



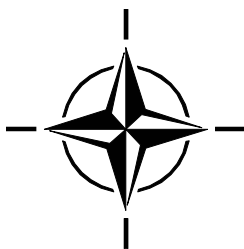
RTO AGARDograph

AG-HFM-152

Survival at Sea for Mariners, Aviators and Search and Rescue Personnel

(Survie en mer pour les marins, les aviateurs et
le personnel de recherche et de sauvetage)

This is the final compilation of the lecture notes, written specifically for
the HFM-152 Technical Course on 'Survival at Sea for Mariners,
Aviators and Search and Rescue Personnel', presented
in Belgium and Portugal in June 2007.



Published February 2008





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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote co-operative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective co-ordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also co-ordinates RTO's co-operation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of co-operation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier co-operation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Preface

This technical course was conceived seven years ago and first presented in the U.S.A., Germany and Spain in 2003. This was most successful and repeated in the Netherlands and Latvia in 2005. This AGARDograph was produced for the recent course that was held in Belgium and Portugal in June 2007. I would like to thank all my colleagues who assisted in the compilation of this document.

Technical Course HFM-152

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Survival at Sea for Mariners, Aviators and Search and Rescue Personnel

(RTO-AG-HFM-152)

Executive Summary

This NATO RTO Technical Course on Marine Survival has been assembled, edited and produced by an international team led by Dr. C.J. Brooks of Survival Systems Ltd., Canada. Key issues that are addressed are as follows:

- Marine accidents and helicopter ditchings continue to happen regularly and quite frequently with a significant loss of life. The latest helicopter ditching statistics are presented. In the majority of cases drowning is the final cause of death.
- In cold water accidents, it is likely that cold shock and swimming failure contribute more to the deaths than hypothermia. Again, drowning is commonly the cause of death, but accident investigators, coroners and pathologists rarely delve into the underlying causes of drowning. A drowning checklist has been developed to improve the situation.
- For helicopters flying over water, much progress has been made in the underwater escape training curriculum, but there is still no standardization on the type of Helicopter Underwater Escape Trainer, the use of exits, the precise number of evolutions and the frequency of refresher courses. The choice of supplementary air-rebreather versus compressed air is also discussed.
- The responses of lightly clothed, young, Caucasian males, to innocuous immersion in relatively calm water bear little resemblance to the real life situation in open water. Therefore testing methods for lifejacket and survival suit performance are not realistic and need revising.
- Survival prediction curves may over-estimate survival times in cold water because survivors drown before they get severely hypothermic and it may underestimate survival times in warmer water.
- Manikin testing for immersion suits and lifejackets shows good promise, but more research is required to understand the inter-relationship between body cooling and drowning with leakage, wave motion, sea sickness, flotation angle, etc.
- Do not forget about non-freezing cold injury. It is much more common than originally thought.
- There are no magic cures for sea sickness.
- Life boat and life raft design and specifications have severely lagged behind other survival technologies. IMO and Military agencies need to revise the specifications for both weight allowances and space allocation, the human factors involved in entering a life raft from the sea and a whole series of human engineering problems related to the operation of them.
- A fully integrated human factors approach is needed to bring new safety equipment on line – this does not mean just having one token human factors engineer on staff, a team is required.
- Marine survival courses must introduce the problem of human information processing under extreme stress into their curriculums.

Survie en mer pour les marins, les aviateurs et le personnel de recherche et de sauvetage

(RTO-AG-HFM-152)

Synthèse

Ce cours technique OTAN RTO sur la survie en mer a été élaboré, rédigé et produit par une équipe internationale conduite par le Docteur C.J. Brooks de *Survival Systems Ltd*, Canada. Ont été abordés les points clés suivants :

- Les accidents en mer ainsi que les amerrissages forcés d'hélicoptères continuent de se produire régulièrement et assez fréquemment, avec un nombre significatif de pertes humaines. Les dernières statistiques d'amerrissages forcés d'hélicoptères sont présentées. Dans la majeure partie des cas, la noyade constitue la cause mortelle finale.
- Lors d'accidents en eau froide, il est fort probable que le choc thermique dû au froid ainsi que l'épuisement à la nage entraînent davantage la mort que l'état d'hypothermie. Là encore, la noyade est souvent la cause mortelle, mais les enquêteurs d'accidents, coroners ou pathologistes recherchent rarement les causes profondes des noyades. Une liste de contrôle 'Noyade' a été élaborée afin d'améliorer cette situation.
- Concernant les hélicoptères volant au-dessus de l'eau, de gros progrès ont été réalisés dans la formation à l'évacuation d'un hélicoptère immergé, mais il n'existe toujours pas de standardisation sur le type d'entraîneur à l'évacuation d'un hélicoptère immergé, l'utilisation des sorties, le nombre précis d'évolutions ni la fréquence des cours de recyclage. Le choix d'un appareil de respiration à circuit fermé supplémentaire plutôt que de l'air comprimé fait également l'objet de discussions.
- Les réactions d'hommes de type caucasien, jeunes et légèrement vêtus en situation d'immersion ne présentant aucun danger et dans une eau relativement calme, sont très loin de celles d'une situation réelle en eau libre. Les méthodes d'essai des performances des gilets de sauvetage et des combinaisons de survie ne sont donc pas réalistes et nécessitent d'être revues.
- Les courbes de probabilité de survie peuvent surestimer les temps de survie en eau froide pour des survivants noyés avant d'être en situation grave d'hypothermie et sous-estimer les temps de survie en eau plus chaude.
- Les essais de mannequins en immersion avec des gilets de sauvetage et des combinaisons de survie ont donné des résultats très prometteurs. Cependant, il est nécessaire d'approfondir les recherches afin de comprendre les interrelations entre le refroidissement du corps et la noyade avec les fuites, le mouvement des vagues, le mal de mer, l'angle de flottaison, etc.
- Ne pas oublier les lésions dues au froid. Elles sont bien plus courantes que ce que l'on pourrait penser.
- Il n'existe aucun remède miracle contre le mal de mer.
- La conception et les spécifications des canots/radeaux de sauvetage sont toujours de niveau largement inférieur en comparaison à d'autres technologies de survie. L'OMI et les agences militaires doivent réviser les spécifications de manière à tenir compte des tolérances de poids et de l'attribution d'espace, des facteurs humains liés à l'entrée dans un canot de sauvetage lorsque l'on est dans l'eau, et de toute une série de problèmes ergonomiques liés à leur fonctionnement.

- Une approche parfaitement intégrée des facteurs humains est nécessaire pour mettre en conformité de nouveaux équipements de sécurité. Cela ne signifie pas seulement d'impliquer un seul ingénieur du personnel dédié aux facteurs humains : toute une équipe est nécessaire.
- Les programmes des cours de survie en mer doivent prévoir d'aborder le problème de la gestion des informations par l'homme dans des conditions de stress extrêmes.



Chapter 1 – Introduction to the RTO Technical Course: Survival at Sea for Mariners, Aviators and Personnel Involved in Search and Rescue – HFM-106

by

Dr. C.J. Brooks
(Course Director)

Your Course Director had the privilege of being taught by such scientists as Peter Barnard, Peter Bennett and David Elliot when he attended his basic Royal Navy Medical Officer Introductory Course in Alverstoke, Gosport, U.K. in 1966.

Then, the R.N. Institute of Naval Medicine was humming with expertise. Many of the staff there and next door at HMS Dolphin had Second World War expertise in survival medicine, and the new nuclear medicine submarine programme had been operating for about 5 years. The Royal Navy Personnel Research Committee met regularly. At this time, it was possible to personally discuss problems with distinguished working scientists such as Hervey, Keatinge, McCance, and Pugh. These were the people who changed our whole mind set about death at sea. Now, we knew it was a series of physiological responses that needed to be addressed by the World's Navies and Industry with better protective clothing, e.g. lifejackets and survival suits. The term hypothermia first came into our survival language. Moreover, the scientists brought about a whole attitude change which was needed in our Survival Training Schools; no longer was drowning due to fate and an acceptable occupational hazard. People could be saved during the survival phase of marine abandonment.

In 1981, it was Golden and Hervey who then made the next significant step forward in cold water physiology. They published the classic work on the four stages in which death can occur from sudden unexpected immersion in cold water. Up until then, our pioneers considered that hypothermia was the most important cause of death after shipwreck. Cold shock and swimming failure were known, but were only considered of academic interest. Even though this was 26 years ago, this information is still only just becoming widely known and the concept applied. Things don't happen very quickly in the marine world!

Over the last 41 years, I have watched this change in philosophy occur. In a small part, I have been able to assist particularly in the human factors of escape and survival from helicopter ditchings and the introduction of emergency breathing systems. As time marched on, it became clear to me that the celestial umpire was calling in many of these experts; we thought they would be there forever to provide their wisdom and advice. Sadly when they retired or died, the universities did not replace them. For some reason, human physiology is considered to be a mature science (not by me!). Many University Faculties consider it is much easier to replace the scientists with mathematical modelers.

In the 21st Century, this of course is the path of least resistance, no need for human ethics committees, models take up much less space than elegant pools, wave tanks, cold chambers, no worries about litigation because no-one gets a non-freezing cold injury and no-one slips on a wet pool deck, etc. Now, for instance here in Canada, all of a sudden, we find that 7 very fine University laboratories producing excellent applied physiological work reduced to only half of this capability, if not less. Canada is not unique, the USA and European countries have had the same experience. We will likely live to regret this decision.

As Burton and Edholm had done reporting on all the 2nd World War work in their book “Man in a Cold Environment” in 1955, this author seeing the writing on the wall asked himself how could we at least document our current survival knowledge learned since then. This would ensure that it could be passed on to future generations with steady updates as more information became available. The loss of hundreds and thousands of sailors would then not have been in vain, and the contribution of many hundreds of test subjects post-war enduring very unpleasant cold water experiments would also be recognized. The research is documented in a Transport Canada report No TP13822E – Survival in Cold Waters – Staying Alive. This is free both in English and in French to anyone who wishes to email and request a copy from the Marine Safety Board of Transport Canada at marinesafety@tc.gc.ca.

In conjunction with this, this author conceived the idea of a lecture series “Survival at Sea for Mariners, Aviators, and Personnel involved in Search and Rescue.” This was first sponsored by the NATO Advisory Group for Aviation Research and Development (AGARD) and now by the Human Factors Medicine Panel (HFM106) of the NATO Research and Technology Organization. My team have conducted the course in six countries over the last 4 years. It has been very well received. Indeed voted the best of all the RTO lecture series in 2005. Because it was a new concept, we simply presented our information on PowerPoint presentations. These were made available to all the students. For the first time in 2007, we have produced a bound volume with a précis of each lecture. I hope you enjoy the course.

Please note that the Programme is very flexible and there is a very good reason for this. Before we arrive at a venue we have no idea of the professional background of the students, their knowledge of the English language and at what level to aim our training. This is because (a) we teach a wide range of topics and (b) our audience comes from an even wider professional and practical background. So for instance in one location, the majority of attendees were physicians, nurses and medical technicians; in another location they were predominantly aircrew; and yet in a third location they were mostly aero-medical training staff. So thanks to Microsoft Power Point, when we review the list of attendees on the day before the course starts, it does not take long to re-arrange the slant on each topic to meet the knowledge levels of each of the audience. Because we only have two days to present the course at each venue, and there is only so much information that people can absorb in this time, we always run the risk of speeding over some topics which may be of more interest to some attendees. We do occasionally get comments on our course critiques saying “we would like more on this subject” or equally “we would like less on this subject and more on another”. I am afraid this is inevitable. However, there are two other good reasons for us to develop the lecture notes on each topic.

We made each lecture a stand alone lecture, so instructors could take the whole text and use it as they see fit. Because of this, you will notice that some data is repeated in each of the lectures. This is unavoidable because each of the topics we discuss which include clinical medicine, physiology, psychology, human engineering and practical survival examples and statistics are all interrelated. We make no apologies for this and strongly advise that anyone entering the field of survival instruction or research must have a broad knowledge in all these areas. To address one area without the others is doomed to failure.

The other reason is that we provide practical training on both afternoons of the course. However, for those who do not want to get wet, or only wish to observe one or two evolutions, then we offer additional classroom lectures and videos. Again in some venues, everyone wants to do the pool work and **additional** pool work. At the other extreme, only one or two people want to jump in! So the other objective of these lecture notes is that if you missed two or three lectures because you were in the pool, then you still have a copy to take home.

Finally, I made reference to my team above and now I must introduce them to you and thank my lecturers who have given their personal time to do this lecture series for you:

- Dr. Mike Tipton
- Dr. Bob Cheung
- Dr. John Kozey
- Mr. Peter Gibbs

I would also like to introduce a new addition to our family, Dr. Tara Reilly. She has worked under all of our supervision over the last 6 years and will also be lecturing on the course.

Finally I have to thank Jackie Jenkins and Conor MacDonald, our graduate students from the Faculty of Health and Human Performance at Dalhousie University, Halifax, Nova Scotia, who have typed out and formatted all the lectures ready for RTO to assemble in one publication. As well I would like to thank Antonio Simoes Re from the Institute for Ocean Technology for providing me with the wonderful photograph below of testing a TEMPSC in ice conditions off the coast of Newfoundland.



Figure 1-1: TEMPSC Testing in Ice.

This may happen to you – So read, mark, learn and inwardly digest the contents of this AGARDograph.

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Chapter 2 – Thermoregulation

by

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Humans belong to a group of animals called “*homeotherms*”. To ensure optimal physiological function and survival, these animals must regulate their deep body temperature within a narrow range despite large changes in environmental temperatures. To do this their heat loss and heat production must be balanced; if it does not they

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will become hyperthermic (hot) or hypothermic (cold), with consequences that range from mild impairment of performance to death.

The equation which describes heat balance is:

$$M-(W) = R \pm C \pm K - E$$

where:

M = metabolic rate.

W = measurable external work.

R = heat exchange to and from ($\pm$) the environment by radiation (R).

C = heat exchange to and from ($\pm$) the environment by convection.

K = heat exchange to and from ($\pm$) the environment by conduction.

E = heat loss (-) to the environment by evaporation.

The unit for each term is generally quoted as watts per square metre of body surface area (W.m⁻²).

- **M(Metabolism).** The chemical reactions of the body liberate energy during metabolism. The biggest cause of variation in energy expenditure is exercise. About 75% of the chemical energy used during muscular contraction is converted to heat.
- **R(Radiation).** All objects possessing heat emit thermal radiation from their surfaces in the form of a wave of energy containing particles within the red-infrared range of the electromagnetic spectrum. The energy from these particles are absorbed by, and transferred to, the atoms of objects they come into contact with. No medium is required for the transfer, thus, radiation is the process by which the energy of the sun travels through the vacuum of space to reach earth.
- **C(Convection).** In a naked person standing in cool air (below skin temperature), air molecules coming in contact with the body will be warmed, the density of the warmed air is reduced causing it to rise and be replaced with cooler air. This process is called “*natural (or free) convection*”. Convective heat exchange is increased by: air (wind) or water (current) movement across the skin (this is called “*forced convection*”); or the movement of the body in air or water (“relative wind speed/water current”). The exchange of heat between a body and its environment through convection depends on the temperature gradient between the two and the relative movement of the fluid (air or water) in which the body is placed.
- **K(Conduction).** This term is used to describe heat exchange between the skin and surrounding surfaces with which it touches. Usually the amount of heat exchanged in this way is small and is dependent upon:
 - a) The temperature gradient between the skin and the surface with which it is in contact;
 - b) The surface area in contact; and
 - c) The thermal conductivity (ease with which heat moves through a substance) of the surface in contact with the skin.
- **E(Evaporation).** Evaporation is the process by which energy transforms liquid into a gas. Thus, evaporative heat exchange only occurs when fluid evaporates from the surface of an object. The heat

required to drive this process is removed from that surface and it is cooled. This is termed the “*latent heat of vaporization*”, for water it amounts to 576 kcal.L⁻¹ (2,408 kJ.L⁻¹). The rate of evaporation depends on:

- The skin surface area that is wet;
- The air movement around the body (wind or body movement); and
- The difference between the vapour pressure at the skin surface and that in the air.

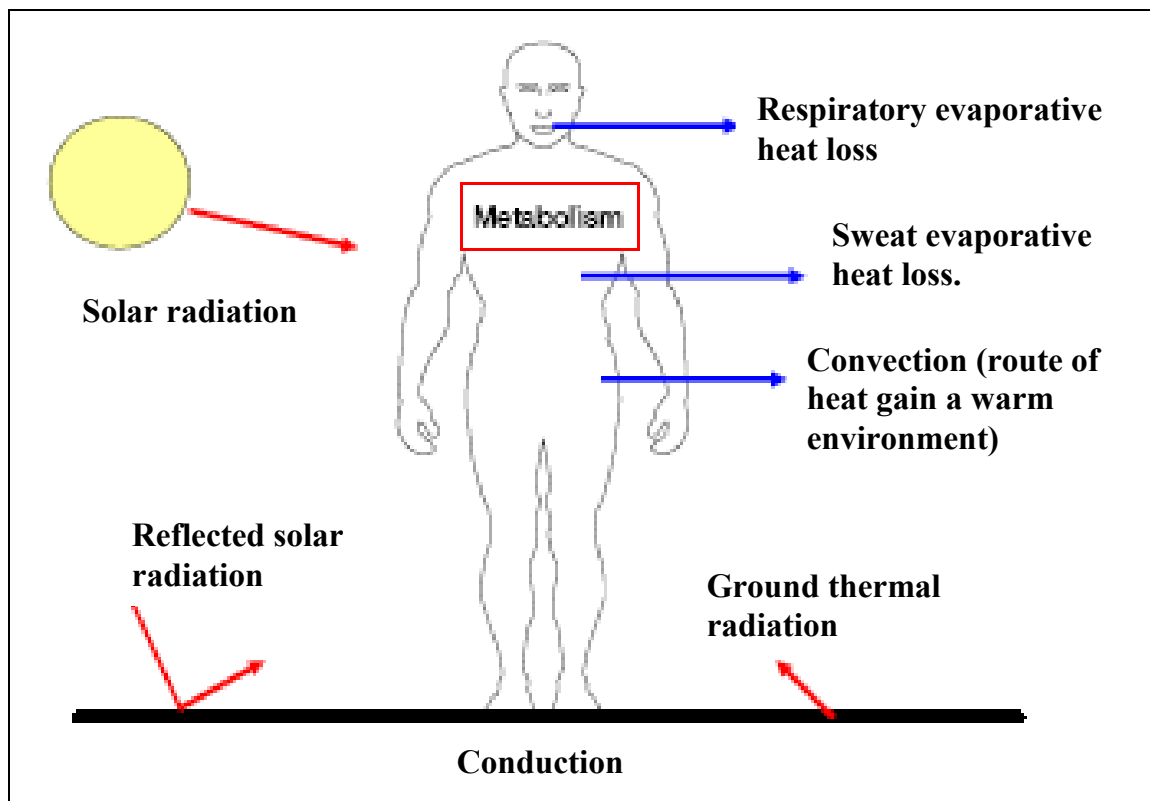


Figure 2-1: Heat Exchange in a Thermoneutral Outdoor Environment (e.g. 25°C, rh 50%)
Red = Heat Gain; Blue = Heat Loss from the Body.

PHYSIOLOGICAL REGULATION (“*THERMOREGULATION*”)

In humans, it is the role of the *thermoregulatory system* to vary the level of heat exchange with the environment so as to maintain deep body temperature within about half a degree Celsius of the normal deep body temperature of 37°C (98.6°F). The body defends its temperature with some vigour and the thermoregulatory system can take precedence over other regulatory systems. For example, body temperature is maintained during starvation, when energy could be saved by permitting body temperature to fall; blood pressure regulation can fail due to increased circulation to the skin (“*vasodilatation*”) in the heat; and sweating is maintained when the body is depleted of water (“*dehydration*”), when cessation of sweating would conserve water.

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In order to control body temperature the thermoregulatory system must be able to sense temperature and respond to changes. Thus, it includes receptors that respond to rises (“*warm receptors*”) and falls (“*cold receptors*”) in temperature. These receptors can be found in areas of the body such as the skin, muscles, spinal cord, and brain. In the skin for example, there are about three times more cold than warm receptors. They are located about 0.18 mm below the surface of the skin; this means that they respond quickly to changes in environmental temperature. In contrast, in the area of the brain that is particularly sensitive to temperature, called the “*hypothalamus*”, there are more warm than cold receptors. These are not stimulated until changes in environmental temperature, or metabolic heat production (e.g. exercise), have an impact on the temperature of the brain via the blood flowing through it.

The thermoregulatory responses evoked are the result of an integration of the inputs from peripheral and central receptors, this integration occurs in the hypothalamus. Thus, the hypothalamus is not only sensitive to its own temperature, it also receives and processes thermal information from the remainder of the body and initiates appropriate responses. The temperature receptors in the brain are more important in determining the type and magnitude of thermoregulatory responses than those in the periphery. This relationship has practical consequences and, for example, explains why hand cooling can be used to cool a hyperthermic individual, but not to re-warm a hypothermic one.

THE RESPONSE OF THE BODY TO FALLING TEMPERATURE

Because we are primarily interested in survival in the sea, the response to cooling are described below.

Increased Heat Conservation

Alteration in Peripheral Blood Flow

When cold, the body shuts (“*vasoconstricts*”) the blood vessels in the skin. This reduces blood flow to the skin and the underlying fatty layer. In so doing, it converts both into an insulating buffer zone on the surface of the body that protects the inner “core” temperature where the vital organs are situated. Insulation is defined as resistance to heat flow, and the thicker the layer of fat beneath the skin (“*subcutaneous fat*”) the better the resulting insulation in the cold. Thus, reducing skin blood flow is the means by which peripheral insulation is employed. The fat beneath the skin can be regarded as “fixed” insulation that changes little in the medium term. It provides approximately the same insulation as cork (1.5 Clo/cm fat). Muscle can also provide significant levels of insulation when it is relatively unperfused by blood, i.e. at rest. However, this source of insulation is lost at relatively low levels of exercise; this includes shivering. The reduction in skin blood flow decreases the amount of heat delivered to the surface of the body. As a consequence skin temperature is lowered and becomes closer to the temperature of the environment; this reduces the gradient down which heat can be lost to that environment.

Increased Heat Production

Shivering

Shivering is the involuntary, synchronous and rhythmic contraction of small parts of skeletal muscles called “*motor units*”. These contract at a rate of about 10 – 20 per second and out of phase with other units. The contractions alternate with motor units of opposing muscles and, as a consequence, large movements are avoided and no external work is done. Heavy shivering may be interspersed with periods of light shivering or rest in the early phase of cooling, but later becomes continuous before progressing into an almost tonic state.

At its maximum, heat production from shivering can reach five or six times resting levels. However, this level of shivering heat production cannot be maintained for very long.

As no external work is performed, all the energy liberated by shivering appears as heat. Some of this heat is immediately lost to the environment, however in most situations shivering can be an effective, if uncomfortable, way to maintain body temperature.

The energy needed for shivering comes from fats and sugar. Of the two, it is sugar (carbohydrate) that is in the shortest supply and, when it runs out, shivering stops. Even with moderate levels of shivering this can occur in as little as 7 hours when no food is eaten. Shivering is also reduced when oxygen levels in the inspired air fall, or carbon dioxide levels increase; this becomes important in situations where ventilation can be inadequate, such as in life rafts. Shivering uses the same skeletal muscles as voluntary exercise and the two can co-exist up to moderate levels of voluntary activity. With mild cooling, shivering is progressively inhibited as exercise intensity increases. With severe cooling the increase in muscle tone associated with shivering can inhibit co-ordinated movement and impair activities such as swimming.

In cold climates, should the heat being produced by the body be unable to balance that being lost to the environment, body temperature will inexorably decline and death from hypothermia will occur when deep body temperature has fallen by about 12°C (22°F).

FACTORS INFLUENCING THERMOREGULATION

It is evident from the above that the thermoregulatory system is influenced by thermal factors such as skin and deep body temperature. However, a wide range of “non-thermal” factors also affects it (Table 2-1). Some of these alter the way the thermoreceptors in the hypothalamus respond to changes in temperature. Others, such as fitness, alter the body’s ability to produce heat or sweat. Each can alter the onset of sweating and shivering, and the sensitivity of these responses.

Table 2-1: Non-Thermal Factors that Influence the Thermoregulatory System

Age	Gender	Fitness Levels
Illness	Injury	Intoxication (Drugs/Alcohol)
Hypoglycaemia (low blood sugar)		Adaptation to Heat/Cold
Raised ambient carbon dioxide / Lowered ambient oxygen		

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Chapter 3 – The Dangers of Sudden Immersion in Cold Water

by

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INTRODUCTION

As you will read repeatedly throughout the papers in this lecture series, death at sea until now has been regarded by many as fate and an occupational hazard. For a full account of sea survival, then the textbook “Essentials of Sea Survival” by Golden and Tipton is recommended for all survival instructors [13].

Hypothermia was described by Herodotus [20] during the Persian/Greek War as far back as 450 BC – but life was cheap and no one paid much attention to the cause of drowning. Brief interest was shown in the 18th Century when James Lind (1792) described post-rescue collapse, Hutchinson (1794) wrote a book “To preserve the health and comfort of sea voyagers”, and Currie (1797) noted hypothermia and post-rescue collapse.

As described in the lecture on immersion suits, the Royal Navy policy of impressments was not discontinued until 1815. So there was no incentive to provide flotation systems, protective clothing and investigate the cause of drowning. After all, their Lordships would argue, if a ship sank in battle there was plenty of flotsam and jetsum to provide support. In 1805, at the Battle of Trafalgar, sailors clung to masts and spars for 15 hours before rescue.

The advent of iron ships in the mid 1850s only exacerbated the drowning statistics. In 1892, the USA was the first nation to regulate the carriage of lifejackets on passenger vessels. They were reluctantly followed by Britain, France, Germany, and Denmark. The Titanic accident in 1912 caused the formation of the International Maritime Organization (IMO) who produced the Safety of Life at Sea (SOLAS) regulations. Now there was international regulation requiring the carriage of life jackets. Lord Mersey in his investigation of the Titanic accident did not ask why the passengers on the Titanic were floating dead in perfectly good life jackets on the surface of the water. The path of least resistance was to assign the diagnosis drowning – and this to a certain degree is still what is happening in 2007.

During the First World War 12,000 Royal Navy sailors, 10,000 merchant seamen and 5,000 German sailors drowned. Yet no one paid much attention to this dreadful statistic, and certainly no serious physiological examination into the cause of death was initiated.

The loss of life was equally dreadful in the Second World War. The Talbot report published in 1946 showed that 20 – 30,000 Royal Navy officers and men had died. One third killed in action and two thirds killed during the survival phase. This two thirds drowned principally due to the cold. They could have been saved if they had the right survival equipment and training. This report precipitated a very extensive research programme under the auspices of the Royal Navy Personnel Research Committee. Numerous publications and reports were produced. The most significant textbooks being:

- Burton, A.C. Man in a Cold Environment 1955 [7]
- McCance, R.A., et al. The Hazards to Men Lost at Sea 1956 [23]
- Nicholls, G.W.R. Survival at Sea 1960 [25]
- Newburgh, L.H. Physiology of Heat Regulation and the Science of Clothing 1968 [28]
- Keatinge, W.R. Survival in Cold Water 1969 [21]
- Smith, F.E. Survival at Sea – MRC report 1976 [30]

All this was excellent, but there was one problem; everyone concluded that the cause of death and drowning was due to hypothermia. The 4 physiological stages of sudden immersion in cold water were known, but the first two stages – cold shock and swimming failure were considered to be only of academic interest.

It wasn't until 1981 that Golden and Hervey [11] produced their classic paper on the 4 stages of immersion. For the first time it became clear why people were drowning and this lecture will concentrate more on the first two stages which probably contribute more to the cause of death than the later two stages. The four stages are as follows:

Stage 1: Initial immersion responses or cold shock. Due to rapid skin cooling. This kills within 3 – 5 minutes of immersion.

On initial immersion, there is a large inspiratory gasp followed by a four-fold increase in pulmonary ventilation, i.e. hyperventilation. This on its own can cause small muscle spasms, tetany and drowning. Along with this, there is a large increase in heart rate and blood pressure. These latter cardiac responses may cause death, particularly in older, less healthy people. These effects last for the first two to three minutes, just at the critical stage of ship abandonment [32, 34] when one is struggling to adjust to the wind and waves and avoid inhalation of water.

Death from cold shock is not uncommon. Here is an example of an incident typical of those that continue to be regularly reported in the Canadian press each year. It demonstrates the practical evidence that cold shock kills.

Teen drowns after lunch-hour plunge (Globe & Mail, April 16, 1998)

Toronto – A 14-year-old high-school student drowned yesterday after jumping into the frigid water of Lake Ontario. Hours after the incident, police still do not know why Peter Arthur went into the water, which was only about 4°C. There were two other teenagers with him at the time. When Peter failed to surface, his friends sought help from nearby construction workers, who called the police. When they arrived they jumped into the lake, which is about 3½ meters deep at that location, and searched for the missing teen for 10 minutes, until the icy water forced them to shore Sgt. McCann said. As the two officers sat on nearby rocks, huddled in blankets, members of the Toronto police marine unit arrived and took over the search. Dragging the area with a net, they located the teen, who by that time had been in the water for about 30 minutes. Firefighters performed cardiopulmonary resuscitation until paramedics arrived to continue treatment. But Peter was pronounced dead at Toronto East General Hospital at 12:55 pm.

The Dangers of Sudden Immersion in Cold Water

Disaster strikes a fishing vessel (October 1992)

The fishing vessel *Nopsa*, a 16.8-metre (55-foot) black cod longline trap vessel, was near the end of a 3-week trip. It was located on the Bowie Seamount, approximately 90 nautical miles west of the Queen Charlotte Islands on British Columbia's north coast. There was a crew of five on board, and after much bad weather the seas were finally calm. At approximately 2155 hours, the crew had 30 of the string of 60 traps on board. The current trap was somewhat heavier than the previous traps, and two of the deckhands were having trouble stacking it on top of the other traps on deck.

On the second attempt, the trap fell to the deck, causing the two deckhands to scramble to safety. One man moved to the center of the vessel, and the other moved to the starboard rail. The crew member who had moved to the rail of the vessel misjudged his location and slipped forward of the guardrail securing the trap storage area and fell headfirst into the water. He was not wearing personal flotation protection. Although the initial response from the crew was laughter, they quickly realized that the deckhand was in distress and began rescue attempts. The crew member was recovered on board within 9 minutes of entering the water; however, he was unconscious by this time and attempts to revive him were unsuccessful. During rescue attempts, a variety of lines and floating objects were thrown well within reach of the man overboard, but he made no attempt to grab onto any of them and aid in his own rescue. He was able only to continue to cry out for help. The water temperature was between 10° and 11°C. [27]

Stage 2: Short-term immersion or swimming failure. Due to rapid muscle and nerve cooling. This kills within about 5 – 30 minutes of immersion.

Again, the newspapers report these tragic preventable accidents regularly.

Son helpless as mom died (Daily News, Halifax, June 5, 2002)

A Chester man who can't swim watched Tuesday as his mother was overcome by frigid, choppy water off Quaker Island, Lunenburg Co. Kathleen Haase, 44, and her son Michael, 25, were spending the day exploring the small grassy island about two kilometers south of Chester. When their small speedboat started to drift away from the island as the tide rose, Kathleen Haase tried swimming after it. She could swim, but the water Tuesday was only about 10°C. Wayne and Geraldine Truck were going past the island in their 11-meter sailboat when they heard the son's distant screams for help. "We didn't see anyone splashing in the water," Wayne Truck said. "She undoubtedly had succumbed." They caught the drifting speedboat and were bringing it back to the island when they discovered Kathleen Haase floating face down in the "bitterly cold" water, about 50 meters from the shore. Rescue crews worked to revive her on the boat ride and in the ambulance to South Shore Regional Hospital in Bridgewater. But she never recovered and was pronounced dead in hospital.

Fishing Technician drowns in Skeena River, B.C. (March 2002)

In another incident, which occurred on 27 March 2002, two fishery technicians were conducting eulachon research in the Skeena River on British Columbia's north coast. Although the portion of the Skeena River on which the technicians were working is not considered "tidal", it is influenced by the tides at the mouth of the river. The water rises and falls on-cycle as water levels change further down the river. The technicians had walked out to an island in the river at low water to conduct part of their survey. When they attempted to return, they found that the river was now too deep to cross back to the mainland. In their initial attempt to re-cross the river, both men filled their chest waders. The technicians returned to the island cold and wet to wait the 5 hours before the river would be low enough to cross. They had no survival gear and were not equipped to start a fire. After some discussion and against the advice of his partner, one of the technicians decided to swim across the channel. The narrowest part of the channel at that time was approximately 90 metres (300 feet) across. Their truck was parked on the far side of the channel next to the highway running alongside the river.

Being in good physical condition and a good swimmer, the technician felt confident he could cross the river to the vehicle and go for help. He removed his chest waders, draped them across his shoulder and began to swim. His partner watched him make excellent progress and decided to also attempt the swim. He later reported that the water was so cold that it hurt too much to continue the crossing, so he returned to the island to monitor the progress of his partner. The swimmer reached within 3 metres (10 feet) of the far shore, at which time he simply sank and subsequently drowned in about 1 metre (3 feet) of water. The river water temperature ranged between 0° and 1°C. The pathologist reported the incident as a "simple drowning". The author questioned a possible relationship between the drowning and the water temperature. The coroner, however, confirmed the pathologist's diagnosis that there was no evidence of hypothermia, and in fact the event was a "simple drowning caused by local cooling". [27]

Swimming failure is much more common than one would expect. It is not diagnosed because the investigator does not delve into the precise history of what happens during immersion. Death certification is simply "drowning". People do not understand that it is very dangerous to swim in cold, dense water. Swimming ability in warm water bears no relationship to swimming ability in cold water. The angle of attack increases, drag increases, stroke rate increases and stroke length decreases [33]. This all adds up to an exhausted human who becomes more vertical in the water and finally disappears beneath the waves. A cry for help expels 4 litres of air from the chest cavity and waving the arms removes the last vestige of buoyancy. This results in the survivor disappearing beneath the waves.

Unfortunately people do not realize that the temperature of water in lakes and rivers does not warm up until very late summer and even then rarely gets much higher than 15°C which is a very dangerous temperature to swim in for any length of time if not wearing any flotation equipment. Again sadly, drowning under such conditions is not an uncommon event.

