Chapter 9C – Immersion Suits: Their Development

by

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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, Gagge, 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 $0.155°C.m^2.W^{-1}$, 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.

$$1 \text{ Clo} = 0.155^{\circ}\text{C.m}^2.\text{W}^{-1}$$
$$1 \text{ Tog} = 0.645 \text{ Clo}$$
$$0.1^{\circ}\text{C.m}^2.\text{W}^{-1}$$

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.

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."

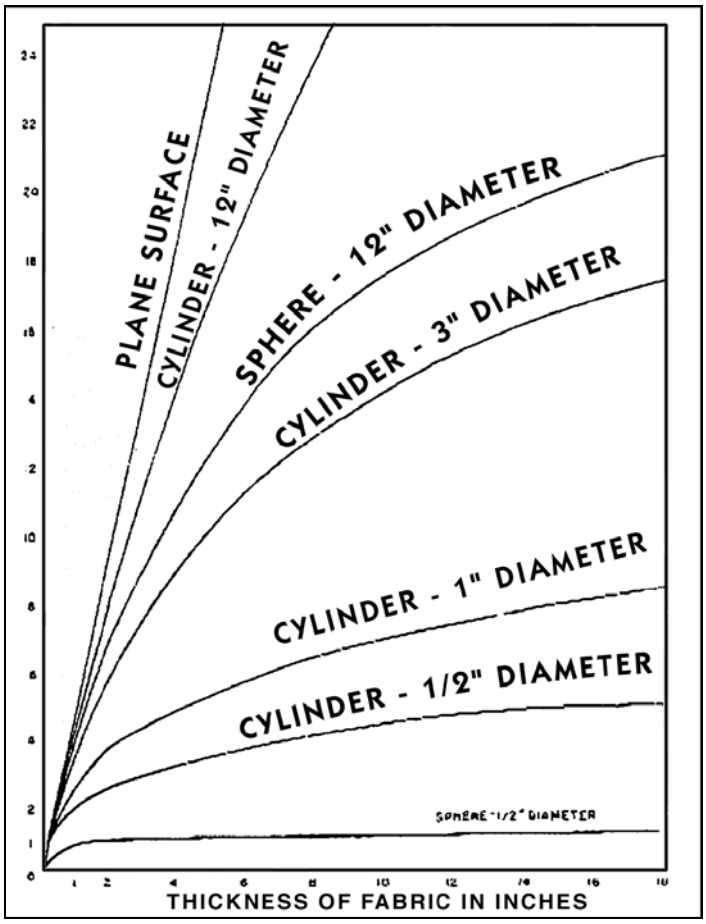

Figure 9C-1: Insulation of Ideal Fabric on a Plane, Cylinders and Spheres. (After Van Dilla, Day and Siple in Newburgh – Physiology of Heat Regulation. 1968, Hafner Publishing Co.)

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."

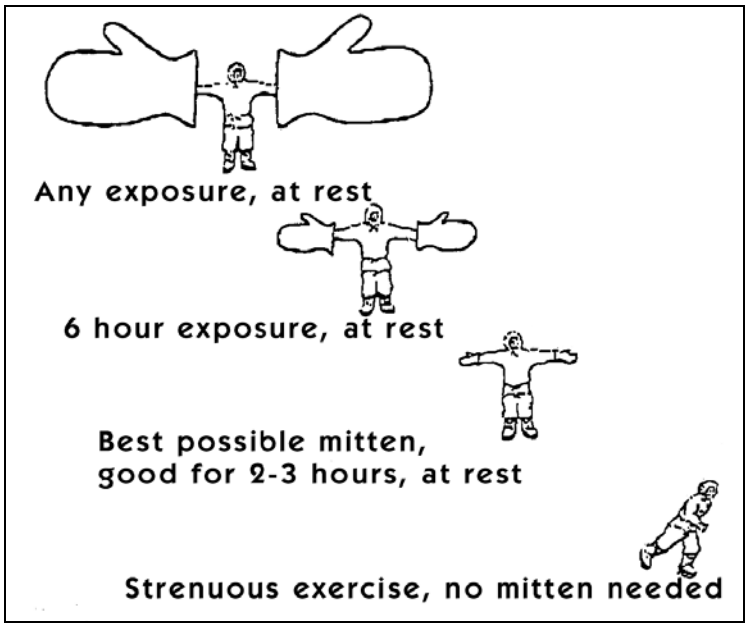

Figure 9C-2: Relative Size of Mittens Needed for Different Exposure Times at Minus 20°F. After Van Dilla, Day and Siple in Newburgh Physiology of Heat Regulation. 1968, Hafner Publishing Co.)

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 loose 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

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.

- 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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