ERGONOMIC CONSIDERATIONS IN MARINE EVACUATION SYSTEM DESIGN AND EMPLOYMENT

DANIKA J. DROVER

Ergonomic considerations in marine evacuation system design and employment

by:

Danika J. Drover

A thesis submitted to the
School of Graduate Studies
in partial fulfillment of the
requirements for the degree of

Master of Science in Kinesiology

School of Human Kinetics and Recreation
Memorial University of Newfoundland

MEMORIAL UNIVERSITY OF NEWFOUNDLAND
April, 2006

St. John's Newfoundland

Library and
Archives Canada

Published Heritage
Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et
Archives Canada

Direction du
Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence
ISBN: 978-0-494-19357-0
Our file Notre référence
ISBN: 978-0-494-19357-0

NOTICE:
The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:
L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

ABSTRACT

This thesis reports on three studies completed in the area of marine safety. The first study focused on the compatibility between the anthropometric characteristics of persons employed in the offshore oil industry in Newfoundland and liferaft and lifeboat evacuations systems employed in the offshore. Findings from this study suggest that manufacturers should consider shoulder breadth, rather than hip breadth measurements as a better criterion for determining seat design and lifesaving appliance occupancy capacities. Furthermore, the typical morphological features of a typical person employed in the Newfoundland offshore are considerably larger than the standards used in the type approval process. This study concludes that testing standards should be reconsidered. The second study assessed the requirements for measuring forces and accelerations acting on humans engaged in marine evacuation systems such as chutes and slides. While no subjects reported pain or injury due to these tasks, the upper limits of loading recorded might have the potential to injure a younger, older or less-fit person. The study concludes that manufacturers should be aware of human tolerance limits when developing evacuations systems. The third study consisted of the measurement of egress times for injured or physically challenged users of marine evacuation systems. Data from the study reported it takes on average 89.3s and a maximum of 129.8s for a mannequin loaded stretcher to descend through a slide and be placed into its final position in the raft. Throughout the trials, mannequins experienced head accelerations of approximately 2 Gs. There was a general trend that heavier stretchers seemed to better secure/restrain the mannequin and resulted in smaller accelerations during the descent. This thesis provides considerable guidance to regulatory bodies and manufacturers in the development, testing and deployment of marine evacuation systems.

ACKNOWLEDGMENTS

I would like to take this opportunity to thank the many whose help and support have guided me through the process of preparing my thesis:

I have to start with Dr. Scott MacKinnon without whom I would not have chosen this extraordinary path. Thank-you for never losing faith in me, for providing me with such a strong support system and for allowing me to take on projects that are so innovative to our field. Without you, this would never have been possible.

To all of my friends and fellow graduate students I would like to thank you for lending me a hand whenever I needed assistance, for putting a smile on my face and for just being yourselves.

Rob Brown, Jim Boone and Graham Small all put a great deal of work, both physical and mental, into this thesis and I truly appreciate all of your efforts. To John Murray and Val Smith, Transport Canada, without your support none of the projects that I have been involved in would have been possible.

Finally, I would like to thank my family. To my parents, Aubrey and Beverley Drover, you have been the center of my world since I was a little girl. Your encouragement and advice throughout this process, as always, has instilled in me the will to succeed. Both of you make me want to be a better person and to make a difference. My love for you has no limits. To my brothers, you all share the ability to make me laugh and you have encouraged me more than you know. I have a great respect for all three of you. For the rest of my family, grandparents, aunts, uncles and cousins, thank-you for making me realize the importance of family.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

EER:	Evacuation, Escape and Recovery
G:	Force due to gravity ($9.81 m.s^{-2}$)
HSE:	Health and Safety Executive
IMO:	International Maritime Organization
LSA:	International Life-Saving Appliance
MES:	Marine Evacuation Systems
OSSC:	Offshore Safety and Survival Centre
SOLAS:	International Convention for the Safety of Life at Sea
TC:	Transport Canada

CHAPTER 1
Introduction

Many people are employed in maritime activities in Atlantic Canada. Some of these important economic activities include oil and gas exploration, commercial shipping and transportation and homeland defense-related activities. In recent Atlantic Canadian history, the search for and recovery of natural and renewable resource activities has changed significantly. Due to declining oil and gas reserves and diminishing fish species stocks, mariners have had to go further offshore and into northern, arctic areas. The consequences of these changes can be severe as moving further away from land has a huge impact on maritime safety. Most important of these issues concerns preparation for evacuation, escape and rescue in the situation when the vessel has to be abandoned. Without proper evacuation appliances the lives of the persons working in such vocations are certainly put in jeopardy.

There have been a number of critical incidences that have required mass evacuation of seagoing vessels. The most famous was the sinking of the Titanic. Aboard the Titanic were 14 conventional lifeboats, two 'emergency cutters' and four Engelhardt collapsible lifeboats, which had a total capacity of 1,178 persons. This was about 1,000 short of the total number of passengers and crew. Ironically, regulations at the time required a maximum capacity of 962 passengers, for regulators had not predicted the evolution of large passenger liners (Howell, 1999). As a consequence, more than 1,500 lives were lost, largely due to a lack of sufficient evacuation preparation and appliances.

The Ocean Ranger was a semi-submersible oil drilling platform that went down off the shores of Newfoundland on February 15, 1982, and resulted in the loss of 84 lives. A Canadian Royal Commission spent two years examining the events surrounding the disaster. The Commission concluded that the Ocean Ranger had design and construction flaws, particularly in the ballast control room and that the crew lacked proper safety training, survival suits and equipment. If proper training and safety appliances, including evacuation suits, had been utilized the outcome may not have been so tragic.

More recently there have been a large number of incidents involving Roll On-Roll Off (Ro-Ro) passenger vessels. In 1994, the Estonia disaster, Europe's worst post-war maritime disaster, took the lives of 852 people. This accident prompted maritime authorities to examine existing safety regulations aboard such vessels.

Yet another area where accidents are on the rise are with 65' fishing vessels. In 1999, the number of fishing vessels 45 to 65 feet that required assistance from the Maritime Rescue Sub-Centre (MRSC) at St. John's represented 38 percent of the total registered vessels of that size for the year (Wiseman et al., 2000). This increase was due in part to the collapse of the cod fishery and the need for inshore fishermen to fish further out to sea and a regulatory environment which limits the length of such fishering vessels to less than 65 feet.

Evacuation appliances have seen great improvements since their conception. The most common and perhaps furthest developed appliance is the lifejacket. In fact, the concept of inflatable devices dates back as far as 870 BC (Brooks, 1995). Since then there has been a considerable amount of progress on issues associated with the safety of lives at sea, not only with regards to lifejackets but in terms of all evacuation appliances. There are now slides and chutes for most types of vessels, liferafts and lifeboats that can accommodate large numbers of people and survival suits allowing people to stay alive in the most frigid of waters. However, current regulations tend to focus on construction standards and do not consider, necessarily, the manner in which a person will employ the system. More importantly, regulations do not necessarily consider important issues such as the morphology of the user, the user's level of training or the differences in environmental conditions found throughout the world. There remains considerable work to be done in the area of marine safety and evacuation system design.

In 1948, an international conference in Geneva adopted a convention formally establishing the International Maritime Organization (IMO). The purposes of the IMO are:

> "to provide machinery for cooperation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships" (pg. 1,IMO, 2005).

The first task of the IMO, which was achieved in 1960, was to adopt the International Convention for the Safety of Life at Sea (SOLAS), the most important of all treaties dealing with maritime safety. The Regulations relating to life-saving appliances and arrangements, contained in chapter III of SOLAS, are intended to ensure that in the event of a catastrophe at sea, passengers and crew have the greatest chance of survival (IMO, 2002). SOLAS dictates construction and testing and performance standards. Most countries adhere to these standards, however, always debate the level of best practices, often because of cost implications. This means that if it came down to a question of evacuation appliances being just safe or as safe as possible, many groups would choose the "just safe" option in light of the economic savings. Canada is one country that does adhere to all conventions and has gone so far as to question some of the current standards and have supported a series of research projects aimed at examining the validity of some of the SOLAS standards.

The fundamental challenge to these standards evolves from the fact that existing marine evacuations systems may not be compatible with the physical characteristics of those employed in maritime industries, particularly in the North Atlantic. For example, there have been changes in anthropometrics related to the type of people working in offshore environments. Initial modern evacuation appliance and survival equipment designs were based on the anthropometric data of Asian populations, who more typically were employed in maritime industries. More recently, particularly with oil and gas discoveries in the North Sea, the Grand Banks of Newfoundland and Northern Central Asia there has been a significant change in the body dimensions, body shape, weight and proportions of those employed in the industry. Furthermore, people generally are getting taller and heavier. This fact, in itself, puts into question the validity of the anthropometric databases that are currently used in the design process. The efficacy of any marine evacuation system is dependent upon its ability to accommodate the physical dimensions of the evacuees. Manufacturers must provide sufficient space and support for those employing these systems. Over the years regulatory bodies have defined the “average” stature and mass of persons likely to employ these systems and manufacturers have used these data to guide them in the design and manufacturing process. However, anthropometric dimensions are not static in magnitude and thus standards require periodic reassessment by both the regulatory and manufacturing communities.

Marine Evacuation Systems (MES) also have to accommodate untrained users. Throughout the world passenger ferries transport inhabitants and tourists to and fro. These ferries must carry evacuation systems that can safely and efficiently remove passengers from the vessel. The average passenger on a ferry will likely not possess the physical attributes of professional mariners and will not have the advantage of being trained to use the devices, other than visual or written demonstrations at the beginning of the voyage. MES should be designed to limit the risk of injury to untrained passengers during the evacuation procedures.

It is surprising how often the manner in which a human interfaces with a MES is overlooked. Ergonomic analyses are necessary components of the regulatory process and must be used in assessing design, construction and training regulations. These analyses have to be revised on a regular basis to reflect changes in equipment design, secular trends regarding human health status and employment demographics.

The purpose of this thesis is to examine critical aspects of MES design and use and to illustrate how overlooking the physical and mental capacity of the user can decrease the effectiveness of the appliance.

CO-AUTHORSHIP STATEMENT

There have been a number of people who have had considerable input into this manuscript.

i) This concept of studying Marine Evacuation Systems safety is attributed to Dr. Scott MacKinnon.

ii) Data for all three studies were collected in a collaborative fashion by Dr. MacKinnon, Robert Brown, James Boone, Graham Small and Danika Drover. For each study instructors or other trained personnel from the Offshore Safety and Survival Centre were employed to assist with data collection. With guidance from Dr. MacKinnon and Mr. Brown, Danika Drover reduced the data.

iii) With guidance from Dr. Scott MacKinnon, Danika Drover prepared the following thesis manuscript.

CHAPTER 2

Review of Literature

2.1 Introduction

People working offshore today still have numerous safety issues that have to be mediated for the sake of safety to passengers and personnel. There have been a range of accidents occurring on seagoing vessels and offshore platforms. Training for safety has been a key issue and there are regulations established by governing bodies about training for safe evacuation. Some of these regulations are under the Canada Shipping Act set forth by Transport Canada (Transport Canada, 2005) while others were introduced by the International Maritime Organization's (IMO) International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (IMO, 1997).

To further the potential for safer evacuation, evacuation modeling is considered in the design and implementation of evacuation plans. These models not only assist in the preparedness for a disaster at sea but will also assist in the process of designing more efficient Marine Evacuation Systems (MES) and training procedures.

Standards that are set forth applying to the design, construction and performance of marine evacuation systems must also be considered and scrutinized. Once these regulations are established, it is imperative that regulators, manufacturers and operators cooperate in their proper implementation. However, the fact remains that manufacturers and operators operate under business models. While conforming to the regulatory environment, costs must be controlled. Unfortunately, profitability and best practices with respect to safety at sea are not necessarily compatible goals and in past history were considered conflicting priorities.

When considering the design of MES it is essential that the abilities and competencies of the end-users are considered. Anthropometrics vary both across and within user populations. Therefore equipment designs must be compatible with the anthropometric measurements of a workforce. Another important factor when designing MES is the physical and mental tolerances of a person employing a MES. When employing a MES the body will experience forces both during the fall and upon reaching the bottom of the device. The inherent design of the MES should attempt to minimize the external forces acting on the individual so injuries do not occur as a result of using the device. Furthermore, emergency evacuations using MES devices are psychologically stressful. Thus MES design should consider how people perceive, make decisions and react under emergency situations. Obviously proper passenger training and preparation and a suitable number of trained personnel used during evacuations will mediate some of these stresses.

In conclusion, issues surrounding MES require a participatory approach in their design, prescription and employment. The regulatory process needs to be in place to guide these goals; however, manufacturers and operators should always consider a best practices approach when a device is installed on a seagoing vessel. The research process is an important part of this process and is needed to inform all stakeholders concerned with safety at sea.

2.2 Safety at Sea

Working offshore remains a dangerous job for all concerned. Although there has been some progress in the reduction of accidents there is still much to be done related to the regulation process, design of emergency equipment and training of personnel in the use of evacuation systems. For the year 1999/2000 the Health and Safety Executive (HSE) in the United Kingdom reported that there were two fatalities and fifty-two major injuries during the twelve month period. This marked a reduction of twenty-two injuries compared with the previous year, however the number of people at risk was reduced from 25,500 down to 19,000 cutting the combined fatality and injury rate only marginally (from 294.1 to 284.2 per 100,000 workers) (SASI, April, 2001). This rate was still significantly above the average for the period between 1994 and 1997 which was around 250 per 100,000 workers. The Minerals Management Service in the US keeps similar figures for the Outer Continental Shelf (OCS). They found that in 2000 there were five fatalities and 63 injuries compared with 5 fatalities and 47 injuries in 1999 (SASI, April, 2001)

It seems that the review of evacuation systems often occurs after some maritime tragedy. Following the loss of so many lives in the 1994 Estonia disaster, the testing of marine evacuation systems (MES) was accelerated. This roll-on/roll-off ferry sank with hundreds of people trapped inside and with more dying because they could not evacuate safely. In early 1997, MES were systematically evaluated under heavy weather conditions (Beaufort Force 6 winds and significant wave stature of 3m). It was found that existing designs of slides buckled and twisted under these weather conditions and would delay the safe evacuation of passengers (Nuthall, 2002 ; Beech, 1997). It is only in these heavy weather conditions that it can be determined whether a MES is properly designed and employed. Industry should be receptive to seeing how these systems work in less than favorable operating conditions - failure to do so will likely result in further maritime tragedies.

The emergency evacuation of an offshore installation is not a simple task. The majority of Northern Hemisphere oil and gas installations are located more than 100 miles offshore and are subject to extreme weather conditions. The problems of safe evacuation of offshore personnel in high winds, poor visibility and rough seas have been highlighted over the past few decades with such events as the explosion of the Piper Alpha platform (Flin et al., 1996), the capsizing of the accommodation rig Alexander Kielland and the sinking of the semi-submersible drilling unit Ocean Ranger (Simoes Re, 1997).

Accidents and fatalities not only occur in emergency evacuations, but have occurred during training scenarios. A fatal accident on board a Peninsular and Oriental Steam Navigation Company (P&O) ferry during an evacuation drill occurred in early 2003. While descending a vertical chute, a female volunteer employee became stuck in a "piked" position, inhibiting her ability to breathe properly. Despite attempts to rescue her, she perished as a result of this accident. After analyzing the reasons for this accident it was noted that there have been many evacuation trials involving over 5000 evacuees in vertical chutes and very few people have been injured (SASI, September, 2003). With this being said it seems that there will always be a conflict between administrations wanting as realistic a drill as possible and shipping companies' duty of care to their evacuees. Ove Roessland, the chairman of the International Appliance Manufacturers' Association (ILAMA) stated that "there are too many accidents occurring because critical parts of life saving appliances are either not serviced or serviced by untrained personnel" (FS, September, 2003).

2.3 Training available to Offshore Personnel

Every MES has its own training program. In some cases every crewmember should obtain a basic MES course which could include on-board training repeated every three months and annual half-day refresher courses in a certified training centre (SASI, April 1995). Although Transport Canada has developed training standards and guidelines, nautical colleges and private corporations are expected to develop course material and deliver the training programs to students (Patterson, 2002). In general, the courses developed by the training providers can be categorized under one of three general headings: personal safety training, technical safety training and marine crew training. While training is very important, education is also necessary to ensure that the development of appropriate safety and environmental systems continues. Canadian universities, such as Memorial University and Dalhousie University, are providing advanced education that relates to the management of safety and the environment in the offshore industry (Patterson, 2002).

Transport Canada has a complete section on crewing regulations under the Canada Shipping Act. Under Part One Division III of the crewing regulations is a section on training which states that "every member of the complement of a ship shall, before the member has completed six months on board ships, obtain a certificate of the member's successful completion of training, at a recognized institution, in marine emergency duties with respect to basic safety" (Transport Canada, 2005).

There are also training regulations set out by the International Maritime Organization. In 1978 there was an International Convention on Standards of Training, Certification and Watchkeeping for Seafarers. This convention was completely revised in the 1995, amendments which entered into effect in February of 1997 (IMO, 1997). Chapter V of the 1995 amendments was on special training requirements for personnel on certain types of ships. At this time, special requirements were introduced concerning the training and qualifications of personnel on board ro-ro passenger ships. Previously, the only special requirements in the Convention concerned crews on tankers. This change was made in response to proposals made by the Panel of Experts set up to look into roll-on/roll-off vessel safety following the capsize and sinking of the ferry Estonia in September 1994. Crews on roll-on/roll-off ferries have to receive training in technical aspects and also in crowd and crisis management and human behavior (IMO, 1997).

The regulations reviewed in this section are a small constitution of those existing in the international regulatory regime. Due to the international trade which occurs in the maritime industry, it is important that all stakeholders are aware of regional and national requirements.

2.4 Evacuation Models

Evacuation models are systems or methodologies to simulate and evaluate the effect of factors critical to the evacuation process (Kim et al., 2004). Because evacuation is mainly dependent on the behaviors of evacuating individuals, evacuation factors are those which significantly affect the behavior of evacuation individuals in egress situations. Evacuation modeling at sea is one of the most important issues in the view of design-for-safety. The problem is that most of the evacuation models used have been developed for the assessment of evacuation from buildings and airplanes. There are currently many international research projects being carried out to develop maritime evacuation models (Kim et al., 2004).

There are six principle steps of Evacuation, Escape and Recovery (EER) modeling. Essentially, following assimilation of data (step 1) and assessment of the key accident scenarios (step 2), the modeling of the escape process (step 3) is conducted. Step 4 involves the evacuation process, step 5 involves the rescue model and in the final step (step 6), the results of the individual component models are integrated to give an overall EER reliability of success probability rating for the emergency systems (Bercha et al., 2003). There are currently 20 evacuation models available and each model has its own purpose. Examples of such evacuation models include EXODUS, *Evi,* and BYPASS. EXODUS was developed by the fire safety engineering group and is a model used to simulate evacuations from complex enclosures (Galea, 2001). The Ship Stability Research Center at the University of Strathclyde developed the evacuability index *(Evi)* and relates to a virtual environment for enhanced effectiveness of evacuation performance through visualization (Vassalos et al, 2001). BYPASS was a model created with the aim to assess the design of a ship with respect to the maximum evacuation time to be met (Klupfel et al., 2000). The most complicated and difficult area in the simulation of evacuation processes is the impact of human behavior. However, there are a number of limitations in simulating human behavior. There are three major factors that have been found to have the most significant effect on evacuation time. These factors are ship listing and motion, crowd density and psychological factors. Although current models are lacking in this cognate area, there has been research conducted to study the effects of these three factors on human behavior in ship evacuation (Kim et al., 2004).

With the use of proper evacuation models at sea comes a greater confidence in the ability to design safer evacuation systems as well as the ability to prepare better persons for evacuation situations. This in turn has the potential to lead to the reduction or even elimination of tragedies at sea.

2.5 Regulations Specific to Marine Evacuation Systems

Few policies and regulations governing the design, construction and performance of Marine Evacuation Systems are currently in place. Canada imposes its own regulatory regime in consideration of those regulations developed by the International Maritime Organization (IMO) and other agencies. This means that Transport Canada regulates the life-saving equipment and therefore sets forth standards applying to the design, construction and performance of marine evacuation systems. If a ship is required to carry liferafts (under Part I or II of the Canada Shipping Act), a marine evacuation system may be substituted for the life rafts and any associated launching devices if the accommodation capacity of the marine evacuation system is at least equal to the accommodation capacity of the liferafts for which the marine evacuation system is substituted (Transport Canada, 2005). For example, a marine evacuation chute and inflatable liferafts with a capacity of 100 people could replace a davit launched rigid liferaft with a capacity of 100 people. The problem with this criteria is that it raises a number of questions. For example, it may be assumed that by substituting one system for another, the persons using the new system will be trained on how to properly employ that system. It must also be understood that the abandonment capacities are consistent from one system to the next and that evacuation can occur within the allotted time regardless of the system used.

The second requirement of MES that are substituted for liferafts is that they must meet the requirements of the International Life-Saving Appliance (LSA) Code (IMO, 2003). There are basic regulations from the LSA code that apply to MES. Chutes and slides, along with the associated platforms, must be constructed to provide a level of strength that meets satisfactorily with the approval of the IMO Administration. They must be designed to allow for the evacuation or passage of passengers who are of various ages and sizes as well as persons with varying degrees of physical capability. The construction of MES must compensate for evacuees to be wearing approved lifejackets (IMO, 2003).

