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Totally Enclosed Motor Propelled Survival Craft Occupant Loading Trials

Technical Report - Unclassified

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SUMMARY

This report describes a study aimed at investigating relative increased occupant loading times and possible diminished occupant capacities of Totally Enclosed Motor Propelled Survival Craft (TEMPSC) operating in arctic waters. The experiment was designed to establish the impact of personal protective equipment (PPE) on habitability by examining changes in loading times as subjects donned various clothing ensembles (i.e. levels of PPE) and performed tasks associated with normal TEMPSC operation (i.e. loading, fastening seatbelts, etc.). The clothing ensembles tested included combinations of base clothing, lifejackets, and marine abandonment suits. The impact of transporting and loading a stretcher into a lifeboat was also examined. The results of this study suggest that PPE can have a direct impact on the time required to load lifeboats, especially as the level of PPE is increased to match the requirements operations in northern regions. Also, design changes may be needed to account for increases in the body dimensions of offshore workers (due to changing anthropometrics and the requirement of marine abandonment suits), as well as to accommodate the loading and transport of injured workers or passengers on stretchers.

National Research Council Canada
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Executive Summary

Survival craft are purposed for temporary refuge in emergency situations, yet the breadth of the environments that they could be subject to may not have been fully addressed in their initial design. As per Taber, Simões Ré, and Power (2011), Totally Enclosed Motor Propelled Survival Craft (TEMPSC) have not been designed for the long-term habitation that may be associated with work in isolated arctic regions. With an increase in tourism, shipping, and resource exploration and extraction in these remote areas, longer search and rescue times are a pertinent and growing cause for concern.

Previous and ongoing research at National Research Council Canada – Ocean Coastal and River Engineering (NRC-OCRE) has demonstrated concern and increased awareness for survival craft operability and habitability in harsh environments. The objective of this work was to define the minimum requirements for the design of evacuation craft that can be utilized by designers, manufacturers, regulators, and operators by combining both the engineering (i.e., materials, hull strength, etc.) and habitability (i.e., loading time, capacity, etc.) for use in northern and arctic environments. The present paper reports on loading times and capacity issues associated with a 50-person TEMPSC.

Testing took place at the NRC-OCRE facility in St. John's, Newfoundland and Labrador, Canada and was carried out in August of 2012. The trials involved the timed loading of 20 subjects into the passenger area of a 50-person TEMPSC to investigate if personal protective equipment (PPE) has any effect on loading time and capacity. Depending on the trial, the subjects were required to don one of three different clothing ensembles: base clothing (Ensemble A), base clothing with a lifejacket (Ensemble B), and base clothing with a marine abandonment suit (Ensemble C). There was also a trial in which that the impact of having to transport and load a stretcher was investigated. Total individual loading times were measured for each subject, along with the overall group times. Timing began when the instruction was given to commence a trial and ended when the subject was seated with their seatbelt fastened. Anthropometric measures were taken per subject.

The results of this study suggest that PPE, along with the increasing size of the North American population, can have an impact on TEMPSC occupant capacities and loading times, as well as contribute to several ergonomic issues throughout these lifeboats. In fact, it is possible that donning various forms of PPE could increase loading times and decrease occupant capacities to the point that they no longer align with the standards developed and implemented by the International Maritime Organization – Safety of Life at Sea Convention (IMO-SOLAS, 1974, as amended). Additional variables indentified as posing threats to the habitability of TEMPSC include the length of the seatbelts (e.g. there were cases in which subjects who had donned marine abandonment suits were unable to fasten their seatbelts), the width of the hatchway (e.g. the stretcher was found to be wider than the hatchway, meaning it had to be tilted to pass through the hatch and into the lifeboat), and the positioning of the stretcher once loaded (e.g. once loaded, the only location in which the stretcher could be accommodated was on the laps of the occupants). Therefore, if maritime regulations relating to TEMPSC design and

habitability are not made to be performance-based (i.e., fit-for-purpose) to the application for which they are implemented, vessels and installations operating in northern waters may be ill-equipped to deal with large scale evacuation, escape, and rescue (EER) events that require the deployment of TEMPSC.

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Glossary

ANOVA	Analysis of variance
CAPP	Canadian Association of Petroleum Producers
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
EER	Escape, evacuation, and rescue
F	F-ratio (test statistic used in ANOVA)
HSE	Health and Safety Executive (United Kingdom)
IMO	International Maritime Organization
LSA	Lifesaving appliance
MODU	Mobile Offshore Drilling Unit
n	Sample size
NRC	National Research Council Canada
OCRE	Ocean, Coastal, and River Engineering
p	p-value (statistical significance)
PERD	Program for Energy Research and Development
PPE	Personal protective equipment
REB	Research Ethics Board
RNLI	Royal National Lifeboat Institution
SD	Standard deviation
SOLAS	Safety of Life at Sea
TC	Transport Canada
TEMPSC	Totally Enclosed Motor Propelled Survival Craft
TR	Technical Report

Totally Enclosed Motor Propelled Survival Craft Occupant Loading Trials

1.0 INTRODUCTION

1.1 Background

For over two centuries, evacuation craft have played a crucial role in the escape, evacuation, and rescue (EER) protocols of a wide variety of maritime industries (Royal National Lifeboat Institution, RNLI, 2011). These industries include natural resource exploration and extraction, shipping, tourism, fisheries, and scientific research. Recently, commercial and industrial operations have been expanding further and further into northern waters as the atmosphere is warming and arctic ice is retreating. In fact, ice extents are at a 33-year low (National Snow and Ice Data Center, 2012), and it has been forecasted that arctic summers could be ice-free by the year 2100 (Stroeve et al., 2007). The increase in the extent and duration of accessibility of these regions poses great opportunity; however, it also brings considerable risk. Factors such as snow, ice floes, isolation, prolonged darkness, and freezing sea spray must now be considered and designed for.

However, the operability of lifeboats in open water and ice is not the only concern of maritime regulators and researchers. There are also gaps in the regulations applied to the internal habitability of lifeboats, and these exist across many areas of maritime operation. This is supported by the work of Taber, Simões Ré, and Power (2011), who found that Totally Enclosed Motor Propelled Survival Craft (TEMPSC) have not been designed for the long-term habitation that may be associated with work in isolated arctic regions. The habitability of a lifeboat directly affects the comfort, health and safety of the survivors whose lives the craft is intended to save and therefore is a primary determinant of the outcomes of EER events. The IMO Guidelines for Ships Operating in Polar Waters (2010a) state that lifeboats operating in these regions should be evaluated with regard to operability, accessibility, seating capacity and overall space, considering the needs of personnel wearing suitable polar clothing. Theoretically, this type of evaluation should serve as the essential component of ensuring occupant safety onboard survival craft. However, because current regulations do not explicitly require designers, operators, or duty holders to demonstrate the capability of lifeboats to protect personnel, the prescriptive nature of many regulations is highlighted, along with the need for research-informed performance-based standards as work expands further into northern climates. As such, modifications must be made to equipment and regulations to ensure that they are fit-for-purpose and therefore consider the potential constraints that arctic environments may place on maritime operations.

The development of TEMPSC is an example of such a modification. Compared to traditional open lifeboats, the benefit of using a TEMPSC, especially when moving into northern regions, is that they provide greater shelter and protection from the elements than traditional open-top lifeboat designs (IMO, 2000). This is reflected in Resolution A.1024(26) of the Guidelines For Ships Operating In Polar Waters that states, “all lifeboats should be either of the partially or totally enclosed type to provide adequate shelter from the anticipated operating environment” (IMO, 2010a, Section 11.5.1, p. 23).

In addition, the requirement of an engine ensures that these survival craft, along with as their occupants, are able to clear the installation or ship from which they were deployed, well as motor to safety and awaiting rescue vessels or land-based stations. This also serves to meet the Canadian Association of Petroleum Producers (CAPP) Atlantic Canada Offshore Petroleum Industry Escape, Evacuation and Rescue Guide (2010) stipulation that operators must ensure that, during a semi-dry or wet evacuation involving the use of TEMPSC, all personnel "be able to embark and be launched safely, clear the installation and survive until rescued; and have a reasonable expectation of avoiding harm during the evacuation process" (p. 23).

The design and operation of TEMPSC are governed by minimum prescribed standards developed and implemented by the International Maritime Organization - Safety of Life at Sea (IMO-SOLAS) Convention (1974, as amended) and Life-Saving Appliance (LSA) Code (2010b). These sets of regulations tend to be very broad and largely apply the same standards to all areas of maritime operation. Although this remains appropriate for certain aspects of marine regulation since they often reflect lessons learned, it may be suggested that it is becoming increasingly inappropriate and unsafe to apply the same standards to vessels and installations operating in the Gulf of Mexico as those in the Arctic. Therefore, as operations continue to push into higher latitudes, regulations must become performance-based, meaning they should be adapted to the inherently unique conditions of a given area.

