as depth limitations, or additional medical screening.

1.16 Rebreather and hybrid EBS have been selected by civilian user groups such as the offshore industry. Helicopter passengers are trained to use the EBS as a primary survival aid, with the EBS partially deployed immediately after alighting on the water, and only activated if capsize or sinking follows. The hybrid EBS carried by offshore workers in the UK is used as a rebreather-only during training to remove any additional risks due to barotrauma. In operational use, the added benefits of the supplementary air would be realised. During training, users are taught to deploy EBS after alighting on the water due to concerns that an EBS in the mouth could cause injury if high impact forces were to be experienced in a real ditching or water impact accident.

1.17 One of the issues in relation to all types of EBS is how the EBS is integrated into the overall survival system. Some EBS are marketed as requiring only a single operation or action to use, but this is not the case when consideration is given to where the EBS is to be carried or fitted into the overall survival system. Pockets are variously provided either within the immersion suit or fitted to the lifejacket, while separate pouches have been provided that fit around the neck or the waist. In some cases the EBS is an integral part of the helicopter suit. In all cases, it is important that the user can locate the EBS and easily remove it from the pocket or pouch if the system is to function effectively. Equipment compatibility must therefore be considered in addition to type design.

1.18 Design specifications for particular EBS thus differ somewhat depending on the target user group (whether that be civilian or military), the environment in which the EBS will be used, and the level and type of training that will be offered to users. When selecting EBS, the end user must carry out a risk assessment looking at likely conditions of use, training needs, and maintenance and servicing requirements before deciding on a suitable device that best matches those requirements.

EBS usage

1.19 Some military aircrew have now been using compressed air EBS for more than 20 years. To date, the compressed air EBS is the only type of EBS known to have been used in a helicopter accident and to have saved lives. According to Brooks and Tipton (2001), whilst HEED (Helicopter Emergency Egress Device - a form of compressed air EBS) has saved lives there have been some problems with its use "due to the fact that the unit was an add-on to some other part of the life support equipment, or that crew failed to complete the necessary pre-flight checks correctly". They comment that when used, EBS should form part of an integrated [compatible] survival system and that in-water training is necessary.

1.20 More recently, EBS usage has been implemented by a number of different industry groups. At the time of writing, the largest user group in the UK are civil helicopter passengers who carry a hybrid EBS when flying offshore to oil and gas installations. All workforce members undergo in-water EBS training as part of their emergency response training (OPITO, 2006). This training is conducted without the additional air provided with the operational hybrid EBS to avoid the small risk of barotrauma during training. If used in a real emergency, the provision of additional air means that users who have not taken a deep breath of air before submersion will still be able to breathe from the EBS. Also in the UK, a design of compressed air EBS is being carried by fire-fighters forming the Maritime Incident Response Group (MIRG). Whilst implemented by various industry groups in the UK, EBS use is not currently mandated by the CAA or EASA for civilian helicopter flights.

1.21 A different system has been adopted in Norway. Members of the offshore workforce fly in an insulated helicopter immersion suit with an integrated rebreather EBS. The Norwegian Oil Industry Federation (OLF) specified that the breathing system should " provide sufficient air supply for 60 seconds of breathing time at a depth of ≤ 2m and at an activity level corresponding to 40 % of maximum aerobic capacity of a person weighing 90 kg" (OLF, 2004). It was also specified that the EBS could be activated using one hand, by one single operation, but also that it should be automatically activated when submerged. Training in the use of EBS was required by this industry association.

1.22 More recently, the workforce flying offshore from the East Coast of Canada have been provided with compressed air EBS. Extensive research was conducted looking at the different EBS options and risk assessments associated with implementation. Following a workshop held by the Canadian Association of Petroleum Producers (CAPP, 2006), it was decided that a compressed air unit represented the "best available technology" for the conditions to be experienced in the Atlantic Canada offshore environment (see Rutherford, 2009). A number of factors influenced this decision. Risk of capsize was considered to be potentially high compared to other offshore areas of operation and the compressed air unit could be deployed either prior to submersion or whilst underwater. The helicopter suit used in this jurisdiction was at the maximum buoyancy level permitted and the compressed air unit was neutrally buoyant, avoiding any added buoyancy. A Review Team consisting of representatives of CAPP, the Offshore Petroleum Boards and industry operators had thoroughly considered all options and looked at issues related to training. The risk of air embolism was considered to be low, but could not be disregarded. As a result, it was decided to conduct training in shallow water, limited to a maximum depth of 1 m. This process was completed in May 2009 when EBS were supplied to all passengers flying offshore from the east coast of Canada. Following the fatal helicopter accident off Newfoundland in March 2009, TSB Canada (2011) recommended that EBS "be mandatory for all occupants of helicopters involved in overwater flights who are required to wear a Passenger Transportation Suit System".

1.23 This demonstrates how EBS usage is increasing, but also how varying EBS solutions have been developed by different authorities to address the differing needs of various user groups. Decisions have been based not only on the level of protection provided by EBS but also consideration of the operating environment, medical implications and training requirements. As there is currently no technical performance specification for EBS, there is no standard means of assessing the minimum performance that will help to protect the health and safety of the end-user.

Performance requirements

1.24 When considering personal protective equipment, the aims of a technical standard are to ensure that adequate protection is provided against the known risks, to establish minimum levels of performance and to ensure that basic health and safety requirements are met. Whilst laboratory tests need to reflect realistic conditions of use they must also be objective and reproducible, allowing test conditions to be standardised in different laboratories. Ergonomic assessments are subjective in nature, meaning that great care must be taken when interpreting the results of tests. For example, it is important to determine whether an effect is due to the performance of the equipment or simply the responses of the test subject to the test environment.

1.25 As previously stated, the overall aim of EBS use is to reduce the risk of drowning by extending the time that a user can breathe underwater. In many cases the user will be suffering from cold shock and will almost certainly be panic breathing. The EBS must therefore perform at high rates of heavy breathing, but for a relatively short period of time (one to two minutes). Work of breathing can be measured using a breathing simulator, allowing reproducible testing and removing the need to expose human test subjects to these extreme conditions. Physical tests of this type measure the performance of the equipment itself without any variability due to the human user. Once the physical tests have been successfully completed, human ergonomic testing provides a means to assess ease of use and focus on operability. By its very nature, human testing is much more subjective.

1.26 To date, little attention has been given to the time taken to deploy EBS. The time available for preparation and deployment of EBS in a helicopter accident will depend upon the type of accident experienced, which influences how much warning time there will be before contact with the water and, perhaps more importantly, how long the helicopter is likely to remain on the water surface.

1.27 Anton (CAA, 1995) studied 15 survivable accidents, considering the warning time available before an impending ditching or impact accident. He found that in 5 cases there was more than 5 minutes warning, in 3 cases there was between 1 and 5 minutes of warning and in 7 cases there was less than 1 minute of warning.

1.28 In the case of a ditching, defined in civil aviation requirements as a controlled alighting on water, occupants will have some warning that water contact is imminent, and therefore some time to prepare for the emergency and think about emergency procedures and evacuation or escape strategy. In the case of vertical descents with limited control, there may be some warning, but in the case of fly-in accidents there will be little or no warning prior to water impact. In this scenario, the occupant has no opportunity to prepare; actions must be immediate and instinctive, using the knowledge and skills learnt in training. EBS deployment therefore needs to be intuitive, requiring little thought to carry out the deployment procedures.

1.29 When considering evidence relating to the time that helicopters stay on the water surface prior to capsize or submersion there is only limited data available. Chen et al (1993) investigated military and civilian survivable accidents (ditchings and water impacts). In cases where time of capsize was known, 82% were reported to have occurred in less than 90 seconds, described as "immediate overturn". In 18% of cases a "delayed overturn" was recorded, where the aircraft capsized after 90 seconds had elapsed. In one of Chen et al's case studies, the pilot of an aircraft that crashed during a final turn for landing stated that the aircraft sank after about 20 seconds. The authors stated that "none of the rotorcraft in which drownings occurred remained upright for more than approximately one minute". Of 98 civil accidents reported by Clifford (1996), 'immediate inversion' was reported in 38% of cases, defined on the basis that the helicopter was known to have inverted or sunk before the evacuation was completed. 'Delayed inversion' was reported in 19% of cases, with the helicopter remaining afloat and upright long enough for occupants to evacuate. Insufficient information was available in the remaining cases. In the report relating to the accident near the Cormorant Alpha platform in the North Sea, in 1992 (AAIB, 1993), it states that "after impact, the helicopter rapidly adopted a right side down attitude and then became fully inverted before it sank. It is not possible to determine a precise time for this but it is thought to have taken only a minute or two". This suggests that, in a significant number of accidents, capsize or sinking occurs during the first minute or two following contact with the water.

1.30 Thus, whereas there may be ample time to deploy EBS in a proportion of accidents such as ditchings in calm or moderate seas, there will be other scenarios where the time available for deployment may be well under a minute. It is therefore important to ensure that the EBS can be deployed quickly and without errors, particularly when considering EBS designed for underwater deployment. Whilst training will help to ensure that users are able to undertake rapid deployment, procedural skills are lost with time. Over a period of years, learnt skills will decay. It is therefore desirable to have deployment and use procedures that are simple to remember.

1.31 One of the other key areas of EBS performance relates to performance in cold water. Many offshore flights where EBS are carried by helicopter passengers and crew are operated over water at a temperature below 10°C. Whilst extensive underwater trials have been undertaken using helicopter simulators, there is currently very little data published regarding the operation and use of different designs of EBS in cold water (see Tipton et al, 1997). Physical tests measuring work of breathing will ensure that the equipment can be used at high workloads, but human testing in cold water will allow an assessment of ease of use when experiencing cold shock. However, for ethical reasons, if such a test is to be undertaken it must provide discriminatory information that adds to knowledge about the safety and performance of the product.

1.32 This study investigates areas of performance where pass/fail criteria could not be set in the 'example draft technical standard' (Coleshaw, 2003) due to a lack of scientific information. Trials were designed and undertaken to improve knowledge about the performance of the different generic types of EBS, and to look at ways in which tests could be performed to provide a valid assessment of performance.

1.33 This report describes both ergonomic and cold water performance trials undertaken with human subjects, to provide data upon which requirements can be based. Assessments were made with the three generic designs of EBS in current use in Europe: a compressed air device, a rebreather device, and a hybrid device.

Aims and objectives

1.34 The overall aim of the project was to produce a full technical standard for helicopter EBS, based on the example draft technical standard published in CAA Paper 2003/13.

1.35 The objectives of the study were:

- To review publications and literature relating to EBS developments during the period 2003 to 2009.
- To develop requirements relating to equipment compatibility, work of breathing, buoyancy, mechanical strength, marking, servicing and maintenance, and information for the user.
- To fill knowledge gaps relating to EBS performance.
- To assess the performance of a sample of three generic designs of EBS, to identify issues and performance indicators that should be included in any future technical standard for EBS, thereby improving the safety and effectiveness of new products.
- To provide data to allow performance and pass/failure criteria to be agreed.
- To develop effective test methods that will evaluate and demonstrate good and poor EBS performance.
- To determine whether a cold water test would provide additional information regarding the performance of each EBS.
- To redraft and complete the technical standard for EBS.

SECTION 2

EBS review

Literature review

2.1 A search of the scientific literature was conducted to determine whether any further research into EBS performance had been published since the completion of the 2003 study. No significant new publications were found.

Training experience

2.2 Training using several different types of EBS was observed. This identified a number of issues relating to deployment and use during shallow water training and during helicopter underwater escape procedure training.

- Deployment speed is affected by the stowage position of the EBS unit and, in particular, the ease of accessing the mouthpiece.
- An EBS unit needs to be carried on the body, but in a position where it does not interfere with the operation of the harness or with the actions that must be undertaken in the helicopter.
- Where a compressed gas system is carried on a lifejacket, the gas bottle should be held firmly, but not so tightly that it is difficult to remove during deployment. The pocket should be firmly attached to the lifejacket to prevent the gas bottle swinging from side to side.
- Mouthpiece design is important:
  - Some individuals found it difficult to make a seal around the mouthpiece - this can generally be alleviated with training, but it is also a design issue;
  - Mouthpieces without a teeth grip may be difficult to keep in the mouth, requiring the use of a hand to keep the mouthpiece in place.
- Some users have problems due to a gag reflex initiated in response to mouthpiece use. These users will need individual attention to overcome the problem if they are to be able to use EBS. This problem is largely generic, although in some cases may be dependent upon the material used to manufacture the mouthpiece.

- Nose clips can be problematic:
  - While some individuals are able to use EBS without a nose-clip, others need a nose clip to cope with breathing from EBS underwater;
  - It is difficult to design a nose clip that fits all users and does not slip off when wet;
  - It should be possible to deploy the nose clip quickly.
- Lanyards can provide a snagging hazard (but no problems have been seen with short lanyards holding nose-clips).
- EBS users must be trained to breathe underwater and, in some cases, to overcome anxieties about being able to breathe underwater (this applied to all designs of EBS observed).
- Purging systems must be simple and effective. When deployed underwater, purging of the mouthpiece requires specific training.
- Safe connections are required between gas cylinders and demand regulators - it should not be possible for connectors to become unscrewed.

SECTION 3

Gaps / improvements to draft technical standard

Approach

3.1 All requirements set out in the example draft technical standard (Coleshaw, 2003) have been reviewed, taking into account available information regarding the known performance and design of different EBS. Similar technical standards, ETSOs covering helicopter crew and passenger equipment and BS/EN/ISO standards covering diving equipment and re-breathing diving apparatus, were used as reference documents to ensure a consistent approach.

3.2 Reference documents included:

- CAA Specification 19, Issue 1 (1991) Helicopter crew members' immersion suits.
- EN 250 (CEN, 2000) Respiratory equipment - Open-circuit self-contained compressed air diving apparatus. Requirements, testing, marking.
- EN 14143 (CEN, 2003) Respiratory equipment. Self-contained re-breathing diving apparatus.
- EASA (2006) Standard for helicopter constant-wear lifejackets for operations to or from helidecks located in a hostile sea area. ETSO-2C504.
- EASA (2006) Helicopter crew and passenger immersion suits for operations to or from helidecks located in a hostile sea area. ETSO-2C503.
- European Commission (1989). Essential health and safety requirements of the PPE Directive (89/686/EEC), as amended 2003.

Compatibility

3.3 Compatibility issues have been reviewed, taking account of the known problems associated with EBS. Requirements have been added to the draft technical standard covering cockpit compatibility, other helicopter equipment such as seat harnesses, compatibility with lifejackets and immersion suits, and snagging (Appendix A; Section 5.4).

3.4 It is suggested that testing should be undertaken in combination with the equipment with which it is to be worn. Given potential use in different parts of the world, this may be a lifejacket only, an immersion suit system only, or both. It is considered that such equipment should be aviation approved equipment, and that testing should be repeated for each combination for which approval is sought.

Marking

3.5 Requirements for markings on the product and further information to be supplied by the manufacturer have been added to the draft technical standard (Appendix A; Section 7). When writing this section, reference was made to similar CAA and ETSO specifications; Part 21, Section A, Subpart Q, referring to identification of products (European Commission, 2003); plus CEN and EU guidance relating to information to be supplied by manufacturers (CEN PPE Forum, 2006).

3.6 Given the size of EBS products it will only be possible to mark equipment with a limited amount of information. Most of the necessary information will therefore need to be provided in 'Information supplied by the manufacturer' (see Section 8 of Appendix A).

Servicing and maintenance

3.7 General requirements for servicing and maintenance have been added to the draft technical standard (Appendix A; Section 9). As with markings, reference was made to aviation and EU guidance documents to determine standard practice.

3.8 Given the complexity of the equipment and the need for high reliability in a life-threatening operational environment, it is considered that all servicing and maintenance should be carried out by a service station approved by the manufacturer.

Mechanical strength

3.9 Review of other standards and discussion with an accredited test house suggests that a specific test of mechanical strength is not needed. In line with EN 250, a general requirement has been added for adequate mechanical strength to resist damage.

Work of breathing

3.10 Consideration was given to requirements for work of breathing and respiratory pressures, taking account of the fact that emergency breathing equipment is used for very short periods of time but under conditions when the body is exposed to psychological and thermal stress. Both of these factors can alter ventilation rates and will thus interact with the effects of using breathing equipment.

3.11 Anxiety can alter breathing patterns, resulting in an increase in ventilatory rate and tidal volume (Masaoka & Homma; 1997, 2001). This is an emotional response and is not related to metabolic factors. As a result, breathing rates are likely to be high during an emergency. It is also known that moderate levels of anxiety are experienced by some during EBS training (Coleshaw, 2006b).

3.12 Breathing will also be affected by sudden immersion in cold water. Cold shock results in an initial gasp, a deep breath in, followed by a period of increased ventilation lasting two to three minutes. This hyperventilation decreases as the body habituates to the cold conditions. Respiratory rate has been shown to peak after about 20 seconds, whilst tidal volume reaches a maximum value after 30 to 40 seconds of immersion (Tipton, Stubbs & Elliot, 1991). These authors thus considered that the threat of cold shock was greatest during the first 20 to 30 seconds of immersion, the responses habituating and declining thereafter. Breathing systems must therefore allow the user to breathe at relatively high rates and tidal volumes.

3.13 Work of breathing can be defined as the additional external work undertaken to use the breathing equipment, or the effort required to overcome the breathing resistance of the equipment. It is the work expended during one breathing cycle, is a product of changes in pressure and volume of the lung, and is measured in $J.L^{-1}$. Whereas a high respiratory work load would be exhausting for a diver working for a number of hours, a high respiratory work load for the EBS user will cause discomfort, but does not have to be maintained for more than a minute or two (the maximum likely period of use).

3.14 Breathing equipment increases the load imposed on the user's respiratory muscles in a number of ways. Breathing resistance is increased by narrow diameters of tubing through which respiratory gases must pass, by valves and by hoses. Particularly in the case of rebreathers with counterlungs, a pressure difference exists between the lung and the counterlung, as a result of differential hydrostatic pressures. This is known as 'hydrostatic imbalance'. The hydrostatic imbalance may be positive, negative or zero, depending on the position of the demand valve (or equivalent device) and the orientation of the user. Any such pressure difference makes the user breathe at either higher or lower lung volumes, which the user tries to resist by muscle tension. A negative imbalance results in breathing at low lung volumes and causes inhalations to feel difficult. A positive imbalance results in breathing at high lung volumes and causes exhalations to feel difficult (Warkander, 2007).

3.15 Respiratory pressure is the differential pressure measured at the mouth during inhalation and exhalation, compared to a reference pressure measured at the mouth at the end of inspiration or expiration when there is no gas flow. Most respiratory equipment standards place limits on respiratory pressure.

3.16 Issues relating to work of breathing were discussed with the Principal Consultant, Diving and Life Support, at QinetiQ, Alverstoke, UK. Likely conditions of EBS use were considered. There was concern that EBS equipment should perform satisfactorily when a user was suffering from cold shock and potentially also panic breathing, when it was estimated that rates of ventilation could be as high as 75 L.min-1. The requirements within the technical standard must therefore reflect high rates of ventilation of this order.

3.17 While panic breathing increases the respiratory demand, it is also important to recognise that evidence from diving incidents suggests that the ability to carry out a respiratory manoeuvre can act as a calming influence and may reduce panic. Similarly, a report of US Navy helicopter water impacts (Barker et al, 1992) suggested that the use of EBS was perceived to have saved lives, but also that "individuals consistently reported a calming effect" with the use of EBS "replacing the post-impact panic frequently experienced with the initial inrush of water, cold shock, and disorientation". Thus, use of EBS could help to limit panic breathing.

3.18 As mentioned previously, cold shock responses also habituate quickly. The ability to carry out the first few breaths, during the first 30 seconds of submersion is critical. On the advice of the QinetiQ diving consultant, limit values for work of breathing, hydrostatic imbalance and respiratory pressure have been reduced from those given in the example draft standard. The requirement for work of breathing is now comparable to an accepted value for maximum (as opposed to normal) work of breathing in commercial diving equipment (c.f. Norsok Standard for Diving Respiratory Equipment; NTSI, 1999). The requirements for respiratory pressure and hydrostatic imbalance are now comparable to values quoted in EN 14143 relating to rebreather equipment.

3.19 The original example draft standard considered safe limits for minimum oxygen (O2) levels and maximum carbon dioxide (CO2) levels for rebreather EBS. In a simple rebreather, where no air or O2 is added and no CO2 is removed, these gas concentrations will be dependent upon the physiological make-up of the individual user and not on the design of the EBS. A requirement has therefore not been included in the draft technical standard. Any effective EBS will extend the available breathing time underwater compared to a breath-hold.

Buoyancy

3.20 A literature search was undertaken to investigate the effects of immersion suit buoyancy on the ease of escaping from a helicopter.

3.21 Brooks and Provencher (1984) undertook trials to relate the effects of additional buoyancy on ease of escape from a helicopter. Initial trials were undertaken in a dive chamber. Trained divers attempted to escape through a simulated helicopter emergency exit, with increasing amounts of added buoyancy, until the diver could not escape. Failures occurred between 160 N and 254 N of added buoyancy. Similar work was then undertaken in an open pool. With a little more space the divers did a little better, with escape failures occurring between 173 N and 267 N. However, a group of non-divers found escape more difficult, with escape failures occurring between 98 N and 178 N. A number of possible reasons for the poorer performance were given including shorter arm reach and less upper body strength.

3.22 In follow-up trials (Brooks 1987, Brooks 1988) undertaken using a helicopter underwater escape training simulator, 12 mixed gender naïve subjects wearing a specially designed immersion suit with 134 N buoyancy were all able to escape from an inverted helicopter simulator, from a seat in the centre of the cabin and 20 cm in front of an unoccupied cabin window seat. The exit measured 51 cm by 66 cm. Brooks concluded at this time that inherent buoyancy in crew/passenger immersion suit systems should not exceed 146N.

3.23 The maximum buoyancy figure cited by Brooks is thus in close agreement with the 15 kg (147 N) requirement in CAA Spec.19 (CAA,

1991) and the 150 N requirement in ETSO-2C502 and ETSO-2C503 (EASA, 2006a and 2006b). In Canada, the requirement for permissible 'escape' buoyancy stands a little higher at 175 N. The Canadian standard "Helicopter Passenger Transportation Suit Systems" (Canadian General Standards Board (CGSB), 2012) states: "The escape buoyancy shall not be greater than 175N, when measured in accordance with Appendix K". Brooks (2003) states that this value was established to assist helicopter suit manufacturers meet the thermal insulation requirements of the Canadian standard, this being 0.116˚C.m2.W-1 (0.75 Clo). The Canadian offshore industry uses an insulated helicopter suit to meet this thermal requirement. Brooks (personal communication) considers that work should be done to reduce the buoyancy of insulated suits, using less bulky materials.

3.24 When considering additional buoyancy due to EBS, if any problems do occur, this is most likely to be seen with a hybrid system. Compressed air systems are unlikely to incur any significant additional buoyancy. Rebreather-only systems may have a small amount of additional buoyancy due to air in any hose connecting the counterlung with the mouthpiece. They will not demonstrate increased buoyancy in use, as air from the lungs is transferred into the counterlung and then back into the lungs. Hybrid systems allow the counterlung to hold the contents of the lung plus additional air from a gas cylinder. This would result in additional buoyancy due to the EBS.

3.25 In relation to this issue, it has been established that a hybrid EBS available on the market has a counterlung with an overall capacity of 9 litres. The gas cylinder discharges between 3 and 3.5 litres of air into the bag. The counterlung was deliberately designed to be oversized, to hold a breath of air from the lungs and the charge of air from the cylinder. In the UK this device is normally worn with a coverall design of helicopter suit that, on most subjects is thought to have a level of additional buoyancy well below the value allowed. The manufacturer does not think that the additional 3 litres of air would lead to the maximum buoyancy value in the suit standard being exceeded.

3.26 Problems could be experienced if an insulated helicopter suit with high inherent buoyancy, of the type worn in Norway and Canada, were to be worn with a hybrid EBS system. This represents a potential compatibility issue. A note has been added to the draft technical standard drawing attention to this issue.

SECTION 4

Ergonomic performance trials

Methods

EBS devices

4.1 Three generic designs of EBS were assessed.

- Rebreather device (RB)
- Compressed air device (CA)
- Hybrid device (H)

4.2 The rebreather device (Figure 1) consisted of a relatively soft plastic moulded mouthpiece with attached nose-clip and hose connecting the mouthpiece to a counterlung. A valve was located half way along the length of the hose, which ensured that the counterlung was closed when the EBS was not in use. When the valve was activated the user was able to breathe into the counterlung. In the operational unit, this valve is automatically activated on contact with water. The water activation capability was disabled for the trials to allow assessment of the manual activation mechanism. Manual activation of the valve was achieved by squeezing together two rings that encircle the hose. The rebreather is normally fitted as an integral part of an insulated immersion suit; the rebreather mouthpiece and hose are contained in a pouch positioned on the right chest, with the counterlung lying over the right chest and running around the back of the neck and over the left chest. A nose clip was fitted to the mouthpiece. The capacity of the counterlung was 9 litres.

Figure 1: Rebreather EBS

4.3 The compressed air device (Figure 2) consisted of a gas cylinder, a high pressure hose, regulator and mouthpiece. The mouthpiece was fitted with a system of valves to help prevent water entering the mouth and reduce the need for purging during underwater deployment. The regulator was also fitted with an integral nose clip. The device was carried in a zipped pouch, strapped around the waist. This device was originally designed for use without practical training.

Figure 2: Compressed Air EBS

4.4 The hybrid device (Figure 3) consisted of a hard plastic mouthpiece assembly, connected to a counterlung by a bellows-type hose. A nose clip was attached to the assembly by a thin wire. The mouthpiece was connected to a two-way switching mechanism. On squeezing a large knob on the mouthpiece assembly, the user was able to switch from breathing to the atmosphere to breathing to the counterlung. On immersion, a small gas cylinder automatically released 3 to 3.5 litres of air (equivalent to one breath) into the counterlung. The device was carried in a pouch sitting on the chest between the lobes of a halter-style lifejacket.

Figure 3: Hybrid EBS

Subjects

4.5 The protocol and procedures for the ergonomic performance trials were approved by the North of Scotland Research Ethics Committee. Subjects were recruited by the use of posters asking for volunteers. Volunteers were sought who had no previous experience of using EBS, who were good swimmers and who were comfortable both in water and underwater. All gave their written informed consent to participate.

4.6 All subjects undertook a medical examination. As the subjects would be using compressed air the medical included spirometry (lung function tests), covering forced vital capacity (FVC), peak expiratory flow (PEF) and forced expiratory volume in 1 second (FEV1). Subjects were requested to abstain from alcohol consumption for 24 hours prior to each pool session.

4.7 All subjects undertook a short training programme 1 to 2 months in advance of the trials. A classroom session described the procedures that would be followed and, in particular, the process of underwater escape from a helicopter simulator. Each of the EBS devices was described and deployment demonstrated by the instructor. Safety issues were discussed. Practical training started with a shallow water session where subjects experienced breathing from a generic rebreather and compressed air device, both during head-out immersion and submersion. Subjects also had the chance to fit the mouthpiece and nose clip of each test EBS device. At no time were subjects allowed to practise full deployment of the EBS. Helicopter escape training followed, consisting of a submersion exercise and a rapid capsize exercise. In both cases, subjects breath-held during escape. No EBS were used for these exercises.

Clothing

4.8 When using the compressed air and hybrid devices, subjects wore a helicopter passenger immersion dry suit with thermal lining over standard clothing. The rebreather device was incorporated into an insulated helicopter suit (with integral hood and boots) worn over standard clothing.