Following evacuation from the vessel, the slide or chute will provide either direct access to a life raft or indirect access via a boarding platform. If a boarding platform is not used then the system must include a quick release mechanism so as to detach the liferaft from the MES. If one is used then the platform is required to provide sufficient buoyancy and the stability which must be provided when the platform is loaded to working capacity. The platform should be designed to provide a safe means of transfer and a working area for operators and must be constructed to provide sufficient strength to secure liferafts that are associated with the chute or slide (Forsey, 2003).

The manner in which the MES performs must also meet the performance requirements of the Life-Saving Appliances Code. The performance level of a system is determined by time trials under specified weather/sea conditions. When it comes to deployment requirements, a system must be capable of being deployed by one person. A system must also be capable of evacuating the number of evacuees for which it is designed within 30 minutes of the abandon ship signal (IMO, 2004). The system must prove to be deployable in unfavorable operational conditions and to remain effective to a practical extent, in icy conditions.

It is essential that manufacturers, operators, trainers and researchers are kept well informed of all regulations. These groups must periodically review the regulations that are put in place to ensure that they are consistent with developing technologies or changes in personnel competencies and passenger characteristics.

2.6 Types of Marine Evacuation Systems

There are a number of companies that are involved in the manufacturing of marine evacuations systems. All companies face regulatory requirements for design and construction and as with all commercial enterprises have to keep manufacturing costs down in order to increase profitability. The main issue is that whether the reported evacuation specifications can be achieved by the operators who purchase these devices or not.

Marine Evacuation Systems have been manufactured since the 1980's. There is quite a range in the variety of MES that are being produced. One particular company manufactures a system that can be launched by a single crewmember and successfully evacuate 100 passengers in 5 minutes and 10 seconds when three units are deployed in calm water. It takes only one and a half minutes for the first person to be evacuated (SASI, v.334, 1997). In 1999 this was the only Marine Evacuation System approved in the world which evacuated passengers directly from the vessel into a large capacity life raft via an inflatable slide, without the use of any kind of boarding platform (SASI, April, 1999). In 1999 the first orders for a MES designed for high speed craft were made. This system was the first to fully comply with IMO SOLAS Chapter 3 requirements and therefore this system continues to be chosen by many of the major ship operators (NA, April, 1999; SASI, v.373, 2000). More recently, a twin chute has been designed to safely evacuate 400 passengers in just 17 minutes (SASI, v.348, 1998). The same company to design the twin chute also fitted the first cruise ship, the SuperStar Leo with its marine evacuation chute (SASI, v.373, 2000). Yet another manufacturer has produced a double-track MES, which is purpose-made for disembarking large numbers of passengers from high density passenger vessels with high freeboards in the event of an emergency or accident at sea. During a functional test 358 persons were evacuated in 10 minutes and 54 seconds (SASI, v.361, 1999). The same company most recently launched a mini-chute MES that can operate from the deck of small vessels or a side-shell door for large ships. The chute stature can vary from 5m to 10m depending upon the model selected (SASI,v.373, 2000; FS, September, 2003).

Knowing that a system must be capable of evacuating the number of evacuees for which it is designed within 30 minutes of the abandon ship signal all of the MES mentioned seem to have very impressive evacuation times. The fact remains though that the majority of these systems are not tested in very realistic conditions and are often evaluated using personnel (i.e. company employees) with a reasonably good knowledge of the system's operation and performance. Harsh weather conditions certainly increase the amount of time required to abandon a ship. Also, on many ships, notably passenger ships, there would be less adequately trained occupants which would once again increase the time that it would take to evacuate. Along with this comes the fact that sometimes training can be unsafe as proven by the death of a female volunteer in Dover (FS, September, 2003). Another important factor is that of a mass casualty situation. When an accident produces high numbers of injured/incapacitated passengers, the time that it would take to evacuate all passengers would undoubtedly increase.

2.7 Anthropometrics

2.7.1. Introduction

Anthropometrics is defined as data relating to physical body dimensions. These body dimensions, body shape, weight and proportions are significantly different for people living and working in different parts of the world. Anthropometry found its origin not in medicine or biology, but rather in the arts. Sculptors and painters were looking for ideal proportions between body parts, in order to give the proper picture of the human body (Beunen et al., 1990). Nineteenth-century anthropology was the basis from which modern surface anthropometry historically arose. This anthropometry was primarily devoted to skeletal classification and description and was largely used to characterize racial differences and to describe supposed evolutionary pathways (Olds, 2004).

During the last thirty-five years there has been an increasing amount of attention devoted to the changes in human stature and rates of growth. Although early research directed its focus to the stature of British and American populations, recent attention has been given to both stature and other anthropometric indicators in other countries (Harris, 1994). It is clear that there have been dramatic changes in the anthropometrics of people in many different part of the world over the last 150 years. This section will discuss some of the possible reasons for these changes as well as present various anthropometric data from around the world.

2.7.2 Economic Status

While genes are important determinants of an individual's stature, it seems that the difference in average statures across populations is largely attributable to things such as economic status, environmental conditions and nutritional status. The use of anthropometric measures to assess a population's physical growth and health has been around for quite some time. In the early 19th century, Louis-René Villermé observed that stature was a gauge of a nation's state of development (Morgan, 2000).

It has been said that the average stature of a population is determined by the interaction between the environment in which a society lives and the resources it commands (Harris, 1997). In other words, stature measures the impact of both environmental and nutritional conditions. The two most important determinants of average stature are disease and diet. Poorly-nourished populations who grow up in disease-ridden environments grow at a slower rate and attain lower final statures than well nourished populations who grow up in disease-free environments (Harris, 1997; Harris, 1994).

Income is a compelling determinant of stature. With a higher income, there is a greater ability to attain a complete diet, to afford better housing and health care which results in an increase in statures (Morgan, 2000). Steckel showed that variations in the statures of adults and children in 22 different countries were closely related to gross national income and the degree of income inequality (Steckel, 1983).

Many factors associated with low economic status have been linked to low maternal weight gain. Several of these factors, including malnutrition during the third trimester of pregnancy can lead to low birth weight, and malnutrition after birth affects growth throughout childhood (Siegra-Riz et al., 1997; Harris, 1994). There have also been anthropometric investigations concerning the statures of people on the slave plantations of the United States and the Caribbean. The average weight of newborn slaves was calculated to be 5.1 pounds, which was well below the figures recorded for other populations at the time (Steckel, 1986a; Steckel, 1986b).

2.7.3 Anthropometrics and Ergonomics

Anthropometric data is a useful building block towards good ergonomic designs (So et al., 2005). In occupational injury prevention applications, anthropometric measurements are used to evaluate the interaction of workers with tasks, tools, machines, vehicles and personal protective equipment. If equipment designs are incompatible with the anthropometric measurements of a workforce, the result could be undesired incidents (Hsiao et al., 2002). Unfortunately there is little information about the anthropometric differences among occupational groups (Hsiao et al., 2002). While some findings have been reported, overall the results indicated that the body sizes and shapes of some occupational groups are quite different. The application of data from one occupational group to another in the design of workplaces, systems and personal protective devices, may be inconsistent with sound ergonomic design principles.

2.7.4 *Anthropometrics across Ethnic Groups*

Table 2.1 documents mass, stature and body mass index (BMI) summarized from a literature search. These data refer to ethnic groups, sexes and ages. In the citations that provided only mean and standard deviation data, the assumption was made that these data were normally distributed and thus percentile information could be derived. These data are summarized at the bottom of the Table 2.1. Following these data, information collected from male and female subjects registered in a basic offshore survival training course necessary for employment in the North Atlantic offshore oil industry are included for comparison purposes. These data were collected from 90 people in June, 2004.

Table 2.1: Summary of anthropometric data across populations

		MALES			FEMALES		
	Percentile	Mass (kg)	Stature (mm)	BMI (kg/m^2)	Mass (kg)	Stature (mm)	BMI (kg/m^2)
	5th	55.0	1625	20.8			
British Adult [1]	50th	75.0	1740	24.8			
	95th	94.0	1855	27.3			
	5th	55.0	1640	20.4			
US Adult [1]	50th	78.0	1755	25.3			
	95th	102.0	1820	30.8			
	5th	61.5	1676	21.9	40.4	1525	17.4
African American Adult [6]	50th	82.5	1778	26.1	79.8	1632	30.0
	95th	103.6	1880	29.3	119.2	1739	39.4
	5th	60.0	1690	21.0			
Dutch Adult [1]	50th	76.0	1795	23.6			
	95th	92.0	1900	25.5			
French Adult Drivers[1]	5th	58.0	1600	22.7			
	50th	73.0	1715	24.8			
	95th	95.0	1830	28.4			
	5th	58.2	1575	23.4	45.5	1488	20.6
French Elderly (70-74 years) [3]	50th	80.4	1680	28.5	66.6	1570	27.0
	95th	102.6	1779	32.4	87.7	1652	32.1
	5th	62.2	1623	23.6	54.5	1500	24.2
Croatian (West) [9]	50th	83.2	1738.4	27.5	74.6	1597	29.2
	95th	104.2	1854	30.3	94.6	1693	33.0

Table 2.1: Continued

	5th	53.0	1630	19.9	42.0	1500	18.7
Iranian University Students[7]	50th	65.0	1723	21.9	55.0	1598	21.5
	95th	84.7	1830	25.3	75.5	1698	26.2
Hong Kong Chinese Industrial Workers[1]	5th	47.0	1585	18.7			
	50th	60.0	1680	21.3			
	95th	75.0	1775	23.8			
	5th	41.0	1560	16.8			
Japanese Adult[1]	50th	60.0	1655	21.9			
	95th	74.0	1750	24.2			
Japanese Adult (40-49 years)[5]	50th	68.0	1690	23.8	54.7	1562	22.4
Japanese Adult (>70 years)[5]	50th	57.6	1595	22.6	49.7	1462	23.3
			MALES			**FEMALES**	
		Mass	Stature	BMI	Mass	Stature	BMI
	Percentile	(kg)	(mm)	(kg/m^2)	(kg)	(mm)	(kg/m^2)
Beijing Young Adult[2]	50th		1730	21.2		1600	20.9
	5th	48.6	1623	18.5	40.7	1500	18.1
Taiwanese Young Adult[8]	50th	63.6	1713	21.7	52.3	1584	20.9
	95th	78.5	1804	24.1	64.0	1668	23.0
	5th	41.6	1474	19.2	41.6	1474	19.2
Cuban Adult[4]	50th	62.7	1569	25.5	62.7	1569	25.5
	95th	72.2	1664	26.1	72.2	1664	26.1

Table 2.1: Continued

SUMMARY	Percentile	Mass (kg)	Stature (mm)	BMI (kg/m^2)	Mass (kg)	Stature (mm)	BMI (kg/m^2)
MEAN POPULATION	5th	53.4	1608.4	20.6	44.1	1497.8	19.7
	50th	70.4	1701.9	24.2	61.9	1571.7	25.0
	95th	89.8	1811.7	27.3	85.5	1685.7	30.0
OVERALL MEAN POPULATION	5th	50.8	1577.3	20.4			
	50th	66.9	1659.9	24.2			
	95th	89.3	1775.9	28.3			
OFFSHORE WORKERS[10]	5th	59.9	1617	22.9			
	50th	88.2	1751	28.8			
	95th	116.4	1884	32.8			

Data Origin	
1	Pheasant, 1998
2	Morgan, 2000
3	Delarue et al., 1994
4	Martinez et al., 2003
5	Japanese Statistics Bureau, 2001
6	Kim et al., 1998
7	Mououdi, 1997
8	Wang et al., 2002
9	Smolej-Narancic et al., 1994
10	MacKinnon et al. 2004

2.8 Impact Forces and Human Tolerance to Injury

2.8.1 Injury and Death Definitions

Impact force is defined as a force resulting from the collision of two bodies over a relatively short time period. Although impact forces generally possess a relatively high magnitude there are no defined limits of either magnitude or duration related to impact forces on the human body (Hreljac et al., 2004). Injury, in cellular terms, is physical damage caused by the excessive transfer of energy (e.g., mechanical) or the lack of essential factors for energy production, such as oxygen or heat (e.g., suffocation). Impact injuries rank in the top 10 leading causes of death worldwide (Razzak et al., 2005). The human body can tolerate very high jolt levels ("jolt" is defined as the 1st order differential of the acceleration-time history) over very short periods of time, usually because the amplitude, or distance traveled, is small. It becomes a serious problem when the duration or amplitude of the collision force increases.

Impact biomechanics involves conducting controlled laboratory studies using human surrogates to determine the injury tolerance of different anatomical regions to direct or indirect loading and to determine the mechanical responses of these different regions to various types of loading (Rupp et al., 2004). Most of these studies have been cadaver studies aimed to estimate dynamic injury tolerance and to reproduce fractures similar to those observed in real-world case studies (Jernigan et al., 2005). Obviously there are ecological validity issues with respect to cadaveric methodologies. Although these designs attempt to produce impacts that would produce injury in a living human, cadaver subjects are usually elderly at the time of death. Also, unlike a live subject, cadaver test data are restricted since cadavers are non-functioning systems (Foust et al., 1977). Anesthetized animals used for impact testing provide an advantage of producing injury within a living system but presents problems in scaling animal response to human response (Foust et al., 1977).

Although impact testing has been conducted for many decades, the major thrust in the development of impact testing came with World War II and the introduction of high performance aircraft. This was when ejection seats were first installed and, during this time, compression tests were carried out by Siegfried Ruff (Crawford, 2003) on cadaver vertebrae to determine the strength of the spinal column under high positive G accelerations over short time-spans. The British began impact testing in 1944 and these tests were carried out on an early ejection-seat test tower using both dummies and human subjects. This work did reveal the risk for vertebral injury (Crawford, 2003).

2.8.2 Age and Relationship to Impact Injuries

Impacts forces have different effects on different people depending on factors such as age, gender and size. Alcantara et al. (2002) studied the mechanical properties of the heel pad under walking impact conditions. With respect to age, results showed that the elderly demonstrated a longer time to peak force and greater peak displacement than the young.

When human impact tolerance was tested using simulations of free-falls and investigations, it was found that most of the children whose falls were investigated landed on their heads while most of the adults landed on their feet or sides (Foust et al, 1977).

This in turn caused a difference in type of injury for different ages. Children would be expected to suffer more skull fractures while adults would be likely to incur lumbar spine fractures if they landed in a sitting position after falling 10 feet and sustain pelvic fracture in feet-first falls of more than 30 feet. In some studies, age proved that it wasn't a factor when looking at impact forces. Rupp et al (2004) looked at injuries to the hip joint in frontal motor vehicle crashes. They found that there are no consistent trends in knee, thigh and hip injuries with age. This is contrary to expectation when considering the lower fracture tolerance found in older adults.

2.8.3 Gender and Relationship to Impact Injuries

Gender differences have also been found when studying injury due to impact forces. Early experiments conducted on the ulna showed that males had a much higher mean fracture loads than females (Pintar et al., 2002). With regards to car crash investigations, whiplash has been found to occur more often in women than men (Viano, 2003). Male occupants have been found to be at lower risk for traumatic brain injury compared with female occupants (Bazarian et al., 2004). Both of the above observations may be explained by the fact that men have increased neck muscle strength and thus less head movement and better body position in the vehicle because of greater stature and weight. Alcantara et al (2002) reported that women presented a shorter time to peak force together with lower peak displacement, energy absorption and lower maximal stiffness than men.

2.8.4 Prevalence of Body Part/Anatomical Location in Impact Injuries

There have been a number of studies that have attempted to define impact tolerance levels for various areas of the body. In a study conducted to evaluate the biomechanics of the human foot-ankle complex under axial impact, it was found that the mean dynamic forces at the plantar surface of the foot were 7.7kN (SD = 4.3) and 15.1 kN (SD = 2.7) for the nonfracture and fracture tests, respectively. The mean dynamic forces at the proximal tibial end of the preparation were 5.2kN (SD =3.1) in the nonfracture group, and 10.2 (SD = 1.5) in the fracture group (Yoganandan et al., 1997).

There seems to be more literature on impact testing regarding the knee. This may be due to the fact that much of the research was done during car crash testing and of all lower extremity injuries sustained in frontal crashes, knee-thigh-hip (KTH) injuries are the most frequent and costly (Rupp et al., 2004). When Melvin et al (1976) performed a study on tolerance levels, the only injury criteria, which was applied at that time to the lower extremities in occupant protection evaluation was 1700 lb. (7.56kN) maximum axial femur force limit. There was research on the impact of lower extremities performed up to this point in time, the earliest suggesting a conservative overall injury threshold level of 1400 lb. (6.23kN) (for the femur) (Melvin et al., 1976, Patrick et al., 1966). In a later study, Melvin et al (1980) found that the fracture-producing forces for lightly padded impacts ranged from 13.3 – 28.5 kN. These force levels were consistent with the findings of his previous tests (Melvin et al., 1976).

Since these early studies there have been a number of statistics released with respect to car crash injuries. Knee-thigh-hip injuries have been found to be the most costly with hip injuries occurring at a rate of 14,000 per year (Rupp et al., 2004). Findings such as these created a new interest in determining injury tolerance of the hip to frontal knee impact loading. In the early 80's, Schneider et al (1983) conducted nineteen tests with the hip joint oriented in a neutral seated posture that is representative of the thigh-to-pelvis angle for a midsize male driver of a passenger vehicle. The average fracture/dislocation tolerance of the hip joint from these tests was 5.7+/-0.3 kN (mean +/- standard error). The majority of these fractures were to the acetabulum. Following 13 of these tests, the test of the knee and femur was repeated with the head of the femur rigidly supported by an "acetabular cup" that distributed forces over the femoral head. In these tests, femoral neck fractures occurred at an average force of 7.6 +/- 0.4 kN. This showed that the tolerance of the femur neck was significantly greater than that of the acetabulum supporting the fact that the acetabulum is the weakest component of the hip (Rupp et al., 2004).

The angle of the knee or hip has also been found to have an effect on impact forces. Lafortune et al (1996) found that initial knee angle flexion caused considerable reduction in effective axial stiffness of the body which improved shock attenuation. In a simulation study by Gerritsen et al (1995) it was estimated that a more flexed knee position at contact would decrease the peak impact force by approximately 68 N per degree of flexion (Derrick, 2004). When looking at hip flexion it was discovered that while the neutral-posture hip tolerance was 6.1 +/- 0.4 kN (mean +/- standard error) the 30 degree flexed hip and 10 degree adducted hip tolerance levels were 4.1 kN and 5.0 kN respectively. This is equal to a 34% average decrease in hip tolerance for 30° flexion and an 18% average decrease in hip tolerance for 10° adduction.

There is some literature on abdominal injuries associated with impact forces. When assessing car crashes, Leung et al (1989) found that 60% of seat belt associated abdominal injuries involving at least moderate laceration of the kidney, liver, pancreas, or spleen (AIS 3), occurred at changes in velocity >30 mph. In laboratory experiments, Rouhana et al (1986) discovered that 0.82 kN of lateral impact force was enough to produce AIS 3 injuries in the liver of rabbits. Viano et al (1989) found that it took an average of 6.10 kN of lateral impact force to the abdomen to produce a AIS 3 injury in cadavers.

When examining arm injuries the literature tends to be much older. Early experiments were conducted by Weber in 1956 and Messerer in 1880 using quasistatic loading tests. Mean fracture loads under three-point bending span for the ulna were 2.26kN for the female and 3.55 kN for the male specimens (Pintar et al, 2002). As reported in Pintar et al (2002), Yamada reported three-point bending loads as a function of age for the radius and ulna bones loaded in anteroposterior direction. The adult average fracture forces were 0.52 kN for the radius and 0.63 kN for the ulna bones and a decrease in bone strength occurred with increasing age (Pintar et al, 2002). Pintar et al (2002) found that the mean piston failure force for the forearm was 2368 N for males and 1377 N for females. They also noted that the mean failure bending moment for all specimens was 94 Nm with smaller occupants with lower bone density having just half of this tolerance (approximately 45 Nm).

There are various models that exist that have attempted to quantify the forces involved in head injury and have served to increase the understanding of the biomechanics of brain injury. There have been attempts to measure head accelerations directly by instrumenting helmets. The problem is that when subjected to abrupt acceleration, the head will usually move inside the helmet, thus providing a dampened acceleration value. With this being said, true human tolerance to brain injury and correlation of force to degree of injury has yet to be measured directly and, as far as it is known, scientific knowledge of brain injury is currently based on results from mannequin, cadaver, volunteer testing and animal and computer models (Olvey et al., 2004).

Table 2.2 documents impact tolerance summarized from a literature search. These data refer to most areas of the body.

