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The above paper is an edited transcript of a lecture delivered to the 1993 Annual Scientific Meeting of SPUMS. It was delivered, as an introduction to Professor Elliott's paper "Neurological deficits after diving" which was published last year in the SPUMS Journal (1993; 23 (3): 160-165).

UNDERWATER ESCAPE FROM DITCHED HELICOPTERS

David Elliott and Michael Tipton

Abstract

Some people fail to escape when a helicopter ditches into the sea. Protective clothing has for years focussed on hypothermia whereas almost no attention has been given to the immediate effects of cold immersion. Sudden immersion in water as warm as 15°C causes physiological effects which may jeopardise through-water egress from an inverted helicopter. A significant reduction of breath-hold duration occurs even when wearing a full dry suit.

A 5 year program developed a simple underwater breathing aid suitable for passengers which avoids the hazards of pulmonary barotrauma and air embolism that can occur when providing compressed gas to a submerged survivor. A counter-lung designed to meet international standards for underwater breathing apparatus (UBA) performance can more than double underwater survival time in 10°C water when compared with maximum breath holding. After operational evaluation in a helicopter dunker, it was concluded that this survival aid can only enhance safety and for some, could be life-saving.

Introduction

A forced landing on the sea is a foreseeable hazard for helicopters but one that, for most passengers, seems reasonably remote. Where the water is cold, wearing an immersion suit has become accepted practice within the oil industry. Though expensive to purchase and maintain such suits have been accepted, together with the costs of practical training, as necessary in the interests of health and safety. In spite of this some persons fail to escape when a helicopter ditches in the sea.

Recognition of the problem

Sudden immersion in very cold water has long been recognised as a cause of almost immediate death among personnel shipwrecked or lost overboard. The provision of survival suits did much to minimise the loss of body heat from survivors and, when oil and gas exploration was extended to the North Sea in the 1970's, the industry provided suitable protective clothing for its helicopter passengers based largely on military experience.

At that time the uninsulated dry suit over suitable heavy clothing was considered an adequate protection against hypothermia due to slow body cooling. Shell's policy in 1980 was that immersion suits were needed only for rescue times greater than 1 hour if the sea temperature was less than 15°C. For lesser durations, heavy winter clothing alone was regarded as adequate.

The perception that hypothermia is the principal hazard to a survivor on immersion in cold water has dominated the protective clothing policies for helicopter passengers in the offshore industry for more than 15 years. However these policies have not yet acknowledged that some people do not survive long enough to reach the phase of slow body cooling and hypothermia.

Among the open water drownings that occur each year, some two thirds happen within 3 m of a safe refuge and among those who disappear in these circumstances, some 60% were stated to have been good swimmers.[1,2] This supports the view that, long before there can be any significant whole body cooling, there are other hazards that must be overcome. These may be considered as the initial and short-term responses to immersion (0-3 and 3-15 minutes[3]) known colloquially as cold shock. This causes an immediate rise of blood pressure and a temporary inability to control ones breathing rate. Characteristically, there may be a sudden inspiratory gasp after which the survivor may not be able to avoid taking a breath even when a wave is passing over his head.

Which is first?

A second misleading perception arises from the use of the term cold shock. This implies that this can only occur in cold water but, because of its large thermal capacity, sea water must be considered cold in most locations including some that are considered to be sub-tropical. An uninsulated person cannot maintain thermal balance when immersed in water below 35°C and the effects of cold shock can be significant below 15°C.

Following the loss of a Bell 212 helicopter in the North Sea in 1981 when one person died after about 40 minutes in the water, a shuttle jacket was introduced for use in flights in which rescue times were expected to be less than 60 minutes. This was a neoprene jacket, with a beaver-tail like the top of a diver's wet suit, but worn over normal clothing and was an improvement thermally on the previous practice of wearing just heavy winter clothing (Figures 1 and 2).

However, it was then shown that even a full immersion suit fails to provide adequate protection against cold shock.[4] The potentially lethal consequences of this are serious for those trapped underwater, as most persons can hold their breath for some 50 seconds on dry land but less than one quarter can remain under water for that time, even when wearing an effective survival suit.