Test procedures

Deployment

4.9 Deployment times were assessed with the subject seated in the helicopter underwater escape trainer (HUET), with harness fitted. The seat used is shown in Figure 4. The seat was fitted with a four-point harness (not shown). An exit was positioned to the right of the seating position. Subjects were instructed to locate the position of the exit with their right hand, and the position of their harness buckle with their left hand, before the start of each deployment.

Figure 4: HUET seat position in helicopter simulator

4.10 After a count-down, subjects were instructed to deploy the EBS as quickly as possible, as if in an emergency. Deployment time included removal of the EBS from its pouch, deployment of the mouthpiece and nose clip and, in the case of the hybrid and rebreather, activation of the device to allow breathing into the counterlung. A note was made if any of these actions was missed. Deployment was undertaken twice, the first time with subjects allowed to use both hands, the second time using one-hand only, if possible. Any problems were recorded.

Endurance

4.11 Ease of use in the face-down posture was measured by asking subjects to deploy the EBS, submerge, and then pull themselves along a rail positioned approximately 0.5m below the water surface (Figure 5). On reaching the end of the pool subjects were signalled to turn and return along the rail in the opposite direction. Subjects continued until they experienced difficulty breathing, up to a maximum of 90 s when they were instructed to surface. Endurance was timed from activation of the device, just before submerging, to the point when the subject surfaced.

Figure 5: Subject 1 using CA, hand-pulling along underwater rail

4.12 On completing the swim, subjects scored effort and comfort of breathing using two scales, the Borg scale and a visual-analogue scale. Both scales have been shown to be reproducible (Wilson & Jones, 1991; Grant et al, 1999) and capable of quantifying feelings of breathlessness exclusively of other sensations (Wilson & Jones, 1989).

4.13 The Borg rating of perceived exertion (RPE) scale (Borg, 1998) rates the perception of exertion on a scale of 6 to 20, where 6 means 'no exertion at all', 11 means 'light', 13 means 'somewhat hard (but still feels OK to continue)', 15 means 'hard (heavy)', 17 means 'very hard (very strenuous, but can still go on)', 19 means 'extremely hard (the most strenuous they have ever experienced)' and 20 means 'maximal exertion'.

4.14 A visual-analogue scale (VAS) was also used to rate the subjective experience of breathing discomfort (dyspnoea) on the basis of shortness of breath. One end of a 10 cm horizontal line was marked 'not at all breathless' (scored 0) and the other end was marked 'extremely breathless' (scored 10). Subjects were required to make a vertical mark through the line to rate the discomfort of breathing during the endurance trial.

4.15 This trial was used to demonstrate whether users of the EBS device would be able to swim in the face-down posture, using a hand-over-hand pulling technique, as if required to move through a helicopter to find an exit before making an escape. Breathing from EBS in the face-down posture may result in 'hydrostatic imbalance' which will increase the work of breathing.

Inversion

4.16 The ability to breathe from EBS whilst inverted was assessed using a shallow water escape trainer (SWET) (Figure 6). Subjects were seated in the SWET and the lap-belt harness fitted. Subjects were instructed to deploy the EBS and then locate the harness buckle and their exit (an opening in the frame of the SWET to their left). The SWET was then inverted (Figure 7). Subjects were instructed to use the EBS for as long as possible, up to a maximum of 60 s. At the end of this time, or earlier if they experienced any difficulty with breathing, they were instructed to release the harness, escape through the 'exit' and surface.

Figure 6: Subject inverted in SWET

Figure 7: Use of EBS in SWET

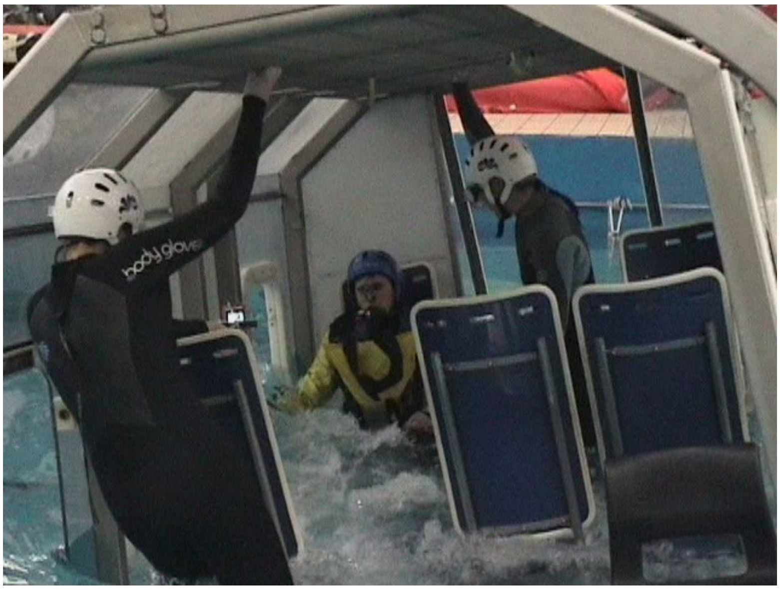
4.17 On completing this exercise, subjects rated the effort and comfort of breathing, again using the Borg and VAS scales.

Helicopter exercises

4.18 Three exercises were undertaken in the helicopter simulator. In each case the subject was seated in the HUET and the 4-point harness fitted.

1. **Submersion:** The HUET was lowered until the subject was immersed to a level just above the waist. An instruction was then given to deploy the EBS as quickly as possible, as if in an emergency. As soon as this was complete, the HUET was submerged. The subject released the harness and escaped through the nearest exit. This test was conducted to assess ease of use, harness compatibility and snagging during escape in the submerged upright orientation.
2. **Capsize:** The subject was instructed to deploy the EBS (as quickly as possible, as if in an emergency) as the HUET was being slowly lowered to the water. The HUET was then rapidly submerged and capsized (Figure 8). As before, the subject then made an escape through the nearest exit. This test was conducted to assess ease of use, harness compatibility and snagging during escape from a capsized/inverted helicopter.

Figure 8: Capsize exercise, subject using EBS



3. **Underwater deployment:** Once the subject was seated and the harness fitted, the HUET was rapidly submerged. The subject took a larger than normal breath before submersion, and deployed the EBS once submerged, before escaping from the nearest exit. This test was conducted to assess whether the different types of EBS could

be used in a water impact scenario where there would be little or no warning, and where users would have no time to deploy the EBS before submersion.

4.19 To deploy the mouthpiece underwater, subjects had to purge the mouthpiece of water. The compressed air device was purged either by blowing out hard or pressing the purge button, using some of the air from the gas bottle to remove water from the mouthpiece. The hybrid device was purged by using part of the breath of air in the lungs to blow water out through the valve, before switching to blow the rest of the breath into the counterlung. The rebreather was purged in a similar manner to the hybrid.

Protocols

4.20 Subjects were split into three groups of three to undertake the trials. Each group completed three sessions, one with each type of EBS, undertaken 1 to 7 days apart. The order of completing the trials with each of the three devices was controlled using a Latin square protocol (shown below).

	Group A	**Group B**	**Group C**
Assessment 1	Compressed air	Hybrid	Rebreather
Assessment 2	Rebreather	Compressed air	Hybrid
Assessment 3	Hybrid	Rebreather	Compressed air

4.21 After each exercise, subjects completed a structured questionnaire (Appendix B). They were encouraged to give as much feedback as possible about the ease of use of each EBS and record any difficulties experienced.

Data analysis

4.22 Single factor analysis of variance (ANOVA) was used to determine significant effects across the three devices. Paired t-tests were used to compare devices for a single variable. For all statistical tests the α level (critical level) of probability was set at 0.05.

4.23 Values are expressed as means ± standard deviation (SD).

Results

Subjects

4.24 Twelve volunteers were recruited initially, two dropping out at an early stage and one dropping out after completing the medical examination. A total of nine subjects undertook the training and the three study sessions. The subject group covered a wide range of sizes, with ages ranging from 18 years to 35 years (Table 1).

Table 1: Subject details

Subject No.	Gender	Height (m)	Mass (kg)	Age (yrs)	FVC (L)	FEV1 (L)	FEV1/ FVC%
S 1	M	1.92	96	35	5.7	4.6	81
S 2	M	1.85	74	18	6.1	5.5	90
S 3	M	1.79	146	20	6.2	5.5	89
S 4	M	1.75	69	21	4.6	4.2	91
S 5	F	1.72	76	23	3.9	3.4	87
S 6	F	1.68	66	20	4.0	3.6	89
S 7	M	1.62	60	21	4.7	3.7	80
S 8	F	1.62	60	25	3.8	3.3	88
S 9	F	1.61	53	19	3.9	3.6	94
Mean		**1.73**	**78**	**22**	**4.8**	**4.2**	**87.8**
SD		**0.11**	**28**	**5**	**1.0**	**0.9**	**4.7**

4.25 All of the subjects were passed as medically fit to undertake the trials. Eight of the nine subjects had normal spirometry, with values for FVC (forced vital capacity), FEV1 (volume exhaled during the first second of forced expiration) and the ratio of FEV1 to FVC all within accepted limits for age and height. Values for subject S7 were borderline, with a ratio of 80%, but he was passed as fit to undertake the trials by the examining physician. Subject S5 suffered from mild asthma; she was allowed to participate with a depth limitation of 3 m. (Medication was kept at the poolside as a precaution).

4.26 The sizes of suit worn by the subjects are shown in Table 2.

Table 2: Suit sizes

Subject No.	Uninsulated helicopter suit size*	Insulated helicopter suit size**
S 1	XL (T)	XXL
S 2	M (R)	XL
S 3	XXL (T)	XXL
S 4	M (R)	M
S 5	M (R)	M
S 6	S (R)	M
S 7	S (R)	S
S 8	S (R)	S
S 9	S (R) / XS (S)	S

* Suit sizes based on chest size and height:

XS = Extra Small S = Small M = Medium XL = Extra Large XXL = Extra Extra Large
(S) = Short (R) = Regular (T) = Tall

** Suit size based on height

S = Small M = Medium XL = Extra Large XXL = Extra Extra Large

Deployment

4.27 Shortest deployment times were seen with the compressed air device, with the hybrid and rebreather devices taking longer to deploy and activate (Tables 3 and 4). In general, few errors were observed when deploying the compressed air device, whereas various issues slowed deployment with the other two systems.

Table 3: Deployment time using two hands, seated in HUET, in air

	Deployment time (s)		
Subject	Compressed Air	Hybrid	Rebreather
S 1	8.1	10.0*	12.1
S 2	6.4	14.0	16.2
S 3	5.4	17.4	13.1†
S 4	6.3	12.1	30.3††
S 5	11.8	12.7	17.0
S 6	5.7	13.3	11.8
S 7	5.1	12.7	13.3†
S 8	9.3	11.8	27.6††
S 9	8.4	13.7	12.8
Mean	**7.4**	**13.1**	**17.1**
SD	**2.2**	**2.0**	**7.0**
Minimum	5.1	10.0	11.8
Maximum	11.8	17.4	30.3

* Nose clip not deployed.
† Subjects had some difficulty breaking 'weak link' security tab on pouch.
†† Subjects unable to break security tab on pouch, EBS being removed through side of pouch.

Table 4: Deployment time using one hand, seated in HUET, in air

	Deployment time (s)		
Subject	Compressed Air	Hybrid	Rebreather
S 1	8.8	15.9	10.4
S 2	6.0	20.6	12.0
S 3	7.5	9.4	11.2
S 4	5.9	12.1	8.7
S 5	7.1	23.2	16.0†
S 6	5.5	19.6	30.9†
S 7	7.4	6.3*	6.7*
S 8	9.6	13.6	19.8†
S 9	8.6	10.2	17.6
Mean	**7.4**	**14.5**	**14.8**
SD	**1.4**	**5.7**	**7.4**
Minimum	5.5	6.3	6.7
Maximum	9.6	23.2	30.9

* Nose clip deployed after activation (not included in recorded time).

† Both hands used to activate EBS.

4.28 It was hypothesised that deployment with one hand would take longer than with two hands but overall this was not found to be the case ($P = 0.86$). With the CA and H devices, some subjects took longer and some took less time with one-hand, suggesting that there was no significant training effect. The slower time when donning the rebreather with two hands was primarily due to the time taken to open the pouch on the first attempt (see below for explanation). When considering one-handed deployment, the compressed air device was deployed in a significantly shorter time when compared to the hybrid ($P < 0.01$) and the rebreather device ($P = 0.05$). There was no significant difference between the deployment times of the hybrid and rebreather devices ($P = 0.91$). It should be noted that one-handed deployment was undertaken with the left hand in all cases, the right hand being used to maintain contact with the exit. All subjects were right-handed.

4.29 Most subjects found the CA and H systems to be relatively easy to remove from the pouch stowage position (See Appendix B for feedback). However, a compatibility problem with the seat harness was experienced with the rebreather system. The stowage pouch holding the rebreather sits on the right chest, with the right harness strap correctly positioned to the right of the pouch. In the dry deployment test, when S5 attempted to deploy the EBS, she was initially unable to find the pouch pull tab which was sitting under the harness strap, and pulled the harness over the top of the EBS and pouch. The EBS was then deployed over the top of the harness strap. In a real event, this might have resulted in the harness strap failing to release effectively. On a number of occasions in the helicopter simulator, the harness strap sat on top of the pouch tab, impairing ease of access to the rebreather pouch.

4.30 The rebreather device was supplied with a security tag provided to prevent tampering and to show that the EBS was ready for use. This should have been a 'weak link'. Of four subjects who attempted to break this link (three male and one female), only one (S3) succeeded with a strong pull. S7 tore the fabric holding the security tag, thereby opening the pouch. S4 and S8 eventually gained access to the EBS through the open side of the pouch, with the tag still in place. Mean two-handed deployment time for those who did not have to break the security tag was 14.0 s ± 2.4 s (n=5).

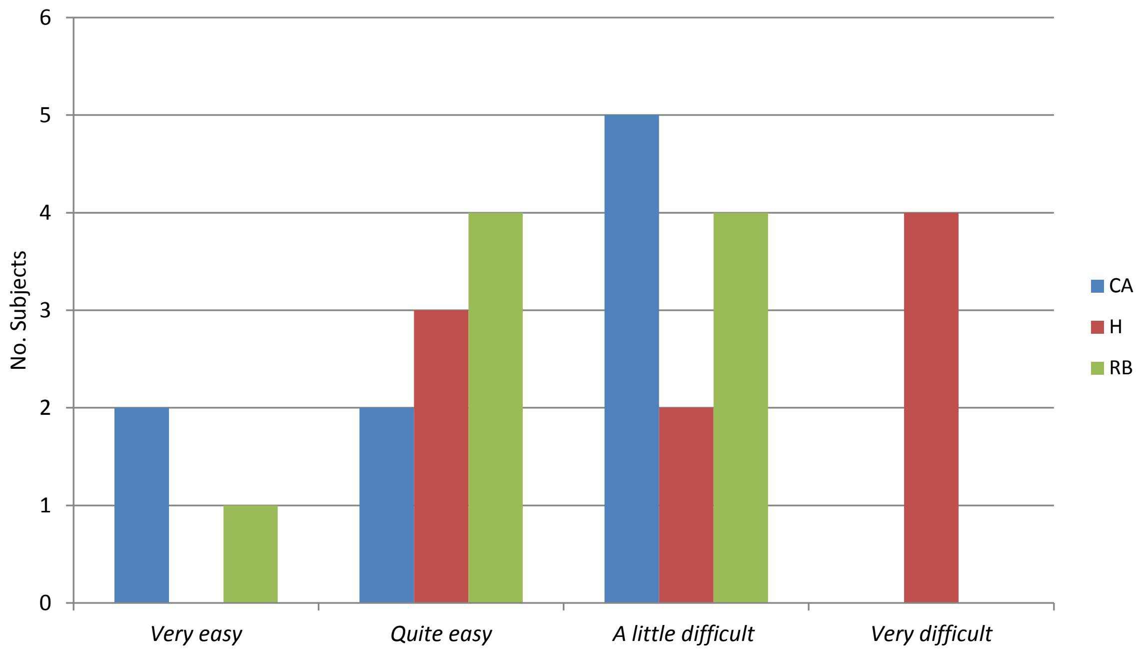
4.31 When deploying the hybrid device, two subjects (S2 and S5) reported some problems locating the mouthpiece which was packed inside the folds of the counterlung. Whilst in some cases subjects were able to immediately grasp the mouthpiece from its stowed position, in others the mouthpiece dropped down and the user had to catch the mouthpiece. A similar pattern was seen with the rebreather, which was generally grasped straight from its stowed position but, on occasions, the bent plastic hose straightened out and the subject had to reach out to catch the mouthpiece. In these instances, deployment time was increased.

4.32 Most subjects found the mouthpieces fitted either 'very easily' or 'quite easily' (Appendix B), although some of the smaller subjects found the compressed air device mouthpiece 'a little difficult' to fit as it was quite large in the mouth and it was made from a rigid material making it more difficult to bite and hold in place.

4.33 All three nose clips caused some problems (Figure 9). The compressed air device nose clip was easy to locate and don, being attached to the top of the mouthpiece. However, some smaller subjects found that it gripped rather hard on the bridge of the nose and they could not adjust it sufficiently to bring it down to a comfortable position. S8 and

S9 reported problems with the nose clip slipping up the nose. Larger subjects did not have this problem.

Figure 9: Subject responses to the question "How easy was it to deploy the nose clip?"



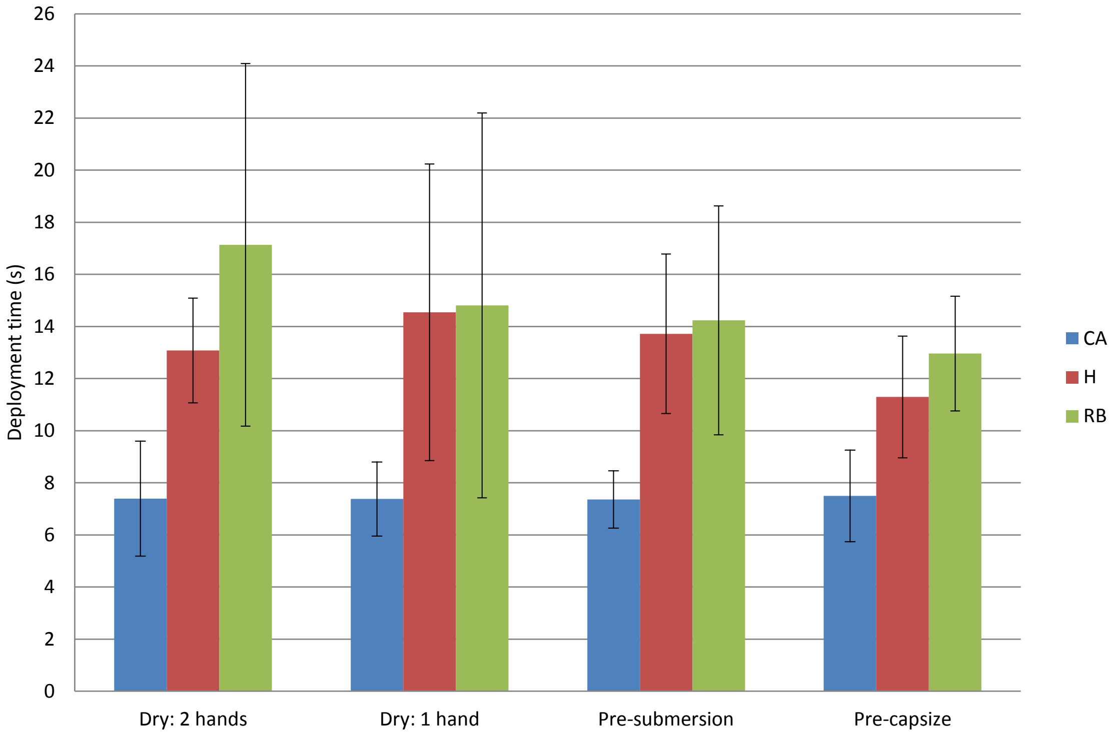
4.34 The hybrid nose clip was considered to be the most difficult to deploy, with some rating deployment as 'very difficult'. With this nose clip, subjects had some problems finding the nose clip and getting it into the correct orientation to allow fitting on the nose, primarily due to the fact that it is attached to the system by a 20 cm length of wire. One-handed deployment was considered particularly difficult as it was possible for the nose clip to slip in the hand. It was then difficult to reposition the nose clip as this required considerable dexterity. Subjects also found it quite hard to grasp and to open the nose clip one-handed. In one case, the wire attaching the nose clip caught around the mouthpiece. (N.B. The manufacturer has already designed a new nose clip that is easier to grasp and open but this was not fitted to the version of the H device used in the trials.)

4.35 The rebreather nose clip was a little stiff to open for the first time, but thereafter was generally found easy to deploy and adjust.

4.36 Subjects did not generally have any problems activating the hybrid device to breathe to the counterlung. Some problems were experienced when activating the rebreather device. When using just one hand (left hand), several of the subjects found it difficult to squeeze the rings together to activate the rebreather, with three of the female subjects having to use both hands to complete this task. (N.B. The operational version of the rebreather incorporates a water-activation mechanism which means that this task would not normally have to be undertaken in a real emergency. This was disabled during the trials to assess ease of manual activation.)

4.37 Figure 10 shows that there was little change in the mean deployment time of the compressed air device over time, with few errors made by subjects. The mean deployment time for the rebreather device improved over the course of the trials. In the first exercise (two hands) subjects had the problem with the security tags. In the second, one-handed exercise, some subjects found it quite hard to manually activate the device. With the hybrid device, the longest deployment times were seen with one-handed deployment, when the subjects found it very difficult to orientate and manipulate the nose clip with one hand. This improved with repetition.

Figure 10: Deployment times (means ± SD) seated in the dry helicopter simulator (Dry: 2 hands and Dry: 1 hand); prior to the submersion exercise with water up to the waist of the subject (Pre-submersion); and prior to the submersion exercise as the helicopter simulator was being lowered to the water (Pre-capsize).



4.38 During the submersion and capsize exercises, subjects were instructed to deploy the EBS with one hand if possible, but to use two hands if they felt they would have done so in an emergency. In many cases, two hands were used. For the hybrid device, two hands were often needed to deploy the nose clip, whilst for the rebreather two hands were sometimes needed to activate the EBS.

Endurance

4.39 Table 5 shows that when subjects swam face-down, slowly pulling themselves along an underwater rail, mean endurance time was shortest with the rebreather and highest with the compressed air device. In the latter case, most subjects completed the 90 second exercise. Subject 5 was mildly asthmatic and found this exercise quite hard with each of the devices.

Table 5: Endurance time undertaking face-down hand-pull swim

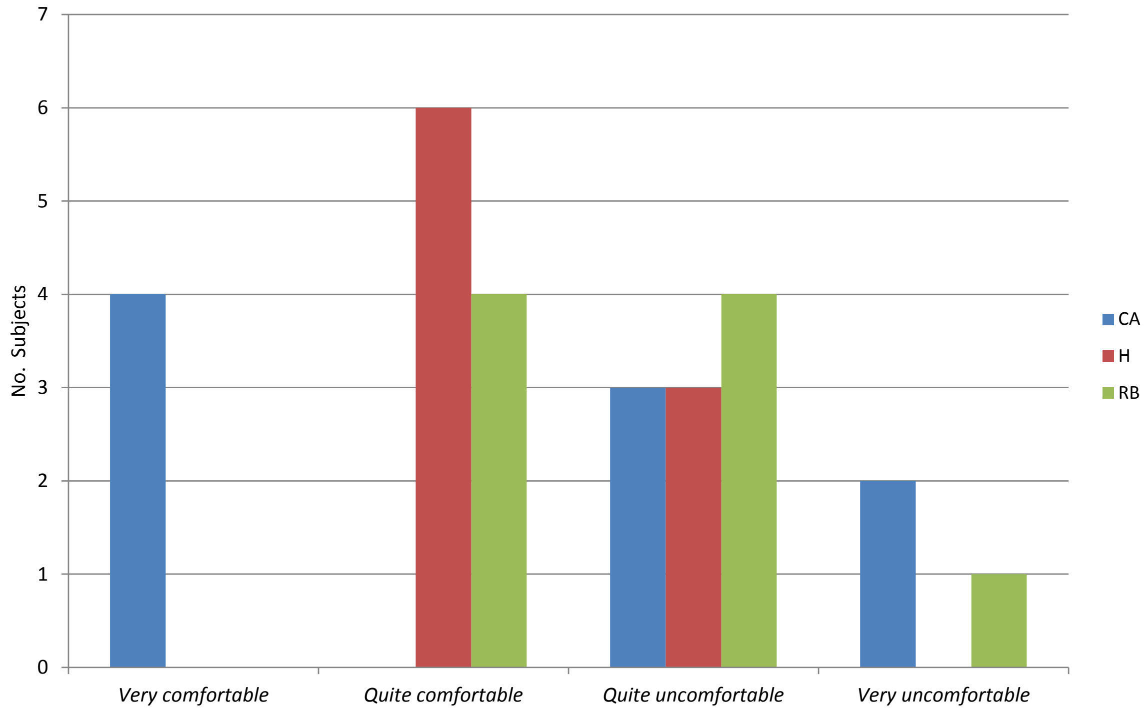
	Endurance time (s)		
Subject	Compressed Air	Hybrid	Rebreather
S 1	64.2	56.8	32.9
S 2	90.0	57.4	35.0
S 3	90.0	73.4	29.1
S 4	90.0	90.0	29.1
S 5‡	49.4	39.8	27.2
S 6	90.0	30.1*	34.5
S 7	90.0	68.6	57.4
S 8	90.0	54.5*	63.8
S 9	90.0	55.9	38.4
Mean	**82.6**	**63.7****	**38.6**
SD	**15.1**	**15.7**	**13.0**
Minimum	49.4	30.1* / 39.8	27.2
Maximum	90.0	90.0	63.8

‡ Subject 5 suffers from mild asthma.
* Gas cylinder did not fire.
** Mean value excludes the two measurements when the cylinder did not fire.

4.40 Two of the measured times with the hybrid device would have been higher if the gas cylinder had fired correctly (N.B. This was thought to have been due to a poolside servicing problem, the cylinder not being tightened firmly enough). When these two data points were removed there was a significant difference between the endurance times for the hybrid and rebreather devices (P=0.002), as might be expected given the additional air supplied with the hybrid. (N.B. Longer times were generally found with subjects at rest, see Tables 11 and 12, on pages 68 and 69.

4.41 Figure 11 shows that subjects were least comfortable swimming face down when using the rebreather device(s), stopping due to difficulty of breathing. One subject experienced water entry into the mouth during the turn. Also with the hybrid EBS, most stopped due to breathing becoming hard, although this was not the reason in two cases. The asthmatic subject stated that the EBS was not the problem, whilst one subject could not give a reason for stopping. Whilst some subjects were very comfortable with the compressed air device, two subjects found it very uncomfortable, one of whom found the mouthpiece to be too large and solid, felt his mouth was very dry and found it hard to move his tongue or swallow saliva. That said, both subjects managed to swim for 90 seconds, suggesting the discomfort did not significantly affect the performance of the CA device.

Figure 11: Subject responses to the question "How comfortable were you when breathing underwater in the face-down position?"



4.42 Overall there were significant differences between EBS in the perceived exertion of breathing measured by the Borg Scale ($P < 0.001$) and the discomfort of breathing measured by the VAS scale ($P = 0.008$) (Table 6).