The Dangers of Sudden Immersion in Cold Water

Divers locate bodies of missing N.S. teenagers (Toronto Globe & Mail, June 22, 2007)

The bodies of two teenage boys who went missing near a Halifax-area lake were pulled from the water yesterday. They were last seen Monday, when they were thought to have been using a section of dock as a raft at First Lake. They did not come home that evening. RCMP divers located both of them at one part of First Lake at about 8:15 pm, Corporal Joe Taplin, a spokesman for the local RCMP detachment, said late yesterday. The boys' bodies were found in about 10 metres of water near the west end of the lake. First lake is several kilometers long and about 700 metres at its widest point. Its depth varies between 3 and 10 metres for most of its 83 hectares but drops in the middle to 25 metres.

Stage 3: Hypothermia.

- Hypothermia by definition is a body core temperature of 35°C or lower. Death occurs from drowning sometime after 30 minutes in the water.

As the deep body temperature falls, humans lapse into unconsciousness. Death may occur in two ways – drowning through incapacitation, and cardiac arrest. Death from drowning will occur in 50% of lightly dressed individual, approximately one hour after immersion in water at 5°C, or two hours in water at 10°C, or in six hours or less at 15°C [10].

If the deep body temperature continues to fall, death occurs on average from cardiac arrest somewhere below a body core temperature of 24°C, however the lowest recorded survived deep body temperature in an accident victim is 13.7°C [8].

COMET (May 1973)

The COMET had 27 persons on board and sank in Block Island Sound, Rhode Island, about seven miles offshore, in 48°F [9°C] water. The COMET had no EPIRB and the only lifesaving apparatus was a 20-person buoyant apparatus. About 15 of the survivors held onto the buoyant apparatus at some point, including two of three who set out in a swamped dinghy to get to the buoyant apparatus. Six others were able to use an 8' X 10' piece of flotsam for partial support. Almost everyone on board had a lifejacket on when they abandoned ship. The two or three people who were not able to get a lifejacket were able to use either the buoyant apparatus or the flotsam. The first death occurred in the dinghy about ½ hour after the sinking. Deaths continued until rescuers happened on the scene 4 hours later. A total of 16 persons died in this time.

Survival predictions were made from experimental data and case histories from shipwrecks. The first classic curve was published by Molnar in 1946 [24]. Since then, there have been attempts to update these survival curves. The latest being by Tikuissis in 1997 [30]. These are all very commendable efforts, but probably are never going to be validated. Caution must be used in interpreting the results for Search and Rescue Organizations. For full details on the subject, please refer to Chapter 7 of “Essentials of Sea Survival” [13].

Stage 4: Post-rescue collapse or circum rescue collapse. Death occurs during or shortly after rescue. The basic cause of death is due to a collapse of blood pressure when the victim is pulled from the water.

Up to twenty percent of immersion deaths occur during extraction from the water, or within hours after rescue [10]. This was first noticed in 1875, by Reinke, a police surgeon in Hamburg. He recorded cases of sailors who had fallen into the canals and harbour and died within 24 hours of being rescued [9]. During the Second World War, the Germans and Allies noted that some of those were rescued alive, died shortly afterwards. Matthes [22] noted how ditched German aircrew who had been conscious in the water and aided in their own rescue, became unconscious and died shortly afterwards. McCance, et al. (1956) [23] found that seventeen percent of those shipwrecked survivors rescued from the water at 10°C or less died within hours of rescue. None of the people rescued from water above 20°C died.

If one understands the basic principles of the physiology of sudden immersion in cold water, then it becomes obvious that to prevent each stage at which drowning can occur, it is essential to develop a survival or immersion suit. It must be designed for the specific occupation that are at risk, i.e. ship abandonment, helicopter ditching, river pilots, etc., and most important it must be integrated with all the other equipment and tested under as extreme conditions as safely possible.

PEOPLE CONTINUE TO DROWN ESPECIALLY IN COLD WATER

This fact was exquisitely pointed out at the Drowning Conference held in Amsterdam in 2003 under the guidance of Dr. Bierens. A full conference proceedings and follow-on work was published in 2006 [3]. Additional data has been added with the very recent Canadian Red Cross publication “Drownings and Other Water-Related Injuries in Canada, 1991 – 2000. Module 2: Ice & Cold Water” by Barrs in 2006 [2]. Both documents are highly recommended for a more in depth review of the problem and general statistics.

Why do so many people still drown and should lifejacket/PFD be mandatory is discussed at length in the report by Smart Risk [14].

EVALUATING THE UNDERLYING CAUSE OF DROWNING

If the underlying cause of the drowning is not known, then how is it possible to prescribe good preventative measures? In cooperation with several agencies in the U.K., Oakley and Pethybridge [29] collected more specific data on drownings in the U.K. between 1991 and 1996. In 2005, Brooks, et al. [5], analysed both B.C. Fishermen’s drownings and in 2006, drownings reported to the Maritime Coastal Agency [6]. In both cases as described in a separate paper on drowning and the underlying causes, there was considerable detail concerning the physical/mechanical problems of the accident, and virtually nothing on the human factors side and the underlying cause of the drowning [4]. An accident investigation checklist is included in the other paper.

SUMMARY

Sudden unexpected immersion in cold water is potentially very dangerous. The water temperature of 15°C or below provokes the physiological reaction or cold shock and swimming failure. This likely contributes to over half of the deaths through drowning. Survival instructors and survival schools have done a good job on training for the protection of hypothermia, but must change the emphasis to the first two stages of immersion. Everyone who earns their living flying over or working on the water must be aware of this fact. Accident

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investigators must attempt to delve into the underlying cause of the drowning, and physicians, physiologists and operators of marine vessels and maritime helicopters must work together with the regulators and industry to improve our protective clothing and content of marine survival courses.

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Chapter 4 – Non-Freezing Cold Injuries

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Cold Injuries can be of the “Freezing” (Frostbite) or Non-Freezing Variety (Non-Freezing Cold Injury, NFCI).

Human tissue freezes at around -0.55°C and depending on the rate of freezing intracellular crystals may form (rapid cooling) causing direct mechanical disruption of the tissues. The more common slow cooling and freezing results in predominantly extracellular water crystallisation that increases plasma and interstitial fluid osmotic pressure. The resulting osmotic outflow of intracellular fluid raises intracellular osmotic pressure and can cause damage to capillary walls. This, along with the local reduction in plasma volume, causes oedema, reduced local blood flow and encourages capillary sludging. These changes can produce thrombosis and a gangrenous extremity. The risk of frostbite is low above air temperatures of -7°C , irrespective of wind speed, and becomes pronounced when ambient temperature is below -25°C , even at low wind speeds.

Non-Freezing Cold Injuries

NFCI is the term given to describe a condition that results from protracted exposure to low ambient thermal conditions, but in which freezing of tissues does not occur. Immobility, posture, dehydration, low fitness, inadequate nutrition, constricting footwear, fatigue, stress or anxiety, concurrent illness or injury can all increase the likelihood of NFCI.

The precise pathophysiology NFCI is poorly understood; the injury appears to be to the neuro-endothelio-muscular components of the walls of local blood vessels. Opinions vary as to whether the primary damage is vascular or neural in origin; or, whether the aetiology is primarily thermal, ischaemic, post-ischaemic reperfusion, or hypoxic in origin. The chronic sequelae of mild to moderate cold injury are: “cold sensitivity” (protracted cold vasoconstriction following a cold stimulus) and hyperhidrosis (local increased sweating), both of which accentuate local cooling and thus increase future risk of cold injury.



Frostbite



Non-Freezing Cold Injury

Figure 4-1 (Pictures courtesy of the Cold Injuries Clinic, Institute of Naval Medicine, UK).

TREATMENT

It is important to establish whether the dominant injury is freezing (FCI) or non-freezing (NFCI) in nature; this determines the preferred method of re-warming. In all cases shelter should be sought. Because casualties with cold injury are likely to be hypothermic they should be kept warm.

Frostbite

All cases of freezing injury should be thoroughly re-warmed by immersion of all the chilled part in stirred water at 38 – 42°C. A topical anti-bacterial should also be diluted into the water bath. Re-warming should be delayed if there is a chance that refreezing may occur.

Thawing a FCI can be intensely painful. Conventional and narcotic analgesics should be provided as necessary. Continuing treatment for FCI is a twice daily, 30-minute immersion of the affected part in a 38 – 42°C whirlpool bath containing an appropriate anti-bacterial.

NFCI

In contrast to those with FCI, patients with NFCI should have their affected extremities re-warmed slowly, by exposure to warm air alone, and must not be immersed in warm water. The early period after re-warming can be very painful in NFCI, even in those without any obvious tissue damage. Amitriptyline (10 – 75 mg in a single dose at night) is the drug of choice for the treatment of pain following NFCI, and should be given as soon as pain is felt. Amitriptyline may cause drowsiness and hypertension.

With either form of injury, once re-warmed, the affected extremities should be treated by exposure to air and early mobilisation. Smoking should be prohibited.

ASSESSING THE RISK OF COLD INJURIES

The cooling power of the environment is the result of air temperature and air movement or movement through air (e.g. as when skiing). These factors are combined into the Wind Chill Index, which illustrates the cooling effect of temperature and wind on bare skin and predicts the associated danger of cold injury.

Table 4-1: Wind Chill Chart – Effect of Increasing Wind Speed on Degree of Cooling at Different Ambient Temperatures

Ambient Temperature (°C)										
	4	-1	-7	-12	-18	-23	-29	-34	-40	-46
Wind Speed (mph)	Wind Chill (Equivalent) Temperature (°C)									
5	2	-4	-12	-15	-21	-26	-32	-37	-43	-48
10	-1	-9	-15	-23	-29	-37	-43	-51	-57	-62
15	-4	-12	-21	-29	-34	-43	-51	-57	-65	-73
20	-7	-15	-23	-32	-37	-46	-54	-62	-71	-79
25	-9	-18	-26	-34	-43	-51	-59	-68	-76	-84
30	-12	-18	-29	-34	-46	-54	-62	-71	-79	-87
35	-12	-21	-29	-37	-46	-54	-62	-73	-82	-90
40	-12	-21	-29	-37	-48	-57	-65	-73	-82	-90
	Less Danger			Increasing Danger. Flesh may freeze within a minute			Great Danger. Flesh may freeze within 30 seconds			

Equivalent temperature is the environmental temperature that would have the same effect on bare skin in the absence of any wind (equivalent cooling power).

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Chapter 5 – The Human Factors of Surviving a Helicopter Ditching

by

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INTRODUCTION

When a helicopter ditches or ‘flies in’ to water it commonly inverts and rapidly sinks. For the full text on the human factors related to escape and survival from a ditched helicopter please refer to the AGARDograph 305(E) by this author [2]. For all of you who attend our courses, whether aircrew, flight surgeons, SAR technicians or survival instructors, or one of the many naval trades, we must continue to be vigilant. There is no excuse for slacking off!

The Human Factors of Surviving a Helicopter Ditching

While Chief Medical Officer for the Air Force about 12 years ago, I had to defend the requirement to continue HUET and EBS training once the new Cormorant (EH 101) maritime helicopter was introduced. I nearly lost the battle because I was arguing with a senior ex-CF104 fighter pilot who was in charge of Air Force operation – an icon to most of the more junior officers around the conference table. He was of the fatuous opinion that with three engines, it would never ditch, moreover he could not be persuaded to accept the fact that the majority of aircraft accidents are caused by some form of human error and less likely due to mechanical problems. Eventually, commonsense prevailed and I won!! Read on – the key points and updated information on helicopter ditchings are outlined in this paper.

BASIC STATISTICS

If you end up in the water, 15% of crew and passengers generally do not get out!

The first reported helicopter ditching occurred on November 1st 1944. Second Lt. Jack Zimmerman had to dive down to extract Private Troche from the flooded R-4 Sikorsky helicopter. No one paid much attention to deaths in helicopter ditchings until 1971 when Glancy [17] reported that in 55% of ditchings the cause of death was drowning/lost at sea. In 1973, Rice and Greear [23] reported that in 40% of their case study, the cause of death was drowning/lost at sea. Then in 1978, Cunningham [15] reported on 234 helicopter mishaps between 1963 and 1975. His significant findings were that the survival rate was 66% without dunker training and 91.5% with dunker training.

The advent of the North Sea Oil in the mid-1970s caused a sudden increase of helicopter ditchings. This resulted in the UK Civil Aviation Authority HARP report in 1984 [12]. This concluded that flying in a helicopter over water was much more dangerous than flying in a fixed wing aircraft over water. This created the requirement to train crew and passengers in helicopter underwater escape trainers and the requirement for the use of realistic exits.

Survival rates in survivable helicopter accidents from the 1980s and 1990s are presented below in Table 5-1 and 5-2 for military mishaps and Table 5-3 for commercial helicopter mishaps. The survival rates are comparable and little change has occurred over the last 35 years.

Table 5-1: Survival Rates in Military Helicopter Ditchings

	No. of Ditchings	Between Years	Survival Rate
French (Giry, et al. 1992, [16])	11	1980 – 1991	65%
Canadian (Brooks 1988, [1])	17	1952 – 1987	76%
British Military (Reader 1990, [22])	94	1972 – 1988	84%
USN/Marines (Kinker, et al. 1998, [19])	53	1985 – 1997	74%

Table 5-2: US Navy / Marine Corps Overwater Survival Mishap Data 1985 – 1997
(Kinker, Loeslein, Contarino 1998 [19])

Day Mishaps	44	Survival Rate	88%
Night Mishaps	23	Survival Rate	53%
Total	67	Average	75%

Table 5-3: Civilian Helicopter Ditchings World Wide 1971 – 1992 (Clifford 1993 [14])

No. of Helicopters	98
No. of Crew and Passengers	902
No. of fatalities	338
Survival Rate	62.5%

New data was reported by Taber and McCabe in 2005 who reviewed worldwide helicopter ditchings between 1971 and 2005. There were 511 accidents, 2478 people were involved and the survival rate was 66%. Of the 1643 people who survived at least 477 (30%) received some form of injury. [24]

The OGP study [13] in 2006 reconfirms the fact that flying in a helicopter is more dangerous than flying in a fixed wing aircraft. It also reconfirms the necessity to continue helicopter underwater escape training. The average offshore fatal occupant rate in 2004 was zero for the North Sea and 4.0 for the Gulf of Mexico.

The fact is that if you ditch in a helicopter there is likely a 15% chance that you will not survive.

DOES THIS SOUND FAMILIAR?

*“The crew member, I believe helped get the door open. I jumped out as soon as I could get my belt off, but my husband was trapped inside. By this time the helicopter had turned me upside down and he was covered in debris, struggling, water up to his mouth and he was straining to keep his head above water. I was about to go back in after him when he was able to get his belt undone and swim free. And I **do mean swim**. The helicopter was going down.”*

The most recent Canadian Military helicopter mishap happened the night of July 12, 2006, in the Atlantic Ocean, just offshore of Canso, Nova Scotia, Canada. Three of the seven occupants did not survive. This is the Directorate’s of Flight Safety for the Canadian Air Force accident report:

“The accident involved a Cormorant Search and Rescue helicopter with a crew of seven. The crew had assumed SAR standby duties and was authorized to conduct a training mission to practice night boat hoists from the fishing vessel Four Sisters No.1, a member of the Canadian Coast Guard Auxiliary. The crew consisted of three pilots (left seat, right seat, and jump seat), two flight

The Human Factors of Surviving a Helicopter Ditching

engineers and two SAR technicians. It was a brand new aircraft, with some new aircrew and fresh crew under training. [A recipe for caution]... The remainder of the crew occupied the cabin area. They comprised of a Flight Engineer (FE), a Flight Engineer under training (FEUT), a SAR Tech Team Lead (SAR Tech TL) and a SAR Tech Team Member (SAR Tech TM).

The aircraft departed Port Hawkesbury [Nova Scotia] just before midnight on 12 July 2006 to rendezvous with the Four Sisters No. 1 at approximately 2 nautical miles (NM) north of Canso, NS on Chebucto Bay. The weather was clear, visibility was good and the water was calm. After locating the ship, the helicopter used the “Over Water Transition Down” procedure and proceeded to the “rest” position, which is 100 ft above the water and a safe distance from the ship just off the hoisting position from which the crew would start the boat hoisting procedure.

At this point, the helicopter descended to 60 feet and the AC directed the flying pilot to go-around. The pilot acknowledged the go-around command and initiated the go-around procedure. During the overshoot attempt, the helicopter entered a nose-low attitude and seconds later the aircraft impacted the water at approx 30 to 50 knots in an 18 degree nose-down attitude with maximum torque being developed by the main rotor. Upon water impact, the front portion of the aircraft was destroyed while the cabin area aft of the forward part of the cargo door remained relatively intact; the aircraft immediately filled with water and rolled inverted. The crew of Four Sisters No. 1 made a “Mayday” call at approximately 0030L hrs 13 July 2006. The aircraft sustained “A” category damage.

The three pilots and the SAR Tech TL were injured, but survived the crash. The two flight engineers and the SAR Tech TM were unable to egress the aircraft and did not survive.

No pertinent technical deficiencies have been discovered to date and the investigation is focusing on environmental and human factors”.

[Courtesy of the Canadian Air Force Flight Safety Office, Ottawa]
http://www.airforce.forces.gc.ca/dfs/docs/Fti/CH149914_e.asp

SO WHAT IS THE PROBLEM?

1) Absence of documentation of any underwater escape training.

Does that mean all our effort has been wasted over the last thirty years? No, it does not. The first observation is that neither the CAA, FAA, JAA nor any other accident investigation bureau ask whether the survivors had HUET training or Shallow Water Egress Trainer (SWET), etc., or not. So we only have anecdotal evidence, survivor’s testimony and Cunningham’s original study to demonstrate the positive effect of training. Our suspicions are that those who have drowned have either had no training or very simple SWET chair training. The latter in our opinion is unsatisfactory for teaching people to escape from an aisle seat, when an exit is blocked or when the potential survivor has to queue to wait for an exit. The SWET chair is good for basic familiarization and for teaching students to use Emergency Breathing Systems (EBS) – but obtaining certification to fly in a helicopter over water having been trained in a SWET chair is leading crew and passengers into a false sense of security (see later in the requirement for training).

2) Universal use of supplemental air has not been achieved yet.

A second observation concerning the apparent non-reduction in fatalities is that many people drown due to the inability to breath hold in cold water (see later). Supplementary air supplies were recommended 20 years ago. Several NATO countries have introduced EBS, and they are now standard issue to the US Navy and Marines

– but only the North Sea and Norwegian Sea Offshore oil and gas operators have provided devices to their passengers (see EBS lecture). They are not used in the Gulf of Mexico where there is the greatest loss of life!

3) Revision of the Human Factors involved in making a safe escape from a rapidly inverted and sinking helicopter.

Let us very quickly review the hazards facing the crew and passengers when they hear the command ‘Ditching, ditching, ditching’.

- It commonly occurs during the critical phases of flight. So it is essential to be alert, mentally and physically prepared during take-off, approach, missed approach, transit, and hover.
- On strap in, it is vital you physically check that you are strapped in correctly, you have your life jacket and immersion suit fitted and secured correctly and that you do a physical and mental check on crash positioning and the procedures to be taken to locate the exit, the jettison lever (if fitted), releasing the seat harness, and the technique to navigate your way out of the inverted, flooded cabin.

The Tiger helicopter accident off the Cormorant Alpha in March 1992 is a classic example of this advice being ignored – 47 seconds in flight, 11 killed! On investigation, several people who drowned did not have their survival suits zipped up correctly. They likely drowned from cold shock. Another person did not strap in correctly and was drowned because he was snagged on his mike cord in the seat head rest. Unfortunately, when some of the Boards of Inquiry are read in retrospect one sees the following typical statements:

New York Helicopter Flight #2434 (AS 360) 4-26-83

- ♦ Question – Of what value were the emergency instructions to you?
- ♦ Answer #1 Passenger – “Absolutely no value. The only thing I knew from the tape was where the door was. It was a terrible ordeal, we were completely on our own to survive as best we could.”
- ♦ Answer #2 Passenger – “Zilch!”

- Drowning is a leading cause of death in helicopter accidents. Cunningham (1978) found that in his study of 196 deaths, 37 drowned even though they were not injured [15]. Drowning was also blamed for 56% of civilian and 80% of military deaths in Clifford’s 1993 report to the Civil Aviation Authority [14].
- Accidents occur very rapidly with little warning. So again it is worth repeating from above, that it is very important that you have mentally practiced all your ditching skills at strap-in, made sure your suit is correctly zipped up, that you know how to locate your exit and secondary exit and find the inflation toggle on your lifejacket, etc.

Hawaiian Helicopters off Molokai 7.14.94

- ♦ Question – What actions did you take before impact?
- ♦ Answer – There were none to take – it happened too fast.

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- A poor crash position will cause your arms and legs to flail, they will be injured and it is unlikely that you will be able to unstrap. The result is that you will drown. You need a good crash position to:
 - a) Reduce strike envelope;
 - b) Stabilization in seat to reduce disorientation;
 - c) Minimize body profile to intruding water; and
 - d) Smaller human target to debris.
- If the survivors have not stowed all their equipment correctly, there is a good chance that in the violence of the ditching, they may be injured by the flying debris to such a degree that they drown before making an escape.
- If the survivors have not paid attention to strapping in correctly, trouble awaits them. They may not be able to release the harness underwater because it is tucked under a bulky immersion suit, and/or the tail of the strap may float across the open end of the lap belt release mechanism making it impossible to find the edge of the catch. There are many testimonies from survivors about this problem. Here is a typical example:

New York Helicopter Flight #2434 (AS360) 4-26-83.

- ♦ Question – Did you have difficulty unbuckling your seat belt?
- ♦ Answer – It seemed to be jammed. It wouldn't release. About this time, I was getting concerned because we were sinking fast and none of us could get our seat belts unfastened.

- Helicopters don't float well (Table 5-4). Expect intruding water. It will be terrifying. One pilot described it like being hit in the chest with a fire hose. It will cause panic, hyperventilation, disorientation, reduced breath holding, cardiac arrhythmias, and drowning.

Table 5-4: Helicopters Do Not Float Well (1980 – 1995)

- ♦ Percentage that sank immediately after ditching
 - Canadian Military.....26% (5)
 - British Military.....50% (47)
 - French Military.....72% (10)
 - British Commercial (CAA).....37% (37)
 - US (FAA) Commercial.....55% (42)

- Then expect to be inverted, and the more rapid the inversion, the greater the likelihood of injury and death (Table 5-5, 5-6 and 5-7).

Table 5-5: Impact Scenario and Number of Fatalities (Chen 1993 [9])

	No. of occupants per overall injury level			Total on Board	% of fatally/ seriously injured
	Fatal	Serious	Minor		
Immediate overturn	23	20	32	142	30.3%
Delayed overturn	1	3	3	44	9.1%

Table 5-6: Helicopters Commonly Invert while Sinking or Floating at the Surface (1972 – 1994)

♦ RAF study	100% (4 cases)
♦ RN study	47% (25 cases)
♦ FAA	66% (51 cases)
♦ CAA	50% (49 cases)

Table 5-7: Helicopter Ditching: Time of Crash and Survivability – Floated vs. Sinking (Taber and McCabe 2005 [24])

No. of ditching reports	511
No. of known position of helo after water entry	382
No. which stayed upright floating	56 (15%)
No. which inverted	326 (85%)
Of the 326 that inverted, No. that capsized immediately	250 (69%)

- This sudden inversion means that not only do the survivors have to escape from being completely submerged, but they have to navigate their way out upside down. This is guaranteed to disorientate everyone on board so adding to the terrible confusion. For example, we mocked up our Helicopter Underwater Escape Trainer to represent an 18 passenger Super Puma. We then loaded it with Survival Systems Ltd. instructors or Canadian Navy Clearance divers. All wore an emergency breathing system. It took 92 seconds for the last person to clear the cabin and arrive back at the surface. Half of the people had to use their EBS. [6]
- Survival statistics for night accidents are much worse than daylight accidents: there was an 82% survival rate for the day mishaps and only 58% for the night mishaps for US Navy / Marine Corps survival data of 24 survivable over water mishaps. [19] The survivor must be able to navigate his/her way to an exit in the darkness as exit lighting is only of minor help. Most of the journey will be done by feel after it has been practiced in the helicopter underwater escape trainer.
- It is most important to receive frequent refresher training. At a minimum at least every 3 years and ideally annually. The SWET chair is not satisfactory because: a) it does not disorientate everyone; and

The Human Factors of Surviving a Helicopter Ditching

- b) does not provide the student the ability to practice crossing one seat directly to a window, or the aisle in case of a blocked exit on the side of the helicopter where the passenger would be sitting. [11]
- Don't forget "cold shock" if the water is below 15°C. During all of the sequence of steps described so far, the survivors are still holding their breath. Hayward has beautifully demonstrated that breath holding ability is reduced by 25 – 50% in water below 15°C [18]. In 0°C water, most people can only breath hold for 12 – 17 seconds to make their escape. Cheung, et al. [10] conducted a trial on 228 offshore oil workers to measure their breath holding ability. Figure 1 below illustrates their breath-holding ability in 24°C water. The water in the North Sea and around the East Coast of Canada rarely warms up to 17°C, and this is only for a few weeks in summer!

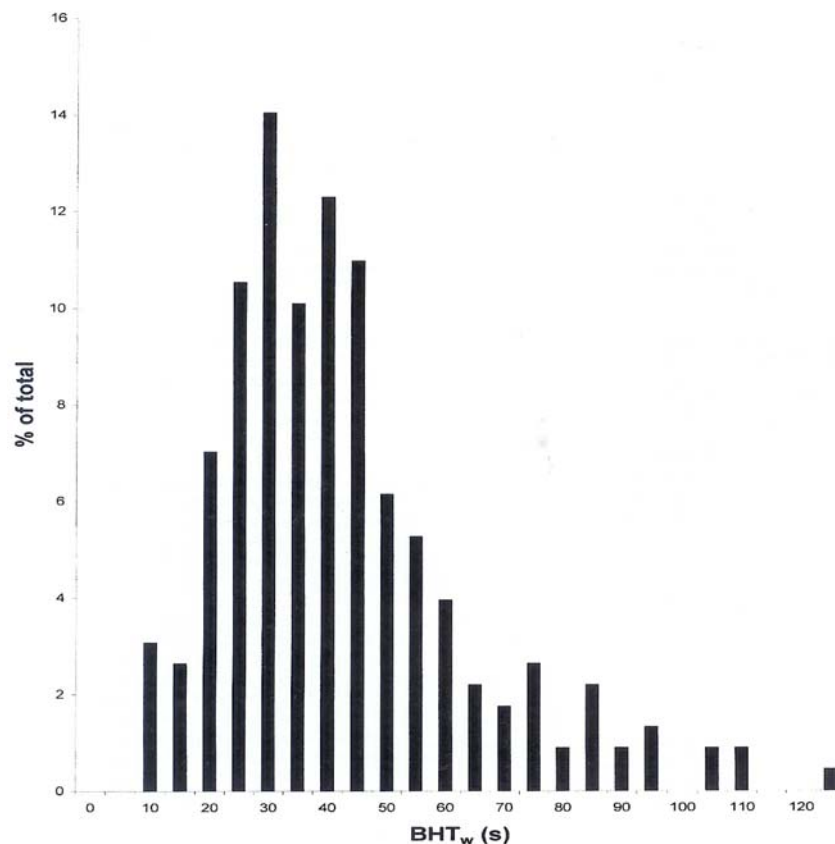


Figure 5-1: A Histogram of BHT Underwater in 228 Subjects (Cheung, et al. 2001).

- Some form of supplementary air – a rebreather or compressed air supply is required to assist those who cannot hold their breath and who would otherwise drown. The pros and cons of each system are discussed in a separate lecture.
- In 1997, Brooks and Bohemier [4] noted that there were at least 23 types of jettison mechanisms in the 35 maritime helicopters examined. Since then there have been at least three more types added to the inventory! So it is important to be trained in the one that you are going to use. Some are placed in quite radically different positions on the door or window, are different in the direction in which the

lever operates, and in the technique for pushing the window out or pulling the window in, etc. Helicopter manufacturers have failed to standardize the exits and ignored this vast diversity in exit design and mechanism over the last 20 years! You better get yourselves trained!

- In 1994, Brooks, et al. [5] conducted an experiment to identify the problem with the underwater location and operation of helicopter emergency exit mechanisms. They advised that all training should have exits fitted to their HUETs. To some degree this has happened, but the number of immersions has not been standardized yet. Some companies and military organizations stubbornly continue to use SWET chairs or HUETs without exits. In 1999, Mills and Muir [21] stated that the minimum competency level of a trainee in HUET should be to “demonstrate the ability, underwater in an inverted HUET, to release a representative seat restraint and escape exit release mechanism, and effect an escape unaided.” To meet this competency level, Mills and Muir found that the trainee had to experience at least one inversion with the exit in. A recent independent study was conducted by Dalhousie University in 2006 reconfirmed these findings [20]. Subjects were divided into three groups with varied training in the HUET: group 1 performed 2 trials with no exits present; group 2 performed 3 trials, including one requiring the exit to be jettisoned; and group 3 performed a total of 6 trials, 4 of which had the exit present. They were tested six months later in one trial with the exit present and Table 5-8 below shows that the trainees benefited greatly from just one practice trial (group 2), and even more from additional practice trials (group 3) in the test configuration.

Table 5-8: Subjects Performance Six Months after Being Trained

Group	Pass (no assistance needed) (Count / % of Group)	Fail (needed assistance) (Count / % of Group)	Total
1	28 (54%)	24 (46%)	52
2	38 (81%)	9 (19%)	47
3	52 (96%)	2 (4%)	54
Total	118 (77.12%)	35 (22.88%)	153

So it is quite clear that a HUET fitted with the exits and allowing trainee’s several practice trials is required to ensure retention and adequate performance of these skills.

- Do not forget that even if you know how the exits work and the location of the mechanisms, loss of gravitational references, increased buoyancy in the immersion suits, poor depth perception underwater, and the underwater magnification effects makes the levers look much closer than they really are. This all adds up to extra problems with making a successful escape.

The Human Factors of Surviving a Helicopter Ditching

You do not want to read this in your next Board of Inquiry or personally experience such an event.

“The crash was so unexpected. There was only a loud “pop” and down we went. I only had one thought – get out of here. I was mad. Mad because nothing worked as it should. Mad because we had no instructions and there were no flotation devices. Terrified because my husband was trapped and then concerned because we had a good distance to cover and he cannot swim well. The water was like ice and I was shaking uncontrollably. Terrified because I was certain that the man next to us had drowned. He didn’t have a chance if his seat belt had jammed as ours did. These were my thoughts at the time it was happening.”

- After making your escape, beware, you are still not home and dry! When you get to the surface, your lifejacket may not inflate if it hasn’t been maintained correctly. Equally, the life raft may have been punctured due to the fact that it has blown up against the side of the helicopter after you landed safely on the water. You can escape from the helicopter into the life raft by the dry method (dry shod) or wet method (swim away). There are problems with both methods and you must review the author’s paper “The Abysmal Performance of the life raft” [3] included in the “Lifeboats and Life rafts” paper of this series. Preferred methods are dry shod and on the windward side, but there simply may not be enough time to do this and the survivors may have to go out however they can before the helicopter sinks. [7, 8]
- Do not believe the life rafts manufacturers who say that it is easy to board the life raft from the open ocean. It may be relatively easy to get into it in a warm swimming pool where most training takes place – but, in fact, it is quite difficult particularly when restricted by a bulky immersion suit – which incidentally may be flooded with water if it leaks, or was incorrectly zipped up, with a life jacket and cold hands. Training in the pool again leads the crew and passengers into a false sense of security. Training should also be done in open water. A lot of work still needs to be done on the design of life rafts for ditched helicopters. So remember, it is much more difficult to get into the life raft in the open ocean compared to the pool exercise you completed on your course.

SUMMARY

Flying in a helicopter over water is potentially very dangerous. In a survivable ditching potentially 15% of crew and passengers will drown in a daylight accident. This may increase to at least 50% in a night time accident. Be protected properly with a life jacket and survival suit. Be trained in a reputable underwater escape trainer fitted with exits and be mentally and physically prepared at all times. Strap in correctly, stow your equipment securely, be particularly alert during the critical phases of flight, assume the crash position on the command “ditching, ditching, ditching,” follow the standard procedures for locating and jettisoning your exit, and you will end up safely ashore.

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The Human Factors of Surviving a Helicopter Ditching

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Chapter 6 – Knowledge of Human Behavior Under Stress and Sleep Deprivation will Enable You to Prevent Accidents and Death

by

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INTRODUCTION

Estonia

“Some people were beyond reach [couldn’t communicate with them] and did not react when other passengers tried to guide them, not even when they used force or shouted at them, some were just sitting in corners, incapable of doing anything.” (Leach, 2005)

If you wish to understand why this happened, please read on.

I recently spoke at a very well attended OGP meeting of the marine and offshore oil industry in Cairo, Egypt. The principle topic was how to develop strategies to prevent accidents, injury, and death. In other words, how to make the work place a great deal safer. Yet, apart from myself and a colleague from Aberdeen, there were only a few other attendees that I met who had any knowledge of human engineering, human physiology or had an applied psychology background; all these disciplines being so important in analysing the causes of accidents and incidents [7, 8]. No one was aware of all the pioneering work done by Professor Reason on human error and Professor Leach on performance under stress [3, 4, 5]. The fact that struck me most was that these attendees were operators, regulators and human resource personnel.

Most of the decisions made at this meeting were designed to close the loop holes and prevent possible short cuts in the procedures that cause accidents. They added yet another layer of rules and regulations to an already highly regulated environment. This was in complete disregard as to how the human processes information under normal or stressful situations. The aviation industry was represented as well. They demonstrated that they had already made some progress with addressing the human factors issue and its relationship to accidents and incidents. In my opinion, the marine and offshore oil industries were way behind. I hope this paper starts to get you back on track.

The objective then is to persuade you to:

- 1) Understand the problem with shift work and examine your shift work policies and practices.
- 2) Introduce good human engineering practices into your operation.
- 3) Use human engineers in all aspects of your business from initial planning all the way through to full scale operations.
- 4) Use human engineers in all your accident / incident / near miss investigations, and pay attention to what they conclude and advise.
- 5) Identify good applied psychology and applied physiology scientists and occupational medicine physicians that can give you additional advice.
- 6) Teach teamwork in emergency procedures. When a problem occurs, there is too much information for a single human to analyse and react **correctly**. The O.I.M. of the rig, the pilot of a 777, and the Captain of a Cruise ship cannot deal with all the problems him/herself. A lot must be delegated and a bond of trust must be developed within the team.
- 7) Don’t fire the guy who screwed up – it may not really be his/her fault, but an endemic problem of the system. Listen to him or her because this may be the only chance you have of learning about what really happened. If the work policy is to fire anyone who commits a slip or an error, you will never discover the root cause, and the problem will re-occur.