Table 2.2: Summary of Impact Tolerance Research Reviewed		
Yoganandan et al. (1997)	Foot Cadaver	- mean dynamic forces at the plantar surface were 7.7kN and 15.1kN for non and fracture tests respectively - forces at the proximal tibial end of the preparation were 5.2 for non and 10.2 for fracture
Patrik et al.(1966)	Lower extremities Cadaver	- fractures of femur were produced as low as 6.67 kN - Conservative injury threshold load level of 6.23 kN later raised to 8.86kN
Patrik (1966)	Lower extremities Human and Cadaver	- a force of 1400 lbs = conservative value for the overall injury threshold level - volunteers tolerate impacts of 800-100lbs for the knee
Powell et al.(1974,1975)	Lower extremities Cadaver	- average femur fracture – 10.04 kN - average patellar fracture – 10.75kN
Melvin (1975)	Lower extremities Cadaver	- max axial femur force limit of 7.56kN
Melvin et al.(1976)	Lower extremities (Lightly padded impact) Cadaver	- max force with no damage – 17.7 kN - max fracture producing force – 18.4 kN
Melvin et al.(1980)	Lower extremities (Lightly padded impact) Cadaver	- impact force necessary for fracture of the femur or patella – 13.4 kN - fracture producing forces occurred between13.3-28.5 kN

Table 2.2: Continued

Rupp et al.(2004)	Lower Extremities Cadavers	- average fracture/dislocation tolerance of the hip joint in vehicle crash tests was 5.7 +/- 0.3 kN - average fracture/dislocation tolerance of the femoral neck was 7.6 +/-0.4 kN
Crawford (2003)	Torso Human and Cadaver	- +ve G forces up to 40 G for up to 0.05s
Viano et al. (1989)	Abdomen Cadavers	- 6.10 kN forces produced AIS 3+ injuries
Leung et al.(1989)	Abdomen Human data	- 60% of AIS injuries occurred at velocity changes>30mph
Webber et al.(1856)	Forearm Cadaver	- mean fracture loads for the ulna were 2.26kN for female and 3.55 kN for male specimens
Messerer (1880)	Forearm Cadaver	- For radius mean fracture force of 1.20 kN for males and 0.67kN for females - For ulna mean fracture force of 1.23 kN for males and 0.81 kN for females - Adult average fracture force was 0.52 for the radius and 0.63kN for the ulna
Pintar et al.(1998)	Forearm Cadaver	- mean failure bending moment for all specimens was 94Nm

2.9 Conclusions

When considering the evacuation of persons from maritime vessels and installations it must be recognized that the safety of passengers is of the utmost importance. In order to ensure safety, a number of issues must be considered. Firstly, proper training concerning the use of MES must be administered and the regulations that are set forth regarding training must be strictly followed. Secondly, evacuation models should be taken into consideration during the design process. Thirdly, regulations regarding the design of MES should periodically be reviewed. Manufacturers, operators, trainers and researchers must be kept well informed of all regulations. Fourthly, the research community should continually seek the knowledge gaps in MES design, manufacturing and installation and must communicate these results to interested stakeholders and regulatory regimes.

CHAPTER 3

Anthropometric Characteristics of Persons Employed in the Newfoundland Offshore Oil Industry: Implications for Construction and Regulation of Marine Evacuation Systems

Abstract

The first part of this study was to measure the physical size (stature, mass, shoulder breadth, hip breadth (standing), hip breadth (sitting)) of a group of seafarers in standard work dress and a typical immersion suit. The second part was to use a statistical model to examine their fit into a 50 person lifeboat when wearing work clothes or an immersion suit.

There were a number of important findings from this study. The International Maritime Organization (IMO) Life Saving Code specifies that seafarers have an average mass of 75kg. The population of seafarers in this study was considerably heavier having a mean mass of 88kg. The wearing of an immersion suit increases the physical size of a seafarer. However, suit sizes are not reasonably considered in IMO design specifications.

The seat pan allocation is currently 430 mm per person. This is not adequate for the seafarer population and needs to be increased. Also, their shoulder breadths were always considerably greater than their hip breadths. Seat design is based on hip breadth and with shoulder breadth seeming to be a more pertinent measure, this measure would have more meaning in seat design.

There are some things that IMO may wish to consider as a result of this study. Firstly, considering the size of seafarer's shoulders when compared to hips, they should consider using the shoulder measurements for space allocation rather than hip breadth.

Also, generating a worldwide anthropometric database to update the LSA code in order to correctly represent the seafarer population in both the weight and space requirement is something that could be taken into consideration.

3.1 Introduction

Anthropometrics is defined as data relating to physical body dimensions. These body dimensions, body shapes, weights, and proportions are significantly different for people living and working in different parts of the world. This fact certainly applies to the offshore industry. For example, the *International Life Saving Appliance Code* specifies an average weight of 75kg for sizing lifeboats. In the Gulf of Mexico, the observed average mass for personnel employed in the oil industry was 95kg (American, 2003). It is absolutely vital that MES design is relative to the anthropometric characteristics of the users. When design is not based on the user, efficiency of the user is reduced and more importantly, safety issues increase.

The efficacy of any marine evacuation system (MES) is dependent upon its ability to accommodate the physical dimensions of the evacuees. Manufacturers must provide sufficient space and support for those employing these systems. Over the years regulatory bodies have defined the "average" stature and mass of persons likely to employ these systems and manufacturers have used these data to guide manufacturers in the design and construction process. However, anthropometric dimensions, particularly mass, demonstrate regular secular changes and thus all standards require periodic reassessment by both the regulatory and manufacturing communities.

Unfortunately, there are few databases derived from samples of sufficient number to provide guidance to government agencies and manufacturing groups. Furthermore, there is some question as to how recent these data should have been acquired to be valid representations of a current working population. There is evidence that, in general, people are getting taller and heavier. There can be no argument that there are secular trends demonstrating increasing stature. In particular, several researchers have identified that Asian and Eastern Asian cultures are demonstrating significant increases in stature over the last several decades (Morgan, 2000; So, 2005). These increases have been identified to occur as a result of an increasing trend towards inter-racial/cultural marriages. While genes are important determinants of stature, studies of many populations under diverse conditions suggest the difference in average statures across populations can also be attributed to environmental conditions, especially for populations in less developed countries.

Increases in mass are obviously related to concomitant increases in stature. However, many public health researchers have recognized that increases in mass are outpacing increases in stature due to increases in the average amount of body fat (i.e obesity) (Stein, 2004). In essence, the average frame or density of a person is getting larger and resulting in increased space requirements.

The demographics of offshore workers indicate an increased diversity in the working population. Developing countries are beginning to explore for and produce oil and gas or contribute working personnel to the industry in increasing numbers. This means that designs must be adjusted for cultural diversity. For example, a design range for 90% of the British for a standing operation would also accommodate 90% of Germans but only 10% of Vietnamese (Process, 2004).

Changes in regulations with regards to the offshore population have dictated needed changes in lifeboat capacity. IMO passed an amendment in May of 2004 requiring every person on a cargo ship to be provided with an immersion suit (IMO, 2005). A paper submitted by China shows that the occupants will need more room when wearing immersion suits than when wearing life jackets. When wearing an immersion suit the width of space taken up was 100mm (530mm) more than without (Chinese, 2004 – DE 47/5/6). Therefore the lifeboats used were found to be insufficient to accommodate the stated number of occupants.

One question to be answered is whether existing designs and regulations accommodate morphologies. This study looks at whether current lifeboat standards are suitable for a Canadian population with a focus on hip and shoulder width. It is hypothesized that many current lifeboat standards are not suitable including that which states that the average mass of those using life saving appliances is 75kg and also that the 430mm seat pan allocation is suitable.

3.2 Methods and Procedures

Data collection took place at the Offshore Safety and Survival Center (OSSC) of the Marine Institute, Memorial University of Newfoundland. 84 subjects (male = 74; female= 10) volunteered to participate in the study. Brookes et al. (2004) reported that between 85-95% of the workers at a Nova Scotia offshore installation were comprised of male employees. Data provided by Sable Offshore Energy Inc. indicated that of the 84 subjects selected at least 5%, but no more than 15%, should be female (Brooks et al., 2004). These statistics are likely very similar to those in the Newfoundland offshore industry meaning that the current sample is a probable representation in sex proportion.

The experimental protocol was approved by Memorial University's Human Investigations Committee. All the subjects were recruited from a pool of seafarers who attend required marine survival training courses at the Offshore Safety and Survival Centre (OSSC). Each subject was shown a copy of the protocol and signed an informed consent form.

3.2.1 *Protocol*

Stature and mass measures were recorded using a standing anthropometer and weigh scale, respectively. Standard structural anthropometric techniques were used to record the hip and shoulder breadth of the sample of 84 subjects. Shown in Figure 3.1 is an image of a standing and seated person and the three breadth dimensions taken using the anthropometer. The three dimensions were: A – Standing shoulder breadth, B – Standing hip breadth, and C – Seated hip breadth.

Figure 3.1: Schematic of the three anthropometric dimensions – the original images are from Van Cott and Kinkade (1972)

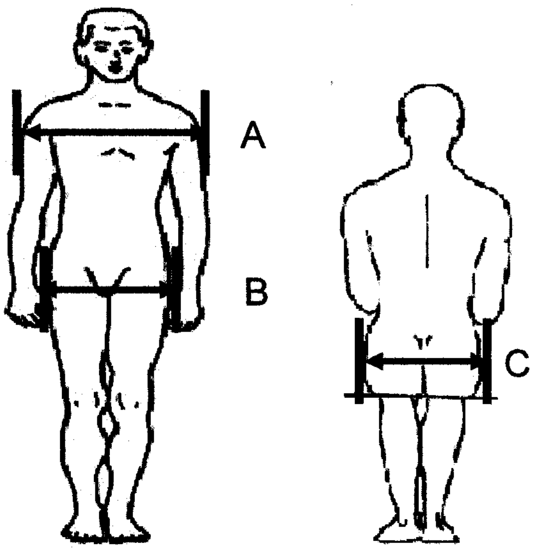
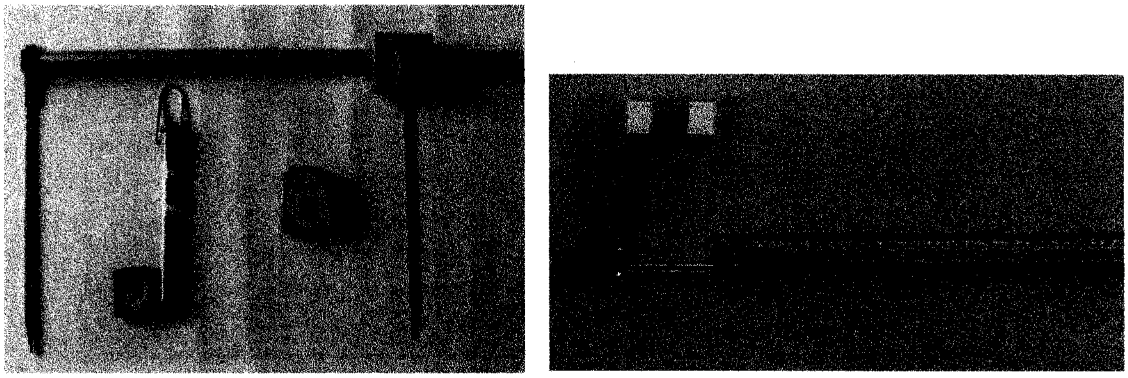


Figure 3.2 illustrates both the Harpenden anthropometer and a custom-built anthropometer that were used to collect the breadth data. Pilot research revealed that the breadths to be recorded would exceed the measurement range of the commercial device; therefore an enlarged version of this device was built to accommodate the wider measures, particularly of those wearing the abandonment apparel. A force gauge was added to the device to record the amount of compression the experimenter produced on the subject's suit during the measurements. This force gauge was important in (a) standardizing the measurement, (b) providing repeatable measurements to identify a comfortable fit in the seat and (c) to consistently reproduce a very tight fit in the seat (Brooks et al., 2004).

Bi-deltoid (shoulder breadth) and bi-trochanteric (hip breadth) measurements were taken on each subject (a) while wearing their standard work clothes and, (b) while wearing an immersion suit worn over the top of their work clothes (this is exactly the condition that would occur in marine abandonment). During the suited condition each measure was first recorded using no compression (maximum breadth) and with a standardized compression of 2700 grams (6 lbs) to represent a very tight fit in the lifeboat (Brooks et al., 2004).

Figure 3.2: Standard Harpenden Anthropometer and new device built for this study



Figures 3.3 through 3.14 show all of the various measurements that were taken, along with a description of each measurement.

Figure 3.3: Statures - The vertical distance from the floor to the vertex (i.e., the crown of the head)

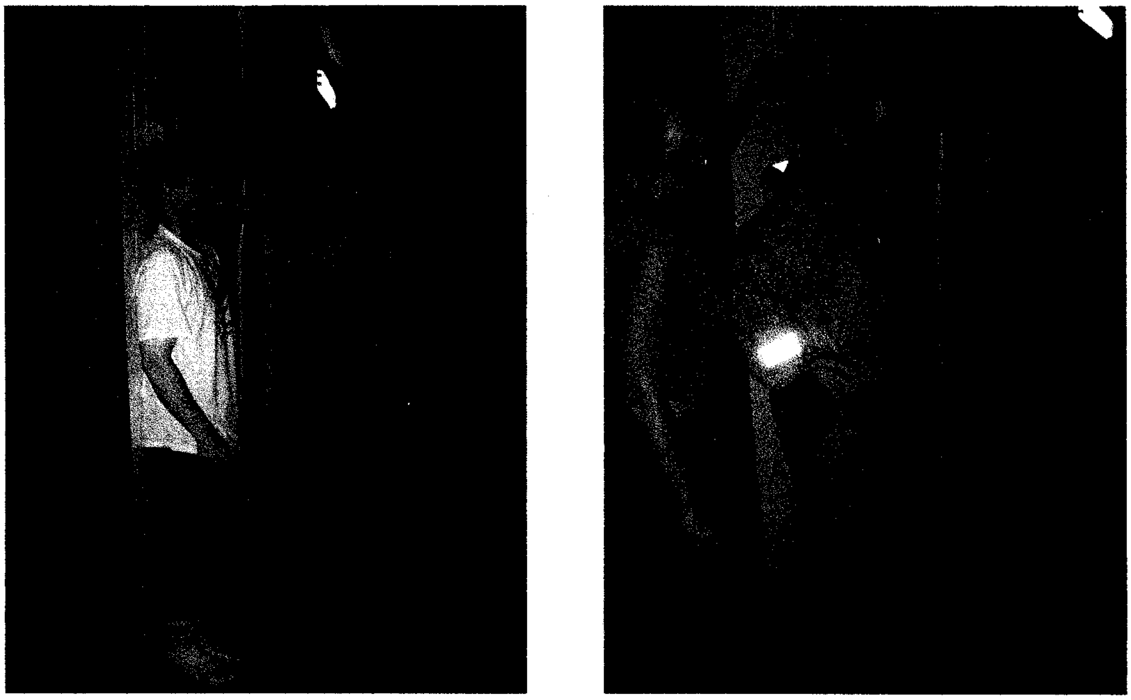


Figure 3.4: Boot length; Distance, parallel to the long axis of the foot, from the back of the heel to the tip of the boot

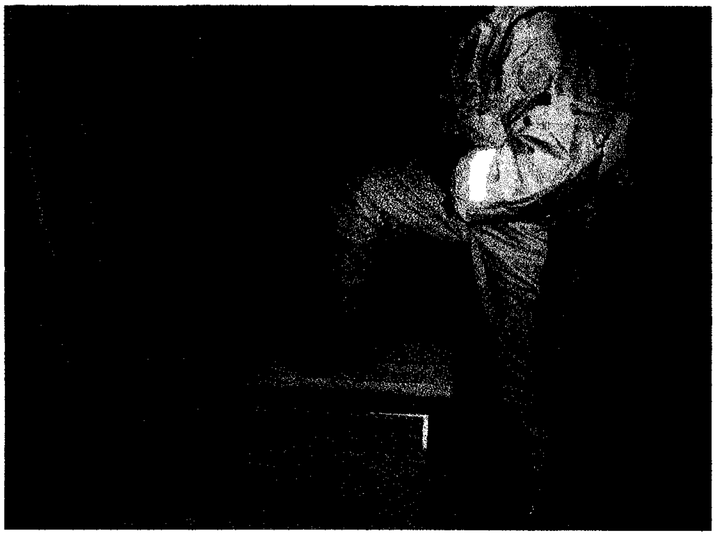


Figure 3.5: Knee Height: Vertical distance from the floor to the medial side of the patella (i.e., the center of the kneecap)

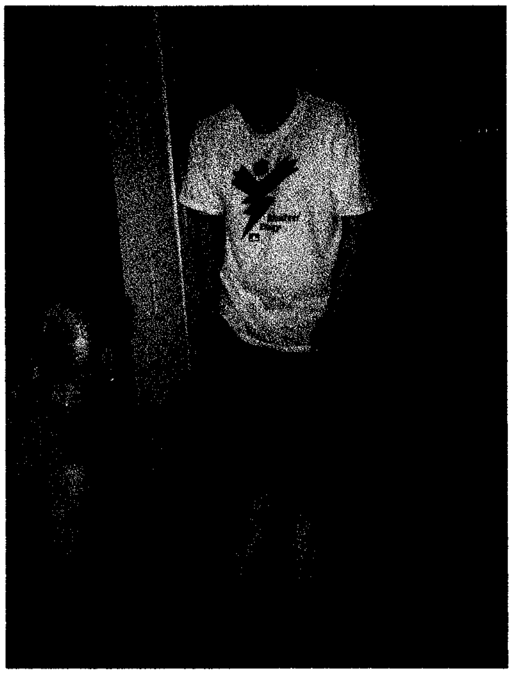


Figure 3.6: Hip height: Vertical distance form the floor to the greater trochanter (a bony prominence at the upper end of the thigh bone, palpable on the lateral surface of the hip)

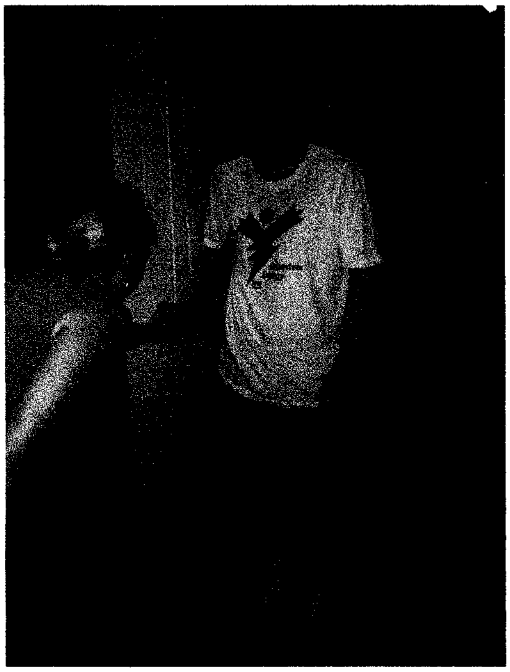


Figure 3.7: Sitting height: Vertical distance from the sitting surface to the vertex (i.e., the crown of the head)

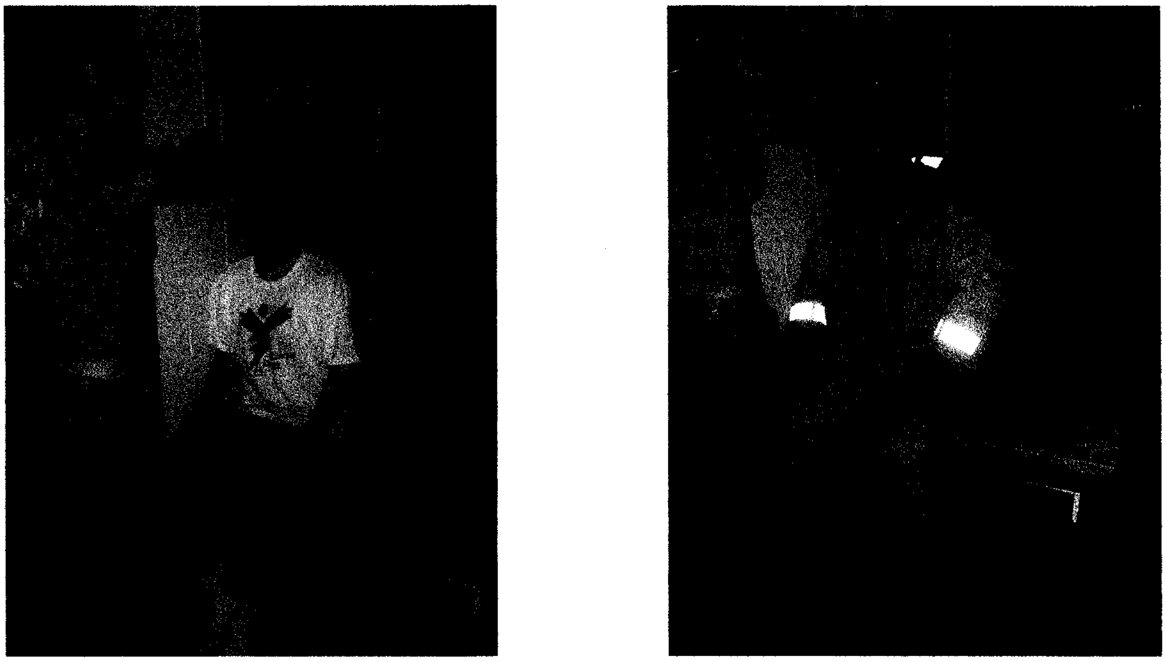


Figure 3.8: Sitting shoulder height; Vertical distance from the seat surface to the acromion (i.e., the bony point of the shoulder)

