# Lifeboat Habitability and Effects on Human Subjects

*Jonathan T. Power*
National Research Council of Canada – Institute for Ocean Technology
St. John's, Newfoundland and Labrador, Canada
Jonathan.power@nrc.ca
*Other Author(s) Name(s): António J. Simões Ré*
National Research Council of Canada – Institute for Ocean Technology
St. John's, Newfoundland and Labrador, Canada
Antonio.simoesre@nrc.ca

ABSTRACT

Lifeboats are the most used marine evacuation craft in both the shipping and offshore industries. The International Maritime Organization (IMO) Lifesaving Appliances (LSA) code does not have criteria for the manoeuvring performance of lifeboats nor for their habitability and effects on human subjects.
During standard seakeeping exercises conducted with a SOLAS approved 20-person lifeboat in Conception Bay, NL two NRC employees (coxswain and assistant) wearing certified immersion suit systems had their skin temperature, deep body temperature, and heart rate measured while performing their assigned duties.
During the morning of July 24th, 2009, the outside air temperature was 14°C and the water temperature was approximately 7.6°C, with little to no cloud cover. While piloting the lifeboat with the hatches closed, the interior temperature of the lifeboat rose from 19.4°C to 28.5°C over the course of approximately two hours. With the immersion suits fully zipped, the coxswain experienced an increase in mean skin temperature of 3.4°C, while the assistant's rose by 2.7°C. The coxswain's mean body temperature rose by 0.74°C, and the assistant's by 1.0°C. After the two-hour time period, both the coxswain and assistant's clothing were heavily soaked with sweat, and both reported moderate levels of thermal discomfort due to the heat.
In the afternoon of the same day, with little to no cloud cover, the outside air and water temperatures registered 15°C and 8.78°C, respectively, . For the afternoon trials, the lifeboat hatches were left open, and the immersion suits were unzipped. Over a two-hour period, the interior temperature of the lifeboat rose by only 0.2°C, the coxswain's mean skin temperature rose by 0.5°C, and the assistant's by 0.5°C. After the two hour afternoon session was completed, both the coxswain and the assistant reported little to no thermal discomfort with the interior temperature of the lifeboat.
Based on these preliminary observations, prolonged occupancy of a sealed lifeboat with a high level of clothing insulation may lead to increased thermal stress on the evacuees..

KEY WORDS: lifeboat; skin temperature; hyperthermia; thermal; heat stress, habitability.

## INTRODUCTION

Lifeboats are the most used marine evacuation craft in both the shipping and offshore industries. SOLAS regulations require all vessels and installations have enough lifeboats on board to cover all personnel on board (POB) and in some jurisdictions the requirement is for 200% POB capacity. Even though lifeboats are widely used, and required by regulations, throughout the marine industry, little work has been done to date that examines the conditions inside these craft; conditions that the occupants may be expected to endure for prolonged periods of time in dangerous environments. Currently, the International Maritime Organization (IMO) Lifesaving Appliances code (LSA) does not specify any criteria for the interior conditions of the lifeboats, including carbon monoxide (CO) and carbon dioxide ($CO_2$) levels, sound levels, or temperature. With no specified maximum values for these levels, a knowledge gap currently exists on how the interior of the lifeboat changes when it is in use.

Our previous work examined the interior conditions of a SOLAS approved lifeboat that was performing ice-maneuvering exercises (Taber et al. 2010). While the lifeboat was performing the exercises with the hatches open, there was little change in the interior environment and the occupants remained somewhat comfortable. However, when the hatches where closed the exercises had in instances to be cut short before CO and $CO_2$ levels exceeded safety limits (Taber et al. 2010). The lifeboat interior temperature also began to rise while the hatches were closed.

While the lifeboat was performing these exercises, one of the occupants measured their skin temperature on a self-contained data logger (Data not published). This preliminary assessment suggested that it might be possible for the interior temperature of the lifeboat, along with the occupants own clothing insulation, to result in increased thermal strain on the occupants.

Seeking to expand on our previous work, we measured the skin temperatures and interior temperatures of a SOLAS approved lifeboat while it was conducting seakeeping exercises to determine if the habitability of the lifeboat changed during normal operations.