Table 6: Perceived exertion and discomfort breathing when undertaking face-down hand-pull swim

	Borg scale rating (6-20)			VAS rating (0-10)		
Subject	Compressed Air	Hybrid	Rebreather	Compressed Air	Hybrid	Rebreather
S 1	7	13	15	0.1	3.7	1.3
S 2	8	10	15	0.1	3.6	7.0
S 3	7	10	16	1.0	5.7	7.3
S 4	11	12	17	1.9	6.3	9.0
S 5‡	15	8	12	5.6	2.7	3.3
S 6	12	10	16	6.0	1.5	7.9
S 7	7	11	14	0.1	1.9	2.3
S 8	8	18	17	1.8	7.8	7.3
S 9	7	12	17	0.1	3.0	6.7
Mean	**9.1**	**11.6**	**15.4**	**1.9**	**4.0**	**5.8**
SD	**2.9**	**2.8**	**1.7**	**2.4**	**2.1**	**2.7**

Borg scale: 6 = 'no exertion at all' 20 = 'maximal exertion'
VAS: 0 = 'not at all breathless' 10 = 'extremely breathless'
‡ Subject 5 suffers from mild asthma.

4.43 Poor correlations were found between endurance times and either the Borg scale rating (CA: r = 0.28; H: r = -0.02; RB: r = -0.11), or the VAS rating (CA: r = -0.26; H: r = 0.48; RB: r = -0.25). (N.B. Results for the asthmatic S5 were removed from this data group).

Inversion

4.44 During the inversion test, most subjects were able to breathe from the EBS for the maximum of 60 s (Table 7). There was no significant difference in the times between EBS types. Several subjects reported problems due to a poorly fitting nose clip during this test, with water going up the nose. In some cases this prevented them from completing the 60 second test. In two cases with the hybrid device, the gas cylinder only fired as the subjects moved to leave the SWET chair. It is uncertain whether this was due to a poorly tightened cylinder or water taking time to reach the activator, but it seems likely that these subjects would have remained inverted for the full 60 s if they had had the benefit of the additional air in the counterlung at an earlier point in time. With the rebreather, S2 stopped the test due to breathlessness (reported in verbal feedback). A similar reason was given by S3, whilst S5 was asthmatic and found the both the endurance and inversion exercises more challenging than other subjects, with each of the EBS.

Table 7: Duration of use with inversion

	Duration of use (s)		
Subject	Compressed Air	Hybrid	Rebreather
S 1	60.0	39.5†	60.0
S 2	(53.0*)	44.6†	43.7
S 3	60.0	60.0	54.0
S 4	60.0	60.0	60.0
S 5‡	53.5	60.0	48.0
S 6	60.0	47.9***	60.0
S 7	60.0	60.0	60.0
S 8	60.0	60.0	60.0
S 9	30.0**	60.0	60.0
Mean	**55.4**	**54.7**	**55.2**
SD	**10.5**	**8.3**	**6.3**

‡ Subject 5 suffers from mild asthma. Nose clip of CA very uncomfortable.

* Subject aborted test after 15 s on first attempt due to a poorly fitting nose clip - water went up the nose and caused him to cough. On the second attempt, gas ran out after 53 seconds - subject felt he could have continued up to the 60 s time limit. This data point was excluded from the analysis.

** Subject stopped due to water up nose after removing uncomfortable nose clip.

*** Subject stopped due to water up nose.

† Gas cylinder only fired as the subject left the SWET chair. If activation had occurred earlier, it was thought that these subjects would have met the 60 s time limit with this EBS.

4.45 Overall, differences in the perceived exertion (Borg scale) and discomfort of breathing (VAS) were not significantly different between devices in the inversion exercise ($P = 0.71$; $P = 0.39$ respectively) (Table 8).

Table 8: Perceived exertion and discomfort breathing when inverted

	Borg scale score (6-20)			VAS score (0-10)		
Subject	Compressed Air	Hybrid	Rebreather	Compressed Air	Hybrid	Rebreather
S 1	7	15	12	0.1	6.3	4.8
S 2	13	12	-	2.5	3.2	-
S 3	11	11	12	1.3	3.3	4.6
S 4	11	8	14	2.6	1.9	6.2
S 5‡	-	6	8	4.7	1.1	2.1
S 6	12	10	11	2.7	1.8	1.7
S 7	17	10	12	0.1	0.8	1.7
S 8	13	16	13	6.5	6.8	4.2
S 9	-	11	13	0.1	2.6	4.0
Mean	**12.0**	**11.0**	**11.9**	**2.3**	**3.1**	**3.7**
SD	**3.0**	**3.1**	**1.8**	**2.2**	**2.1**	**1.7**

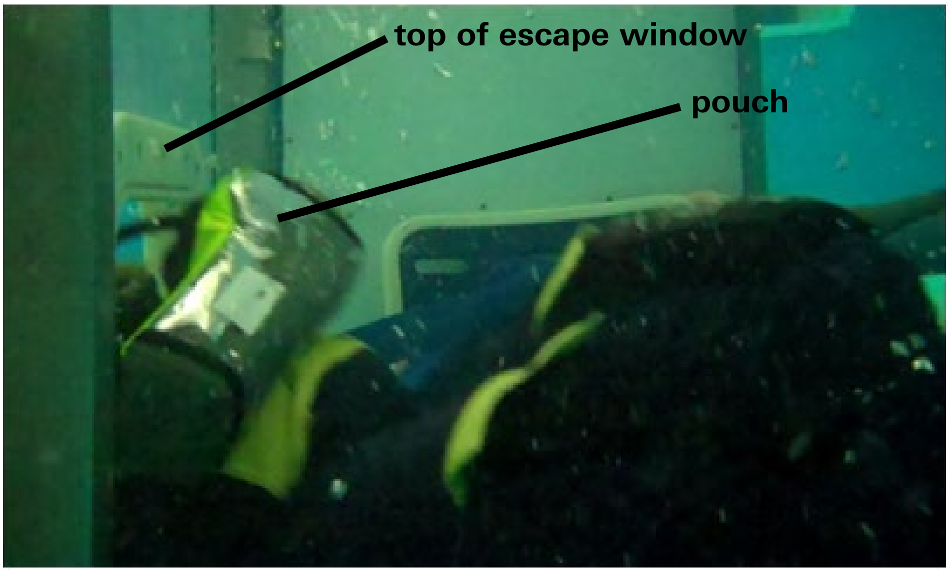
Borg scale: 6 = 'no exertion at all' 20 = 'maximal exertion'
VAS: 0 = 'not at all breathless' 10 = 'extremely breathless'
‡ Subject 5 suffers from mild asthma.

Helicopter escape - submersion and capsize

4.46 All subjects completed the submersion and capsize exercises successfully with each of the three EBS devices. Whilst there were no cases or actual snagging that prevented escape, some factors slightly checked the progress of the subjects during the escape process. These factors were influenced by the orientation of the subject as they escaped through the window, and whether the helicopter simulator was upright or inverted. When upright, any buoyancy caused the subjects to float up towards the upper sill of the escape window, whilst when inverted they tended to be forced towards the lower sill of the window.

4.47 With the compressed air device, the pouch fitted around the waist of the user was, on a number of occasions, seen to be caught across the corner of the window as subjects escaped (Figure 12 shows S3). The subjects had to adjust their position a little to progress through the exit.

Figure 12: CA pouch angled across corner of window frame as subject (face-up) escapes through window



4.48 With the suit incorporating the rebreather system, subjects were generally very aware of the buoyancy of the suit as soon as they released their seat harness, meaning that they had to pull themselves down to escape through the window in the submersion exercise (trapped air escaped from the suit during the first 10 to 15 seconds underwater). Comments included "very, very buoyant", "shot up like a rocket", "rose to roof, had to really pull myself down to the window and out". Subjects reported that this made it much more difficult to escape. These problems were significant, but were due to the suit and not the EBS.

4.49 Whilst there was no additional buoyancy due to the rebreather itself, the bulk and position of the counterlung affected ease of escape in some cases. Subject 1 commented that something at the back of his head caught as he went out through the window, although it "did not hamper escape". The underwater video footage showed the counterlung behind the head causing the progress of some subjects to be checked during escape (Figures 13, 14). Whilst there was no actual snagging, the subjects had to pull themselves down further to clear the top of the window. This problem was not observed in the capsize exercises where the buoyancy pulled subjects towards the bottom of the inverted window, meaning that the counterlung did not impede escape in these exercises.

Figure 13: Counterlung behind head of S1

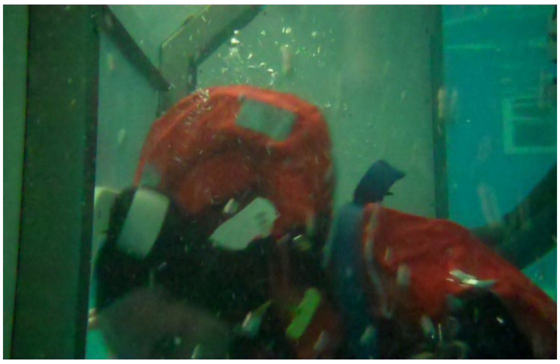
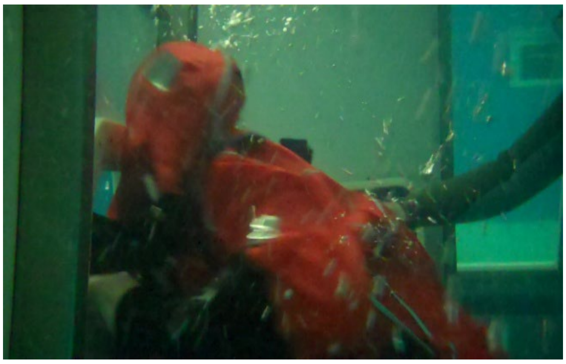


Figure 14: S1 escaping through exit



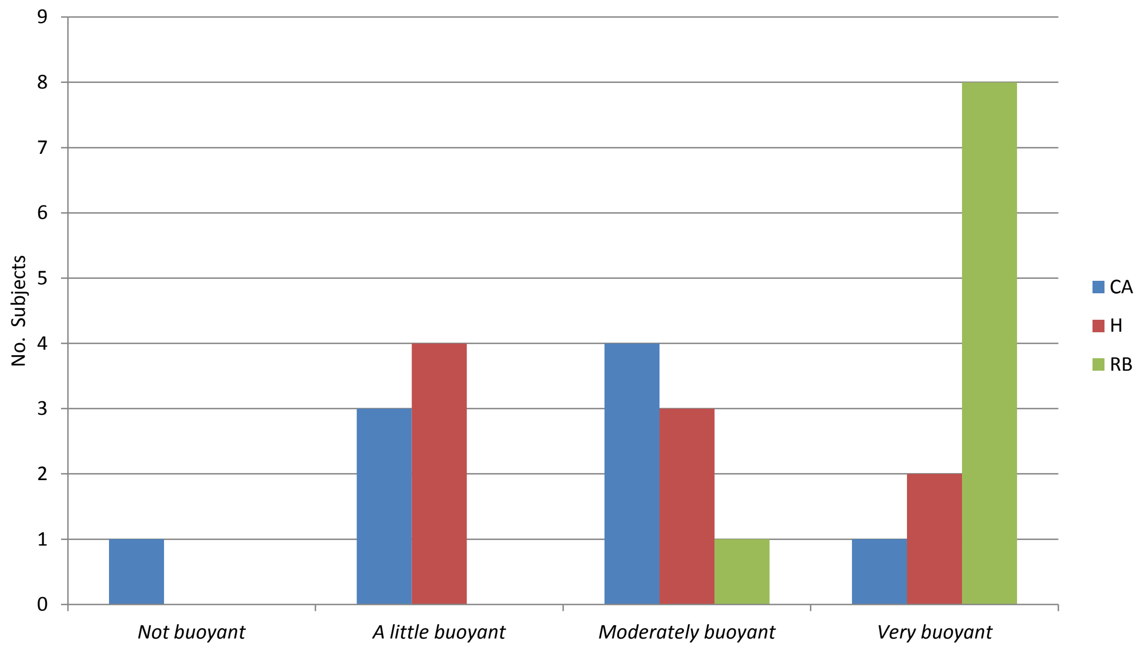
4.50 When asked about the level of buoyancy experienced during escape, most problems were caused by the suit used with the rebreather rather than buoyancy due to the EBS itself (Figure 15).

4.51 When considering the perceived buoyancy reported by subjects, there was little overall difference in the responses from subjects using the compressed air device compared to those given when using the hybrid device, despite the added buoyancy associated with the hybrid. This was supported by the fact that eight of the subjects reported 'no difficulty' and just one reported 'moderately difficult' when asked how difficult it was to escape from the helicopter when using the hybrid.

4.52 One further harness compatibility problem was noted when subjects attempted to escape following submersion. The pouch of the compressed air device was attached around the waist, sitting just above the harness buckle. On attempting to release the harness buckle during the escape process, the left shoulder strap of the harness failed to release from the buckle on a number of occasions. The unreleased left shoulder strap created some resistance, although all of the subjects were able to pull free from the harness as they moved to their right to escape through the window.

4.53 Following both upright submersion and capsize exercises some subjects responded positively to the question of whether snagging occurred during escape (Appendix B). Based on the verbal feedback and visual footage these responses appear to relate to aspects that hindered escape through the window, requiring the subject to make a slight change in position to then escape through the window. There was no evidence of any part of the suit or EBS system catching in a way that required remedial action or that caused any damage to the equipment.

Figure 15: Following submersion, subject responses to the question "How buoyant did you feel when attempting to escape from the helicopter simulator?



Underwater deployment

4.54 All nine subjects were able to deploy underwater and escape using the compressed air device, with all but one finding deployment either 'very easy' or 'quite easy' (Appendix B - CA). Some purged the mouthpiece by blowing out hard and some used the purge button (Table 9). Three subjects reported some water in the mouthpiece (Appendix B), causing coughing in one subject (S9). The video record showed that three subjects managed underwater deployment of the CA with one hand and all but one used the nose clip.

4.55 Similarly, when using the hybrid device all nine subjects were able to deploy underwater and escape. Three subjects found deployment underwater to be relatively easy whilst six found it 'a little difficult' (Appendix B - H). With this device, subjects were able to clear the device by starting to blow out before activating the counterlung. This proved sufficient to clear the mouthpiece, with only one subject reporting some problem with water in the mouthpiece. Eight of the subjects were observed to use two hands for deployment, with just two subjects reporting problems finding the mouthpiece underwater. One reported that the pouch moved up under the chin making it difficult to find the tab and open the pouch. Only one subject deployed the nose clip, one could not find it and the remainder did not try.

4.56 With the rebreather, more problems were experienced. Just four of the subjects managed to get some of their breath into the counterlung, although one still had some water in the mouth (Table 9). Three failed to purge the mouthpiece of water and two failed to activate the counterlung. All of the subjects were observed to use both hands for at least part of the underwater deployment. (N.B. This EBS is not designed with the intention of deploying the system underwater.)

4.57 Three subjects wore swimming goggles during the HUET exercises and commented that this made deployment of EBS easier, particularly when underwater.

Table 9: Feedback from subjects following the underwater deployment exercise

Subject	Compressed Air	Hybrid	Rebreather
S 1	Successfully deployed nose clip and mouthpiece. "Mouthpiece cleared with a big blow".	"Didn't put on nose clip. Found mouthpiece OK, clicked button". Cleared easily, didn't feel any water in mouthpiece.	Deployed mouthpiece, blew into bag but felt water coming back. Managed to rebreathe some air despite water in mouth.

Subject	Compressed Air	Hybrid	Rebreather
S 2	Some difficulty fitting nose clip. Deployed mouthpiece and purged by blowing out hard.	"Fine. Found tab but difficult to find mouthpiece". Mouthpiece deployed, cleared and activated during breath out - "worked perfectly - able to breathe in and out".	Successfully deployed mouthpiece, managed to breathe in and out OK. On releasing harness, buoyancy caused him to float to surface inside HUET. "Could have escaped". ‡
S 3	"Took few seconds to locate". Mouthpiece and nose clip deployed. Blew out hard to purge.	Managed to deploy mouthpiece but didn't use nose clip. "Big blow out, hit switch". Gas cylinder did not fire* so no additional air in bag.	Deployed mouthpiece but not nose clip. Water up nose before he had a chance to purge. Surfaced inside HUET.
S 4	"Big blow to clear - no water in mouthpiece". Nose clip took two attempts to fit, secured second time. Breathing no problem".	EBS pouch moved up on submersion making it difficult to find tab to open pouch. Mouthpiece found immediately but didn't find nose clip. Some water in mouthpiece but successfully cleared. Able to breathe from bag and make escape.	Successfully deployed mouthpiece; able to blow air into bag and rebreathe from bag (even though some water in bag).
S 5	Mouthpiece deployed but nose clip not fitted (sitting to side of nose). Cleared by blowing out.	Found mouthpiece OK. Did not use nose clip. Able to breathe from bag OK. "No water sucked back into mouth".	Took half a breath of air in before submersion, managed to deploy mouthpiece. "Breathed out and got breath back, no water".

Subject	Compressed Air	Hybrid	Rebreather
S 6	Mouthpiece and nose clip deployed. Purged with button and escaped.	Found and deployed mouthpiece, didn't have time for nose clip. Able to breathe from bag.	Mouthpiece and nose clip deployed. Breathed out into bag, but got water in mouth on breathing back in. Held breath from this point and escaped.
S 7	"Deployment fine". Purged whilst bringing mouthpiece to mouth. No water in mouth.	"Mouthpiece covered up, difficult to find. Managed to deploy mouthpiece, hard breath out to clear water, activated counterlung half way through breath. Then able to breathe fine from bag.	Did not clear mouthpiece. Held breath and escaped.
S 8	"Little bit of panic". Water in mouthpiece - able to purge, some water still in mouthpiece but not a problem.	Mouthpiece and nose clip deployed. Breathed out and activated - able to breathe from bag.	Mouthpiece and nose clip deployed. Breathed out hard but forgot to activate. (Previously decided to surface in HUET and not attempt to escape).
S 9	Mouthpiece and nose clip deployed, but took in "lung-full" of water when putting in mouthpiece. Cleared device and breathed out. Escaped but coughing on surfacing.	Found mouthpiece OK. Did not use nose clip. Cleared mouthpiece OK, not aware of any water entering bag.	"Panicked". Took half a breath of air in before submersion, managed to deploy mouthpiece but didn't activate to breathe into bag. Escaped (on breath-hold?).

* Some problems experienced during trials with resetting and replacement of gas cylinders to the hybrid rebreather. The cylinder must be tightened "very firmly" for the pin to fire correctly.

‡ The video shows that the subject did not activate the device.

SECTION 5

Cold water trials

Methods

EBS devices

5.1 The same three EBS devices described in 'EBS Devices' on page 35 were assessed in cold water; the rebreather (RB), the hybrid device (H) and the compressed air device (CA). A training version of the rebreather was used for these cold water trials so that the same suit and clothing could be used for all devices, standardising the level of thermal insulation provided. The rebreather training device was in the form of a vest, with the same rebreather mouthpiece and hose system and counterlung as that found in the operational system. There was no water activation on this training device, nor was there a manifold at the connection of the hose to the counterlung.

Subjects

5.2 The protocol for the cold water trials was approved by the University of Portsmouth Ethics Committee. Volunteers gave their written informed consent to participate. All subjects underwent a medical examination prior to participation, including a 12-lead ECG to exclude any individuals with cardiac arrhythmias. Any with cardiovascular or peripheral vascular disorders, or with a history of cold-induced illness, were also excluded. An ethical limit of 40 years of age was set for these cold water trials. Subjects were requested to abstain from alcohol and caffeine consumption for 24 hours prior to each trial session.

5.3 Subjects were recruited who were competent swimmers and who had no prior experience of using EBS. Each subject was briefed about the trial procedures and given a training session with each EBS device covering deployment in water with the subject immersed to the neck, deployment in air followed by immersion to the neck in cool (25°C) water and deployment in air followed by submersion. The aim of this training was to familiarize the subjects with the equipment and procedures, and to reduce any training effects to allow comparison of EBS performance in the two water temperatures. Safety procedures were also explained and practised.

Clothing

5.4 Subjects all wore a standard range of clothing (cotton trousers, cotton T-shirt, cotton long-sleeved shirt, woollen jumper, underwear, woollen socks). A helicopter passenger immersion dry suit with integral thermal liner was worn over the standard clothing (neither the hood nor gloves were worn during the exercises).

Test procedures

5.5 Subjects were instrumented with thermistors (Grant Instruments, Cambridge, UK) to measure skin temperature at four sites (biceps, chest, thigh, calf) for the calculation of mean skin temperature (Ramanathan, 1964). A 3-lead ECG (HME Lifepulse, England) and heart rate monitor (Heartsafe, Accurex, UK) were fitted to monitor heart rate and rhythm throughout each trial.

5.6 A medical officer or paramedic was present during all cold water immersion exercises.

5.7 Subjects were seated in a chair and frame structure secured with a two-point lap belt harness (Figure 16). They were lowered into a tank of water, at a reproducible rate, using an electronic winch (CPM, F1-8; 2-8; 5-4, Yale, Shropshire, U.K). For the immersion exercises, the subjects were seated at rest for 2 minutes before deploying the device with one hand and then being lowered into the water up to the neck level. For submersion exercises, the subjects were seated at rest for 2 minutes before deploying the device with one hand and then being lowered into the water until the top of the head was just below the water surface. Subjects took a 'slightly larger than normal' breath before activating or using the EBS devices. Exercises were undertaken in water at two temperatures; 'cool' water trials were conducted in water at 25.1 ± 0.1˚C and 'cold' water trials in water at 12.0 ± 0.1˚C. The subject was removed from the water either when they used a pre-agreed hand-signal to indicate that they wished to stop, having reached their limit of comfortable use, or after 90 seconds, whichever was the shorter. When using either the hybrid or rebreather, subjects exhaled maximally into the counterlung at the end of each exercise.

Figure 16: Subject seated prior to cold immersion

5.8 Deployment time was taken as the time from the instruction to deploy to the point when the subject was able to breathe from the EBS. Duration of use was taken as the time spent breathing with the EBS, whilst either immersed or submerged. Both were measured using a digital stop-watch.

5.9 As in the ergonomic performance trial a visual-analogue scale (VAS) was used to rate the subjective experience of breathing discomfort (dyspnoea) on the basis of shortness of breath (see 'Test Procedures' on page 38 for a description of the scale).

5.10 Subjects also filled in a short questionnaire rating device ease of use, comfort of using the device, ease of breathing, comfort of breathing and overall confidence in the device, using a 5-point Likert scale ranging from 1 (negative rating) to 5 (positive rating).

5.11 At the end of each exercise expired air gas concentrations in the rebreather and hybrid counterlungs were sampled and measured using a calibrated gas analyser (Servomex 1400, UK). The volume of gas remaining in the compressed air device was measured and subtracted from the original volume to calculate the amount of gas used.

Protocols

5.12 Subjects visited the laboratory on two occasions. On arrival, subjects were familiarised with the EBS products in room air before being instrumented and dressed in the standard clothing and suit. On the first visit they undertook training and performed three exercises with each of the EBS designs (nine in total) in cool (25˚C) water. On the second visit they performed two exercises with each EBS design (six in total) in cold water at (12˚C). The order in which the EBS were used was counterbalanced across subjects to prevent order effects and bias.

5.13 Training involved a deployment in air followed by a 30 second immersion to the neck in cool water, breathing from the EBS, plus a deployment in air followed by a 30 second submersion in cool water.

5.14 Five exercises were conducted with each subject using each EBS:

1. Cool water (25°C): Subject immersed to the neck and EBS deployed with EBS pouch underwater. Deployment time measured.
2. Cool water (25°C): EBS deployed in air. Subject then immediately immersed to the neck. Deployment time and duration of use measured.
3. Cool water (25°C): EBS deployed in air. Subject immediately lowered into water until submerged. Deployment time and duration of use measured.
4. Cold water (12°C): EBS deployed in air. Subject then immediately immersed to the neck. Deployment time and duration of use measured.
5. Cold water (12°C): EBS deployed in air. Subject immediately lowered into water until submerged. Deployment time and duration of use measured.

5.15 On completing each exercise, subjects provided feedback and rated any breathing difficulty on the visual-analogue scale and responded to the questions about ease and comfort of breathing on the 5-point Likert scales.

Data analysis

5.16 Single factor analysis of variance (ANOVA) was used to determine significant effects across the three devices. Paired t-tests were used to compare devices for a single variable. For all statistical tests the αlevel (critical level) of probability was set at 0.05.

5.17 Values are expressed as means ± standard deviation (SD).

Results

Subjects

5.18 Eight healthy, non-smoking, subjects were recruited, aged 25 ± 4.5 years and covering a good range of heights and mass (Table 10). All were confident in water, whilst six of the eight reported being comfortable when swimming underwater. None had previous experience of using EBS.

Table 10: Subject details

Subject No.	Gender	Height (m)	Mass (kg)	Chest Size (cm)	Suit Size
S 10	F	1.66	65.0	81	SR
S 11	M	1.81	100.6	106	MT
S 12	M	1.84	70.6	90	ST
S 13	M	1.73	61.9	85	XSR
S 14	M	1.87	75.7	97	MT
S 15	M	1.78	69.0	88	ST
S 16	F	1.58	51.1	83	XSR
S 17	F	1.62	67.0	81	SR
Mean		**1.74**	**70.1**	**89**	
SD		**0.11**	**14.3**	**8.7**	

Key: XSR = Extra Small Regular SR = Small Regular ST = Small Tall MT = Medium Tall

Immersion and submersion in cool and cold water

5.19 When immersed to the neck in either cool or cold water there was no significant difference in the durations of use between the three types of EBS or between cool and cold water (Table 11, Figure 17). Five of the eight subjects were able to breathe from each of the three devices for the maximum set limit of 90 seconds. Shorter durations of use were seen with three subjects breathing from the RB when immersed in 25˚C water. When immersed in 12˚C water, one subject using the CA, one subject using the H and two subjects using the RB showed durations of use of less than 90 seconds (Table 11).

Table 11: Duration of use when immersed to the neck in cool and cold water

	25˚C Immersion			12˚C Immersion		
Subject	CA	H	RB	CA	H	RB
S 10	90	90	90	90	90	90
S 11	90	90	90	90	90	90
S 12	90	90	90	90	90	90
S 13	90	90	70	61	60	64
S 14	90	90	74	90	90	75
S 15	90	90	90	90	90	90
S 16	90	90	90	90	90	90
S 17	90	90	29	90	90	90
Mean	**90.0**	**90.0**	**77.9**	**86.4**	**86.3**	**84.9**
SD	**0.00**	**0.00**	**21.4**	**10.3**	**10.6**	**9.9**

5.20 Whilst there was no significant effect on duration of use between cool and cold submersions, significant differences between devices were seen when subjects were submerged in both cool (P = 0.004) and cold (P = 0.023) water (Table 12, Figure 14). All subjects were able to breathe from the hybrid for the maximum 90 seconds when submerged in water at 25˚C; seven out of eight subjects achieved the 90 second limit with the compressed air device, whilst only five exceeded 60 seconds and one achieved 90 seconds with the rebreather. When submerged in water at 12˚C, duration of use was longer with the hybrid device than that seen with either the rebreather (P = 0.003) or the compressed air device (P = 0.03). When submerged in the cold water, seven subjects managed to use the hybrid device for 90 seconds, four subjects managed to use the compressed air device and one subject managed to use the rebreather for 90 seconds. If 60 seconds had been used as a test limit, then one subject would have failed with the hybrid device, four with the compressed air device and six with the rebreather. By comparison, most subjects had been able to use each of the EBS devices when immersed to the neck in cold water (Table 11).