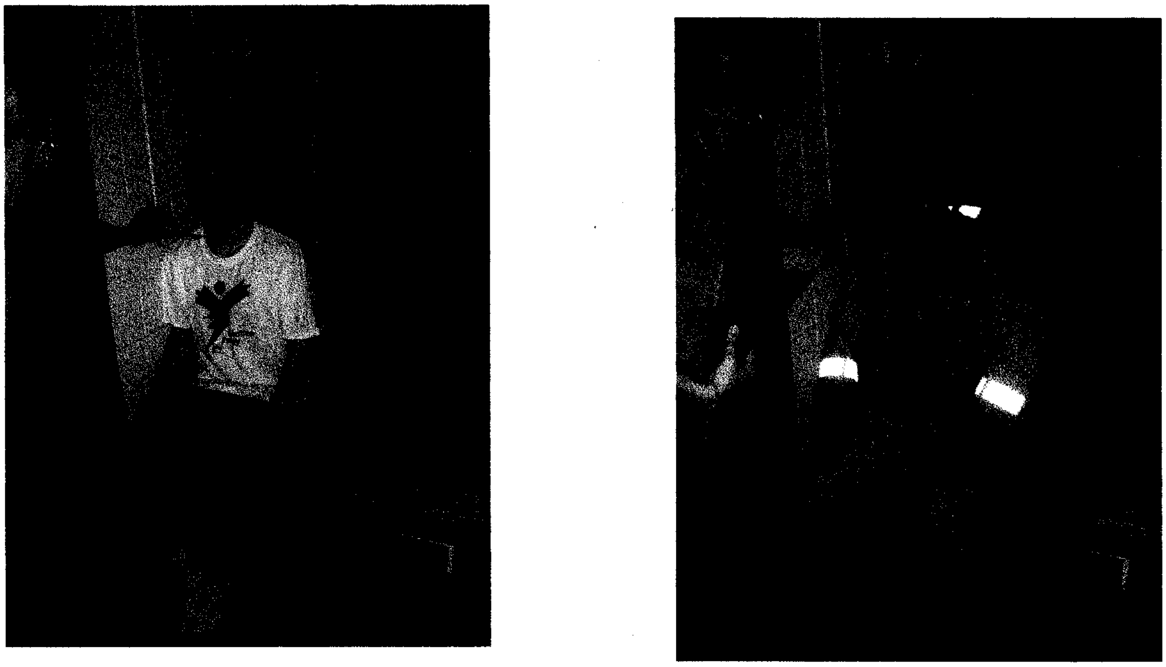


Figure 3.9: Shoulder breadth (bideltoid): Maximum horizontal breadth across shoulders, measured to the protrusions of the deltoid muscles

Figure 3.10: Hip breadth: Maximum horizontal distance across the hips

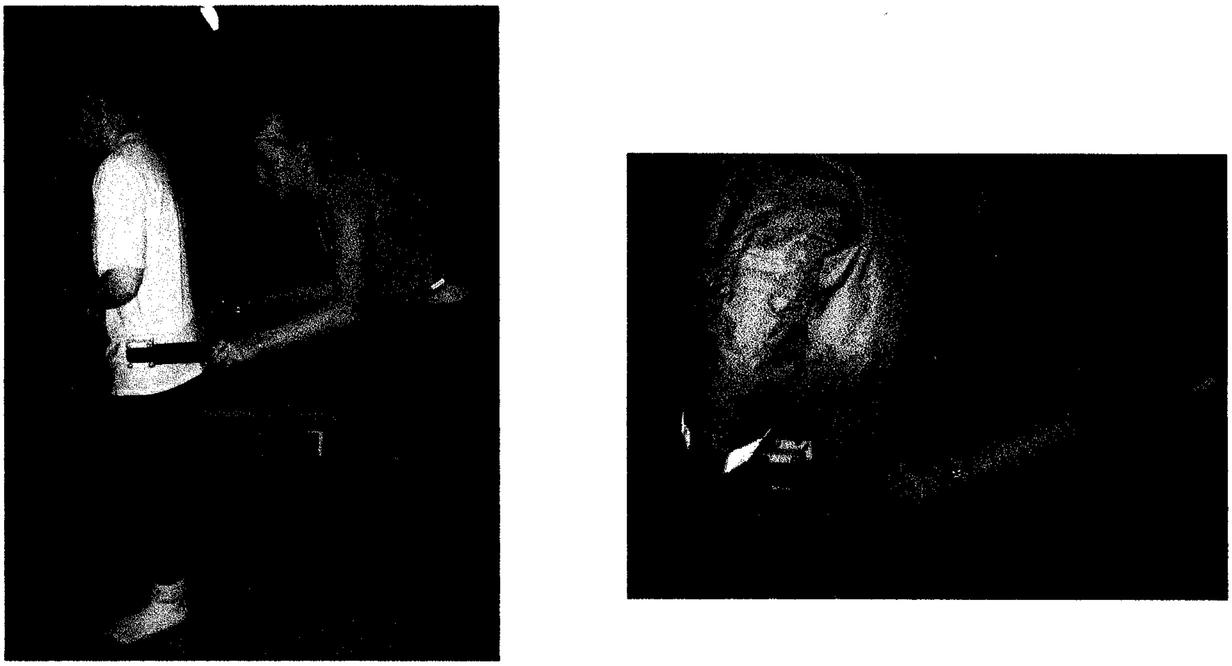


Figure 3.11: Hip breadth (seated): Maximum horizontal distance across the hips in the sitting position

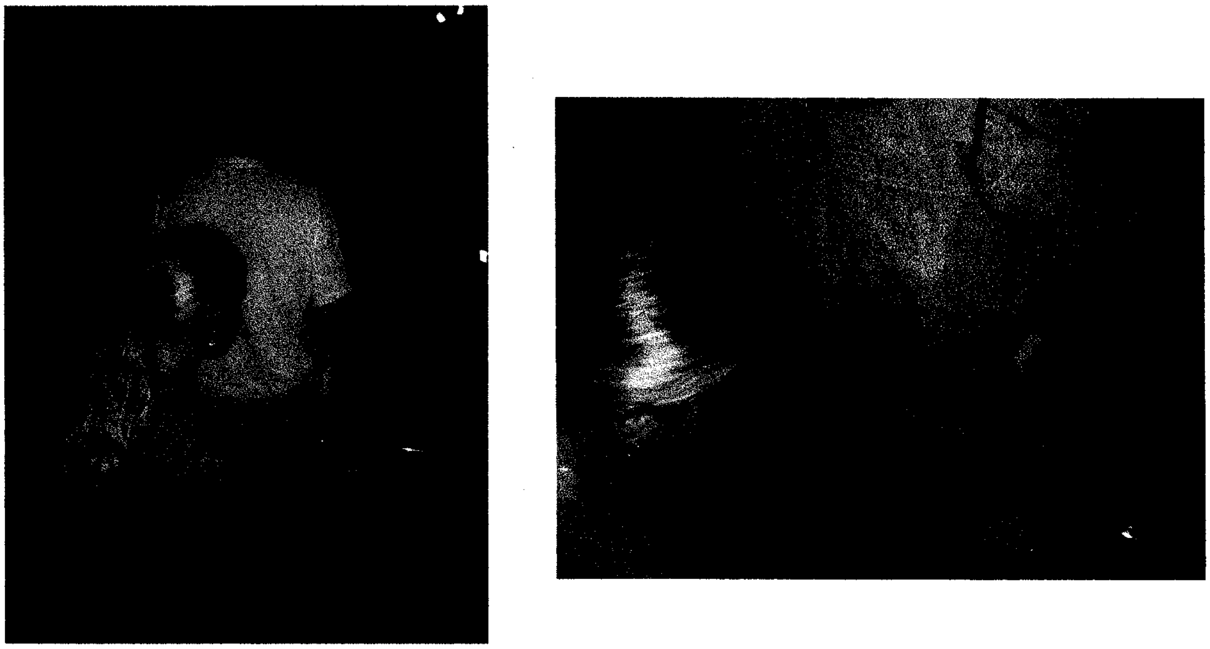


Figure 3.12: Shoulder breadth (compressed); Maximum horizontal breadth across shoulders, measured to the protrusions of the deltoid muscles accompanied with 6 lbs of pressure

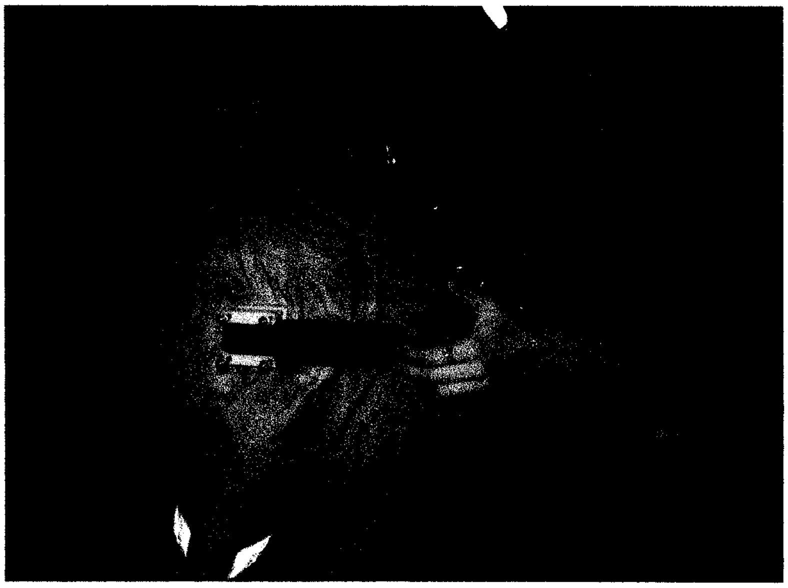


Figure 3.13: Hip breadth (compressed): Maximum horizontal distance across the hips accompanied with 6 lbs of pressure

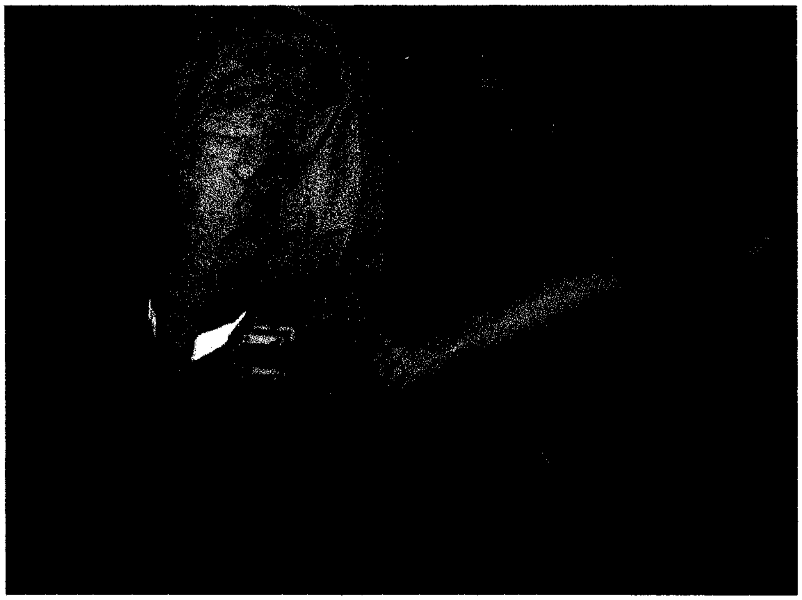
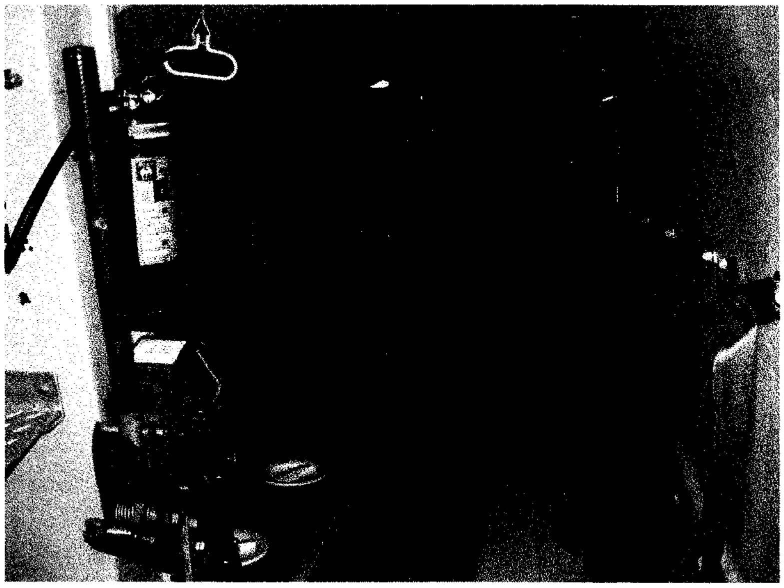


Figure 3.14: Seated hip breadth (compressed); Maximum horizontal distance across the hips in the sitting position accompanied with 6 lbs of pressure

These data were considered in further additional calculations and observations concerning the practical application of fitting humans into the normal allotted seat space in davit launch lifeboats (Figure 3.15). This was accomplished using a Monte Carlo approach, which compared the shoulder and hip breadth of a random sample of the subjects to the linear space allocation of 430 millimeters in the IMO Life Saving Appliance Code. The subject's were modeled as being seated side-by-side just touching each other. The cumulative length was the addition of the breadth measure of each person as one moved along the row.

Figure 3.15: Interior view of a davit launch lifeboat



3.3 Results

3.3.1 Structural Anthropometry

The results of the 84 seafarers tested at the Marine Institute are shown in Tables 3.1 and 3.2. Table 3.1 provides a description of age, physical dimensions and marine/offshore experience. Table 3.2 shows the differences in physical dimension for shoulder breadth and hip breadth (standing) and hip breadth seated in work clothes (control) and wearing a survival suit.

The mean age of the seafarers was 37.7 years, body mass of 88.4 kg and man height of 1751 mm. In nine cases the body mass could not be measured due to previous commitments of the subjects. In these cases, the subjects participated in a dunking trial prior to the measurement process and their wet weight was measured but not the dry weight.

The mean shoulder, hip breadth standing and hip breadth seated of the seafarers while wearing the work clothes were 514, 368 and 386 mm, respectively. Compression values were not taken when wearing the work clothes. When wearing the immersion suit these values increased to 553, 385 and 425 mm respectively. When compressed these values decreased to 484, 338 and 362 mm respectively. This represents a change of 69 mm for the shoulder, 47 mm for hip standing and 63 mm for the hip breadth seated dimensions.

Table 3.1: Descriptive Statistics for the Seafarers (n=84)

	Mean	**SD**	**Median**	**Min**	**Max**
Age (yr)	37.7	9.6	37.0	23.0	62.0
Experience (yr)	5.4	6.1	3.0	0.0	25.0
Mass (kg) (n=75)	88.4	17.4	86.4	57.8	143.2
Height (mm)	1751	81.5	1748	1534	1947
BMI (kg/m^2) (n=75)	28.6	4.5	27.8	19.9	41.8

Table 3.2: Descriptive statistics for the Seafarers' hip and shoulder dimensions for different conditions (n=84)

Dimension	**Condition**	**Work clothes**		**Suit B**	
		Mean	SD	Mean	SD
Shoulder breadth	Normal	514	46	553	49
	Compressed	*	*	484	40
Hip breadth standing	Normal	368	31	385	30
	Compressed	*	*	338	26
Hip breadth seated	Normal	386	31	425	35
	Compressed	*	*	362	30

*Measurement not taken

Tables 3.3, 3.4, and 3.5 show the results of using a Monte Carlo approach to apply the data to the fit of the humans in the normal allotted seat space. Table 3.3 demonstrates the average number of people that could fit into a 50 person lifeboat using the compressed shoulder and hip measurements. Table 3.4 gives the average number of people using hip measurements both with and without an immersion suit and table 3.5 gives the average number of people using shoulder measurements both with and without an immersion suit.

Table 3.3: Model for Seafarers compressed in suit

Hip #1	Hip #2	Hip #3	Hip #4	Hip #5	Hip #6	Hip #7	Hip #8	Hip #9	Hip #10	Shoulder #1	Shoulder #2	Shoulder #3	Shoulder #4	Shoulder #5	Shoulder #6	Shoulder #7	Shoulder #8	Shoulder #9	Shoulder #10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
55	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

■ Mean of 55 subjects ▩ # subjects that can fit into lifeboat

Table 3.4: Model for Seafarers' hip width

No Suit #1	Suit #1	No Suit #2	Suit #2	No Suit #3	Suit #3	No Suit #4	Suit #4	No Suit #5	Suit #5	No Suit #6	Suit #6	No Suit #7	Suit #7	No Suit #8	Suit #8	No Suit #9	Suit #9	No Suit	Suit #10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
55	51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	52

■ Mean of 55 subjects ▩ # subjects that can fit into lifeboat

Table 3.5: Model for Seafarers' shoulder width

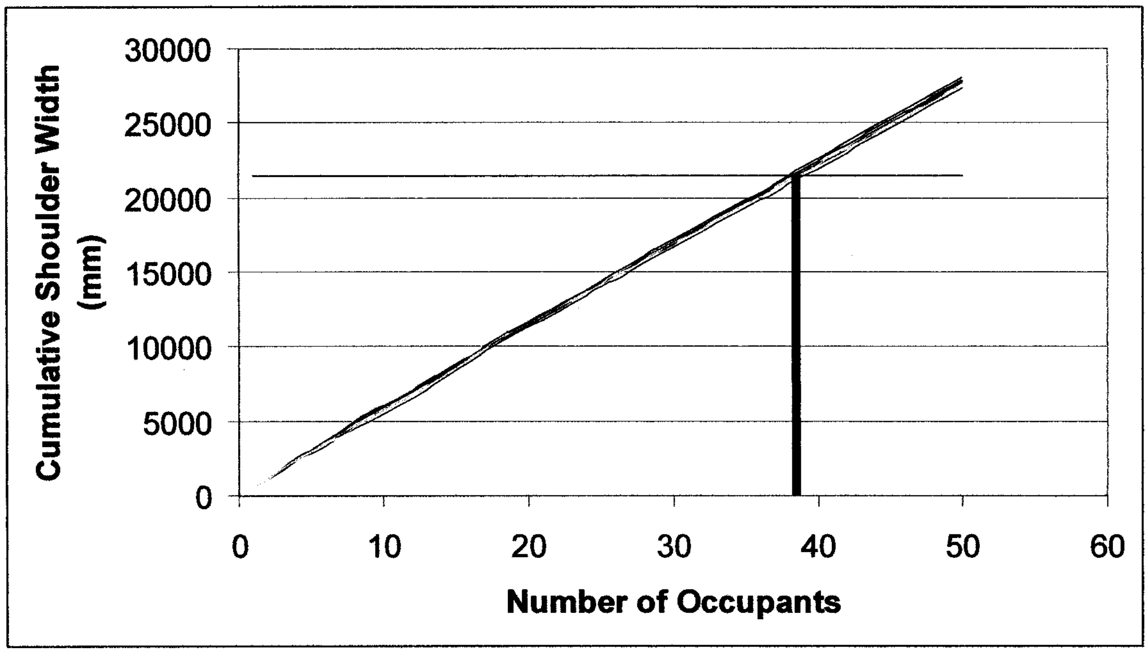
No Suit #1	Suit #1	No Suit #2	Suit #2	No Suit #3	Suit #3	No Suit #4	Suit #4	No Suit #5	Suit #5	No Suit #6	Suit #6	No Suit #7	Suit #7	No Suit #8	Suit #8	No Suit #9	Suit #9	No Suit	Suit #10
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
42	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

■ Mean of 55 subjects
▨ # subjects that can fit into lifeboat

After measuring various aspects inside the fifty person lifeboat it was found that the design of the lifeboat accommodated for a seat width was 440 mm. For fifty people to fit into the 50-person lifeboat that would make 22,000mm in linear space along the bench system. The seat width measured was in accordance with IMO standards as they specify a minimum seat accommodation of 433mm In this model the criterion value of 430 mm of linear space for each seafarer was used. Taking the example of the 50 person lifeboat, this would mean that when seated side by side the space requirement would be (50 x 430 = 21500mm). From the sample of 84 seafarers, 55 people were randomly extracted and their linear dimensions used to determine the linear space requirements. Ten different random samples were created from the complete anthropometric data set.

Table 3.4 proves that, whatever the linear requirement (IMO specifications or design specifications), you can get 50 persons or more in a 50 person lifeboat (based on hip width). The important thing to note here is that it is not hip width but shoulder width that should be considered when designing these lifeboats. When in a lifeboat, a person must be seated comfortably with the torso square to the bench. This allows the harnessing system to work properly, reducing the likelihood of injury to the occupant during impact. Table 3.5 provides very different results as it suggests that only 39 to 42 persons can fit into a 50 person lifeboat (based on shoulder width). If occupants are meant to be seated as stated above to reduce the chance of injury, then no more than 39 people should be placed in a 50 person lifeboat. This fact is supported graphically in Figure 3.16 with a plot of the cumulative length versus randomly selected subject anthropometrics as they entered the model. In the figure a horizontal line is drawn at the required space of 21500mm. It can be easily seen that this line is passed once 39 persons enter the lifeboat. It should also be noted that although the manufacturer designed its lifeboat to have a seat width greater than the regulated 433mm it is still unable to accommodate anything near the 50 people that it is intended for.

Figure 3.16: Fit of subjects in 50 person lifeboat



3.4 Discussion

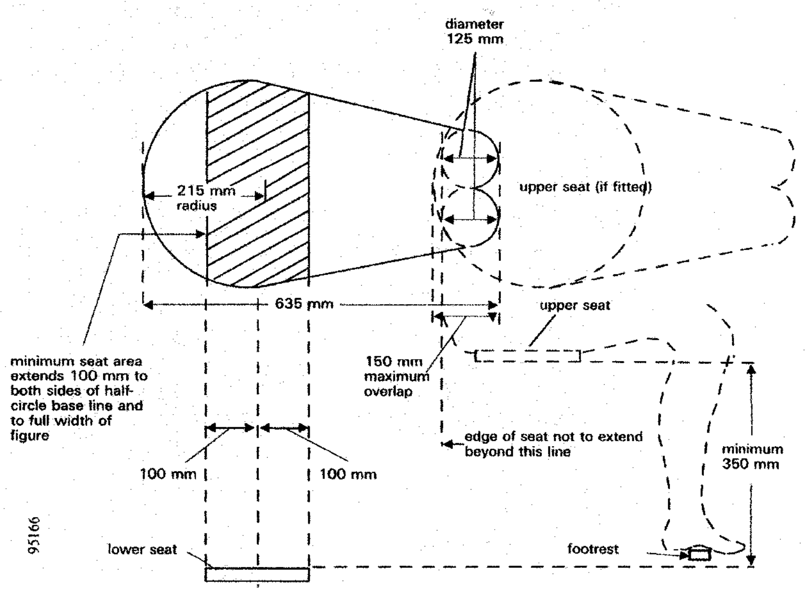
The current IMO standards (2003) lists a typical weight and seat width assignment for lifeboats and states:

"The number of persons which a lifeboat to be launched by falls shall be permitted to accommodate shall be equal to the lesser of:

4.4.2.2.1 The number of persons having an average mass of 75 kg, all wearing lifejackets, that can be seated in a normal position without interfering with the means of propulsion or the operation of any of the lifeboat's equipment."