Previous and ongoing research has increased awareness and demonstrated concern for lifeboat operability and habitability in harsh environments. The present report discusses the human factors portion of the work carried out by National Research Council Canada – Ocean Coastal and River Engineering (NRC-OCRE) and funded by the Program for Energy Research and Development (PERD). The goal was to define the minimum requirements for the design of evacuation craft (lifeboats) that can be used by designers, manufacturers, regulators and operators by combining the engineering factors (i.e., materials, hull strength, etc.) with the habitability factors (i.e., capacity, air quality, etc.) for fit-for-purpose application in northern and arctic environments. More specifically, this report provides an assessment of loading times and the occupant capacity of a 50-person TEMPSC.

1.2 Study Objective

This portion of the TEMPSC performance and habitability project carried out by NRC-OCRE has the following objective: to determine relative changes in TEMPSC loading time and capacity as occupants don varying levels of PPE and are tasked with loading a stretcher.

2.0 METHODOLOGY

2.1 Ethics

The National Research Council (NRC) Research Ethics Board (REB) approved the study protocol (NRC REB # 2011-54). Trials took place at the NRC-OCRE facility in

St. John's, Newfoundland and Labrador, Canada in August of 2012. Prior to testing, all subjects gave their written informed consent and completed a medical history questionnaire.

2.2 Subjects

A sample size (*n*) of 20 healthy, naïve individuals (10 female, 10 male) between 19 and 53 years of age was included in the study. Throughout the duration of the experimental protocol the TEMPSC was sitting on a trailer and the engine was not running, meaning it was not necessary to recruit subjects with previous experience operating lifeboats. On the days of testing, all subjects came wearing the requested base clothing ensemble (closed-toe footwear, cotton socks, denim jeans and a long-sleeved cotton shirt). Several standard demographical and anthropometric measures were taken prior to testing, including: height, weight, foot length, waist circumference, and body fat percentage. A summary of some of these measures is provided in Table 2.1, with the full dataset is included in Appendix 1.

Table 2.1: Subject demographic and anthropometric information.

***n* = 20**	**Age (years)**	**Height (cm)**	**Weight (kg)**	**Body Fat (%)***
Mean	27.5	173.5	83.4	25.7
SD	10.74	9.28	18.06	7.34

*Calculated as an average of values obtained independently via the bioelectrical impedance scale and skin fold calipers.

2.3 Pre-Testing Setup and Facilities

The trials took place with the TEMPSC sitting on a trailer in a large ventilated storage shed (Figure 2.2). A private area was set-up, external to the lifeboat, to accommodate the measuring of individual subject anthropometrics.

2.4 Equipment and Instrumentation

2.4.1 Clothing Ensembles

The three clothing ensembles (A, B, and C, as described below) were intended to represent varying levels of PPE and are comprised of several types of attire. Ensemble A consisted of base clothing (cotton socks, denim jeans and long-sleeved cotton shirt) that may be representative of the kind worn by passengers or workers onboard an arctic vessel or installation ship while in covered areas with heating and ventilation (e.g., dining halls, personal quarters). Ensemble B consisted of an IMO-SOLAS approved lifejacket that would likely be worn during EER events onboard some shipping vessels and cruise ships (Figure 2.1, left). Ensemble C consisted of an insulated Transport Canada (TC) certified marine abandonment suit that may be part of certain offshore oil and gas operator's EER protocols (Figure 2.1, right).

Figure 2.1: An IMO-SOLAS approved lifejacket (left), and a TC approved FitzWright marine abandonment suit (right).

2.4.2 50-Person TEMPSC

Trials were conducted using a TEMPSC built in accordance with the requirements put forth by the IMO-SOLAS Convention (1974, as amended) and the LSA Code (2010b) (Figure 2.2). The lifeboat used was a KISS700 model manufactured by Schat Harding, with dimensions of: 6.49m (length), 2.91m (width) wide, and 2.85m (height). It is rated for 50 occupants, with no modifications made. This model has the coxswain's seat located towards the aft end of the boat near the starboard loading door in an elevated position relative to the majority of the cabin space and occupant seating. However, the coxswain's chair in this TEMPSC has been rotated 90º so that it faces the starboard side of the vessel and hangs above a portion of the starboard occupant seating (Figure 2.4). Also, because the occupant seating is arranged symmetrically in two separate rows with their own hatchways, it was only necessary to load subjects along one side of the vessel. The starboard side was chosen because of the potential for occupant loading complications due to the position of the coxswain's seat. Each side of the TEMPSC would typically hold 25 individuals; however, the coxswain's seat was left empty and a temporary bulkhead was constructed with sandbags in order to block off access to the four seats at the end of the row (two on the left bench and two on the right, Figure 2.4). This provided room at the end of the boat for research team members to film the trials, as well as monitor the subjects as they entered and exited the TEMPSC. Therefore, only 20 subjects were involved in each of the trials.

Figure 2.2: 50-Person TEMPSC sitting on a trailer within the NRC-OCRE shed (left), and the scaffold stairs and platform (right).

Figure 2.3: 50-Person TEMPSC bow hatchways (left), and loading platform and starboard side bow hatchway (right).

Figure 2.4: A view of the starboard TEMPSC bench seats from the stern hatch (left), and the coxswain's chair (right). The bulkhead created using blue and purple sandbags can be seen at the far end of the bench seats.

2.4.3 Stretcher

One trial was conducted in which subjects wearing base clothing were asked to load a Stokes Litter (Figure 2.5) into the TEMPSC. Four subjects were selected at random to carry and load an empty Stokes Litter (without floatation) into the TEMPSC along with 15 other subjects. Four subjects carrying the stretcher, plus 15 other occupants, along with the theoretical injured occupant, would mean that the starboard side of the vessel is now loaded to its 20-occupant maximum.

Figure 2.5: Stokes Litter with (left) and without (right) floatation.

2.4.4 Video and Time Recording Equipment

Throughout each of the trials, video was recorded from four locations: a tripod-mounted camera at the aft end of the starboard side of the TEMPSC aimed back at the entrance hatchway (camera 1, Figure 2.6, left); a wall-mounted fisheye camera located internally above the entrance hatchway aimed toward the aft section of the starboard side of the craft (camera 2, Figure 2.6, right); a second tripod-mounted camcorder located external to the lifeboat on the loading platform (camera 3, Figure 2.7, left); and a camera mounted externally above the starboard side hatchway (camera 4, Figure 2.7, right). A fifth hand-held camera used to record video during the stretcher loading trial. This camera followed the group of four subjects who were instructed to carry the stretcher (camera 5, Figure 2.8). Filming began a few seconds before each of the trials began and was terminated a few seconds after the subjects were seated with their seatbelts fastened and the qualitative reporting of subject comfort was complete.

Similarly, two stopwatches were used throughout the trials to record overall group loading times. Timing began when the first subject reached the loading platform and ended when the last subject fastened their seatbelt. The internal clocks within the video cameras would serve as the primary means of measuring group and individual loading times, and the stopwatches were included as additional reference points or backups if needed.

Figure 2.6: A screenshot from camera 1 (left) and camera 2 (right) during the loading trials.

Figure 2.7: A screenshot from camera 3 (left) and camera 4 (right) during the loading trials.

Figure 2.8: A screenshot from camera 5 during the loading trials.

2.4.5 Measurement Equipment

A bioelectrical impedance scale (BF-350 Body Composition Analyzer, Tanita Corporation of America, Illinois, USA) was used to measure body fat percentage. This unit also contains a scale that gave the subject's weight. Skin fold calipers were used to measure skin fold thickness at four anatomically landmarked sites (biceps, triceps, subscapular, and iliac crest). The subjects were escorted individually to a private room where they were asked to remove their shirts so that the calipers could be applied directly to the areas of interest. The measured values were then totaled and body fat percentage was estimated using the Durnin-Womersley method (Durnin & Womersley, 1974).

Foot length and waist circumference were measured using a soft measuring tape. Foot length was measured with footwear and socks removed. Similarly, the subjects were asked to remove their shirts to allow for waist circumference measurements to be taken. Height was measured using a rigid measuring tape that was securely affixed to a wall. Measurements were taken while an individual stood with their back, heels, and head aligned squarely against the wall.

2.5 Testing Protocol

Five trials, including an initial practice run in base clothing, were performed with subjects loading into the lifeboat in three different clothing ensembles. Prior to carrying out the trials, instructions were given as to the proper loading procedure. This involved lining the subjects up along side the TEMPSC, ascending the stairs to the landing, and entering the TEMPSC through the starboard side bow hatchway (Figure 2.3, section 2.4.2). The subjects were instructed to load and select seats fore to aft, alternating left to right as they filled the craft (starting with seat position 1 and finishing with 20, Figure 2.9). Once seated, the subjects were required to fasten their seatbelt and then place their hands on their lap to indicate that they have completed the loading protocol. For each trial, the order in which the subjects were lined up and entered the TEMPSC was randomized, and loading times and video data were recorded. The randomized subject loading sequence for each trial is provided in Appendix 2.