The significance of this observation should be considered in the context of work that was already in hand by the US Coastguard (USCG) following two helicopter ditchings in 1979 when the water temperature was around 14°C. Of nine crewmen, all trained in helicopter escape and all wearing immersion dry-suits, only three survived.[5] None of those who perished had significant injuries but all had drowned. Following this, an emergency underwater breathing device was developed by the USCG and evaluated by the US Navy Experimental Diving Unit in 1981.[6] The device (HEED-1) was a 12 litre rebreathing bag on the air-crew life jacket, filled from cylinders of oxygen but with no carbon dioxide scrubber. Maintenance costs are high, training is not without risk and the apparatus is not made available for use by passengers.

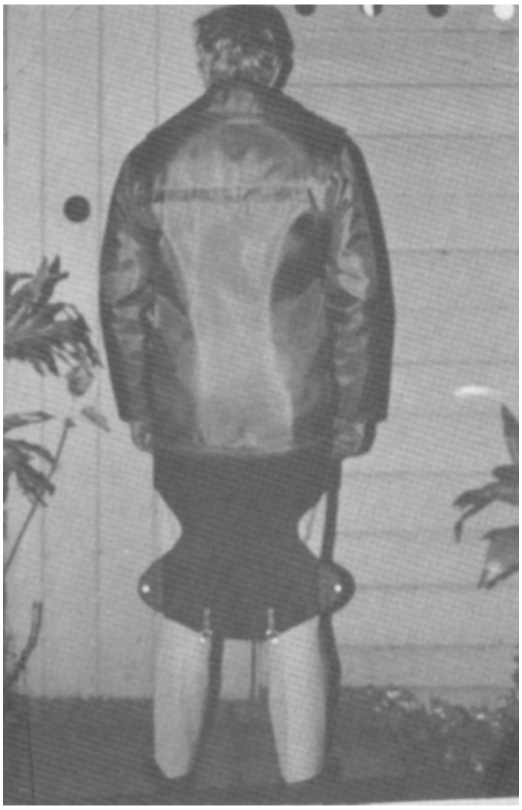

Figure 1. This jacket, similar in design to the one mentioned in the text, but designed for sailing, was available in Australia in the 1970s. The beaver tail clipped up inside the back until required.

Figure 2. The front of the jacket showing the beaver tail fixed in position.

Concurrent with the subsequent development of the Shell counter-lung rebreather, the US Navy (USN) introduced the Helicopter Emergency Egress Device (HEED-2). In the years 1981 to 1983 there had been 29 Navy and Marine Corps helicopter accidents in which the fuselage inverted or sank.[5,7] Twenty seven air crew drowned thus providing the stimulus for this alternative underwater breathing aid. The USN device is essentially the same as the miniature bottle of compressed air (Air 11) carried by some scuba divers in case their primary gas cylinder runs out of air. HEED-2 is a 5 x 25 cm aluminium cylinder charged with air to about 13 bar and it has a single-stage regulator. It was adopted for official use in 1986 but, like HEED-1, purchase and maintenance costs are high, and there is the serious hazard of pulmonary barotrauma with the risk of gas embolism both in training and when used in an emergency. There have been reports that the bottles have been found to be empty when needed and also it can be difficult to purge the mouthpiece of sea-water before breathing from it, particularly when upside down. The USN device is also only available to air-crew.

The underlying problem

How long is needed for trained and uninjured passengers to escape from a helicopter which suddenly rolls and sinks? Consider that, from the moment of the last breath before submersion, during the period of inversion and re-orientation, removing a window or following another survivor out, to arrival at the surface, the total duration underwater needed by a survivor is likely to be longer than the time taken in the ideal circumstances of a helicopter underwater escape trainer (HUET). The US Navy, the US Coast Guard, the RAF, the Institute of Aviation Medicine and the Royal Navy have all suggested, informally, times of around 45 to 60 seconds.

Breath-hold duration underwater in some persons can be a matter of only 10 to 20 seconds. In a recent trial using a realistic helicopter mock-up, 30% of trained undergraduate volunteers were not able to complete a simulated escape on breath-hold alone.