4.4.2.2.2 The number of spaces that can be provided on the seating arrangements in accordance with Figure 3.17. The shapes may be overlapped as shown, provided footrests are fitted and there is sufficient room for legs and the vertical separation between the upper and lower seat is not less than 350 mm."

Figure 3.17: Seating arrangement in a davit launch lifeboat



First and foremost, the seafaring population that has been measured is considerably heavier than the IMO standard. Eighty-five percent of people had a body mass value greater than 75 kg. The average for this population was 88 kgs. The study that was performed at Survival Systems Ltd. in Nova Scotia found an average of 86kg, which is very similar to the current study. In two other studies, the mean self-reported measures on 357 offshore oil workers was 89 kg (Brooks et al., 2001) which is again comparable to this study. In another recent study one hundred subjects who were a mixture of marine operators, offshore oil workers and fishermen had a mean body mass value of 90 kg (Reilly et al., 2004). Although weight is not a good estimator for space allocation, it is an essential measurement for overall weight, stability and impact testing of lifeboats (Brooks et al., 2004). While these masses do not likely represent the masses of typical ferry, cruise ship passengers or even offshore workers from non-North American/Northern European countries, the marine evacuation systems available to the maritime industry are meant to service both the tourism and commercial industries and thus should be designed for the largest of the occupants. Furthermore, these data are reported mean values and, from a statistical perspective, implie that 50% of the subjects examined in these studies have masses larger than the means. Therefore, it is suggested that the IMO initiates an international review of basic human anthropometry (weight, height, hips and shoulders) with a view to increasing the current body mass value of 75 kg. It is recommended that the mass of an average test subject be increased to 90kg from the current value of 75kg (Canadian, 2005 – FP50/14).

Probably the most important finding is related to the importance of using shoulder breadth measurements to establish design criteria. In this study, 83 of the 84 seafarers while wearing work clothes had an uncompressed shoulder breadth measurement, greater than the 430 mm. All mean shoulder breadth measurements with an abandonment suit (with or without compression) exceeded the 430 mm. A comparison was made between shoulder breath and hip breadth (seated) measurements. In all cases in work clothing, the shoulder breadth was significantly greater than the hip breadth (seated) by an overall mean value of 128 mm. Therefore the IMO standard for maximum linear width of the seat should be increased to 555mm based on a standard derived from the upper torso anthropometrics rather than the hip dimensions.

Another important finding is that the existing space allocation of 430 mm prescribed in the IMO code is not suitable for most North American and Northern European offshore populations. This was demonstrated in the Monte Carlo model. During a launch into rough seas or during an awkward flight and landing by the lifeboat the occupants would be at risk for back injury. This observation has been made in the design of free-fall lifeboats (Nelson et al, 2004 - DE48/5) and is likely true for davit-launch lifeboats. Asymmetrical seating can also be very uncomfortable for a seated occupant which discomfort would be further exacerbated if sea conditions were rough and there was an extended elapsed time from abandonment to rescue during which time occupants must remain seated and employ the restraining harnesses.

These safety issues must force regulators, manufacturers and users to reconsider existing designs of MES. If there is an attempt to fit 50 persons into a 50 person lifeboat the risk of injury to the passengers will be high. Regulations must be changed to increase the allocated seat pan width in order to either push manufacturers to design lifeboats with wider seats or to at least lower the maximum number of persons permitted to fit in current lifeboats.

The effect of the increases in occupant size and the use of shoulder versus hip breadth are shown to reduce the current capacity rating of a lifeboat. Using the model and the shoulder breadths presented in this report and the criterion value of 430 mm per seafarer in work dress the current rating of a 50-person boat should be reduced by 14%. The presence of the abandonment suit increases the size of the seafarer and this would reduce the current capacity rating by closer to 22%. It is important to note here that even in work clothes (no suit) there is a space allocation problem.

The findings of this study could have major effects on the actual design of these lifeboats and on the manufacturers and operators of such boats. If, rather than reducing the current capacity rating, it was decided that the lifeboat would actually be redesigned to accommodate 50 people (as in this case) then manufacturers would have to spend vast amounts of money to do so. So, although it seems that changes must be made, the question arises whether those changes should be made to the capacity rating, or to the design itself.

CHAPTER 4
Measurement of Forces and Accelerations on Users of Marine Evacuation Systems

Abstract

The purpose of this study was to assess the requirements for measuring forces and accelerations acting on humans engaged in marine evacuation systems (MES) such as chutes and slides. The slide used was manufactured by RFD Ltd and is a 13.5m long single track SeaCAT MES that terminated into an open collection raft 5m in diameter. The chute was a 6m high Selantic SES-TC passenger vessel MES that also terminated into an open collection platform. Forces acting upon a person during an evacuation can be affected by MES design, environmental forces on the MES and subject experience and morphology.

Loads experienced on the feet and head of able-bodied, volunteer participants were measured as each individual progressed through the MES. Summary data reveal that loading from 2 to 3.5 times body mass were experienced by the subjects while engaged in the slide. External loading of 1.5 to 5 times body mass were experienced as subjects descended through the chute. While no subjects reported pain or injury due to these tasks, the upper limits of loading recorded might have the potential to injure a younger, older or less-fit person.

4.1 Introduction

Forces acting upon a person during an evacuation of a marine vessel can be affected by the marine evacuation system (MES) design, environmental forces on the MES and subject experience and morphology. While shipboard instruction is provided to passengers regarding procedures and strategies for evacuation system use, in the case of chutes and slides, it is unlikely that passengers will have an opportunity to practice critical evacuation tasks, especially under conditions of physical and mental stresses typical of abandonment situations. Thus it is necessary to consider the forces to which a passenger will be exposed under such evacuation conditions and assess how MES design may influence these magnitudes. In addition, situations where persons being evacuated cannot react to mediate these external forces (i.e. persons who are physically challenged or incapacitated) it becomes paramount that MES are designed to minimize the physical stresses placed on passengers.

The purpose of this study was to measure the forces exerted upon a person descending through two different MES. This would allow implications to be made for injury when performing such a task, for someone to become stuck within the MES and for evacuation time using such MES.

4.2 Methods

Thirty-seven subjects volunteered to participate in the study. The experimental protocol was approved by Memorial University's Human Investigations Committee. All subjects provided written consent before participating in this study. Subject demographic information is contained in Table 4.1.

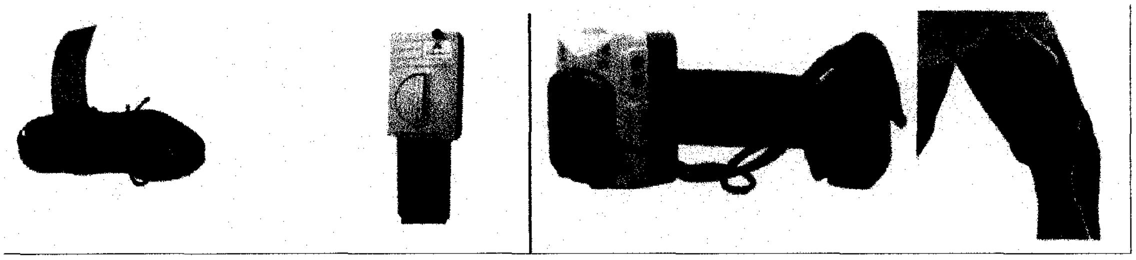
Table 4.1. Subject Demographics

	Mean +/- SD
Age	33.0 +/- 12.3 years
Mass	62.0kg +/- 14.4kg
Stature	162.4cm +/- 8.7cm
Sex	17 females/ 20 males

4.2.1 *Protocol*

Subjects arrived at the Offshore Safety and Survival Centre, Memorial University of Newfoundland and were briefed on general procedures and asked to choose proper fitting coveralls. A subject was then escorted to the pool deck where the foot pressure system (F-Scan System, Tekscan, Boston MA) was fitted to the subject's feet and then calibrated to the subject's mass (see Figure 4.1).

Figure 4.1: F-Scan Foot Pressure Measurement System



A customized helmet, housing a triaxial accelerometer (Silicon Designs, Issaquah, Washington) was placed on the subject's head and securely fastened with a chin strap (see Figure 4.2). A SOLAS approved "keyhole" lifejacket was donned by the subject and was then properly fitted and secured by a researcher (see Figure 4.3).

Figure 4.2: Helmet with triaxial accelerometer (location of accelerometer is indicated)

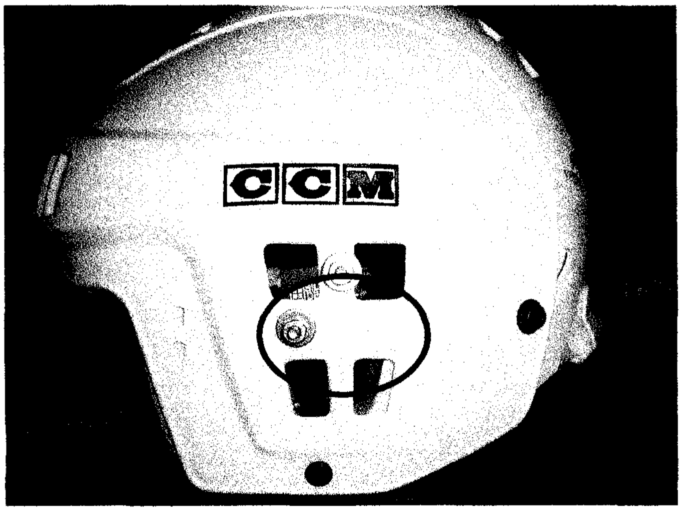


Figure 4.3: Researcher securing lifejacket

Installed at a height of 6m above the water surface, the evacuation slide is a single track SeaCAT model manufactured by RFD Ltd. and has a total length of 13.5m. The slide is manufactured from Posterior Urethral Valves (PUV) and fabric and makes an angle of approximately 26° with the horizontal (recommended angle is in the range of 25°-30°). The slide is installed on a rigid support structure with a boarding area of approximately 6m^2. The slide terminates onto an open 25 person capacity collection platform. The diameter of this platform is approximately 5m.

The subject was escorted by a researcher to the disembarkation point for each system (refer to Figures 4.4 and 4.5). The subject was then briefed using a standardized procedure script for descending the marine evacuation system. For safety purposes, the subject was allowed to ask the researcher questions about the task at hand. A researcher descended ahead of the subject for the first trial of each system to demonstrate a standard technique

Figure 4.4: RFD slide MES

Figure 4.5: Selantic chute MES

Table 4.2: Marine Evacuation Systems - physical dimensions and description

Marine Evacuation System	**Dimensions**
RFD Slide (Belfast, Ireland) 13	13..5m long single track SeaCAT marine slide. The width of slide is 0.66m in between the inflated chambers
Selantic Chute (Norway)	Suspended from a 6m platform (only 6 of the 12 cells in use)

4.2.2 Data Collection

Video cameras were strategically placed throughout the facility to ensure a continuous visual record of the evacuation events. Once turned on, these cameras were synchronized in time. Data collection from the foot pressure system was started by an external trigger. The accelerometer data were synchronized to the foot pressure signal by a simultaneous head tapping and foot stomping action by the subject. These actions were distinct enough to discriminate between trials. Video records could also be employed to distinguish better the first data point of the trial.

The subject was then positioned at the entrance of the system and was instructed to proceed quickly but in a "safe" manner through the evacuation device. Once at the bottom of the device, trained personnel assisted the subject to the edge of the collection platform and the foot pressure collection system was stopped. The head acceleration system collected continuously throughout all the subject's trials. The subject performed three repeated trials for each system. Once all 6 trials were complete (3 slides and 3 chutes), the accelerometer data logger was stopped and both the foot pressure and accelerometer data were downloaded to a computer for further analysis.

4.2.3 Data Reduction

4.2.3.1 Trial Durations

Video from two different camera angles were analyzed for each of the systems. For the slide, these angles consisted of a view looking down over the top of the slide and a view above the collection platform. With regards to the chute there was a camera placed directly over the chute disembarkation point as well as a side view at the bottom of the chute. This video was analyzed to get frame numbers for the start of the three taps, the first movement of the subject on the system and the point when the feet touched the collection platform. This allowed for the duration of each trial to be calculated. Figure 4.6 illustrates the locations of the cameras and also the four action zones and the three translation zones for the slide. Figure 4.7 provides the locations of the cameras as well as the three action zones and the three translation zones for the chute.

Figure 4.6: Zone definitions and camera locations for the slide

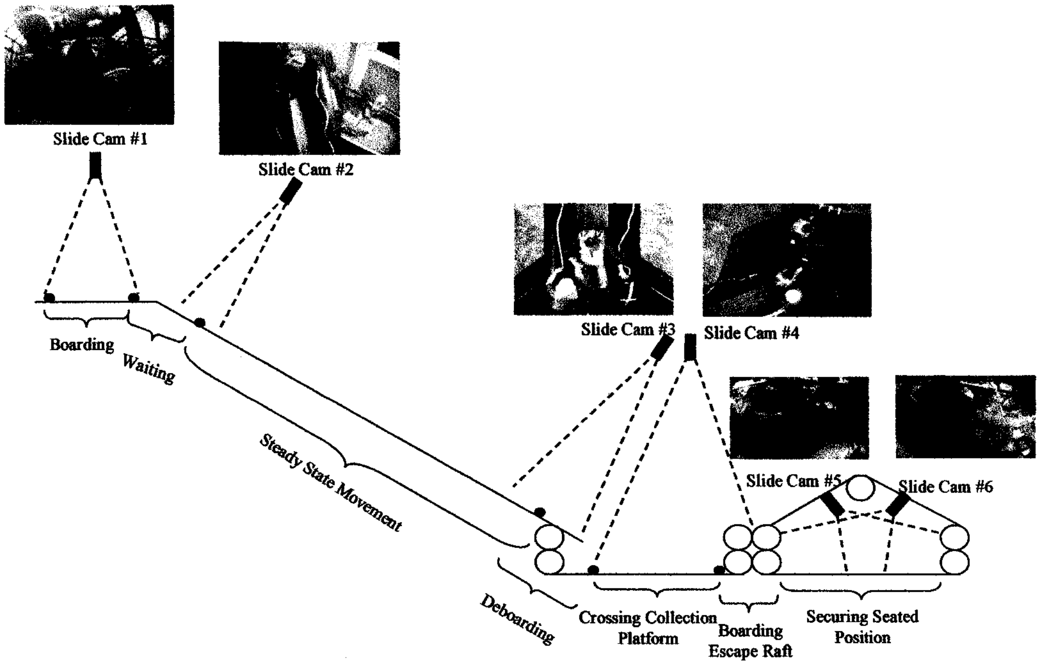
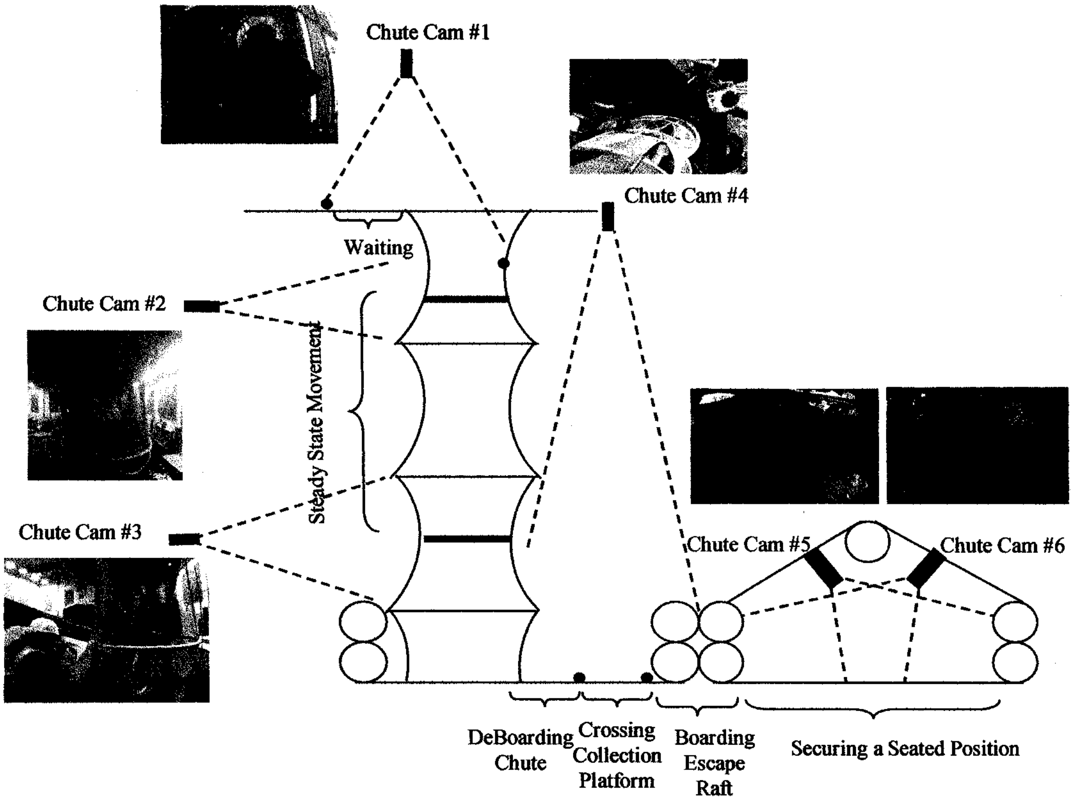


Figure 4.7: Zone definitions and camera locations for the chute



4.2.3.2 Foot Pressures

The foot pressure data were recorded throughout the duration of each trial and was sampled at 20Hz. For each trial the maximum forces were determined for both the left and right foot. The sum of the maximum values for both the left and right foot was found for each trial for data reporting purposes.

4.2.3.3 Head Accelerations

All accelerometer data were recorded at 20 Hz. Because of the constant changing of the head positions (i.e. sometimes a subject would sit up, other subjects would lie down on the slide), a resultant scalar quantity of the X, Y and Z accelerations were considered in the final data reduction.

4.3 Results and Discussion

Results included in this chapter are collapsed across all subjects. In all cases, where applicable, the mean, maximum and minimum values (with standard deviations) are reported. Due to instrumentation and methodological limitations only 1 person could be tested at a time.

Table 4.3: Summary of time (seconds) required to move through evacuation appliance

	Slide		Chute	
	Mean Time (s)	Max Time (s)	Mean Time (s)	Max Time (s)
Mean	6.39	7.99	12.10	15.80
Sd	1.83	3.03	5.34	7.48
Max	11.11	17.27	25.12	37.31
Min	4.16	4.55	5.16	5.86

Age matched mean data for slide task time compare well to previously reported simulation exercises that included 278 participants (Brown, 2005). In this study, the slowest participant took over twice as long as the average person to negotiate the device.

Chute data are not as comparable to existing research (Brown, 2005). In the current study, times were approximately 50% shorter. In the evacuation scenario reported in Brown (2005), several persons were engaged in the chute device at the same time. In this simulation protocol, the "slowest" person will influence the overall group time at progressing through the evacuation system.

Tables 4.4 and 4.5 represent novel data with respect to marine evacuation research. Included in these tables are maximum forces and accelerations experienced by participants while engaged in the slide and chute devices. It should be noted that no subjects were injured or complained of injury or pain during the testing session. So it can be assumed that the values reported are within levels that can be tolerated by a healthy, adult participant.

Table 4.4 reflects the maximum kinetic profiles acting on participants descending the RFD slide. The loads on the feet are expressed as absolute magnitudes (kilograms and Newtons) as well as relative to body mass. On average, subjects experienced foot loads almost 3 times body mass. Maximum values were up to 3.5 times body mass, noting that the standard deviation is quite large. These values may seem high but are equivalent to someone jogging/running in shoes on a solid substrate, such as pavement (Hreljac, 2004). Accelerations at the head were similar in magnitudes – approximately 2.3-4 G's. The explanatory factor is the fact that both the slide and the collection platform are made of compliant shock absorbing characteristics. It would be expected that these values would be greater if the collection platform was positioned on a solid surface or was moving due to ocean or climatic conditions.

Table 4.4: Summary of forces (kg/Newtons) and accelerations (G) acting on feet and head of subjects descending the RFD Slide

	Sum of Foot Load (kg/N)	**Sum of Foot Load (% Body Mass)**	**Head Accelerations (G's)**
Mean	229.52/2252	299.32	2.31
Sd	62.66/615	81.71	0.37
Max	336.10/3297	358.70	3.03
Min	114.00/1118	200.00	1.77

Table 4.5 includes the kinetic profiles upon persons descending the Selantic Chute. The forces acting on these participants were somewhat greater than those experienced by the same individuals descending the slide. On average, the relative loading on the feet were similar to the slide (i.e. approximately 3 times body mass).