The first trial was a practice run in base clothing, intended to familiarize the subjects with the process and the interior of the boat. The second trial involved subjects in base clothing again, however they were in a different (randomized) order. During the third trial the subjects donned IMO-SOLAS approved lifejackets over their base clothing. The fourth trial required that each subject don a TC approved marine abandonment suit. Lastly, the fifth trial involved a return to the base clothing, but this time four subjects were randomly selected to be responsible for loading a stretcher into the TEMPSC, along with the rest of the randomized subjects. For trial five, basic safety instructions were provided, but the method of loading was left entirely up to the subjects in order to assess how people may react in an emergency situation with little instruction. The stretcher was picked up near the bottom of the stairs, carried up the stairs, and loaded into the lifeboat. For safety reasons, the stretcher was left empty and stripped of its floatation when loaded into the TEMPSC. Subjects were asked about their comfort while seated at the end of each trial and qualitative data was recorded when necessary. The trial matrix provided in Table 2.2 summarizes the conditions per trial. Following these trials, anthropometric measures were collected from all 20 subjects including height, weight, waist circumference, foot length, and body fat percentage.

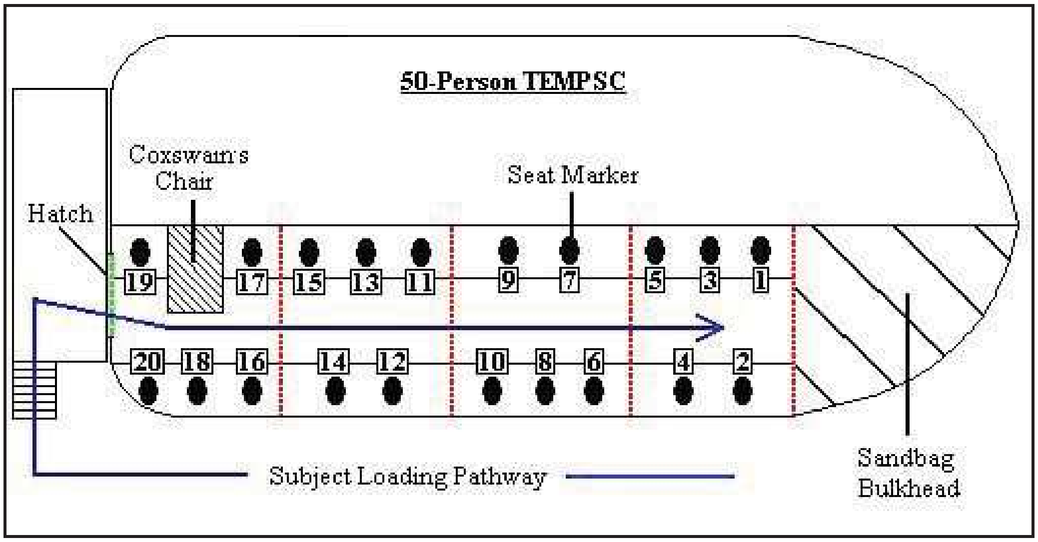

Figure 2.9: The subject loading direction and seating sequence (1-20).

Table 2.2: Trial matrix.

Trial	Number of Subjects	Condition
-	20	Practice (Base Clothing)
1	20	Base Clothing
2	20	Life Jacket
3	20	Marine Abandonment Suit
4	19	Base Clothing & Stretcher

2.6 Data Analysis

Loading time data was analyzed with reference to the video logs as well as the stopwatches. For data analysis purposes, the TEMPSC was divided into quartiles (Q1-4, Table 2.3, right; Figure 2.10). There were five occupant seats per quartile. The lines separating the sections are theoretical and were superimposed to facilitate data analyses; they were not physically present within the TEMPSC during the trials.

Total group timing measurements were recorded for each trial. Individual timing measurements were broken down using four discreet timestamps (T1-4, Table 2.3, left; Figure 2.10). Timestamp 1 (T1) was the point at which the subject's foot first touched the loading platform. Timestamp 2 (T2) was the point at which the subject first crossed the plane of the open hatchway. Timestamp 3 (T3) was the point at which the subject reached their seat. Finally, Timestamp 4 (T4) was the point at which the subject fastened their seatbelt and placed their hands on their knees. These unique timestamps would allow the loading sequences of each subject to be broken down into three distinct sections: time to approach and enter the TEMPSC (T1-T2); time to travel down the TEMPSC and approach their seat (T2-T3); and time to take their seat and fasten their seatbelt (T3-T4).

Table 2.3: The locations at which timestamps were recorded (left) and quartiles were sectioned within the 50-person TEMPSC (right).

Timestamp	Location/Time
T1	Platform Reached
T2	Hatchway Entered
T3	Seat Reached
T4	Seatbelt Fastened

Quartile	Location	Number of Subjects
Q1	Aft	5
Q2	Mid-Aft	5
Q3	Mid-Fore	5
Q4	Fore	5

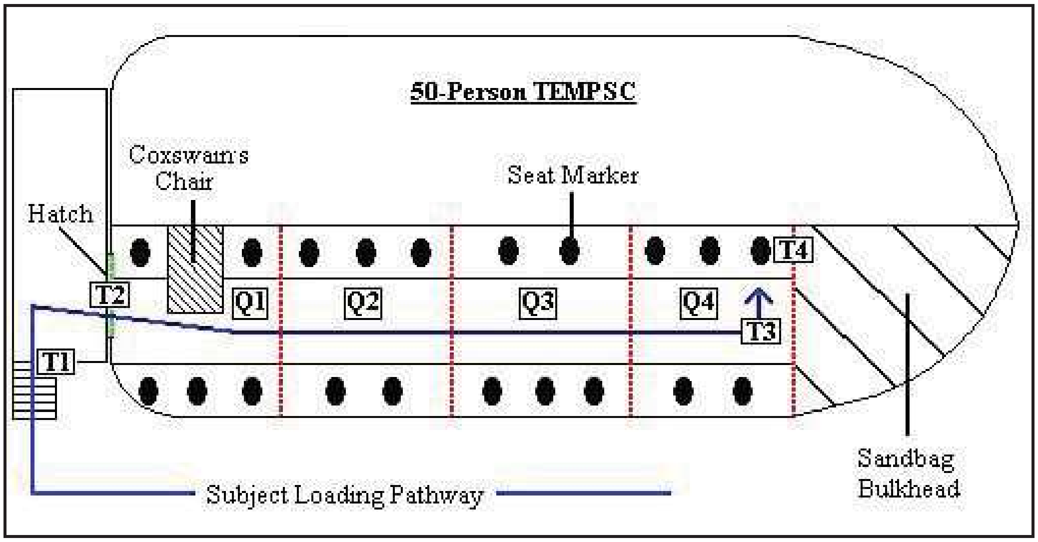

Figure 2.10: Diagram indicating the locations at which timestamps were recorded (T1-4) and the quartiles were divided (Q1-4).

Descriptive statistics, comparisons of multiple means, and post hoc tests were carried out using the SPSS statistical software package. Since the test for homogeneity of variances revealed that the variance between the groups (i.e. clothing condition) was not similar, a Welch Test (i.e. a Robust Test of Equality of Means), rather than an analysis of variance (ANOVA), was carried out to determine if the differences between the mean individual times per condition are statistically significant at the $p < .05$ level. Total group times could not be compared in the same way because they are single discrete values, and not means calculated from a subset of two or more discrete values. Additionally, a Tukey post-hoc test was carried out to explore the data for possible between-group differences.

3.0 Experimental Results

3.1 Subject Anthropometrics

The individual measurements from the twenty subjects are summarized in Table 3.1. Again, the full individual measurement dataset is included in Appendix 1. As indicated by the relatively large standard deviations, the population was quite varied in terms of both demographical and anthropometric measures.

Table 3.1: Subject demographic and anthropometric data.

	Age (years)	Height (cm)	Weight (kg)	Body Fat (%)	Foot Length (cm)	Waist Circumference (cm)
Mean	27.5	173.5	83.4	25.7	26.1	92.0
SD	10.74	9.28	18.06	7.34	1.41	15.53
Max	53	194.8	113.1	40.2	29.2	122.5
Min	19	154.0	52.3	12.0	23.7	64.0

3.2 Group and Individual Loading Times

The total group loading time measurements as recorded by the video equipment and stopwatches are presented in Figure 3.1. Overall, there was an increase in the total time required to load the TEMPSC when moving from base clothing to increasing levels of PPE, with subjects who had donned marine abandonment suits needing the greatest amount of time. It should be noted that two of the subjects (2 and 9) could not fasten their seatbelts during the marine abandonment suit condition. These points have been identified as outliers and were therefore not included in the statistical analyses. However, it should be noted that a total trial duration of 96 seconds is not totally accurate since the buckling of a given seatbelt was said to mark the end a subject's individual loading time. The complete dataset of the group and individual loading times is included in Appendix 3.