In February 2006, over 1,000 people died in the Al Salam Boccaccio '98 ferry accident in the Red Sea. Egypt's Minister of Transport vowed that 'whoever was responsible won't go unpunished whatever post they hold'. When I ask you the audience whether you think this a splendid idea, my bet is that the majority will agree. The objective of this paper is to politely suggest this may not be the best approach if you wish to prevent a repeat of such an accident!

What authority do I have to be so cavalier to suggest a different approach? First, as mentioned above, we now have superb scientific documentation by Reason and Leach to explain why people behave as they do in different normal and stressful situations. I will quote this excellent documentation freely throughout the presentation. Second, I have been a working physician, accident investigator, and scientist for 41 years now. Therefore, as one old master mariner said, "Brooks, you have walked the walk". I will just give you three typical occupational medicine nightmares that I unfortunately experienced on a regular basis:

First, I spent four years in two brand new Royal Navy nuclear submarines in the 1960s, and it amazed me to see how the reactor panel operators coped with the illogical way in which the knobs, dials and switches were all set up, and the rigmarole of actions they needed to carry out when the reactor scrambled. Not only that, but there were persistent steam leaks in the engine room which caused a temperature rise to 35°C and 100% relative humidity! Four hour watches were reduced to 1 hour. How we managed not to have an accident, I will never know! The basic problem was complete ignorance of how the human operates equipment and stubborn denial by Senior Management and marine architects that there was a problem.

Second, I was asked to consult on a new NATO Communication Centre. Once commissioned, the absenteeism rose dramatically and the number of staff who reported on sick parade also rose proportionally. The Admiral asked "How can this be! It's a brand new building!" Why? Very simple: no human engineer was consulted on how to design the interior of the building; staff were required to conduct 12-hour shifts; the seating was uncomfortable and unadjustable; the lighting and flicker from the fluorescent tubes was causing headaches; the CRT's were all placed in fixed positions and not adjustable either; the reflection on the screens from the flickering tubes was dreadful; and the noise from the crypto machines clattering away 24 hours a day was enough to drive anyone insane.

Third, when I moved to Canada I used to fly in the Sea King helicopter to conduct Search and Rescue missions. The Buaer lifejacket that I wore was outdated (introduced into the USN in 1946), and did not provide enough buoyancy to keep the nose and mouth out of the water if you were incapacitated. There had even been one accident where a pilot had been seriously injured due to the poor performance of the lifejacket. However, the Board of Inquiry dealt with all the machinery aspects of the aircraft accident, but as far as I could ascertain, had ignored the pure human side of the accident. Again, through ignorance or denial, they failed to ask why the pilot was injured due to the poor performance of the lifejacket. Fortunately, I was later able to design a new and improved lifejacket which replaced the old one, **mind you this took 8 years to achieve!**

So I have given you three examples from land, sea, and air where consultation with human engineers and physicians with occupational medical expertise ahead of time would have prevented absenteeism, chronic illness, unnecessary stress, injury accidents, very expensive refits and replacements, and worst of all death.

Consultation with human engineers and occupational medicine physicians ahead of time will prevent absenteeism, chronic illness, unnecessary stress, injury, accidents, very expensive refits and replacements, and death.

In the next 45 minutes, I am going to briefly explain how humans *process* information in their brains under normal conditions, how humans *process* information under stressful conditions, and last, how humans *behave* under stressful conditions. To amplify on this you must buy and read three books: J.T. Reason's Human Error; J.T. Reason's Managing the Risks of Organizational Accidents; and J. Leach's Survival Psychology. These should be in the cabin of every ship's captain and O.I.M. in the office of every helicopter operations manager, and should be mandatory reading for all Human Resource Managers, Marine and Aviation accident investigators and all survival instructors.

HOW DO WE NORMALLY PROCESS INFORMATION?

The intention is not to make you into instant psychologists, but to explain not only how we manage to function very successfully in our whirlwind environment, but also explain our limitations. Once we expect people to operate outside their limitations, or design regular and emergency (survival) equipment that is not **very** easy to understand and operate particularly under stressful conditions, that is precisely when accidents, injuries, and death occur.

The Normal Reflex Arc

This is the fundamental automatic response that we all possess to protect us from extreme danger. When you put your hand on something extremely hot or cold, the temperature and pain receptors instantly sense this. They transmit the signal through a sensory afferent nerve to the spinal cord in the dorsal root ganglion. It is immediately transferred across the spinal cord by interneurons to the efferent motor nerve. Then the motor nerve sends the signal to the local muscle which produces a rapid contraction. This causes the hand to withdraw from the hot or cold item. The whole sequence of events occurs in a split second. Only after the reflex has occurred is a signal sent to the brain that says 'Wow! That was very hot or very cold or extremely painful.'

This explains why under extreme circumstances some people respond to the threat (correctly or incorrectly) hardly even knowing what they have done until after they have done it. The common expression used in the English language for this is the "knee jerk" reaction (Figure 6-1 below).

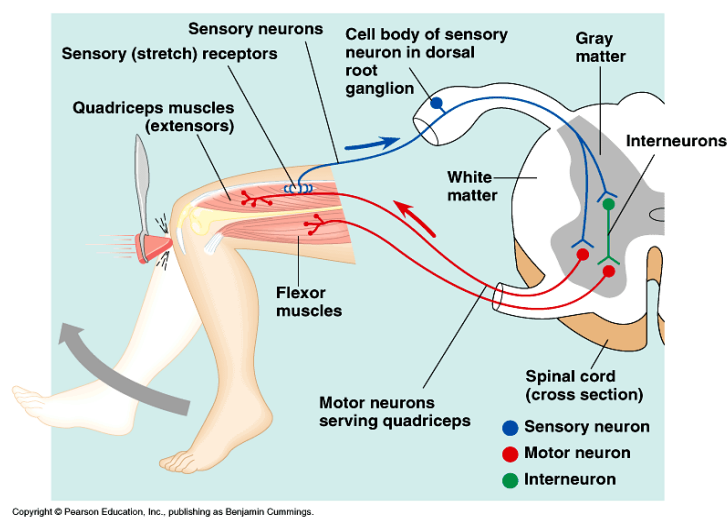


Figure 6-1: The "Knee Jerk" Reaction (Courtesy of Pearson Education Inc.)

Normal Human Information Processing

The reflex arc has been inherited from the lower animal kingdom. As man developed, the capability of our brain also developed. What separates us off from other species is that we can process information now, rather than just rely on simple reflex arcs to cope with daily problems.

We have evolved so that all the sensations such as vision, hearing, taste, smell, hot, cold, vibration, pain and posture are constantly being fed into a sensory register or *input selector* of our brain by ‘telephone lines’. Here the information is encoded and put into a central processing unit (*short-term* or *working memory*). What is most important to know is that **the number of ‘telephone lines’ to the central processing unit is very limited**, and for your operations you should consider it to be only one line. This makes the processing system a single channel analyser. This explains why people will swear that they did not hear an alarm sound when they were completely immersed in some other complex task, even if the alarm was very loud. They will be correct because their telephone line was busy processing the other information and could not process any more information. This is one of the primary reasons why under emergency conditions, no single person can deal with a complex problem on their own. In the usual annual round of cost cutting, the temptation is to remote many aspects of the operation to reduce staff. Beware of this, the level at which the alarms are set, may not leave the skeleton staff enough time to process the information, before the catastrophe.

The human brain uses a sensory register to process all the information received by the sensory organs (eyes, ears, nose, skin, etc.) – but there is essentially only one telephone line to send this to the central processing unit, the short-term or working memory. Due to this limitation, the human can only process one complex task at a time. Therefore, vital information will not be processed if other colleagues do not share the task components. This is the prime reason for working as a team.

Returning to the Central Processing unit, the information is entered into the *short-term* or *working memory*. Here, it is compared in the thought decision making process section with other information and experiences which may already be in *long-term memory*. The parcels of information that are learned are then stored and available for comparison to any following information entered into working memory. These parcels of information are called schemas. However, if no schema is present, working memory alone is used, which is a very time consuming process, and has a limit on how much information it can hold and process in a given time. Then the schema is developed and a response is generated. This response is then stored in *long-term memory* for a more rapid future response. In a nutshell, as we grow up, each of these life experiences (benign and dangerous) are entered into our long-term memory as separate schema. Most important, if there is no rehearsal of these schemas between working and long-term memory, then the fine detail in the schema fades and it is not remembered for later use when it may be life-saving. That is why we do refresher training. This process of normal, non-stressful decision making takes about 0.1sec to happen. Remember this too, it is also very important. This illustrated human information processing chart in Figure 6-2 is quite complex, and for practical purposes and for teaching your staff how to understand what is happening, I have modified it and made this much simpler to understand. For the academics in the audience please forgive me.

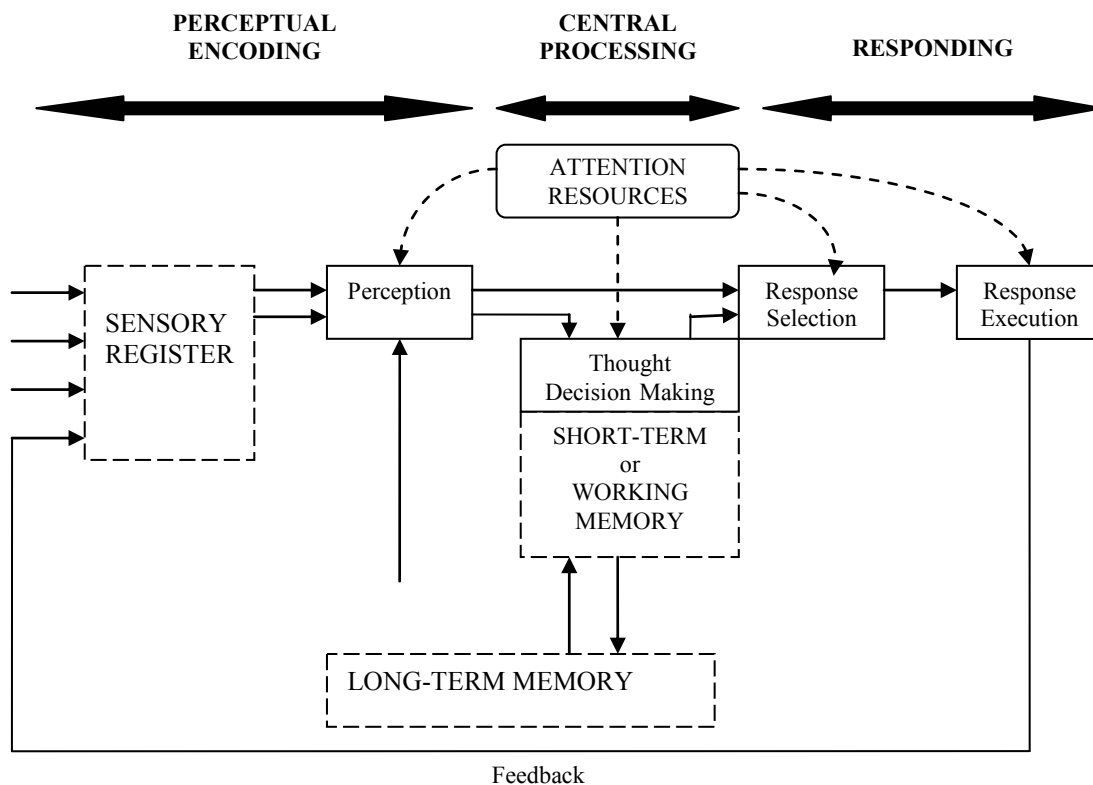


Figure 6-2: A Model of Human Information Processing (Adapted from Wickens, Lee, Liu and Becker 2004 [9]).

Every second of the day, information is entered into our short-term or working memory, compared to previous experience, stored in the long-term memory, and an appropriate response is made.

These parcels of information called schemas allow us to make rapid responses in approximately 0.1 seconds on all our daily life decisions (opening the front door, changing gear in the car, etc.).

Without repetition, these schemas fade from long-term memory, and this is the very reason for: a) developing as many schemas for emergency procedures as possible (repeated practical exercises); and b) to prevent the skills from fading out of long-term memory and needing to be relearned (which takes 100 times longer to process).

Simplified Human Processing Diagram

In Figure 6-3 you can see I have reduced the flow chart to an input selector, a single channel analyser, a short-term or working memory, a long-term memory, a rehearsal mechanism, and the response. I have also added the Supervisory Attentional System (SAS) (see next paragraph). This is basically all you need to know.

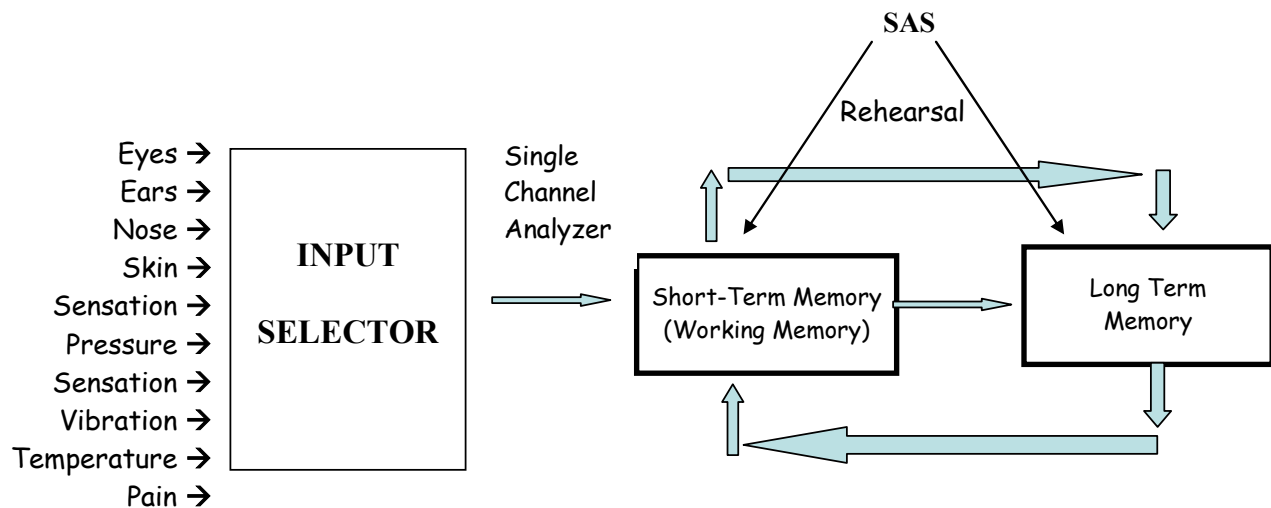


Figure 6-3: A Simple Diagram to Show How Human Information is Processed.

Control of Complex Unusual Situations that Don't Fit into Schemas Already Learned and Practiced

The control of complex tasks is done by the Supervisory Attentional System (SAS) in the cerebral cortex of the brain. Its functions are:

- Planning and decision making;
- Error correction and trouble shooting;
- Solving novel or poorly understood learned sequence of actions; and
- Solving problems in technically difficult or dangerous environments requiring the overcoming of a strong habitual response.

As you can see, this is precisely the system your brain uses in all your daily decision making, more than routine operations, on an oil rig, the bridge and engine room of a ship, and the cockpit of an aircraft. It is also in every other walk of life – doctors in the emergency room, etc. However, and this is the most important lesson to note: the SAS is very vulnerable to overload if events unfurl too quickly and it can be easily disabled. It is a very poor responder (which appears odd – one would think for such a critical system, it would be very quick); it takes over 100 times as long to process a problem compared to the normal system. Therefore, response times take about 8 – 10 seconds, which may not be fast enough when you are dealing with a serious fire, a ballast problem, an in-flight complex approach in poor weather, etc. [5, 7]

The Supervisory Attentional System (SAS) takes care of all the critical decision making in complex situations. It is slow and takes 100 times longer to process information compared to information stored as normal schemas. It can be quickly saturated with information and disabled as a result. Hence, this is the most important reason to have people working as a team when a complex difficult and potentially dangerous situation occurs.

Human Behavior Under Stress

So now you know how the brain processes information. Next, you must understand how people behave when they are under stress. Stress effects performance of everyone, from workers on the shop floor all the way through to senior personnel managing the operation. The essential textbook that must be read by all of you is Professor John Leach's book called "Survival Psychology". [3]

WHY DO PEOPLE APPEAR TO BEHAVE SO ODDLY?

Can you explain the answers to these three questions?

Question 1: In the 1994 Estonia marine accident, why would people still be pestering the Purser's Office to exchange money at 01:00 when the ship had a 30° list and was obviously sinking in the Baltic Sea gale?

Question 2: In the King's Cross Tube Station Fire in November 1987, Judith Dingley saw the smoking escalator and tried to prevent people going down it: "I stood there with my arms stretched out like Jesus on the cross saying 'don't go up there, there is smoke.' But nobody stopped" [3]. Why do you think people did this?

Question 3: In the very rapid sinking of a tug in the Gulf of St Lawrence in mid Winter, why did two very experienced Master Mariners pace backwards and forwards from one wing of the bridge to the other and doing nothing as the water rose above their knees, and simply drown, whereas a much younger and less experienced deck hand standing right next to them quickly put on his survival suit and survived?

Leach uses an easy to follow dynamic model of an accident and describes the wide spectrum of behavior during each developing stage of the accident. This consists of 5 phases:

- 1) Pre-impact phase – threat and warning stage;
- 2) Impact phase;
- 3) Recoil phase;
- 4) Rescue phase; and
- 5) Post-trauma phase.

Armed with this information you will be able to very simply analyse exactly what happened in many national and international disasters, and most important in incidents and accidents in your own departments. Irrespective of the type of catastrophe or extreme predicament (i.e. earthquake, fire, shipwreck, aircraft accident), humans appear to follow the same pattern of responses.

PRE-IMPACT PHASE – THE THREAT

In this phase, even though there is a known threat, the usual behavior is inactivity, self-denial, a sense of immunity "it will never happen to me". These are all **very normal** responses to be expected. Why does it happen? Planning and preparation costs money and uses human resources – there is always something more important to spend the money on, it is also inconvenient and generally the population is apathetic about supporting the project when the threat seems so far away (just think about examples like nuclear war, the Aberfan coal tip accident, living under a volcano, the chronic problem of deaths from failures of davits in TEMPSC launches). Some people even think that planning for a disaster may even precipitate one! – "Don't even think about it!"

Here are two perfect examples of the same threat, yet very little action has been taken to resolve the problem. Are you prepared for it and are you trained appropriately?

CHIRP Report No.200140

“During a routine drill the brake lever arm dropped to its stops and there was no braking effect whatsoever. The boat ran down to the water and was dragged alongside at 16 knots. The painter was ripped free, the forward falls torn away, and the boat was struck by the propeller... This is another unfortunate case of the failure of a lifesaving device now more noted for mechanical problems, injuries and deaths, rather than lifesaving.”
(Safety at Sea May 2006)

... and in the July edition of Safety at Sea:

Fatal Accident at Malta Freeport

“One crewman died and two others were injured during a lifeboat aboard the general cargo ship *Bluemarlin* at Malta’s Freeport on 16 June, just a few hours after the Madeira-registered ship had arrived at the port. The three men were hurt when a lifeboat fell from its supports into the sea.”
(Safety at Sea July 2006)

Attention has been paid to the self denial problem, and in the June 2007 Safety at Sea Journal, 15 new ferries are going to be commissioned by Indonesia as a result of the loss of confidence in their ferry system.

Indonesia Ferry Accident

“480 fatalities occurred in June 2000 off North Maluku; more than 20 in the same area the following year; about 150 feared dead on the sinking of the *Digul* in July 2005; another loss in February 2006 near Kupang; at least 350 fatalities in the Senopati Nusantara disaster on 30 December last year; and, more than 50 killed on *Levina I* on 22 February 2007.”
(Safety at Sea June 2007)

PROFESSOR REASON’S SWISS CHEESE MODEL OF AN ACCIDENT

I am going to introduce Professor Reason’s Swiss Cheese model to you [7]. This interfaces perfectly with Professor Leach’s model of an accident at the pre-impact phase. This concept is very useful for identifying where the breakdown in equipment or supervision occurs. For simplicity I am going to use it to demonstrate a failure in supervision that can occur at different levels of supervision from the shop floor all the way up to the

senior management. Each level is represented as a layer of Swiss Cheese (Figure 6-4). These layers are in constant lateral motion. Theoretically, each layer of supervision can stop an unsafe act, and ultimately prevent an accident. If the act is not caught at the first layer of the cheese and passes through a hole, then theoretically it will be caught in the next layer – but, if not, then it will be caught by the next layer, etc. However, if it is not caught by any layer and the series of holes all line up in each of the layers, then the accident happens.

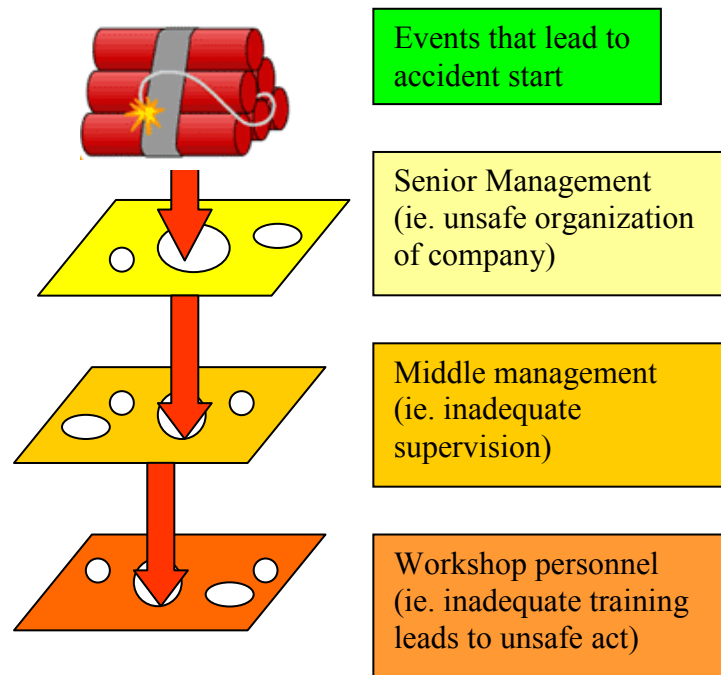


Figure 6-4: Modified Version of Reason's Swiss Cheese Model (after Reason, 2005).

The Herald of the Free Enterprise is a typical accident where all the holes unfortunately lined up and approximately 200 passengers drowned. There was a known threat – sailing with the bow cap open. However, the day the accident occurred, there was no watch-keeper at the bow cap, there was great urgency to sail to meet the tide, and the bow cap was open (working level), middle management (master mariners on the bridge) wanted additional warnings and senior management thought the watch-keeper at the bow cap was adequate. All three layers of the Swiss Cheese had their holes lined up and the accident happened!

“Townsend Car Ferries Ltd are at fault at all levels, from the Board of Directors down to the junior superintendents. From top to bottom, the body corporate was affected by the disease of sloppiness.”

Mr. Justice Sheen (24 July 1987).

Li and Harris [6] derived another human factors analysis model from Reason's Swiss Cheese model. It is also a useful tool to guide accident investigations and develop accident prevention strategies (Figure 6-5).

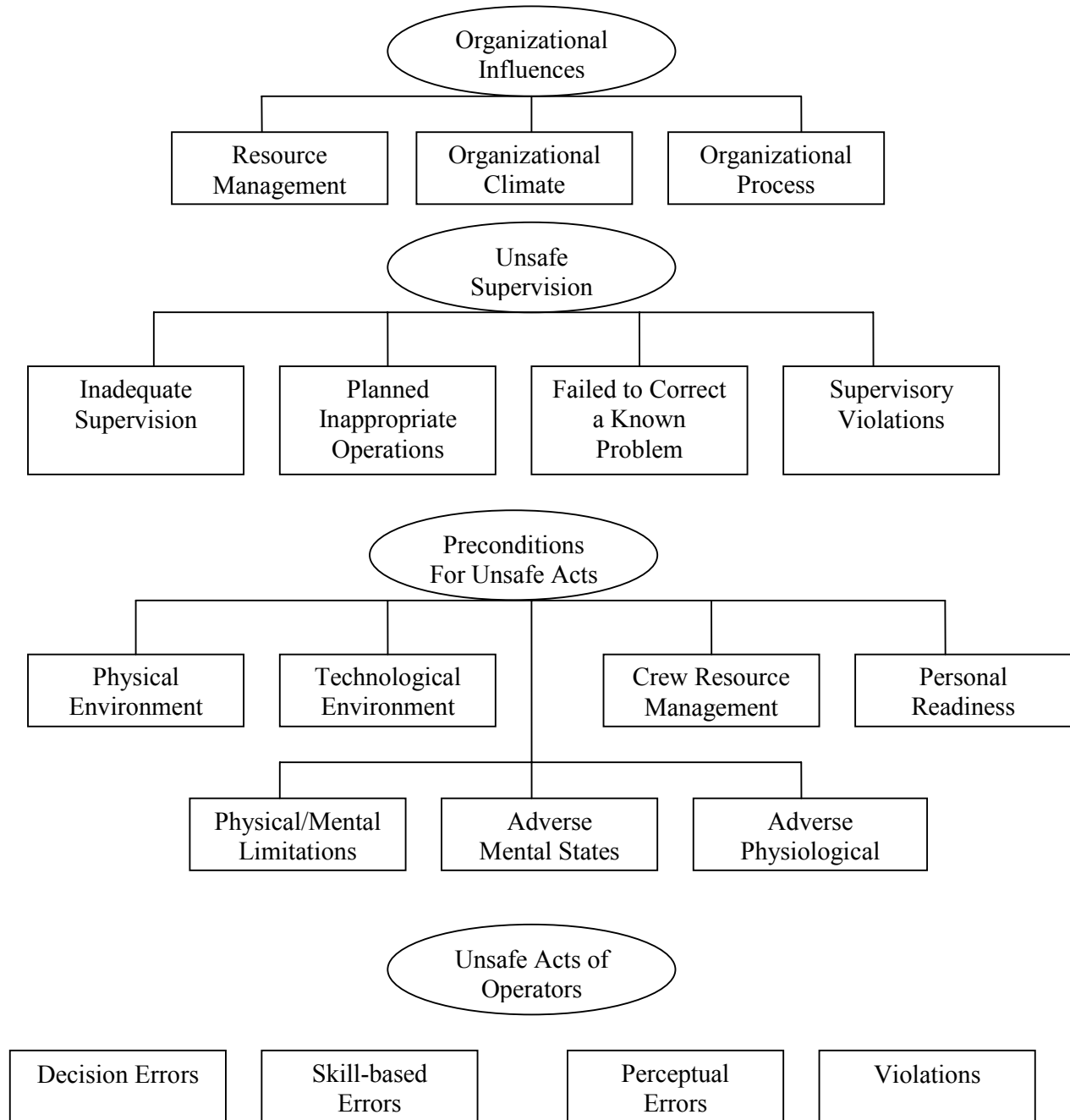


Figure 6-5: The Human Factors Analysis and Classification System (after Li, W., Harris, D. 2006 [6]).

PRE-IMPACT PHASE – THE WARNING

Reverting back to Leach’s model, when the warning occurs the threat appears real. Behavior ranges from hopeless apathy (Estonia), over-activity (sinking tug in the St. Lawrence river), self-denial (Estonia), and

ignoring warnings (King's Cross Fire). The lesson to learn here is that warnings are no good without information. You all know exactly what happens when there is a false alarm with the fire alarm. Basically no one does anything in a hurry. This is precisely what happened as the author was writing this paper in the hotel in Stavanger, Norway. The majority of rooms were full of English speaking oil workers waiting to go offshore the following morning for a crew change. The announcement was in Norwegian and not a person responded! Fortunately it was a false alarm! So **when you are in charge you must truthfully let the people know what is happening**. It is no good saying the flight is delayed. People are fed up with this, they need to know why and for how long. Then they too can plan and prepare.

PERIOD OF IMPACT

Irrespective of race, creed, sex, and level of training, each one of you will perform under one of three categories as illustrated in the curve distribution below in Figure 6-6.

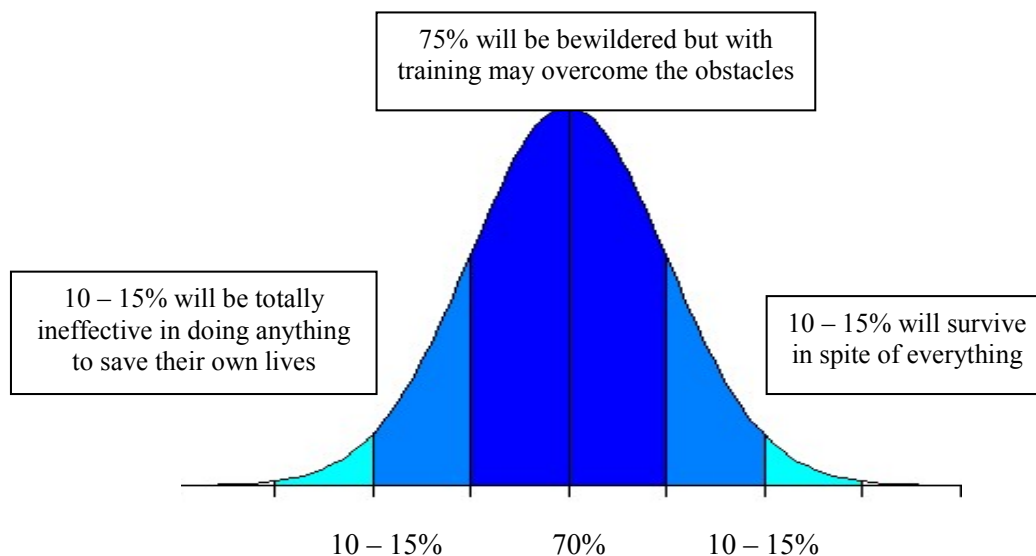


Figure 6-6: Bell Curve Distribution for Individual Reaction Due to Stress at the Period of Impact.

Under extreme stress, 10 - 15% of the population will exhibit behaviors that impair their ability in making a successful escape, such as paralyzing anxiety, confusion, and screaming [4]. Another 10 - 15% will be able to assess the situation and gather their thoughts quickly. They will succeed in formulating good decisions, and execute their plan of action well. The remaining 75% of the population will be bewildered and stunned, but with good training can follow the correct procedures to make a successful escape from whatever hazard confronts them. Their actions are mostly automatic in nature, and they will function more slowly as a result of the shock and amazement of the present situation.

Under stress at the time of the accident (period of recoil):

- 10 - 15% will survive in spite of everything
- 75% will be bewildered but with training may overcome the obstacles
- 10 - 15% will be totally ineffective in doing anything to save their own lives

It is very important to understand this model. Because no one knows how **YOU** or anyone else will behave under these stressful situations until it really happens. You must be prepared to accept that some of your staff will indeed be rendered totally useless, and it may indeed be **you**.

Regular training certainly helps. This develops the appropriate schemas so that the brain does not need a lot of time to process complex tasks – the closely-matched schema is already in long-term memory and therefore the decision-making process does not have to rely on the slow and time consuming working-memory to come up with a new schema. Remember, the Supervisory Attentional System can rapidly be overwhelmed in a stressful situation, and it bears repeating that it takes 100 times longer to process the information.

THE PERIOD OF RECOIL

This occurs after the danger has been removed. Several types of behavior can be expected ranging from hyperactivity, an attitude of dependency, a feeling of total disbelief that the accident has occurred, anger, guilt, and complaints about the most trivial thing. One fact that was noted in the pre-impact phase is that people are still looking for information, especially those in the bewildered category. They tend to follow anyone who claims to have some authority (a policeman, an engineer, a clergyman, etc.) – but the people who claim to have some authority may be in fact providing irrational, irresponsible advice which can lead to the demise of those who follow them. In one marine accident, the Nurse suggested that no one could swim with their clothes on, so she told them to undress before abandoning ship. The majority of the bewildered survivors died from hypothermia. They didn't have the extra insulation that clothing would have provided!

PERIOD OF POST-TRAUMA

The scope of this problem is too extensive to be discussed within the time allocated to this lecture. This is the time when the victims' lives have to be rebuilt.

However, it is important to understand that when you interview survivors after the accident, both the time and visual observations of the event can be seriously distorted during a highly stressful life threatening escape. The first testimony is the most reliable. After this, repeat questioning may extract inconsistencies and major changes in evidence. The brain tries to fill in the evidence after the fact in an attempt to rationalize the whole event.

SHIFT WORK, SLEEP PATTERNS, AND SLEEP DEFICIT

The majority of humans need 8 hours sleep a night. Human's sleep pattern, or circadian rhythm, falls into two types – larks and owls. Larks wake up early, and are most productive in the mornings until noon. After that, it tails off. They generally like to be in bed early and suffer badly from jet lag. Owls wake up later and their productivity peaks in the afternoon and early evening. They can stay up all night, but have a hard time getting up in the morning.

Neither cope well with shift work, especially after the age of 40 when humans sleep patterns tend to deteriorate. Just look at the average age of your staff and think about this when you are planning your operations.

So in order to avoid accidents and incidents, you must know your people and understand their sleeping habits, e.g. it is hopeless to keep asking one of your brilliant engineers to do a task every morning (when it can be

done at any time in the day) if he/she is an owl! Don't decide to do any major exercise or engineering project in the middle of the night when everyone's natural performance is at its lowest **unless it is absolutely necessary**. If you do proceed, get extra help.