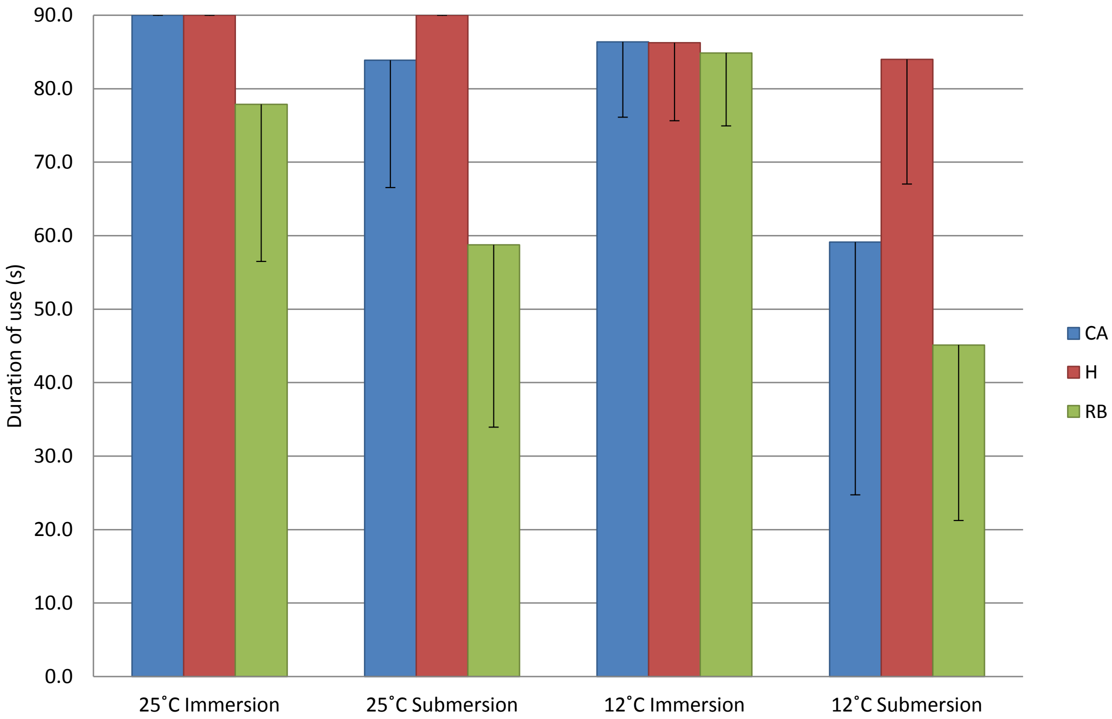
Table 12: Duration of use when submerged in cool and cold water

	25˚C Submersion			12˚C Submersion		
Subject	CA	H	RB	CA	H	RB
S 10	90	90	32	24	90	29
S 11	90	90	72	90	90	61
S 12	90	90	15	14	90	15
S 13	90	90	50	26	42	41
S 14	90	90	68	49	90	55
S 15	90	90	67	90	90	90
S 16	41	90	76	90	90	46
S 17	90	90	90	90	90	24
Mean	**83.9**	**90.0**	**58.8**	**59.1**	**84.0**	**45.1**
SD	**17.3**	**0.00**	**24.8**	**34.4**	**17.0**	**23.9**

5.21 Figure 17 shows that submersion in cold water at 12˚C had the greatest effect on duration of use across the EBS devices. When comparing the durations of use for all devices in all conditions, times were significantly shorter for the submersion (70.1 ± 26.9 s) than for the immersion exercises (85.9 ± 11.5 s); P = 0.011.

5.22 When a comparison was made for all devices, then durations of use were significantly shorter in the cold submersion exercise (62.8 ± 29.9) compared to the cool immersion exercise (86.0 ± 13.2) (P = 0.001). When considering just the submersion condition, then duration of use in the cold water (62.8 ± 29.9) was shorter than duration of use in cool water (77.0 ± 21.7), this comparison being close to significance (P = 0.055).

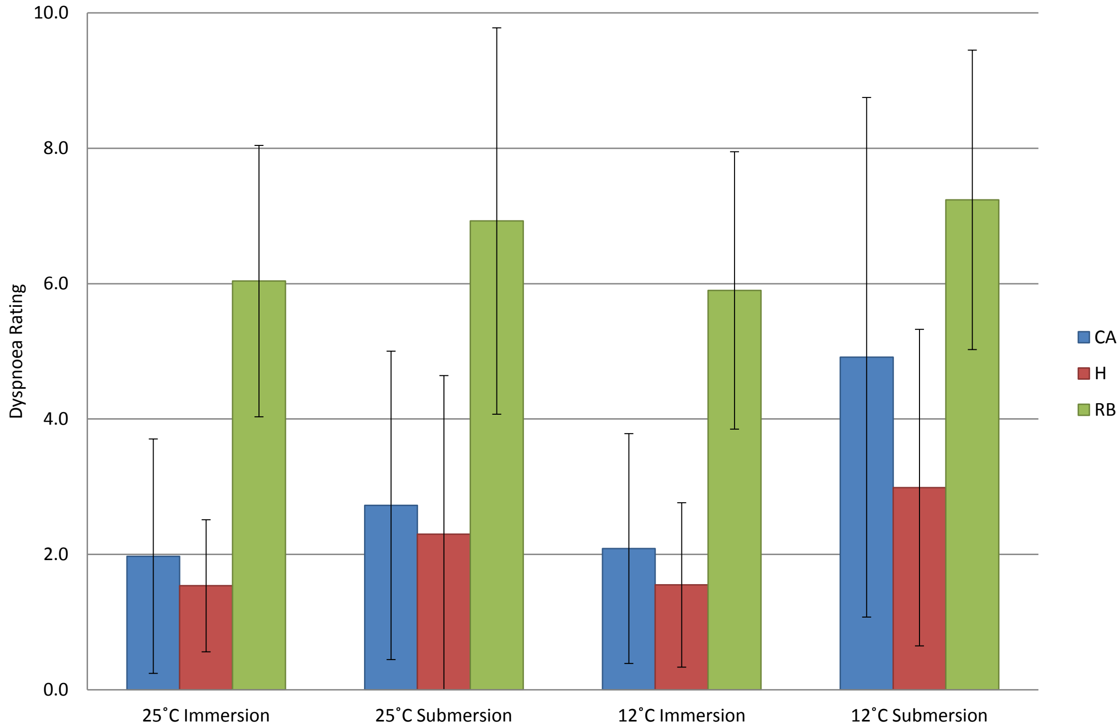
Figure 17: Duration of use (mean ± SD) seated upright, either immersed to the neck or submerged, in cool (25˚C) and cold (12˚C) water.



5.23 Some feedback was given by subjects regarding their reasons for terminating exercises in cold water before the 90 second limit. Subject 10 terminated the CA submersion partly due to feeling restriction around the neck caused by the survival suit. Subject 12, when using the rebreather, reported that he could not breathe in sufficiently to be able to continue with the submersion, stopping after 15 seconds. Subject 13 reported that he had terminated all of the cold exercises due to his hands being painfully cold. With the hybrid and rebreather devices he also reported slight light-headedness at the end of the submersion. When using the rebreather Subject 15 reported that he felt that "air was running out" towards the end of the exercise, despite managing to complete the 90 second exercise, whilst Subject 17 stopped after 24 seconds, commenting that breathing on this device was really difficult.

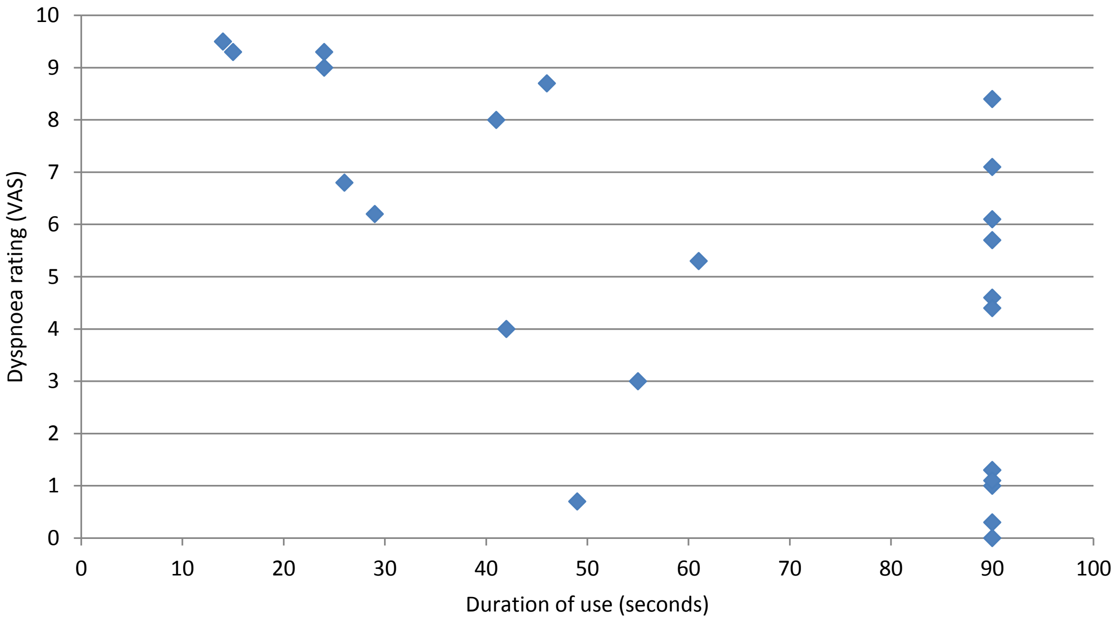
5.24 The shorter mean durations of use during submersion were accompanied by mean dyspnoea ratings (levels of breathlessness) that were a little higher for the submersion exercises (4.5 ± 3.2) than for the immersion exercises (3.3 ± 2.6), this difference just reaching significance (P = 0.05). When ease of breathing was considered across conditions (Figure 18), there was a significant difference between the performance of the different EBS devices (P<0.001), with greater difficulty found with the RB compared to CA or H.

Figure 18: Difficulty breathing (mean ± SD) rated on a 10-point dyspnoea scale, where: 0 = 'not at all breathless' and 10 = 'extremely breathless'.



5.25 Whilst there appeared to be some correlation between the duration of use (time spent submerged) and dyspnoea rating with those lasting less than 30 seconds reporting high breathlessness scores, there was wide variability in the breathlessness ratings for those who spent more than 40 seconds submerged (Figure 19). Dyspnoea ratings for those who managed to breathe for the full 90 seconds ranged from 0.3 to 8.4 on the VAS scale, where 0 related to a score of 'not at all breathless' and 10 related to a score of 'extremely breathless'. This may reflect both differences in the perception of breathing difficulty between subjects, and different levels of tolerance. The ergonomic trials also demonstrated greater sensitivity with the Borg scale than with the VAS scale.

Figure 19: Dyspnoea rating as a function of duration of use when submerged in cold water



5.26 In the cold water exercises (12˚C), small increases in mean heart rate were observed from the resting (pre) level to rates measured after 1 minute of immersion (Table 13), but these differences were not significant. Whilst mean skin temperatures were somewhat lower after 1 minute of submersion in the cold water (32.5 ± 1.0˚C) compared to cool water (34.0 ± 1.0˚C), in both water temperatures there was no significant change in mean skin temperature during the first minute of submersion from the resting (pre) level (25˚C: +0.3˚C; 12˚C: +0.1˚C).

Table 13: Heart rates (mean ± SD) resting before (pre) and after 1 minute of immersion or submersion in cold (12˚C) water

	Heart rates (beats per minute)					
	Immersion			Submersion		
	CA	H	RB	CA	H	RB
Pre	75 ± 21	75 ± 18	76 ± 22	76 ± 24	77 ± 17	76 ± 20
1 min	78 ± 20	79 ± 16	81 ± 20	78 ± 22	81 ± 15	79 ± 19

5.27 As expected, oxygen levels were a little higher and carbon dioxide levels were a little lower after use of the hybrid device compared to the rebreather (Table 14). For the rebreather, oxygen levels were higher after the submersion compared to the immersion exercises (P<0.001), presumably due to the shorter mean duration of use. There were no significant differences in gas concentration due to water temperature.

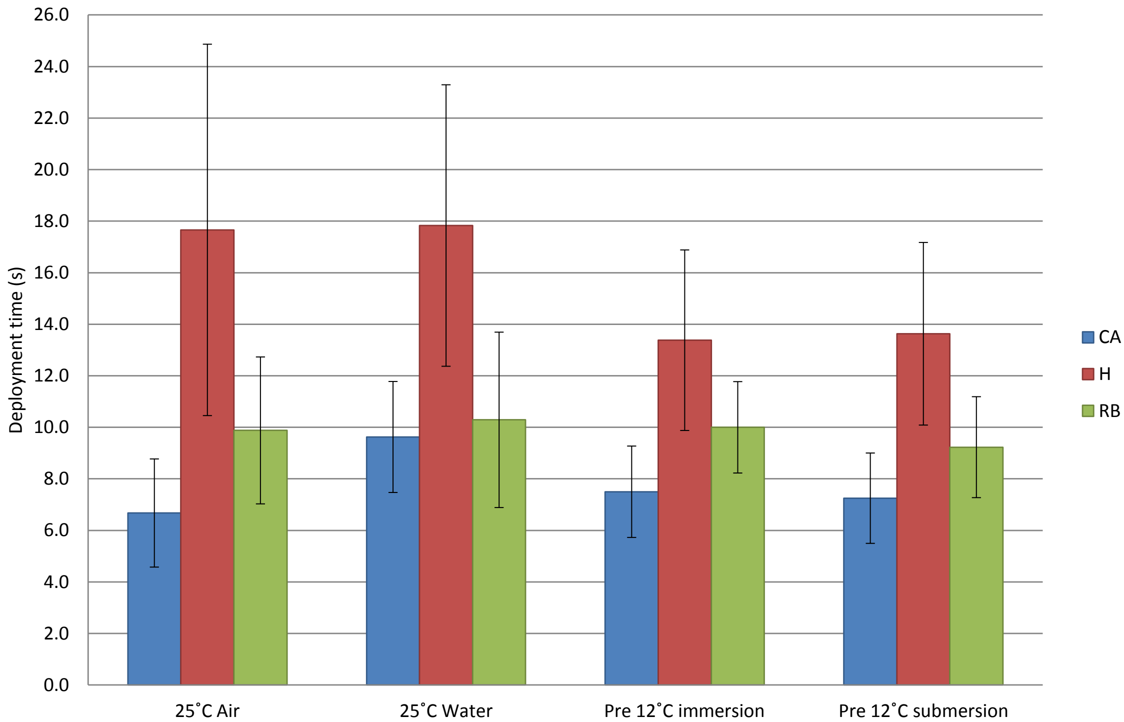
Table 14: Gas partial pressure (mean ± SD) and volume of gas consumed (end of exercise)

	Cool (25˚C)			Cold (12˚C)		
	Gas used (l)	Partial pressure (kPa)		Gas used (l)	Partial pressure (kPa)	
	CA	H	RB	CA	H	RB
O2 Immersion		13.3 ± 0.5	9.3 ± 1.2		13.3 ± 0.9	9.2 ± 2.1
O2 Submersion		12.4 ± 2.8	11.8 ± 2.7		13.3 ± 1.0	12.8 ± 2.4
CO2 Immersion		6.5 ± 3.0	6.2 ± 0.8		5.5 ± 0.9	6.2 ± 1.0
CO2 Submersion		5.4 ± 0.4	5.6 ± 1.4		5.6 ± 0.6	6.6 ± 2.9
Gas used (l) Immersion	13.9 ± 3.8			20.4 ± 6.5		
Gas used (l) Submersion	17.6 ± 4.8			22.0 ± 12.4		

5.28 With the compressed air device, mean gas consumption increased in the cold water exercises compared to the cool water exercises, presumably due to a cold-induced increase in ventilation.

5.29 Deployment times (Figure 20) were not a critical part of the cold water trials but values were measured to allow comparison with the ergonomic performance trials (see Table 4 on page 47 and Figure 10 on page 51). Some differences in the equipment used and EBS version can account for some differences seen in the results measured.

Figure 20: Time to deploy EBS (mean ± SD) using one hand, in air, immersed to neck in water at 25˚C, and prior to immersion and submersion in water at 12˚C.



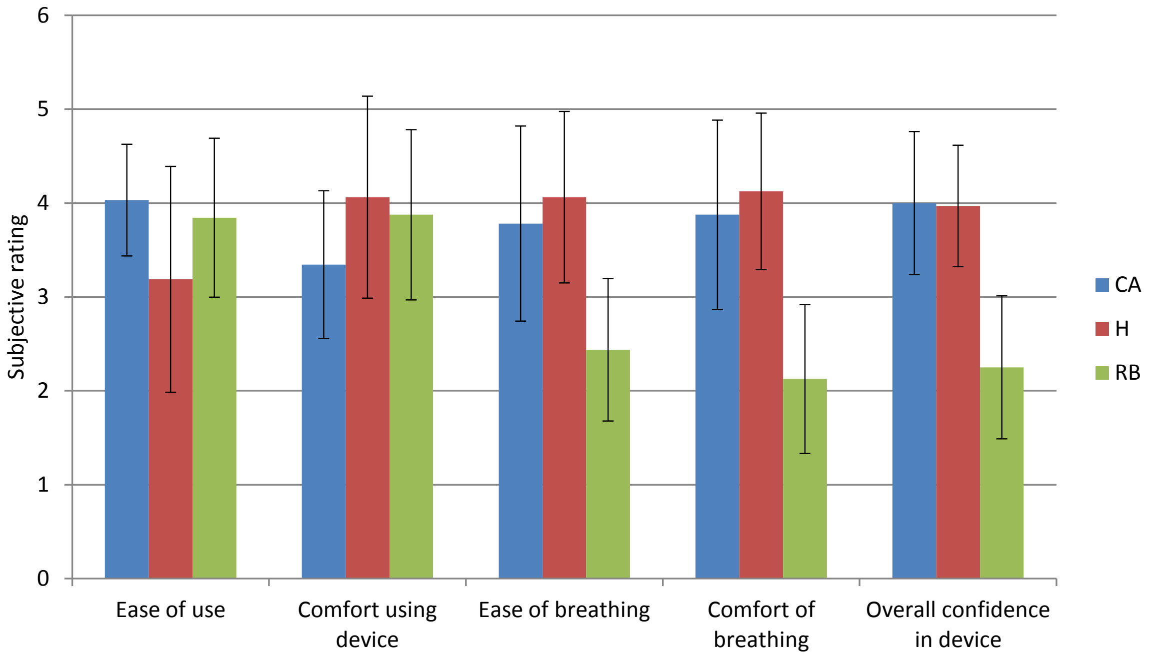
5.30 As in the ergonomic performance trials, deployment times were shortest with the compressed air device. When measured in air, prior to the first immersion exercise in water at 25˚C (Table 15), mean deployment time was slowest with the hybrid device (17.7 ± 7.2 seconds) compared to the rebreather (9.9 ± 2.9; $P = 0.007$) and the compressed air device (6.7 ± 2.1 seconds; $P < 0.001$), which were also different ($P = 0.008$). Deployment time of the compressed air device was consistently short, but took a little longer in water. Deployment of the hybrid improved on the second visit to the laboratory (cold water exercises), suggesting a training effect. Minimum deployment times with the rebreather were similar to the compressed air device, although there was a greater variability in times with the rebreather. This is a different result from the ergonomic trials, but can be accounted for both by a different subject group, but more importantly, by differences in the rebreather design with no security tag to break, and no harness shoulder strap to cause compatibility problems.

Table 15: Deployment time in air

	Deployment time (s)		
Subject	Compressed Air	Hybrid	Rebreather
S 10	8	20	10
S 11	5	15	5
S 12	6	20	10
S 13	11	33	14
S 14	6	18	12
S 15	5	12	8
S 16	5	12	12
S 17	8	11	8
Mean	**6.7**	**17.7**	**9.9**
SD	**2.1**	**7.2**	**2.9**
Minimum	5	11	5
Maximum	11	33	14

5.31 Figure 21 shows the combined mean subjective responses recorded on completion of the cool and cold water immersion and submersion exercises. In terms of overall confidence in the device, the hybrid device and the compressed air device were rated more highly than the rebreather (3.9 ± 1.0; 3.8 ± 0.9; and 2.9 ± 1.1 respectively).

Figure 21: Subjective rating of ease of use, comfort and confidence (mean ± SD), where: 1 = negative rating and 5 = positive rating



5.32 Overall the hybrid device was rated most highly (when the scores from the five questions were combined), although the hybrid was rated below the other two devices for ease of use (P<0.005). When considering ease of use of the hybrid, several of the subjects found the knob, which must be squeezed to activate the unit, to be quite hard to operate. One subject commented that it would be helpful if the nose clip was attached to the mouthpiece, and two others reported difficulties with the nose clip. Two subjects noted that the inflated counterlung floated up towards the chin on immersion. On a number of occasions the gas cylinder did not activate immediately on initial immersion.

5.33 The compressed air device rated lower than the hybrid and rebreather for comfort of use (P<0.005). Several subjects found the rigid mouthpiece to be uncomfortable and some found it difficult to get a good seal around the mouthpiece. The nose clip was found to be ill-fitting and/or uncomfortable by four of the subjects. Some resistance to breathing was noted by two subjects; whilst air was available on demand subjects were aware of the effort required to breathe with compressed air.

5.34 When considering the ease and comfort of breathing the rebreather scored significantly lower than the compressed air or hybrid devices (P<0.001), which was reflected in the rating for overall confidence in the device (P<0.001). Several subjects reported some difficulty breathing from the bag, and light-headedness at the end of an exercise. Some problems were caused by a small amount of water entering the counterlung, sticking the surfaces together and preventing inflation (N.B. Unlike the operational unit, the training version of the rebreather did not have a manifold that would have helped to reduce this problem). It was noted that the nose clip was hard to open on first use, but thereafter there was not a problem. When considering deployment, one subject commented that deployment of the rebreather required only common sense.

SECTION 6

Discussion

Principles of standard development

General

6.1 The purpose of a technical standard is generally to provide the minimum design and performance standards for a particular type of equipment. Where possible, design requirements should be kept to a minimum, allowing the manufacturer to be innovative when developing new design types, and allowing improvements in design to be made. Wherever achievable, requirements should therefore be based upon objective measures of performance.

6.2 It has been argued by some standard-writers that pass/fail criteria should be focussed on physical tests, with human tests concentrating upon design issues that can be improved. Whilst this is sound in principle, it is considered important that products should meet certain requirements for usability and that ergonomic tests should be passed. In the case of EBS, the critical physical tests are the measures of breathing performance (Section 6.2; Appendix A), using a breathing machine with a wide range of ventilation rates and simulating different body orientations. If the physical requirements for breathing performance are met, the EBS will then undergo the range of ergonomic tests using human subjects to assess usability. In the proposed technical standard, these tests must be passed. That said, it is certainly true that improvements to design can often be undertaken to address any usability problems.

6.3 When considering the results of the current research and trials in the light of the development of a technical standard for EBS, it is important to be able to distinguish between those aspects of performance that are due to the design of the EBS and those that are due to the responses of the individual user that might be expected whatever the type and however good the design of a particular EBS. As an example, all subjects are likely to experience the effects of skin cooling and some degree of cold shock when exposed to cold water, resulting in an increase in ventilation. The EBS must therefore be capable of being used when rate and depth of ventilation are high. However, there may be cases where a cold water test is stopped because the subject is suffering from severe cold discomfort and not because they are having difficulty breathing using the EBS. Care must therefore be taken when setting pass/fail criteria, ensuring that a failure is based only on poor performance or poor usability of the equipment. Allowance must be made for some tests to be repeated if the reason for stopping the test is not related to EBS performance.

6.4 Since ergonomic performance is measured in a testing laboratory, using procedures that can be reproduced, the tests included in the standard may not necessarily directly relate to actual conditions of use. They should be relevant to the possible risks associated with use of the equipment, but with tasks broken down so that specific performance measures can be assessed. It is also the case that they cannot reproduce every realistic scenario. The technical standard should provide the means to assess the product against accepted minimum levels of performance. Manufacturers should aim to design products that exceed these minimum performance standards where possible and as required by the client or user group. Performance may be enhanced above the levels stipulated in the minimum performance requirements of the standard to meet specific risks and requirements of a particular user group or operating environment.

Level of protection

6.5 One of the design principles of the PPE Directive (European Commission, 1989) is that the manufacturer must consider the foreseeable conditions of use and design a product such that the user *"can perform the risk-related activity normally whilst enjoying appropriate protection of the highest possible level"*. Thus, the level of protection offered must be appropriate to the level of risk.

6.6 Whilst this is a responsibility of the manufacturer, the end-user (particularly if the purchaser of PPE is an employer) must also take responsibility for risk-assessing the environment in which a particular item of PPE is to be used. In the case of EBS, for example, consideration must be given to water temperatures that might be expected in the event of a helicopter ditching or water impact; the colder the water temperature the greater the likelihood that cold shock will be experienced and the more difficult it will be to breath-hold when underwater. The type of helicopter immersion suit used, the level of insulation provided, the clothing worn under the suit and the amount of skin exposed will all influence the level of risk in relation to cold water exposure. Sea conditions throughout the year in the area of helicopter operations must also be considered when assessing risk. In sea states up to 4 or 5 there is a reasonable chance that the helicopter will remain upright following a ditching for long enough for occupants to be evacuated from the cabin. In higher sea states, ditching capability is greatly reduced, with a much higher risk of capsize. In these conditions, the benefits of carrying EBS are obvious.

6.7 Like the manufacturer, the end-user must consider all of the foreseeable conditions that might be experienced and determine whether a given EBS design will meet their requirements and particular conditions of use. In particular, the end-user will need to assess the level of risk and ensure that an adequate level of protection is offered by their chosen EBS product. This should be influenced by factors such as the sea keeping performance of the helicopter and the provision of means to mitigate the consequences of capsize such as the proposed side-floating scheme that retains an air gap in the cabin in the event of capsize (CAA, 2005; Denante et al, 2008; Jackson & Rowe, 1997; Jamieson, Armstrong & Coleshaw, 2001).

Deployment

Ease of deployment

6.8 No information was found in the published literature looking specifically at the time needed to deploy EBS, and only limited information about ease of deployment, despite this being a critical component when considering emergency use of the equipment. In the review of US military water impact accidents (Barker et al; 1992), "donning/removal" problems were cited in 5 of the 19 cases where problems using EBS were reported. During this early period of EBS use, removal of the EBS from a pocket was a problem and the integration of this particular EBS into the suit system was later redesigned. The means of carrying EBS to allow rapid deployment remains an issue, with many different systems and stowage positions currently in use.

6.9 The deployment exercises conducted in this study demonstrated that a simple and intuitive design of EBS is needed if quick emergency deployment times are to be achieved. Tasks and actions need to be kept to a minimum to allow users to be able to remember their instructions. The greater the number of steps that have to be taken to deploy the unit, the more chance that an error will be made, whether that be the omission of an action, wrong action or wrong order.

6.10 Successful deployment was achieved when the user was able to locate the mouthpiece or nose clip from an expected position and carry out each part task without error. Time was wasted if a component could not be found, or could not be grasped and held in the correct position/orientation at the first attempt. This was particularly important for one-handed deployment. In a real emergency, the ability to deploy one-handed is important to allow users to keep the other hand free for locating the nearest exit, taking into account the fact that this could be on either side of the user. Ease of one-handed deployment will also be influenced by the location of the EBS pouch which may favour one hand if not located centrally on the body. Thus, some EBS might be easier to deploy with the right hand whilst others might be easier with the left hand. However, the hand used in an emergency will depend upon the exit location and to which side of the body it is situated, and may not be the favoured hand in terms of ease of deployment.

6.11 All three EBS used in the trials incorporated an enclosed pouch to hold and protect the EBS. In each case, a small amount of time was needed to open the pouch. Some EBS are carried in an open pocket rather than a pouch. This means that the user does not have to undo a zip or Velcro during deployment, saving a second or two. However, to hold the EBS effectively the EBS must fit quite tightly in the pocket. It would then be necessary to ensure that all users are able to remove the EBS from the pocket without problems. The position of the pouch or pocket is critical in terms of ease of access but, for helicopter crew, it must also be in a position where it will not interfere with or impede the normal activities of operating the aircraft.