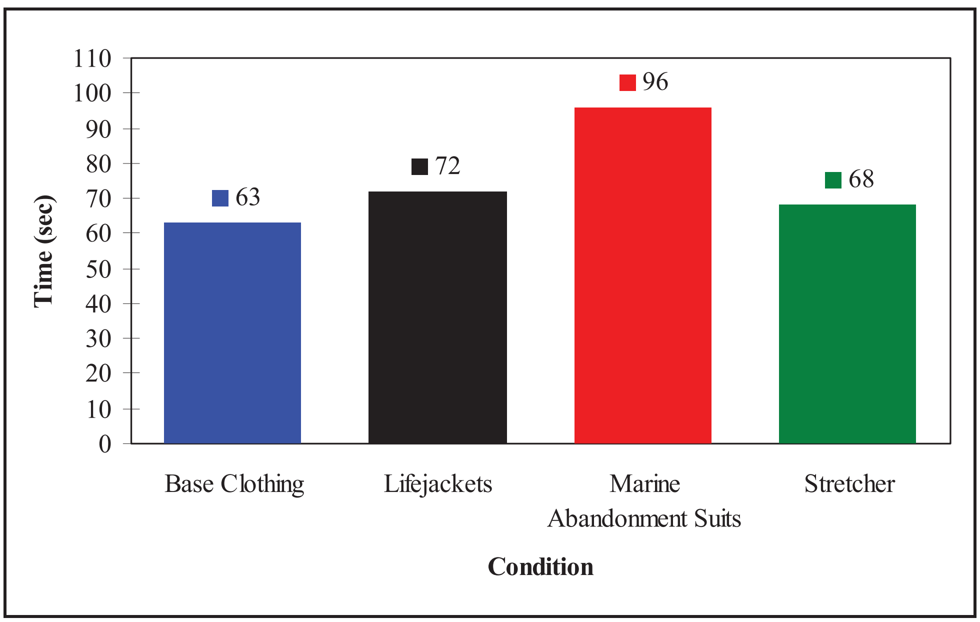

Figure 3.1: Group loading times across all conditions (i.e., all trials).

Individual loading time data are presented in Table 3.2. These followed a similar trend to that of the group loading times. Relatively large standard deviations (*SD*) and ranges between minimum and maximum values were seen across all conditions. The Welch Test indicated that there was a statistically significant difference between groups

($F(3, 38.5) = 7.389$, $p = .001$). A Tukey post-hoc test showed that the loading time during the marine abandonment suit condition (38.3 +/- 13.43 sec) was significantly higher than that of the base clothing (22.9 +/- 6.14 sec, $p = .001$), the lifejacket (28.7 +/- 7.68 sec, $p = .014$), and the stretcher (28.2 +/- 9.97 sec, $p = .010$) conditions. There were no statistically significant differences between any of the other groups.

Table 3.2: Mean individual subject loading times across all conditions.

Condition	Mean (sec)	*SD* (sec)	Maximum (sec)	Minimum (sec)
Base Clothing	22.9	6.14	33	14
Lifejackets	28.7	7.68	42	15
Marine Abandonment Suits	38.3	13.43	63	17
Stretcher	28.2	9.97	48	12

Subject numbers are plotted against time for each of the four conditions (Figure 3.2). There is considerable within-subject variability when comparing the loading times across all conditions. For example, looking at the data for subject 4 in Figure 3.2, there is a relatively large variance in their loading time depending on the condition (roughly 16 seconds in base clothing and 64 in a marine abandonment suit). More generally, the most notable differences occur between the trials in which subjects loaded in base clothing compared to those in which they loaded after donning marine abandonment suits.

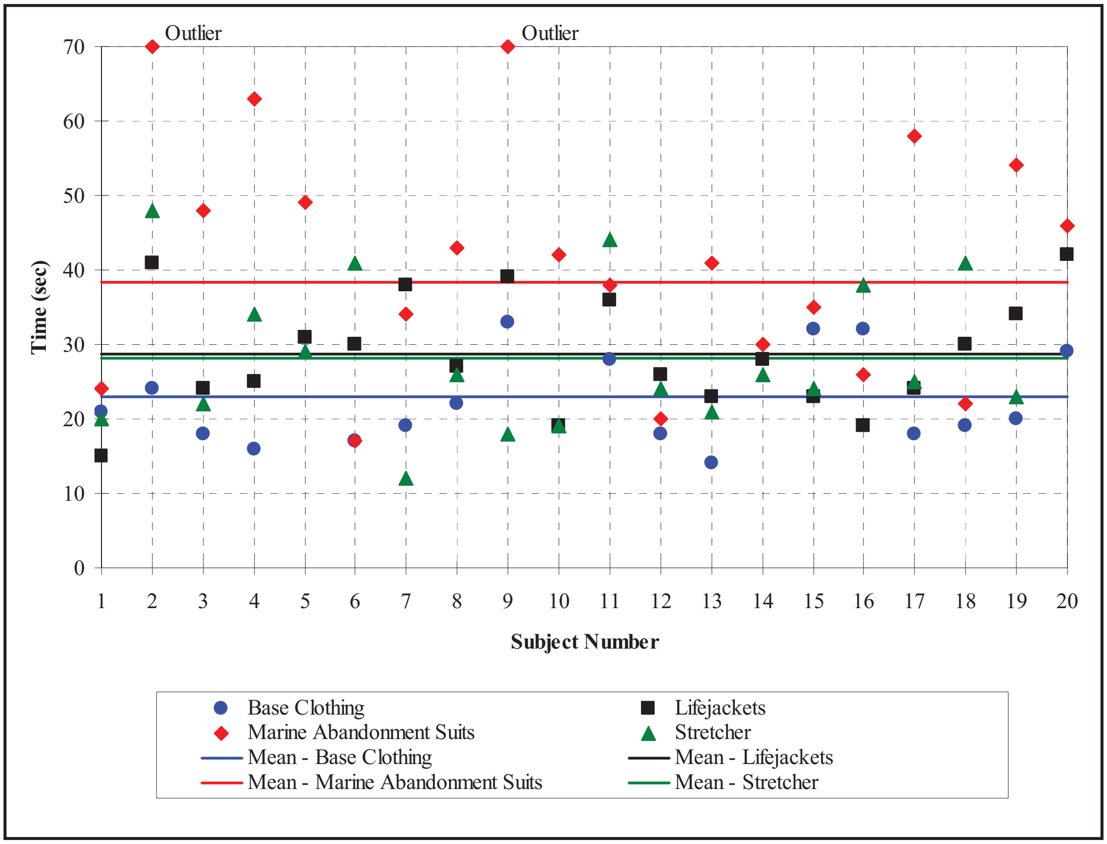

Figure 3.2: Individual subject loading times and means across all conditions by subject number.

Again, the interior of the TEMPSC was divided into quartiles to compare and assess possible differences in the pace of loading. As may be expected, a back-up effect was seen as the loading protocol progressed, resulting in increased loading times seen across all conditions when moving from Quartile 1 to Quartile 4 (Figure 3.3).

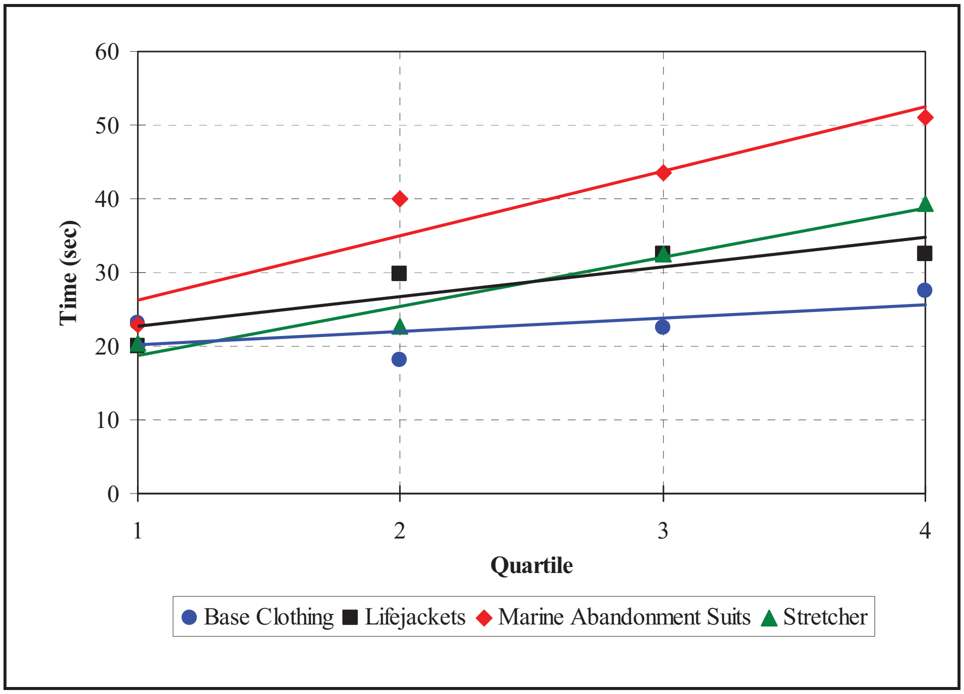

Figure 3.3: Group loading times and trend lines across all conditions by quartile (Q1-Q4).