There was an extensive review on the health and performance of shift workers in the Occupational Medicine Journal in 2003, which is recommended to everyone. Two very significant papers concluded:

“Both safety and productivity are reduced at night. This reduction probably reflects on a number of underlying factors, including impaired health, a disturbed social life, shortened and disturbed sleep, and disrupted circadian rhythms.” (Folkard and Tucker, 2003, [2])

“Irregular work hours seem to exert strong, acute effects on sleep and alertness in relation to night and morning work. The effects seem, however, to linger and also affect days off. The level of the disturbance is similar to that seen in clinical insomnia, and may be responsible for considerable human and economic costs due to fatigue related accidents and reduced productivity.” (Akerstedt, 2003, [1])

THE NECESSITY TO HAVE A GOOD HUMAN ENGINEER IN ALL YOUR OPERATIONS

So far I have described how and why the brain is not very good at coping with complex problems when it is stressed out, tired, or operating out of its normal circadian rhythm. Therefore, it is imperative that all emergency equipment and systems should be simple to understand and easy to operate in all adverse conditions. I am just going to run through some slides to provide some good examples that have happened. I have not had to search very long and hard for them! It will become very obvious that the engineers have never considered the human in the design equation. You must use human engineers in all your projects from initial design right through to the full operation. There are also some very good occupational medicine physicians, applied psychologists, and physiologists who can give you additional help. It will save you millions of dollars in refit bills and damages, both to the human and equipment. Most importantly, it will decrease the number of injuries and the unnecessary loss of life.

Strong messages to take back to the rig, the ship, the squadron and staff in head quarters:

- Regular training is essential to develop as many survival schema as possible.
- The brain is not good at coping in emergencies, it can basically only analyse one complex problem at a time and it is **slow**.
- Reducing staff may in the short term save money, but in the long term costs a lot more. Remote systems puts more stress on the remaining crew which leads to accidents because they: a) can't process the information fast enough; or b) take dangerous short cuts to do the job.
- Shift work is a necessary evil. There is a penalty to be paid in both safety and productivity at night.
- Don't plan to conduct complex tasks, both mental and physical, in the middle of the night. If the task is vital, get extra help.

- Don't do complex tasks **immediately** after a crew change when workers may be jet lagged, sea sick, hung-over, etc.
- A well trained team in which authority is delegated and there is complete trust is essential both to prevent and cope with accidents.
- You are all Alpha males or females – there is no shame however in delegating authority when you are not well, over-tasked, or stressed out.
- In a major incident/accident, 15% of people in spite of training, race, creed, sex, age, etc., will be useless and you will not know who that is until the crisis occurs. Be prepared for this – it will happen.
- Don't fire the guy who makes the mistake and “apparently” precipitated the accident. He/she likely holds the key to the true root cause of the problem.
- Use more human engineers, applied psychologists, physiologists and occupational medicine physicians in your business, right from planning up to operations. It will save you millions of dollars in refit bills and damages, both to the human and equipment. Most importantly, it will cut down on the number of injuries and unnecessary loss of life. It will make your safety record the envy of your competition and your shareholders.

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Chapter 7 – The Principals of Emergency Breathing Systems (EBS) for Helicopter Underwater Escape

by

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INTRODUCTION

Due to the fact that breath-holding ability in water below 15°C is considerably reduced [7]. The average breath-holding ability of a typical group of offshore workers is about 40 seconds [5], and the time for total clearance of 18 people from a typically fully loaded Super Puma helicopter is between 23 and 92 seconds [2, 3]. It is essential now to have some form of supplemental air for every crew and passenger on board a helicopter flying over water. For a detailed discussion about the implementation of an EBS system into service, please refer to Brooks and Tipton's AGARDograph AG-341 [4] and Coleshaw [6].

Over the past two decades, the three types of Emergency Breathing Systems have been increasingly put into service with helicopter operators for crew and passengers. Military helicopter aircrew very successfully pioneered the equipment. Anecdotal evidence such as the following statement has become common: "Without my emergency breathing system, I would not be here today".

With the increase in oil exploration, helicopter passenger flights over the sea and the media attention when one helicopter ditches and lives are lost, helicopter operators and oil companies are striving to make flight in these machines as safe as possible. The successful track record of these systems, the increase in safety training and safety technology has now made it possible for passengers to carry these systems. It is very important for everybody who may be involved in the implementation of a system that they understand the differences and limitations of each type. The object of this paper is to broaden your knowledge and understanding of these systems.

TYPES OF SYSTEMS

There are three types of systems which can be used for helicopter underwater escape. These are compressed air, a rebreather and finally a hybrid rebreather.

A Compressed Air System

A compressed air system is based on a well proven self-contained underwater breathing apparatus, which most people know as a SCUBA set. This system is a scaled down SCUBA set and operates on exactly the same principal. A high-pressure aluminum cylinder normally charged to 3000 psi or 206 bars of compressed air (21% O₂ + 79% N₂). The pressurized gas is then fed into a step down regulator called a first stage regulator normally found on the top of the aluminum cylinder. The gas pressure is stepped down from 3000 psi to approximately 130 psi. From there, it is fed via a low-pressure hose to a second stage regulator known as a demand valve. This senses the ambient pressure and therefore the user can demand air from the system with little or no resistance. The only resistance experienced is caused by having to inhale against a small pre-set valve, which allows air into the demand valve or mouthpiece. This type of breathing apparatus is classed as an open circuit demand system. This means that when the user breathes out, the exhaled air leaves the demand valve and enters the water. None of the expelled air is collected and reused again, as in the case of a closed circuit demand system.

System Specification

Working pressure between 1800 psi – 3600 psi
Air volume between 42 litres – 80 litres of air
Weight is approximately 3 lbs.
Duration approximately 21 breaths @ 21 feet deep.

The duration of the equipment is based on a starting pressure of 3000 psi and a breathing rate of 10.5 breaths per minute. (Max depth 45 feet)

A Rebreather System

The second system is a rebreather, which is based on exhaling and rebreathing your own air. Because the exhaled air contains un-metabolised oxygen, it can be rebreathed many times before the oxygen is used up. The air, which has been collected at atmospheric pressure (the surface), can be inhaled and exhaled into a bag known as a counter lung when the user is unable to hold their breath anymore.

System Specification

Air for the system is breathed at atmospheric pressure. (Max depth 12 feet)

Breathable air volume = Lung volume

System weight = Approximately 2.25 lbs

Contains an activating device to shut the counter lung off from the atmosphere

Mouthpiece and nose clip

Flexible hose

Counterlung

A Hybrid Rebreather

This system works on the same principle as a rebreather, but it also contains a six-inch 3.5-litre cylinder of compressed air fitted to the counterlung. This air cylinder can be activated by a salt water activated automatic inflator or manually using an emergency manual inflator pull cord. The compressed air is supplied to the counter lung before immersion in the water. The reason for the additional source of air is to provide some air for those who did not get a breath of air before going underwater. Pre-filling the counterlung also has the advantage that it helps make the system easier or more comfortable to breathe in and out underwater.

System Specification

The specifications are the same as a rebreather except for an automatic inflator and a compressed air cylinder.

THE ADVANTAGES AND DISADVANTAGES OF COMPRESSED AIR SYSTEMS VICE REBREATHING SYSTEMS

Compressed Air System

The advantage of a compressed air system is that once the demand valve is placed in the mouth, it will supply the user with an instant supply of air at any stage of the ditching on the surface or underwater. It works well under any orientation of the body and down to a depth of more than 45 feet. The duration of these systems can vary from 2 minutes to 6 minutes depending on the size of the cylinder; the volume of air; the working pressure of the unit; and most important, the breathing rate of the person using it. There are several types available from reputable companies that make and supply diving equipment. Several of these systems have already been successful in saving lives in ditching accidents.

There are only two disadvantages of a compressed air system. First, very rarely, especially in the scenario of helicopter underwater escape or escape training, the user can suffer some form of pulmonary over-inflation

injury if it is not used correctly [1]. This type of injury is caused by the air in the lungs or any space in the body increasing in volume due to a decrease in pressure on ascent (Boyle's Law). If the user does not exhale on the way to the surface, or does not breathe normally when using this equipment, it can cause this type of injury. Second, the system will run out of air without warning.

Rebreather and Hybrid Rebreather System

The positive features of a rebreather is that it is somewhat simpler in design, but with the addition of a compressed air cylinder which converts it into a hybrid system, another layer of complexity related to use and maintenance is added. In either system, the main disadvantage is that it requires a number of steps to make it operational during a critical part of flight. The system, currently the most popular used in North Sea, requires the human to physically perform up to six separate steps after the impact phase of a helicopter ditching to make it work. If these procedures are not carried out the system is rendered inoperable and the survivor could drown.

The system must be activated before immersion as there is no purge capability and it cannot be operated underwater. As technology advances, it may be possible to operate a rebreather underwater if some form of automatic shut off valve is used to stop water entering the mouthpiece or breathing tube. This type of automatic shut of valve is being investigated by some of the major survival suit manufactures. Unlike the compressed air system, which senses ambient pressure and gives the survivor the ability to demand air at any depth, the rebreather does not have that feature. As depth and orientation changes it becomes more difficult to exhale and rebreathe from the counter lung. This becomes particularly noticeable if the helicopter is sinking and the survivor's body is not aligned with the counter lung and the air contained within it. It is not easy to learn to control exhalation and inhalation compared to a compressed air system. The tendency is to breathe quickly, which causes you to hyperventilate and it needs a great presence of mind to control the breathing rate. A rebreather is designed to operate above 12 feet. However, the survivor may be as deep as 30 feet or more particularly, if the helicopter has inverted and sunk rapidly and is floating only by an air pocket trapped in the tail section. Then, if a hybrid rebreather is used, the hazards of pulmonary over inflation injuries are identical to that of a compressed air system. With a rebreather or hybrid rebreather, as you rebreathe your own air, the build up of carbon dioxide rapidly causes the survivor to hyperventilate, with the potential of losing consciousness. This is at a time when a survivor must be in full control of his or her mental faculties.

TRAINING AND MAINTENANCE REQUIREMENTS

All of these systems require training. This training should consist of classroom theory training, and because none of these systems are universal in their use, it also requires specific practical pool training specific to the unit. This must be done before doing practical egress training in a suitable helicopter simulator. Regular practical wet refresher training is essential so the operator retains the skills to use the equipment quickly and efficiently. Both in training and operations, the latest models of compressed air systems are relatively cheap to service and maintain. The author has no experience of servicing or maintenance of the rebreather in operations, but for training, it is considered more expensive to use. With the spread of infectious diseases and the difficulty of sterilizing the counter lung, a new or totally sterilized counter lung must be used each time.

INTEGRATION WITH OTHER SURVIVAL EQUIPMENT

This type of equipment is often designed as an add-on to a major part of survival equipment. If not carefully thought out, it can be detrimental to its performance and usability and also cause problems with other life

support equipment. There are many different types of these systems and they can only be placed in few positions. The positions are the aviation lifejacket, the flying suit or survival suit, or finally mounted in the helicopter. Whatever position is selected, it is imperative that skilful human engineering is used to match the system to the equipment and the aviation environment. Otherwise it can be detrimental to the performance of the system and catastrophic to the user.

CONCLUSION

In the 21st century, it has now become clear from scientific work and anecdotal evidence from helicopter ditchings, that to prevent the crew and passengers drowning through inability to breath-hold while making either a simple or complex escape, some form of supplemental air is required, especially in water below 15°C.

Currently there are three systems available for operators. The pro's and con's of each system have been described in order that they will work as advertised, a caution has been added concerning the importance of implementing practical wet training and requirement for ensuring an extensive human engineering integration.

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Chapter 8 – Seasickness: Guidelines for All Operators of Marine Vessels, Marine Helicopters and Offshore Oil Installations

by

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This review is written for the NATO lecture series: NATO RTA “Survival at Sea for Mariners, Aviators and Personnel Involved in Search and Rescue”. It provides a brief historical perspective, updated scientific information on the phenomenon, susceptibility and management of seasickness. It is designed to provide the latest data on seasickness for all those who earn their living working on or flying over the water.

INTRODUCTION

Many different forms of transport, from surface vehicles (land and sea) to air and space vehicles, cause motion discomfort with symptoms ranging from nausea to vomiting and/or retching in susceptible individuals. These symptoms are collectively known as motion sickness. The most dreaded kind of motion discomfort occurs on long duration voyages where the susceptible individuals often feel that they are effectively imprisoned in the nauseogenic environment. Seasickness is the most widely experienced form of this oppressive motion

sickness. Reports of seasickness, also known as “kinetosis” and “naupathia” date back as far as the authors of Greek mythology, who were familiar with the discomforts associated with seasickness. It seems likely that humans suffered from seasickness well before they could make written records of it. Lord Nelson was a chronic sufferer of seasickness, even on his final voyage to fight at Trafalgar. Sir Charles Darwin never missed a chance to get off the boat during his famous voyage on the Beagle because he too succumbed to seasickness.

Irwin [68] recorded the term “motion sickness” as follows:

Seasickness, or motion sickness, as it might be more correctly named – for not only does it occur on lakes and even on rivers, but, as is well known, a sickness identical in kind may be induced by various other motions than that of turbulent water – is essentially a disturbance of the “organs of equilibration”

Usage of the term “motion sickness” was popularized by Sir Frederick Banting during the Second World War when seasickness and airsickness were studied together. However, with the advance in knowledge and technology, the term “motion” is a misnomer as the symptom characteristics can be evoked as much by the absence of expected motion as by the presence of unfamiliar or apparent conflicting motion. For example: simulator sickness and cyber sickness (sickness induced by computer generated virtual displays) are examples of conditions where the evocative stimulus is the absence of physical motion stimuli and the presence of visually induced apparent sensation of self motion. The term “sickness” is also a misnomer as it carries a connotation of “(affected with) disease”. It obscures the fact that motion sickness or seasickness is a normal physiological response of a healthy individual without organic or functional disorder, when exposed to unfamiliar or conflicting motion of sufficient severity for a sufficient period of time. **Hence, seasickness and other associated forms of motion sickness (airsickness, carsickness, simulator sickness and space sickness) can now be defined as a maladaptive response to real and apparent motion.** However, it should be noted that visually induced sickness comprises a number of motion sickness-like signs and symptoms, with slightly different profiles from true motion sickness. Visually induced sickness is generally less severe, but the after-effects (flashback from cyber sickness) can appear much later after the initial exposure. Therefore it is important to distinguish the stimuli that were used when evaluating the results of laboratory studies on the effects and countermeasures of motion sickness.

SIGNS AND SYMPTOMS

The cardinal signs of seasickness are pallor and/or flushing in the facial area, cold sweating, vomiting or retching. Facial pallor arises from the constriction of surface blood vessels. Sweating often occurs even when the thermal conditions would not make this necessary. The cardinal symptom of motion sickness is nausea; often, it is a precedent to vomiting. Vomiting can sometimes occur without nausea. The physiological mechanism of vomiting and retching is identical except that vomiting involves the forced expulsion of stomach contents and psychologically it is more gratifying afterwards, as it usually provides a rapid relief from nausea. However, retching is unproductive (no expulsion of stomach contents) and usually the feelings of malaise linger for a while. There are other signs and symptoms associated with motion sickness.

They commonly occur in an orderly sequence as follows:

- Stomach (epigastric) awareness;
- Stomach discomfort;
- Pallor;

- Cold sweating;
- Drowsiness;
- Yawning;
- Feeling of bodily warmth;
- Increased salivation;
- Nausea; and
- Vomiting/retching.

The common after-effects with motion of long duration [99] are:

- Persistent headache (especially frontal);
- Apathy;
- Lethargy;
- Anorexia;
- General malaise;
- Persistent dizziness;
- Light-headedness or disorientation;
- Belching/flatulence; and
- Feeling miserable or depressed.

In addition, there is a symptom complex known as Sopite Syndrome that is centering on irresistible drowsiness. The typical symptoms of Sopite include:

- Frequent yawning;
- Drowsiness;
- Disinclination for work, both physically and mentally; and
- Avoidance of participation in group activities.

Generally, the symptoms characterizing this syndrome are interwoven with other symptoms, but under two circumstances this syndrome may become the sole overt manifestation of motion sickness:

- 1) When the intensity of the eliciting stimuli is closely matched to a person's susceptibility and the syndrome is evoked either before other symptoms of motion sickness or in their absence; and
- 2) During prolonged exposure in a motion environment when adaptation results in the disappearance of motion sickness symptoms except for responses characterizing the sopite syndrome.

In general, the time scale for the development of motion sickness symptoms is determined primarily by the intensity of the stimulus and the susceptibility of the individual. Therefore, individuals vary in their response: for instance, certain individuals may experience many of the above effects, feeling ill for a considerable amount of time, but they may not vomit; others may have a relatively short warning period (few signs and symptoms), vomit and feel better almost immediately. The rapid relief is partially attributable to the fact that salivation, stomach disturbance, respiratory and heart rate changes are also part of the organized chain of events that comprise the act of vomiting. If exposure to the motion continues, nausea increases in intensity and

results in vomiting or retching. In more susceptible individuals, the cyclical pattern may last for several hours or in extreme cases, for days. Dehydration and disturbance of electrolyte balances in the body brought about by repeated vomiting compounds the disability.

The pathognomonic signs of vomiting and retching in visually induced sickness (non-motion or limited motion based simulator) are rare [15], while other overt signs such as pallor, sweating and salivation are more common. However, vomiting appears to have a sudden and sometimes unexpected onset, and occurs often without accompanying prodromal symptoms. Postural changes have also been observed immediately after simulator flights. As briefly earlier, the more serious problems associated with simulator sickness are residual after-effects which have been documented by a number of studies [5, 36, 74, 91, 129] including illusory sensations of climbing and turning, perceived inversions of the visual field and disturbed motor control.

AETIOLOGY OF MOTION SICKNESS

The combination of sensorimotor systems involved in bringing about the onset of motion sickness and in the maintenance of spatial orientation awareness is identical. It involves the visual, vestibular (organ of balance) and the somatosensory receptors (tactile cues and non-vestibular proprioception such as joint receptors, Golgi tendon organs and muscle spindles). The vestibular apparatus is incriminated in motion sickness and visually induced sickness. Labyrinthine-defective individuals are immune to motion sickness [51, 75, 116, 117] and visually-induced sickness [15]. Sudden unilateral loss of vestibular function gives rise to symptoms of motion sickness including vomiting. More than a century ago, Irwin [68] suggested that sensory conflict (where sensory signals from the eyes and the organ of balance do not agree) was the principal cause of motion sickness. However, the prescribed conflict is not limited to signals from the visual system, the vestibular system and somatosensory receptors. These signals are also at variance with the information that the central nervous system expects to receive [31, 112]. Therefore, the conflict theory of motion sickness holds that in an environment conducive to motion sickness, the pattern of sensory inputs concerning orientation and motion is in conflict with the pattern of inputs anticipated on the basis of past experience.

This theory of a simple conflict causing sickness is insufficient, as it does not explain habituation to provocative stimuli or the after-effects of exposure to such stimuli. It does not explain why such a conflict should produce vomiting. Nevertheless, the sensory conflict theory is satisfactory as all known causes of sickness can be accommodated by this theory and it suggests some useful preventive measures. A further modification suggested that conflicting sensory inputs are interpreted centrally as neurophysiological dysfunction caused by poisoning [124] and that some evidence concerning the basic validity of this “poison” theory was provided by Money and Cheung [98] and Ossenkopp, et al. [106]. Watt [132] suggested that motion sickness is significant as it serves as a warning against inappropriate motor strategies that are causing undesired changes in vestibular function, and the subsequent disruption of normal sensorimotor integration. The ability of the human sensory system to resolve the motion experienced depends on the frequency of oscillation because the different senses do not all respond to the imposed acceleration. However, the severity of the signs and symptoms of motion sickness increases as a function of exposure time and acceleration intensity.

FREQUENCY OF MOTION AND SUSCEPTIBILITY

Early empirical and experimental observations suggested that vertical motion (heave) is the predominantly nauseogenic stimulus in the normal gravity ($1G = 9.8 \text{ m/s}^2$) environment. Data concerning the frequency of motion and motion sickness are derived from early surveys conducted at sea relating passenger seasickness questionnaire responses to their exposure to linear and angular motion. It concluded that vertical oscillation

(heave motion) was the best predictor of motion sickness and that other linear (horizontal) or angular motions (roll, pitch and yaw) were less significant [82]. Because of the high inter-correlation between various types of ship motion, these surveys could not distinguish the separate contributions of each type of motion. As a result, early controlled laboratory studies employed largely vertical linear oscillation as the primary stimulus to provoke motion sickness and there were no controlled data relating frequency of motion to the nauseogenicity of horizontal motion until much later by Golding and Markey [47].

For example, laboratory studies using vertical oscillation showed that sickness increases with decreasing frequency to at least about 0.2 Hz. Alexander [3] used a modified elevator to expose seated, blindfolded subjects to motion at frequencies of 0.22, 0.27, 0.37 and 0.53 Hz (magnitudes ranging from 1.96 to 5.47 m/s²) for 20 minutes; there was a significant increase in nauseogenicity as frequency decreased. Their results also suggested that increases in motion magnitude did not necessarily increase the incidence of vomiting. O'Hanlon and McCauley [104] and McCauley, et al. [89] investigated the responses of over 500 subjects seated with their heads against a backrest with eyes opened in an enclosed cabin that oscillated vertically. Subjects were exposed to five frequencies 0.167, 0.25, 0.33, 0.5 and 0.6 Hz and various magnitudes from 0.278 to 5.5 m/s² RMS for a maximum of 2 hours. The highest percentage of vomiting was at 0.167 Hz and the incidence of vomiting decreased gradually towards 0.3 Hz and a more rapid decrease with higher frequency. There was limited evidence suggesting that motion sickness incidence further decreased at frequencies below 0.167 Hz. Lawther and Griffin [81] conducted a similar study, measuring the motion of car ferries operating in the English Channel and the consequent sickness among passengers. Data were analyzed for 17 voyages of up to 6 hours in duration, involving over 4900 passengers. The results were similar to those of O'Hanlon and McCauley in that the strongest correlations between motion sickness incidence and motion were in the vertical (heave) direction, both in magnitude and duration of exposure. In addition, position aboard a vessel is a significant factor in how the subjects perceive a given motion. Data collected by Lawther and Griffin [81] were from very large passenger ships that typically have relatively small pitch and roll movements. An incident wave tends to excite vertical oscillation (heave) of the vessel at its natural frequencies of buoyancy. It will excite the hull over a range of frequencies in heave, roll and pitch in which the vessel is compliant. In most vessels this happens most often at vessel motion frequencies of 0.1 to 1 Hz, which is particularly nauseogenic to humans.

It is not surprising that the traditional view that vertical motion is the principal stimulus for vibration induced motion sickness has been challenged. Wertheim, et al. [133] suggested that pitch and roll when combined with small heave motion, which in themselves are not sickness provoking, produce more motion sickness than claimed by the classic model. The motion parameters were: heave frequency at 0.1 Hz (with RMS between 25 and 32 cm; G between 0.02 and 0.035) pitch frequency at 0.08 Hz (with RMS from 4.9° to 9.9°, G between 0.01 and 0.022), roll frequency between 0.05 and 0.07 Hz (with RMS between 7.1 and 9.9°, G between 0.003 and 0.014). Frostberg [42] investigated motion sickness occurrence in a group of 40 subjects exposed to 7 different combinations of lateral and roll oscillation and reported that combined roll and lateral oscillation caused greater sickness than either roll oscillation or lateral oscillation alone.

In general, the larger the vessels, the less likely seasickness will afflict the ship's complement at a given sea state and condition [135]. However, large mobile drilling platforms and super-tankers of immense displacement and dimensions with high structural flexibility and low inherent structural damping can exhibit vibrations frequencies below 2 Hz. Naval vessels such as light cruisers and destroyers tend to heave, pitch and roll at frequencies of 0.13 to 0.33 Hz that are particularly nauseogenic. Because of the heave component of the composite motion of the vessel, susceptibility to seasickness can be shown to increase monotonically as a simple geometric function of the lateral distance of the subject from the effective centres of rotation of the vessel [11]. Smaller vessels such as Coast Guard patrol boats, passenger and pleasure craft can experience

violent motion that include abrupt yawing and large amplitude roll, pitch and heave in severe weather that will provoke motion sickness as well as shipboard injury.

PERFORMANCE

There are three general aspects of major importance to the problem of human performance degradation in a moving environment:

- 1) Motion sickness incidence (MSI);
- 2) Motion induced interruptions (MII); and
- 3) Motion induced fatigue (MIF).

MSI and MII will interfere with task performance due to sickness symptoms and the loss of balance. MIF caused by added muscular effort to maintain balance can interfere with cognition or perception, especially in long duration tasks.

As eluded previously, true manifestations of seasickness share an underlying physiological mechanism and definable frequency range of oscillatory motion that is provocative. In addition to signs and symptoms of motion sickness, there are also documented changes in behaviour and performance such as: loss of well-being, distraction from task, decreased spontaneity, inactivity, being subdued, decreased readiness to perform and decreased muscular and eye-hand coordination. Other serious related problems have been documented, sometimes without overt sickness. For example, spatial disorientation, sleep disturbance, postural disequilibrium, mal de débarquement and altered gaze reflex that will affect visual acuity [45, 49, 59, 60, 77, 80]. Perhaps the greatest impact of seasickness in the operational environment is maintaining effective watch-keeping. The functional ability of all marine vessels is degraded in severe weather conditions, primarily due to the adverse effects of ship motion on crew performance. From the crew's perspective, loss of well being interferes with the ability to perform task and can become a liability to others as well. Seasickness can also affect the ability of passengers (troops) to carry out duties immediately after landing. The sight and smell of vomitus in a confined space can affect morale. It has been reported that severe seasickness erodes the will to survive and the affected individuals are less able and less willing to take positive action to aid survival.

Commercially, FPSO (Floating Production Storage and Offloading) vessels are increasingly being used to operate in deep water where the operating environment can be very extreme. The crew on these vessels must often work under extreme weather conditions, in shifts throughout the day and night for up to three weeks at a time, or even longer if the weather prevents crew changes. Seasickness and its after-effects, motion-induced fatigue and motion-induced interruptions are a potential problem for the safety and health of crewmembers at sea. A questionnaire-based survey [22, 25] based on 2255 returned questionnaires revealed that the crew complained of a variety of problems including:

- Sleep disturbance;
- Task completion;
- Task performance;
- Loss-of-concentration;
- Decision-making; and
- Memory disorders.

Specifically, the correlation between sleep disturbance and ship motion was relatively high. There were relatively few complaints of seasickness. These results are consistent with the findings by Colwell [33] in a NATO sea trial. The results suggested that significant correlation between fatigue and cognitive performance is at least partly influenced by ship motion effects on sleeping and low level of motion sickness. There appears to be no apparent habituation among subjects who participated in more than 2 shifts offshore. In general, it is apparent that the number of safety, health and performance issues increases with the deterioration of weather conditions.

MOTION SICKNESS AND INDIVIDUAL SUSCEPTIBILITY

Reason and Brand [112] suggested three relevant characteristics of an individual that might affect susceptibility to motion sickness: receptivity, adaptability, and retentiveness. Receptivity is defined as the initial reactivity, the internal amplification or the range of motion stimuli that produce a response. In other words, motion sickness is more of a problem to a receptive individual. Adaptability is the ability to adapt to the motion and to reduce sickness symptoms. It is suggested that those who report a greater history of problems with motion sickness tend to adapt more slowly to novel motion. Retentiveness is the ability to retain the adaptation during abstinence periods, and ability to reinstate adaptive responses upon re-exposure to the motion. It is the ability to retain the internal model of motion and to adapt to the same stimulus in successive exposures. The greater the retentiveness the less chances of sickness in subsequent exposure to the same motion. Genetically, susceptibility to motion sickness was reported to be one of the significant differences in concordance between monozygotic and dizygotic twins [2]. A single nucleotide polymorphism of the α 2-adrenergic receptor increases autonomic responsiveness to stress induced by off-axis rotation at increasing velocity [41]. Volunteers with the 6.3-kb allele had greater signs and symptoms of motion sickness mediated by the autonomic nervous system. However, it is unclear whether this is a marker for motion sickness susceptibility, per se, or a general marker for autonomic sensitivity. A recent postal survey conducted in an age-matched sample of monozygotic and dizygotic adult female twins [113] indicated that 40% of respondents reported moderate susceptibility to motion sickness. The pattern of responses among twins suggested a significant genetic contribution.

AGE AND SUSCEPTIBILITY

Early scientific literature suggested that susceptibility fluctuates with age [30, 97, 128]. Infants below the age of 2 are generally immune. Susceptibility appears to be at its highest level between 2 and 12. There is a significant decline between the ages of 12 and 21 [111]. However, a longitudinal study in the squirrel monkey (with a typical life span of 13 – 15 years) indicated that there were no significant differences in the susceptibility level (as measured by latency to vomiting and retching and cumulative sickness scores) throughout a 10-year period [16].

GENDER AND SUSCEPTIBILITY

There were a number of survey questionnaires and subjective reports that involves large sample of population suggested that females are more susceptible to seasickness [1, 34, 56, 81, 83, 102, 127]; airsickness [84]; short haul flights [127]; trains [71]; carnival devices, performing gymnastics [85, 111]; and military flight simulators [76]. However, other reports suggested that there were no difference between gender in seasickness susceptibility [87], during coach journey [125], visually induced sickness [69, 107] and vestibular Coriolis cross-coupling induced sickness [23]. It was explained that female are more susceptible to motion sickness

because of the hormonal fluctuation especially during the menstrual cycle. The origin of this explanation can be traced to an early observation made by Schwab on one female. Schwab [114] described "... a nurse in the army medical corps who successfully crossed the Atlantic on a small vessel during rough weather without being ill, but who became nauseated and vomited in calm sea of the Mediterranean when her menstrual period began". Grunfeld and Gresty [58] observed a slight increase in the number of sickness events reported during premenstrual and perimenstrual phases. Cheung, et al. [21] reported that the menstrual cycle appears to have no influence on subjective symptoms and cutaneous blood flow increases under controlled laboratory conditions. In addition there is a lack of commonality between the types and levels of hormones that are released during motion sickness and those that are involved in different menstrual phases. Clemens and Howarth [32] reported that susceptibility to virtual simulation sickness varies over the menstrual cycle as a consequence of hormonal variation. Using a relatively mild provocation of a video game, only the most susceptible part of the population would have experienced significant motion sickness. In addition, the stimulus dose of a video game is difficult to control as it is under the control of the subject to a great extent. A later study by Golding, et al. [48] using a staircase profile Coriolis cross-coupling stimulus suggested that there was a small but significant trend that motion sickness susceptibility was maximal at day 5 and decreasing through days 12 and 19 to a minimal at day 26 premenstrual of the menstruation period. A lengthy staircase profile of successive motion exposures may introduce a possible confounding habituation effects. The authors suggested that it is unlikely that hormonal fluctuation account for the greater susceptibility in women since the magnitude of the fluctuation is only about one-third of the overall difference between male and female susceptibility (based on previous surveys). The variance in these laboratory findings is similar to the different results obtained by surveys studies as stated above. It might be that there is no reliable result of the menstrual cycle on motion susceptibility and that it is a random observation between studies.

AEROBIC FITNESS AND SUSCEPTIBILITY

Whinnery and Parnell [134] reported that 2% of endurance trained subjects complained of motion sickness with 38% progressing to vomiting, while 23% of untrained subjects experienced motion sickness with 7% progressing to vomiting. A longitudinal study by Cheung, et al. [14] concluded that tolerance to vestibular stimuli decreased as the subject's aerobic capacity improved. Aerobic capacity has been reported to be specifically linked to signs and symptoms of motion sickness of vasomotor origin including stomach discomfort, nausea and vomiting [110]. Vasomotor symptoms (epigastric discomfort, nausea and vomiting) are significantly increased in aerobically fit individuals.

MOTION SICKNESS AND CORE TEMPERATURE CHANGES

Among the other signs of motion sickness, body temperature has received a renewed attention in recent investigations leading to the hypothesis that motion sickness can facilitate the development of hypothermia. The report on this phenomenon dates back to 1874 when Hess described that the body temperatures of seasick patients were found to be at least half a degree (Fahrenheit) lower than those of the same persons under normal conditions. In addition, early observation of seasickness also indicated that victims of seasickness showed marked pallor, cold and clammy extremities and a slightly subnormal temperature [9, 12, 73]. Other temperature signs reported include coldness of the extremities [9, 90] and lower skin and oral temperature [62, 63].

A case report by Golden [46] described that two occupants who had been shivering violently for 3 or 4 hours before capsizing, were both seasick and ultimately lost their lives. Investigation into the Alexander L. Kielland (an oilrig accommodation platform at sea) disaster (27 March, 1980) revealed that most survivors rescued from

the TEMPSC (totally-enclosed motor-propelled survival craft, i.e. lifeboat) suffered from hypothermia and seasickness at the time of rescue [105]. Recent studies by Mekjavic, et al. [92], Sweeney, et al. [123], and Nobel, et al. [103], all suggested that subjects exhibit potentiation of core cooling although some of these observations did not reach statistical significance. None of these studies consider the susceptibility of the individuals and the severity of the stimuli. The idea that all seasick survivors in a cool environment are particularly susceptible to hypothermia may be overly stated. A recent laboratory study suggested that the decrease in body temperature could be related to the level of susceptibility. The decrease in core temperature did not reach statistical significance once the subjects (of all level of susceptibility level) habituated to vestibular Coriolis cross coupling induced stimulus in 4 consecutive days [26, 28].

PREVENTION AND COUNTERMEASURES TO SEASICKNESS

Prevention of seasickness can take several forms, for example, elimination or reduction of the cause (the motion environment) which is not practical unless the affected individual withdraws from that type of occupation. The second possibility is the isolation of the body from the cause. For example, it has been suggested that in situations where the dominant stimulus is a changing linear acceleration in a defined axis, as in a heaving ship, the sickness is less severe when the stimulus axis is in the longitudinal (Z) axis of the head than in the antero-posterior (X) axis [130]. Finally, one can minimize the effects of the cause by pharmacological treatment and/or desensitization training.

It has been demonstrated in the laboratory and in the field that certain drugs can reduce the incidence and severity of motion sickness. Unfortunately, none can completely prevent motion sickness in the population at risk under all conditions of provocative stimulation. In addition, none of the drugs of proven efficacy in the treatment of motion sickness are entirely specific and all have side effects [138], which severely limit their utility in the working environment. There have been some attempts to study the impact of anti-motion sickness drugs on psychomotor performance. Paul, et al. [108] concluded that, among 25 mg promethazine, 50 mg meclizine, 50 mg dimenhydrinate, 25 mg promethazine plus 60 mg pseudoephedrine and 25 mg and 10 mg of d-amphetamine, only the last combination was free from having an effect on psychomotor performance and did not increase sleepiness. Unfortunately, the study was conducted without subjecting the participants to provoking motion. It is unknown which medication was in fact, effective in ameliorating motion sickness in those individuals and their correlation with psychomotor performance. In addition, it is well known that the pharmacokinetics (rate of absorption and metabolism) of medication varies under different stressful environments [88].