## METHODS

All measurements were conducted on two NRC-IOT employees while they were conducting standard seakeeping exercises with a SOLAS approved 20-person lifeboat (Figure 1). NRC's Research Ethics Board (REB) was consulted as to whether or not ethics approval would be required for this investigation. Since the two NRC-IOT employees were performing activities that fell within their job descriptions, ethical approval was not required.

Figure 1 NRC-IOT SOLAS approved 20-person lifeboat

Deep body temperature was measured using CorTemp gastro-intestinal pills (HQ Inc., Palmetto, FL, USA), which transmitted wirelessly to the CorTemp Data recorder (also manufactured by HQ Inc.). Heart rate was measured using a Polar Heart Rate monitor (Polar, Lake Success, NY, USA), which also transmitted wirelessly to the CorTemp Data recorder.

Skin temperature was measured at 12 sites (Figure 2) using heat flow sensors (Concept Engineering, Old Saybrook, CT, UA) that were connected to self-contained data loggers (ACR Data Systems, Surrey, BC, Canada). The loggers and heat flow sensors were protected from mechanical stress by a plastic guard, sealed inside a splash proof bag, and contained on the employees in the pocket of a thin mesh vest.

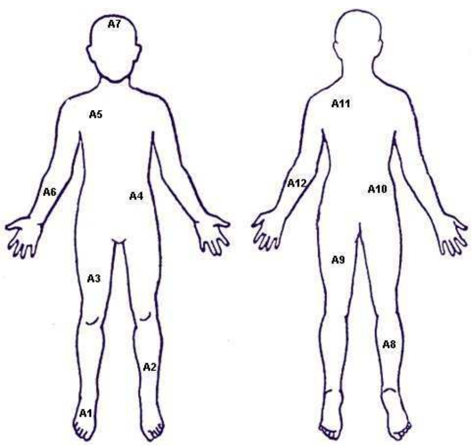


Figure 2: Skin temperature measurement sites.

Mean skin temperature was calculated by weighting the measurements from the 12 sensors by the values based on work by Hardy and DuBois (Hardy and Dubois 1938). Due to the lack of hand measurements, the final mean skin temperature values was divided by 0.95. The formulae used for calculating mean skin temperature was:

$(\sum$ (Measurement Site * Weighting Value))/0.95 = mean skin temperature

Both employees wore wool socks, cotton pants, cotton undershirts, and cotton long sleeved over shirts. Prior to the beginning of the trials, the employees donned a White's Marine Abandonment Suit (White's Manufacturing, Victoria, BC, Canada), which is a Transport Canada certified immersion suit.

Air temperatures as well the humidity, inside and outside the lifeboat, were measured using HTM 2500 sensors which were recorded using an onboard, NRC-IOT built Data Acquisition System (DAS).

Standard seakeeping exercises were performed with the hatches closed for select runs, and with the hatches open for others. The two employees were instructed to keep their immersion suits fully zipped during certain runs, and to have their suits unzipped for others.

## RESULTS

The mean water temperature during the morning of July 24th, 2009 was 7.6°C, and the air temperature was 14°C. While piloting the lifeboat with the hatches closed during a 2 hour run, the interior temperature of the lifeboat increased from 19.4 to 28.5°C, with a maximum temperature of 30.1°C measured. During this time, both instrumented NRC-IOT employees had their immersion suits fully zipped. The lifeboat coxswain's mean skin temperature increased by 3.4°C, and the assistant's by 2.7°C (Figure 3).

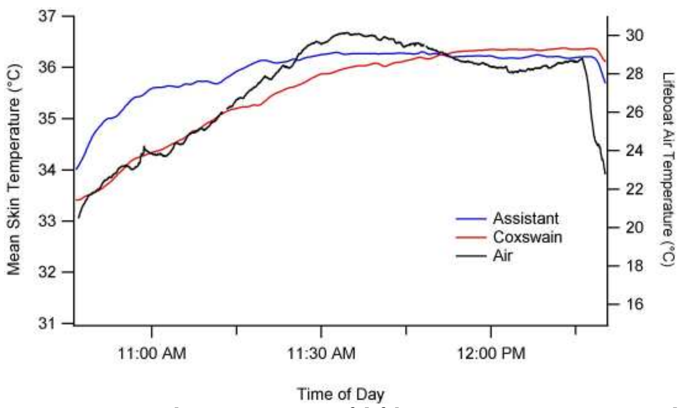


Figure 3: Mean skin temperature of lifeboat coxswain, assistant, and interior air temperature during 2-hour sea keeping exercises (AM). Exterior air temperature = 14°C, water temperature = 7.6°C.