The two existing underwater breathing aids, HEED-1 and HEED-2, are both available commercially but each introduces the potential survivor to additional hazards, requires considerable training and is considered to be suitable only for air-crew.

The alternative of re-breathing one's expired air from a simple counter-lung is not an original concept. However, a simple bag is, of itself, inadequate to meet the need.

"Air pocket" counter-lung development

The question to be answered was whether or not the use of a counter-lung, without a supplementary supply of compressed gas from a cylinder, would prolong underwater time. An associated question was whether the gas available by exhalation from a full vital capacity after breath-hold would be sufficient or whether it would be necessary first to partially fill the counter-lung with some air, preferably also from the lungs, before submersion.

Manned trials with several prototypes were undertaken at the National Hyperbaric Centre, Aberdeen. From these a number of conclusions emerged but many were true only for the prototype which has since been changed. However, the use of oxygen to pre-fill the counter-lung provided no significant advantage. These trials did reveal some problems with counter-lungs. An important one was "shut off" of the bag while much of the gas needed was still captive in a distant part of the re-breathing bag.

Static and dynamic unmanned trials on five prototype designs of counter-lung were undertaken using a head and torso breathing-manikin. This was mounted in a tank of water so that it could be rotated into each possible orientation of the user: vertical upright; vertical head-down; horizontal face-down; horizontal face-up; horizontal 90° lateral rotation left, and right. The breathing characteristics of the counter-lungs were examined using the physiological acceptance criteria for underwater breathing apparatus.[8] Subsequent unmanned trials of 6 litre and 10 litre triangular counter-lungs indicated that the position and attachments of the bag were critical to its performance. The best results were obtained with the bag close to the torso but without compressing it. The turning moment induced by the larger counter-lung was high. On the basis of these results the 6 litre bag was selected and the project moved to the next phase which was to determine the optimum procedure for the use of the counter-lung.

The first tests were conducted in the dry environment with various subjects taking in a deep breath, holding it to their maximal breath-hold duration and then, at the break-point, rebreathing with the counter-lung to the maximum duration. This was compared with persons who, after taking a maximal breath, rebreathed immediately without any prior breath-holding. This was done at rest and at two levels of exercise. The results indicated that it was possible to adopt the style which would also be the safest.

By first holding one's breath as long as possible and not rebreathing, the subject might be able to make a successful escape. By using the counter-lung only after the breath-hold, the use of an counter-lung becomes the alternative to drowning. Tests were continued in warm water and confirmed the ability of persons to use an air pocket in all orientations and to remain submerged for some 60 seconds.

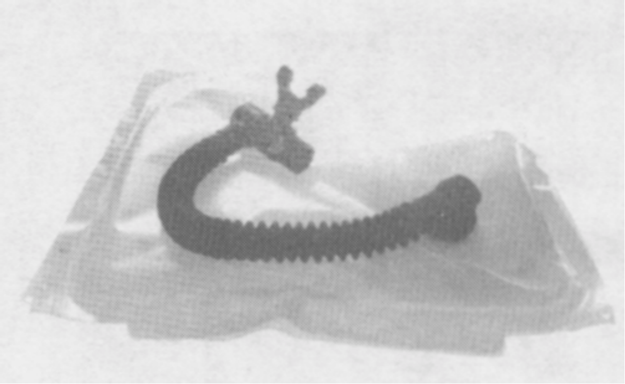

Figure 3. The final counter-lung. The most important tubing, that within the counter-lung, is not visible.

At this stage the counter-lung was fitted with an internal manifold to ensure a better distribution and enhanced emptying. In this way a counter-lung was developed which could be breathed from in any orientation underwater, which would not be subjected to "shut off", which was sized to keep breathing resistance to a minimum and which did not need to be filled with additional gas but could be used with the subject's own maximal breath (Fig. 3).

The next objective was to confirm the breathing characteristics of the counter-lung when the subject was dressed in an immersion suit (Fig.4) with a life jacket. The total underwater duration was limited to 70 seconds by the experimental design and so the maximum times for the potential use of the counter-lung were not determined. Each individual was subject to two testing immersions: one in 25°C and the other in 10°C water, chosen to represent the average temperature in the UK sector of the North Sea. It was apparent from these results that the counter-lung significantly extended the time that all subjects could spend at rest and under cold water when compared with their maximum breath-hold time.