Those given drugs must be warned that the drugs may impair their ability to drive or operate machinery and that they should refrain from the consumption of alcohol as it will increase the sedating effect. The mechanisms of action of commonly used agents are poorly understood. It has been postulated that these agents suppress integration of sensory stimuli in the vestibular nuclei or the electrical activities in the vestibular nuclei. Some of these drugs (e.g. dimenhydrinate) in fact, were shown to suppress nystagmus during rotation.

There are four major classes of pharmaceuticals that have been used:

- 1) Antimuscarinics (Scopolamine/Hyosine);
- 2) Antihistamines (Cyclizine, Meclizine/Bonamine);
- 3) Anticholinergics – with antimuscarinic and antihistamines properties (Promethazines “Phenergan”, Diphenhydramine “Benadryl”, Dimenhydrinate “Dramamine”); and
- 4) Sympathomimetics (Amphetamine, Ephedrine).

The three relatively effective and commonly used drugs (promethazine, dimenhydrinate, and scopolamine) are central depressants that can affect brain activities and cause drowsiness or sleepiness and dizziness. They should not be taken by those in whom an impairment of skilled performance could jeopardize safety. There is a place, however, for the administration of anti-motion sickness drugs to crew members during the early stages of training. The possible performance decrement due to sickness must be weighed against side effects that may be produced by the drugs.

The commonly used dosage and duration of action are listed below:

Antimuscarinics

1) Scopolamine

- 0.3 – 0.6 mg Scopolamine HBr (+ 5 mg of Dexedrine).
- Oral dose, acts within 0.5 – 1.0 hour, lasts for 3 – 4 hours.
- Transdermal therapeutics system (TTS) patch applied 18 hr before lasts for 48 – 72 hours; it delivers a loading dose of 200 mg and a controlled release at 10 mg/hr.
- It exhibits high variability between subjects in both effectiveness and incidence of side effects.
- It is non-selective for 5 types of muscarinic receptors found in vivo.

Side effects of Scopolamine:

- Autonomic nervous system: Reduced salivation, bradycardia, blurred vision (reduced accommodation).
- Central nervous system: reduced short term memory, impaired attention, and lowered feelings of alertness.

2) Zamifenacin

It is an M3 and M5 muscarinic antagonist which was as effective as scopolamine in human subjects when tested using the rotating chair.

Antihistamines H₁ Receptor Antagonists

These are less efficacious than antimuscarinics and are more commonly used due to high safety and longer duration.

- 1) 50 mg Dimenhydrinate (Dramamine, 8-chlorotheophylline salt).
- 2) 50 mg Cyclizine HCl (Marzine) has been displaced in the US by the longer acting meclizine, oral dose, acts within 1 – 2 hours, lasts about 6 hours.
- 3) 50 mg Meclizine (Bonamine, Ancolan, Postafene), 1 – 24 hours before exposure to motion.
- 4) Cinnarizine (and its derivative, Flunarizine 10 or 30 mg single dose) with low incidence of sedation, but unavailable in the US [118]. Common side effects include: sedation, spatial disorientation, reduced hand-eye coordination, reaction time, psychomotor performance tasks such as digit substitution, critical flicker fusion threshold, etc. Those side effects may last 8 – 12 hours after ingestion.

Antimuscarinics/Antihistamines

These drugs are frequently described as antihistamines that also have anticholinergic effects. At therapeutic doses, they are highly anticholinergic. They exert antagonistic action on the parasympathetic system and relax voluntary muscle and they are short acting.

- 1) 25 mg Promethazine HCl (Phenergan) + 25 mg pseudo-Ephedrine, Promethazine is more anticholinergic than diphenhydramine (Benadryl).
- 2) Oral dose, acts within 1 – 2 hours, lasts for 8 – 12 hours.
- 3) Side effects include drowsiness and sleepiness.
- 4) Diphenhydramine is effective in humans during turbulent flights and in the laboratory.

Sympathomimetics

Amphetamine is effective in rotating chair [17, 78] and commercial transatlantic cruises [136, 137]. However, studies using vomiting as end points reported no benefits in swing sickness, acrobatic flight transatlantic troop-ships or small craft in heavy seas [119, 128]. The differences in findings could be a result of the different duration of testing, severity of stimuli, different end-points and different motivational factors.

SECOND GENERATION NON-DROWSY ANTIHISTAMINES

Due to the unwanted side effects of drowsiness in antihistamines, there is merit to the experimental testing of “second generation” antihistamines as they do not cross the blood brain barrier. They bind selectively to peripheral H_1 receptors and are less likely to cause drowsiness and have a relatively longer duration of action. For example, a single large dose (300 mg) of terfenadine (Seldane®) was shown to have a statistically significant therapeutic effect as an anti-motion sickness drug [79]. However, over the past few years there has been increasing evidence of cardiotoxicity with terfenadine and astemizole not related to their antihistaminic potency, but due to the blockade of the delayed rectifier potassium current leading to prolongation of QTc (QT interval corrected for heart rate) and with the possibility of ventricular arrhythmias [37]. Cheung, et al. [24] reported that cetirizine (Reactine®), at dosage of 10 mg/d and fexofenadine (Allegra®) at dosage 60 mg/d did not significantly influence the amount of vestibular cross-coupling stress that subjects could tolerate before reaching the symptom of definite nausea. Furthermore, no significant difference were noted in the total number and severity of symptoms displayed. It appears that the selective peripheral actions of cetirizine and fexofenadine are of no benefit in the prevention or treatment of laboratory induced motion sickness. These research findings raise additional questions regarding the relationship between the sedative action and the anti-emetic effectiveness of the H_1 receptor antagonist.

FIELD EVALUATION OF ANTI-MOTION SICKNESS DRUGS

During a voyage traversing the Drake Passage between Argentina and the Antarctic Peninsula that took 2 – 3 days at 11 knots with gale force winds and sea swells up to 9 m [43] conducted a sea trial evaluation of anti-motion sickness drugs. Ninety-eight percent (260/265) of the passengers participated in the study, with ages ranging from 15 – 87 years (115 males and 145 females). The number of individuals and the type of anti-motion sickness drugs that were used are listed as follows:

191 subjects used medications in the following proportion and types:

- 67 (35%) used meclizine
- 60 (31%) used transdermal scopolamine
- 28 (15%) used dimenhydrinate
- 16 (8%) used cinnarizine
- 20 (10%) used acupuncture wrist bands

Their finding in decreasing order of efficacy is: Scopolamine > Meclizine > Dimenhydrinate > Cinnarizine > Acupressure.

OTHER UNCONVENTIONAL TREATMENTS

Acupuncture has been used to treat gastrointestinal symptoms in China. A commonly used acupuncture point is P6, the Neiguan point on the pericardial meridian, located about 3 cm from the distant palmar crease, between the palmaris longus and flexor carpi radialis tendons. Various forms of acupuncture therapy are available as alternative treatment of motion sickness. There are a number of studies which suggest that acupressure is effectiveness in treating visually induced sickness [66, 67] and seasickness [10]. However, commercial devices such as wristbands, sea bands and other forms of acupressure therapy have been investigated under controlled scientific studies [13, 131] and found to be ineffective in reducing nausea and vomiting as induced by motion in humans. Furthermore, Miller and Muth [96] suggested that acupressure is ineffective in treating cross coupled induced sickness.

There are many other unproven treatments offered for ameliorating motion sickness. A variety of herbal (ginger-root), homeopathic (Cocculus, Nux Vomica, Petroleum, Tabacum, Kreosotum, Borax and Rhus Tox) remedies have been proposed. In particular, some studies on the effectiveness of ginger roots have been performed. Ginger root was reported by Mowry and Clayson [100] to have prophylactic effects. In a controlled sea trial of ginger root, fewer symptoms of nausea were reported after ginger root ingestion; however, the difference was not statistically significant [57]. However, Stott, et al. [121], Stewart, et al. [120] failed to substantiate the effectiveness of ginger roots. A controlled double-blind study revealed that powdered ginger root (*Zingiber officinale*) had no influence on experimentally induced nystagmus [65]. Any reduction of motion sickness symptoms derived from ginger roots may be acting at the gastric system level. In general, most of these herbal remedies have not been found consistently effective and the various purported evidence is confusing at best. It is possible for the alternative remedies to appear beneficial by a combination of the placebo effect and habituation to the environment. It is, however, prudent to avoid any purported effective commercial devices until scientific validation is available.

BIOFEEDBACK AND RELAXATION THERAPY

Biofeedback uses operant conditioning to control autonomic responses. Physiological measures such as heart rate, blood pressure, body temperature, and galvanic skin resistance are commonly chosen as control parameters in “biofeedback” training. However, it is not clear whether a consistent and reliable relationship exists between motion sickness and these measures [35, 50, 52, 54, 55, 61, 97]. Moreover, individuals vary greatly in the extent to which they can benefit from biofeedback training. Training conducted in the laboratory situation may not transfer to operationally relevant situations, which involves active integration with other tasks [8, 93, 94, 95, 115]. It appears that biofeedback and other behavioural techniques can modify the physiological responses of some individuals and ameliorate the anxiety that accompanies certain noxious situations, but it remains to be

seen whether these responses bear a direct relationship to the symptoms of seasickness and other forms of motion sickness.

DESENSITISATION

The most suitable non-pharmacological intervention at least for airsickness in the military environment appears to be habituation to the nauseogenic stimuli. Various desensitisation schemes have been shown to be helpful for those who do not develop sufficient protective habituation during the course of normal flight training [4, 6, 20, 38, 40, 44, 53, 70, 86]. As mentioned earlier, motion stimuli tend to provoke sickness when the motion elicits patterns of sensory stimulation that do not conform to those expected on the basis of past experience. Therefore, exposure to the nauseogenic manoeuvre is essential. This exposure also provides the individual affected by motion sickness with the opportunity to improve their ability to predict the spatial sensory patterns that are generated by the spatial consequence of their actions. This ability is crucial to resolve the sensory conflicts or neural mismatch in an altered gravito-inertial environment and thus the stimulus is less able to provoke motion sickness.

Earlier studies suggested that habituation to slow (yaw) rotation to the right have been shown to result in suppression of responses to both right and left yaw rotation [50]. Rapid adapters to sudden stop visual-vestibular interaction also showed rapid adaptation to parabolic flight and rapid to average adaptation to cross-coupled stimulation in the slow rotation room [53]. Tolerance acquired using real motion (rotating chair that also tilted $\pm 40^\circ$ in the roll and pitch planes) could transfer to circular- and linear-vection [39]. On the other hand, it was shown that habituation to vertical linear acceleration did not increase tolerance to Coriolis acceleration [109]. Similarly, tolerance acquired to the cross-coupled angular motion did not result in an increase in tolerance to vertical oscillation [4]. Although there has been no sea trial to determine the degree of improvement in tolerance to ship motion that results from tolerance gained from ground-based training, Cheung and Hofer [26] suggested that that desensitization to one provocative motion could be transferred to a less provocative motion stimulus.

SOME PRACTICAL RECOMMENDATIONS TO MINIMIZE THE OCCURRENCE AND/OR DELAYING THE ONSET OF SEASICKNESS

Behavioural Measures

- 1) Be well informed about the causes of seasickness; have a thorough understanding of what sensory systems are involved and be familiar with the signs and symptoms of motion sickness.
- 2) It is useful to be familiar with one's symptom development of motion sickness on the ground, beginning with mild Coriolis stimulation, and progressively moving to more provocative and specific stimuli.
- 3) Do not dwell on past experience of seasickness (motion sickness) or worry about the occurrence of seasickness because anxiety will only inhibit habituation to the provocative environment.
- 4) For those who have a choice, but this is often not the case. An individual should not sail unless he feels fit and well. Do not go out to sea when you are hung over or have an upset stomach. Recent illness and fatigue all cause debility and adversely affect an individual's general ability in the air. They also make one prone to seasickness especially during severe sea state.

- 5) Affected individuals should discuss their symptoms of seasickness, as early as possible, fully and frankly with the on-board medical staff. It will facilitate recovery and prevent misunderstanding when the effects of seasickness decrease an individual's performance. The ship captain or whoever is in charge of the vessel or helicopter, should be aware of the cause and symptoms of seasickness could make minor adjustments, when possible, to assist the individual to habituate quickly. The affected individual should be given every opportunity to be in at sea whenever there is an opportunity for habituation/desensitisation.
- 6) Affected individuals are likely to develop some degree of anxiety about their sickness problem. Minimizing the anxiety by introducing the personnel (such as pilots/aircrew) gradually to the type of motion that might be experienced using ground-based devices (e.g. six degrees-of-freedom motion platforms) might be useful. However, it is understood that mariners may not have such privilege. In those cases, a self-desensitisation procedure such the torso-rotation technique [26] may be introduced under the supervision of a physician or medical staff, who is familiar or have been taught about the procedure.
- 7) It is useful to be involved and to concentrate on the task at hand which can minimize the introspection and attention to bodily function. This is evident by the fact that the person least likely to be motion sick is the pilot of the aircraft. or driver of the car. However, when it is not possible to be in control of the vessel, involvement in some absorbing task is better than being preoccupied with the state of one's stomach.
- 8) Do not self-medicate with over-the-counter anti-motion sickness drugs. In certain operational personnel, the attending physician may decide to prescribe some form of medication. Be aware that all the current effective anti-motion sickness drugs have side effects. These side effects include dryness of the mouth, sleepiness, and dizziness. In some cases serious visual disturbance includes double vision.
- 9) Food Consumption: The fear of seasickness sometimes results in avoidance of food intake, but experimental studies have found no evidence that the time of day of motion exposure or its relation to meal times has any effect on the incidence of motion sickness. Excessive consumption of food may be best avoided since it may increase the volume of vomitus, and therefore, both the fear of sickness and the extent of any subsequent inconvenience. It is generally agreed that vomiting is less unpleasant when the stomach contains something to vomit than an empty stomach. It is recommended that personnel should maintain a normal light consumption of food and drink.
- 10) Avoidance of Alcohol: It is well known that the after-effects of alcohol (hangover) adversely affect an individual's general ability. Alcohol can cause semicircular canal conflict by developing a density gradient with the membranous canal. It has also been shown that alcohol affects the visual feedback of target position during voluntary and involuntary head movement [7]. After the blood alcohol concentration has been raised high enough¹ and the alcohol has subsequently disappeared from the blood, it continues to have measurable effects [139] on the brain, on the vestibular system, and in some cases on blood sugar. Motion sick individuals have observed that their susceptibility to for example, air sickness, is increased by even moderate amounts of alcohol in the previous 24 hours [122], and this effect of alcohol has also been observed on tolerance to cross-coupled stimulation during desensitization treatment [4]. Of course, excessive consumption of alcohol can result in vomiting without provocative motion.

The eight-hour rule is quite inadequate for heavy drinking², since there would still be significant concentrations of alcohol in the blood eight hours after a peak blood alcohol concentration of 150 mg%.

¹ Depending on the individual and the speed of ingestion, in most cases four to six drinks, would be sufficient to raise the blood alcohol concentration over 100 mg% which is certainly high enough.

² Heavy drinking is defined as having a blood alcohol concentration of 150 mg% among occasional drinkers in a social setting.

Under some circumstances, there are measurable decrements of pilot performance even at 14 hours after a peak blood alcohol concentration of only 100 mg%. The current recommendation for commercial airline pilots is 24 hours after a blood alcohol concentration of 150 mg% before flying. For those taking anti-motion sickness medications, it is important to note the increased sedation from alcohol.

Environmental Considerations

- 1) When possible, locate critical stations or passengers seating for those who are susceptible near the ship's effective centre of rotation and align the affected individual with a principal axis of the ship's hull.
- 2) Provide optimal environmental conditions, suitable temperature and ventilation when possible.
- 3) Provide an external visual frame of reference when possible.
- 4) As far as motion sickness treatment medications, etc., there is no "magic bullet". The affected individual should consult a physician to experiment with a number of standard anti-motion sickness drugs under supervision.

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Chapter 9A – Life Rafts and Lifeboats: An Overview of Progress to Date

by

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INTRODUCTION

The most under studied, under funded item and out of date piece of equipment in the helicopter over-water operation is the inflatable life raft. This was brought to the attention of the NATO community in 1998 in an RTO paper titled “The abysmal performance of the inflatable life raft in helicopter ditchings” by this author [9]. On the marine side, the introduction of the Totally Enclosed Motor Propeller Survival Craft (TEMPSC) has been an improvement over the open “Titanic” type of life boats, but these life boats still have a long way to go in design.

In general, aviation and marine engineers and operators do not consider the life raft/lifeboat/TEMPSC in their design/survival equation. This is left as a blank box “to be filled later” with the current “approved” life raft. Naturally, when it becomes time to purchase the life raft – which incidentally is a very expensive piece of equipment, management which may not be co-located with the designers and operators, do little consultation with them. They often choose the cheapest item paying little or no attention to the integration and fit on the ship/rig/helicopter and the training of the crew and passengers. The purchased item may perform very poorly in a ditching, marine abandonment procedure although, there is nothing wrong with the life raft itself!

From time to time, worried pilots and upset coxswains contact this author and request us at Survival Systems Ltd to visit their local operation and examine their lifeboats and life rafts. It becomes blatantly obvious that a purchase order has been issued for an approved lifeboat or life raft, yet no thought has been given about integration into the helicopter, the ship or the oil rig, or indeed any specific local environmental requirement. Middle and Senior Management sit back and feel happy that the lifeboat/life raft has been purchased and approved, but at the working level everyone struggles to fit a very expensive square peg into a round hole. Requests for returns, modifications, etc., are immediately rejected until the first incident/accident/loss of life occurs. A very serious accident was recently just avoided when it was discovered that the roof of a new free fall TEMPSC compressed in on a launching. The distance of travel was enough to cause serious injury to any occupants sitting in the upper row of seats. Fortunately these were not manned on the first launch!

This self-denial attitude is common in all aspects of safety management. It has been addressed extensively by Professor Reason in his textbooks on human error and Professor Leach's textbook on the Psychology of Survival. This topic is discussed in a separate lecture in this RTO series. This is the perfect example of where human engineer consultation should be brought in at the design stage, when it costs very little to do. Implementation of design change and retooling for manufacturing at a later stage adds unnecessary costs. Band-aid solutions that don't really work are often hastily instigated, but are necessary because the high cost of re-design is prohibitive. Professor John Kozey will present a lecture to you in the series on this very problem.

A recent visit to an FPSO gas/oil rig tanker revealed that even though a TEMPSC had been fitted at the stern to allow escape of the engine room staff, there was no coxswain posted back aft to launch the boat, none of the engineers had a clue how to do it either. Until the problem was pointed out to them, they had never even thought about how to escape! There was a variety of other simple physical problems with the boat itself such as no de-icing equipment on the release mechanism and the windshield – all simple things that should have been taken into consideration when ordering the boat, indeed in the initial design of the boat.

The next section contains a reprint and modification to the original paper submitted to RTO in 1998 – “The abysmal performance of the inflatable life raft in helicopter ditchings” by this author [9].

INTRODUCTION OF THE LIFE RAFT INTO FIXED WING AIRCRAFT

The inflatable life raft or dingy was introduced into aircraft in the 1930s. The Royal Navy Fleet Air Arm and the Royal Canadian Air Force [30] suspended it between the longerons at the aft end of the biplane fuselage. Just prior to World War II, the free-floating multi-seat dinghy was added to the inventory of aviation lifesaving equipment [40]. Llano [29] reviewed 35% of the 4 – 5000 ditchings in World War II and the Korean War. He concluded that the life raft had been of great value, but in virtually every case there was reference to **a struggle to get into it**. This was only made worse if the crewmember was injured or simply exhausted. Many survivors recommended deflating the life raft before entry and/or climbing into an uninflated life raft before inflating it.

In 1965, Townshend [41] reviewed inflatable life raft performance in commercial fixed wing aircraft accidents and concluded that often the installation of life support equipment had been done as an after-thought when the rest of the aircraft design had been completed, and in many cases, imperfect installation had not improved survival. There are many similar comparisons with introduction of the inflatable life raft into helicopters post World War II.

INTRODUCTION OF THE LIFE RAFT INTO ROTARY WING CRAFT

Post WWII, once the helicopter became proven and reliable, military organizations commenced to fly them over water. There have been a steady number of ditchings, but the Boards of Inquiry appear to have paid little attention to trends, good or bad in the performance of the inflatable life raft, and until the 1990s there does not appear to have been any formal publications on their performance. With the offshore oil industry boom in the early 1970s, there was a rapid increase in the use of the helicopter to do short flights over water for servicing the rigs and transfer of crew. They also experienced ditchings and problems with the life raft became public. In 1984, Anton [4] completed the first review of the performance of the life raft in seven survivable commercial helicopter accidents in the North Sea. He confirmed the worst fears expressed by Townsend. Such problems with stowage of the life raft not close to exits in the fuselage; poor engineering designs for quick deployment; difficulty with securing the raft to the fuselage; little protection from puncture; poor design causing difficulty with entry. Like introduction into fixed wing aircraft, introduction into the helicopter had come as an afterthought from the original helicopter design. In addition, the training aircrew received was poor and virtually non-existent for passengers.

A brief review of the success/failure of launching is presented in Table 9A-1 below. Even after the life rafts were launched, Anton reported on a “rather gloomy picture” and this is presented in Table 9A-2. Thus in only one (G-BEID) of the seven accidents did the life raft perform as specified, and even in this case it was difficult to retain it to the side of the helicopter for boarding.

Table 9A-1: Life Raft Deployment (Courtesy of Dr. D.J. Anton)

G-ASNM	Difficult to launch due to weight and small exit.
G-AZNE	Pilot chose to swim to ship rather than to attempt to release life raft, helicopter sank rapidly.
G-ATSC	Launched by passengers.
G-BBHN	Unable to deploy due to inversion and raft trapped.
G-BEID	Deployed by crew, difficult to retain against side of helicopter.
G-BIJF	Life raft broke free from mounting. Not used.
G-ASNL	Both life rafts launched by crew.

Table 9A-2: Life Raft Damage (Courtesy of Dr. D.J. Anton)

G-ASNM	Punctured by contact with tail rotor. Upper compartment deflated, canopy would not erect.
G-ATSC	Life raft boarded prematurely. Boarding passengers interfered with correct inflation. Unable to top up due to lack of correct adapters. Tear in side of life raft, plugged with leak stoppers.
G-ASNL	Both life rafts punctured by contact with aircraft.

Life Rafts and Lifeboats: An Overview of Progress to Date

In 1984, the Civil Aviation Authority [38] produced 40 recommendations from the Helicopter Airworthiness Review Panel (HARP) for improving helicopter safety. This included improvements to boarding ramps in life rafts, protection from puncture and recommendations to remove external protuberances from helicopter fuselages that could snag or damage the raft.

The four U.K. helicopter operators (Bristow, Bond, B.A.H. and B. Cal.) collaborated with RFD Aviation and produced a new life raft [24]. The great advantage of the new Heliraft is reversibility, the inflated fender tube that becomes the structure for the canopy, the ease of entry and rescue from, and compartmentability in case of puncture. The entire North Sea Fleet of 150 helicopters was fitted out with the Heliraft by the end of 1995 which was no mean feat.

LIFE RAFT PERFORMANCE IN HELICOPTER DITCHINGS SUBSEQUENT TO 1983

In 1984, Brooks reviewed the Canadian Air Force water survival statistics for the previous 20 years [7]. Out of the nine helicopter accidents, there were three Sea King accidents where problems were noted. In one case, the helicopter rolled over on top of the six-man life raft and rendered it useless; in one case it was difficult to launch the multi-placed raft; and, in one case, it was impossible to launch at all. In one of these three cases, it was reported that all the crew had difficulty boarding the raft.

In 1995, the Cord Group [19] completed a retrospective examination of helicopter life raft performance in a mixture of civilian and military up until 1995 for the National Energy Board of Canada. This is quoted in total for the use of survival instructors in training establishments.

In May 1984, a Boeing Vertol G-BISO [21] was en-route to Aberdeen from the East Shetland Basin with a full load of 44 passengers and three crew. Following a flight control system malfunction, it ditched eight miles north-west of the Cormorant Alpha Rig and capsized 82 minutes after touchdown. The First Officer turned the aircraft 40° to the right of the wind to see if this would provide better conditions for launching the life rafts from the right side. However, the aircraft started to roll an estimated $\pm 10^\circ$ and the blades could be seen disturbing the water as they passed close by. The aircraft was turned back into the wind. All crew and passengers evacuated successfully. The first life raft had been launched through the forward right ditching exit with the painter secured around the arm of one of the passenger seats. After some passengers had entered the life raft through the forward right exit, it was either dragged or blown out of reach. More passengers went through the rear right exit and clambered forward along the top of the sponson in order to reach the life raft. Approximately nine passengers had boarded when the painter parted allowing the life raft to drift behind the aircraft. The second life raft was also launched through the forward right exit and the painter similarly secured. Two passengers had entered this life raft when its painter also parted and one and one-half hours later both rafts had drifted clear of the aircraft. Approximately 10 minutes later, the remaining passengers escaped through the rear right exit into the water and drifted behind the aircraft where they were picked up either by surface vessels or, by one of three rescue vessels.

In March 1985, an S61 helicopter en-route from the offshore oilrig SEDCO 709 to Halifax airport ditched following loss of transmission oil pressure [14]. All 17 occupants boarded two life rafts, but most consider themselves very lucky that they survived. It was a calm day and the sea state was also calm. The following day, there was a raging blizzard and no aircraft flew offshore. The narrative reads as follows:

“After the pilot in command had shut down the helicopter engines and stopped the rotor, he moved aft to the passenger cabin. Once he had passed the airframe mounted ELT to the passengers,

the life raft was pushed away from the helicopter. As the raft moved into the outer limit of the rotor arc, the rotor blades were striking the water dangerously close to the raft and the occupants had difficulty keeping the raft from being struck by the rotor blades. After launching the No. 1 life raft, the pilot, co-pilot and remaining passengers inflated the No. 2 life raft beside the aircraft and stepped directly into it. The raft was then pushed away from the helicopter and it drifted under the tail pylon. The three occupants had difficulty keeping the raft clear of the stationary tail rotor blades as the helicopter was pitching and rolling in the water. The No. 1 life raft had a 4-inch tear from rubbing against helo and as a result, the lower buoyancy chamber deflated. By the time the rescue helicopter arrived, the occupants were sitting in 18 inches of water.”

In 1987, the E. and P. Forum reviewed two accidents [22]. The first was a Bell 214ST helicopter (G-BKEN) that made a controlled ditching into the sea 16 miles North of Rosehearty, Scotland (15 May 1986). Eighteen passengers and two crewmembers successfully transferred to two life rafts. The second accident occurred in December 1986 and was just survivable. In this case, a Puma 330J flew into the sea off Western Australia, it overturned rapidly and sank, and no life rafts were deployed. Thirteen of the fifteen crew and passengers escaped and were rescued from the sea. This latter accident emphasized the point that in a poorly controlled ditching in very turbulent water, the likelihood of deploying life rafts, which are stowed within the fuselage is virtually impossible [8]. Moreover, if the helicopter is inverted and flooded, no one can proceed backwards underwater to release the life raft from its stowage.

In March 1988, a Bell 214ST helicopter (VH-LAO) [6] ditched off Darwin, Australia rapidly flooded and inverted. The two 12-man life rafts, which can be released by the pilots from the console in the cockpit, were not deployed because the rotor blades were still turning. It was too late and not possible to do it later with the rapid flooding and inversion. So, 15 passengers and crew evacuated into the sea. The crew then decided to duck dive into the fuselage to get one raft out. After several attempts, this was successful. After it was inflated, five to six survivors got onboard, then the bottom flotation tube was punctured by contact with one of the helicopter doors. The raft then partially filled up with a mixture of seawater and Avtur making everyone violently sick from the fumes. The raft could accommodate no more than six survivors in this punctured condition. The rest of the survivors remained in the sea for approximately one hour and ten minutes before rescue.

In October 1988, while on a SAR mission off the northwest coast of Scotland, the pilot of a S61N helicopter G-BD11 became disoriented, and the helicopter struck the sea and immediately rolled over [1]. The life raft inflated as advertised, but the boarding ramp was very slow to inflate, rendering it useless at the critical time that it was needed. Once on board, it needed the combined effort of the four survivors to free the canopy from its stowage. An analysis following the accident revealed that an incorrect procedure had been conducted, and that the painter line should have been cut before attempting the canopy erection.

In November 1988, an S61N helicopter (G-BDES) was tasked on a non-scheduled public transport service from Aberdeen to three oil installations [20]. On return to Aberdeen, it suffered a sudden loss of main transmission oil pressure and the pilot had to ditch ninety miles North East of Aberdeen. The two pilots and four passengers scrambled onboard the first life raft after activating the external release lever, but the remaining seven passengers were unable to reach or deploy any life raft; they spent 41 minutes in the sea before rescue. The co-pilot in the raft had to fend it off from an aerial and the tail rotor which both came close to puncturing it.

In 1989, the E and P Forum reviewed a further three more accidents [23]. The first was a S61N helicopter (G-BEID) en-route from the “Safe Felicia” in July 1988 that did a controlled ditching off Sumburgh, Scotland.

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With rotors fully run down, the forward cabin passengers egressed with no problem, but the passengers in the rear cabin had difficulty launching and boarding their life raft. Ultimately, two crew and nineteen passengers were rescued.

The second accident was a Super Puma (LN-OMC) that ditched in the North Sea also in July 1988 and floated for ten minutes. The first life raft was blown by the wind against the fuselage and rendered useless. All 18 passengers and crew evacuated into the second life raft.

The third accident was a Bell 206 EI that ditched in February 1987 into the Gulf of Mexico in a six to eight foot sea. The sharp corner of the front door punctured the life raft rendering it useless. The pilot and passenger remained onboard until rescued by boat.

In 1989, Reader [35] published the British military experience with 94 helicopter ditchings for 1972 to 1988. He reported that the biggest problems with safety and equipment in order of frequency were:

- a) Problems with life raft inflation;
- b) Inadequate seat belt restraint; and
- c) Loss of a life raft.

There were ten accidents where he specifically cited difficulty with life rafts (Sea King – 4; Wessex – 5 and Wasp – 1) and in a further seven Sea King accidents, he noted that all the life rafts were lost.

In November 1991, a Bell 214ST (VH-HOQ) with fifteen passengers onboard departed the Skua Venture helipad for Troughton Island, Australia, but through mechanical problems had to ditch barely twenty feet above the pad [5]. The pilot made a controlled water landing and deployed flotation bags. The co-pilot activated the two life rafts, which were both launched. However, only the starboard one cleared the floats and inflated. The port life raft slid into the water and did not inflate automatically. One of the survivors while still in the fuselage pulled on the life raft painter and inflated it. Whereupon the 17 crew and passengers evacuated into the two rafts. At this point, the starboard float burst, the helicopter rolled over and the rotor blades came down on top of the starboard life raft. The Lady Cynthia's rescue boat came to the rescue and towed the life raft clear of the blades before rescuing the survivors.

In March 1992, a Super Puma (G-TIGH) shuttling 15 passengers from the Cormorant Alpha platform to the accommodation vessel "Safe Supporter" 200 hundred metres away crashed into the sea only 47 seconds after lift-off [2]. The life raft in the right cabin door was released from its stowage, shortly after the door had opened on impact, the inflation probably being initiated by the short painter. It suffered major damage. It did, however, inflate at least partially and provide support for possibly six personnel. Because it was so badly damaged, it was extremely unstable in the water and overturned on several occasions. The second life raft, under Seats No 5 and No 6 adjacent to the left cabin door, was not deployed. One crew and ten passengers perished. This precipitated a further examination by the C.A.A. of helicopter offshore safety.

In 1993, the F.A.A. [16, 31] published two reports on 77 rotorcraft ditchings between 1982 and 1989. The National Transportation Safety Board investigated 67 of them and the U.S. Army investigated the remainder. In the first report, there was only a small observation section on the availability, use and performance of person flotation equipment. The details on the performance of life rafts were very scant. Out of a total number of 204 occupants, 111 used some form of personal flotation device and only 24 made use of a life raft. The overall summary was that in the cases studied, the people did not generally use life rafts. In the second report, the findings were as follows:

“Life rafts stored near the chin bubble are often lost when water flows out the chin bubble. The rapid overturning of the rotorcraft requires occupants to egress immediately rather than locate the life raft then egress. The effects of wave action on the floating helicopter often preclude re-entry for the purpose of extracting the life raft. Re-entry is not advisable with current systems because of the frequency of delayed separation of the floats from the rotorcraft. Access to the life raft should be improved in the common event of the overturned helicopter. Locations to consider include exterior of the rotorcraft, exterior access panels, near the rotorcraft floor by an exit and integrated with the flotation system.”

In March 1995, a Super Puma helicopter (G-TIGK) en-route to the East Brae production platform experienced a tail rotor lightening strike and the pilot conducted an immediate ditching [3]. The 16 passengers and two crewmembers made a miraculous escape into one life raft. Unfortunately, the second life raft was deployed and blew up against the side of the fuselage and was rendered useless. Also in 1995, a Bell 214ST helicopter ditched in the Timor Sea and immediately rolled over. The two pilots onboard egressed safely, but one had to dive back into the fuselage to release the life rafts.

Finally for 1995, the Civil Aviation Authority [18] published their review of helicopter offshore safety and survival. The findings related to the life raft were:

“As a result of previous shortcomings in the performance of life rafts carried in helicopters, the new ‘Heliraft’ was developed in 1985 and is now in service throughout the offshore fleet. Its reversible design is sandwiched between and a hood, which can be erected on either side, with all equipment and attachments duplicated; it thus avoids the problem of accidental damage (as was demonstrated in the Cormorant Alpha accident), is of a size and weight that permits it to be handled by one person in reasonable wind and sea states, and is more readily boardable by survivors from the sea by means of a ramp and straps.”

PROGRESS POST-1995

When a helicopter ditches and the crew and passengers have a matter of a minute to make a decision, they have four options how to evacuate the fuselage into the life raft. The first choice is on which side to abandon the helicopter, the leeward or the windward side. Attitude and direction that the helicopter has landed on the water during the accident may have predetermined this choice. Exiting from the leeward side causes more difficulties with clearing the life raft from the fuselage and the strike envelope of the blade because the helicopter will drift quicker than the human can paddle, whereas exiting on the windward side causes more likelihood of the life raft being blown up against the side of the fuselage and difficulty with keeping it close to the side for entry.