After completion of the 2-hour seakeeping exercises, both the assistant and coxswain's clothing inside the immersion suit were wet to the touch with sweat. Both NRC-IOT employees reported moderate levels of thermal discomfort due to the increased temperatures inside the lifeboat. While breaking for lunch, both sets of underclothing were dried out before being worn by the employees again.

During the afternoon series of seakeeping exercises, the water temperature was 8.78°C and the outside air temperature was 15°C. While conducting these series of exercises, the lifeboat hatches were open and the employees had their immersion suits un-zipped. With the lifeboat hatches open, the interior lifeboat air temperature dropped 3.5°C during the 2-hour exercises. Over the duration of the tests, the coxswain's mean skin temperature rose by 1.4°C, and then dropped to values that were 0.5°C greater than starting values by the end of the exercises (Figure 4). The assistant's mean skin temperature rose by 0.8°C, and then by the end of the exercises, dropped 0.5°C below pre-exercise values (Figure 4).

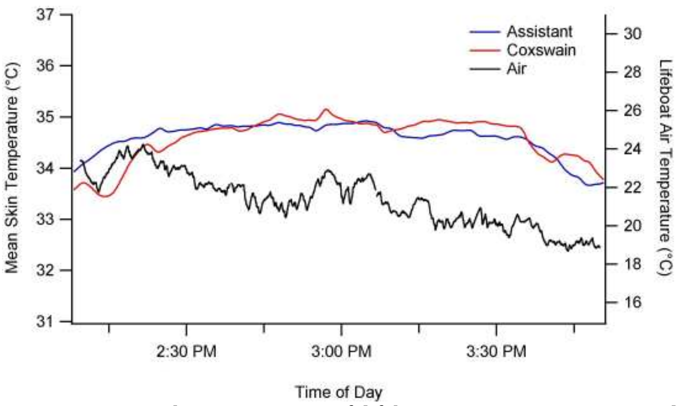

Figure 4: Mean skin temperature of lifeboat coxswain, assistant, and interior air temperature during 2-hour sea keeping exercises (PM). Exterior air temperature = 15.0°C water temperature = 8.8°C

**DISCUSSION**

The preliminary observations presented in this paper suggest that the thermal comfort of a sealed lifeboat may be reduced after only a short period of time. During the morning sea keeping exercises, the interior temperature of the lifeboat rose 8°C in as little as 45 minutes. In agreement with our earlier work (Taber et al. 2010), having the lifeboat hatches sealed results in a decrease in ventilation throughout, resulting in rising temperatures. The interior lifeboat temperature reached a maximum of 30.1°C, and remained somewhat constant throughout the rest of the morning. A temperature of 30.1°C may have been the value at which a thermal steady state was achieved, at which point the lifeboat was able to lose heat to the environment at an equal rate to which it was generating it (Figure 2). The heat sources contributing to this rise in temperature were the lifeboat engine, solar radiation creating a green house effect, and the employees themselves.

Since there were only 3 people in the lifeboat during the morning exercises, it is highly likely that the interior temperature could have been much higher if a full complement of 20 were onboard. The additional occupants (3 to 20) represent additional heat sources that would have caused the lifeboat interior temperature to reach higher values before a new thermal steady state could be achieved. It is possible that the relationship between the number of people in a lifeboat and lifeboat interior temperature is not a linear one, and would undoubtedly be heavily influenced by external weather conditions such as the amount of direct sunlight the lifeboat receives, and the water and air temperature.

After the morning sea-keeping exercises were completed, both the coxswain and assistant reported moderate levels of thermal discomfort. Both employees were sweating heavily and all of their clothing under the immersion suit was damp to the touch. Each employee reported feeling very uncomfortable and the assistant reported that he found it difficult to breathe at times in the lifeboat due to the increased temperature.