Seating position is also plotted against time for each condition (Figure 3.4). There is a clear increase in loading times as the level of PPE is increased, as well as marked increase in loading time as the later participants had to transport and load the stretcher during the stretcher condition. Again, there is evidence of a back-up effect as the subjects located at the lower seating positions (i.e. first to enter) loaded into the lifeboat more quickly than those at the higher seating positions (i.e. last to enter). However, this appears to only hold true for quartiles 1-3 (i.e. seating positions 1-15). Once the loading protocol reached seating positions 16-20 there was a noticeable decrease in loading time. This is likely due to the decreased hatchway-to-seat distance that these occupants have to travel, resulting in decreased loading times. Two separate logarithmic trendlines have been fit to each of the conditions in order to more clearly highlight this feature of the data. Although some of the fits are quite poor (as shown by their low R^2 values), the lines are intended more to facilitate general comparisons between conditions rather than describe specific features of the data.

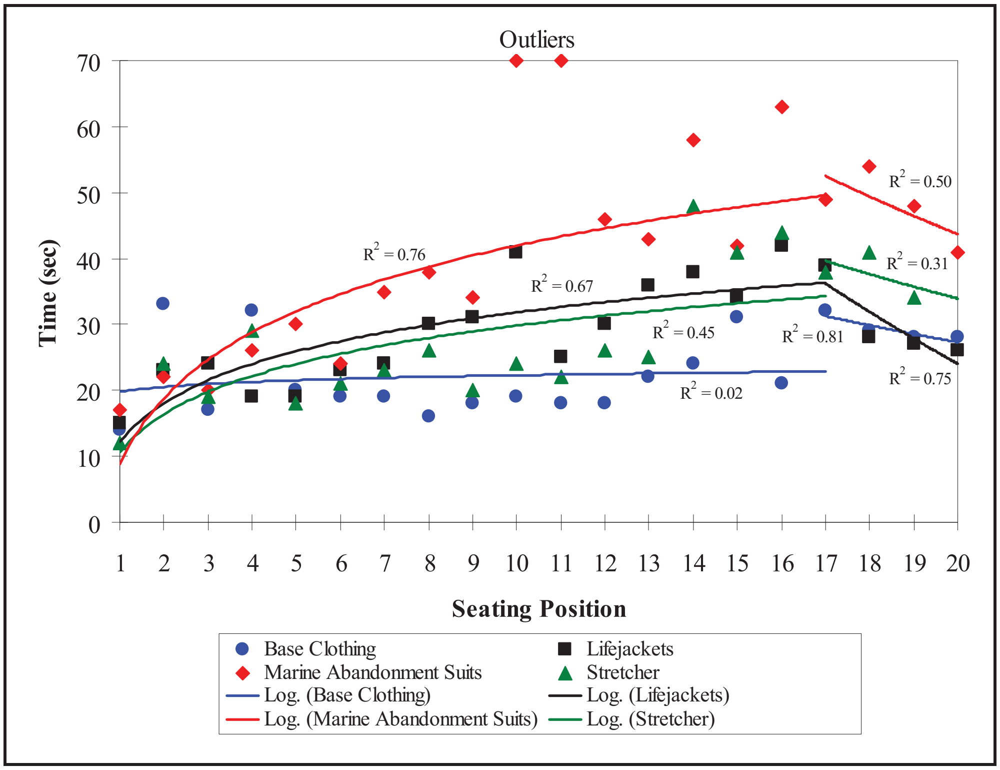

Figure 3.4: Individual subject loading times across all conditions by seating position.

Individual loading times were also broken down by markers, or timestamps, throughout the loading protocol (i.e. time required to move across the loading platform and enter into the boat, T1-T2; time required to move from the hatchway to a given seat, T2-T3; and time required to fasten the seatbelt, T3-T4) (Table 3.3). Across all conditions, on average, the seatbelt-fastening phase of the loading protocol required the greatest amount of time.

Table 3.3: Mean loading times broken down by condition and timestamp.

Timestamp	Condition and Loading Times (sec)			
	Base Clothing	Lifejackets	Marine Abandonment Suits	Stretcher
T1-T2	6.6	7.8	11.6	9.7
T2-T3	5.9	8.2	11.6	8.2
T3-T4	10.5	12.8	15.2*	10.3
Total	22.9	28.7	38.3	28.2

*Note: during the marine abandonment suit condition subjects 2 and 9 were unable to fasten their seatbelts and are therefore considered outliers and not used in the calculation of the mean.

4.0 Discussion

The findings of this study are important when assessing issues related to the habitability of a TEMPSC because they pertain to integral aspects of EER protocols: loading time and occupant capacity. It may be suggested that loading times and occupant capacities should be of primary concern for TEMPSC designs and regulations since most other factors related to occupant comfort, health, and safety arise after evacuees are already onboard.

4.1 TEMPSC Capacity

Throughout the trials, nearly all of the subjects were able to fasten their seatbelts regardless of the clothing condition; however, there were two subjects who were unable to fasten their seatbelts during the marine abandonment suit trial (Table 4.1). Remembering that the waist circumference measurements were taken directly against the skin, there is a discrepancy between the waist and seatbelt circumferences. In fact, in light of the measurements in Table 4.2, it would appear as though both of these subjects should be able to fasten their seatbelts. Although it would be a contributing factor, a relatively snug fitting suit would not have produced the 3.74cm to 4.30cm increases in waist radius needed to equal that of the seatbelts given that the suits are only 0.65cm thick (Table 4.2). Instead, the inability to fasten their seatbelts is more likely due to the bulkiness of the suits. The particular model of marine abandonment suit used during the trials comes in a universal size, meaning the suit will fit differently depending on the size and stature of the individual wearing it. Bunching of fabric around the waist, along with possible visual and spatial issues as the other subjects loaded into the boat around them, likely prevented these subjects from be able to fasten their seatbelts.

Table 4.1: Subjects' ability to fasten their seatbelts by condition.

Condition	All Subjects Able to Fasten Seatbelts?	Number of Subjects Unable to Fasten Seatbelts	Subject Numbers of Those Unable to Fasten Seatbelts
Base Clothing	Yes	-	-
Lifejackets	Yes	-	-
Marine Abandonment	No	2	2, 9
Stretcher	Yes	-	-

Table 4.2: Circumference measurements pertaining to subjects unable to fasten their seatbelts.

Subject Number	Waist Circ. (cm)	Seatbelt Circ. (cm)	Additional Radius Needed for Waist to Equal Seatbelt Circ. (cm)
2	122.5	146.0	3.74
9	119.0		4.30

There were also capacity issues regarding the loading and internal positioning of the stretcher. Due to their prevalence in maritime regulations, stretchers appear to be the preferred means of evacuating incapacitated workers and passengers from vessels and installations. For example, the CAPP requires that, "the operator shall ensure that the means of semi-dry evacuation are of sufficient capacity to evacuate all personnel, including injured personnel, on the installation at any given time" (2009, p. 23). With more specific reference to stretchers, section 4.4.3.4 of the LSA Code states that, "the lifeboat shall be so arranged that helpless people can be brought onboard either from the sea or on stretchers." Similarly, regulation 11.6 of IMO-SOLAS as well as 10.3.5 and 10.4.5 of the IMO Mobile Offshore Drilling Unit (MODU) Code state that, "survival craft muster and embarkation stations shall be so arranged as to enable stretcher cases to be placed in survival craft" (1974, as amended; 2009). Especially with respect to the increased risk associated with work on oil and gas installations, there is a high potential for one, or more, stretcher cases to be loaded into lifeboats during emergency evacuations. However, despite comprising a potentially integral part of EER protocols, the highly developed evacuation procedures used onboard vessels and offshore installations provide little guidance on how to accommodate casualties and stretcher cases during emergencies (Brown and MacKinnon, 2005).

For instance, there does not appear to be any particular model of stretcher included in the SOLAS or LSA standards (Brown & MacKinnon, 2005). However, the MODU code stipulates that, "each unit should be provided with a stretcher capable of being used for lifting an injured person into a helicopter" (2009, Section 10.9), meaning the rigid frame of a Stokes Litter, such as the one used in the current report, would be acceptable. Without a standard design, loading procedure, or designated location within the lifeboat on which to position it, the subjects transporting the stretcher required additional help from subjects who had entered ahead of them. Even without the flotation pontoons attached, during the trials the stretcher had to be tilted as it was passed through the hatchway and into the TEMPSC, as it was 63cm wide while the hatchway was only 60cm wide (Figure 4.1, left). Tilting the stretcher to allow it to pass through the hatchway would place an injured person laying on the stretcher at increased risk during loading into the TEMPSC, as well as increase the strain on the stretcher porters since the load would now be uneven and awkward. The addition of the pontoons would necessitate an even greater tilting of the stretcher.

Once through the hatchway, the stretcher had to be received and guided in by the other subjects already onboard, highlighting the second main issue with regard to stretchers onboard TEMPSC. Since there is no designated area on which the stretcher can rest, there is no other option but to place the stretcher across the laps of the occupants seated along either side of the craft (Figure 4.1, right). If the floatation pontoons been attached the stretcher would likely have been too wide to fit between the seated occupants and be placed on their laps. TEMPSC occupants are likely to experience ill health and seasickness due in large part to being subjected to increased levels of ambient CO_2, temperature, and relative humidity (Taber et al., 2011), as well as high sea states and adverse weather conditions (Landolt, 1992). The additional discomfort of having an incapacitated person lying on a stretcher placed on their laps would add to an already precarious situation and further decrease the habitability of the TEMPSC. These deleterious effects could be compounded if multiple stretcher cases had to be loaded into a given lifeboat. Perhaps more troubling, given the current design and occupant ratings of 50-person TEMPSC, it may not even be possible to accommodate more than two stretchers at a time.