Trials were then carried out with moderate exercise to test the effectiveness of the counter-lung procedure during a simulated helicopter underwater escape in warm and cold water. The maximum duration for this test was limited by the experimental design to 60 seconds. The results show that to rebreathe with the counter-lung could extend underwater duration by a factor of not less than 2.5. The results suggest that if 30 seconds were needed for a successful escape in these particular conditions, with breath-hold all would fail but with the counter-lung all might succeed (Fig. 5).

Having demonstrated the potential value of the counter-lung the final phase of the trials program was to confirm that it had no adverse effect on manoeuvrability and

Figure 4. Survival suit with built in counter-lung with the mouthpiece displayed.

the ability to escape from a HUET. A group of six experienced instructors and six naive subjects volunteered to take part in these trials. The training process included first simple submersion while breathing from the counter-lung after a maximal breath-hold and then on a shallow water escape trainer (SWET) chair in which the subject could be inverted before switching to the counter-lung. Each subject then pushed out a side window and egressed using the counter-lung towards the surface.

The instructors then made 4 exits underwater from the HUET using the counter-lung: position 1 a simple exit starboard through an open window; position 1 an exit port side after releasing the life raft; position 2 turning 180 degrees to release the life raft; position 3 moving aft through the cabin to release the life raft (Fig. 6). Having successfully completed this phase the instructors made an exit from the pilot seat by the bulkhead door and then out of the main cabin through a type 4 window, at 0.47 by 0.65 m the smallest in commercial helicopters. This proved to be easy even for one instructor at 1.85 m tall and weighing 105 kg.

The naive subjects (4 males, 2 females) followed a similar training plan but omitting the relatively difficult seats 2 and 4. One subject failed to egress the HUET within 60 seconds, which was the pre-agreed ethical limit to underwater duration and the counter-lung was required by the subjects in 30% of exits. There were no problems