The second choice is whether to inflate the life raft immediately on launching and wait the critical 30 seconds for full inflation prior to boarding in a dry condition (dry shod or dry method), or to launch the life raft in its package using the first survivor out to swim it clear of the strike envelope prior to inflation, each subsequent survivor swims out along the painter to join the first one out (wet shod or wet method).

Because no formal scientific evaluation had been completed on the problem, the National Energy Board of Canada tasked the CORD Group to evaluate the current training standards, the direction of evacuation and the two techniques for inflation, the dry method or wet method. The first experiment conducted using the Nutec Super Puma helicopter simulator in the Bergen Fjord [12, 19] recommended that the dry method be taught as the method of choice. The wet method should be taught as an alternative method in case there is no time to

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wait for the life raft to inflate and the helicopter is potentially about to capsize. Evacuation, wherever possible, should be conducted on the windward side and that pilots required more realistic training than simple wet dinghy drills in the swimming pool.

A second series of experiments [13] were conducted to increase the subject data pool from the first experiment and to evaluate the advantages and disadvantages of using both the traditional aviation life raft and the new RFD Heliraft. The original findings from the first experiment were confirmed. In addition, it was concluded that the Heliraft had many distinct advantages over the traditional raft: it was reversible and needed no righting and it was far easier to enter from the pitching helicopter. It was noted that both styles of life raft needed relocation of the painter to insure the life raft hauls up tight to the fuselage without the boarding ramps in the way. Finally, in order to assist training of aircrew, a ditching survival compass was designed for decision making as to which side of the helicopter and which method of evacuation should be used.

In January 1996, the Norwegians had a Super Puma LN-ODP accident into the North Sea [26]. In four metre seas, the crew first deployed the starboard life raft on the windward side where it was blown on its side up against the fuselage. The crew then decided to deploy the second life raft on the port side. This life raft was launched on the leeward side and a dry evacuation was attempted. It was impossible to paddle the life raft clear of the fuselage because the helicopter drifted faster than the survivors could paddle. As a result, the life raft was struck by the tail rotor, was punctured and sank. Those already in the raft then swam back to the still floating helicopter (one passenger nearly drowned when pushed underwater by the tailskid). Once back in the fuselage and after much effort, the pilots forced the original starboard life raft down onto the water, but in the process of cutting the entangled sea anchor, inadvertently cut the painter. As a result, the survivors nearest to the door did not have the strength to hold it in position close to the fuselage because the helicopter was drifting faster than the life raft; only three survivors and one pilot were able to get into it before it drifted clear on the windward side. The personnel in the life raft were hoisted by a rescue helicopter before the remaining pilot and 13 passengers were hoisted from the floating fuselage 50 minutes after ditching.

In 1996, Kinker, et al. [28], completed an analysis of the performance of US Naval and Marine Corps life raft performance over a 19-year period. Mishaps involving the AH-1, UH-1, H-46, H-53 and H-60 helicopters were studied between 1977 and 1995. They also confirmed the poor performance of the life raft. In only 26% of the 67 survivable over-water accidents was the life raft deployed. They further concluded that for the last 20 years there has been a unique and dangerous circumstances surrounding raft accessibility and helicopter egress which had not been addressed. Life rafts were too large and cumbersome, not only to lift, but to fit through emergency exits; they were inaccessible for rapid launching and often positioned 10 to 15 feet from the visible exits; and, even if launched, in the case of the multi-placed raft, often float several feet underwater before inflation (if the inflation ring has not been pulled), so making locating the raft difficult.

DISCUSSION

A literature review of the performance of the aviation life raft in helicopter ditchings has been presented. Records just post-war are scant, but in the last 20 years more complete. It is clear from the more recent civilian and military data that modified inflatable marine raft has simply been fitted into the cockpit and/or fuselage of the helicopter as an after-thought following the design of the helicopter.

Thirteen years ago, the first purpose built helicopter aviation raft was put into service. This has only partially solved the problem because there has been no regard for the human dynamics involved in the requirement for split second decisions in the ditching process, and the problem with difficulty with boarding is just as serious as it was when the original marine inflatable life raft was introduced 60 years ago!

In 50% of accidents, the helicopter will capsize and sink rapidly and, in the remainder of the cases, balance precariously on the water surface. The crew and passengers are thus faced with imminently drowning from the in-rushing water. This is compounded by disorientation from inversion and inability to see underwater, inability to locate levers to jettison doors and hatches and worst of all, a 50% reduction in breath holding ability in water below 15°C [11, 17, 25]. There is no time left for them to locate a life raft, struggle to maneuver it to an exit, which is often at some distance away, heave it out and wait for inflation. Even when it is inflated, it is not easy to board or be rescued from, and while tethered to the helicopter runs the serious risk of puncture from sharp edges on the fuselage or a blade strike. There is now good evidence to support these comments.

Anton's series reported only one out of seven accidents where the life raft worked as advertised. Brooks and Reader both reported problems with Canadian and British military life raft deployments. The data presented in this paper of 15 civilian helicopter accidents between 1984 and 1996 shows that only one accident in which the life rafts worked as specified; and finally Kinker and his colleagues published the USN/Marine data over the last 19 years where the life raft was utilized only 26% of the time.

Considering the rapid advance in technology for the helicopter engines and airframes, the life supports systems have not only lagged behind by 40 years, but in recent years have not been considered in the fundamental design of new airframes. Two approaches should be taken, first consideration be given to keeping the helicopter or a portion afloat and using this as the primary safe haven for the crew and passengers from drowning and hypothermia (and there has been some preliminary work on this); however, this does not solve the problem of the fly-in where a life raft is necessary or for capsizing in heavy sea states. In this case, a whole new concept is required to design a person-mounted life raft that may incorporate personal flotation and hypothermia protection, and most important of all be easy to board, and be strong enough to resist puncture. NATO countries, in conjunction with helicopter manufacturers and human factors research laboratories, should jointly fund such a programme.

One would have thought that all that had happened and been written about the philosophy for when and when not to evacuate the helicopter into the life raft and the unsuccessful performance of the inflatable marine helicopter life raft over the last 25 years, that things should have been improved by now. This does not seem to be the case.

**State Supervision of Mines
Health & Safety Information Bulletin
21st November 2006
NOGEPA rescue helicopter**

“As a result of a total power failure on a offshore platform on the evening of 21 November 2006, 13 persons were evacuated from the platform to Den Helder, departing from the mobile drilling installation that was located adjacent to the platform (and was connected to it by a bridge). During the evacuation, the NOGEPA rescue helicopter used for this purpose (call sign G-JSAR), had to make an emergency landing on the sea around 23.30 hrs due to technical problems, approximately 12 nautical miles to the North West of Den Helder. All passengers and the two pilots left the helicopter by jumping into the sea. The two other crew members were able to activate a small life raft and made use of this. After 75 minutes, all passengers, pilots and crew members were rescued and taken to a safe location by a ship belonging to Rijkswaterstaat [the Directorate General for Public Works and Water Management]”.

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So this is the state of affairs at present. It is rumored that there is a new square section in development by a French manufacturer, but no one has seen this in operation yet. In summary, the key issues for helicopter operators, some of which are under investigation at present are:

- Consideration to make the helicopter float. The Civil Aviation Authority are looking into the potential of side floating helicopters.
- If this is not feasible and there is a future for the helicopter aviation life raft, then:
 - a) It should be stowed external to the fuselage.
 - b) Positioning of painter lines should be carefully thought out and maybe have to be made interchangeable depending on the helicopter type.
 - c) Boarding the life raft from the open ocean is very difficult and an improved system is needed. Don't believe the manufacturers when they say it is easy to board their life raft – it may be easy in a warm swimming pool and this gives students a false sense of security!
 - d) Erection of the canopy, particularly in any increase in sea state and wind conditions is either very difficult or impossible especially with cold hands or gloved hands. New designs are required.
 - e) The life raft must be designed as an integrated part of the whole helicopter operation, i.e. stowage, deployment, and the steps to conduct a dry shod or wet evacuation from the cockpit and the cabin, wearing different types of immersion suits, and under typical weather conditions, sea and air temperatures.

ISSUES WITH THE TEMPSCs

Structural Problems

All appeared to be well with the design of the new totally enclosed motor propelled survival craft (TEMPSC) until the Alexander Kielland and Ocean Ranger accident. Certainly in the former and likely in the latter, the “off load” release mechanisms proved totally unsatisfactory [32]. Since then there have been a number of accidents where people have been killed because of problems with the on-load release hooks. Through premature or unexpected opening, one or both hooks lets go. Thus the lifeboat becomes suspended vertically or drops completely into the water. A lifeboat incident study was done by OCIMF, INTERTANKO and SIGTTO in 1994 and 2000 [33]. The causes of the accidents were:

- a) Design fault;
- b) Equipment failure;
- c) Failure to follow correct procedures;
- d) Lack of proper communication;
- e) Lack of proper maintenance; and
- f) Lack of proper training.

In 2006, a large study was conducted by Burness Corlett for the British Maritime Coastal Agency [34]. They concluded that the unstable nature of some current hook designs is a direct cause of many serious and fatal lifeboat accidents; and it is entirely possible to design an on-load release hook which has stable characteristics.

Incidents continue to happen and six free-fall lifeboats on the Kirstin platform in the Norwegian Sea and the Vesle Grikk B platform in the North Sea sustained structural damage during testing [39]. Furthermore, 56 lifeboats have been re-enforced since June 2006 following the roof compression problem alluded to earlier.

In summary, we still have a long way to go in the design of new lifeboats and considerations that humans have to operate them and survive in them for potentially many hours.

Human Factors Problems

Manufacturers have forgotten that humans have to drive them and that there is a requirement to sit in them for many hours as survivors. Also, the regulators, the International Maritime Organization (IMO) are using out-dated anthropometric data for allocation of seat space and weight allowance.

The book “Rescues on the High Seas” is highly recommended to all course attendees and survival instructors [15]. This describes what really happens in the life threatening situation of rig abandonment into a TEMPSC. This will set the scenario for what human requirements are essential on board a TEMPSC. It might encourage manufacturers to consult with more human engineers and operators of lifeboats before finalizing the design of a lifeboat. For instance, in some lifeboats the coxswain has to sit athwartships in the vessel – what sense is there in this? In some lifeboats, in order to obtain approval for a certain maximum load requirement, all sorts of nooks and crannies have been assigned as seat positions and an appropriate set of colored seat harnesses have been screwed to the bulkhead. In these positions, even a gnome in an immersion suit would have difficulty fitting in there! Below is an excerpt describing the difficulties experienced by people immersed in water trying to board a life raft:

Seward Phoenix Log, August 21, 1997

By Roger Kane

Sail S Sank in Bering Sea (Tug)

“A patrolling C-130 happened to be in the area and dropped life rafts and we made some effort to get into the life rafts, but we couldn’t. The rafts are almost impossible to board, especially if you are in a weakened state.”

In 2006, SOLAS regulations require every person on board a cargo ship to be provided with an immersion suit. This is an excellent step forward. But, it has created several problems. The first is that the space and weight allocation defined in the 2003 IMO Life Saving Appliance (LSA) Code [27] are too low. The 430 mm buttock width and 75 kg average weight were established many years ago, before people started to grow taller and expand their girth. For many years now, most survival training schools have realized that it has not been possible to load any of the lifeboats to full capacity, even when the students were just wearing work coveralls and no lifejackets. So the addition of the immersion suit only compounds the problem.

In 2005, a typical maritime offshore oil training class of 41 people was measured in Dartmouth, Nova Scotia (39 male, 3 female) [10]. Their ages ranged from 18 – 56 years. Over 70% of the group measured in **work clothes only** exceeded the 430 mm space allocation at the hips, and the shoulders were even wider. The average weight was 87 kg, 12 kg over the IMO specification.

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Currently there is an impasse between the ship owners, the manufacturers of the lifeboats, and the IMO on revision of the LSA Code. IMO has postponed any action until 2008. What more can I say!

Work has also been done at Survival Systems Ltd. by Reilly, et al. [36, 37] on the decrease of functional reach when wearing immersion suits inside a TEMPSC [10]. The important findings critical for lifeboat and immersion designs are:

- 1) Wearing the immersion suit produces a significant reduction in the maximum reach envelope in regions other than immediately in front of the worker.
- 2) Measure of circumference yield the largest increase followed by vertical measures, breadths, and lastly depths.
- 3) The heavier the individual, the less of a contribution the suit makes to the increase in circumference measurements.
- 4) Suit sizing for the smaller subjects should be reviewed, as there is excess material in regions of the chest and waist circumference, in particular.
- 5) If boots are designed to be integrated with the suit, boot sizing is critical because it dictates the suit size.

The lecture started off noting the poor progress made with the development of the lifeboat and inflatable life raft. Two more accidents were reported in the Safety at Sea journal in May 2006 and July 2006. How many more lives will be lost before our regulators and industry get serious about improving the safety standards.

CHIRP Report No.200140

“During a routine drill the brake lever arm dropped to its stops and there was no braking effect whatsoever. The boat ran down to the water and was dragged alongside at 16 knots. The painter was ripped free, the forward falls torn away, and the boat was struck by the propeller...This is another unfortunate case of the failure of a lifesaving device now more noted for mechanical problems, injuries and deaths, rather than lifesaving.”
(Safety at Sea May 2006)

There rests my case.

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Chapter 9B – All You Need to Know About Life Jackets: A Tribute to Edgar Pask

by

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FROM BIBLICAL TIMES TO THE MID 1800s

For full details on the development of life jackets you are referred to *Designed for Life – Life jackets through the ages* by this author [4].

It may not surprise you to know that pneumatic life jackets have been in existence since biblical times. There is a stone carving in the British Museum showing Assur-Nasir-Pals' army crossing a river or moat to attack a castle in 870 B.C. The soldiers are wearing inflated animal skins. It may also not surprise you to know that when the Dalai Lama escaped across the Bramaputra River in 1959, he also used inflated yak skins for flotation.

However, while impressments existed (that is where sailors were forcibly 'pressed' into service in the Royal Navy), the provision of flotation devices was not encouraged. To provide a life jacket gave the sailor the potential opportunity to escape and swim ashore. The Admiralty argued that if the ship sank, there was plenty of buoyant material on which to float or cling on to, i.e. masts, spars, wooden water barrels. The policy of impressments was not discontinued until 1815.

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So there was little development of the life jacket until the mid 1800s – but by 1811, such features as the importance of fitting the crotch strap had been recognized in life jacket design such as Mallison's Seamen's Friend and Bathers companion. 200 years later the lesson of the crotch strap has still not been learned. Three experienced and well equipped yachtsman drowned because their life jackets failed them due to lack of a crotch strap. [9]

All three crew of the British yacht 'Ouzo' were found to have drowned following a 'close proximity incident' with a car ferry in August 2006. Given the favourable sea state (3-4) with a water temperature of 18°C, and the optimal amount and type of clothing they were wearing, a survival time of at least 24 hours could have reasonably been expected. Sadly because they were not wearing crotch straps on their 150N lifejackets, the jackets had slipped up the torso, thereby altering their flotation angle to near vertical, resulting in drowning when consciousness was significantly impaired from hypothermia (Golden, personal communication).

ADVENT OF IRON SHIPS (1850) UNTIL THE TITANIC ACCIDENT (1912)

The first serious decision to manufacture life jackets in quantity was precipitated by the loss of 20 out of 24 river pilots on the River Tyne in the U.K., when their boat capsized in 1851. Capt. John Ross Ward did the first human factors study of different methods of flotation, experimenting with cork, hair, rushes and air. This resulted in the National Life-Boat Institution introducing his own patent cork life jacket which had 24 lbs of buoyancy. This design remained in service even after the Second World War – one hundred years later!!

The introduction of iron ships in the 1850s meant that (a) the ships sank faster and (b) there was little flotsam and jetsum to provide flotation. As a result, marine drowning statistics promptly increased. In 1852, the U.S. was the first country to introduce legislation requiring the carriage of lifejackets for every passenger on board commercial vessels. Slowly the remainder of the maritime world followed suit – Britain (1888), France (1884), Germany (1891), and Denmark (1893).

In 1902, Kapok, the fluffy seed hair of the Bombax tree was first approved as a flotation medium by the U.S. Coast Guard. It has had a checkered career: it is very comfortable to wear and it provides good buoyancy; but if squashed flat, which commonly occurs when stowed in tight compartments, or sat on frequently, which is often the case, then the Kapok rapidly loses its buoyancy. It also loses its buoyancy when exposed to fuel oils such as occurs in marine accidents where there has been a fire and or explosion. Now, it has generally been replaced by various synthetic foams, but is still approved for use in some countries.

In 1904, the General Slocum, a New York Long Island ferry, set afire and beached. 955 people drowned and the investigation revealed that 8 ounce iron bars had been inserted into the cork life jackets to make up the required production weight of the life jacket! Not only this, but many of them were so rotten that upon ship abandonment, the seams split and the granulated cork simply spilled into the water. This is why many countries still insist that a certain number of inherently buoyant life jackets in each batch produced are cut open and examined to check the quality of inherent buoyancy, and ensure that history does not repeat itself.

In 1912, 1480 crew and passengers drowned after the sinking of the SS Titanic off the coast of Newfoundland. The Maritime Nations finally convened, and formed the International Maritime Organization (IMO) and more specifically, the Safety of Life at Sea Committee (SOLAS). A new international regulation was introduced. This required that all commercial vessels carry a 15.5 lb buoyant life jacket for every crew member and passenger.

THE FIRST WORLD WAR (1914), THE SECOND WORLD WAR (1939), AND THE INTERVENING YEARS

In 1914, the Empress of Ireland sank in the Gulf of St Lawrence off Rimouski in 14 minutes. 1012 crew and passengers drowned. There were plenty of life jackets, but in the confusion of a very dark and hurried ship abandonment, many could not locate their life jackets; and many who wore them were found floating *face down* in the water. No one paid much attention to this most significant observation.

During the First World War, the Royal Navy lost 12,000 sailors, the British Merchant Navy lost 10,000 seamen, and the German Navy lost 5,000 sailors. The general mentality was still that loss of life was fate and an occupational hazard. In 1915, the Carley Float was introduced. This looked like a life raft and was constructed around an oval tubular frame covered in canvas. The floor was filled with a grating which flooded freely, and there were becketed lines strung around the outside of the float. The idea was that very sick people could sit inside the float (still up to their waists in water!) and the more healthy people could cling to the becketed lines on the outside. This principle of floating people **in** the water rather than **out** of the water was Royal Navy teaching up until the 1950's! It was general policy up until the end of the Second World War that ship's companies were issued Carley Floats for ship abandonment.

The US Navy introduced head support for their life jackets in the 1920's. When the SS Vestris sank in the Chesapeake Bay in 1928, 112 crew and passengers drowned. Yet again, it was noted that they were all wearing cork block life jackets, but floating *face down*. The Captain of the USS Wyoming recommended to SOLAS that a US Navy style head support would be helpful and should be included in the specifications for new commercial life jackets, but again, no one paid any attention to this fact.

The Royal Navy went to War in 1939 with a crude Admiralty Pattern 14124 inflatable life ring which provided about 8.5 lbs of buoyancy. Up until then, no one had examined the behavior of an unconscious human in the water. This was to change quite suddenly.

The loss of precious RAF fighter pilots who drowned during the Battle of Britain was the catalyst to conduct research and look into the problem. They wore the Mae West, which was considered to be **the** best life jacket. It had about 15 lbs of inherent buoyancy and 20 lbs of inflatable buoyancy from the CO₂ cartridge. However, the Air Sea Rescue services found the pilots lying *face down* with fully inflated life jackets. How could this be?

This resulted in the pioneering work of Macintosh and Pask on the behavior of an unconscious human in the water with and without a life jacket. In 1940/41, Pask was anaesthetized, intubated and lowered into the deep end of the Farnborough swimming pool [10, 11]. Much to everyone's surprise – he sank! Over many weeks, he was fitted with all the different allied and enemy life jackets to assess flotation angle, self righting capability and times, and freeboard. Due to his selfless dedication to human service, one can honestly say he is the father of the modern life jacket. All of the SOLAS, ISO and other standards stem from this work. Due to the secrecy of the War work, it was not published in the British Journal of Industrial Medicine until 1957 [9, 10, 12]. However, the potential dangers to which he exposed himself were entirely understated in the paper. The British Standard BS3595 introduced in 1963 was the culmination of all this work for the commercial marine operators. It has basically been copied and modified worldwide ever since.

Concurrently with the loss of the British fighter pilots, the Luftwaffe noticed that they had also drowned many of their pilots. Their very efficient Air-Sea Rescue Service considered that many of the deaths occurred

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around or shortly after rescue and correctly assumed it was some form of post-rescue collapse (see lecture on the dangers of sudden unexpected immersion in cold water). This observation led to the unfortunate Dachau experiments. However, after the sinking of the Bismark, Lt. Kentrat in U-74 who was first on the scene noted that at least 40 corpses were bobbing up and down in their life jackets with their heads *face down* in the water. The Kriegsmarine immediately modified all of the Naval life jackets to provide better self-righting and added head support. All of Pask's experiments demonstrated that the design of the German life jacket was far superior to anything worn by the Allies.

THE PRODUCTION OF THE NEW INFLATABLE LIFEJACKET (1946 – 1960)

In 1946, the Royal Navy Talbot Report concluded that 30 – 40,000 officers and men had died at sea during the Second World War. One third had been killed in action and two thirds had drowned in the survival phase. This was principally due to poor survival equipment. As a result, the Royal Navy Personnel Research Committee undertook an extensive research programme which included the work of Pask and work at the Royal Navy Medical School, several UK University laboratories with an interest in cold water physiology, the Medical Research Council and Industry interested in producing new survival equipment. From this was created the new RFD Admiralty pattern 5580 inflatable life jacket; a marvel in design simplicity, performance and durability. It was introduced into the Royal Navy in 1952 and has been copied all over the world, and is still in service in 2007.

In the early 1950s, the US Navy also concluded that the majority of their drownings at sea had been due to poor equipment. They too conducted three very large trials and introduced a copy of the RN pattern 5580 life jacket in 1955. The only other Naval development since then has been issue of the 275 Newton Hazardous Duty type life jacket for the Royal Marines, the addition oro-nasal splash protection and improvements in manual and automatic inflation devices for all lifejackets.

DEVELOPMENT OF COMMERCIAL STANDARDS (1960 – 2007)

As recreational boating became more popular, there were more people out on the water with a consequential increase in civilian drowning statistics. By 1971, the US Coast Guard recorded 20.2 deaths per 100,000 registered boats. It commenced a series of studies between 1969 and 1974 to look at human performance in the water with different levels of flotation. [3, 5, 7, 8]

In 1973, it introduced the 70 Newton (15.5 lb) Personal Flotation Device (PFD) Standard into the recreational boating community. This has been an outstanding success and by 1993, when it changed the method of reporting, the drowning statistics were reduced to below 4 fatalities per 100,000 registered boats.

The next step was for all the National and International Regulators to introduce new standards based on the work of Pask, that of the RNPRC and the U.S. Coast Guard studies. Briefly these are:

- 1973 US Coast Guard Type I – Type 5 PFD standard.
- 1975 Air Standardization Coordination Committee – 35 lb pneumatic life jacket in one action.
- 1974/84 5th IMO SOLAS Convention – approval for inflatable life jackets, self righting in 5 seconds and 120 mm freeboard.
- 1976 US Coast Guard UL1191 components for life jackets.

- 1990 US Coast Guard UL1123 Marine Buoyant Device.
- 1994 ISO/CEN standards for 50, 100, 150 and 275 Newton life jackets.
- 1995 US Coast Guard U.L.1180 standard for inflatable PFDs.
- 2003 Amalgamation of all ISO/CEN standards under one standard.
- 2003 New IMO/SOLAS life jacket standard.

REMEMBER – IT IS VERY EASY TO DROWN

The basic drowning statistics can be found in Bierens – Handbook of Drowning [2]. It is a new book published in 2006. This is highly recommended for all survival instructor and maritime aircrew. It only takes the inhalation of 150 mls of sea water to drown. The average worldwide drowning statistics are 7.4 per 100,000 population. By comparison, it is 13.1 in Africa, 4.4 in Brazil, 1.9 in the Netherlands, 1.4 in Australia and 1.2 in Canada. A second new book produced by Dr Peter Barss in 2006 for the Canadian Red Cross is called Drowning – Ice and Water Immersion, a ten year study. This extends the information in the Bierens book and is also highly recommended [1].

This paper was being revised ahead of time for the R.T.O. publication. On the day of completion, this article appeared in the local newspaper.

**Fisherman dies after falling overboard,
The Chronicle Herald, Halifax
July 9, 2006**

A 35-year-old man is dead after falling off a fishing vessel near Newfoundland. The vessel was about 25 kilometres off Bonavista when search-and-rescue officials were called Saturday at around 12:30 p.m. A Cormorant helicopter was dispatched from Gander, Newfoundland, as well as a Coastguard vessel and a fast rescue craft. The body of the man, who has not been identified, was found about two hours later. He was not wearing a lifejacket. RCMP have taken over the case and are investigating.

I am sure you read the same articles in your papers too. What an unnecessary waste of a life, a huge domestic/social catastrophe for the family, and of course a huge expenditure of precious funds to conduct the search and then conduct the investigation. This could have been prevented by the use of a life jacket. Why do we still not learn?

The front cover shows Dr. Dick Allan wearing the Crewsaver Crewfit lifejacket while sailing single handed many miles offshore. He clearly demonstrates that a modern life raft is comfortable, efficient and causes minimal restriction to body movement.

SO WHERE ARE WE IN 2007?

Considering that no progress was made on the understanding of how a human floated in water for the first half a million years, we have done well to progress this much since 1945 – but we must not rest on our laurels!

All You Need to Know About Life Jackets: A Tribute to Edgar Pask

There are still over 140,000 open water deaths each year [6]. What are the issues that still need investigation and resolution?

- The relationship between the fit of the life jacket and freeboard.
- Should testing be done in turbulent water rather than still water?
- If so, how turbulent should it be?
- The importance of designing life jackets and immersion suits together as an integrated unit.
- Emphasis on the importance of:
 - a) Face/airway protection; and
 - b) Use of crotch straps.
- If humans are used for testing life jackets for approval:
 - a) How many subjects should be used?
 - b) What should be the male/female ratio?
 - c) What should be the anthropometric sizes?
- The development of a good system to test infant (under 10 kg) lifejackets.
- Should manikins be used for testing life jackets?
- If reference life jackets are used for comparative testing, how should they be validated in the first instance, and indeed after use should they be revalidated after a set time or number of immersions?

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Chapter 9C – Immersion Suits: Their Development

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INTRODUCTION – BIBLICAL TIMES UP UNTIL 1939

For an extensive review of this immersion suit topic, please refer to Brooks “Survival in Cold Waters – Staying Alive.” [5] It is quite astonishing that over the centuries, thousands of humans have drowned in cold water. It is only in the last 50 years that anyone has taken this death toll seriously. Death was attributed to drowning from an inability to stay afloat and attributed to vague terms, such as exposure. This is because death at sea was, and to some degree still is taken for granted. According to the International Labour Organization, Fishermen experience 24,000 deaths each year. They simply consider it as an occupational hazard and fate [20]. Until post-Second World War, any attempt at protection was to float the person in rather than out of the water.

Since biblical times, there was a vague understanding of the dangers of cold water immersion, but little positive action was taken by Maritime Nations. As stated above, loss of life at sea was accepted as fate and an occupational hazard. Wrecking was not made illegal until 1807 and the Royal Navy’s use of impressment was not abandoned until 1815. Thus, such items as lifejackets and immersion suits, which could be used to aid escape from impressments were not encouraged.

Little specific design of immersion suits was conducted until the middle of the 19th Century. The only work on survival equipment had been the pioneering work of Captain John Ross Ward. He developed a life jacket in 1851 for the National Lifeboat Institution [21]. Then in 1869, Captain Stoner invented a patent life saving apparatus, which was revolutionary for the time and addressed all the fundamental modern day requirements of a survival suit; they were all designed and integrated together. It included a waterproof suit, a lifejacket, head protection, a signaling device and paddles for aiding passage through the water.

In 1912, no one paid attention to the observations by Lawrence Beesley [3]. He was a survivor from the Titanic who noted that the victims wearing lifebelts and in cold, but calm water had died of cold. The official cause of death was given as drowning. The International Maritime Organization Safety of Life at Sea (SOLAS) Committee was formed directly as a result of this accident, but no thought was given to personal thermal protection. Everyone was obsessed with floating in and not out of the water. At the outbreak of the Second World War little serious research had been conducted on lifejackets, the behavior of an unconscious person in water and virtually nothing on survival suits.

PHYSIOLOGICAL STUDIES CONDUCTED IN EUROPE AND NORTH AMERICA 1939 – 1945

Basic immersion suits were developed by the Royal Canadian Air Force for their Trans-Atlantic ferry pilots and Frankenstein’s in the UK for their Hurricane pilots on the Murmansk convoys [1]. They were simple waterproof suits made from leather or neoprene fabric closed by a waterproof zip and rubber seals at the neck and wrist. Since then, very little improvement in concept has occurred. In 1941, Gage, Burton and Bazett [11] were having trouble explaining to the soldiers, sailors and airmen how much insulation to add or subtract to their clothing to keep them warm. This of course depended on the outside air temperature, their level of exercise/work and whether they were resting or not. They conceived the unit of Clo as a measure of clothing insulation, which could also be used by heating engineers, physicians and physiologists. It is defined as $0.155^{\circ}\text{C}\cdot\text{m}^2\cdot\text{W}^{-1}$, and 1.0 Clo is the insulation required to maintain comfort when a resting human is in an environment of 21°C , 50% relative humidity and with an air movement of 0.1 metres/second. The European equivalent to a Clo used for sleeping bags and duvets insulation is the tog, which is 0.645 Clo. Clo value and its measurement will be discussed later.

$$\begin{aligned}1 \text{ Clo} &= 0.155^{\circ}\text{C} \cdot \text{m}^2 \cdot \text{W}^{-1} \\1 \text{ Tog} &= 0.645 \text{ Clo} \\&= 0.1^{\circ}\text{C} \cdot \text{m}^2 \cdot \text{W}^{-1}\end{aligned}$$

PHYSIOLOGICAL STUDIES CONDUCTED IN EUROPE AND NORTH AMERICA 1945 – 1970

In 1946, the results of the Talbot Report [25] (see lecture on the dangers of sudden, unexpected immersion in cold water) initiated a whole series of cold water physiological experiments. The objective was to find out the best way to protect a human in cold water. Most important to note is that as a result of all this work, everyone assumed that death would be caused by drowning/hypothermia. This resulted in the production of several key text books and reports which are mandatory reading for anyone involved in survival training or who fly over cold water for a living. They should be read in conjunction with any project involving immersion suits. These include:

- Man in a Cold Environment (Burton and Edholm 1955) [4];
- Survival in Cold Water (Keatinge 1969) [15];
- Safety and Survival at Sea (Lee and Lee 1989) [17];
- The Hazards to Men in Ships Lost at Sea (McCance 1956) [18];
- Physiology of Heat Regulation and Science of Clothing (Newburgh 1968) [19]; and
- Survival at Sea (Smith 1976) [24].

Hall and Polte's work in 1960 [13] on immersion suits was most significant for examining how to provide insulation in the suit. There were four practical findings that came out of it for the designers of immersion suits:

- a) Suits lost 57% of their insulation through hydrostatic squeeze when the human was immersed to the neck. This new Clo value was called the Immersed Clo value.
- b) A leakage of as little as one litre of water into the suit reduced the insulation by 22%.
- c) Maximal body insulation, which is approximately 4 Clo per inch thickness of fabric does not significantly prevent the hands from cooling down.
- d) It was possible to categorize all the different survival equipment by their Clo or insulation value and prescribe different Clo values for different operations.

PRACTICAL IMMERSION SUIT TRIALS 1970 – 1980

By the beginning of the 1970s, the general opinion was that hypothermia was the principle cause of death from sudden cold water immersion and that the best protection was a dry suit. However, manufacturers found it difficult to mass produce affordable immersion suits for constant wear. Good quality waterproof zips were expensive and cheaper alternatives did not work; quality control on the production of the suits was poor, so even brand new suits leaked. The only alternative to the neoprene or chloroprene coated fabrics was ventile fabric which was expensive to manufacture and assemble into suits. With the difficulty of making a truly dry suit and facing the consequences of it being too hot and uncomfortable for constant wear, thoughts were given to producing wet suits.

Immersion Suits: Their Development

It is important for the reader to have a definition of what is a dry suit and what is a wet suit.

- a) A dry suit is designed to function by keeping the insulation worn beneath it dry. This is achieved by the use of water tight seals, zips and impermeable material. A dry suit may or may not have insulation (insulated and uninsulated suits).
- b) A wet suit should be a close fitting garment which functions by trapping a layer of water next to the skin. This allows only a small volume of water to enter the skin/suit interface. This is warmed and does not have a significant effect on the inherent insulation provided by the suit.

Operational trials were conducted in realistic conditions to assess how long humans could survive in various wet or dry suits. The conclusions from each experiment revealed similar findings. To survive in North Atlantic type water, which rarely warmed up above 16°C and was often in the single digits, a dry suit was essential. Up until this time there was still no internationally recognized immersion suit standard.

There was also a much bigger customer demanding better suits and that was the offshore oil industry. Their sponsorship and funding were the key to the improvement in immersion suits over the next 27 years.

1980 – 2007: THE OFFSHORE OIL INDUSTRY REQUIRES IMMERSION SUITS

By 1980, a whole series of second generation suits were being manufactured and tested. These were principally being used by the now well developed offshore oil industry for both helicopter ditching and ship/rig abandonment. Most military operators' piggy backed onto this work. After the Alexander Keilland accident in 1980 and the sinking of the MS Malmi, the Norwegians and Finns evaluated a number of suits with now familiar names such as: Aqua Suit, Bayley, Beaufort, Fitz-Wright, Helly-Hansen, Imperial, Lifeguard, Liukko, Manu, Multifabs, Nokia, Nord 15 and Shipsafe [16].

Generally, there was still dissatisfaction with the suits and only too familiar comments:

- Flotation position was not satisfactory (too little freeboard);
- Small people nearly get lost in the suit after a five meter jump into the water;
- Leakage on glove seal with suit;
- One size suit does not fit everyone;
- All zippers need regular maintenance;
- Very difficult to swim in the suit;
- Leakage into the suit, which in some cases caused great difficulty in boarding life raft;
- Poor durability of fabric; and
- Requirement for good maintenance.