Figure 4.1: A Stoke's Litter being loaded into a 50-person TEMPSC (left), and the stretcher once placed inside a fully loaded lifeboat (right).

Although the TEMPSC used in the experiment could accommodate a full complement of 20 subjects during each of the trials, previous work by NRC-OCRE has shown that it is possible for the donning PPE to result in diminished occupant capacities onboard TEMPSC (Baker et al., 2012). A mean occupant weight of 75kg is generally used by IMO-SOLAS (1974, as amended); however, this is a prescriptive standard that does not necessarily account for the additional weight of bulky cold weather PPE. As such, the IMO Guidelines for Ships Operating in Polar Waters (2010a) increased this to 82.5kg. It is important to note that this increase is stipulated in a guideline, not a regulation or standard, meaning it is not a strict design requirement enforced by IMO. Regardless, considering that the population included in the current study had an average weight of 83.4kg, and that a paper by Kozey et al. (2009) that studied 84 workers from the Newfoundland and Labrador offshore area (off the eastern coast of Canada) had a mean weight of 88.2kg, the increase in the mean weight of workers in northern offshore regions proposed by the IMO guideline may still be inadequate. Instead, these values support the more realistic mean weight suggested by the HSE in a paper entitled "Big Persons in Lifeboats" (2008), as well as a Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) safety directive (2010), of 100kg. Given that a weight of 100kg likely over-estimates the average offshore worker in the North Atlantic and includes the estimated weight of the average immersion suit, both the HSE and the C-NLOPB maintain that this is a more representative appropriate value to employ in the development of occupancy and other safety regulations for the offshore industries.

However, although this may be regarded as a progressive safety measure, its ramifications warrant further consideration. For example, increased occupant anthropometrics would have inherent implications for the survival craft used by these individuals while travelling and working offshore. Currently, the amount of space allotted per person onboard TEMPSC is not appropriate given the increase in the assumed mean anthropometric dimensions among populations of offshore workers (i.e. moving from 75 to 100kg). As a result, the existing ratio of survival craft to individuals onboard vessels and installations needs to be adjusted. These adjustments could involve either increasing the number of TEMPSC (i.e., a retrofit to supply more survival craft, meaning fewer people per craft), or decreasing the overall capacity of the main ship (i.e., having fewer people onboard would mean the existing survival craft could accommodate all passengers during an EER event). In an effort to highlight this point, anthropometric data from 100 people was pulled from a database containing numerous measures taken from 2391 North Americans (Society of Automotive Engineers, 2003). This was a convenience sample selected to achieve a 100kg mean weight. Once the desired weight was found, the corresponding mean buttock-to-knee length and shoulder breadth measurements were calculated (Table 4.3). These values were then used to produce a rough estimate of the 2D space occupied by an "average" occupant. The derived occupant outline was then superimposed over a scaled AutoCAD model of a 50-person TEMPSC (Figure 4.2).

Table 4.3: Measurements used to estimate seating capacity within the 50-person TEMPSC.

Source and Sample Size (*n*)	**Weight (kg)**	**Buttock-to-Knee Length (cm)**	**Shoulder Breadth (cm)**
CAESAR (2003), *n* = 100	99.9	62.2	58.8

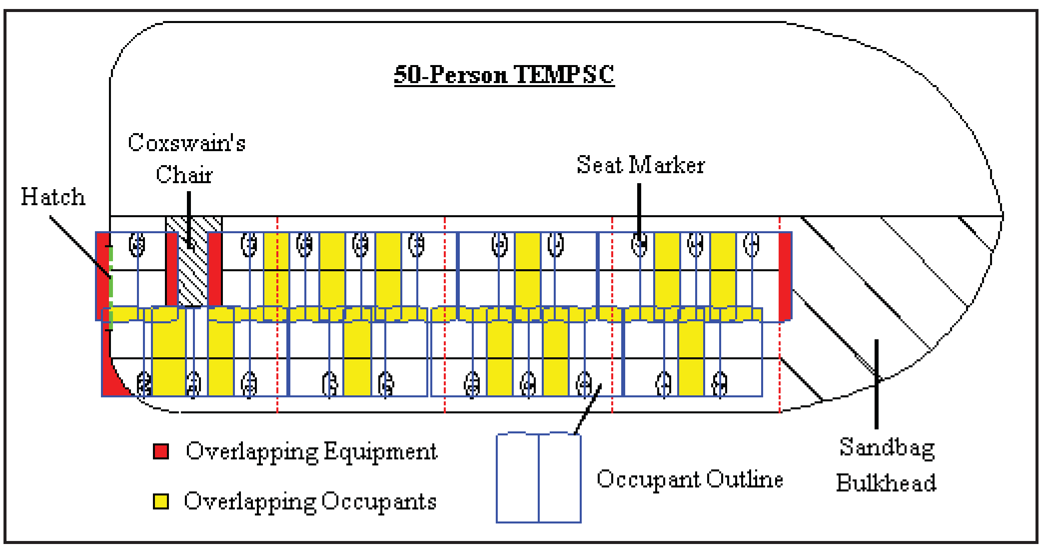

Figure 4.2: An estimate of occupant capacity of a 50-person TEMPSC based on the 100kg mean occupant weight proposed by the HSE and C-NLOPB.

The figure shows that there is considerable overlap between the occupants and the rigid structures within the TEMPSC (e.g. coxswain's chair and cabin walls). Section

4.4.2.2 of the LSA Code states that seating may overlap as long as there "is sufficient room for legs" (2010b); however, this clearly is not the case with the current arrangement. It is unlikely that 20 individuals could fit in the space provided, let alone adjust their positioning so that there would adequate room to accommodate their lets. Moreover, as was the conclusion of the work by Baker et al. (2012), this suggests that the IMO-SOLAS (1974, as amended) requirement of 43.0cm of space allotted per person onboard lifeboats and life rafts must be adjusted to account for increasing anthropometrics among North American populations, as well as the additional bulk added by the donning of arctic PPE. In order to alleviate this overlap, the occupancy of this section of the lifeboat would have to be reduced from 20 to 13 (not including the coxswain) (Figure 4.3). If this were expanded to include the entire craft, it would result in the 50-person TEMPSC being down-manned to a rated occupancy of 34. Although essential for ensuring the comfort, health, and safety of those onboard, it is important to note that reducing the rated occupancies of TEMPSC would have major implications for offshore operations. In order to respond to the new lifeboat occupant ratings, operators would have to either increase the number of TEMPSC onboard their vessels and installations so that there were fewer people per craft, or decreasing the number of people onboard so that the existing survival crafts could accommodate all passengers and workers during an EER event.

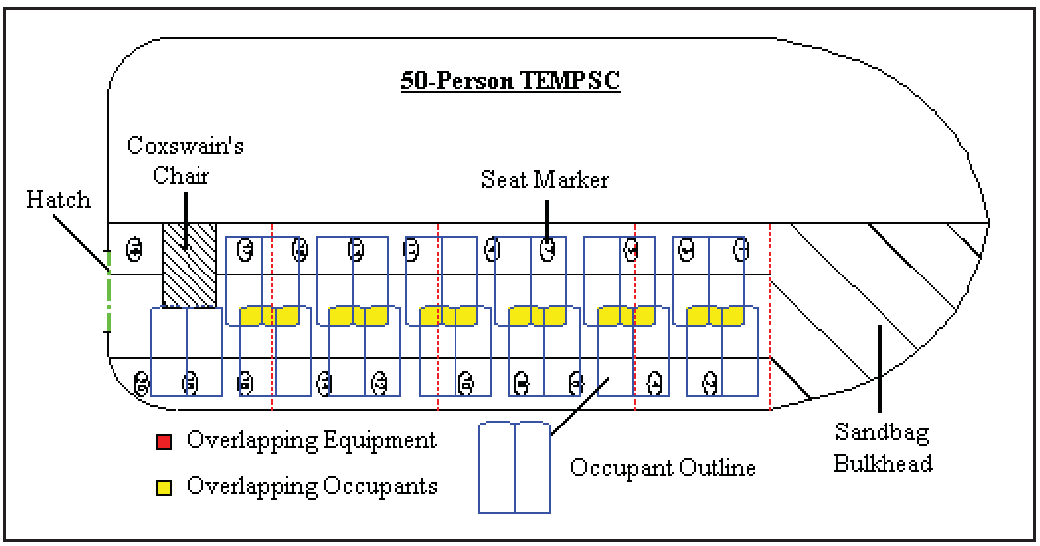

Figure 4.3: An estimate of the adjusted occupant capacity of a 50-person TEMPSC needed to accommodate the 100kg mean occupant weight proposed by the HSE and C-NLOPB.