However maximum foot loading of approximately 5 times body mass were recorded. Similarly, the head accelerations were observed to increase to 5G's. While obviously within tolerable limits for the volunteer subjects, these values are now approaching stresses that may not be tolerable by older individuals.

Table 4.5: Summary of forces (kg/Newtons) and accelerations (G) acting on feet and head of subjects descending the Selantic Chute

	Sum of Foot Load (kg/N)	**Sum of Foot Load (% Body Mass)**	**Head Accelerations (G's)**
Mean	222.54/2183	290.21	3.62
Sd	95.41/936	124.42	0.53
Max	464.70/4559	495.94	5.00
Min	122.10/1198	111.61	2.37

It was initially assumed that shorter times within the evacuation device would be associated with higher impact forces for both load on the feet and accelerations felt at the head. However, this association was not significant and likely reflects the varying strategies participants employ to slow down the speed of progression near the debarkation point of the device. Similarly, it was expected that body mass would be directly related to load experienced at the feet. Again, regression statistical analysis found no association between these two parameters. Table 4.6 includes the r values for the paired regression analyses performed on the data.

Table 4.6: r values for the paired regression analyses performed on the data

	r
Time versus foot pressure for slide	0.320
Time versus foot pressure for chute	0.076
Time versus head acceleration for slide	0.035
Time versus head acceleration for chute	0.230
Mass versus foot pressure for slide	0.230
Mass versus foot pressures for chute	0.076
Mass versus head acceleration for slide	0.326
Mass versus head acceleration for chute	0.141

In describing regulations about the construction of marine evacuation systems the current IMO Life-Saving appliances code states that:

> 6.2.1.1 "The passage of the marine evacuation system shall provide for safe descent of persons of various ages, sizes and physical capabilities, wearing approved lifejackets. From the embarkation station to the floating platform or survival craft."

When descending the slide and the chute there were forces acting on the body that were approaching potentially harmful levels. Many of these forces may not affect a healthy young adult but could very well have adverse effects on elderly adults or persons in poor condition.

It is likely that maximal forces exerted on the body increase when the person is unable to control both the rate of movement through an evacuation appliance as well as body posture. This lack of control is likely to due to a combination of several factors including the experience of the person descending the appliance, the design of the evacuation device, including the materials of fabrication and the instructions provided by trained personnel during the evacuation procedures. It is believed that the forces experienced by persons descending marine evacuations systems can be reduced if these people are well trained prior to an evacuation. Therefore, it is recommended that all people who have the potential to use such systems are educated on the proper technique to use when descending a MES. It is suggested that those working offshore go through a regular training session whereby they actually get the opportunity to descend a MES, similar to the one that would be available to them in a real life situation, and then be critiqued on their technique. By doing this the potential for injury, or worse could be minimized while the safety of everyone descending the evacuation appliance could be maximized. Simply put, if ergonomic principles are applied during the design and training stages, risk to the user will be reduced.

Other factors not tested in this experimental design would also influence the magnitude of the kinetic profiles experienced by persons within the appliances. These include congestion within the appliance, slide and chute deployment lengths, orientation relative to the collection platform and environmental conditions at the time of evacuation (i.e. ambient lighting, wind, water/wave conditions). Considering that the chute was only 6m high and the slide only 13.5m long, one concern that must be taken into account is the potential forces acting on the body during descent from much higher platforms. Platforms can be up to and above 3 times greater than those used in the current study. Also, it can be assumed that many evacuations occur in very poor weather conditions and things such as waves and wind could cause further unwanted movement of the MES and therefore increased forces acting on the body. These reasons alone demonstrate the potential for the existence of much greater forces on the body. As mentioned before, it is recommended that more empirical data be collected using various marine evacuation systems. If the expected high forces exist in these different systems then regulatory changes with respect to design should be considered to ensure the safe descent for all persons.

4.4 Conclusions

It is believed that the methodology described in this chapter provides a valid and reliable means of assessing forces and accelerations acting on persons deployed through marine evacuation systems. It is believed that kinetic measures of the feet and head provide sufficient information to understand the demands of a person being moved through chutes and slides.

In the current study, the magnitudes of the kinetic measures that were taken were not necessarily considered significantly large. With this being said, the magnitudes found were still approaching potentially harmful levels.

The empirical data provided in this study are meant to reflect a first attempt at understanding the issue at hand. It is clear that limited valid research has been conducted in the past and more research, similar in approach to this study, must be done to establish benchmark guidelines for future product evaluations.

It is recommended that more benchmark empirical data be collected employing this methodology. A variety of marine evacuation systems should be assessed, particularly in more realistic marine environments. However, future researchers should be cautioned about the risks to volunteer subjects. Risk assessments should be considered prior to all data collection and only trained safety and survival experts should be employed to assist in the data collection process.

CHAPTER 5

Measurement of Egress Time for Injured or Physically Challenged Users of Marine Evacuation Systems

Abstract

A study was conducted at the Offshore Safety & Survival Centre of Memorial University's Fisheries and Marine Institute to determine the time associated with evacuating stretcher cases using marine evacuation slides and chutes. The slide used was manufactured by RFD Ltd and is a 13.5m long single track SeaCAT MES that terminated into an open collection raft 5m in diameter. The chute was a 6m high Selantic SES-TC passenger vessel MES that also terminated into an open collection platform. Mannequins weighted to simulate a 12 year old 50% British male, a 50% British female and an 87% British male. These three weighted mannequins were strapped into three types of stretchers (Ferno Basket, Stokes Litter and Sked Stretcher) to give a total of 9 different test conditions.

Data were collected through eight strategically placed synchronized video cameras allowing for repeatable, consistent analysis of times associated with each phase of the simulated evacuations. In addition, accelerations of the mannequin's head were collected in three directions in an attempt to give an indication of the accelerations experienced by the casualty throughout the evacuation.

Data from the study suggest that it takes on average 89.3s and a maximum of 129.8s for a loaded stretcher to descend through a slide and be placed into its final position in the raft. The Ferno Basket appears to have been the most efficient as it was on average 1.3s faster than the Sked trials and 5.3s faster that the Stokes Litter trials.

An attempt was made at fitting a Ferno Basket and Stokes Litter into the chute device, however, it was not possible to safely get either stretcher into the first cell of the device and the attempts were abandoned. It was possible to move a loaded Sked through the chute due to its flexible nature. However, doing so took more than 30min and required two personnel to travel with the casualty at all times.

Throughout the trials, mannequins experienced head accelerations of approximately 2 Gs. There was a general trend that heavier stretchers seemed to better secure/restrain the mannequin and resulted in smaller accelerations during the descent.

5.1 Introduction

Computerized simulation tools are being employed at the design stage to assess the efficacy of evacuation for passenger vessels. Evacuation models require accurate human performance data to validate existing evacuation simulation models. To date, human performance research has involved the use of representative able-bodied persons using marine evacuation systems (MES), however, it is more realistic to assume that a portion of the population of persons requiring evacuation could be injured or physically challenged, thus requiring the assistance of crew members and possibly specialized evacuation equipment.

Evacuation procedures for ocean-going vessels must be reviewed regularly and it has been suggested that current emergency evacuation procedures may no longer be appropriate, particularly for large cruise ships (Anon, 2000). Even on offshore installations with highly developed procedures for evacuation, escape and rescue there is little if any published guidance on how to handle casualties, particularly stretcher cases, during evacuation (Coleshaw et al., 1998). In most evacuation training scenarios, the focus is on evacuating fit, semi-experienced personnel and assumes limited probability for multiple stretcher cases. Passenger vessels pose inherent risks because they carry relatively untrained passengers that may not be able to assist themselves during vessel evacuations. There may be numerous elderly, infants and physically challenged individuals on such vessels and all would likely require special assistance.

Safety of Life at Sea (SOLAS) regulations state that passenger ships are required to have survival craft capable of being launched with their full complement of persons and equipment within a period of 30 minutes (IMO, 2004). Whether this performance standard considers special assistance cases, along with uninjured passengers, must be considered.

The purpose of this study was to determine the time required to evacuate simulated incapacitated persons secured in various stretcher types from a fixed platform embarkation point using common MES such as slides and chutes to an inflatable liferaft.

5.2 Methods

5.2.1 Equipment and Facility

Data collection took place at the Offshore Safety and Survival Center (OSSC) of the Fisheries and Marine Institute, Memorial University of Newfoundland. In an attempt to make the research trials as realistic as possible, the two MES chosen were an evacuation slide (Figure 5.1) and an evacuation chute (Figure 5.2) specifically designed for use on passenger vessels.

Each MES terminated into an open collection platform to which was secured a 42 person liferaft (Figure 5.3). This was a raft decommissioned from the Marine Atlantic Inc. super ferry fleet that operates year-round in the Cabot Strait between Newfoundland and Cape Breton.

Installed at a height of 6m above the water surface, the evacuation slide is a single track SeaCAT model manufactured by RFD Ltd. and has a total length of 13.5m. The slide is manufactured from Posterior Urethral Valves (PUV) and fabric and makes an angle of approximately 26° with the horizontal (recommended angle is in the range of 25°-30°). The slide is installed on a rigid support structure with a boarding area of

Figure 5.1: Evacuation slide with collection raft used during ASES testing

Figure5.2: Evacuation chute with collection raft used during ASES testing

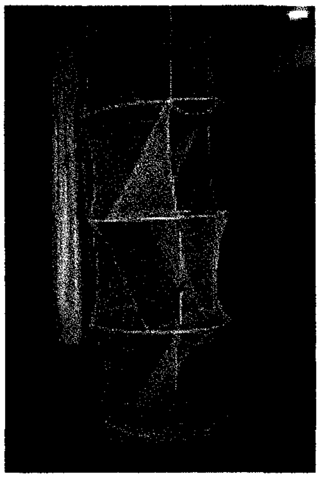


Figure 5.3: Escape raft (42 person) used during ASES trials

approximately $6m^2$. The slide terminates onto an open 25 person capacity collection platform. The diameter of this platform is approximately 5m.

Viking Lifesaving Equipment Ltd. provided the chute (Figure 5.2) on loan for research activity – model Selantic SES-TC. This passenger vessel chute is oval in shape which makes it suitable for use with lifejackets. In addition, the exit at the collection platform requires little effort in comparison to offshore type designs. The chute terminates into an open 12 person capacity liferaft approximately 3.5m in diameter.

Three different stretchers were used during these tests, since no particular model or design is considered standard. A rope system with two lines was used – a belay to control the stretcher from the top of the slide and a tag line accessed by personnel at the collection point to guide the stretcher during the descent. The belay line was managed by one person trained in rope rescue procedures. Details of the stretchers are given in Table 5.1 along with unloaded masses, including ropes and carabiners.

Three identical articulated rescue mannequins, (Dacon Inc., Stabekk) were used in the study as non-ambulatory passengers requiring assistance during evacuation (Figure 5.4). Mannequin masses (Table 5.2) were chosen to give light, medium and heavy weights, representing a 50th percentile 12 year old British boy, a 50% British female and an 87% British male respectively (Pheasant, 2003).

Figure 5.4: Articulated mannequin

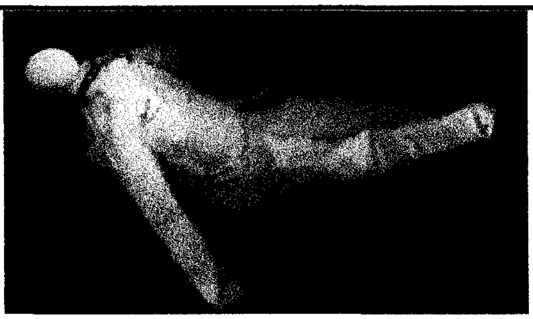


Table 5.1: Stretcher Descriptions

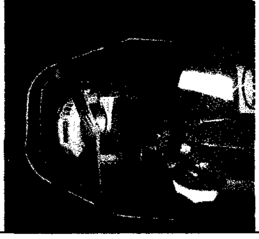
Stretcher Name	Photograph	Unloaded Mass (kg)	Construction Material
Ferno Basket		11.0	Fibreglass construction
Sked Stretcher		5.9	Flexible plastic construction
Strokes Litter		20.0	Stainless Steel Construction with Moulded plastic basket

Table 5.2: Mannequin descriptions

Weight Category	Demographic	Actual Mass (kg)
Light Weight	50th Percentile, 12 year old British male	39.7
Medium Weight	50th Percentile British Female	62.7
Heavy Weight	87th Percentile British Male	86.2

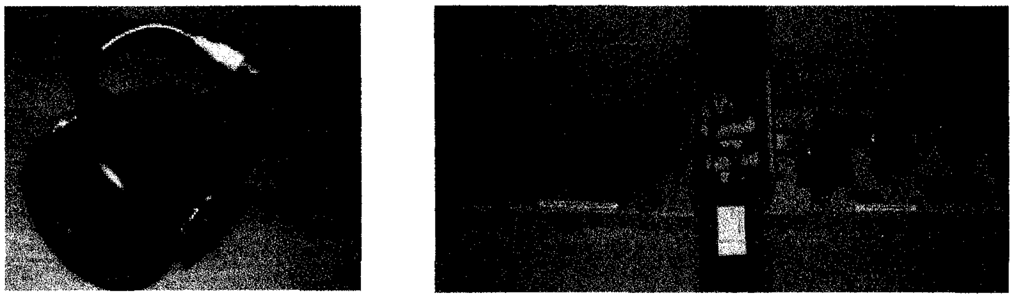
5.2.2 Preparations and Testing

5.2.2.1 Data Acquisition

Video was recorded from four different camera angles for each trial in order to determine the egress times during various phases of the simulated evacuation. Specific zones were defined for each LSA where egress time depended on either a translational movement or a single action-type movement.

In all, four weatherproof Opticom CB-01 closed circuit black and white television (CCTV) cameras (Figure 5.5a) were installed in the test facility and wired to a central monitoring and control location. Four cameras were monitored and recorded to digital video tape (Figure 5.5b). Four Canon ZR60 digital camcorders were used to record the data in digital format. All remotely wired CCTV cameras were powered by a single 12V regulated power supply, while the camcorders were powered by a separate source to allow for synchronization of the video record as the recorders were collecting.

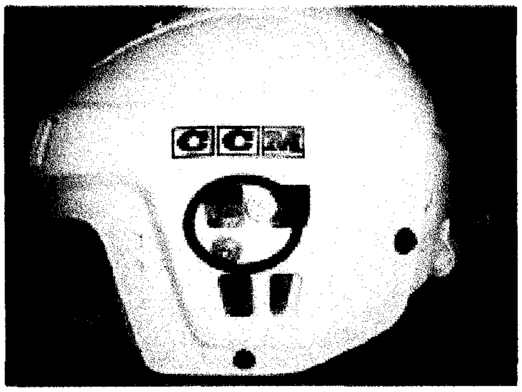
Figure 5.5: (a) CCTV camera and (b)Data collection and monitoring station



(a) (b)

In addition, a customized helmet (Figure 5.6), housing a triaxial accelerometer (Silicon Designs, Issaquah, Washington) was placed on the mannequin's head and securely fastened with a chin strap.

Figure 5.6: Helmet with triaxial accelerometer (location of accelerometer is indicated)



5.2.2.2 Test Matrix

With only two independent variables (mannequin mass and stretcher type) having three conditions each, a test matrix was devised to test all combinations of the conditions for both the slide and chute. The resulting 3x3 test matrix is shown randomized in order of testing in Table 5.3 for both MES. Each test condition was repeated three times consecutively with sufficient time between trials to reduce the effects of fatigue upon the rope handlers and stretcher handling crew on the collection platform. Tests for the chute with the Stokes Litter were removed from the test matrix due to the fears that the stretcher would very likely damage the mesh of the chute and would not likely be employed in real-life situations.

5.2.3 Test Procedures

Each stretcher was handled by one group of trained personnel at the top of the MES and one group of trained personnel at the bottom in the collection platform. During each test, the loaded stretcher unit was positioned at the top of the MES. Before any movement of the stretcher occurred, the helmet on the head of the mannequin was tapped three times on the left side. This synchronized the acceleration data with the video data. Once movement began, the belay line was eased to start the stretcher moving through the device. The pace and direction of the stretcher was controlled by both the belay line and a person in the collection raft with access to a tag line. On arrival to the collection platform, four OSSC personnel transferred the stretcher unit across the collection platform and into the middle of a 42 person liferaft.

Table 5.3: Test matrix

Test No.	**MES**	**Mannequin Mass (kg)**	**Stretcher Device**
1	Chute	39.7	Ferno Basket
2	Chute	39.7	Sked
3	Chute	62.7	Ferno Basket
4	Chute	62.7	Sked
5	Chute	86.2	Ferno Basket
6	Chute	86.2	Sked
7	Slide	39.7	Ferno Basket
8	Slide	39.7	Stokes Litter
9	Slide	39.7	Sked
10	Slide	62.7	Ferno Basket
11	Slide	62.7	Stokes Litter
12	Slide	62.7	Sked
13	Slide	86.2	Ferno Basket
14	Slide	86.2	Stokes Litter
15	Slide	86.2	Sked

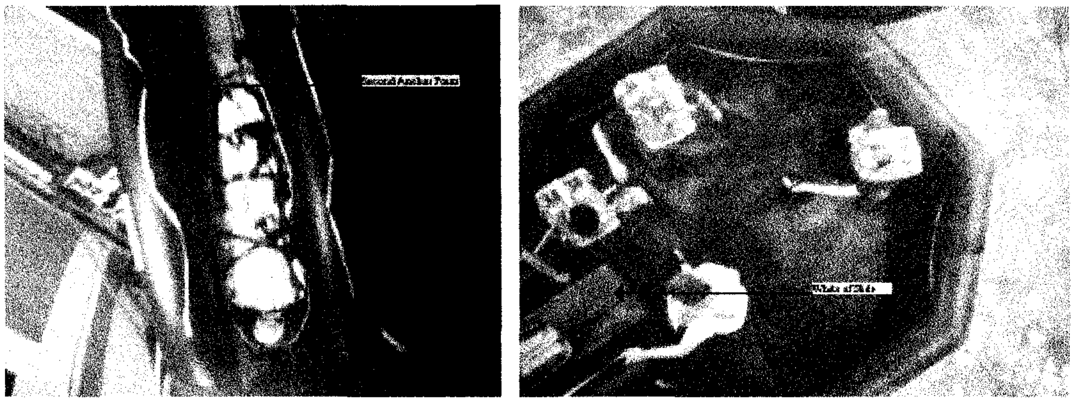
5.2.4 Data Reduction

Data were collected from the video record by observing points on the test apparatus in reference to the stretcher as it was being transported through the slide. The reference points and associated zones are outlined for the slide Table 4. A total of 8 zones were defined for the slide in an attempt to provide as much detail in the analysis as practical and possible. Figure 5.7 indicates the reference points for both the top and the bottom of the slide.

Table 5.4: Slide Zones and Data Collection Reference Points

Zone	**Reference for Start of Zone**
1	First tap on the mannequin's head
2	When the stretcher moves
3	Foot of the stretcher passes the second anchor point on the slide's left side grabline (Figure 8)
4	Foot of the stretcher reaches the end of the slide and none of the white sliding material can be seen (Figure 9)
5	Foot of first carrier first leaves the collection platform to enter the liferaft
6	Second carrier is in the liferaft and the stretcher starts to move again
7	Foot of third carrier first leaves the collection platform to enter the liferaft
8	Fourth carrier is in the liferaft and the stretcher starts to move again

Figure 5.7: (a) Top of slide zone reference point and (b) Bottom of slide zone reference point



(a) (b)

Figure 5.8 illustrates the locations of the cameras and also the four action zones and the three translation zones for the slide. Figure 5.9 provides the locations of the cameras as well as the three action zones and the three translation zones for the chute.