6.12 Some deployment errors were also caused when a component was obstructed, examples being the seat harness obstructing a pouch, or a nose clip snagging on another part of the system. Such compatibility issues should be addressed at the design stage of EBS development. Given that harness design will be aircraft-specific, EBS manufacturers need to assess a range of generic harness designs to reduce the risk of future compatibility problems.

EBS design-specific issues

6.13 When considering the three generic designs of EBS evaluated in this study, Figure 10 shows that time to deploy the compressed air device was not affected by condition or training, with little difference in deployment time across the four ergonomic performance trial exercises. Deployment of this device was found to be straightforward, with few errors made. One-handed deployment was achieved without problems. The only issue with the deployment of this device related to the fit of the nose clip and the limited range of adjustment. This was particularly difficult for the smaller subjects.

6.14 With the other two generic designs, some deployments were quick and unproblematic whereas others were slowed due to various problems causing errors. When considering the hybrid device, somewhat longer deployment times were observed, with more problems experienced when attempting to deploy the device one-handed than when deployed two-handed. There were a number of issues that resulted in error, increasing the time taken to deploy this EBS. The greatest problems related to the nose clip, with the majority of subjects finding this nose clip to be difficult to deploy. The nose clip was attached to the mouthpiece by a wire and therefore was not in a fixed position in relation to the mouthpiece. Subjects had to locate the nose clip and then turn it to the correct orientation in their hand before fitting to the nose. This took a little time but was achievable with two hands. With one hand subjects found it to be much more difficult. Some location problems were also experienced in relation to the mouthpiece. When the pouch cover was removed, the EBS mouthpiece was found within the folds of the counterlung, positioned over the chest. In most cases the user was able to fold back the fabric and immediately locate the mouthpiece. In others, the hose flopped down, with the mouthpiece dropping to the waist level. The user then had to relocate the mouthpiece. On the positive side, there were no problems activating this EBS with one hand.

6.15 In the ergonomic performance trials longer deployment times were seen with the rebreather device, although shorter times were measured in the cold water trials. This was thought to have been due to three key issues. The first problem related to a security tag that should have been a ‘weak link’. Subjects were not able to break this link, the component being too strong for the intended use. In a real incident, inability to open the pouch would delay escape and would be likely to increase the level of panic experienced. This demonstrates the need to check whether means provided to prevent tampering are fit for purpose. The mean time to deploy the rebreather (Table 3; two hands) was thus longer than it would otherwise have been.

6.16 Once the rebreather had been removed from its pouch, the mouthpiece was generally easy to find although in some cases the hose sprang out and away from the body, meaning that the user had to ‘catch’ the mouthpiece to deploy it. This was another example of an unexpected event causing delay. There were also some compatibility problems with the four-point harness in the ergonomic performance trials, the harness sitting over the pouch making it more difficult to open the pouch. Quicker deployment times were measured in the cold water trials reflecting the lack of security tag problems and the use of a waist harness with no shoulder straps. When attempting to deploy this device with one hand the only problem related to the mechanism used to activate the EBS, allowing breathing in and out of the counterlung. Three female subjects all had to use two hands to squeeze the rings together. (N.B. In the operational unit, the EBS should activate automatically on water entry.)

6.17 In general, the design of mouthpieces can vary considerably, with some found to be more comfortable than others. The technical standard requires a range of subject sizes which should allow the fit of the mouthpiece to be assessed for a wide range of mouth sizes. Some designs (e.g. with a teeth grip) may be easier to hold in the mouth than others. Training experience has shown that some subjects will demonstrate a gag reflex when inserting a mouthpiece (Coleshaw, 2006b). Such individuals may need additional training time or a different mouthpiece design.

Nose clips

6.18 Nose clips are an accessory item offered as one option for preventing water entering the nose. While they may be of great benefit to some users, they can also be regarded as a problem if they cannot be deployed very quickly and efficiently or if they do not fit well. It should be possible to design out fiddly nose clips so as to achieve the optimum deployment time required. A poor design will waste time and distract the EBS user from the important task of escaping from the helicopter.

6.19 It is recognised that it is very difficult to design a nose clip that fits all members of a population, particularly when used in water. Nose shape varies considerably, particularly between different ethnic groups. It is therefore very difficult to design a nose clip that comfortably fits all users and all potential user groups. Manufacturers may need to consider offering more than one nose clip design to accommodate different user populations. Similar arguments would apply if a partial face mask were to be used for nose occlusion.

6.20 With each of the generic EBS studied, some problems were experienced with the nose clips. It has previously been argued that nose clips are not necessary, but the inversion test demonstrated the value of effective nose clips. Several subjects stopped the exercise due to the nose clip not fitting well, with water going up the nose. However, those who were happy to remain underwater without a nose clip chose not to use one when undertaking the underwater deployment test (upright). For this group of users, deployment time would be improved by ignoring the nose clip. It is therefore suggested that deployment instructions should normally focus on deployment of the mouthpiece and activation being undertaken first. This will allow the user to breathe from the device sooner rather than later, before then donning the nose clip if time allows. That said, this will not be possible with all designs. The CA device used in the trials had a nose clip integral to the mouthpiece that was designed to be fitted before the mouthpiece, guiding the mouthpiece into place. Given the design of this particular device, this would add little to overall deployment time, particularly in a well-trained user, as the nose clip and mouthpiece are fitted in one relatively easy action. The design had the advantage that the subject did not have to search for the nose clip, considerably reducing overall deployment time compared to some other devices with separate nose clips, demonstrating that small compromises sometimes have to be made when considering overall performance. For this reason, an insistence on mouthpiece deployment before nose clip deployment could be considered to restrict design. The fundamental performance criterion in this case relates to rapid deployment, however achieved.

6.21 All three of the generic designs of EBS studied used a nose clip to prevent water entering the nose. It should be noted that this is not the only means available to prevent water entering the nose. It has been suggested that a face mask could be used, both to achieve this aim and to improve the vision of the user when underwater (members of the Canadian offshore work force are provided with a half face mask to help vision during underwater escape). Any alternative system used, whether it be a face mask or other form of nose occlusion, would similarly have to be assessed to ensure that a good seal could be achieved, that a suitable stowage position could be found that allowed rapid removal and deployment, and that it was compatible with other equipment used.

Measured deployment times

6.22 In the example draft technical standard 10 seconds was suggested as a target maximum deployment time. This target figure was based on a desirable maximum deployment time, giving consideration to the short time between water impact and submersion in many helicopter water impact accidents. It was not based on documented evidence of the actual time to deploy a typical EBS. The ability to deploy with one hand was considered desirable to allow subjects to keep one hand locating the nearest exit or escape route. This requirement would also favour designs with simple deployment procedures. The current assessment of realistic deployment times has shown one-handed deployment times to range from 5.5 seconds to more than 30 seconds across the three designs investigated. Quickest deployment times were observed with the generic compressed air device, reflecting the simplicity of this device and the fact that it was specifically designed for use without practical training. It seems unlikely that any device could be fully deployed in much less than the recorded mean deployment time of the compressed air device assessed in these trials (7 seconds). Whilst most subjects were able to fully deploy this device within 10 seconds, there were some instances where subjects took a little longer than 10 seconds to deploy the device. A maximum deployment time requirement of 10 seconds could therefore have resulted in potential failure of this device despite no ergonomic problem being identified. It should be noted that most test pass/fail criteria require all subjects within the sample group to meet a given requirement. The average time for a sample group will therefore be below any maximum limit set.

6.23 More variable times were seen with the other two devices assessed. In general, rebreather and hybrid devices are likely to take a second or two longer to deploy than a compressed air device as, once the mouthpiece is in place, the user must take a deep breath and activate the system. It therefore seems possible that a 10 second deployment time limit could exclude many rebreather and hybrid devices. In the cold water trials, deployment of the generic rebreather, which was considered to be straightforward and intuitive, took between 5 and 14 seconds to deploy (Table 15). (N.B. In this group the harness and security tab problems were removed). In the ergonomic performance trials, during the two-handed and one-handed deployment of the hybrid and rebreather (Tables 3 and 4), undertaken when subjects were still unfamiliar with the particular EBS devices, deployment times were below 20 seconds in most but not all cases. Video footage of the trials shows that deployments taking less than 15 seconds were straightforward and generally without error, whilst those taking longer than 20 seconds tended to reflect problems being experienced by the users. Most of these problems could potentially have been removed by changes to the design of the products.

6.24 When studying the deployment times observed for the hybrid and rebreather it should be noted that some subjects, after fitting the nose clip and mouthpiece, sometimes waited for a 'good' deep breath before activating the device and breathing out into the counterlung. In a real emergency, without any spare time, they would be more likely to take a single deep breath and activate. In some cases, the measured deployment times may therefore have been a little longer than might be expected in reality. During approval testing, subjects would have to be instructed to take a single breath in and then activate the system to breathe out.

Time available for deployment

6.25 EBS will be used in helicopter accidents when capsize and/or sinking occur before the occupants have had time to evacuate from the cabin. In the event of a helicopter ditching (a controlled landing on water) occupants are likely to have time to prepare for evacuation. In high sea states where the helicopter might still be at risk of capsize, rebreather and hybrid EBS could be deployed as a precautionary measure, with the user breathing to the atmosphere (and only activating the device in the event of submersion). Compressed air devices are not designed to be used in this manner as the air supply would be used up. In helicopter crashes with limited or no control, occupants may have little or no warning of the water impact. Accident reports show that the helicopter inverts or sinks either immediately or after a short delay in about 60% of all water impacts (Rice and Greear, 1973; Brooks, 1989; Clifford, 1996). What is not certain is just how much time there is between water impact and capsize or sinking in survivable crashes. Various estimates can be found in reports relating to helicopter water impacts:

- Clifford (1996) provided flotation information regarding 56 accidents, where the helicopter remained afloat and upright for long enough to enable occupants to evacuate in 19 cases and inverted or sank before evacuation could be completed in 37 cases.

- The RHOSS report (1995) analysed 15 survivable accidents into three categories; in 5 cases there was more than 5 minutes warning, in 3 cases there was between 1 and 5 minutes warning, and in 7 cases there was less than 1 minute of warning. However, they did not provide any indication about how long the helicopter remained afloat after water impact.
- In a study of civilian and US army water impact accidents (Chen et al, 1993, p36), the authors state that "none of the rotorcraft in which drownings occurred remained upright for more than approximately one minute". They also provided several case reports, with one case where the pilot considered that the aircraft sank after about 20 seconds.
- Jamieson et al (2001) studied reports from 11 accidents, where capsize occurred within 1 or 2 minutes of impact with the sea in six of the cases.
- Coleshaw (2003) cited two accidents in the North Sea where capsize was thought to have occurred within about 30 seconds.

6.26 Most accident reports are unable to provide a specific time. More typical is the accident report following the Cormorant Alpha accident (AAIB, 1993) which states "after impact, the helicopter rapidly adopted a right side down attitude and then became fully inverted before it sank. It was not possible to determine a precise time for this but it was thought to have taken only a minute or two". In a review of underwater egress, Ryack et al (1986) considered that helicopters will often begin to sink within a minute and that this might occur in as few as 20 seconds. Whilst not being very specific, these reports do provide a good basis for consideration of the time available for deployment of EBS in the event that a helicopter capsizes or submerges 'immediately' on impact.

6.27 In addition, the risk of facial injuries from deployed EBS when the helicopter contacts the water should be borne in mind. EBS should therefore not be deployed prior to a water impact even if the opportunity arises, as users are likely to be exposed to large accelerations. In the case of a ditching accelerations can be expected to be much lower, but EBS deployment should ideally still be undertaken after the helicopter has alighted on the water. In this eventuality there is more likely to be time to deploy the EBS on the surface, but there is still a chance that available time may be limited if the helicopter ditches into heavy seas when there will be a high risk of capsize.

Overall assessment

6.28 Taking all factors into account it is therefore suggested that a maximum deployment time of 20 seconds be used for the EBS deployment test. This time should cover all parts of the deployment process, including fitting of a nose occlusion system.

6.29 If EBS are to be deployed underwater, then deployment must be achieved within the breath-hold time of the user, suggesting the need for a stricter deployment time for EBS demonstrating this level of performance. Mean maximum breath-hold times of 20.5 ± 3.9 seconds (5˚C water), 17.2 ± 3.7 seconds (10˚C water) and 21.1 ± 5.6 seconds (15˚C water) have been reported for EBS users undertaking a simulated underwater escape exercise, wearing an uninsulated helicopter suit (Tipton et al, 1995; Tipton et al, 1997). Breath-hold times are shorter in some subjects in some instances, with times as low as 10 seconds having been recorded. There is also likely to be some variability in the breath-hold time of individual users; in the Tipton et al 1997 study, with repeat tests under similar conditions, breath-hold times varied by several seconds in any given subject. The current trials also demonstrated that some subjects may choose not to spend time using a nose clip in the underwater deployment situation, thereby reducing the time needed for deployment. It may be that some will cope with water entering the nose during the stresses of a real emergency whereas they might not tolerate it in a relatively controlled test or training environment. Others are unlikely to cope without the provision of a nose clip. It is therefore proposed that for EBS designed for underwater deployment it should be possible to locate and remove the EBS from its stowage and deploy at least the mouthpiece within 10 seconds, whilst it should be possible to fully deploy the EBS including the nose occlusion system within a time of 12 seconds (also see 'Underwater Deployment' on page 98 and 'Revision of the Technical Standard' on page 104).

6.30 It seems likely that, in a real emergency, helicopter occupants are likely to use both hands if they have any problems when deploying EBS. This may not be a problem whilst the user is still seated with the harness secured, but could mean that contact with an exit or escape route is lost if it occurs after the harness has been released. When just one hand is used to deploy the EBS the hand of choice is likely to be influenced by which hand is used to locate the nearest exit, the opposite hand generally being used to deploy the EBS. Ease of deployment may be affected by the storage position of the EBS. In the crash scenario possible injuries also make one-handed deployment desirable. It is therefore considered that one-handed deployment is an essential feature if underwater deployment is to be achieved during emergency use, and is desirable for all EBS.

Endurance

General

6.31 EBS are required to provide users with the ability to breathe underwater for sufficient time to escape from a capsized and/or submerged helicopter. When undertaking simulated underwater escape exercises in cool water, escape can take as little as 25 to 30 seconds to complete (Bohemier et al, 1990; Coleshaw and Howson, 1999; Kozey et al, 2006). Escape times can be longer when a full complement of passengers is assessed (Brooks, Muir and Gibbs, 1999). It has been reported that groups such as the Coast Guard, military, civilian operators and training establishments have estimated that 40-60 seconds are required to make an escape in real conditions (Tipton et al, 1995). Where use of EBS has been specified by end users, there is generally a requirement for the system to allow the user to breathe underwater for a minimum of 60 seconds (e.g. OLF, 2004). It therefore seems important to include a test to ensure that EBS will provide this level of performance. Previous research has not usually studied time underwater of more than 60 seconds. The maximum time underwater was set at 90 seconds in the current study to provide further information about limits of use and gather more information about which types of product can exceed the 60 second duration performance level.

Effort of breathing

6.32 A number of factors increase the effort of breathing in water. As with any form of physical exertion, when heavy loads are experienced, the muscles involved will fatigue quite quickly over time. Thus, while low respiratory workloads will be tolerated for relatively long periods, high workloads will be tolerated for much shorter periods of time. Warkander (2007) used the analogy of a very heavy backpack that could be carried for a few minutes but that could not be carried for hours. It is therefore desirable to keep the work or effort of breathing within acceptable limits, but these might be higher than those generally accepted for an activity such as diving that is conducted over a number of hours. Within this limit, the EBS user must be able to undertake the level of activity required during escape.

6.33 Immersion affects ease of breathing due to the pressure applied to the body, pressure increasing the deeper the body is immersed. When upright, hydrostatic pressure forces blood into the chest. This can reduce lung volume (though the effect will be small at the depths considered in this study). Cold has a similar effect. Cold causes the peripheral blood vessels to constrict, reducing skin blood flow and shunting blood into the body core in an attempt to reduce heat loss. This effect will be limited by use of a well insulated immersion suit.

6.34 Breathing systems also provide some resistance to breathing, increasing the effort of breathing. Breathing resistance will be affected by factors such as the diameter of a hose or mouthpiece aperture. Posture also has an effect due to a difference in pressure between the lung and the breathing apparatus. This is known as hydrostatic imbalance. A negative imbalance causes breathing at low lung volumes and results in inhalation feeling difficult whilst a positive imbalance causes breathing at high lung volumes and results in exhalation feeling difficult (Warkander, 2007). Hydrostatic imbalance increases the effort of breathing with all diving equipment but can be a particular problem with rebreather counterlungs. For example, if the user is face down in the water, and the counterlung is positioned on the chest, then the pressure acting on the counterlung will be higher than the pressure acting on the lungs, causing hydrostatic imbalance. Users are more likely to be able to cope with this if they have experienced the effect during training and have some understanding of the cause.

Assessment of breathing exertion

6.35 EBS use and the work or effort of breathing has already been discussed in 'Work of Breathing' on page 31 of this report, where a physical test of the work of breathing was considered. This physical test will be undertaken to ensure that EBS perform effectively at the high levels of breathing exertion that might be expected when suffering from cold shock and panic breathing. This test should exclude any products where the work of breathing exceeds accepted limits. In addition to this physical test it was also considered to be important to undertake an ergonomic assessment, involving a hand-over-hand pull along an underwater rail, undertaken over the likely time that might be taken to escape from a helicopter. Such an assessment would thus cover ease of use issues such as maintaining a good seal at the mouth and keeping the mouthpiece in place whilst manoeuvring in water, as well as ease and comfort of breathing.

6.36 In the trials, two scales were used to assess perceived exertion and breathlessness during the underwater assessment. The Borg and VAS scales produced similar end results when comparing the three generic devices, but more significant differences were measured with the Borg scale. Whilst both scales are widely used and either would be acceptable, the Borg scale showed greater sensitivity, with significant differences between the three types of EBS being evident. The Borg scale therefore appears to have the better potential to demonstrate a difference between good and poor performance.

6.37 In general, poor correlations were found between endurance times and the ratings of breathing exertion and breathlessness for any given EBS. Subjects were told that the exercise would last for 90 seconds, at which point they would be stopped and could surface, but that they could stop the exercise earlier if breathing became difficult. At the end of the exercise subjects were asked to rate exertion over the period of the swim and not base the assessment on just the exercise end-point. These ratings should therefore relate to the general performance of the EBS during the activity. It is also the case that those subjects who were willing to accept a certain level of discomfort may have pushed themselves harder and managed to remain underwater for longer than subjects who were not willing to accept breathing discomfort.

6.38 If this subjective rating is to be used to pass or fail devices, then consideration must be given to what level of breathing exertion is acceptable for a device used in an emergency environment, for a very short period of time. It therefore seems appropriate to allow a rating of 'hard' breathing exertion, but exclude levels of breathing exertion rated as 'extremely hard'. An upper limit of 'very hard' is therefore suggested. All devices will have had to meet the requirements for breathing performance (clause 5.5 of the Technical Standard, covering maximum levels for work of breathing, peak to peak respiratory pressures and hydrostatic imbalance) before ergonomic testing with human test subjects is carried out. This should exclude any products where work of breathing is unacceptable. This is not to say that breathing will be comfortable if values for a particular device are close to the maximum limits. Nonetheless, if the work of breathing is found to be unacceptable the subject will stop the test early and the EBS will fail this particular test. It can therefore be questioned whether a rating of breathing difficulty is necessary. One advantage of using the rating is that if a subject does stop the test before completion, and a relatively low rating of breathing difficulty is recorded, then questions should be asked about why the subject stopped the test. If the reason was not because the effort of breathing was unacceptable then the test should be repeated on that same subject.

EBS design and type-specific issues

6.39 With the CA device, only one subject rated exertion above 12 on the Borg scale (between 'light' and 'somewhat hard'), the one outlier being the asthmatic subject. With the H device, all but one subject rated exertion between 8 (between 'extremely light' and 'light') and 13 ('somewhat hard'). The outlier subject did not have the advantage of additional air in the counterlung as the cylinder had not fired, and had problems with poor seal on the nose clip and mouthpiece. With the RB device, the asthmatic subject stopped the test early due to problems regulating her breathing. The remaining subjects all provided ratings of exertion ranging from 14 (between 'somewhat hard' and 'hard/heavy') and 17 ('very hard').

6.40 These ratings of breathing exertion measured with the generic EBS devices represent the differences that might be expected for the three different design types. When swimming face-down, it is expected that the work of breathing will be higher with a rebreather, due both to hydrostatic imbalance and to the gradually increasing levels of carbon dioxide in the counterlung. If only a small breath is taken by the user, then there is also a risk of the counterlung partially collapsing following inspiration, making it harder to then breathe back out into the bag. Hybrids are likely to make the work of breathing a little easier due to the additional gas in the counterlung and the longer time before high carbon dioxide concentrations are reached. With gas provided on demand at the mouthpiece, work of breathing would be expected to be lower with compressed air devices, up to the point where the gas supply runs out. Panic breathers will empty a compressed air device much more quickly that those who are able to stay relatively calm. However, for all EBS types, the effort of breathing with a particular device will be dependent upon specific design features that affect breathing resistance.

6.41 Some problems with the automatic release of air into the counterlung of the hybrid device were experienced when carrying out this test, reducing the level of performance that could otherwise have been achieved. This was thought to have been due to the gas cylinder not being tightened sufficiently by the research team. The instructions supplied with the device state that the cylinder should be screwed in "tightly". Further investigation showed that re-arming instructions provided by the manufacturer of this component (when used for lifejackets) stated "the gas cylinder must be VERY FIRMLY TIGHTENED into the black inner body". This raises some concern about how an end user can be sure that the gas cylinder is sufficiently tightened and, perhaps, a torque loading should be specified. Measures need to be taken to ensure that, where additional air is provided in a hybrid device, reliable release of gas is achieved. Servicing thus needs to be undertaken by trained and experienced staff who are aware of the potential problems if the cylinder is not sufficiently tightened. It is therefore suggested that servicing and maintenance be carried out by a service organisation approved by the manufacturer. It is also important that users be told about the manual inflation of the gas cylinder during training, so that gas can be released if the automatic release is slow to activate.

Test procedures

6.42 Whilst most EBS on the market are already designed to provide at least 60 seconds endurance, in the current research some subjects found it difficult and uncomfortable to swim face-down in the water for a full 60 seconds, particularly when using a rebreather type EBS. In a test procedure, it will be necessary to standardise the distance covered in a set time. This activity was chosen to simulate cross-cabin helicopter escape, with subjects pulling themselves hand-over-hand along an underwater rail. In a real incident, EBS users are likely to remain seated for a period before releasing the harness and attempting to escape, either through a nearby exit or a longer cross-cabin route if that is not possible. It is therefore suggested that the test procedure should be based on subjects deploying the EBS, breathing underwater at rest for a short period (10 seconds) and then undertaking the hand-pull activity, covering a minimum distance (10 m) within a given time; the test lasting 60 seconds overall. The hand-pull activity should include at least one turn, again simulating the real environment where a user may have to change direction whilst attempting escape. This will help to show that the mouthpiece will stay in place and not cause undue difficulty to the user. It is suggested that the test be undertaken at a depth of less than 1 m so that hydrostatic imbalance can be experienced, but without any undue health concerns associated with pulmonary barotrauma at greater depths (the latter relating to compressed air and hybrid devices only).

6.43 When conducting a test using a hybrid device it may be necessary to repeat the test if the gas cylinder does not fire on immersion to ensure that the EBS performance can be adequately assessed. If during testing there is evidence that the gas cylinder is not firing correctly (as seen in the endurance trial), then the reason for this failure should be investigated and resolved before the EBS can be passed as meeting the standard.

Inversion

6.44 During a helicopter capsize there will be a period of time when occupants are suspended in their seats in an inverted posture before the harness is released and the occupant attempts to make their way to an exit. This time might be extended if, for example, the occupant had problems when attempting to release the harness. It is thus important to check the ability of users to breathe from EBS whilst inverted. In the current trials, the inversion procedure was performed under controlled conditions, as it would be very difficult to check specifically the effects of the inverted posture during a helicopter escape exercise.

6.45 The results of the inversion test showed that most subjects were able to breathe from the generic EBS whilst inverted. Some problems that were experienced related to the nose clip which let in water due to poor fit. This therefore provided a good test of nose clip performance. In a real emergency, tightly fitting nose clips will be tolerated. It may be necessary to have slightly looser fitting nose clips (of the same design) for training where discomfort will be less well tolerated, but where there is time to adjust and obtain a good fit. In either situation, they must remain secure on the nose when underwater.

6.46 Whilst some subjects reported breathlessness with the rebreather, most felt that breathing in the inverted posture was easier than breathing when face-down. This was reflected by significantly lower Borg scale ratings given for the rebreather following the inversion test compared to the endurance (face-down swim) test ($P<0.001$). It should however be noted that the inversion test did not involve exercise and this could account for the higher work of breathing during the face-down hand-pull exercise. With these particular products hydrostatic imbalance may have been lower in the inverted position, but this could differ with other rebreather products dependent upon the position of the counterlung.

6.47 With the hybrid device there were two cases where the air cylinder only fired as the user left the SWET chair. These subjects had therefore conducted the test using a device that was working as a rebreather only. One of the subjects was aware that the cylinder had not fired and this may well have contributed to his decision to stop the test early. (Training needs to include instruction relating to the manual release of the gas to cover this eventuality). In realistic use, the cylinders may have fired at an earlier time due to greater water movement around the inflator. As discussed with the endurance exercise, it may be necessary to repeat a test if the cylinder does not fire and the reason for late firing should be investigated.

6.48 This 60 second exercise using subjective reporting scales (Borg and VAS) did not show any significant differences between the performances of the three specific designs of EBS used in these trials. In the technical standard it would still be important to check that the exertion of breathing whilst inverted was not excessive and also that the nose clip design was acceptable and provided a good seal when the user was inverted.

Use of EBS during submersion and capsize

General

6.49 The overall aim of the helicopter simulator exercises was to assess ease of use of EBS in a more realistic environment. Whilst individual components of the operation and use of the equipment have been studied in the previous exercises under more controlled conditions, it is considered important to look at the whole sequence of events and tasks which must be undertaken in the correct order during helicopter escape. When used in the technical standard, the exercises will assess performance with a range of body orientations in the water combined with physical activity and the restrictions imposed by leaving the helicopter seat and escaping through the exit window.

Harness compatibility

6.50 One specific issue that was identified by the trials related to harness compatibility. The deployment exercise in air demonstrated problems where either the harness was sitting over the EBS impairing deployment of the EBS, or where there was the potential for the EBS to cover the harness buckle and thereby prevent the operation of the buckle. The helicopter submersion exercise provided information about release of the harness underwater, with the subject leaving their seat to move towards an exit to one side of the body. This demonstrated how it was possible for the EBS to obstruct harness release, although there were no cases where subjects were unable to free themselves from the harness. In a test procedure, it would be important to establish that it was the EBS that obstructed and caused the problem and that it was not a simple case of the buckle not being fully turned or operated. The capsize exercise puts the harness under a different load, with the user suspended upside down in their seat. This may change the relationship between harness and EBS positions, making it important to assess compatibility during capsize.