4.2 Loading Time

The LSA Code (2010b) states that, "lifeboat[s] shall be so arranged that it can be boarded by its full complement of persons in not more that 3 min from the time the instruction to board is given" (4.4.3.2). This study has shown that increasing levels of PPE (i.e. moving from base clothing, to lifejackets, to marine abandonment suits) results in increased TEMPSC loading time per person, with the marine abandonment suit condition being significantly greater than any of the others (p = .001). Furthermore, it has shown that 20 occupants are able to load into one side of a 50-person TEMPSC in times ranging between 63 and 96 seconds, depending on their level of PPE. Even with a full complement of 25 occupants loaded into this side of the lifeboat, along with the possible confusion and congestion that may occur when loading both sides at the same time, it is unlikely that these factors would have increased the loading times beyond the three minute (180 second) maximum allowable duration. However, it is important to note that this regulation is prescriptive and thereby applies to all TEMPSC in all areas of operation. In other words, it maintains that lifeboats should be designed in such a way that individuals involved in EER events are able to load into them in no more than three minutes, regardless of whether or not they are abandoning to a 20-person or a 150-person TEMPSC.

In order to estimate times for larger occupant groups, the times recorded during the trials were used to predict loading times for TEMPSC with greater capacities (Table 4.4). Recorded group loading times were divided by the number of occupants tested (20) to determine a per occupant time. These values were then multiplied by 50, 80, and 150, respectively, to estimate new group loading times. Since most models of TEMPSC are loaded simultaneously through two hatchways, the predicted times were divided by two to provide more accurate estimates. Although loading via two hatchways is an effective means of reducing overall loading times, it is predicted that occupants loading into a 150-person TEMPSC after donning marine abandonment suits would require six minutes to fully load into the lifeboat, double the three-minute loading standard set by IMO. The loading time for individuals wearing marine abandonment suits as they evacuated into an 80-person TEMPSC and base clothing when doing so into a 150-person TEMPSC were also estimated to require more than three minutes. Moreover, remembering that trials were conducted without the panic and confusion of a true EER event, it may be suggested that these estimates are likely conservative and that actual loading times for TEMPSC may be much higher *in situ*.

Table 4.4: Recorded and predicted loading times for various models of TEMPSC.

Clothing Condition	**Number of Occupants**	**Recorded Loading Time (min:sec)**	**Predicted Loading Time (min:sec)**	
			1 Hatch	**2 Hatches**
Base Clothing	20	1:03	-	-
	50	-	2:38	1:19
	80	-	4:12	2:06
	150	-	7:53	3:52
Marine Abandonment Suits	20	1:36	-	-
	50	-	4:00	2:00
	80	-	6:24	3:12
	150	-	12:00	6:00

Individual (i.e. within-subject) loading times showed variance depending on the clothing condition and, as may be expected, followed the trend of increased PPE contributing to increased loading times. This variance suggests that some individuals are able to load within a consistent period of time, while PPE and especially marine abandonment suits more conspicuously impede others. The back-up effect seen during the occupant loading, caused primarily by delays at T3 and T4 when the subjects were trying to position themselves at their seat and adjust their seatbelts, produced increasing delays with higher levels of PPE. As the first subjects entered the TEMPSC, they were able to move directly to their seats, sit down, and attempt to fasten their seatbelts (Quartile 1). However, as the loading continued, the subjects who had loaded previous to them increasingly impeded the progression of the later subjects (Quartile 2-4). The added bulk of the lifejackets and marine abandonment suits made it more difficult for the subjects to move throughout the lifeboat and interact with some of its features (i.e. seating and seatbelts), thereby increasing loading times. Looking specifically at the Quartile 4 loading times (Figure 3.3, section 3.2), it is likely that the stretcher condition took longer than the lifejacket condition because all of the stretcher carriers were seated in this final quartile. The added task of carrying and loading the stretcher would have contributed to this discrepancy.

A closer look at the stretcher condition is provided in Figure 4.4. The last four subjects to enter the TEMPSC (seated at positions 16-20) were tasked with carrying and loading the stretcher. Again, the four subjects tasked with transporting the stretcher were the last to enter the lifeboat and required help from those already onboard to receive and guide the stretcher into position inside the TEMPSC. This occurred before all of the other subjects had fastened their seatbelts, resulting in notably longer loading times for those individuals seated at positions 14 and 15. This is clearly indicated in Figure 4.4 as the loading times for these positions are markedly greater than all of the preceding seating positions and are instead closely comparable to the four subjects who were tasked with transporting the stretcher. Thus, loading a stretcher into a TEMPSC not only has implications for the capacity of lifeboat, but also affects loading times. Increased loading times will be most profound for those directly involved with transporting and loading the stretcher; however, as discussed, once onboard the TEMPSC one or more stretchers will detract from the comfort, health, and safety of all of its occupants.

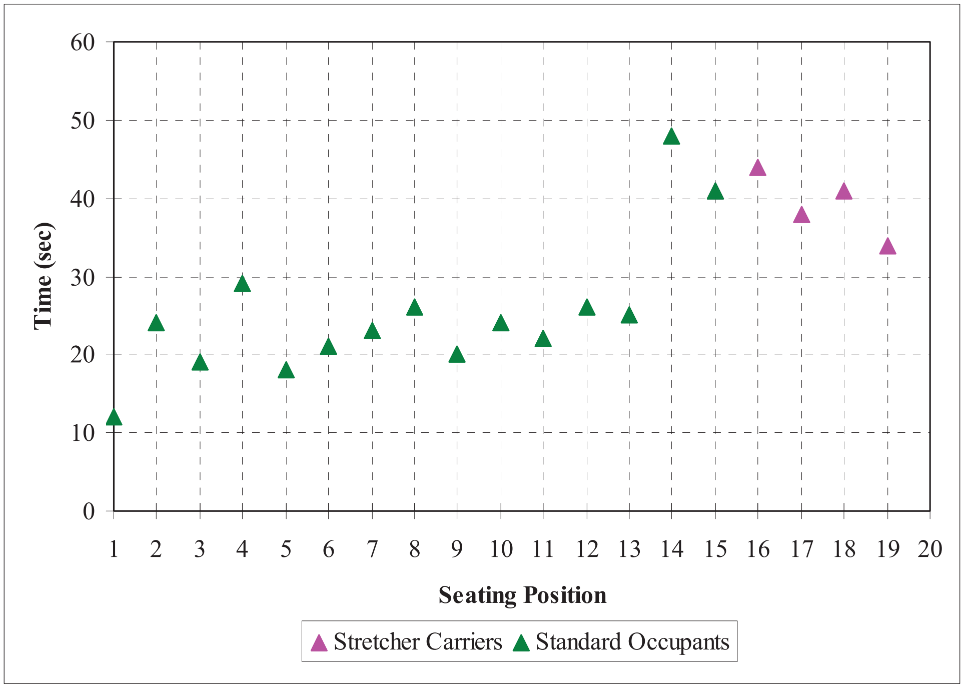

Figure 4.4: Individual subject loading times during the stretcher condition (Trial 4) by seating position.

5.0 Conclusion and Recommendations

Overall, the results of this study suggest that PPE can have an impact on the capacities and loading times associated with TEMPSC. Donning various forms of PPE has been shown to increase loading times, especially when looking at the predicted times for abandonment into an 80 or 150-person TEMPSC. In fact, in the case of marine abandonment suits onboard a 150-person lifeboat, loading times are predicted to double the three-minute standard set by IMO-SOLAS (1974, as amended). It has also been shown that stretcher cases can impact loading times, as well as decrease the comfort, health, and safety of those onboard since there are no designated locations in which to position the stretchers during TEMPSC operation. With increased levels of PPE, larger occupants, and possible stretcher cases, there will be an increase in the time required to load survival craft, along with a decrease in the number of people who can fit safely onboard.

Currently, international maritime regulations pertaining to occupant capacities and loading times of survival craft may be inadequate for vessels and installations operating in arctic waters. As a result, this may restrict the ability of these survival craft to ensure the safe and timely evacuation of all those onboard during EER events. There is a clear need to redesign TEMPSC in order to mitigate the potential impact of PPE and stretchers on capacity and loading times. Until this is possible, reducing occupancy ratings of survival craft or increasing their numbers onboard vessels and installations would help alleviate many of the factors that can reduce habitability onboard TEMPSC. If maritime regulations relating to the design of TEMPSC occupant capacities are not made adaptable (i.e., fit-for-purpose) to the region in which they are implemented, vessels and installations operating in arctic waters may be ill-equipped to deal with large scale EER events that require the deployment of TEMPSC. Both the C-NLOPB (2010) and the HSE (2008) have been proactive in creating directives that account for the addition of PPE and the increase in anthropometrics of North American populations, and it is recommended that other offshore regulators and operators follow suit.

Based on the results of this study it is recommended that:

1) The amount of space allotted per person onboard lifeboats and life rafts is not appropriate given the increase in loading time and anthropometric dimensions due to the donning of PPE. As a result, the existing ratio of survival craft to passengers onboard vessels needs to be adjusted. These adjustments could involve either increasing the number of TEMPSC (i.e., a retrofit to supply more survival craft, meaning fewer people per craft), or decreasing the overall capacity of the main ship (i.e., having fewer people onboard would mean the existing survival craft could accommodate all passengers during an EER event). Adjusting occupancies would result in more space available per person thereby making it easier for individuals wearing PPE to carry out loading protocols. In turn, this would likely decrease loading times for larger models of TEMPSC and bring them into alignment with the existing three-minute standard. This change could be applied to all vessels and installations, regardless of their area of operation; however, it is most necessary for those operating in arctic waters because these regions require the bulkiest PPE (e.g., marine abandonment suits).