Figure 5.8: Zone definitions and camera locations for the slide

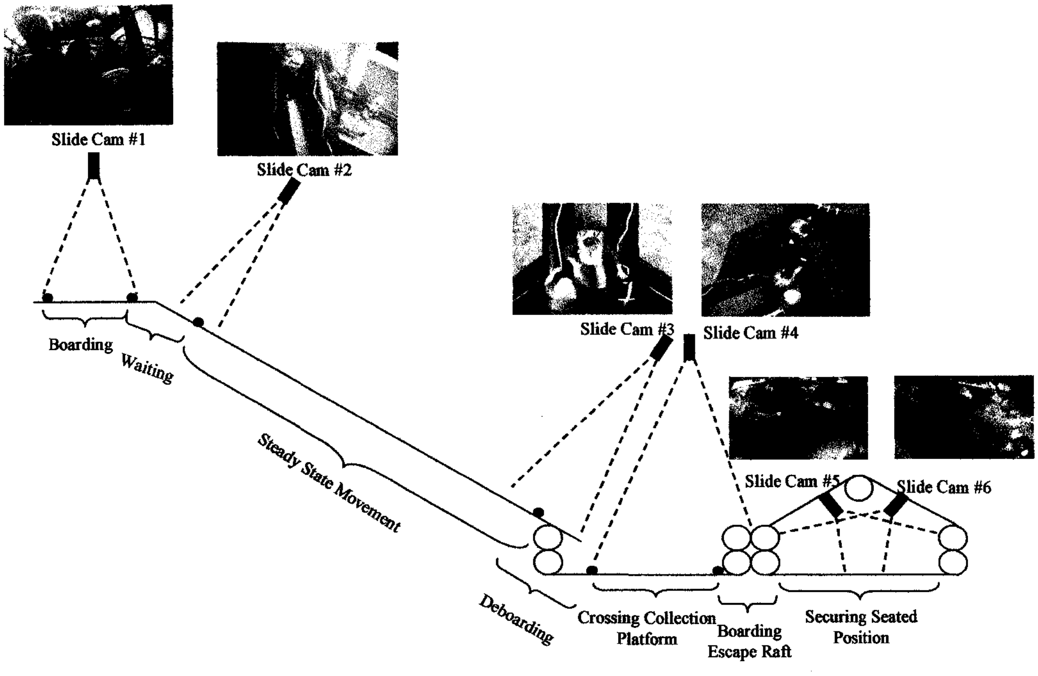
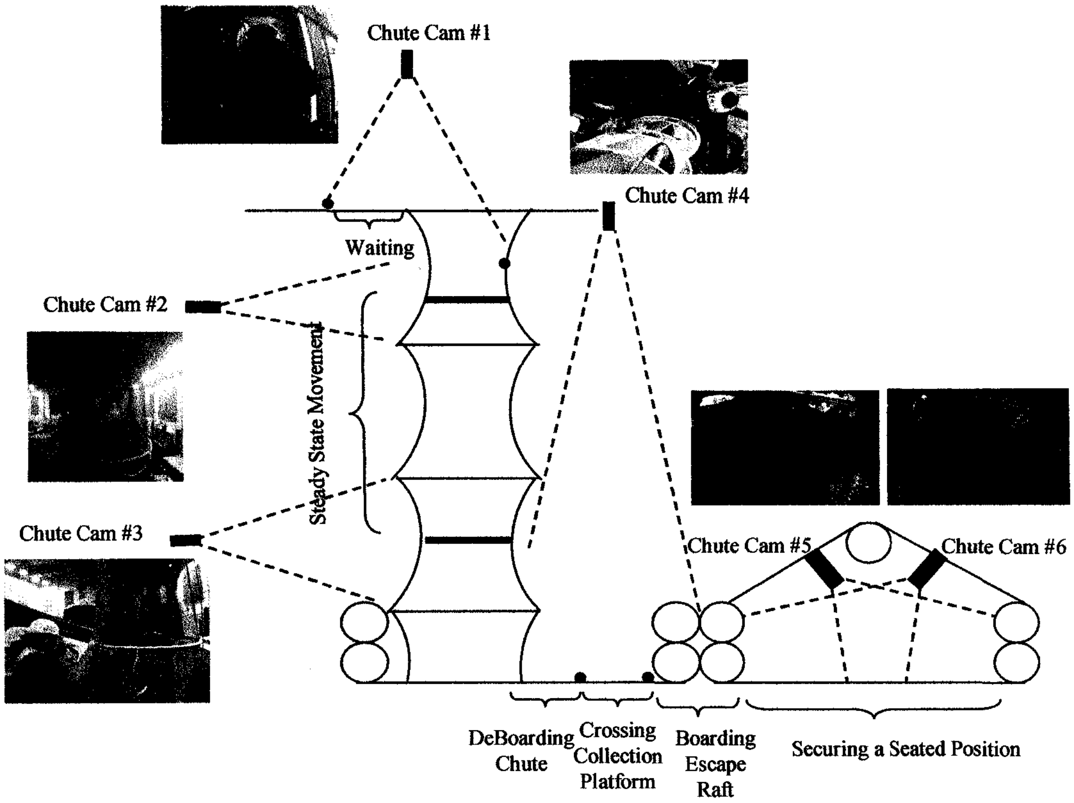


Figure 5.9: Zone definitions and camera locations for the chute



The following considerations apply to the data analysis and the defined zones:

1. The end point for each zone always occurs at the start of the next zone.
2. The end of the test occurred when the stretcher was resting in the centre of the liferaft.
3. Times for movement of the stretcher through each zone in each test were captured as frames from a common reference point. Using frame count meant the time data is accurate to 1/30 of second.

To further reduce the potential for error and inconsistencies in analysis, all data were reduced by the same person.

5.3 Results

5.3.1 Slide Data

Results from the slide video analysis are summarized in Tables 5.5 and 5.6. Table 5.5 shows the video analysis results for the time spent in each zone for each condition. Table 5.6 gives the time it took to get the each of the empty stretchers back to the disembarkation platform.

Table 5.5: Results from analysis of video for stretcher egress trials on a slide

Trial	**Time by Zone(s)**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Ferno Basket, Light Weight, Test 1	55.8	6.3	26.3	12.0	13.7	12.4	14.4	7.0
Ferno Basket, Light Weight, Test 2	10.1	12.6	13.8	10.8	20.3	4.0	14.4	5.4
Ferno Basket, Light Weight, Test 3	20.1	5.3	15.9	8.1	11.0	8.8	27.2	6.4
Stokes Litter, Medium Weight, Test 1	6.0	6.4	13.4	7.5	26.7	13.3	21.1	15.6
Stokes Litter, Medium Weight, Test 2	5.5	4.5	15.6	6.3	11.2	14.3	34.1	11.5
Stokes Litter, Medium Weight, Test 3	4.7	3.9	15.0	7.5	9.5	10.0	25.0	6.9
Ferno Basket, Medium Weight, Test 1	6.0	2.6	11.1	11.3	19.1	10.6	14.2	12.1
Ferno Basket, Medium Weight, Test 2	6.3	2.1	9.2	6.6	15.7	9.1	14.6	7.6
Ferno Basket, Medium Weight, Test 3	6.7	2.6	8.0	6.1	12.0	6.9	21.5	9.0
Sked Stretcher, Heavy Weight, Test 1	3.7	4.1	13.1	13.8	21.0	17.0	27.8	6.6
Sked Stretcher, Heavy Weight, Test 2	5.7	1.3	10.2	15.3	11.5	6.6	23.6	8.9
Sked Stretcher, Heavy Weight, Test 3	3.8	2.6	11.6	16.0	8.3	6.2	22.0	9.8
Stokes Litter, Heavy Weight, Test 1	3.3	1.8	10.5	10.9	26.4	6.4	21.9	13.6
Stokes Litter, Heavy Weight, Test 2	8.1	1.4	11.6	10.8	10.3	8.2	15.9	8.5
Stokes Litter, Heavy Weight, Test 3	5.1	1.9	10.4	22.0	12.5	13.7	17.4	11.1
Ferno Basket, Heavy Weight, Test 1	3.8	2.0	10.9	25.6	16.5	8.3	31.9	14.6
Ferno Basket, Heavy Weight, Test 2	3.1	1.6	9.7	27.8	9.9	8.5	15.7	8.9
Ferno Basket, Heavy Weight, Test 3	2.9	2.1	10.9	36.0	14.8	7.7	19.7	5.2
Sked Stretcher, Light Weight, Test 1	2.4	4.8	14.3	39.7	17.0	4.6	15.5	6.5
Sked Stretcher, Light Weight, Test 2	5.2	3.9	13.7	46.8	9.5	8.3	14.8	9.9
Sked Stretcher, Light Weight, Test 3	4.0	3.3	14.6	41.4	15.2	3.5	19.1	6.7
Stokes Litter, Light Weight, Test 1	3.9	2.6	35.9	11.2	9.6	8.2	15.3	8.2
Stokes Litter, Light Weight, Test 2	3.5	3.1	16.6	44.5	10.3	5.8	13.0	9.9
Stokes Litter, Light Weight, Test 3	3.2	1.9	44.4	5.4	8.5	5.1	13.4	8.5
Sked Stretcher, Medium Weight, Test 1	3.0	3.2	17.1	34.9	15.8	5.0	20.5	4.8
Sked Stretcher, Medium Weight, Test 2	2.6	4.2	14.1	34.6	12.7	7.5	14.6	8.2
Sked Stretcher, Medium Weight, Test 3	2.8	2.8	16.1	41.0	12.8	8.3	13.8	6.5

Table 5.6: Results for sending empty stretchers to the top of the slide

Trial	Time (s)
Stokes Litter, Test 1	28.3
Stokes Litter, Test 2	26.2
Stokes Litter, Test 3	32.0
Ferno Basket, Test 1	25.9
Ferno Basket, Test 2	19.1
Ferno Basket, Test 3	20.5
Sked Stretcher, Test 1	24.3
Sked Stretcher, Test 2	21.4
Sked Stretcher, Test 3	21.7

Considering a simple assessment of stretcher egress on slides, the task is defined by two intervals (Figure 5.10):

1. Movement of the stretcher from the time it was lifted for placement on the slide until it reached the bottom. These data are presented as Table 5.7.
2. Movement of the stretcher from the bottom of the slide across the collection platform to its final position in the liferaft. These data are presented as Table 8.

Dividing the data also allows for consideration of which portion of the evacuation results in greater accelerations for the casualty in the stretcher.

Figure 5.10: Belay and transfer of the loaded Stokes Litter

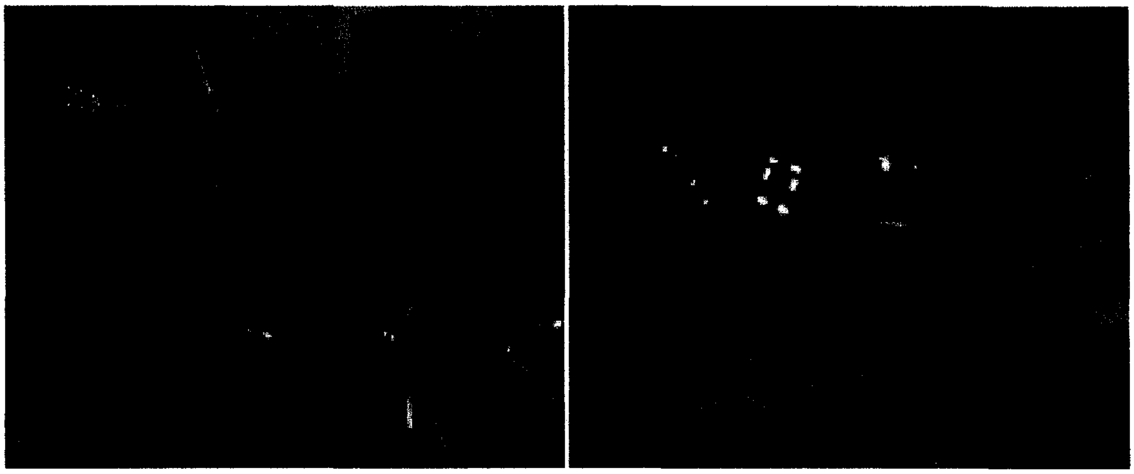


Table 5.7: Evacuation times for Interval 1

Trial		Sked			Ferno			Stokes	
#	45.6kg	68.6kg	92.1kg	50.7kg	73.7kg	97.2kg	59.7kg	82.7kg	106.2kg
1	19.0	20.2	17.2	32.5	13.7	12.9	38.5	19.8	12.3
2	17.6	28.2	11.5	26.4	11.2	11.3	19.7	20.1	13.0
3	17.9	18.9	14.2	21.2	10.7	13.0	46.3	18.8	12.3
Mean	18.2	22.4	14.3	26.7	11.9	12.4	34.8	19.6	12.5
Max	19.0	28.2	17.2	32.5	13.7	13.0	46.3	20.1	13.0
Min	17.6	18.9	11.5	21.2	10.7	11.3	19.7	18.8	12.3
Stdev	0.7	5.0	2.9	5.7	1.6	1.0	13.7	0.7	0.4

Table 5.8 Evacuation times for Interval 2

Trial		Sked			Ferno			Stokes	
#	45.6kg	68.6kg	92.1kg	50.7kg	73.7kg	97.2kg	59.7kg	82.7kg	106.2kg
1	83.3	81.8	86.1	46.6	67.3	96.8	52.4	84.3	79.2
2	89.4	67.6	65.8	54.8	53.7	70.7	83.5	77.4	53.7
3	85.8	82.4	62.3	61.5	55.3	73.3	40.8	59.0	76.6
Mean	86.2	77.3	71.4	54.3	58.8	80.3	58.9	73.6	69.8
Max	89.4	82.4	86.1	61.5	67.3	96.8	83.5	84.3	79.2
Min	83.3	67.6	62.3	46.6	53.7	70.7	40.8	59.0	53.7
Stdev	3.1	8.4	12.9	7.5	7.4	14.4	22.1	13.1	14.0

5.3.2 Accelerations

Table 5.9 contains novel empirical data regarding the forces acting upon casualty evacuations. The information in this table reflects the scalar quantity of accelerations acting on the head of the mannequin. The persons handling the simulated casualty were all OSSC personnel. All were instructed to handle the stretcher/mannequin assembly with utmost care.

Generally, the mannequin was experiencing head accelerations of approximately 2 G's. There was a general trend that the heavier stretchers seemed to better secure/restrain the mannequin and resulted in smaller accelerations during the descent. The largest accelerations occurred in Interval 2 – the transfer from the collection platform to the adjoining liferaft. These values would likely be even larger under extreme motion environments, when the likelihood of operator/rescuer stumbling is greatest.

Table 5.9: Maximum accelerations (G) acting on mannequin's head while descending the slide (Interval 1) and being removed from collection platform to final position in liferaft (Interval 2)

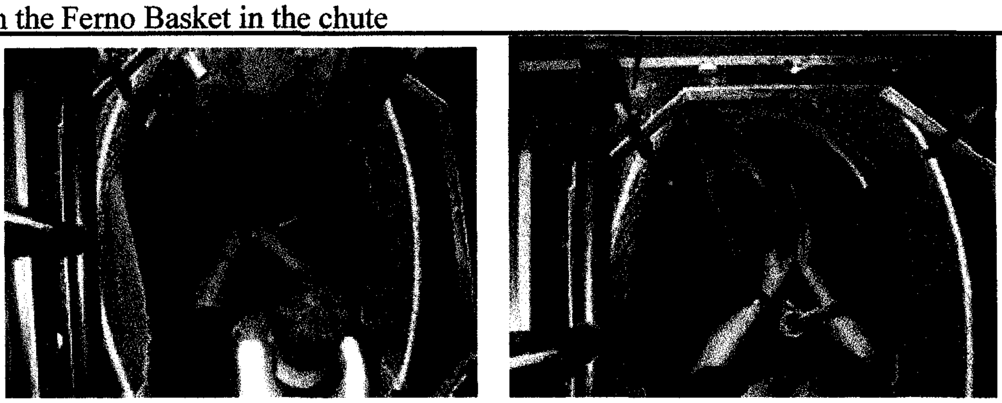
Interval 1	**Sked**			**Ferno**			**Stokes**		
	45.6kg	68.6kg	92.1kg	50.7kg	73.7kg	97.2kg	59.7kg	82.7kg	106.2kg
Max. G	2.07	1.90	2.03	1.58	1.82	1.94	1.60	1.71	1.67
sd (G)	0.54	0.23	0.30	0.25	0.45	0.14	0.33	0.19	0.41

Interval 2	**Sked**			**Ferno**			**Stokes**		
	45.6kg	68.6kg	92.1kg	50.7kg	73.7kg	97.2kg	59.7kg	82.7kg	106.2kg
Max. G	2.51	2.02	2.72	1.56	1.74	2.10	2.08	2.29	1.99
sd (G)	0.91	0.34	0.83	0.15	0.24	0.40	0.45	0.47	0.41

5.3.3 Chute

As discussed in the test matrix development, the Stokes Litter was not considered an option for evacuation through the chute simply because its size, design and construction would very likely damage the chute device. An attempt was made at fitting an unloaded Ferno Basket into the chute (Figure 5.11a and Figure 5.11b), however, it was not possible to safely get the stretcher into the first cell of the device and the attempt was abandoned. In fact, even removing the empty Ferno Basket from the chute proved to be a difficult task.

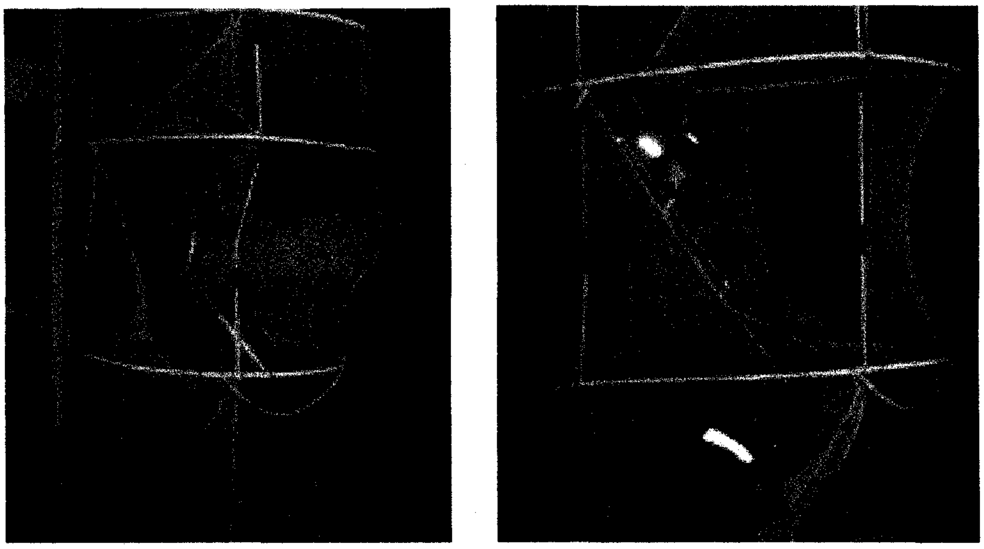
Figure 5.11: (a) Attempting to fit the Ferno Basket into the chute and (b) Attempting to turn the Ferno Basket in the chute



(a) (b)

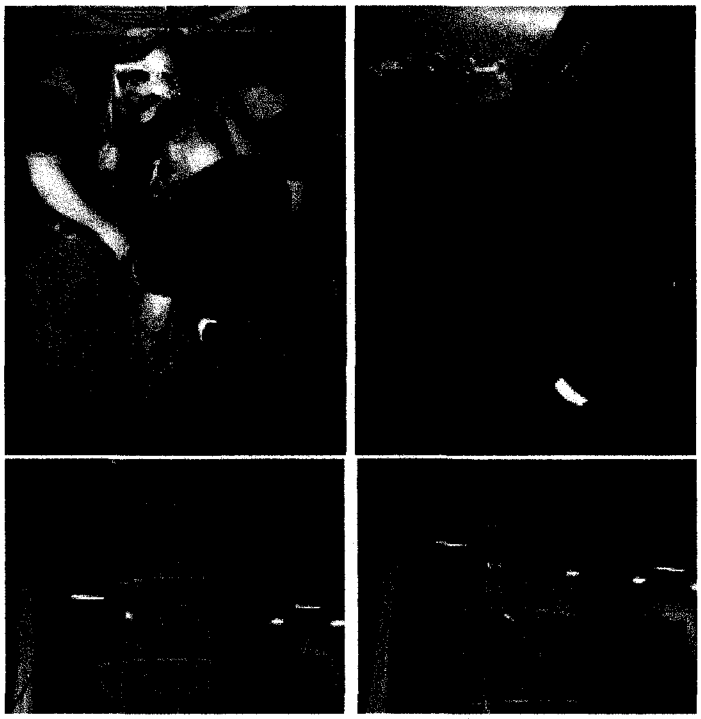
It was possible to move a loaded Sked through the chute due to its flexible nature (Figure 5.12). However, doing so took more than 30min and required two personnel to travel with the casualty at all times. Throughout the trial, the handlers were required to twist the stretcher in often unnatural positions to make the turns for each cell – turns were required to try and prevent striking or scraping the face of the casualty as the stretcher moved from cell to cell and slid over the chute material. The heavy mannequin was used for this trial (test no. 15 from the test matrix in Table 3).

Figure 5.12: Sked stretcher being moved through the chute



In an effort determine if the unnatural twists and turns would actually be possible to perform with a real human, one of the investigators volunteered to be evacuated through the chute in the Sked (Figure 5.13). The mass of the volunteer was 89kg (not including the Sked mass).

Figure 5.13: Sked stretcher being used to evacuate one of the investigators



The time required to perform this task again exceeded 30min. From considerations of casualty comfort, the investigator indicated considerable concern at each turn of the Sked and general discomfort at having to constantly resist motions throughout the evacuation. Had the casualty not been fully conscious and in good health, the experience may have resulted in further injury.

5.4 Discussion

The International Maritime Organization indicates the evacuation time allowed for complete abandonment of a ship should not exceed 30 minutes (IMO, 2002). In the case of passenger vessels equipped with a MES as the primary evacuation system, this 30 minute period shall be sufficient "to enable the total number of persons for which it [the system] is designed, to be transferred from the ship into the inflated liferafts" (IMO 2003). The problem with this regulation is that it does not consider the number of possible stretcher evacuation cases.

Data from the current study suggest that it will take on average 89.3s and a maximum of 129.8s for a loaded stretcher to descend through the slide and be placed into its final position in the raft. The Stokes Litter and Ferno Basket are both solid frame construction whereas the Sked is not. When considering that the Sked had a higher evacuation time compared with the first two stretcher types, it can be inferred that the Sked is the least efficient stretcher for evacuating a passenger ship via a slide MES. It is not surprising that the trials using the heavy mannequins saw faster times going down the slide. However, with increased momentum, the ability to safely carry an injured person across an open collection platform may decrease.

The Ferno Basket appears to have been the most efficient as it was on average 1.3s faster than the Sked trials and 5.3s faster that the Stokes Litter trials. Examination of interval 2 results showed that it took approximately the same amount of time to transfer the Ferno Basket and the Stokes Litter, 64.4s and 67.4s respectively. On the other hand there was an increase in the average time that it took to transfer the Sked as it took 78.3s, 11s longer than the Stokes Litter and 14s longer than the Ferno Basket.