The immersion suit worn by each employee was of very high quality, and had watertight seals around the wrists and neck. As a result of this tight sealing, a mico-climate was created inside each immersion suit. A normal thermoregulatory response to increasing deep body and skin temperature is to sweat. The cooling power of sweat is dependent on the ability of the sweat to evaporate, as it is the heat lost to evaporate it that cools the body. Once the vapor capacity of air reaches maximum, the air can retain no more liquid. This is the reason that sweating proves to be ineffective on days when the humidity of the air is extremely high. With sweat unable to change to a gaseous state via evaporation, its power to cool the body is lost. In the relatively small volume of the micro-climate inside the immersion suit, it is highly probable the air reached is maximum vapor capacity quickly, rendering the ability for the employees to sweat to cool themselves ineffective.

In addition to the decreased comfort due to wearing damp clothing, there is an added danger that the sweat soaked clothes can reduce the thermal protective properties of an immersion suit. Previous work by Tipton and Balmi has shown that 500ml of water leakage over the torso can reduce clothing insulation by up to 30%. (Tipton and Balmi 1996) The amount of sweat produced by each employee was not measured, but it was sufficient to dampen the entire underclothing to the point where it felt wet to the touch. In a disaster scenario, if evacuees are wearing immersion suits with sweat soaked clothes their predicted survival time may be reduced due to the presence of water into the suit. In effect, the participants may already have a deleterious amount of leakage in their suit without ever having entered the water.

In contrast to the morning sea keeping exercises, the temperature values measured in the afternoon where remarkably different for both the lifeboat and employees. During the afternoon trials, all the lifeboat hatches where open (1 aft, 1 port, 1 starboard, 1 stern) and exterior air was able to freely blow through the lifeboat. Throughout the course of the afternoon, the interior lifeboat temperature decreased from 23.9°C to 19.0°C, which was only 4.0°C higher than the ambient air (Figure 2). With the increased ventilation due to the hatches being open, the lifeboat was able to successfully dissipate the heat generated and keep the interior temperature from rising.

Both the coxswain and assistant unzipped their immersion suits for the afternoon trials. As a result the coxswain and assistant's mean skin temperature did not increase to values similar to those seen in the morning trials. The coxswain the assistant reported feeling more much comfortable during the afternoon trials, and there was negligible sweat buildup on their under clothing.

The most obvious recommendation to help reduce the thermal strain placed on the lifeboat occupants is to pilot the ship with the hatches open, and with all immersion suits open.. This may not be possible to do in all situations, and can be dangerous in others. By having all the hatches open, the water tight integrity of the lifeboat is compromised and increases the chance of taking on water, especially in high sea states. If the lifeboat is maneuvering through hazards such as fires or sour gas clouds, then there may no choice but to operate with the hatches closed. Having the lifeboat occupants unzip their suits while inside would be inadvisable as well. If the integrity of the lifeboat was to become compromised the occupants may be expected to abandon it quickly into the water. If the suits are unzipped prior to abandoning it, then there is the chance they may not be fully closed before entering the water. It can be difficult to ensure a proper closure and seal with some immersion suits under ideal conditions; adding in the challenges of cramped lifeboat in a panicky situation would not increase the likelihood of success.

In conclusion, these initial observations suggest that there may be risks in operating a TEMPSC completely closed with occupants dressed in clothing that offers a high level of thermal protection. The TEMPSC used in these sea trials did not have the capability to dissipate the heat gained from multiple sources, resulting in rising interior air temperatures and increased thermal strain on the occupants. It can be expected that with more occupants inside the lifeboat, the rise in temperatures measured here, both for the interior air and with the occupants themselves, will increase to levels that may prove to detrimental to their safety. It is strongly recommended that properly designed lifeboat ventilation systems be implemented such that the integrity of both the lifeboat and the occupant's immersion suit do not have to be compromised to relieve thermal strain.

**REFERENCES:**


Hardy, J.D., and DuBois, E.F. *The technic of measuring radiation and convection*. Journal of Nutrition, 1938; 15: 461-75.

Taber, M. J., Simões Ré, A., and Power, J. *A preliminary ergonomic assessment of piloting a lifeboat in ice.* Safety Science. 2010. (in press).

Tipton, M.J. and P.J. Balmi, *The effect of water leakage on the results obtained from human and thermal manikin tests of immersion protective clothing.* Eur J Appl Physiol Occup Physiol, 1996. 72(5-6): p. 394-400.