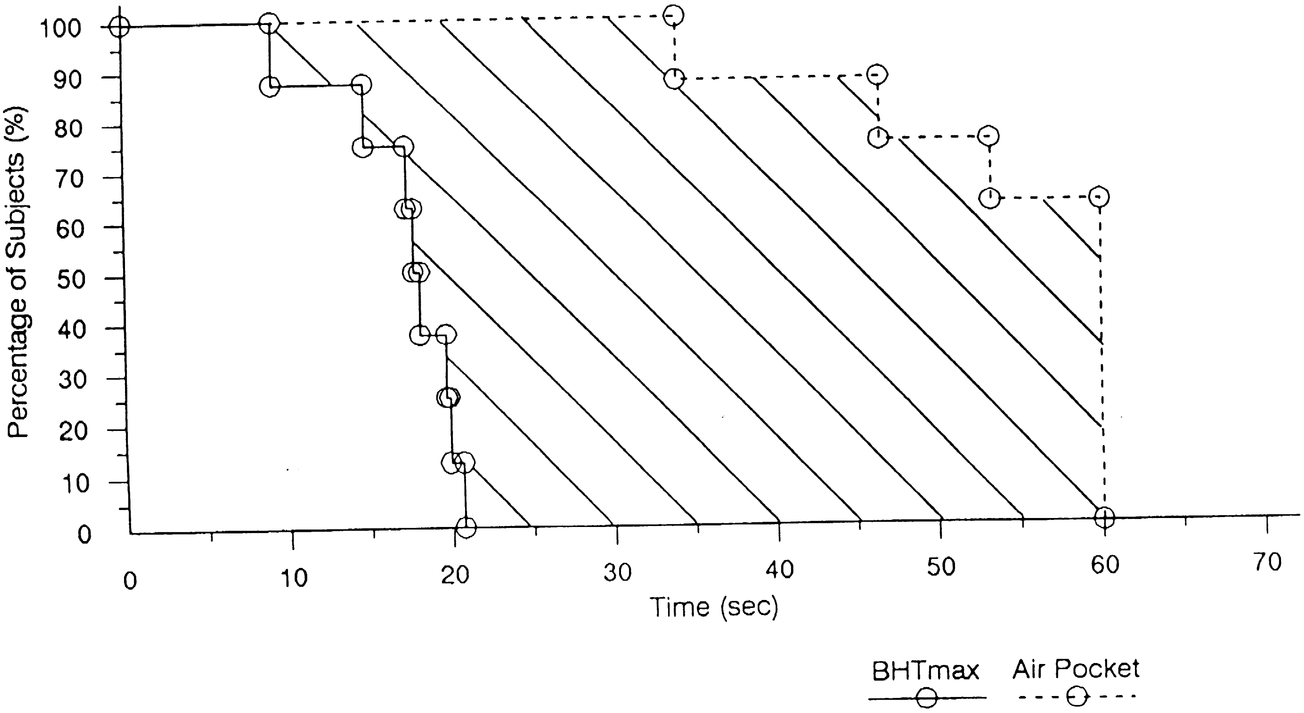

Figure 5.

The percentage of subjects able to remain submerged for any given time when breath-holding (BHT max) or when using the counter lung.

Exercising submersions. Water temperature 10° C. Counterlung worn with a “dry” survival suit. Test subjects were not exposed for more than 60 seconds.

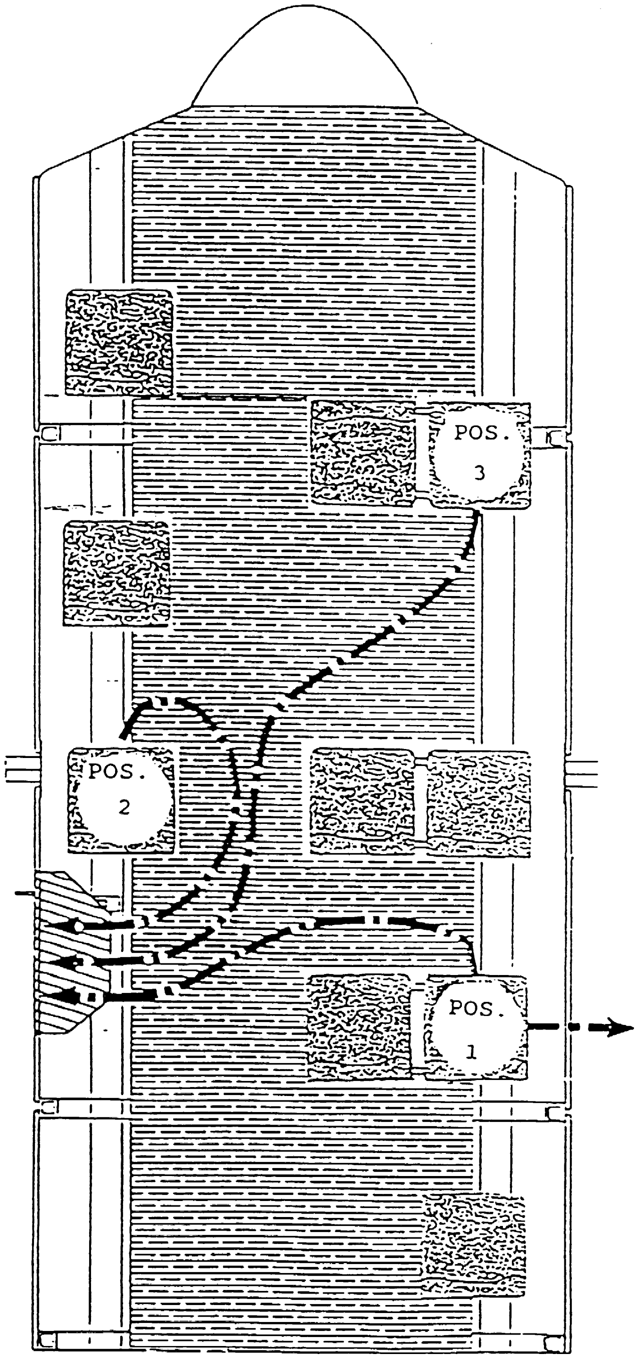

Figure 6. The S-61 METS configuration with starting positions 1, 2 and 3 marked. The arrows show the route to the liferaft encasement and exit point.

associated with snagging or buoyancy and all found it easy to use.