It would be preferable to use devices such as slides and chutes only for able bodied individuals, although manufacturers suggest these devices can handle stretcher cases as well. The difficulty becomes whether the required amount of time to evacuate passengers will be sufficient to evacuate a ship in time. The assumptions used for this project were that the stretcher case can only be evacuated from the vessel using slides and chutes of the design and manufacture available at the OSSC. The assumption must also be made that the devices are representative of similar systems.

It must be acknowledged that these evacuations were performed under ideal conditions – indoors and protected from harsh weather conditions and heavy seas. It should also be noted that these data do not include the time required to get the casualty situated in the stretcher or removed from the stretcher. Thus, reported times should be considered ideal.

This research identifies several issues that should be of interest to regulatory bodies. In a mass casualty situation, the number of injured personnel could easily exceed the number of uninjured and trained personnel (Coleshaw et al, 1998). In the current study all evacuation personnel were in good health. It is recommended that all crewmembers of passenger vessels obtain basic MES training under as realistic conditions as possible.

Proper belay and rope systems were used for each trial of this study and coordinated by instructors trained to use these specific devices. When a stretcher ultimately arrives at the device boarding platform, the equipment available to control the lowering of the stretcher is not regulated and hence a simple hauling system was rigged and used for the duration of the tests performed. The training of the crew member in charge at this location is also assumed to be of a high standard. In a real life situation it is safe to assume that these rope systems would not likely be available. In reality, even if extensive evacuation gear were made available to ship's crew, most would not be able to use these devices efficiently unless under ideal evacuation conditions. Furthermore, regulations make no provision for the number of stretchers to be carried by these vessels. Certainly, sufficient numbers should be placed onboard to ensure casualty packing and stretcher return are not limiting factors in the evacuation process. More research effort is required to properly define the scenarios related to such work and to suggest areas for additional crew training.

In addition, questions exist with regard to the handling of stretcher cases on arrival to the collection platform – how many crew are available to perform the lift, what is their experience in such cases, are these individuals also medical emergency personnel? Do collection platform crews accompany the stretcher into the liferaft or hand it off to additional personnel already inside the liferaft? If there is more than one person requiring a stretcher, is the first evacuee removed from the stretcher so it can be sent back to the top of the MES for repackaging another individual? The answer to this question depends on the reason the individual is in the stretcher to begin with – if an injury, it is unlikely that medical emergency personnel will want to remove that person from the stretcher. However, if the individual is elderly or physically handicapped, it may be feasible to remove them from the stretcher to use it for evacuation of another person. If the stretcher is returned back to the top of the MES for additional use, is it returned using the MES or is it simply raised using the rope handling equipment outside the confines of the MES? The assumption made for the present work is that the stretcher would be hauled back up the slide but it would not be practical to return the stretcher to the top of the chute through the inside since the likelihood of getting the stretcher stuck inside the chute is high.

Compared to the real world situation, questions are raised as to whether crew would accompany a stretcher from the collection platform to the inside of the liferaft or if these personnel would remain in the collection raft and hand-off the stretcher to crew and emergency personnel inside the liferaft. The most likely reason stretcher handlers would remain in the collection platform would be to receive additional stretcher cases. Ultimately, this question of procedure is more a decision of the crew at the time of the emergency and their judgment of the situation than it is a defined methodology.

From the attempts made to lower the stretcher in the chute it is believed that the time required to plan and perform this operation would be considerable and significantly slow the progress of the overall evacuation. Based on the limited efforts described, it is not recommended that this type of chute design be employed for the evacuation of stretcher cases.

5.5 Conclusions and Recommendations

In describing regulations about the performance of marine evacuation systems the current IMO Life-Saving appliances code states that:

"A marine evacuation system shall be:

6.2.2.1.1 capable of deployment by one person"

6.2.2.1.2 such as to enable the total number of persons for which it is designed, to be transferred from the ship into the inflated liferafts within a period of 30 min in the case of a passenger ship and of 10 min in the case of a cargo ship from the time the abandon ship signal is given"

Findings indicate that stretchers can be successfully evacuated using a slide, however, it has been deemed not practical or safe to evacuate stretcher cases through chutes similar in manufacture to the Selantic system described in this report.

The regulation above states that the evacuation system should enable the total amount of persons for which it is designed to be transferred into the inflated liferafts. This regulation obviously does not take stretcher cases into consideration as much less people would be able to fit into a liferaft with even one stretcher case involved. Also, based on the study's findings, in an evacuation involving a large number of stretcher cases, it would be extremely difficult to evacuate all healthy passengers, injured/disabled passengers and vessel personnel in the 30 minute period unless sufficient numbers of appropriate devices and associated equipment were available to well-trained personnel.

Recommendations from this work include:

1. Better definition of the ship's requirements for handling of stretcher cases is important should a vessel in peril require evacuation of multiple stretcher-confined casualties via MES.

2. Equipment available for evacuating stretcher cases in MES should include, at a minimum, simple load rated hauling systems with specialized rope rated for lifting of loads involving humans. This equipment should be operated by crew members trained properly in rope handling techniques for such situations.
3. When possible, stretcher cases should be evacuated through means other than MES. MES should be used only as a last resort.
4. Chutes of the type used in this work should not be employed for evacuating stretcher cases.
5. Other chute designs may work more safely and effectively, however, further testing would be required to ensure this is the case.
6. If no other means but chutes as used for this present study are available for evacuating stretcher cases an alternate means of evacuating stretcher cases may be to use technical rope handling to lower the stretcher over the side of the vessel and into a collection platform, liferaft or lifeboat, as long as crew are properly trained and properly equipped.

CHAPTER 6

Summary

The studies discussed in this report have all successfully provided insight into some of the critical aspects of MES design. It has been found that a number of current regulations that are in place are deficient and that some points that should be considered by regulatory bodies haven't been taken into account.

By collecting anthropometric data on an offshore population a number of important discoveries were made. Firstly, the current regulation states that the average mass of a person using a lifeboat is 75kg. It is suggested that this mass be increased to 90kg from the current value. Secondly, the current seat allocation for a lifeboat is 430mm. This is based on hip breadth (seated) measurements. It was found that average shoulder breadth measurements were much larger and therefore the IMO standard for maximum linear width of the seat should be increased to 555mm based on a standard derived from the upper torso anthropometrics rather than the hip dimensions.

Currently, impact data for marine evacuation does not exist. This study examined some of the forces that do act on the body during evacuation using MES. The forces were found to reach potentially harmful levels that could have especially adverse effects on elderly adults or persons in poor condition. With this being said it is suggested that regulatory bodies gain further insight into impact data and consider including such into future regulations for MES design.

Current regulations state that an MES shall enable the total number of persons for which it is designed to be transferred from the ship into the inflated liferafts within a period of 30 min. In the final study discussed in this report, mannequin loaded stretchers were moved through a MES to find both the time it took to evacuate a casualty in a stretcher and to determine the forces acting on the stretcher. The main finding was that evacuating a casualty is a time consuming event and, if a mass casualty situation was to occur, it would be extremely difficult to evacuate all passengers within the regulated 30 minutes. Therefore, it has been suggested that every ship's requirements for handling of stretcher cases is evaluated and that, when possible, stretcher cases should be evacuated through means other than MES.

REFERENCES

Alcantara E, Forner A, Ferrus E, Garcia A, Ramiro J (2002) Influence of age, gender, and obesity on the mechanical properties of the heel pad under walking impact conditions. *Journal of Applied Biomechanics.* 18:345-56

American Bureau of Shipping (2003) The Application of Ergonomics to Marine Systems. Online: http://www.eagle.org/rules/downloads/86-Ergo.pdf

Anon (2000). New directions for passenger ship safety. *Naval Architect,* July/August: 42-3

Bazarian JJ, Fisher SG, Flesher W, Lillis R, Knox KL, Pearson TA (2004) Lateral automobile impacts and the risk of traumatic brain injury. *Annals of Emergency Medicine.* 44(2):142-52

Beech E (1997)Evacuation systems on trial. *Safety at Sea International,* 334:7

Bercha FG, Brooks CJ, Leafloor F (2003) Human performance in arctic offshore EER. *Prepared for the 13th International Offshore and Polar Engineering Conference.* Honolulu, Hawaii, USA. 25-30 May 2003

Beunen G, Broms J (1990) Kinanthropometry: roots, developments and future. *Journal of Sport Sciences,* 8(1) 1-15

Brooks CJ (1995) Lifejackets through the ages. *Mustang Engineered Technical Apparel Corp.* Canada

Brooks CJ, Kozey JW, Dewey SL, Brown RC, Howard KA, Drover DJ, MacKinnon SN, McCabe J (2004) Research studies to investigate the impact of immersion suit use in an emergency situation. Report Submitted to Transport Canada by Survival Systems Limited. November

Brooks CJ, McCabe J, Lamont J (2001) What is the Survival Suit Designed to Do, and Will it Work for Me in the Event of a Ditching or Ship Abandonment? Presented at the NATO-RTO Blowing Hot and Cold: Protecting Against Climatic Extremes Symposium. Dresden, Germany. October

Brown R (editor) (2005). Abandonment Trials Report. Formulation of Immediate Response and Evacuation Strategies through Intelligent Simulation Assessment and large-scale Testing (Fire Exit). Confidential Project Report GRD2-2001-50055

Canadian Submission to International Maritime Organization (2005) Sub-Committee on Fire Protection, 50th session of IMO, Fire Protection Committee (FP 50/14)

Chinese Submission to International Maritime Organization (2004) Sub-Committee on Ship Design and Equipment, 47th session of IMO, Design and Equipment Committee (DE 47/5/6)

Coleshaw S, Mills, F (1998). Evacuation of Casualties. *Safety at Sea International,* 348: 21-4

Crawford H (2003) Survivable Impact Forces on Human Body Constrained by Full Body Harness. Prepared for the Health and Safety Executive, Glascow

Delarue J, Constans T, Malvy D (1994) Anthropometric values in an elderly French population. *The British Journal of Nutrition,* 71:295-302

Derrick TR (2004) The effects of knee contact angle on impact forces and accelerations. *Medicine in Science and Sports Exercise,* 36(5):832-7

Drover DJ, MacKinnon SN, Brown RC, Boone J, Small G (2005). Measurement of egress time for injured or physically challenged users of marine evacuation systems. 36th Annual Conference of the Association for Canadian Ergonomists, Halifax, NS

Flin R, Slaven G, Stweart K (1996). Emergency decision making in the offshore oil and gas industry. *Human Factors,* 38(2), 262-277

Forsey H. (2003) *Marine Evacuation Systems: Chutes and Slides.* Unpublished technical report, Institute for Marine Dynamics, National Research Council, St. John's, NL

Foust D (1977) Study of human impact tolerance using investigations and simulations of free falls. *Proceedings of the Twenty-first Stapp Car Crash Conference.* 3-51

FS (2003) Safety equipment: accidents raise safety concerns. *Fairplay Solutions, 84, September, 18*

Galea ER (2001) *Predicting evacuation and circulation in planes, trains, buildings and ships using the EXODUS software. Proceedings of Conference on Pedestrian and Evacuation Dynamics, Duisburg, Germany*

Gerritsen KGM, Van Den Bogert AJ, Nigg BM (1995) Direct dynamics simulation of the impact phase in heel-toe running. *Journal of Biomechanics,* 28:661-68

Harris B (1997) Growing taller, living longer? Anthropometric history and the future of old age. *Aging and Society,* 17:491-512

Harris B (1994) Health, height, and history: an overview of recent developments in anthropometrics history. *Social History of Medicine,* 7(2):297-320

Howell R (1999) *The Myth of the Titanic*, St. Martin's Press, New York

Hreljac A (2004) Impact and overuse injuries in runners. *Medicine and Science in Sports and Exercise,* 36(5):845-9

Hsiao H, Long D, Snyer K (2002) Anthropometric differences among occupational groups. *Ergonomics,* 45(2); 136-52

International Maritime Organization (2005) Action Dates. Online: http://www.imo.org/Conventions/mainframe.asp?topic_id=262

International Maritime Organization (2002) Interim guidelines for evacuation analyses for new and existing passenger ships. MSC/circ.1033.

International Maritime Organization (2003) *Life-Saving Appliances Code*. United Kingdom:IMO.

International Maritime Organization (2003) Measures to Prevent Accidents with Lifeboats. Sub-Committee on Ship Design and Equipment, 47th session, Agenda item #5. 24 December 2003

International Maritime Organization (2004) *Safety Of Life At Sea* (consolidated edition). United Kingdom:IMO.

International Maritime Organization (1997) International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978, as amended in 1995 and 1997 (STCW Convention), and Seafarer's Training, Certification and Watchkeeping Code (STCW Code); London, 1997

Japanese Statistics Bureau (2005) Stature, Weight and Girth of Chest by Specified Age and Sex (1985--2001). Online: http://www.stat.go.jp/data/chouki/zuhyou/24-05-b.xls

Jernigan MV, Amber LR, Stefan MD (2005) Sever upper extremity injuries in frontal automobile crashes: the effects of depowered airbags. *American Journal of Emergency Medicine,* 23:99-105

Kim H, Park JH, Lee D, Yang YS (2004). Establishing the methodologies for human evacuation simulation in marine accidents. *Computers and Industrial Engineering, 46(4:* 725-740

Kim KS, Robbins D, Turner M (1998) Anthropometric determinants of risk factors in an African American population. *American Journal of Human Biology,* 10(2) 249-58

Klupfel H, Meyer-Konig M, Wahle J, Schreckenberg M (2000) Microscopic simulation of evacuation processes on passenger ships. In Bandini S, Worsch (Eds.), *Theoretical and practical issues on cellular automata, 63-71.* Berlin: Springer

Lafortune MA, Lake MJ, Hennig EM (1996) Differential shock transmission response of the human body to impact severity and lower limb posture. *Journal of Biomechanics,* 29(12):1531-7

Leung Y, Tarriere C, Lestrelin D, Hureau J, Got C (1989) Submarining injuries of 3 pt. belted occupants in frontal crashes. *Society of Automotive Engineers Paper No. 896052.* Warren, Pennsylvania

MacKinnon SN, Brown R, Drover D (2005). Measurement of Forces and Accelerations on Users of Marine Evacuation Systems. Report Submitted to Transport Canada by Memorial University of Newfoundland. August 31

MacKinnon, SN, Drover D (2004) Anthropometric measurements of north atlantic offshore workers trained in a Newfoundland facility. Internal Report.

Martinez CP, Diaz ME, Toledo EM (2003) Anthropology and Style of Life in Middle Age Women. *Collegium Antropologicum,* 27(1):151-9

Melvin JW (1975) Impact response and tolerance of the lower extremities. *Proceedings of the Nineteenth Stapp Car Crash Conference.* 543-59

Melvin JW, Nusholtz, GS (1980) Tolerance and response of the knee-femur-pelvis complex to axial impacts – impact sled tests. _*University of Michigan, Highway Safety Research institute Final Report No. UM-HSRI-80-27,* June

Melvin JW, Stalnaker RL (1976) Tolerance and response of the knee-femur-pelvis complex to axial impacts. *Biomechanics Department, Highway Safety Research Institute MVMA Project No. 4.18.* October

Messerer O (1880) Uber elasticitat and festigkeit der menschlichen knochen. Stuttgart, Germany

Morgan S (2000) Richer and Taller: Stature and Living Standards on China, 1979-1995. *The China Journal,* 44:1-39

Mououdi MA (1997) Static anthropometric characteristics of Tehran University students age 20. *Applied Ergonomics* 28(2):149-50

NA (1999) First orders for RFD's new Marin-Ark evacuation system. *Naval Architect,* April, 14

Nelson JK, Fredericks TK, Mackinnon SN (2004) Canadian Sub-Committee on Ship Design and Equipment, 48th session of IMO, Design and Equipment Committee (DE 48/5)

Nuthall K (2002) European commission takes action on ro-ro safety. *Safety at Sea International,* May, 10-11

Olds T (2004) The rise and fall of anthropometry. *Journal of Sports Sciences,* 22(4):319-30

Olvey SE., Knox T, Cohn KA (2004) The development of a method to measure head acceleration and motion in high-impact crashes. *Neurosurgery,* 54:672-677

Patrick LM (1966) Forces on the human. *Proceedings of the Ninth Stapp Car Crash Conference.* 237-260

Patrick LM, Kroell CK, Mertz HJ (1966) Forces on the human body in simulated crashes. *Proceedings of the Ninth Stapp Car Crash Conference*

Patterson A (2002) Evolution of Training for the Maritime Oil and Gas Sector on the Canadian East Coast. *Presented at: Canada-Brazil Health, Safety, and Environment Seminar and Workshop.* Rio de Janeiro, Brazil, 11-12 March 2002

Pheasant S (1998) *Bodyspace: Anthropometry, Ergonomics, and the Design of Work, 2nd Edition,* Taylor and France, London.

Pheasant, S (2003) *Bodyspace.* London: Taylor & Francis

Pintar FA, Yoganandan N, Eppinger RH (1998) Response and tolerance of the human forearm to impact loading. *42nd Stapp Car Crash Conference Proceedings.* 65-76

Powell WR, Advani SH, Clark RN, Ojala SJ, Holt DJ (1974) Investigation of femur response to longitudinal impact. *Proceedings of the Eighteenth Stapp Car Crash Conference,* SAE Paper No. 741190, Dec

Process Contracting Limited (2004) Bridge Ergonomics. Online. http://www.processforusability.co.uk/Documents/Bridge_anthropometry.pdf. May 2004

Razzak JA, Sasser SM, Kellermann AL (2005) Injury prevention and other international public health initiatives. *Emergency Medicine Clinics of North America,* 23:85-98

Reilly TJ, Kozey JW, Dewey SL, Brooks CJ (2004). Structural Anthropometry of Atlantic Offshore Workers, (in press)

Rouhana SW, Ridella SA, Viano DC (1986) *Proceedings of the Thirtieth Stapp Car Crash Conference.*

Rupp JD, Schneider LW (2004) Injuries to the hip joint in frontal motor-vehicle crashes: biomechanical and real-world perspectives. *Orthopedic Clinics of North America,* 35:493-504

SASI (1999) Evacuation systems. *Safety at Sea International*, 361, April, 20-22

SASI (2003) Evacuation chute tragedy examined. *Safety at Sea International,* September, 34

SASI (1995) Marine evacuation systems training. *Safety at Sea International, April, 14-16*

SASI (1997)Marine evacuation systems update. *Safety at Sea International, 334, 17-19*

SASI (1998) Marine evacuation systems update. *Safety at Sea International, 348, 16-18*

SASI (2001) Offshore evacuation improving the breed. *Safety at Sea International, April, 8-14*

SASI (2000)Safe Methods of Evacuation. Safety at Sea International, 373 , 17-18

Schneider LW, Robbins DH, PFlüg MA, Snyder RG (1983) Development of anthropometrically based design specifications for an advanced adult anthropomorphic dummy family. *Volume 1. Report No. DOT-HS-806-715. Washington, DC: US Department of Transportation, National Highway Traffic Safety Administration*

Siegra-Riz, AM, Hobel, CJ (1997) Predictors of poor maternal weight gain from baseline anthropometric, psychosocial, and demographic information in a Hispanic population. Journal *of the American Dietetic Association,* 97(11):1264-68

Simoes Re AJ (1997) *Evacuating Offshore Structures.* Asamex International Proceedings, paper no 5.

Smolej-Narancic N, Chaventre A, Rudan P (1994) Anthropometric variation and population structure of the Island of Pag, Croatia. *Human Biology,* 66:275-98

So RHY, Lam FCY, Goonetilleke R (2005) Anthropometric data of the Hong Kong Chinese population: a literature review and its application to a seated barbecue site design. Online: http://www.google.ca/search?q=cache:GRFlD71PugwJ:www-ieem.ust.hk/dfaculty/ravi/papers/paper5.pdf+population+anthropometric+references&hl=enrth

Steckel, R (1986a) A peculiar population: the nutrition, health and morality f American slaves from childhood to maturity. *Journal of Economic History,* 44:721-41

Steckel, R (1986b) Birth weight and infant mortality among american slaves. *Explorations in Economic History,* 23:173-98

Steckel, R (1983) Height and oer capita income. *Historical Methods*, 16:1-7

Stein, R (2004). Data find a taller, fatter America since 1960, Washington Post

Transport Canada (2005) Canada Shipping Act. Online: www.tc.gc.ca/acts-regulations/GENERAL/C/CSA/menu.htm.

Vassalos D, Kim H, Christiansen G, Majumder J (2001) *A real-time interactive mesoscopic model for passenger evacuation simulation in a virtual ship environment and performance- based evaluation. Proceedings of Conference on Pedestrian and Evacuation Dynamics, Duisburg, Germany*

Viano DC (2003) Seat Influences on female neck responses in rear crashes: a reason why women have higher whiplash rates. *Traffic Injury Prevention,* 4(3):228-239

Viano DC, Lau IV, Andrzejak DV, Asbury C (1989) Biomechanics of injury and lateral impact. *Accident Analysis and Prevention,* 21(6):535-51

Wang MJ, Wang EM, Lin YC (2002) The anthropometric database for children and young adults in Taiwan. *Applied Ergonomics,* 33(6):583-5

Webber CO (1859) Chirurgische erfahrungen and untersuchungen. Berlin

Wiseman M, Burge H (2000) Fishing vessel safety review (less than 65 feet). Prepared for Fisheries and Oceans Canada. Online: http://www.safetynet.mun.ca/pdfs/CFVSafetyReview.pdf

Yoganandan N, Pinar FA, Kumaresan S, Boyton M (1997) Axial impact biomechanics of the human foot-ankle complex. *Journal of Biomechanical Engineering,* 119(4): 433-437