Snagging

6.51 A second issue that was investigated during these exercises was the possibility of the EBS system snagging during helicopter escape. The term snagging can be used in a number of ways. Dictionary definitions variously refer to: the action of catching, tearing or being damaged on a jagged projection; to be halted or impeded as if on a snag; to become entangled with some obstacle or hindrance. Snagging hazards might take the form of a tape loop or large toggle that could catch and have to be untangled before the individual could make their escape. When testing for snagging it is necessary to look for evidence that a part of the equipment has caught on a projection, that something has become entangled or has halted progress. In the current study there were instances where either the pouch or counterlung of the EBS changed the profile of the individual, meaning that they had to make an adjustment to their posture during egress through the window. These cases (for examples see Figures 12, 13 and 14) slowed the subjects by a second or two but did not unduly delay escape, the subjects pulling themselves clear. It is considered that some of the issues seen could be improved through small design modifications. Escape might similarly be hindered by a shoulder catching on the side of the exit but this would not be defined as snagging. Whilst there were no cases where the equipment caught on a projection, requiring remedial action to be taken and thereby hindering or preventing escape, subjects did report snagging in some cases. This suggests that the meaning of snagging must be defined and explained to test subjects, and that the question should be specifically directed at the EBS. Any equipment damaged during the escape process, and any evidence of catching that requires intervention on the part of the user should be recorded.

6.52 The change in profile could be an issue for individuals of large stature and it is therefore important to ensure that such individuals are able to escape through the minimum acceptable size of helicopter escape window (432 mm x 355 mm / 17 in x 14 in). CAP 562 (CAA, 2009) states that underwater escape through a window of this size "has been satisfactorily demonstrated by persons of a size believed to cover 95% of male persons wearing representative survival clothing and uninflated lifejackets", although it is also recommended that larger persons do not sit adjacent to windows smaller than 483 mm x 432 mm (19 in x 17 in). In the European standard for helicopter crew and passenger immersion suits (EASA, 2006b; ETSO-2C503), the helicopter escape test must be undertaken with a 432 mm x 355 mm / 17in x 14in window, using at least one subject with a shoulder width measurement of at least 500 mm (19.7 in). This must be possible with the same size of individual using EBS.

Buoyancy

6.53 Buoyancy, mostly caused by air trapped within clothing and insulation within a helicopter immersion suit, has a significant effect on the ease of escape from a helicopter. When submerged, buoyancy will lift the person out of their seat as soon as the harness is released. Following capsize, it will initially push the person up into the inverted seat. Buoyancy becomes a problem when the harness is released, making it more difficult to move towards the exit. The more the buoyancy, the more effort the individual will have to exert to overcome the upward force. Only once through the exit, or if there is an exit above the individual, will it help and reduce the effort needed to swim to the surface. If the person can maintain a grip on the fixtures on route to the exit, then added buoyancy has less impact. When considering the trapped buoyancy of an immersion suit system, then large individuals in large size suits, are likely to present the highest values of measured buoyancy. However, these large individuals are more likely to be able to cope with levels of buoyancy close to the 150 N maximum value allowed by the European helicopter suit standards (EASA, 2006a and 2006b). Smaller subjects in loosely fitting suits with proportionately more buoyancy, but at levels below the allowed limit of 150 N, may have more problems making an escape. It is therefore important to assess ease of escape from the helicopter to evaluate the overall effect of added buoyancy.

6.54 Hybrid EBS will increase the overall level of buoyancy experienced by the user due to the additional air that is released into the counterlung. In the generic hybrid assessed in these trials, buoyancy was increased by 30 N to 35 N (3.0 l to 3.5 l air released). Dependent upon the suit used with the hybrid EBS, this could take the total buoyancy of the suit system above the 150 N limit (EASA, 2006a; EASA 2006b). A note has been added to the compatibility clause of the Technical Standard (clause 5.4) to address this issue stating “hybrid rebreathers using additional compressed air may not be compatible with insulated helicopter immersion suits that have the maximum permissible buoyancy”. It is also important that information should be provided to users if buoyancy could cause compatibility problems. That said, in the current trials, using a dry coverall style helicopter immersion suit with thermal liner, subjects using the generic hybrid device did not experience any undue buoyancy problems that could be attributed to the EBS, and did not experience any significant difficulty when escaping from the submerged helicopter.

6.55 As reported previously (Coleshaw, 2003), the US Coastguard experience using a rebreather vest with 40 lb (18 kg / 180 N) buoyancy, demonstrated the benefits of using hand-over-hand techniques to escape from a helicopter simulator. By keeping hand contact, the EBS user will be more able to overcome any buoyancy effect experienced, as well as being more likely to be able to find their designated route to an exit when experiencing disorientation. This technique would, however, need to be included in training with the EBS to be effective.

Underwater deployment

General

6.56 Some EBS products are designed for underwater deployment whereas others are not. For underwater deployment to be successful the deployment of the EBS must be reasonably intuitive, enabling deployment to be completed within the breath-hold time of the user (‘Overall Assessment’ on page 88). The design also needs to limit the amount of water that can enter the mouthpiece assembly (dead space) between submersion and deployment of the EBS in the mouth. The dead space of a rebreather will depend on the position of the activation valve that blocks off the counterlung. If water does enter, it must be possible to easily purge the water from the mouthpiece. Manufacturers must balance the size of this dead space against the ability to efficiently purge water from the mouthpiece.

Compressed air EBS

6.57 Compressed air EBS were originally conceived for military use, with the intent that they would be deployed underwater, if needed. Most compressed air EBS will be provided with a purge button as an active means to clear water from the mouthpiece, some of the stored gas from the cylinder being used to blow the water out. Purging technology has the disadvantage that some of the air supply will be used up, reducing the amount available to the user. Alternatively, the user may choose to blow any water out through the exhaust valve or small amounts of water may be swallowed.

6.58 The CA used in the trials was designed to need a minimal amount of purging, with two non-return valves reducing the dead space and the amount of water entering the mouthpiece. If working as designed, any water that does enter the mouthpiece can be removed by blowing out hard through the exhaust valve. Alternatively, a purge button is provided. Subjects in the current study confirmed that it was relatively easy to deploy the CA underwater, with a third choosing to use the purge button and the remainder of the group blowing any water out of the mouthpiece using their own breath.

Rebreather EBS

6.59 Rebreather systems are designed primarily for the ditching scenario, with the intention that the system will be deployed whilst the helicopter is still on the water surface. If submersion is rapid, and underwater deployment is the only option, it is essential that the user inhales a full breath of air before submersion. Any water that enters the mouthpiece of the EBS must be blown out using exhaled air. This water will either be blown into the counterlung, or in some cases, it might be blown out through the activation valve. If inverted, it may be preferable to swallow the water. The amount of water that has to be cleared will depend on the internal volume (dead space) of the mouthpiece system and may depend upon whether or not the activation valve (which when closed blocks off the counterlung) is open at the time of submersion.

6.60 The generic rebreather evaluated in the trials was specifically designed for deployment before submersion. It was not intended for deployment underwater. This unit had a greater dead space that could have filled with water due to the activation device being situated part way along the hose, away from the mouthpiece. The operational unit has a water activation device fitted to the hose that opens the valve and ensures that the user is able to breathe to the counterlung as soon as they become fully immersed or submerged. This removes the need to manually activate the EBS. It will have the advantage that deployment time in air will be reduced and the user does not need to remember to squeeze the activation mechanism. However, it means that if the user does not have time to deploy the EBS before submersion, the valve in the hose will be open and the counterlung may be open to water entry. In the current study this EBS was used with the water activation disabled so that the manual activation mechanism could be assessed and to allow control over when the device would activate following water entry. Subjects attempted underwater deployment, having to use some of their lung-full of air to clear water from the mouthpiece and part of the hose before activating the valve and then attempting to breathe from the bag. Not surprisingly, less than half of the subjects managed to get some air into the rebreather, but none were able to use the EBS comfortably in this (unintended) manner. (The technique of clearing water by blowing it into the bag was not attempted, but could have improved the performance of the system).

Hybrid EBS

6.61 Hybrid systems are based on the rebreather technology but with additional air provided to the user. The aim is to provide some functionality in the event that the user has insufficient time or fails to take a breath of air before submersion. If the EBS has to be deployed underwater, then exhaled air must be used to clear the mouthpiece of water. As with a rebreather, the water must either be blown into the counterlung, or in some cases, it might be blown out through the activation valve. The advantage of a hybrid EBS over a rebreather is that even if exhaled air is used to clear the mouthpiece, the user should still have the equivalent of a normal lung-full of air in the counterlung.

6.62 The hybrid device used in the trials was designed with the activation valve as part of the mouthpiece and consequently a relatively small dead space that must be cleared of water in the event of underwater deployment. The current trials demonstrated that this particular design could be successfully deployed underwater. After taking a deep breath before submersion, subjects were able to use the first part of their exhaled air to clear water from the mouthpiece before then switching to the counterlung, the remainder being used for rebreathing. Alternatively, the very small amount of water that could enter the mouthpiece could have been blown into the counterlung. This latter method has the advantage that no breathable air is lost. This latter method is therefore preferable. The additional 3.0 l to 3.5 l of air released into the counterlung helped to ensure that a full lung of air could be breathed back in. All nine subjects were able to deploy and use the hybrid in this way during the underwater deployment exercise. If a deep breath had not been taken a user would have to swallow any water from the mouthpiece. Most subjects were able to locate the mouthpiece underwater, although one had difficulty. Also of note was the fact that only one of the subjects attempted to locate and deploy the nose clip, opting to reduce deployment time and increase their speed of escape. This should be a personal option. For those who can cope without nose occlusion the process is simplified, with one less action to take. Others will be helped by nose occlusion, and will be protected as long as the mouthpiece is deployed first. The results of the inversion test suggested that there may be a greater need for nose occlusion during a capsize.

Performance in cold water

Conditions of use

6.63 The cold water performance study was conducted both to learn more about this aspect of EBS performance, but also to determine whether a cold water test would add to the knowledge about EBS performance given the ethical issues surrounding exposure of test subjects to cold. As an ethical principle, a test of this type must provide information that could not be gained in any other way.

6.64 Helicopter EBS are generally provided for use in cold water, with the effects of cold shock being a major hazard during the first few minutes of immersion or submersion. Cold shock will increase rates of ventilation and thus require a higher level of EBS performance. Whilst most of the body surface will be protected from the cold by the use of an immersion suit, the head (face at least) and hands are likely to be exposed to the cold water during the initial stages of a water impact incident. Both are areas of the skin with a high density of cold receptors capable of responding to rapid skin cooling. Also, cold shock responses resulting in stimulated ventilation and shortened breath-hold times have been measured in response to face-only immersion in water at 0 and 10°C (Jay et al, 2007). In a real event, the cold-induced increase in ventilation could be exacerbated by panic breathing.

6.65 The conditions of use of EBS in cold water may thus be severe, but it is important to ensure that any test must not endanger the personnel performing the test. Trials were therefore undertaken in water at 12°C, a temperature considered sufficient to initiate cold shock, but within ethical limits designed to protect the safety of the test subjects, agreed by the University of Portsmouth ethics committee. Where helicopters operate over water that is below 12˚C for a significant part of the year a decision may be made to undertake further testing at a lower water temperature. If this were to happen, careful consideration would need to be given to the risks to which volunteer human test subjects would be exposed and the ethics of undertaking such testing. In this case, it should be remembered that the EBS will undergo physical testing for breathing performance in water at a temperature of 4˚C, ensuring that the equipment will perform adequately at this temperature.

Measured cold water performance

6.66 The results of the cold water trials supported the need for a cold water test of EBS, with a significant decrement in performance when EBS were used during submersion in 12˚C water. The most important finding was the fact that a significant reduction in EBS performance was only found when exposure to cold was combined with submersion. When considering all three EBS devices, mean duration of use was 14 seconds less during cold water submersion compared to cool (25˚C) water submersion, representing an 18.5% reduction in endurance time. This is perhaps not surprising when considering the fact that the stimulus for cold shock is a rapid fall in skin temperature. Due to the thermal protection offered by the helicopter immersion suit there was no significant fall in mean skin temperature measured over the body trunk and limbs. This suggests that during the first few minutes of head-out immersion, the suit was able to protect the body surface from the effects of cold shock whereas exposure of the unprotected head initiated cold shock responses. This ties in with the fact that there is a high density of cold thermal receptors in the facial area. Also, it is during the period when the head is submerged that the EBS must function effectively. The situation where there has been insufficient time to don the suit hood is the worst case and this should be represented during testing.

6.67 The shorter submersion times in cold water were generally associated with an increase in dyspnoea rating on the VAS scale, but it was not the case that all of those with high ratings had short durations of EBS use. In those subjects who managed to use the EBS for the full 90 seconds a wide range of dyspnoea ratings were observed, from ratings close to 'not at all breathless', to high ratings close to the maximum. Those who completed the test did so either because they were not experiencing breathing difficulty or because they felt able to cope with the level of breathing difficulty experienced. It would appear that the subjects who completed the test with high ratings of breathing difficulty were more willing to persevere despite some difficulty, coping better with the situation than those who stopped the test early. It must be remembered that, when ergonomic testing of the EBS is carried out, the EBS will already have undergone a physical test to measure the work of breathing. Any devices with excessively high breathing resistance would fail this physical test. EBS undergoing the human cold water test should therefore have previously demonstrated breathing performance within maximum limits of tolerance. In the case of emergency breathing equipment used for a very short period of time, then it seems reasonable that a certain amount of breathing discomfort should be tolerated.

6.68 Where subjects gave a reason for terminating the exercise early, the reason was not always associated with breathing difficulty. One subject cited painfully cold hands, whilst another reported discomfort due to the suit seal. During EBS testing, the critical question would be whether the test was stopped due to difficulty breathing related to the performance of the EBS or, due to another reason associated with the cold or other test conditions. In those test subjects who were not able to complete the required time submerged in cold water, an assessment of dyspnoea should be made, and the subject questioned to ensure that the reason for terminating the test was due to the performance of the EBS and not due to other reasons causing discomfort.

Cold water test duration

6.69 As mentioned previously, most EBS are specified as extending underwater survival time, allowing users to breathe underwater for at least 60 seconds. Most assessments of EBS performance to date have thus been conducted over a period of 60 seconds. The current research looked at performance over 90 seconds to extend the knowledge base regarding realistic performance levels. In the cold submersion assessment, it was found that subjects either terminated the trial during the first 60 seconds or were able to continue for the full 90 seconds. This suggests that if there are any problems with EBS performance they are likely to be experienced during the first 60 seconds. A test with a maximum duration of 60 seconds would therefore be adequate to assess minimum performance. A longer test could be conducted where the manufacturer wished to demonstrate a higher level of performance or where this was required by the end-user on the basis of their risk assessment.

Gas concentration

6.70 The gas concentrations measured in the counterlungs following the cool and cold water exercises generally remained within acceptable limits. Tolerance of exposure to high carbon dioxide and low oxygen levels will depend on the degree of change in concentration and the duration of exposure. It has been reported that the critical partial pressure of oxygen in the lungs that will cause loss of consciousness is between 4 kPa and 5 kPa, whilst levels under 8 kPa would only be tolerated for short periods. Levels of carbon dioxide of about 8 kPa have been reported to cause dizziness and headache, whilst loss of consciousness may occur at a concentration of about 10 kPa (Sterba, 1990). These gas concentrations provide a limit for the effectiveness of a rebreather EBS, those having a low tolerance of hypercapnia in particular, being likely to terminate an exposure early. However, when considering the performance of EBS, the effects of hypercapnia and hypoxia will be a cause of subject variability, and will not be affected by the design of the rebreather. It is therefore suggested that these measurements should not be included as a performance requirement. Test houses may choose to measure gas concentrations to ensure the safety of the test subjects during the cold water test. The measurement of gas concentration during the pool trials would be more difficult to achieve. In this case, test houses would need to set clear end-points for test subjects, encouraging them to terminate a test if experiencing any symptoms such as dizziness.

Revision of the Technical Standard

6.71 When undertaking revision of the draft technical standard, consideration has been given to a number of factors including the basic health and safety requirements of the PPE Directive (European Commission, 1989), technical standards relating to similar products (EASA, ISO and CEN standards), the levels of EBS performance accepted by current end users and the generic performance levels measured in the current trials.

6.72 One further major consideration relates to the foreseeable conditions of use for which helicopter emergency breathing systems have been designed. Two different types of EBS have been identified in relation to performance. One type is capable of being deployed underwater, following rapid submersion. The other type performs optimally when deployed in air, as the user must take a breath before submersion for the EBS to function.

6.73 Two categories of EBS performance have therefore been defined within the technical standard. Category 'B' systems have been defined as those EBS with the capability to be successfully deployed in air. These designs of EBS are suitable for ditchings where there is sufficient time to deploy the equipment prior to submersion. Rebreather designs will allow the user to breathe to the atmosphere as long as the helicopter remains upright and on the surface. If the helicopter subsequently capsizes it must then be possible to immediately switch to underwater mode, breathing from the counterlung. Category B systems will have some capability in other water impact accidents where capsize or sinking is somewhat delayed, when there is still time to deploy the EBS before submersion occurs. However, EBS that cannot be successfully deployed underwater will likely have limited capability in high impact accidents when capsize or sinking occurs immediately after impact, with insufficient time to deploy before submersion. Deployment within the cold water breath-hold time of the user is not critical for a ditching scenario. However, it is desirable that all EBS are simple, easy and thus quick to deploy in an emergency, when unexpected capsize is always a possibility. It is also desirable that, even in a ditching, the EBS can be deployed after alighting onto the water to avoid the possibility of injury. A deployment time of 20 seconds is therefore proposed for Category B systems.

6.74 Category 'A' systems have been defined as those EBS with the capability to be deployed underwater. These designs of EBS are suitable for use in the worst case water impact accidents where capsize and/or sinking occur immediately after impact, as well as controlled ditchings where capsize may occur some time after the helicopter alights on the water. In the former case, the user may choose to use the EBS only if problems are experienced during escape. Alternatively, submersion could occur before the helicopter occupant has had time to deploy the EBS, meaning that the EBS must be deployed underwater. It follows that it must be possible to deploy Category A devices within the breath-hold time of the user. As discussed previously, mean breath-hold time in cold water is in the region of 17 to 21 seconds, but some individuals' minimum breath-hold times may be as low as 10 seconds. It should therefore be possible to locate and remove the EBS from its stowage and deploy at least the mouthpiece within 10 seconds. It is proposed that it should be possible to fully deploy Category A systems, including the nose clip or nose occlusion system, within a maximum time of 12 seconds. (N.B. If the maximum time is recorded for a group of test subjects is 12 seconds then the average time for the group will be less than 12 seconds).

6.75 The differentiation between Category A and B devices is thus limited to the capability to be deployed underwater and the deployment time requirement in relation to this. Most of the other performance requirements relate to both categories of EBS.

6.76 Whilst many users will choose to employ both hands to deploy EBS quickly, it is considered desirable that all EBS are capable of being deployed with only one hand if necessary, allowing the other hand to be used to maintain contact with the aircraft structure to locate the nearest exit. This should be achievable with either hand. In the case of Category A devices, if deployed underwater in a real emergency, it must be possible to keep a hand-hold whilst deploying the EBS. In addition, in a water impact the user may be injured and may have only one functioning hand. It is therefore proposed that deployment time should be measured when the EBS is deployed with one hand only, and with either hand.

6.77 It is proposed that deployment should be timed in air, to enhance reproducibility and allow test houses to more easily time and observe any problems experienced during rapid deployment. For Category A devices, the test subject must also demonstrate the ability to deploy the EBS underwater, allowing an assessment of whether a good seal can be obtained and whether the EBS can be adequately purged.

6.78 The requirements relating to the effort of breathing have been revised somewhat and are now comparable with maximum, as opposed to comfortable limits set in other standards for underwater breathing equipment (e.g. NTSI, 1999; CEN, EN 14143:2003). Effort has been made to balance the safe limits for breathing effort against the very short period of use needed for this emergency breathing system. Whilst most diving equipment could be used for many minutes up to several hours, emergency breathing systems will be used for just a few minutes maximum. A certain amount of breathing discomfort may therefore be tolerable. There is a desire to allow products to be developed that are simple and easy to use, and that are as light and manageable as possible without prejudicing design strength and efficiency.

6.79 It is proposed that breathing performance (work of breathing) should be measured on a breathing machine at simulated depths of 0.1 m and 4.0 m. While compressed air systems may perform effectively at depths greater than 4 m, rebreather systems are likely to have increasingly limited capability as depth increases. This must be considered along with the likelihood of helicopter occupants making a successful escape as depth and the time underwater increases. It is desirable that manufacturers are able to provide users with information about operational depths and limits of use.

6.80 Other performance requirements have been refined, giving consideration to the foreseeable conditions of use. Compatibility requirements have been added, relating in particular both to the lifejacket or immersion suit that might be worn with the EBS and to the aircraft harness.

6.81 Ease of use and manoeuvrability requirements have again taken account of the foreseeable conditions of use, covering endurance time whilst manoeuvring underwater, inversion, underwater escape and capsize scenarios. It was considered desirable to include a cold water test given the likely conditions of use and the impact that water temperature has on breath-hold and underwater endurance times. This was justified by the reduced performance measured when cold exposure was combined with submersion.

6.82 Finally, new sections have been added to the standard covering marking, information supplied by the manufacturer, servicing and maintenance. Whilst the performance tests will help to ensure that equipment provides the desired level of protection, it is also very important that end users have the information needed to use the equipment correctly, that adequate training is provided, and that equipment is adequately serviced and maintained to ensure reliability when used in an emergency. User, training, service and maintenance manuals will all help to ensure that an optimum level of performance and protection are provided.

EBS training issues

6.83 Whilst the main aim of this study was to develop a technical standard for EBS, during the completion of the work some issues were identified that may be of benefit when considering training procedures.

6.84 The in-depth consideration of the foreseeable conditions of use demonstrated the need for rapid deployment of EBS in a water impact scenario. In this case, EBS deployment must either be achieved before capsize and/or submersion, or once underwater, during the cold water breath-hold time of the user. In the case of a ditching, it is current practice to only commence deployment once the aircraft has alighted on the water to avoid any risk of mouth or facial injuries. Once on the water surface the ditched helicopter is at risk of capsize. Thus, while there is not the urgency of a water impact accident, it is still desirable to be able to deploy the EBS promptly and correctly so that it will be ready for use if needed. In either case, there is a need to train the user to deploy EBS as quickly as possible and without mistakes. Current training methods generally focus on gradually building the skills of the user, to the point when they are comfortable using the EBS. This could be developed to ensure that, once familiar with the device, the user is capable of carrying out rapid deployment.

6.85 The users of Category 'A' EBS will also have to be trained in underwater deployment techniques to ensure that this type of device can be used to full effect. This is likely to put more stress on some individuals who are uncomfortable when underwater, requiring careful planning of the training. It is recognised that some individuals are able to cope underwater without a nose clip or nose occlusion whereas others will not cope without a nose clip. Training should provide EBS users with an opportunity to explore their own particular needs and develop a strategy for future use if ever required in a real emergency.

6.86 The trials demonstrated that breathing underwater with EBS is not always comfortable, particularly if the time underwater is extended towards a minute or more. For rebreathers, breathing will become more laboured with time. The user must learn to breathe against hydrostatic pressure and understand that breathing resistance may change with body orientation in the water. They should also understand that breathing may become more difficult and strenuous as depth increases. It has been acknowledged that breathing may become rather uncomfortable, but that this is limited by the short period of use for which helicopter EBS are designed. Training should make users aware of this so that they will be fully prepared.

6.87 Different problems are presented by compressed air devices. Again, users must learn to breathe from the EBS when underwater, in this case becoming accustomed to positive pressure. Also, the trainee should understand that the supply of gas will last longer the more controlled their breathing. They must learn about the risks of using compressed air and the need to continue breathing without holding the breath. This also applies to hybrid EBS that provide additional compressed air. If training with the hybrid EBS is undertaken without the use of gas cylinders (i.e. training with a rebreather-only system), the trainee must understand how breathing performance will change (for the better) when the additional gas is available in a real situation. Users of hybrid EBS should also be taught about the manual as well as automatic release of gas from the cylinder, to ensure they have the benefit of the additional gas.

6.88 Given that capsize can occur in both ditching and water impact events, it seems sensible to train all EBS users how to clear water from the mouthpiece of the EBS. This may take the form of a purge button on compressed air devices, or blowing water out into the counterlung in the case of rebreathers and hybrid EBS. This skill should help to reduce levels of stress during use.

6.89 The overall aim of training should be to ensure that EBS can be used as efficiently as possible so that, in the event of a ditching or water impact accident, the EBS user is able to carry out the necessary emergency procedures and concentrate upon escaping from the helicopter.

SECTION 7

Conclusions

- Requirements relating to the work of breathing need to comply with accepted safe limits of use, taking into account the conditions of use of EBS.
- For EBS to be easy to use in an emergency, deployment procedures must be simple and intuitive.
- Deployment actions should be kept to a minimum to allow users to be able to remember their instructions and carry out the tasks in the correct sequence.
- It should be possible to deploy the EBS with one hand, and with either the left or the right hand.
- Full deployment of any EBS should be achievable within 20 seconds. This time should include the time to break any security tags, open the pouch/pocket, locate and deploy the mouthpiece, deploy a nose clip and, in the case of rebreathers or hybrids, activate the system allowing the user to breathe into the counterlung.
- It must be possible to deploy EBS designed for underwater deployment during a breath-hold in cold water. Full deployment of this category of EBS (Category A) should therefore be achievable within 12 seconds. It should be possible to deploy the mouthpiece within 10 seconds.
- More work is needed to improve methods of nose occlusion. Where nose clips are used they need to be easy to open but secure when in place and when the skin is wet. Nose occlusion systems need to fit a wide range of face or nose sizes and shapes.
- Nose clips that are held in a relatively fixed position in relation to the mouthpiece appear to be easier to locate and deploy quickly than those that are not fixed.
- Any security tags or stitches provided to prevent tampering or inadvertent use of EBS should be provided as weak links that can easily be broken in the event of emergency deployment.
- It is desirable that components such as the mouthpiece are held in a fixed position so that they can be located with ease during deployment.

- Compatibility should be assessed using the shoulder and waist straps of typical helicopter seat harnesses, including four and five point harnesses.
- The face-down underwater swim (endurance trial) provided a means of checking endurance times when carrying out some physical activity. This would be impractical to carry out in cold water. The hand-over-hand action simulated the activity that would be undertaken in a real accident when crossing a submerged helicopter cabin.
- The endurance trial also provided a means of assessing the work of breathing, with higher levels of breathlessness reported in the prone (face-down) posture for the rebreathers.
- At least one turn in the face-down underwater swim test would allow an assessment to be made regarding the likelihood of the mouthpiece being displaced during manoeuvres underwater.
- Effective nose clips are needed to prevent water entry up the nose. The inversion test was effective in showing up problems with poorly fitting nose clips.
- When a hybrid device is assessed, it will be necessary to check that the gas cylinder fires reliably and provides the additional air to the user as specified.
- Snagging should be assessed during HUET submersion and capsize exercises. The term 'snagging' should be defined, and should be specific to problems caused by the EBS.
- The additional buoyancy provided by a hybrid EBS should not prevent escape from the helicopter through a minimum size exit window.
- For EBS to be deployed underwater the mouthpiece dead space, where water could collect, should be minimised. Users should be provided with instructions and training about how to deploy if underwater.
- A cold water test in water at a temperature of 12˚C should be included in the technical standard. This test should involve submersion of the head to ensure that the effects of cold shock are experienced. Any hood or gloves should not be worn for the test unless they are normally worn during flights.
- Detailed servicing and maintenance procedures are needed to ensure reliability during operational use of EBS. Servicing and maintenance should be undertaken by a servicing station approved by the manufacturer.

SECTION 8

Further work

8.1 The current work demonstrated many problems with the design and rapid donning of nose clips. Nose clips provided as a separate item can take time to orientate and fit, whilst it is very difficult to design a nose clip that fits all sizes and shapes of nose. Further research into the design of different means of preventing water from entering the nose would therefore be beneficial.