2) Further research should be conducted to determine the necessary design changes to account for increases in anthropometrics and the possible requirements of marine abandonment suits and stretchers. More specifically, seatbelt lengths and hatchway widths must be increased to accommodate larger occupants, the bulkiness of marine abandonment suits, and the loading of stretchers.

3) Next generation TEMPSC designs should include an area in which a stretcher can be placed once loaded. This could involve a designated section of the lifeboat's floor or bench space, or possibly a shelf or hook system. Also, it should be considered that mass evacuations might necessitate the loading of more than one stretcher. This is especially pertinent for larger models such as 150-person TEMPSC since most vessels and installations operating in the Arctic would only need four of these lifeboats onboard to meet the requirement of 200% occupancy (IMO-SOLAS, 1974, as amended). For instance, with as few as two lifeboats needed to evacuate an entire oil platform, it may be necessary to have two or more stretchers loaded into each TEMPSC.

4) Protocols should be set in place to ensure that safety regulations specifically pertaining to occupant anthropometrics are reviewed and adjusted on a regular basis. Additional research may be necessary to determine the specific timeframe in which these standards should be reassessed. Special cases for review may need to be identified, such as the development of novel PPE, since they may alter the way in which individuals interact with their environment (i.e. tools, workstations, EER equipment, etc.).

6.0 References

Baker, A., Power-MacDonald, S., Petrie, L. & Monk, J. (2012). *Lifeboat and Life Raft Diminished Occupant Capacity Study*. Transport Canada Technical Report (TR-2012-01).

Canada-Newfoundland and Labrador Offshore Petroleum Board (2010). *Safety Notice – Evacuation Capacity*. Internal Safety Directive 2010.01.

Canadian Association of Petroleum Producers (2010). *Atlantic Canada Offshore Petroleum Industry Escape, Evacuation and Rescue Guide (2010-0017)*. Retrieved from http://www.capp.ca/library/publications/

Canadian Standards Association (2010). *Temperature and Humidity Standards for Workplaces in Canada*. Retrieved from http://www.hc-sc.gc.ca

Coastal Response Research Center (2009). *Opening the Arctic Seas: Envisioning Disasters and Framing Solutions*. Retrieved from http://www.crrc.unh.edu/workshops/arctic_spill_summit/arctic_summit_report_final.pdf

Durnin, J. & Womersley, J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 mean and women aged 16-72 years. *British Journal of Nutrition*, 32: 77-97.

Health and Safety Executive (2008). *HSE Information Sheet: Big Persons in Lifeboats*. Retrieved from http://www.hse.gov.uk/offshore/infosheets/is12-2008.pdf

International Maritime Organization (2010a). *Guidelines for Ships Operating in Polar Waters (Resolution A.1024(26))*. United Kingdom, London: IMO Publishing.

International Maritime Organization (2010b). *Life-Saving Appliances – Including LSA Code, 2010 Edition.* United Kingdom, London: IMO Publishing.

International Maritime Organization (2009). *MODU Code (Code for the Construction and Equipment of Mobile Offshore Drilling Units)*. United Kingdom, London: IMO Publishing.

International Maritime Organization (2006). *Report to the Marine Safety Subcommittee on Radio Communication and Search and Rescue (COMSAR 10/16)*. United Kingdom, London: IMO Publishing.

International Maritime Organization (2000). *Surviving Disaster – Life-Saving at Sea.* United Kingdom, London: IMO Publishing.

International Maritime Organization (1974, as amended). *International Convention for the Safety of Life at Sea (SOLAS), 2009 Consolidated Edition.* United Kingdom, London: IMO Publishing.

Kozey, J., Brooks, C., Dewey, S., Brown, R., Howard, K., Drover, D., MacKinnon, S., & McCabe, J. (2009). Effects of human anthropometry and personal protective equipment on space requirements. *Occupational Ergonomics*, 8, 67-79.

Landolt, J. & Monaco, C. (1992). Seasickness in totally enclosed motor propelled survival craft: remedial measures. *Aviation, Space and Environmental Medicine*, 63, 219-25.

National Snow and Ice Data Center (2012). *Arctic sea ice extent settles at record seasonal minimum*. Arctic Sea Ice News and Analysis. Retrieved from http://nsidc.org/arcticseaicenews/2012/09/arctic-sea-ice-extent-settles-at-record-seasonal-minimum/

Royal National Lifeboat Institution (2011). *History of the RNLI – Lifeboats*. RNLI Heritage Trust. Retrieved from http://www.rnli.org.uk/assets/downloads/historyfactsheet.pdf

Society of Automotive Engineers (2003). *CAESAR Measurements (North American Edition)* [CD-ROM]. CAESAR 3-D Anthropometric Database.

Stroeve, J., Holland, M., Meier, W., Scambos, T., & Serreze, M. (2007). Arctic sea ice decline: faster than forecast. Geophysical Research Letters, 34, L09501. doi:10.1029/2007GL029703

Taber, M., Simões Ré, A., & Power, J. (2011). A preliminary ergonomic assessment of piloting a lifeboat in ice. *Safety Science*, 49, 139-147.

Appendix 1 – Subject Demographics and Anthropometrics

Subject Number	Gender	Age	Height (cm)	Weight (kg)	Body Fat (%)*	Foot Length (cm)	Waist Circumference (cm)
1	F	22	184.0	105.8	36.4	25.7	96.0
2	M	45	174.0	113.1	24.3	26.0	122.5
3	M	25	178.0	94.7	22.7	27.6	101.5
4	M	21	182.0	85.0	15.7	27.6	94.5
5	M	22	173.0	82.3	18.9	27.6	97.0
6	M	45	177.0	94.9	26.9	27.0	107.5
7	F	37	165.0	77.1	35.3	24.5	94.9
8	F	23	177.0	77.9	29.4	27.3	75.9
9	M	45	175.5	110.9	24.5	26.0	119.0
10	F	22	181.0	95.7	33.1	26.0	91.6
11	F	22	167.1	70.0	31.3	25.1	82.4
12	F	21	157.1	58.1	26.8	24.5	74.6
13	F	22	166.0	57.9	27.0	24.5	84.0
14	F	21	171.0	54.3	22.3	25.1	64.0
15	M	22	194.8	93.8	17.0	29.2	87.8
16	M	19	178.0	85.8	17.9	27.6	92.0
17	F	21	168.0	91.3	40.2	25.7	105.2
18	M	21	176.5	75.6	12.0	25.4	79.0
19	F	21	154.0	52.3	24.6	23.7	68.0
20	M	53	170.2	90.7	27.9	25.7	102.0
Mean		27.5	173.5	83.4	25.7	26.1	92.0
SD		10.74	9.28	18.06	7.34	1.41	15.53
Max		53	194.8	113.1	40.2	29.2	122.5
Min		19	154.0	52.3	12.0	23.7	64.0

*Calculated as an average of values obtained independently via the bioelectrical impedance scale and skin fold calipers.

Appendix 2 – Randomized Subject Loading Sequence

Seating Position	Subject Number and Condition			
	Base Clothing	Lifejackets	Marine Abandonment Suits	Stretcher
1	13	1	6	7
2	9	15	18	4
3	6	17	12	15
4	15	10	16	18
5	19	16	14	10
6	18	13	1	5
7	7	3	15	9
8	4	18	11	20
9	17	5	7	11
10	10	2	2	13
11	12	4	9	19
12	3	6	20	14
13	8	11	8	16
14	2	7	17	1
15	5	19	10	12
16	1	20	4	3
17	16	9	5	8
18	20	14	19	17
19	14	8	3	2
20	11	12	13	6

Appendix 3 – Loading Times and Trial Log

Trial Number	Condition	Number of Subjects	Time (sec)
1	Base Clothing	20	63
2	Lifejackets	20	72
3	Marine Abandonment Suits	20	96
4	Stretcher	19	68

Subject Number	Loading Time (sec)			
	Base Clothing	Lifejackets	MA Suits	Stretcher
1	21	15	24	20
2	24	41	*	48
3	18	24	48	22
4	16	25	63	34
5	31	31	49	29
6	17	30	17	41
7	19	38	34	12
8	22	27	43	26
9	33	39	*	18
10	19	19	42	19
11	28	36	38	44
12	18	26	20	24
13	14	23	41	21
14	28	28	30	26
15	32	23	35	24
16	32	19	26	38
17	18	24	58	25
18	19	30	22	41
19	20	34	54	23
20	29	42	46	**
Mean	22.9	28.7	38.3	28.2
SD	6.14	7.68	13.43	9.97

*Note: during the marine abandonment suit condition subjects 2 and 9 were unable to fasten their seatbelts and are therefore considered outliers and not used in the calculation of the mean.

**Note: during the stretcher condition subject 20 was not included, as this individual would theoretically be occupying the Stokes Litter.