Then in 1981, Golden and Hervey [12] published their classic work on the physiology of sudden cold water immersion (see lecture on the dangers of sudden unexpected immersion in cold water). Slowly, but very slowly, operators began to realize that the majority of drownings were due to cold shock and swimming failure, not hypothermia. By 1986, Hayes [14] provided a very clear and precise performance specification for an immersion suit that was to:

- Minimize the occurrence of cold shock;

- Prevent hypothermia and non-freezing cold injuries;
- Reduce the likelihood of post-rescue collapse; and
- In conjunction with personal flotation devices prevent drowning from wind and wave splash as well as from facial immersion.

As human testing became more expensive and human ethics committees less amenable to using humans simply to test suits to a specific standard, there was an increase in the use of thermal manikins to do this job. As a result of the Ocean Ranger accident in 1982 off the Grand Banks of Newfoundland, Canada introduced specific survival suit standards for ship abandonment suits (revised in 2005, [10]) and helicopter passenger suits (CGSB 1999) [9]. This standard has now been copied and slightly modified by C.E.N. and IMO/SOLAS to suit their own international purposes. In Canada, the preferred method to measure the Clo value is by the use of a thermal manikin, but for various reasons, there is still some resistance in Europe to using the manikin. So the overall preferred test is to still use humans (see later).

By the mid-1990s, it was being noted that the equipment in service both for the military and commercial operations had performed “surprisingly poorly” during real accidents. There are still about 140,000 open water deaths reported each year (see lecture on Sudden, unexpected immersion in cold water). How could this be when there is such a range of tests and regulations to theoretically prevent this? The answer is that many of the tests are innocuous and not realistic. The tests must either re-create the tasks that may have to be undertaken and/or the environmental conditions which may exist during the accident, or enable prediction of the decrement that will be seen in more adverse conditions. In 1995, Tipton [26] demonstrated this very clearly with a group of twelve subjects who undertook two immersions wearing identical clothing in two tests: Test A and B. However, in test B, simulated wind (6 knots), waves (15 cms) and rain (36 L/hr) were introduced as well as a 15 second period of initial submersion. The estimated survival time was reduced from 6.8 hours in Test A to 4.8 hours in Test B.

By the late-1990s, Gortex was slowly replacing other fabrics for the outer fabric of suits. There was a vast improvement in the quality of the waterproof zips, but neck and wrist seals durability and comfort still remain a problem, and the modern immersion suit looks very similar to the one introduced 60 years ago. Brooks noted research was stalled in 1986 and little has changed in 2007 [6].

SPECIFIC ISSUES TO ADDRESS WITH IMMERSION SUITS

Readers may think that death from sinking in cold water is a thing of the past – the Titanic, the Empress of Ireland, the Lusitania, etc. Nothing could be further from the truth. At opposite ends of the world, two accidents occurred within a day of each other only recently. They emphasize that a personal immersion suit is just as necessary today in the 21st Century as when humans took to the water millions of years ago and in my introduction I have quoted from the latest statistics for 2007 in the Safety at Sea Journal.

Ferry Founders off China (Halifax Chronicle Herald, November 26, 1999)

On Thursday, more than 24 hours after the ship’s first distress call, just 36 people had been rescued from the cold seas after sinking of the 9000 tonne Sashun ferry with 312 passengers and crew.

**10 Reported Dead in Ferry Sinking (Oslo)
(Halifax Chronicle Herald, November 27, 1999)**

Ten people died and another 11 were missing and feared drowned after an ultra-modern Norwegian ferry sank in chilly, rough seas off western Norway on Friday.

Hopes of finding any of the missing alive were fading hours after the sleek Sleipner catamaran, with 88 people aboard, went down in the North Sea after hitting the rocks near Haugesund in stormy weather after nightfall.

Why is it so Difficult to Keep the Fingers Warm?

The reasons for this have been superbly explained by Beckman et al in 1966 [2], in their review on the control of body heat loss in aircrew subjected to water immersion. This is quoted directly from their paper in Aerospace Medicine in April 1966 and summarized the pioneering work done by Newburgh, Spealman and Van Dilla in the 1940s [19].

“Insulative values of materials are normally described in terms of flat surface insulation. Although the insulative value of material on a flat surface is directly related to its thickness, the relationship is not as simple on shapes like cylinders and spheres. The relationship of thickness of fabric in inches to the effective insulation in CLO is seen in Figure 9C-1. On the bottom line of this graph, it is seen that as the thickness of the insulative fabric surrounding a ½-inch sphere is linearly increased, the insulative value increased only slightly and no significant increase in insulative value is provided by increasing fabric thickness beyond 1 inch. The insulative effect of increasing the thickness of the insulative fabric around a cylinder of ½-inch diameter is only slightly better than for a sphere. This figure illustrates why it is difficult, if not impossible to provide adequate insulation for thin cylinders such as fingers and toes. It has long been known that it is almost impossible to provide adequate insulation in the form of gloves for the fingers and hands in extremely cold Arctic weather. For this reason, mittens rather than gloves have been provided so that the fingers and hands may be made into a ball to improve their surface area to mass ratio. A theoretical solution proposed by van Dilla, et al., to the problem of providing adequate insulation for Arctic troops in –50°C weather with a 30 knot wind is equal in magnitude to those of providing adequate thermal insulation for personnel immersed in freezing water.”

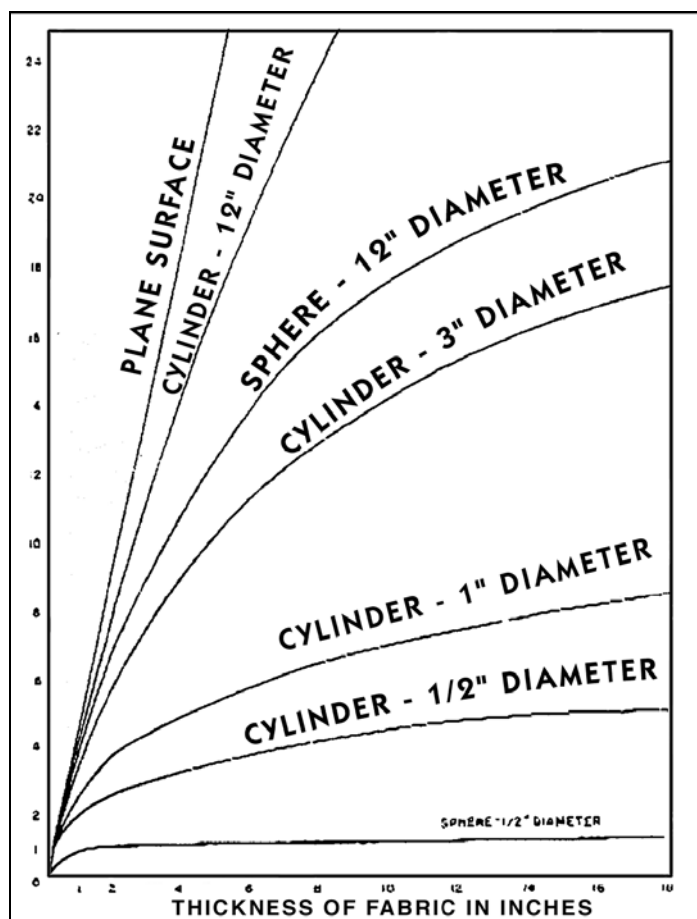


Figure 9C-1: Insulation of Ideal Fabric on a Plane, Cylinders and Spheres.
 (After Van Dilla, Day and Siple in Newburgh – Physiology of Heat Regulation. 1968, Hafner Publishing Co.)

Because of these physical facts, it is very difficult to insulate the fingers. Van Dilla produced a simple figure (Figure 9C-2) to show the relative size of the mitten required to insulate the hands under different work loads."

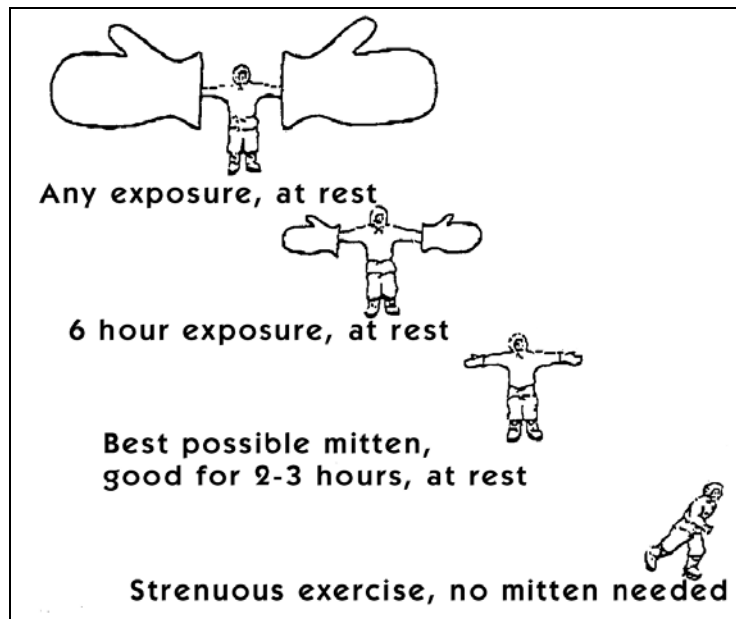


Figure 9C-2: Relative Size of Mittens Needed for Different Exposure Times at Minus 20°F. After Van Dilla, Day and Siple in Newburgh Physiology of Heat Regulation. 1968, Hafner Publishing Co.)

Added to this, the human originated in the tropics (see lecture on the dangers of sudden, unexpected immersion in cold water). Therefore, as stated previously the fingers have a small mass to large surface area ratio and are designed as radiators to lose heat not preserve heat – even more importantly, to defend heat loss, the blood flow to the hands is reduced in the cold to about 200 mls per minute when the body is fully vasoconstricted. Compare this to a blood flow of 3 – 4 liters per minute when the body is maximally vasodilated in the heat. So in essence you are simply insulating unheated (unperfused) fingers in a cold water situation.

THE EFFECTS OF WAVE MOTION ON IMMERSION SUIT INSULATION

Immersion suits standards generally require that suits are tested on humans in calm stirred water. What is the effect of wave motion on this insulation? The answer is not entirely clear. Only half of the research has been conducted and then it was stopped due to lack of funds – but the current opinion is that there is a loss of about 14% in suit insulation in one metre waves compared to still water. Whether this increases as the wave height increases has not yet been established [7].

HOW MUCH BUOYANCY IS ALLOWED IN A HELICOPTER CREW OR PASSENGER SUIT?

Human experiments were conducted in the 1980s with men and women to establish how much buoyancy would inhibit a person's escape from an inverted flooded helicopter cabin. Failures occurred between 36 and 57 pounds of added buoyancy. Females and males with short arms failed at lower added buoyancies due to shorter reach and reduced upper body strength. Finally, a decision was made to establish a standard maximum of 42 pounds (175 Newtons) of added inherent buoyancy. A compromise had to be made in order to achieve

the required 0.75 immersed Clo of thermal insulation. This could not be practically done if the inherent buoyancy was less than 175 N. Subsequent tests in the helicopter underwater escape trainers worldwide have shown that this appears to be a reasonable compromise – but ideally, in the concept for new suits the less inherent buoyancy the better.

FLOTATION ANGLE

The ideal flotation angle is for the body to be resting at 45° to the oncoming waves. However, the additional buoyancy in the suits to protect from hypothermia prohibits this from happening. The majority of people adopt a horizontal position in the water. This problem has certainly been known since World War II; it was alluded to by Smith in his “Survival at Sea” book review for the Medical Research Council in 1976 [24], but was not formally recognized until a presentation made by McDonald at the Robert Gordon Institute (RGIT) in 1983: “The overall buoyancy of a very large percentage of thermal protective suits negate the self-righting characteristics of approved life jackets. Suits with inherent buoyancy also show no potential for self-righting, indeed most are equally stable with the wearer face down or face up.” Therefore, with this in mind, only by integrating the whole system from the basic design can the flotation angle be improved in the next generation of suits. Note Stoner had conceived this principle back in 1869!

NECESSITY TO PROVIDE THE REASONS FOR WEARING AN IMMERSION SUIT IN SURVIVAL COURSES

Over the last 30 years, this author has noted complaints about wearing immersion suits and many misconceptions about their capability. Between January and June 2001, 357 trainees attending one of four Survival Systems Ltd. marine courses were randomly selected and questioned about general knowledge related to their immersion suits. Prior to the course, the questionnaires asked about the knowledge of the dangers of immersion in cold water and the ergonomics of the survival suits that were worn during the course. The answers confirmed our suspicion that the general knowledge of the dangers of cold water immersion is poorly understood and hypothermia was the only one of the four stages of immersion identified, and the workers really did not know the reasons for wearing a survival suit.

On completion of the course, there was a general improvement in this knowledge with over 50% of students being able to list the chronological order of the four stages correctly. The general parameters related to the general size, shape and fit of the suits that were worn during the training week followed a normal distribution curve. Generally, people were relatively satisfied. There was no correlation between extremes of sizes, ages and sex and satisfaction or dissatisfaction. The water integrity of the suits was better than expected. This was attributed to better standards, manikin testing, better quality control by manufacturers and a surprise finding that duct tape was being used by the instructors just before the students went out to sea for their practical immersions. The option of providing duct tape at ship abandonment stations is a good idea, especially for females with very thin wrists. The overall confidence factor in the suit was higher than anecdotal evidence would suggest. [8]

MEASUREMENT OF CLOTHING INSULATION

Clo value can be measured using humans or an immersion thermal manikin. There are advantages and disadvantages associated with the use of both humans and manikins. For example, using humans carries medical and ethical responsibilities; failure to estimate or measure mean skin temperature, heat production and

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heat flux accurately introduces error, as does the estimation of changes in heat storage when deep body temperature is falling. In its favor, the human technique is more representative in terms of position in the water and fit of the suit; regional fluctuations in heat loss and insulation can be pinpointed subjectively (“it feels cold here”) as well as objectively. Also, because a steady state is not required (falls in body temperature can be accounted for), the heat flux technique is quick and can be used to measure the effect of human movement such as swimming; the human technique also allows deep body temperature to be measured and this insulation to be directly related to this variable.

The benefits associated with the use of manikins include avoidance of the medical and ethical consideration associated with human testing, easier logistics and greater reproducibility. Other advantages include:

- a) There is no limit to the number of times the manikin can be immersed in the water.
- b) Tests with a manikin give accurate segmental insulation according to strict engineering principles.
- c) There is no limit on the temperature of the water.
- d) The angle of the manikin in the water is consistent and so the Clo value for each suit is consistent and it is possible to do comparative tests between different suit designs.
- e) The suits can be tested in greater than Beaufort 3 sea conditions.
- f) The cost of testing each suit is relatively inexpensive.
- g) Subtle improvement in suit design to improve Clo value can be observed on the manikin where many consistent tests can be done. These improvements cannot be observed on small numbers of humans with different physiological responses to the same conditions.
- h) All the cold thermal tests can be conducted on the manikin, yet the leak tests and ergonomic tests can still be done on the human in warm water.
- i) It avoids the need to withdraw the human prematurely from the water for physiological limitations assigned by the ethics committee.

Disadvantages of this method include the mistake that many people make of assuming that a manikin reacts like a human. A manikin does not react the same way as a human (it does not vasoconstrict, the generation and delivery, and therefore distribution of heat throughout the respective bodies differ). As a consequence, the results from a manikin can be misinterpreted. Another weakness in the technique is that to relate the insulation measured on a manikin to alterations in deep body temperature required the use of a mathematical model, with all the assumptions and limitations which that entails. More research is required to validate these assumptions.

Although CEN and ISO still insist on human testing, there are disadvantages to this too. These include:

- a) It is often difficult to get human subjects to sit in 2°C water for six hours. So, the subject pool to which statistics are applied can be small. This is one of the reasons why all the experiments so far have been conducted on small numbers of subjects.
- b) Human subjects do not all behave in the same ways in cold water, i.e. some cool off quicker than others. So, selection of the “right” slow coolers may pass a suit, whereas selection of rapid coolers will fail a suit.
- c) It is important not to choose cold acclimatized subjects.
- d) It is very expensive to use humans because of the requirements for medical ethics approval, physician services at the pool, etc.

- e) For evaluation of suits that may fail the test, there is a likelihood of inducing non-freezing cold injury in the human subjects, so ethically and morally, human ethics committees are becoming increasingly unwilling to approve such experiments for pure suit testing to the standard. Alternatively, low peripheral temperature will result in subjects being removed from the water for medical/ethical reasons before a test has been completed.
- f) The flotation angle for testing is inconsistent. The suit manufacturer can add a high buoyancy lifejacket (which may not be worn with the suit) to obtain better freeboard and hence less chance of neck seal leakage and less hydrostatic squeeze on the back of the suit. This results in better overall insulation, which may not be the case in the survival situation.
- g) The suits can only be tested in calm, stirred water or in a pool with a wave maker. Testing in the open ocean in a sea state greater than Beaufort 3 is not only cost prohibitive, but unlikely to be approved by an ethics committee.

SIZING OF SUITS AND FITTED SUIT VERSUS ONE SIZE FITS ALL

Depending on the operation whether military or commercial, the personnel will be provided with a fitted suit or a “once only one-size-fits all” type suit. Obviously a fitted suit is the best choice – but this is not always possible either from a financial or a practical stand point. Irrespective of which suit is chosen, it is important to have the correct anthropometric dimensions of the population. In 2005, Reilly et al addressed this problem and the two papers [22, 23] are recommended to both operators and suit manufacturers.

It is also important to understand the critical measurements and fabric allocation in the “one-size-fits all” suit to get at least a reasonable fit, and the effects of reduction in total effective reach when either type of suit is worn.

STATE OF IMMERSION SUIT TECHNOLOGIES IN 2007

Points to examine in purchasing new suits:

- The difficulty of achieving a good neck seal. The only proven, reliable way is to use a continuous rubber collar around the neck. Split neck seals tend to leak.
- Wrist seals are also best designed using a continuous rubber collar, but suits can be very quickly made unserviceable if the seals are not well powdered and the occupant punctures the seal with a finger or thumb.
- Entry into the suit can be made from the front or the back. There are pros and cons to both methods. Ideally the suit must be donned single-handedly and the zip closure must be of good quality and regularly lubricated, otherwise the suit will leak badly.
- Observe the entry method into the suit, and how easy or difficult it is to reach the end of the waterproof zip and operate it. Back entry suits are the best for presenting a smooth working surface on the front of the body, but cannot always be zipped up single handed. Diagonal zips are satisfactory but don't forget to ensure the closed zip is at the top of the suit and not at the bottom. Horseshoe zips are good if you have to work with the suit half donned. It is possible to tie the sleeves around the abdomen and then slip it on later before abandonment or going flying.

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- Gloves are better provided for as a separate item stowed on the sleeve rather than incorporating them into the suit itself. There is no perfect glove. In a cold situation, blood flow to the hands is reduced to the minimum and it is impossible to insulate thin cylinders practically and adequately.
- Rubber Wellington type boots integrated into the suit are the best option for footwear, but must be sized. Necessity and cost may require the substitution of expandable sockettes. Irrespective of this, the footwear size then becomes the principle criteria for whether the person can fit into the suit.
- There are now a large variety of outer shell fabrics for the suit and inner thermal liners. Having a separate inner liner makes it easier to launder and maintain the suit and match the required insulation with the thermal environment.
- Examine the anthropometric size of your operators before choosing a suit. Overall, the quick don, once-only suit with drawstring around the neck provides a cheap, practical compromise that was well proven during the Falklands War. It is very useful for donning quickly over existing clothing prior to abandonment. Remember a one size fits all suit is a compromise and may not fit anyone, but with good design it will do the job.
- For both neck and wrist seals there are several different types of rubber material. Choose carefully, some are more flexible and comfortable than others. Check carefully with the manufacturers because there is an alternative method to gluing the wrist seals on to the suit. This makes it much easier and quicker to replace seals, the suit remains out of service for a much shorter time and there is no need to have the lingering smell of toluene-based glues in the workshop atmosphere.
- Thermal manikins are promising for doing the thermal testing, but more funding and research is needed to validate their results.

CURRENT REGULATIONS

Currently, written in English, there appear at least 11 sets of regulations ratified or in draft pertaining to immersion and related suits. These are:

- Canadian General Standards Board. Marine Abandonment Systems. CAN/CGSB-65.16-9 [10] 2005.
- Canadian General Standards Board. Helicopter Passenger Transportation Suits. CAN/CGSB-65.17-99 [9].
- Canadian General Standards Board. Marine Anti-Exposure Work Suit. CAN/CGSB-65.21-95.
- US Coast Guard Department of Transportation. Life Saving Equipment. Part 160 Chapter 1 of 46 CFR. (Sub-part 171 – Immersion Suits, Sub-part 174. – Thermal Protection Aids.) Consolidated Edition 2001.
- IMO Life-Saving Appliance Code 2003. London. MSC.48(66).
- Testing and Evaluation of Life Saving Appliances Resolution. MSC.81 (70). 2003.
- Civil Aviation Authority. Helicopter Crew Members Immersion Suits. Specification No. 19, Issue 1. 15 April 1991.
- Air Standardization Coordination Committee. ASCC Standard 61/12 (Methodology for Evaluation of Anti-Exposure Clothing in Cold Water Immersion Using Human Subjects).
- ISO Immersion Suits. Part I: Construct wear suits, requirements including safety. ISO 15027-1. 2003/03/15.

- ISO Abandonment Suits. Part II: Abandonment suits, requirements including safety. ISO 15027-2. 2003/03/15.
- ISO Immersion Suits. Part III: Test methods. ISO 15027. 2003/03/15.
- Draft Issue 2 JTSO-XXX Helicopter Crew and Passenger Integrated Immersion Suits for Operations to or from Helidecks in a Hostile Sea Area.
- Personal Protection of Helicopter Passengers in the Event of a Ditching. Shell Health, Safety and Environment Committee. February 1996.

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Chapter 10 – Drowning is Not a Helpful Diagnosis Written on the Death Certificate

by

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INTRODUCTION

A cursory look at the title of this paper may give the readers the impression that this is of little interest to them. This is a very false assumption. This paper is of great importance for anyone who is involved in accident investigation where a drowning has occurred. It is also of great importance to all marine survival instructors and health and safety managers. Only by understanding the underlying causes of the drowning, is it possible to establish the correct equipment and training preventive measures.

Over the centuries, hundreds and thousands of people who earn their living working on or over the water have drowned, particularly in cold water. It is only in the last 50 years that anyone has taken this death toll seriously.

Drowning is Not a Helpful Diagnosis Written on the Death Certificate

Records of death from immersion in cold water date back to ancient times. During the Greek-Persian war (circa 450 BC), Herotodus was able to distinguish death from drowning compared to hypothermia [8]. Yet, it was not until the middle of the Second World War, and the analysis of the losses after the cessation of hostilities that the UK and Germany recognized the dangers of sudden cold water immersion [10, 11]. It was not until the Korean war that the United States also realized there was a problem [13].

Consequently, over the last half of the 20th Century, there has been considerable human experimentation performed internationally in cold water physiology. The pioneering work was done in the mid 1940s and 1950s, but by the 1960s, it was forgotten and needed to be relearned. A full summary of this work can be found in the new book written by Golden and Tipton in 2002 [7]. The loss of life in the new Offshore Oil Industry created a demand for more research to produce better immersion suits. This created a flurry of new experimentation in the 1980s and 1990s.

In 1981, Golden and Hervey produced their classic work on the four stages in which death may occur in a cold water accident [6]. These are: stage 1, cold shock, which kills within 3-5 minutes of immersion; stage 2, swimming failure, which kills within the first 30 minutes of immersion; stage 3, hypothermia, which kills after 30 minutes of immersion; and finally, stage 4, post rescue collapse, which kills during or shortly after rescue. Tipton provided a review of the initial response of cold shock in 1989 and conducted further experimentation to explain the phenomena of swimming failure [12].

Until relatively recently, stage 1 (cold shock) and stage 2 (swimming failure) were considered of academic interest only. As a result, regulators, teaching establishments and survival suit manufacturers all concentrated their efforts on protecting the human from hypothermia. In this regard, they have done a very good job. As a result, cold wet bodies removed from the water were assumed in many cases to have died from hypothermia, yet they had not been in the water long enough to become hypothermic.

Even though there are well established teaching programs, good regulations and much improved life saving equipment, there are still 140,000 open water deaths worldwide each year [6]. Barss reported in 2006 that 2,007 people died of cold water immersion in Canada between 1991 and 2000 [1]. What has been overlooked is the significance of the first two stages – cold shock and swimming failure as a cause of death. The severity of the effects of cold shock appears to be most dangerous to the human when suddenly immersed in water below 15°C. Below this temperature, the cold shock response is potentially lethal.

This physiological information has not been disseminated to accident investigators, emergency room physicians, coroners and pathologists. As a consequence, they have not realized the significance of the first two stages. Their line of investigation has not asked the specific questions that might indicate that one or both of these stages contributed to drowning. A typical accident report contains many pages related to the mechanical condition of the vessels and navigation aids, etc., but because the investigators are often under educated in the subject, the human factors aspect is often summarized in less than one paragraph. Here the final published “official” cause of death is listed as “exposure”, “presumed drowned” or “drowned”.

To be able to introduce a good public health program to prevent drowning, it is essential to identify the physiological causes that lead up to the tragic event. Only then can preventive action can be recommended. For instance, the wearing of a personal flotation device will keep the struggling victim afloat during the dangerous first five minutes of immersion during stage 1; this is paramount. Wearing a flotation device is also critical to prevent swimming failure during stage 2. Finally, a combination of flotation device and immersion suit are essential to prevent hypothermia and post rescue collapse in stages 3 and 4. However, if it is not possible to determine which stage caused the drowning, the precise cause of drowning, then it is not possible to introduce a public health policy.

STUDIES CONDUCTED BY SURVIVAL SYSTEMS LTD. FOR THE BRITISH COLUMBIA WORKERS COMPENSATION BOARD

As a result of the True North II accident in Georgian Bay in June 2000, the principal author reviewed the policies on survival in cold water for the Marine Safety Directorate of Transport Canada. Recommendations were made to improve the knowledge of the dangers of cold shock and swimming failure and the part they play in drowning [3]. As a result, this publication was received by the Workers' Compensation Board (WCB) of British Columbia (BC). Their accident investigators inquired as to whether their colleagues were asking the correct questions in their accident investigation process when workers drowned. They suggested a review of their drowning records.

In 2002, the WCB BC requested Survival Systems Limited, Dartmouth, Nova Scotia, to conduct a retrospective analysis of all deaths due to water immersion in British Columbia. The objectives of this investigation were to:

- a) Review all the accidents involving drowning;
- b) Reclassify deaths into the four stages of immersion (where possible);
- c) Draw conclusions on the principal cause(s) of death;
- d) Make recommendations on what protective measures to adopt; and
- e) Develop a simple check list for WCB investigators, coroners and pathologists to use when investigating a drowning accident.

The first data that was analysed [3] found that between 1976 and 2002, there were 128 deaths: 56 (44.4%) were fishermen; 22 (17.5%) worked in the logging industry; 17 (13.5%) were operating motor vehicles; and 31 (24.6%) were involved in a diverse range of types of accidents from a variety of occupations including a health care worker, a lifeguard and a trail guide. Several years of fishing accident data were missing from this study because the records could not be located at the time. The data was later found and a second study [4] which specifically analyzed all fishermen deaths in water was conducted. In this study, it was found that 130 fishermen died from water immersion in 89 inshore and offshore accidents between 1976 and 2002.

RESULTS OF THE TWO BC WCB STUDIES

Common to both studies was that there was critical missing information such as: water temperature; body core temperature on admission to hospital; previous medical history; swimming ability; and witness testimony. This information would have been extremely helpful in determining whether cold shock, swimming failure, hypothermia, or post-rescue collapse contributed to the drowning or there was some completely different cause such as entrapment or a heart attack from a previous pre-morbid condition, etc. It is important that all those who are involved in the diagnosis of cause of death are educated about human physiology in cold water in order to make the appropriate diagnosis. However, examination of the files revealed that at all levels of the investigation (marine investigator, coroner, and pathologist), there was little understanding of cold water physiology. Moreover, each of the team appeared to be working somewhat in isolation of each other.

Each accident report that was reviewed contained many pages related to marine items such as navigation aids, ship's structure and stability, yet there was only a single paragraph or sentence related to the death and the survival equipment worn or carried on board. Retrospectively, in some cases it was possible to estimate a number of water temperatures. Thus, 95% of the fishing industry drownings occurred in water below 15°C. Even though this was helpful, it was still only possible to re-categorize 22 of the 130 deaths into one of the

Drowning is Not a Helpful Diagnosis Written on the Death Certificate

four stages of the immersion incident. The water temperature of the drownings in the logging industry ranged from 5 – 14.7 °C and it was possible to re-categorize 4 of the 22 deaths into one of the 4 stages. Finally, for the motor vehicle accidents the water temperature ranged from 8 – 11.5 °C and it was possible to re-categorize only 1 of the 15 deaths into one of the four stages.

As a result, to insure all the critical information on a drowning death is recorded correctly for future analysis, a new common drowning investigation checklist was developed for the BC WCB (see Annex) and a series of lectures were also provided to their accident investigation team and safety policy makers. This educated them about cold water physiology and the dangers of sudden unexpected immersion in cold water.

REVIEW OF THE U.K. MARITIME AND COASTGUARD AGENCY CG-15 INCIDENT REPORTS

As a result of the aforementioned work and the efforts of the U.K. Maritime and Coastguard Agency (MCA) to reduce Maritime and Fishing Vessel fatalities [9, 14, 15] Survival Systems Limited were asked to conduct a similar study for them. The objective once again being to investigate the underlying cause of the drowning deaths.

A similar protocol was developed for this investigation as for the BC WCB as described above. Records were examined back to 1975. It was not possible to review every report for each year, but all records were examined in detail for 1975, 1978, 1982, 1992, 1994 – 1997, and 2004. The findings were very similar to those found at the BC WCB offices. All the CG-15 incident reports were meticulously filled in, and there were volumes of paperwork on the technical aspect of each accident. Yet, when it came to the human data and the cause of death, generally there was one sentence which ended in the word “unfortunately drowned”. Because there was so little human factors data or recorded witness testimony, it was quite impossible to re-categorize any drowning deaths at all. A report was produced to advise them how to proceed in the future [5], particularly in how to harvest the medical and human factors data, and how to use the International Code of Diagnosis to maintain medical confidentiality and be able to record the human data.

CONCLUSION

The marine and accident reports from two large government agencies (BC WCB and UK MCA) have been examined. The objective was to identify the underlying causes of death from drowning. Then, prescribe the way ahead to reduce the number of drownings and save unnecessary loss of life.

In both agencies, there was excellent record keeping, but it was all related to the technical aspects of the accident. At all levels of the accident investigation team, there was little understanding of cold water physiology, and each member of the accident investigation team (investigator, coroner, and pathologist) tended to work in isolation of each other. There was very little human factors or medical information recorded. Except in a few Canadian cases, this made it virtually impossible to understand the true cause of death, and therefore impossible to make recommendations on how to improve safety. From the details in the Canadian fishing accidents, 95% of drownings occurred in water below 15°C. This confirms that sudden unexpected immersion in water below 15°C is very dangerous and should be emphasized on all marine survival training courses. The use of flotation equipment would appear to be the first common sense approach – but support for this idea could neither be supported nor rejected because there was not enough data to draw any conclusions whatsoever.

Advice has been given to both agencies on the best course to proceed in the future, and a specific checklist has been developed for all investigators of drowning accidents (see Annex). It is hoped that these investigations have provided insight into a worldwide problem of water immersion deaths, and will result in improved diagnosis and record keeping of all accidents in order to save more lives.

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ANNEX

INVESTIGATION FORM - WATER RELATED INCIDENTS (Fill in a separate form for each worker)

PART 1 – Physical Information

- Category of Incident (Fishing, Logging, Diving, MVA, etc) _____
- If Vessel involved Name Of Vessel _____
 Length of Vessel _____
 Vessel Registration Number _____
 Vessel License Number _____
- If Vehicle involved, type of vehicle (type, make and model) _____
- Speed of vehicle or vessel at time of accident _____
- Activity of vehicle or vessel at time of accident _____
- Turnaround time of the vehicle vessel _____
- Estimated distance from shore or edge of river _____ (metres, kilometres)
- Did incident occur in: ☐ice ☐water
- Depth of water _____(metres)
- Time of day _____(24 hour clock)
- Daylight: ☐yes ☐no Twilight: ☐yes ☐no Darkness: ☐yes ☐no
- Weather conditions: Observed Estimated
 Air Temp (°C) _____ _____
 Water Temp (°C) _____ _____
 Sea State (metres) _____ _____
 Wind Speed (knots) _____ _____
 Direction _____ _____
- Brief description of the incident:

PART 2 – Human Factors Information

- Number of people involved _____
- Number of persons injured _____
- Number of persons fatally injured _____

Injured Workers Information

- Name _____ Date of Birth _____
 - Height _____ Weight _____
 - ☐ Fatal ☐ Injury
 - Body Core Temperature at Site ____°C Body Core Temperature at Hospital ____°C
 - Could worker swim? ☐ well ☐ average ☐ poor ☐ no ☐ not known
 - Did the worker sustain injuries other than immersion injuries? ☐ yes ☐ no ☐ not known
 - If yes, describe

 - Had worker taken any survival training? ☐ yes ☐ no
 - If yes, explain

 - Was worker alive when entered the water? ☐ yes ☐ no ☐ unknown
 - Does autopsy clarify whether worker was alive or dead upon entry ☐ yes ☐ no
- *If the worker was dead before entering the water then this is not a water related incident and there is no need to proceed further. If it remains unclear as to the condition of the worker prior to entering the water then continue as if the worker were alive as s/he entered the water.**
- If a motorized vehicle or piece of equipment was involved, was a seat belt available?
☐ yes ☐ no
 - Was a seat belt used? ☐ yes ☐ no
 - Was the worker physically trapped within the vessel, vehicle, etc.? ☐ yes ☐ no
 Describe:

 - Do post mortem reports aid in answering above questions? ☐ yes ☐ no ☐ undetermined
 - How easy or difficult is it to operate the doors/windows underwater? Describe.