8.2 There is concern that the additional buoyancy of a hybrid EBS could make the overall buoyancy of a helicopter suit system exceed the current 150 N maximum. A similar problem exists with insulated helicopter suits. Previous experience suggests that users wearing extra large suits, with greater trapped buoyancy, are most likely to be close to the 150 N limit, but it may be argued that these large subjects would be more able to cope with additional buoyancy and make a successful underwater escape. Small subjects may be within the limit but have problems due to a higher proportionate amount of added buoyancy. It is therefore suggested that further work be conducted to study the relationship between body size, helicopter suit size, additional buoyancy (due to suit and EBS) and the ability to escape from a submerged helicopter.

SECTION 9

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SECTION 10
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APPENDIX A

Proposed draft technical standard

A1 The example draft technical standard published in 2003 (Coleshaw, 2003) has been extensively revised and expanded. Requirements and test methods have been split into two sections. Clauses have been added to bring the specification more in line with ETSO specifications (e.g. ETSO-2C503; ETSO-2C504).

A2 Text in *italics* provides the reasoning behind some of the requirements and test methods.

TECHNICAL STANDARD: HELICOPTER EMERGENCY BREATHING SYSTEMS

1 Purpose

1.1 This technical standard prescribes the minimum standards of design and performance for helicopter emergency breathing systems (EBS), used to reduce the risks of drowning in the event of submersion. The technical standard aims to ensure that the equipment user is able to carry out the necessary emergency procedures whilst being provided with the optimum level of protection under foreseeable conditions of use. It also aims to ensure that the equipment presents a minimal hazard in relation to escape from the helicopter, and that the equipment has no detrimental effect on the health and safety of the user or on the performance of other equipment.

2 Scope

2.1 This technical standard applies to breathing systems for use by helicopter crew and passengers in the event of a ditching or impact with the water.

2.2 An emergency breathing system is a system designed to significantly extend the survival time underwater, thereby improving the probability of successfully escaping from a submerged helicopter cabin.

2.3 Two categories of emergency breathing systems are addressed by this standard:

<u>Category 'A'</u>

Category 'A' systems have the capability to be deployed both in air and underwater. These designs of EBS are suitable for use when capsize and/or sinking occurs immediately after contact with the water.

<u>Category 'B'</u>

Category 'B' systems have the capability to be successfully deployed in air. These designs of EBS are suitable for ditchings where there is sufficient time to deploy the equipment prior to submersion. However, they will likely have limited capability in water impact accidents if capsize and/or sinking occurs immediately after impact.

NB: A ditching is defined as 'an emergency landing on the water, deliberately executed, with the intent of abandoning the rotorcraft [helicopter] as soon as practical. The rotorcraft is assumed to be intact prior to alighting on the water with all controls and essential systems, except engines, functioning properly'. A water impact is defined as 'any contact with water that is not a ditching'.

2.4 EBS may use compressed gas, use a counterlung for rebreathing, or both (hybrid EBS). For the purpose of this technical standard, an emergency breathing system may include one or more of the following components:

- mouthpiece;
- hose;
- counterlung;
- gas cylinder;
- regulator;
- purge button;
- activation device (associated with a counterlung);
- nose clip or other form of nasal occlusion.

3 Normative references

EN 250:2000	Respiratory equipment - Open-circuit self-contained compressed air diving apparatus - Requirements, testing, marking.
EN 14143:2003	Respiratory equipment - Self-contained re-breathing diving apparatus.
EN ISO 15027-3:2002	Immersion suits - Part 3: Test methods.
EASA	Certification Specification: CS-25 Book 1 - Appendix F.
ISO 12894	Ergonomics of the thermal environment - Medical supervision of individuals exposed to extreme hot or cold environments

4 Abbreviations

BTPS	Body temperature, ambient pressure, saturated with water vapour
CO_2	Carbon dioxide
EBS	Emergency breathing system
J	Joules
kPa	kilo Pascal
l	litres
min	minutes
N	Newtons
O_2	oxygen
PO_2	partial pressure of oxygen
PCO_2	partial pressure of carbon dioxide
s	seconds

5 Requirements

5.1 General

5.1.1 Independent testing shall be conducted, with the test programme agreed with the certification authority in advance.

5.1.2 Where applicable, EBS shall be tested 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 normal service, and from the intended storage position (5.7).

5.1.3 It shall be demonstrated that the EBS equipment is reliable and will function correctly on demand/activation when tested according to 6.

5.1.4 EBS shall comply with the requirements for breathing performance (5.5). The ergonomic performance assessments using human subjects test the practicability, ease of use and comfort of the equipment, ensuring that the design of the device is fit for purpose.

5.1.5 All samples shall pass all objective tests to meet the requirements of this technical standard. Any test stopped for reasons which were not directly related to EBS performance shall be excluded and the test repeated. Due to the high variability between human subjects, and the difficulty in assessing some subjective measures, it is permitted that an EBS does not completely meet the requirements of a subjective test in a single example and in no more than one test subject. In these circumstances, two other subjects within the same weight category and with the same sex should be subjected to the same test. If this additional test is still not clearly passed then the EBS shall be deemed to have failed, whilst if it is clearly passed then the EBS may be deemed to have passed the test overall.

5.1.6 Not all of the requirements and/or tests described in this technical standard will necessarily be appropriate for a given design of equipment.

5.1.7 If a compressed gas other than air is used, consideration shall be given to any additional testing that may be required.

5.2 Design

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

(PPE Directive basic health and safety requirement).

5.2.2 The EBS shall be simple to deploy and capable of being operated with either hand. The number of deployment actions shall be minimised, ideally, with no more than one action being required to activate the system on submersion (e.g. for a rebreather system, opening the valve of the counterlung).

(Necessary for emergency deployment, particularly when no warning of emergency. Capability for one-handed operation allows the user to maintain contact with the aircraft exit. The nearest exit may be on either the left or the right side. Simple deployment techniques will lend themselves towards one-handed capability).

5.2.3 The equipment shall not have any sharp edges or protruding parts which may injure the user, or damage the lifejacket, immersion suit or other emergency equipment.

(PPE Directive basic health and safety requirement).

5.2.4 Where a counterlung is incorporated into the system, the counterlung shall have sufficient breathable capacity to accommodate an expired volume of at least 6 L. In the case of hybrid EBS, additional capacity shall be provided equivalent to the volume of air discharged into the counterlung from the gas cylinder. The counterlung shall be designed to prevent collapse, taking panic breathing into account.

(Counterlungs need to accommodate high tidal volumes plus, in the case of hybrids, the additional gas discharged into the counterlung. Panic breathing may result in high tidal volumes. Poorly designed counterlungs collapse when emptied, causing high breathing resistance when the user attempts to breathe out into the bag).

5.2.5 In EBS designed for underwater deployment (Category A), the design shall minimise the amount of water that can enter the mouthpiece (dead space). It shall be possible to expel this water from the mouthpiece. This shall be tested according to 6.4.4.5.

(This water must be cleared from the mouthpiece for the EBS to be fully functional).

5.2.6 Subjects shall be provided with a means to prevent water entering the nose that is easy to deploy and effective when used underwater. Nose occlusion systems shall be designed to fit a wide range of user sizes. Nose clips shall be easy to open with either hand.

(Many users are unable to use EBS without a nose clip, particularly during training. Nose shape varies considerably, particularly between different ethnic groups. It is therefore very difficult to develop a nose clip that comfortably fits all users. Other means of occluding the nose may be used.)

5.2.7 Where an EBS includes a harness to fit the EBS to the body, this shall allow correct positioning on the body when used according to the manufacturer's instructions.

(PPE Directive basic health and safety requirement).

5.2.8 Gas cylinders and connections with demand regulators shall comply with the appropriate national or international specifications and shall be approved and tested with respect to the rated working pressure.

5.3 Materials

5.3.1 The materials used shall have adequate mechanical strength to resist damage. Testing shall be carried out according to 6.2, 6.4.3, 6.4.4, 6.5.

5.3.2 The materials used shall have sufficient resistance to changes caused by the effects of temperature. There shall be no signs of degradation to the materials and the EBS shall remain functional following temperature cycling, tested according to 6.1.

5.3.3 Any fabric used to cover, retain or secure the EBS on the user 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 CS-25 Appendix F Part 1 or other equivalent approved method.

5.3.4 All non-metallic materials shall be resistant to micro-biological growth.

5.3.5 All metallic components shall be made of corrosion resistant materials or must be protected from corrosion.

5.3.6 Any high pressure parts and connections shall meet the requirements of EN 250:2000; 5.5.

5.3.7 All parts that have to be cleaned and/or disinfected shall be easy to clean, insensitive to the cleaning agents and disinfectants recommended by the manufacturer and remain functional after having been cleaned or disinfected. Recommended cleaning or disinfectant products shall not have any adverse effect on the user.

5.4 Compatibility

(The EBS must not impair the performance of any other equipment in the aircraft or worn by the helicopter occupants).

5.4.1 The EBS shall be designed such that, when stowed, the crew shall be able to carry out all normal and emergency functions and movements necessary for the operation of a helicopter and its equipment, without any impediment or discomfort.

5.4.2 The EBS shall be designed, and the materials used in its construction chosen, to have no features which would be likely to have any detrimental effect on the performance or operation of other equipment in the helicopter. EBS shall not impair the performance of the seat harness or hinder harness release. EBS shall not impede or prevent escape from a submerged helicopter. Testing shall be carried out in accordance with 6.4.3, 6.4.4.

5.4.3 The EBS shall not impair the performance of, and shall be compatible with, any approved lifejacket or immersion suit that is intended to be worn with it. The performance of the EBS, suit and/or lifejacket combination shall be tested in accordance with Appendix 2 of ETSO-2C502, ETSO-2C503 or ETSO-2C504, as appropriate. The compatibility assessment shall include consideration of the total additional buoyancy (clause 5.9) provided by an immersion suit / EBS combination and the effect this may have on helicopter underwater escape (see note below). Testing shall be carried out in accordance with 6.4.3, 6.4.4.

NOTE: Hybrid rebreathers using additional compressed gas may not be compatible with insulated helicopter immersion suits that have the maximum permissible buoyancy.

(The PPE Directive states that "If the same manufacturer markets several PPE models of different classes or types in order to ensure the simultaneous protection of adjacent parts of the body against combined risks, these must be compatible". EBS may or may not be made by the same manufacturer as the suit and/or lifejacket worn with it.)

5.4.4 Potential snagging hazards shall be reduced to a minimum. Any part of the EBS that might pose a snagging hazard during flight (see 5.4.1), emergency evacuation, escape or rescue shall be suitably covered, protected or restrained. Testing shall be carried out in accordance with 6.4.4.4 and 6.4.4.5.

5.5 Breathing performance

(Consideration has been given to the maximum limits of breathing performance allowed for other underwater breathing apparatus, making allowance for the fact that EBS is intended for emergency use only, for periods of only a few minutes maximum. Reference has been made to the requirements and test methods described in EN 14143:2003 Respiratory equipment - Self-contained re-breathing diving apparatus.)

5.5.1 Manufacturers should endeavour to keep work of breathing to as low a level as possible. When measured at ventilation rates between 10.0 $L.min^{-1}$ and 62.5 $L.min^{-1}$ (BTPS), work of breathing shall not exceed 3.0 $J.L^{-1}$.

5.5.2 Peak to peak respiratory pressure shall not exceed 5.0 kPa (50 mbar) relative to the reference pressure (measured at the mouth at the end of exhalation, with no flow). The inspired and expired respiratory pressures shall not exceed 2.5 kPa (25 mbar) each.

5.5.3 Hydrostatic imbalance shall be between +2.5 kPa (+25 mbar) and -2.5 kPa (-25 mbar) relative to lung centroid pressure, measured in at least the head-up vertical and face-down (prone) position.

5.5.4 Breathing performance (5.5.1, 5.5.2, 5.5.3) shall be measured in water at a temperature of 4 ± 1°C. Testing shall be carried out in accordance with 6.2.

5.5.5 If the EBS is intended for use in water temperatures less than 4 °C the manufacturer shall state the minimum operational temperature and the breathing performance of the EBS shall be tested at that temperature.

NOTE: The values specified for breathing performance are considered to be maximum acceptable levels. Manufacturers should endeavour to keep the values as low as possible.

5.6 Safety devices

5.6.1 Where compressed gas is used, a contents gauge or equivalent shall be provided on the gas cylinder. Alternatively, it shall be possible to check that the EBS is ready for use and has not been tampered with since servicing.

(It is necessary to be able to check that gas cylinders are full. In the case of rebreathers and hybrid EBS it is necessary to be able to check that the counterlung has not been used since its last service; e.g. rebreathers may have anti-tamper stitches on the pouch).

5.6.2 The risk of inadvertent operation or activation by the user shall be minimised, including the inadvertent release of gas from the cylinder.

5.6.3 Where a security tag or stitching is used, this shall be a weak link that is easy to break during emergency deployment. Testing shall be carried out in accordance with 6.4.3.1.

5.7 Deployment

5.7.1 It shall be possible to fully deploy Category 'A' EBS in less than 12 s, using one hand only. This shall be achievable with both the right hand and the left hand. It shall be demonstrated that the mouthpiece can be deployed within 10 s. Testing shall be conducted in dry conditions, according to 6.4.3.1.

(This deployment time relates to water impact accidents where there may be little or no warning. There will be a high likelihood that the helicopter will capsize and/or sink soon after impact. If deployed underwater, it must be possible to deploy during a breath-hold, giving consideration to the effects of cold shock. Single-handed is worst case in terms of deployment and reflects the possibility of only one hand being usable, or needing to maintain contact with the nearest exit for orientation.)

5.7.2 It shall be possible to fully deploy Category 'B' EBS in less than 20 s, using one hand only. This shall be achievable with both the right hand and the left hand. Testing shall be conducted in dry conditions, according to 6.4.3.1.

(Category 'B' devices are designed primarily for the ditching scenario where there is a much higher likelihood that occupants will have sufficient time to deploy the EBS whilst on the water surface. The maximum deployment time stipulated assumes that deployment will not commence until after the aircraft has alighted on the water when it is then at risk of capsize.)

5.7.3 For EBS designed for underwater deployment (Category 'A' EBS) it shall be demonstrated that full deployment can be achieved following submersion, tested in accordance with 6.4.3.2. Test subjects shall be able to clear water from the mouthpiece if necessary, and achieve a good seal at the mouth.

5.7.4 Where a nose clip is provided, the manufacturer's deployment procedure should normally encourage the user to fit the mouthpiece before the nose clip.

NOTE: Other nose occlusion systems may be fitted in one action with the mouthpiece (e.g. if part of a partial face mask or in a fixed position integral to the mouthpiece).

(The ability to breathe through the mouthpiece is the most critical step of deployment. Some users may be able to use the EBS without the need for the nose occlusion. In these cases fitting of a nose clip should normally be the last step. However, some EBS with a nose clip integral to the mouthpiece may require the nose clip to be fitted before the mouthpiece; the benefits and disbenefits of such designs should be carefully considered.)

5.8 Ease of use and manoeuvrability in water

5.8.1 Test subjects shall be able to achieve a good seal at the mouth, whilst manoeuvring underwater in different orientations. This shall be tested according to 6.4.4.1.

5.8.2 Each test subject shall demonstrate their ability to use the EBS for 60 s whilst pulling themselves along an underwater rail in the face-down position. Rating of the exertion of breathing shall not exceed 17 (very hard). This shall be tested according to 6.4.4.2.

(This requirement relates to longer escape routes, where the users may have to pull themselves from hand-hold to hand-hold across the cabin before finding an exit. EBS with unacceptably high breathing resistance or high levels of hydrostatic imbalance should have been excluded during physical testing.)

5.8.3 Each test subject shall demonstrate their ability to use the EBS for 60 s whilst inverted. Rating of the exertion of breathing shall not exceed 17 (very hard). This shall be tested according to 6.4.4.3.

(There is a need to assess whether the user can breathe from the EBS whilst inverted underwater, tested in a controlled manner).

5.8.4 Each subject shall demonstrate their ability to use the EBS whilst successfully completing underwater escape from a submerged and capsized helicopter. No part of the EBS shall snag or unduly hinder egress. The system shall not cause injury to the user nor impair the performance of other equipment. This shall be tested according to 6.4.4.4.

(This requirement aims to cover all aspects of helicopter underwater escape, including compatibility with other equipment).

5.9 Buoyancy

5.9.1 The additional buoyancy of deployed EBS shall be no more than 40 N. This shall be tested according to 6.3. This test will not be required for open circuit compressed gas systems or for simple rebreather systems where no additional gas is added to the counterlung.

5.9.2 The additional buoyancy due to an approved helicopter immersion suit, clothing and EBS shall be no more than 150 N when tested in accordance with EN ISO 15027-3:2002, clause 3.11.7.2. If this requirement is not fully met, further underwater escape exercises shall be undertaken, in accordance with 6.4.4.4, with the affected subject sizes, to ensure that the additional buoyancy does not prevent users from escaping from the helicopter. These additional tests shall include a cross-cabin escape from a seat on the opposite side of the helicopter to the emergency exit specified in 6.4.2.4. If the affected subjects are able to escape without undue impediment due to buoyancy, then the approval authority may allow additional buoyancy up to a maximum of 170N for these subjects.

(Hybrid EBS devices combine a rebreather counterlung with the provision of additional breathable air. This adds buoyancy to the user. When added to the inherent buoyancy of a helicopter suit and the clothing worn with it, the total buoyancy may make it very difficult for the user to escape through an underwater exit. 150N is the generally accepted upper limit for escape. However, body size and build will influence the ability to escape with a given amount of buoyancy. The amount of trapped buoyancy in an extra large suit will be much greater than that in a small suit, but the user may be able to overcome this level of buoyancy due to greater stature.)

5.10 Cold water performance

5.10.1 Each test subject shall demonstrate their ability to use the EBS in both cool (25˚C) and cold (12˚C) water for a minimum of 60 s. Rating of the exertion of breathing shall not exceed 17 (very hard). Testing shall be carried out in accordance with 6.5.

(Cold shock is known to significantly reduce breath-hold times and affect the control of ventilation, so it is necessary to assess the effects of cold water immersion. The time taken to escape from a capsized helicopter in real conditions has been estimated to be of the order of 45 to 60 seconds. There is therefore a desire for EBS to enable underwater breathing for a period of at least 60 seconds. It is accepted that breathing may be uncomfortable for this short period. Ethical procedures will allow the subject to stop the test if breathing becomes too difficult or stressful.)

6 Testing

6.1 Temperature cycling

6.1.1 The EBS shall be alternately exposed to temperatures of +65˚C and -30˚C. These alternating temperatures need to follow immediately after each other and the following procedure is acceptable:

a) an 8 h exposure at (65 ± 2)˚C to be completed in one day;
b) the EBS removed from the heat chamber the same day and left exposed to ordinary room conditions until the next day;
c) an 8 h exposure at (- 30 ± 2)˚C to be completed in one day;
d) the EBS removed from the cold chamber the same day and left exposed to ordinary room conditions until the next day;
e) the above procedure (a) to (d) to be repeated a further 9 times.

6.1.2 Following temperature cycling, the EBS shall be visually inspected for signs of degradation to the materials. If there are no signs of degradation, it shall be demonstrated that the EBS is functional.

6.2 Breathing performance

6.2.1 The EBS shall be mounted on a mannequin, secured in a realistic position simulating normal use, in accordance with the donning and use instructions supplied by the manufacturer (8.2 i)).

A breathing simulator shall be used to measure the breathing performance of the EBS, using a sinusoidal gas flow with a maximum variation of ± 3 % in both the frequency and amplitude of the wave form. If this wave form greatly affects the results for certain types of equipment, a more realistic wave form may be used in any additional tests that may be carried out. It shall be possible to test the EBS in different orientations on the breathing simulator.

When tested in water, the equipment shall be immersed to a depth sufficient to preclude surface effects.

6.2.2 Breathing performance shall be measured in water at a temperature of 4 ± 1°C. Testing shall be conducted at simulated depths (at the mouthpiece) of 0.1 m and 4.0 m. A range of tidal volumes from 1.0 l to 2.5 l and breathing rates of 10 to 25 breaths per minute shall be used.

6.2.3 Breathing performance shall be measured in accordance with EN 14143:2003, clause 6.3.2.

6.2.4 Hydrostatic imbalance shall be measured in accordance with EN 14143:2003, clause 6.4.

6.3 Buoyancy

6.3.1 The buoyancy of hybrid EBS shall be determined by measuring the maximum underwater weight of the EBS when deployed. The hybrid EBS shall be activated prior to evaluation, with the additional air discharged into the counterlung. The EBS shall be placed in a net bag and immersed in a tank of water at 20 ± 1˚C, using weights if necessary to fully submerge the equipment. Care should be taken 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 buoyancy of the hybrid EBS shall be calculated from the difference in the two values of immersed weight.

6.4 Ergonomic performance

6.4.1 Subjects

6.4.1.1 Manned tests shall be carried out by naïve subjects with no previous experience of using the EBS under evaluation.

6.4.1.2 At least 8 subjects shall be used, with at least one subject in each of the following height and weight categories:

Height	Weight
1.45 m – 1.65 m	< 60 kg
1.45 m – 1.65 m	> 60 kg
1.65 m – 1.80 m	< 75 kg
1.65 m – 1.80 m	> 75 kg
1.80 m – 2.00 m	< 90 kg
1.80 m – 2.00 m	90 kg - 100 kg
> 1.70 m	100 kg - 115 kg
> 1.70 m	> 115 kg

The subject group should be representative of the user population in terms of age and gender, but with no more than 75% representing one gender. One or more of the subjects shall have a shoulder (bi-deltoid) width measurement of at least 500 mm.

(Size ranges are adjusted and expanded compared to those used in previous similar standards to reflect a more realistic size range for the adult occupational groups who use helicopter EBS. A recent study of helicopter passengers (CAA, FOD-27, 2005) found the average mass of male passengers to be 87.6 kg.)

6.4.1.3 Each subject's medical history shall be known to be satisfactory. They shall be medically examined and certified fit to undertake the test procedures. Where compressed gas is to be used, this medical assessment shall include spirometry. Measured lung function shall be within the normal range.

(Compressed gas EBS may be classified as diving equipment under certain jurisdictions. Whilst the equipment will not be tested in water deeper than 3 m there is a small risk of hyperbaric injury. Care should therefore be taken when selecting and medically assessing test subjects).

6.4.1.4 Each subject shall have some experience or be given training in helicopter underwater escape procedures. The generic use of EBS shall be demonstrated, with practical experience of inserting a mouthpiece and breathing underwater either with compressed gas or rebreathing from a counterlung as appropriate. **The EBS under evaluation, or an EBS of the same type design, shall not be used for this training.**

(The aim is to assess the performance of the EBS, not the skill of the test subject. Test subjects should therefore be comfortable breathing underwater and when undertaking the underwater escape exercises.)

6.4.1.5 Each subject shall wear the following test clothing:

- Cotton underwear;
- Woollen socks;
- Cotton long sleeved shirt;
- Heavy cotton trousers;
- Appropriate footwear.

In addition, a long-sleeved woollen pullover shall be worn for the cold water test (6.5).

Where applicable, an ETSO approved lifejacket and/or immersion suit shall be donned over the test clothing.

(Representative clothing should be worn for testing. However, subjects could suffer from heat stress if too much clothing is worn in pool tests in water at 25˚C. Hence the additional layer is required for the cold water test only.)

6.4.2 General

6.4.2.1 Testing shall demonstrate acceptable compatibility between the EBS and any lifejacket and/or immersion suit with which it is intended to be used. Accordingly, tests shall be carried out in combination with each approved aviation lifejacket and/or approved helicopter immersion suit for which approval is sought. Hood and gloves shall not be used during testing unless this is necessary for sealing the suit. Accessories such as goggles shall not be worn unless they are an integral part of a lifejacket/suit system.

6.4.2.2 Underwater tests shall be carried out in a pool at a water temperature of 20°C to 25°C, at water depths between 0.1 m and 3.0 m. The pool shall be equipped with an underwater handrail at a depth of between 0.2 m and 0.5 m.

6.4.2.3 The inversion test (6.4.4.3) shall be undertaken using a shallow water escape trainer (a frame fitted with a seat and harness, with the seat floating at water level, allowing the subject to be inverted with the upper body below water).

6.4.2.4 Further testing shall be undertaken using a helicopter simulator. High backed seats shall be used fitted with a four-point or five-point harness. Escape exercises shall be conducted using an emergency exit with an opening not greater than 432 mm by 355 mm (17" by 14"). The top of the opening shall be at least 300 mm below the water surface.

(Size of exit relates to an 'escape window' as defined by CAA (*Leaflet 44-30, CAP 562, Book 2, Chapter 44, p1107, 2011)).*

6.4.3 Deployment

6.4.3.1 Each test subject, wearing an ETSO-approved helicopter immersion suit and lifejacket, as applicable, shall attempt to deploy the EBS from its stowed position. This shall be undertaken whilst seated in dry conditions, restrained by the four-point or five-point harness, after reading the manufacturer's instructions and following a demonstration of the manufacturer's recommended deployment procedure. Deployment time shall include, as appropriate, the time to break any security tag or stitches, open the pouch/pocket, locate and deploy the mouthpiece, deploy a nose clip or equivalent device and, in the case of rebreathers or hybrids, activate the system allowing the user to breathe into the counterlung. Subjects shall be timed from a signal to deploy the EBS to a point when the subject indicates that the EBS is functional and that they are able to breathe using the system. In the case of hybrid and rebreather EBS, subjects shall take a single breath before activating the system.

For both Category 'A' and Category 'B' EBS only one hand shall be used when deployment is timed. The test shall be conducted once using the right hand and once using the left hand.

6.4.3.2 For Category 'A' EBS designed for underwater deployment, the deployment procedure shall be repeated with the subject immersed (upright). The subject shall be seated in the helicopter simulator next to the emergency exit, with the harness fastened. The subject shall be instructed to deploy the EBS once the head is fully submerged, and shall demonstrate their ability to clear any water from the mouthpiece and breathe from the EBS following the deployment procedure. The subject may choose not to deploy the nose clip in this test.

(This test should demonstrate that the EBS is capable of being deployed underwater and that subjects are able to clear the mouthpiece of water and successfully breathe from the EBS).

6.4.4 Ease of use, manoeuvrability and helicopter escape

6.4.4.1 Each subject shall deploy the EBS, submerge, and then demonstrate their ability to breathe underwater in the vertical head-up position. It shall then be determined whether the subject is able to achieve a satisfactory mouth seal whilst manoeuvring in different orientations including the prone (face-down) position and the vertical head-down position.

6.4.4.2 Each subject shall deploy the EBS and immediately submerge, breathing on the EBS in a face-down position for 10 s. The subjects shall then pull themselves along an underwater rail in a face-down posture, using a hand-over-hand technique. A distance of 10 m to 12 m shall be covered underwater with at least one 180˚ turn. The test shall be timed from the point when the subject submerges to the point when they surface. The test shall end after 60 s underwater or earlier if the subject considers that the work of breathing has become unacceptable. If the subject surfaces before 60 s, it shall be determined whether the subject had to stop due to experiencing difficulty with breathing or for some other reason (in which case the test can be repeated). On completing the test, the subject shall rate their overall perception of the exertion of breathing using the scale provided in Annex 1.

6.4.4.3 Each subject shall be seated in the shallow water escape trainer, with the harness fastened. The subject shall deploy the EBS and then be inverted immediately. The test shall end after 60 s or earlier if the subject considers that the work of breathing has become unacceptable. If the subject surfaces before 60 s, it shall be determined whether the subject had to stop due to experiencing difficulty with breathing or for some other reason (in which case the test can be repeated). On completion of the inversion test, the subject shall rate their overall perception of the exertion of breathing using the scale provided in Annex 1.