Test criteria

Performance objectives have been set for the use of a counter-lung with no supplementary compressed-gas cylinder. Other breathing aids and procedures may introduce the hazard of lung over-pressure during ascent with a consequent risk of serious medical complications due to gas embolism. It is important to emphasise that the counter-lung which has no supplementary compressed-gas cylinder, should also **not** be "primed" by filling it with air before submersion.

The performance objectives, test procedures and past criteria cover many non-physiological aspects such as fire protection and durability. The recommended acceptable program includes unmanned testing on a breathing machine which can model the human pulmonary system in selected orientations upright, head-down and forward at 90° and 270°. The results should be reviewed using the standards of the "Guidelines for the Minimum Performance Requirements and Standard Unmanned Procedures for Underwater Breathing Apparatus" (1984) Department of Energy and Norwegian Petroleum Directorate. The counter-lung is then tested in warm (25°C) and cold (10°C) water at rest and with moderate exercise to ensure that, when used as recommended, it provides the healthy subject wearing an approved immersion suit with a significantly prolonged duration underwater when compared to simple breath-holding.

The manned tests need to be repeated every time that the counter-lung is fixed to any new type of survival suit with which it has not been used previously. For instance, it may not be compatible with a relatively tight fitting design if it is to be worn between the suit and the individual's clothing. In this circumstance it would need to be fitted to the outside of the suit and in some other conditions it may need to be fitted to the life jacket.

Conclusions

The "Air pocket" counter-lung:
is relatively inexpensive;
provides no special difficulties for training;
is simple to use;
is compatible with any position in the water;
does not introduce the additional hazard of pulmonary barotrauma and gas embolism;
can be validated for use with other survival suits;
can enhance safety to an extent which may be life-saving for a proportion of passengers.

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ARTICLES OF INTEREST REPRINTED FROM OTHER JOURNALS

WHY US DIVERS DIED IN 1990

In the past, Undercurrent's annual series, "Why Divers Die", has been based on studies performed by John McAniff at the National Underwater Accident Data Center (NUADC).

Recently, McAniff merged his effort with the Divers Alert Network (DAN), which has for four years been reporting on recreational scuba accidents. This expanded DAN report is based on information from more than 130 treatment facilities in the United States, the Caribbean and Pacific territories.

Undercurrent is pleased to bring you the DAN 1990 Report on Diving Accidents and Fatalities with the belief that by reading these accounts, we will become safer divers.

Undercurrent takes all responsibility for editorial changes and errors.

NUADC has been collecting scuba fatality information for the past twenty years. Since 1989 DAN and NUADC have been collaborating in this effort. This report covers those fatalities which occurred to United States citizens who were recreational divers throughout the world in 1990.

NUADC has reviewed studies of diver population and estimates the active diver population in the US to be 2.45 to 3.1 million at the end of 1990. The difficulty of comparing these studies was the lack of a consistent definition for an active diver. Divers may be excluded in one study because they were under 18 years of age or included in another study if they dived more than twice a year. Certification was not necessarily a criterion for being an active diver.

All figures include individuals engaged in training for entry level certification while excluding those taking resort sessions. Technical diving is included in the active diver population, but is not considered recreational and is discussed separately. Technical diving can be loosely defined as an avocation which uses specialized techniques, equipment, training and skills to advance beyond the present limits of recreational diving.

There are several reasons why a range is used when describing the number of active divers. No reliable numbers are available to determine how many new divers are certified each year. NUADC estimates there could be 550,000 newly certified divers yearly. Not all will remain active after the first year of diving. Drop out continues for several years adding to an unknown cumulative drop out rate. Although 550,000 individuals may have received a first time certification, the total active diver increase in 1990 was between 100-150,000 certified divers due to the overall drop out rate, and that some people re-enter after dropping out.

Deaths

For 1990, 95 recreational scuba diving fatalities were reported. Four of these deaths were foreign nationals and 91 were US citizens. Eleven victims had not been