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- If the reports do help, then was worker physically drowned (i.e. entrapped) or did they drown by other means?
☐yes, physically drowned ☐no, drowned by other means
- Was worker observed to: (tick appropriate box)
 - ☐ make ineffective swimming strokes/struggle violently and appeared to be alive/conscious and even reaching for life rings etc?
If so, for how many minutes? _____
 - ☐ Commence to swim either to other vessel or shore?
If yes, how many minutes or hours? _____.
What distance was covered before worker seen to succumb? _____(metres/kilometres)
- Can you conclude how soon after water entry did worker succumb?
 - ☐ within first 5 minutes
 - ☐ between 5 and 30 minutes
 - ☐ after 30 minutes
 - ☐ at or shortly after rescue
 - ☐ unknown
- Length of time in water before retrieval?
 - ☐ under 5 minutes
 - ☐ between 5 and 30 minutes
 - ☐ over 30 minutes
 - ☐ over 1 hour
 - ☐ unknown
- Were the above estimations determined from:
 - ☐ witness testimony
 - ☐ investigator's estimation (an estimate is encouraged if it is possible and there is no witness testimony)
 - ☐ other (i.e. video) Describe _____
- How well clothed was the victim?
 - ☐ light ☐medium ☐heavy ☐unknown

Briefly describe how worker was clothed:

- Did worker wear a lifejacket, floater coat, pfd, etc.?
 - ☐yes ☐no ☐unknown.

Describe type, make, age and model:

- Did flotation device perform to specifications? ☐yes ☐no ☐unknown
- If 'no', describe what went wrong:
 - ☐ unable to put on while in the water
 - ☐ came off in the water
 - ☐ not secured correctly
 - ☐ poor maintenance

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- ☐ inappropriate selection of gear
- ☐ did not inflate
- ☐ punctured
- ☐ damaged
- ☐ did not provide enough buoyancy
- ☐ other, describe:

- Were PFD's/Lifejackets carried on vessel or in vehicle? ☐yes ☐no ☐unknown
- Were there enough PFD's/Lifejackets for all on board? ☐yes ☐no ☐unknown
- Did worker wear an immersion suit? ☐yes ☐no ☐unknown
Briefly describe the type (make and model number):

- Were immersion suits carried on the vessel? ☐yes ☐no ☐unknown
- Were there enough immersion suits for all on board? ☐yes ☐no ☐unknown
- Did immersion suit perform to specifications? ☐yes ☐no ☐unknown
- If 'no', describe what went wrong:
 - ☐ sinking occurred too quickly to locate and don.
 - ☐ stowed in a place already underwater
 - ☐ physically stowed in an inaccessible place
 - ☐ no knowledge that suits were on board
 - ☐ suits leaked badly
 - ☐ no training in how to don/doff the suits
 - ☐ poor maintenance
 - ☐ other, describe:

- Were lifeboats, liferafts or skiffs carried? ☐yes ☐no ☐unknown
 - What type?

- Were lifeboats, liferafts or skiffs deployed? ☐yes ☐no ☐unknown
- If deployed, did they perform to specifications? ☐yes ☐no ☐unknown
- If 'no', describe what went wrong:

With Launch

- ☐ in ability to launch
- ☐ vessel sank too quickly to launch
- ☐ didn't know how to launch
- ☐ too much list to launch
- ☐ already underwater
- ☐ weather made it too difficult to launch
- ☐ got entangled
- ☐ blew up against side of sinking vessel
- ☐ failed to inflate

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- ☐ punctured
- ☐ crew too cold and fatigued to launch
- ☐ other, describe:

When in Water

- ☐ capsized
- ☐ blew over
- ☐ deflated
- ☐ washed overboard
- ☐ inability to get back in after being washed overboard
- ☐ flooded
- ☐ other, describe:

- How many hours/days did the worker work in the last:
 - 24 hours _____ hrs
 - last one week _____ days
 - last one month _____ days
- Was there any medical condition that contributed to the incident (i.e. Epilepsy, Diabetes, Heart Disease, etc.)
 - ☐yes ☐no ☐unknown
 - If 'yes', describe: _____
- Were any other medication, drugs or alcohol involved? ☐yes ☐no ☐unknown
 (Ask specifically about antihistamines and anti-fungals and whether medication was prescribed or over-the-counter)
 Describe: _____
- Include a brief description of the autopsy results:

- State the Coroners Cause of Death:

- Final determination
 - ☐ Drowning from entrapment
 - ☐ Drowning from Cold Shock
 - ☐ Drowning from Swimming Failure
 - ☐ Drowning or Death from Hypothermia
 - ☐ Drowning or Death from Post Rescue Collapse
 - ☐ Drowning or Water Related Death from Undetermined Cause
 - ☐ Drowning – Other _____

Checklist for water related fatalities: C.J. Brooks, K.A. Howard, S. Neifer

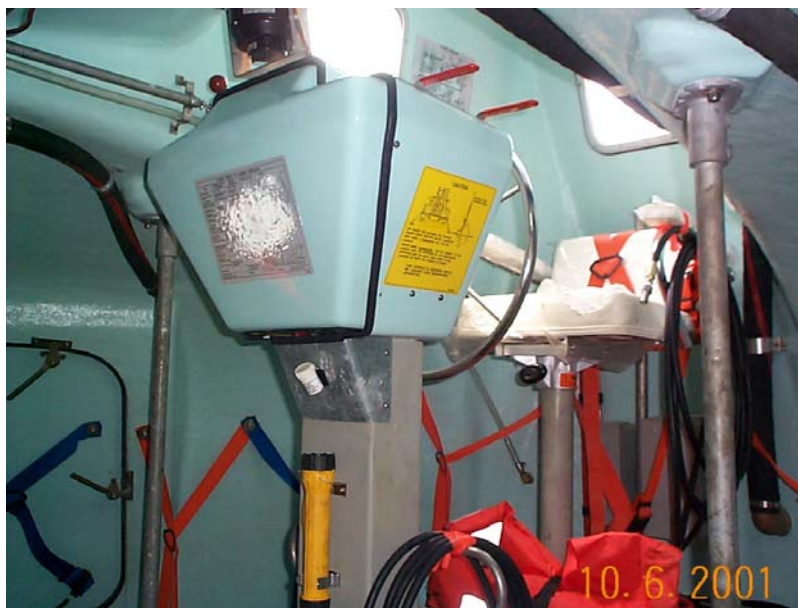
Chapter 11 – An Application of Human Factors in Life Support Equipment and Emergency Egress

by

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INTRODUCTION

Our world is filled with thousands of devices, tools, machines and products which when assembled into functional units form systems. By definition a system is a set of elements developed to achieve an objective. A well designed system considers the relations amongst the elements and the boundaries around the elements to provide for the proper considerations of the interaction of the elements to the overall objective. Generally systems have a defined input, process and output.

In terms of the design, operation and control, systems range from very simple to very complex. In many industrial sectors, these systems can range in type from manual to mechanical to finally automatic. In order for these systems to achieve their optimal level of performance they must at sometime interface with humans and therefore the human becomes an important element in the total system. Many people would argue that the human may be the most important element in the system and that the system must “fit the task to the human”. Fitting the task to the human is a phrase first introduced by Grandjean in 1981. The process of considering the job of fitting the task to the human describes the science of Human Factors and is also known as Ergonomics. At least from my perspective the terms Human Factors and Ergonomics are interchangeable and for the remainder of this chapter I will use the term Human Factors to avoid any confusion to the reader.

Human Factors generally considers the three major elements of a system to be the Human, Machine(s) and the Environment. The Human-Machine-Environment (HME) approach considers the work and system design as a complex interaction of individual elements of the system and the more importantly the interaction of the elements within the system. For example, if you were to analyze your present situation as you are reading this chapter or your current workplace, and I were to ask you to list a number of components or factors in the HME system, you might begin with a list similar to the entries presented in Table 11-1. Take a moment look around your particular area and expand this list.

Table 11-1: A List of the HME Components

Human	Machine	Environment
• Age • Sex • Height • Vision • Reading ability/education	• Lamps • Books – page and font size • Chairs • Tables • Pencils/pens	• Temperature • Noise • Air quality • Lighting • Humidity

Notice that I have focused on mostly physical elements of all three components, it is important to also consider cognitive function and other characteristics of these elements equally. Looking at this list identify those elements that have some degree of variability for example, the age range may be from 20 to 50+ years, the temperature in a standard classroom can vary from 18 to 25°C (or greater) and you can add other values for many of the items listed. The last part of this exercise is to link elements in one column to elements in the other column(s). For example, vision can be related to the books and the lighting as well as the tables and chairs. This means that to successfully read this material you require adequate lighting, probably a comfortable chair and desk and hopefully large enough print (font size) to be able to read under the circumstances. Therefore to attain an optimal performance from you as a representative of the human element, we need to consider how to design and control the machine and environmental factors in the system.

Hopefully through this simple exercise you will appreciate the following points:

- The human is an important element in the system but brings a great deal of variability to the system.
- Many of the other elements and their associated variability can be designed into the system or alternatively, adjusted or if necessary, designed out of the system.
- Without radical organizational steps, human variability is the most difficult to “control” without measures such as pre-screening or standardization of qualifications.

Proper design for the human will achieve the optimal match between the human and the task(s) which should increase the system productivity and improve overall health and safety. However, designing for the human can only be accomplished if we know the characteristics of the user population. This is true for all designs and all equipment associated with work. In the absence of direct measures of the intended population our alternatives are to find surrogate data sets and plan with that data. This can be problematic in many respects due to the variations in body size that exist globally as well as the variations that exist in different occupational groups. For example, anthropometric characteristics of industrial populations vary greatly based on global region, proportional differences between sexes and mostly likely some individual self-selection based on physical demands of the work. Some of our recent work on human anthropometry related to offshore workers is a classic example of these differences. Through a series of studies we have been able to show that offshore workers in North America are approximately the same stature as their European counterparts, but are on average 14 kilograms heavier (Reilly, Kozey and Brooks 2005). This average increase in body mass will influence maximum carrying capacities and the “fit” of air and sea craft used to transport the workers. While we also have other body dimensions for this population which were reported in the paper there are no other comparable reports for other groups around the world. For instance, the I.M.O. Life Saving Appliance Code prescribes weight and space allocation for lifeboats. The 75 kg weight and 430 mm buttock width is grossly inadequate for North American operators, and using the buttock width is incorrect too. The code should use shoulder width.

SYSTEM THINKING

Vincente (2003) offers a new perspective on the relationship between human factors, design and human or societal needs. He suggested the five basic Human Factor needs in design are physical, psychological, team, organizational and political (Figure 11-1) and he uses the analogy of a ladder with each of these “needs” forming a separate rung on the ladder with the lowest rung being the physical and the highest the political.

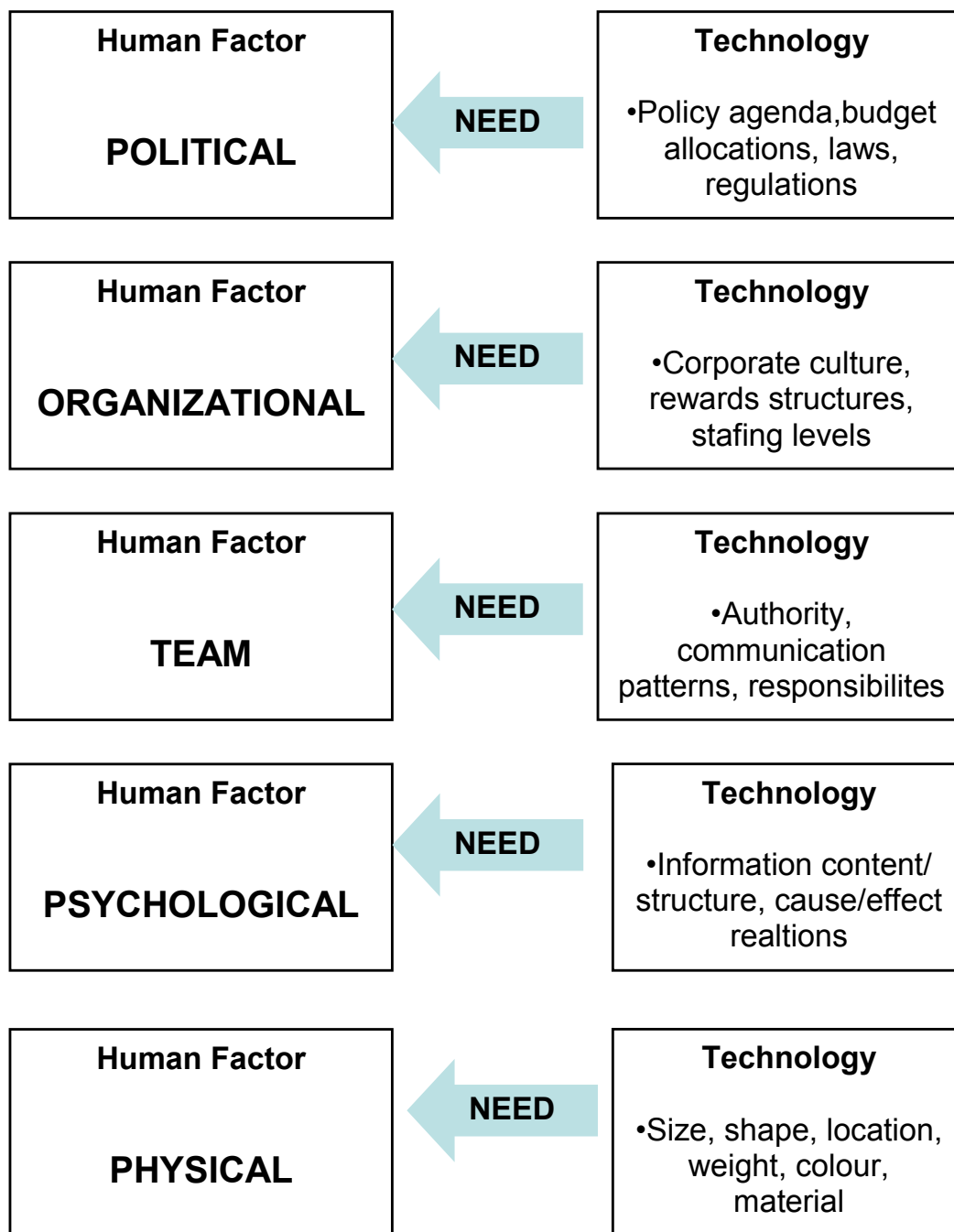


Figure 11-1: A Modification of the Human-Tech Ladder Proposed by Vincente (2003). Design should begin by understanding a human or societal need then tailoring of the specific human factor.

To elaborate on the application of his views I will present some recent research results related to helicopter egress. Then I will discuss how these could impact on design and training issues related to helicopter ditchings. I will focus the applications of these results on the physical and psychology “rungs” and finally the political “rung” of his Human-tech ladder.

Physical (Size, Shape, Location)

Designers of helicopters must consider the human as an integral part of the design process. This then determines where objects can be located, the forces and motions required to operate objects such as handles and other factors related to the ease of use of the handles. This seems simple enough, but it demonstrates some of the complexities involved in design trade-offs. For example, if we consider the reach envelope of the human operator, it is recognized that specific areas within the envelope should be related to the functions of the human while in the aircraft. A prime area of concern is the area immediately in front of the individual and this area should be reserved for frequent, important and often lifesaving tasks. In the case of the pilot and co-pilot this area should be reserved for flight related operations. For passengers and crew in the aft portion of the helicopter, the area immediately in front should be reserved for their important tasks. However, it is likely that the area they may require would be less than that of the pilot and co-pilot. For both groups an emergency jettison handle would be low in terms of frequency of use and therefore can be located away from the prime reach areas. However, the importance of the use of the handle is very high which means that it should be located very close to the prime reach areas, but positioned and designed to prevent unintended activation.

Brooks, Bohemier and Snelling (1994) found that the handles were typically located away from the reach areas immediately in front of the people which would seem appropriate. However, they discovered that the location of the handles varied greatly from one design to the next. This creates difficulties in developing training programs for emergency egress. In essence, training programs had to account for the unique locations of the handles in each helicopter. Furthermore, the many different helicopter configurations and the subsequent errors that were produced in locating the mechanism were complicated by the fact that typically the person would be inverted and underwater. They suggested that release mechanisms should be the same size, shape and position across the helicopters. Later, Brooks and Bohemier (1997) examined the doors, windows, hatches and escape mechanisms on 35 different military and civilian helicopters. They found that there were 23 different types of jettison mechanisms and that the arc of rotation or direction of pull was highly variable. They again highly recommended the development of fewer mechanisms and a standardization of the type, operation and location of these handles.

There are two obvious issues that were highlighted by these papers. The first issue is the development of a standardized handle and jettison mechanism which would reduce the additional training required to find and operate the handles for the different aircraft. The second point is that in the absence of standards for the handle and handle mechanism means there is a requirement for individualized training to both locate and operate each available type. Thus, while freedom is provided at the design phase for the handles and locations, training costs are increased to account for the variability in size, type and location of the handles across the different helicopters, and if aircrew and passengers are flying in different types of helicopters, then there is the problem of learning, unlearning and relearning various schemas to operate the levers when one only has 15 seconds warning of a ditching and only 20 – 30 seconds of breath-holding ability underwater. There is no time for a mistake, if one is made you drown.

Psychological (Information Content, Structure, Cause/Effect Relations)

In Vincente's scheme this means that the type of actions required to manipulate the handle and the subsequent response should be compatible. Again this is a classic Human Factors principle of motion that should be applied to all designs. The motions required to operate the handle should provide feedback (content) to the person indicating that the window has been successfully jettisoned. The motion should be intuitive and require very little information processing. This would imply that the motion should be directed away from the body and that a continuation of the motion would provide feedback that the intent of motion (window or hatch release) has been successful.

Again referring back to the papers of Brooks, Bohemier and Snelling (1994) and Brooks and Bohemier (1997) it is apparent that this principle is not applied to many of the handles and jettison mechanisms. The result (cause/effect) of not applying this basic principle is the occurrence of performance errors of the individual at an instance where time is critical. Brooks and Bohemier (1997) present for example the case where the handle is mounted on fuselage and remains in that position after the window has been released. This provides no feedback to the user regarding whether or not the release was successful which then requires a second action which is to determine if the opening is available for egress. This problem will affect not only the person immediately beside the egress point, but any other crew member who may have to use this point of egress as well.

The **Team** (Authority, communications patterns, responsibilities) and **Organizational** (Culture, rewards structures, staffing levels) rungs of Vincente's ladder are more difficult to describe in terms related to the research to date on helicopter egress. They are however important to many of the factors that may lead up to the reasons for the emergency incident. This includes the normal chain of command (Team) in the helicopter and the climate for safety and preparedness of the company, crew and passengers (Organizational) during such an event. Vincente offers a number of practical examples of these and I would prefer to direct you to those fine examples. I will focus on the final rung being that of policies and regulations.

Political (Policies, Budget Allocation, Regulations)

The final step in the application of human factors can be more broadly interpreted in the context of emergency egress. Hopefully the two examples used for the handle type and location will be seen as simple cases where standardization would be beneficial to the safety of the passengers and crew. I would also like to discuss the issue of training more directly. In many jurisdictions around the world there is a requirement that individuals who fly in a helicopter over water receive helicopter underwater egress training (HUET). This requirement has evolved based on the evidence that training will significantly increase the likelihood of performing a successful egress from a survivable helicopter ditching (Cunningham, W.F., 1978). There is little question that this is a positive step in helicopter/marine safety and has undoubtedly saved many lives. However, what is not clear in this safety movement is the actual content of the HUET programs and thus the content varies from region to region. The variation in content of the HUET programs seems to be influenced to some extent, by the time and cost associated with the training as well as the effect the training may have on the retention of the individuals in the chosen profession. In other words, not everyone enjoys the training and anecdotally it appears that some people opt out of the profession because of the training. However, the actual number of people who do so is difficult to determine.

In order for training to be effective a balance is needed between the fidelity (realism) of the training and the potential adverse affect the training may have on the individual, and others involved. Recently we completed a study involving 191 subjects which compared three different levels of helicopter egress training to see if there was an effect on simulated escapes (Kozey, McCabe and Jenkins, 2006). A balanced, randomized design was used to assign subjects to one of three groups in which each group received a different number of training trials and the fidelity of the groups was altered. The groups were balanced for sex (males and females), and a self reported measure of swimming ability which we referred to as water comfort. Table 11-2 shows the mixture of trials and conditions that the groups underwent.

Table 11-2: Description of the Different Training Conditions for Session I

Group	Conditions	Training Trials	# of Trials
1	1	Immersion, Straight In, No window	1
	2	Immersion, 180° inversion, No window	1
2	1	Immersion, Straight In, No window	1
	2	Immersion, 180° inversion, No window	1
	3	Immersion, 180° inversion, Window in	1
3	1	Immersion, Straight In, No Window	1
	2	Immersion, 180° inversion, No Window	1
	3	Immersion, 180° inversion, Window in	4

As you can see the first two conditions for all groups consisted of making an underwater egress from a Modular Egress Training System (METS) in which there was an opening immediately beside the subjects, but jettisoning a window was not required. Condition 3 for Groups 2 and 3 required the subjects to jettison a standard push-out window prior to making their egress. Group 2 received one trial of this condition and Group 3 received 4 trials of pushing out the window. At the conclusion of the training session 96.8% of the subjects successfully completed Condition 2 (immersion, 180° inversion, No window). The success rate for the first attempt of Condition 3 (immersion, 180° inversion, Window in) was 83.1% and with practice the success rate for the subjects in Group 3 rose to 95.2% for this condition.

Six months after the training session, 153 of the initial 191 returned for a single trial in which the subjects received one trial of condition 3 (immersion, 180° inversion, window in). This would be precisely what they would be confronted with in a helicopter ditching months or years after receiving a HUET course. However there was a wide and systematic change in the percentage of successful subject across the three groups. Table 11-3 shows how significant the addition of the exit makes to the ability to escape from an inverted flooded helicopter six months after training (Session II). Overall 77% of the subjects successful completed the egress. Group 1 which had received no exposure to the push out window and only 2 training trials of the egress had a 54% success rate. Group 2 which received 3 trials in total, one of which involved the push out window had an 81% success rate. Subjects in Group 3 completed 6 training trials in total, four involving the use of a push out window, had a 96% success rate. Clearly there is a major benefit to exposing the subjects to the push out window trials versus trials that do not involve the window and to allow for practice of the task.

Table 11-3: Performance in Session II

Group	Pass	Previous Exit Practice
1	54%	0
2	81%	1
3	96%	4
Total = 153	118 (77%)	

How then does this example relate to policy? It is hoped that these results clearly demonstrate that from a Human Factors point of view, physical fidelity and practice should be included in all training programs.

Hopefully the industries and training organizations around the world will move to create a single international standard that requires the individuals to jettison the appropriate window mechanism, and that training without an exit may well lead the passengers into a false sense of security.

CONCLUSION: TAKE HOME MESSAGE

The purpose of this paper was to demonstrate the importance of human factors research and to show how this knowledge can be used at various organizational levels. The examples used were related to helicopter egress and similar examples exist in a variety of different applications (Vincente, 2003). What is important for you the reader and practitioner to realize is the huge potential you have to contribute to the improved performance of systems and lastly, to understand why it is important to have your input presented early in the design phase of any project.

Shown in Figure 11-2 is an adaptation of a figure from Gawron, Dennison and Biferno (1996) which shows the cost of changes to a system (or product) depending on the status of the product in the development and production phases. If we consider the costs of Human Factors input at the initial conceptual phase to be a value of 1 then we can see how rapidly the costs will rise the later into the production cycle the change is suggested. These costs can reach as high as 1,000 to 10,000 times the initial cost once the product reaches the production stage. To explain this increase in cost Gawron, et al., present a graphic similar to the one shown in Figure 11-3 which relates the development of a product and the point at which costs are “locked in”.

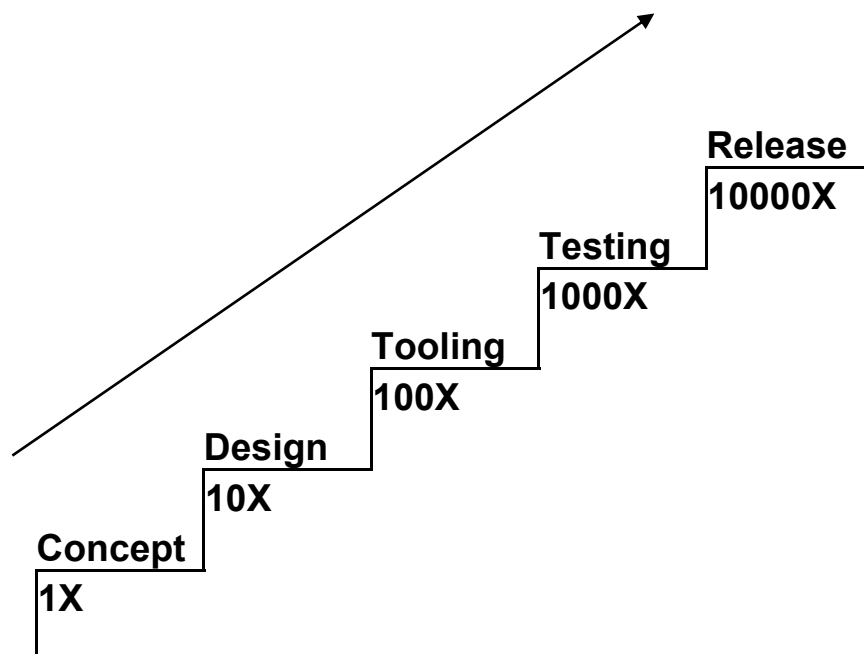


Figure 11-2: The Costs of Design Changes as Proposed by Gawron, et al. (1996).

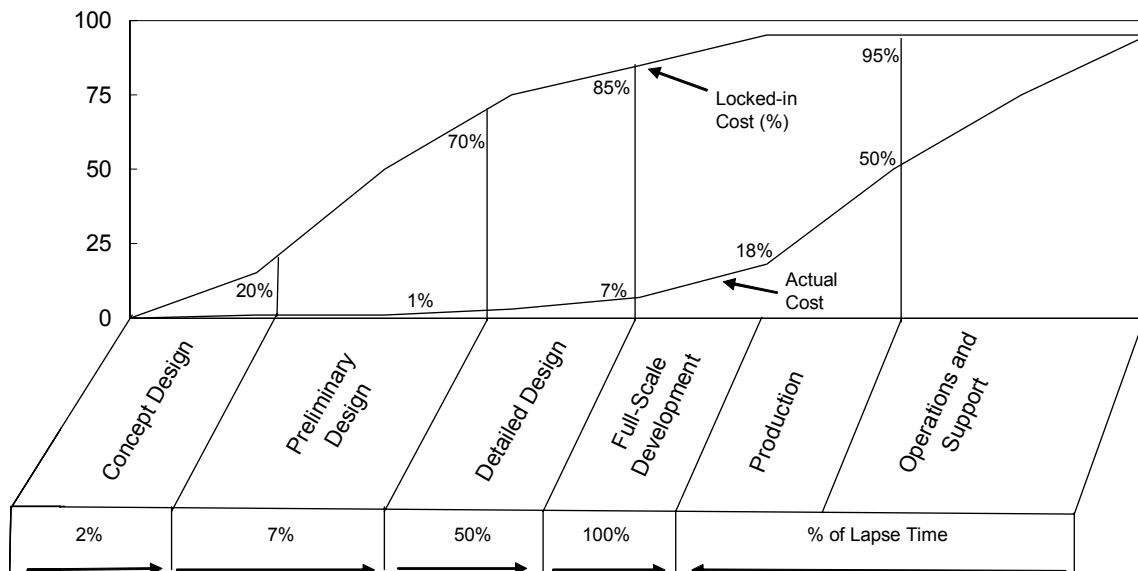


Figure 11-3: Life Cycle Costs as Modified from Gawron, et al. (1996).

As one can easily see early in the production phase much of the costs associated with production become locked in and therefore the costs associated with changes to the product will grow dramatically. While this example applies to the production of a product a similar profile exists for the different levels as shown on Vicente's ladder. Once standards and policies have been established changes to the standard can become quite high and will be resisted by groups already using the existing standard.

So although you may or may not be a Human Factors specialist, you do have expertise in the subject matter in general and your feedback into the design cycle is important. It will most likely be effective if the knowledge and information you have can be present and discussed at the earliest possible phase. This is not always an easy task, but creating a line of communication from you to the design team will in the long run, likely provide important knowledge and impetus for future change and an overall better system and of course save lives.

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Chapter 12 – Fitness Requirements for Offshore Rescue

by

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INTRODUCTION

Fitness standards have been employed by the police, fire fighters, industry, transport, and defence [1 – 7]. These standards include measures of strength, endurance, anthropometrics, flexibility, motor skills, and cardiovascular capabilities.

The general approach employed to produce a scientifically underpinned and defensible fitness standard for offshore rescue was as follows:

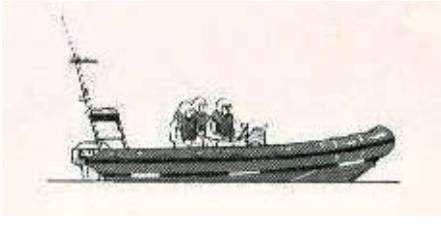
- Identify the critical and generic tasks associated with maritime search and rescue;
- Establish minimum performance requirements for safe and successful work;
- Measure the physiological demand of these tasks (metabolic/musculoskeletal);
- Measure crew maximum performance on these tasks and on potential easy to measure predictive tests; and
- Identify the final physical fitness tests which may be a combination of predictive tests and direct work simulations.

METHODS

Questionnaire Administration

To develop the fitness standard for the Royal National Lifeboat Institution (RNLI), in the United Kingdom and Ireland, 2000 questionnaires were administered to lifeboat crew with a 50% return rate. Additionally, 50 out of a possible 233 stations were visited to identify and measure the physiological demands the critical tasks.

The critical and most demanding physical tasks for the two boat types were identified as:

	
All Weather Lifeboats (ALB) Man overboard recovery (MOB) Equipment (Salvage pump) carrying Casualty handling	Inshore Lifeboats (ILB) Man overboard recovery (MOB) Anchor recovery Getting back into the boat

Evaluation of the Critical Tasks

Following this, the minimum performance requirements for these tasks were identified by consultation with operations experts. Isometric and dynamic simulations of the critical tasks were developed. The following

tests were administered on a sample of volunteer subjects (N=56) who were members of the RNLI lifeboat crew:

Maximal performance on:

- 1) The critical field tasks.
- 2) Simulations of the critical field tasks.
- 3) Physical selection tests which may predict performance on the field tasks or simulations:
 - a) Strength: Back, Biceps 15° and 90°, Triceps (at nose and waist height), Trapezius, Grip, Grip Endurance.
 - b) Anthropometrics: Height, Weight, Biacromial breadth, Circumferences: biceps, waist, forearm, wrist, shoulder, chest, hip height, arm and hand length.
 - c) Skinfolds: chest, triceps, subscapular, biceps, abdomen, suprailiac.

Correlation of the Critical Tasks with the Simulated Tasks

To determine if the simulations are valid measurements of performance on the work tasks in the field, the maximum performance on the field task (i.e. MOB recovery) and maximal performance on the simulation were correlated. The relationships between performance on the field/simulations and performance on the physical selection tests determine if any of the physical selection tests can predict critical task performance.

RESULTS

Overall the measures of back strength, grip endurance, and grip strength were determined to be predictive of task performance, and with the calculation of prediction intervals the required levels of strength and endurance were established to ensure 95% of individuals who are capable of performing the critical tasks are accepted into the RNLI. These predictive physical selection tests are currently administered to potential and existing lifeboat crew to ensure they are fit for purpose. Existing crew members are also required to demonstrate competence on the critical tasks in the field after one year of experience. In addition, a cardiovascular step or walking test was recommended to ensure that the crew members possess the minimum level of cardiovascular fitness to cope with an emergency response or multiple recoveries.

CONCLUSION

As a result of the present project it is possible to recommend a minimum fitness standard based on the critical generic tasks undertaken by lifeboat crew. Some of the tests are direct measures of performance and therefore simulate a critical task. Others are indirect tests based on the relationship between the PST and performance on the critical tasks. The latter approach to testing is easier to administer, but has more inherent error.

Fitness Requirements for Offshore Rescue

Table 12-1: Performance Requirements (kg) for ILB and ALB Prospective Lifeboat Crew Members

Predictive Tests (potential and current crew members)	Field Tests (current crew members)
Back Strength (kg) (predicting anchor recovery time) FAIL 38 BORDERLINE 43 PASS 77 GOOD PASS	Rescue a 35 kg “dummy” over the relevant ILB using Method of Best Practice (MOBP).
Grip strength (kg) (predicting anchor recovery time and anchor freeing) FAIL 29 BORDERLINE 32 PASS 46 GOOD PASS	Pull a rope with a resistance of 15 kg 50 m in 45 s. Crew should be able to re-board the boat via the stern.

Predictive Tests (potential and current crew members)	Field Tests (current crew members)
Back Strength (kg) Requirements for ALB lifeboat crew (predicting casualty handling and salvage pump) FAIL 30 BORDERLINE 34 PASS 66 GOOD PASS	1.5 m lift of 35 kg using lifeline strops.
30s Grip endurance (kg) Requirements for ALB lifeboat crew (predicting casualty handling and salvage pump) FAIL 11 BORDERLINE 12 PASS 20 GOOD PASS	10 m carry of 20 kg, repeat using right and left hands, using MOBP.
10s Grip endurance (kg) Requirements for ALB lifeboat crew (predicting casualty handling and MOB recovery) FAIL 22 BORDERLINE 25 PASS 41 GOOD PASS	Stretcher carry for 10 m with a resultant load of 35 kg, use MOBP.
Grip Strength (kg) Requirements for ALB lifeboat crew (predicting casualty handling and salvage pump and MOB recovery) FAIL 32 BORDERLINE 35 PASS 53 GOOD PASS	

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14. Abstract This AGARDograph summarizes the current scientific knowledge of sea survival for mariners, aviators, search and rescue technicians and medical staff. The text discusses key issues such as drowning through cold shock and swimming failure induced by immersion in water particularly below 15°C, survival prediction curves and non-freezing cold injuries. It emphasizes the importance of integrating good human engineering practices at the beginning of a project involving survival equipment such as lifejackets, life rafts and lifeboats. Manikin testing to evaluate survival suit insulation is described. The latest helicopter ditching statistics and helicopter underwater escape protocols are presented. Practical advice is given on the causes and treatment of seasickness. Finally a discussion is had on the importance of understanding how humans mentally process information under stress and why this should be included in every survival school curriculum.																																							





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