6.4.4.4 For the underwater escape exercise, the subject shall be seated in a helicopter simulator next to the emergency exit, with the harness fastened. The subject shall deploy and then use the EBS while escaping through an emergency exit (as defined in 6.4.2.4).

At least two escape procedures shall be completed:

- EBS deployed following water contact but before submersion. Helicopter simulator to be submerged, remaining upright. Subject to then escape through the emergency exit.

- EBS deployed following water contact but before submersion. Helicopter simulator to capsize. Subject to then escape through the emergency exit.

6.4.4.5 In the case of EBS designed for underwater deployment (Category 'A' EBS) a further procedure shall be completed:

- Helicopter simulator to be submerged, remaining upright. EBS deployed following submersion. Subject to then make an underwater escape through the emergency exit.

Ease of use during escape shall be assessed, including the ability to expel water from the mouthpiece. Any snagging due to the EBS shall be recorded.

(An underwater deployment exercise following capsize was considered for Category 'A' EBS, but was not included for a number of reasons:
1) Capsize exercises are difficult to observe;
2) Such a test could be unduly stressful for subjects and test houses must provide justification when seeking ethical approval;
3) Whilst the ditching scenario can be defined, the impact/crash scenario is ill-defined;
4) Use of EBS whilst inverted is assessed in the inversion test (6.4.4.3)).

6.4.4.6 Each test subject shall then board an approved helicopter liferaft fitted with boarding facilities, without assistance, with the EBS mouthpiece restowed (as, and if, directed in the manufacturer's instructions to the user) and the lifejacket inflated. Any snagging due to the EBS shall be recorded.

6.4.4.7 For each procedure, subjective comments shall be recorded relating to ease of deployment, freedom of movement, compatibility with other equipment and snagging.

NOTE: 'Snagging' covers events where part of the EBS becomes caught on other equipment, hindering escape and/or rescue, or any entanglement that causes damage to the EBS or associated equipment.

6.5 Cold water performance

6.5.1 Cold water performance testing shall be assessed following satisfactory completion of 6.1 to 6.4.

6.5.2 Ethical approval for this test shall be gained, and appropriate medical cover provided, following the principles of ISO 12894. Withdrawal criteria shall be set.

6.5.3 Subjects shall be selected in accordance with 6.4.1.1, 6.4.1.2, 6.4.1.3 (this may be the same or a different subject group to that used for the ergonomic tests). Clothing shall be worn in accordance with 6.4.1.5. Subjects shall be fully trained in the use of the EBS test device in warm water before performing this cold water test.

6.5.4 The test shall be conducted in a chamber at an air temperature of 20˚C to 25˚C. Subjects shall be seated in a chair fitted with a 4-point harness. It shall be possible to lower the chair into water, at a fixed rate, from a starting position where the subject's feet rest 10 ± 5 cm above the water surface.

The subject shall deploy the EBS following the manufacturer's instructions and then be lowered immediately into the cool (25˚C) or cold (12˚C) water until the top of the head is just below the water surface. The subject shall remain submerged for a maximum of 60 s. Duration of use shall be timed from the point of submersion to the point when the subject surfaces. On completing the test, the subject shall rate their overall perception of the exertion of breathing using the scale provided in Annex 1. If the subject surfaces before 60 s, it shall be determined whether the subject had to stop due to unacceptable difficulty breathing or some other reason (in which case the test can be repeated after resting in air for at least 15 minutes).

(The aim of this test is to determine the duration of use of the EBS in cold water. It is the EBS device and not the subject that is being assessed. Some subjects may stop the test for reasons that are not directly related to the test aim e.g. cold hands. This should not be a reason for failing the device. If the subject stops again for a reason not related to breathing difficulty a substitute test subject of the same height weight category should be used.)

7 Marking

7.1 All EBS shall be permanently and clearly marked with at least the following information:

a) name, trademark or symbol identifying the manufacturer or authorised representative;
b) manufacturer's serial number;
c) date of manufacture and / or obsolescence;
d) date at which service and maintenance are due, and/or an inspection stamp, as applicable.

If there is insufficient room for all of this information on the product, the information supplied by the manufacturer shall include that information that could not be marked on the EBS.

8 Information supplied by the manufacturer

8.1 The manufacturer shall supply with each EBS, information which enables trained and qualified persons to use the EBS in a safe manner.

8.2 Each EBS shall be supplied with the following information, which shall be given in the official language(s) of the country(s) where it is sold:

a) name and address of manufacturer or authorised representative;
b) manufacturer's model designation;
c) serial number;
d) date of manufacture and / or obsolescence;
e) whether Category 'A' or Category 'B' and consequent limitations on use;
f) other limits of use, as applicable, including maximum period of use, factors limiting period of use and maximum depth of use;
g) description of the EBS, including type (e.g. compressed air system, rebreather system or a combination of the two (hybrid design)), and components;
h) pre-use examination, checks required before use and how to carry them out;
i) easily understood donning and use instructions (illustrations may be used);
j) the level of training needed before use;
k) compatibility with other equipment, as applicable (NOTE: for hybrid EBS, buoyancy issues should be considered in relation to EBS and immersion suit compatibility);
l) foreseeable misuse that might injure the user;

m) storage, use, cleaning, disinfecting, servicing and maintenance instructions (see 9.0);
n) any necessary packaging requirements for transport;
o) applicable specification or ETSO number.

9 Servicing and maintenance

9.1 The procedures for inspecting, servicing and maintaining the EBS shall be established and described by the manufacturer within a manual. This shall include means of cleaning and disinfecting the EBS. Cleaning, maintenance or disinfectant products recommended by the manufacturer must have no adverse effect on the EBS or user when applied in accordance with the relevant instructions.

9.2 The frequency of inspection and servicing shall be stated by the manufacturer.

9.3 Servicing and maintenance shall be undertaken by a service station approved by the manufacturer.

9.4 Where users are required to carry out pre-use inspection and checks, instructions shall be included in the information supplied by the manufacturer.

9.5 EBS shall be required to be immediately removed from service for repair or replacement if damage or deterioration is discovered that may lead to the EBS failing to function effectively.

9.6 Procedures shall be put in place to ensure the traceability of components.

<u>Annex 1 - Rating of breathing effort</u>

Instruction:

While using the EBS underwater, we want you to rate your perception of the effort of breathing, how easy or difficult it feels to you, based on your feeling of breathlessness. This should be based on how you feel during the test, not just the point when you stop.

Try to be as honest as possible. Don't underestimate or overestimate. It is your own feeling of breathing effort that is important - what other people think is not important. Look at the scale and the descriptions and then give a number.

Any questions?

6	**No breathing exertion**
7	
8	**Extremely light**
9	**Very light** - comfortable breathing, equivalent to light exercise.
10	
11	**Light**
12	
13	**Breathing is somewhat hard** - still felt OK, could have continued.
14	
15	**Hard (heavy breathing)**
16	
17	**Very hard** - you could still have continued but you had to push yourself hard.
18	
19	**Extremely hard** - breathing was extremely strenuous, the most breathless you have ever been.
20	**Maximal breathing effort**

(*Rating scale based on Borg's RPR (rating of perceived exertion) scale: Borg G; Borg's perceived exertion and pain scales. Champaign, IL: Human Kinetics. ISBN: 0-88011-623-4*).

APPENDIX B

Questionnaires used in ergonomic performance trials with collated responses

EBS STUDY ***SUBJECT QUESTIONNAIRE***

Subject No: SUMMARY DATA **Date:** ....

EBS assessed: COMPRESSED AIR SYSTEM (CA)

Instructions for Completing the Questionnaire

Please fill in this questionnaire as honestly as possible, giving <u>your</u> views and describing your experiences. Try not to be influenced by anything you may hear others say.

You should answer ALL the questions by ticking the appropriate box and writing comments in the spaces provided. We ask that you record as much detail as possible since your opinions are very important to our results.

The results will be reported anonymously.

EXERCISE 1A: DEPLOYMENT - TWO HANDS

1. How easy was it to remove the EBS from its pouch/stowage position?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
5	3	1	0

2. During deployment, how easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	0	3	6

3. How easy was it to fit the mouthpiece in your mouth?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
4	3	2	0

4. How comfortable did the mouthpiece feel in your mouth, once correctly positioned?

Very Uncomfortable	*Quite Uncomfortable*	*Quite Comfortable*	*Very Comfortable*
1	2	5	1

5. How easy was it to deploy the nose clip?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
2	3	3	1

6. Did you experience any problems activating the EBS (allowing you to breathe from the unit)?

Yes	*No*	*Not applicable*
0	0	7

EXERCISE 1B: DEPLOYMENT - ONE HAND

7. Was it possible to deploy the EBS with one hand?

Yes	*No*
9	0

8. How easy was it to remove the EBS from its pouch/stowage position?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
4	4	1	0

9. During deployment, how easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	1	3	5

10. How easy was it to fit the mouthpiece in your mouth?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
3	3	3	0

11. How easy was it to deploy the nose clip?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
2	2	5	0

12. Did you experience any problems activating the EBS (allowing you to breathe from the unit)?

Yes	*No*	*Not applicable*
0	0	9

Please describe any problems experienced or any specific factors that made the EBS either difficult or easy to deploy:

....

....

....

....

EXERCISE 2: UNDERWATER ENDURANCE

13. How easy was it to deploy the EBS?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
4	4	1	0

14. How comfortable were you when breathing underwater in the face-down position?

Very Uncomfortable	*Quite Uncomfortable*	*Quite Comfortable*	*Very Comfortable*
2	3	0	4

15. Were you able to maintain a good seal around the mouthpiece whilst underwater?

Yes	*No*
9	0

Please describe any breathing difficulties experienced whilst pulling yourself along underwater:

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If you were unable to complete the 90 second swim, what caused you to stop?

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16. If you completed the 90 second underwater swim, do you think that you could have continued breathing from the EBS for a longer period of time?

Yes	*No*
7	0

EXERCISE 3: BREATHING WHILST INVERTED

17. How comfortable were you when breathing underwater in the inverted position?

Very Uncomfortable	*Quite Uncomfortable*	*Quite Comfortable*	*Very Comfortable*
1	4	3	1

18. Were you able to maintain a good seal around the mouthpiece whilst inverted underwater?

Yes	*No*
8	1

19. Were you able to breathe underwater for the maximum duration of 60 seconds?

Yes	*No*
7	2

If you were unable to breathe whilst inverted for 60 seconds, what caused you to stop?

....

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....

Please describe any breathing difficulties experienced whilst inverted:

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EXERCISE 4: HELICOPTER UNDERWATER ESCAPE - UPRIGHT

20. How easy was it to deploy the EBS when seated in the helicopter simulator, partially submerged?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
6	2	1	0

21. How easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	1	3	5

22. How many hands did you use to deploy the EBS

One	*Two*
6	3

23. Did you use the nose clip?

Yes	*No*
9	0

24. If yes, how difficult was it to deploy the nose clip?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
0	3	5	1

25. Did the nose clip help in breathing underwater?

Yes	*No*
6	3

26. Did the nose clip stay in place during your escape?

Yes	*No*
9	0

27. Did the EBS get in the way when securing the seat harness?

Yes	*No*
5	2

Not completed by 2 subjects

28. Did any part of the EBS interfere with the operation of other items of equipment when seated in the helicopter?

No problems	*Slight problems*	*Serious problems*
8	1	0

If yes, please describe any problems experienced:

....

....

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29. How difficult was it to escape from the helicopter?

Very Difficult	*Moderately Difficult*	*A Little Difficult*	*No Difficulty*
0	0	5	4

30. Did you experience any snagging when escaping through the exit window?

Yes	*No*
4	5

If yes, please describe:

....

....

....

31. How buoyant did you feel when attempting to escape from the helicopter simulator?

Very Buoyant	*Moderately Buoyant*	*A Little Buoyant*	*Not Buoyant*
1	4	3	1

32. If you did feel buoyant, do you consider that this affected your ease of escape?

Yes, made escape much more difficult	*Yes, made escape a little more difficult*	*Did not affect ease of escape*
0	5	3

If yes, please describe:

....

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33. Did the bulk of the EBS affect your ease of escape through the escape window?

Yes	*No*
1	8

EXERCISE 5: ESCAPE FOLLOWING CAPSIZE

34. How easy was it to deploy the EBS when seated in the helicopter simulator during descent?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
5	2	2	0

35. How easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	0	2	7

36. Did you use the nose clip?

Yes	*No*
9	0

37. If yes, how difficult was it to deploy the nose clip?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
1	3	5	0

38. How many hands did you use to deploy the EBS?

One	*Two*
5	4

39. Did the EBS mouthpiece stay in your mouth during the capsize?

Yes	*No*
9	0

40. Did you suffer from disorientation following the capsize?

Yes	*No*
3	6

41. How easy was it to breathe using the EBS whilst inverted?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
1	0	3	5

42. Did you experience any problems when releasing yourself from your seat harness?

Yes	*No*
3	6

If yes, please describe:

....

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43. How easy was it to breathe using the EBS during escape through the exit window?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
6	2	0	1

44. How difficult was it to escape from the helicopter?

Very Difficult	*Moderately Difficult*	*A Little Difficult*	*No Difficulty*
0	2	3	4

45. Did you experience any snagging when escaping through the exit window?

Yes	*No*
3	6

If yes, please describe:

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Any other comment?

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EXERCISE 6: UNDERWATER DEPLOYMENT AND ESCAPE

46. How easy was it to deploy the EBS when underwater?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
4	4	1	0

47. How easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	1	4	4

48. How many hands did you use to deploy the EBS?

One	*Two*
4	5

49. Did you have any problems with water entering the mouthpiece?

Yes	*No*
3	6

If yes, please describe any problems experienced and how you coped with this situation:

....

....

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50. Did you use the nose clip?

Yes	*No*
8	1

51. If yes, how difficult was it to deploy the nose clip?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
0	4	4	0

52. If no, was this a problem?

Yes	*No*
0	1

(Continued overleaf)

Any further comment:

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Signed: .... **Date:** ....

EBS STUDY SUBJECT QUESTIONNAIRE

Subject No: SUMMARY DATA **Date:** ....

EBS assessed: HYBRID SYSTEM (H)

Instructions for Completing the Questionnaire

Please fill in this questionnaire as honestly as possible, giving your views and describing your experiences. Try not to be influenced by anything you may hear others say.

You should answer ALL the questions by ticking the appropriate box and writing comments in the spaces provided. We ask that you record as much detail as possible since your opinions are very important to our results.

The results will be reported anonymously.

EXERCISE 1A: DEPLOYMENT - TWO HANDS

1. How easy was it to remove the EBS from its pouch/stowage position?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
4	5	0	0

2. During deployment, how easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
1	1	1	6

3. How easy was it to fit the mouthpiece in your mouth?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
5	4	0	0

4. How comfortable did the mouthpiece feel in your mouth, once correctly positioned?

Very Uncomfortable	*Quite Uncomfortable*	*Quite Comfortable*	*Very Comfortable*
1	0	5	3

5. How easy was it to deploy the nose clip?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
0	4	3	2

6. Did you experience any problems activating the EBS (allowing you to breathe from the unit)?

Yes	*No*	*Not applicable*
1	8	0

EXERCISE 1B: DEPLOYMENT - ONE HAND

7. Was it possible to deploy the EBS with one hand?

Yes	*No*
9	0

8. How easy was it to remove the EBS from its pouch/stowage position?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
4	4	1	0

9. During deployment, how easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	0	5	4

10. How easy was it to fit the mouthpiece in your mouth?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
4	5	0	0

11. How easy was it to deploy the nose clip?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
0	3	2	4

12. Did you experience any problems activating the EBS (allowing you to breathe from the unit)?

Yes	*No*
0	9

Please describe any problems experienced or any specific factors that made the EBS either difficult or easy to deploy:

....

....

....

....

EXERCISE 2: UNDERWATER ENDURANCE

13. How easy was it to deploy the EBS?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
4	5	0	0

14. How comfortable were you when breathing underwater in the face-down position?

Very Uncomfortable	*Quite Uncomfortable*	*Quite Comfortable*	*Very Comfortable*
0	3	6	0

15. Were you able to maintain a good seal around the mouthpiece whilst underwater?

Yes	*No*
8	1

Please describe any breathing difficulties experienced whilst pulling yourself along underwater:

....

....

....

....

....

If you were unable to complete the 90 second swim, what caused you to stop?

....

....

....

....

16. If you completed the 90 second underwater swim, do you think that you could have continued breathing from the EBS for a longer period of time?

Yes	*No*
1	0

EXERCISE 3: BREATHING WHILST INVERTED

17. How comfortable were you when breathing underwater in the inverted position?

Very Uncomfortable	*Quite Uncomfortable*	*Quite Comfortable*	*Very Comfortable*
1	3	4	1

18. Were you able to maintain a good seal around the mouthpiece whilst inverted underwater?

Yes	*No*
9	0

19. Were you able to breathe underwater for the maximum duration of 60 seconds?

Yes	*No*
6	3

If you were unable to breathe whilst inverted for 60 seconds, what caused you to stop?

....

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....

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Please describe any breathing difficulties experienced whilst inverted:

....

....

....

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EXERCISE 4: HELICOPTER UNDERWATER ESCAPE - UPRIGHT

20. How easy was it to deploy the EBS when seated in the helicopter simulator, partially submerged?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
3	4	2	0

21. How easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	0	8	1

22. How many hands did you use to deploy the EBS

One	*Two*
3	6

23. Did you use the nose clip?

Yes	*No*
9	0

24. If yes, how difficult was it to deploy the nose clip?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
0	2	5	2

25. Did the nose clip help in breathing underwater?

Yes	*No*
7	2

26. Did the nose clip stay in place during your escape?

Yes	*No*
8	1

27. Did the EBS get in the way when securing the seat harness?

Yes	*No*
1	5

Not completed by 3 subjects

28. Did any part of the EBS interfere with the operation of other items of equipment when seated in the helicopter?

No problems	*Slight problems*	*Serious problems*
9	0	0

If yes, please describe any problems experienced:

....

....

....

29. How difficult was it to escape from the helicopter?

Very Difficult	*Moderately Difficult*	*A Little Difficult*	*No Difficulty*
0	1	0	8

30. Did you experience any snagging when escaping through the exit window?

Yes	*No*
2	7

If yes, please describe:

....

....

....

31. How buoyant did you feel when attempting to escape from the helicopter simulator?

Very Buoyant	*Moderately Buoyant*	*A Little Buoyant*	*Not Buoyant*
2	3	4	0

32. If you did feel buoyant, do you consider that this affected your ease of escape?

Yes, made escape much more difficult	*Yes, made escape a little more difficult*	*Did not affect ease of escape*
1	4	4

If yes, please describe:

....

....

....

33. Did the bulk of the EBS affect your ease of escape through the escape window?

Yes	*No*
2	7

EXERCISE 5: ESCAPE FOLLOWING CAPSIZE

34. How easy was it to deploy the EBS when seated in the helicopter simulator during descent?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
2	5	2	0

35. How easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	0	5	4

36. Did you use the nose clip?

Yes	*No*
9	0

37. If yes, how difficult was it to deploy the nose clip?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
0	2	5	2

38. How many hands did you use to deploy the EBS?

One	*Two*
2	7

39. Did the EBS mouthpiece stay in your mouth during the capsize?

Yes	*No*
9	0

40. Did you suffer from disorientation following the capsize?

Yes	*No*
2	7

41. How easy was it to breathe using the EBS whilst inverted?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
1	1	3	4

42. Did you experience any problems when releasing yourself from your seat harness?

Yes	*No*
2	7

If yes, please describe:

....

....

....

43. How easy was it to breathe using the EBS during escape through the exit window?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
4	3	1	1

44. How difficult was it to escape from the helicopter?

Very Difficult	*Moderately Difficult*	*A Little Difficult*	*No Difficulty*
0	3	3	3

45. Did you experience any snagging when escaping through the exit window?

Yes	*No*
5	3

If yes, please describe:

....

....

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Any other comment?

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EXERCISE 6: UNDERWATER DEPLOYMENT AND ESCAPE

46. How easy was it to deploy the EBS when underwater?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
2	1	6	0

47. How easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
1	2	5	1

48. How many hands did you use to deploy the EBS?

One	*Two*
2	7

49. Did you have any problems with water entering the mouthpiece?

Yes	*No*
1	8

If yes, please describe any problems experienced and how you coped with this situation:

....

....

....

....

....

50. Did you use the nose clip?

Yes	*No*
1	8

51. If yes, how difficult was it to deploy the nose clip?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
0	0	1	0

52. If no, was this a problem?

Yes	*No*
1	5

(Continued overleaf)

Any further comment:

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Signed: ………………………………………………… **Date:** …………………

EBS STUDY ***SUBJECT QUESTIONNAIRE***

Subject No: SUMMARY DATA **Date:** ....

EBS assessed: REBREATHER SYSTEM (RB)

Instructions for Completing the Questionnaire

Please fill in this questionnaire as honestly as possible, giving your views and describing your experiences. Try not to be influenced by anything you may hear others say.

You should answer ALL the questions by ticking the appropriate box and writing comments in the spaces provided. We ask that you record as much detail as possible since your opinions are very important to our results.

The results will be reported anonymously.

EXERCISE 1A: DEPLOYMENT - TWO HANDS

1. How easy was it to remove the EBS from its pouch/stowage position?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
1	2	2	4

2. During deployment, how easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
1	3	3	2

3. How easy was it to fit the mouthpiece in your mouth?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
3	5	1	0

4. How comfortable did the mouthpiece feel in your mouth, once correctly positioned?

Very Uncomfortable	*Quite Uncomfortable*	*Quite Comfortable*	*Very Comfortable*
1	1	2	5

5. How easy was it to deploy the nose clip?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
0	5	4	0

6. Did you experience any problems activating the EBS (allowing you to breathe from the unit)?

Yes	*No*	*Not applicable*
3	6	

EXERCISE 1B: DEPLOYMENT - ONE HAND

7. Was it possible to deploy the EBS with one hand?

Yes	*No*
8	1

8. How easy was it to remove the EBS from its pouch/stowage position?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
2	2	2	3

9. During deployment, how easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
1	3	2	3

10. How easy was it to fit the mouthpiece in your mouth?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
3	6	0	0

11. How easy was it to deploy the nose clip?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
1	4	4	0

12. Did you experience any problems activating the EBS (allowing you to breathe from the unit)?

Yes	*No*
4	5

Please describe any problems experienced or any specific factors that made the EBS either difficult or easy to deploy:

S1 - Tube [hose] quite long - made locating mouthpiece a little difficult.

EXERCISE 2: UNDERWATER ENDURANCE

13. How easy was it to deploy the EBS?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
2	2	4	0

Not answered by one subject.

14. How comfortable were you when breathing underwater in the face-down position?

Very Uncomfortable	*Quite Uncomfortable*	*Quite Comfortable*	*Very Comfortable*
1	4	4	0

15. Were you able to maintain a good seal around the mouthpiece whilst underwater?

Yes	*No*
8	1

Please describe any breathing difficulties experienced whilst pulling yourself along underwater:

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If you were unable to complete the 90 second swim, what caused you to stop?

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16. If you completed the 90 second underwater swim, do you think that you could have continued breathing from the EBS for a longer period of time?

Yes	*No*	*Not applicable*
0	0	9

EXERCISE 3: BREATHING WHILST INVERTED

17. How comfortable were you when breathing underwater in the inverted position?

Very Uncomfortable	*Quite Uncomfortable*	*Quite Comfortable*	*Very Comfortable*
0	0	9	0

18. Were you able to maintain a good seal around the mouthpiece whilst inverted underwater?

Yes	*No*
9	0

19. Were you able to breathe underwater for the maximum duration of 60 seconds?

Yes	*No*
6	3

If you were unable to breathe whilst inverted for 60 seconds, what caused you to stop?

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Please describe any breathing difficulties experienced whilst inverted:

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EXERCISE 4: HELICOPTER UNDERWATER ESCAPE - UPRIGHT

20. How easy was it to deploy the EBS when seated in the helicopter simulator, partially submerged?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
1	5	3	0

21. How easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	2	5	2

22. How many hands did you use to deploy the EBS

One	*Two*
2	7

23. Did you use the nose clip?

Yes	*No*
9	0

24. If yes, how difficult was it to deploy the nose clip?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
0	4	5	0

25. Did the nose clip help in breathing underwater?

Yes	*No*
8	1

26. Did the nose clip stay in place during your escape?

Yes	*No*
8	1

27. Did the EBS get in the way when securing the seat harness?

Yes	*No*
4	3

Not completed by 2 subjects

28. Did any part of the EBS interfere with the operation of other items of equipment when seated in the helicopter?

No problems	*Slight problems*	*Serious problems*
8	1	0

If yes, please describe any problems experienced:

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....

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29. How difficult was it to escape from the helicopter?

Very Difficult	*Moderately Difficult*	*A Little Difficult*	*No Difficulty*
1	3	2	3

30. Did you experience any snagging when escaping through the exit window?

Yes	*No*
3	6

If yes, please describe:

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31. How buoyant did you feel when attempting to escape from the helicopter simulator?

Very Buoyant	*Moderately Buoyant*	*A Little Buoyant*	*Not Buoyant*
8	1	0	0

32. If you did feel buoyant, do you consider that this affected your ease of escape?

Yes, made escape much more difficult	*Yes, made escape a little more difficult*	*Did not affect ease of escape*
5	3	1

If yes, please describe:

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33. Did the bulk of the EBS affect your ease of escape through the escape window?

Yes	*No*
1	8

EXERCISE 5: ESCAPE FOLLOWING CAPSIZE

34. How easy was it to deploy the EBS when seated in the helicopter simulator during descent?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
2	5	2	0

35. How easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	0	7	2

36. Did you use the nose clip?

Yes	*No*
9	0

37. If yes, how difficult was it to deploy the nose clip?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
0	5	3	1

38. How many hands did you use to deploy the EBS?

One	*Two*
3	6

39. Did the EBS mouthpiece stay in your mouth during the capsize?

Yes	*No*
9	0

40. Did you suffer from disorientation following the capsize?

Yes	*No*
2	7

41. How easy was it to breathe using the EBS whilst inverted?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
0	2	4	3

42. Did you experience any problems when releasing yourself from your seat harness?

Yes	*No*
1	8

If yes, please describe:

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43. How easy was it to breathe using the EBS during escape through the exit window?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
2	7	0	0

44. How difficult was it to escape from the helicopter?

Very Difficult	*Moderately Difficult*	*A Little Difficult*	*No Difficulty*
1	3	1	4

45. Did you experience any snagging when escaping through the exit window?

Yes	*No*
1	8

If yes, please describe:

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Any other comment?

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EXERCISE 6: UNDERWATER DEPLOYMENT AND ESCAPE

46. How easy was it to deploy the EBS when underwater?

Very Easy	*Quite Easy*	*A Little Difficult*	*Very Difficult*
1	1	3	3

47. How easy was it to locate the EBS mouthpiece?

Very Difficult	*A Little Difficult*	*Quite Easy*	*Very Easy*
1	3	3	1

48. How many hands did you use to deploy the EBS?

One	Two
1	7

49. Did you have any problems with water entering the mouthpiece?

Yes	*No*
5	3

If yes, please describe any problems experienced and how you coped with this situation:

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50. Did you use the nose clip?

Yes	*No*
4	4

51. If yes, how difficult was it to deploy the nose clip?

Very easy	*Quite easy*	*A little difficult*	*Very difficult*
0	3	1	1

52. If no, was this a problem?

Yes	*No*
0	3

S9 had problems with deployment and did not answer questions on underwater deployment.

(Continued overleaf)

Any further comment:

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Signed: .... **Date:** ....