QUANTIFICATION OF HUMAN PERFORMANCE IN MARINE ABANDONMENT SITUATIONS THROUGH CONTROLLED EXPERIMENTATION

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ABSTRACT

Recent advancements in computer software, coupled with IMO MSC circular 1033 have lead to the development of computer-based simulation of the evacuation process on passenger ships. In order for these simulation models to be accurate and useful, it is imperative they use realistic data for passenger movement throughout the evacuation process. Due to the nature of ship abandonment, quantifying human performance in actual abandonment situations is very difficult. For this reason, simulation inputs must rely on results of controlled, well-defined experiments.

A significant amount of unique research at the Offshore Safety & Survival Centre of Memorial University of Newfoundland has attempted to quantify human performance during various aspects of the abandonment process. This paper outlines experiments conducted to quantify abandonment times for a variety of life saving appliances for ambulatory and non-ambulatory individuals wearing several types of personal floatation apparatus for passenger vessels as well as offshore applications. Results from testing are also provided in the context of evacuation simulation as well as for consideration in training environments.

INTRODUCTION

The development of models that simulate complex human behaviour in emergency situations have been the subject of numerous studies covering a wide variety of evacuations from buildings and airlines to passenger ships. Ship evacuations pose numerous additional difficulties in emergency situations as passengers are often unfamiliar with the marine and motion environment, specialized equipment and general marine procedures. With the implementation of IMO MSC circular 1033, all newly built ships must have undergone a formal evacuation assessment to determine if changes at the design stage might improve a ship’s ability to be evacuated. Currently, more than 20 evacuation models are available (Kim et al., 2004) to designers in the shipbuilding industry.

Due to the inherent variability of human behaviour, especially in stressful situations, models that predict evacuability of ships are generally probabilistic in nature (Vassalos et
al., 2002). These probabilistic models typically predict a range of evacuation outcomes given a set of input distributions for human behaviour. This is an advantage over deterministic models which would predict the same result every time with the same given set of input parameters. Still, input distributions for human behaviour during evacuation must be properly quantified in order to provide a realistic basis from which to carry-out probabilistic modeling.

The work described in this paper is a summary of several projects undertaken at the Offshore Safety & Survival Centre (OSSC) of Memorial University of Newfoundland in an effort to quantify human performance related to passenger movement during the abandonment phase of ship evacuation. It represents a good start at quantifying basic aspects of the abandonment process in a way that can be used in probabilistic modeling for ship evacuation assessment.

GENERAL TEST SETUP

Four different full-scale life saving appliances were utilized throughout the work outlined in this paper (Figure 1) – a vertical escape chute, a single track marine slide (both installed 6m above the water), a davit launched liferaft and a totally enclosed motor propelled survival craft (TEMPSC). All equipment was setup in a controlled, well-lit lab-type environment with calm water and generally dry conditions. This setup represents the base-case situation – controlled abandonment. Personnel acting as crew during the tests were experienced mariners and provided realistic, consistent instructions and guidance to subjects where required. Subjects were identified by unique numbers allowing researchers to determine if correlations existed between personal characteristics and performance.

For passenger vessel setups, subjects were untrained personnel wearing normal street clothes and SOLAS approved lifejackets. For offshore platform or commercial vessel setups, subjects were trained personnel wearing only immersion suits. For non-ambulatory person abandonment setups, articulated mannequins were weighted to published anthropometric guidelines and secured in stretchers.

DATA ACQUISITION

Elapsed time through or into the various LSA components was the main independent variable measured in the tests described. Therefore, data acquisition was primarily by video recording at 30Hz. Cameras were mounted (Figure 2) at the start of different zones for each of the LSAs and synchronized to facilitate continuous monitoring of each subject throughout the abandonment process. The zones were further grouped as either translational or action (depending on the LSA) to permit modeling of more general cases the when equipment modeled is not exactly the same as that in the lab. Questionnaires were also completed by subjects to determine a variety of detailed information relating to age, gender and their previous experience with similar situations.
Figure 1  LSAs used in the studies quoted: davit launched liferaft (top left), single track marine slide (top right), TEMPSC (bottom left) and vertical chute (bottom right)

Figure 2  Example of typical data acquisition setup for marine slide zones
RESULTS AND DISCUSSION

Except where noted, results from the trials reported in this paper deal mainly with untrained personnel – assumed representative of those onboard passenger vessels. The authors present below temporal results for:

- lifejacket donning,
- abandonment trials using four different LSAs
- abandonment trials in a chute only involving trained and untrained personnel and
- abandonment trials for non-ambulatory (stretcher) cases.

**Lifejacket Donning**

SOLAS approved lifejackets were utilized throughout these tests. Subjects were assembled into groups of not more than 50 persons and given brief instruction on the proper donning method. Each group was video taped throughout the donning process which began when the researchers called start and ended with each subject raising his/her hand when finished. Times were tabulated for those subjects that could clearly be seen raising a hand. The resulting distribution of donning times is approximately lognormal (Figure 3) with a mean of 38.5s and a standard deviation of 11.8s. The overall sample size for this data is 180.

Figure 3  Distribution of lifejacket donning times

**Untrained Personnel in Four Different LSAs**

A total of 275 subjects were involved in these trials which represent abandonment under controlled baseline conditions. Population statistics are summarised in Table 1. Summarised results shown in Figure 4 indicate that in general, males are faster than females and that overall abandonment time tends to increase with age on all four LSAs utilised. However, it is clear that little variation is seen in abandonment time for lifeboats and davit launched liferafts, regardless of age or sex.

Analysis of the time required to move into a seating position in a floating liferaft is provided in Figure 5 as a function of liferaft fullness. These data indicate a general trend...
that time required to become seated decreases as the liferaft fills to capacity according to a least squares regression fit to the scatter plot.

Table 1  
Population statistics for test subjects (overall sample size: 275)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Male (40%)</th>
<th></th>
<th>Female (60%)</th>
<th></th>
<th>Overall</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Dev.</td>
<td>Mean</td>
<td>Standard Dev.</td>
<td>Mean</td>
<td>Standard Dev.</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.8</td>
<td>0.1</td>
<td>1.65</td>
<td>0.1</td>
<td>1.7</td>
<td>0.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>83.2</td>
<td>11.3</td>
<td>68.8</td>
<td>14.3</td>
<td>74.7</td>
<td>14.9</td>
</tr>
<tr>
<td>Age</td>
<td>38.2</td>
<td>14.1</td>
<td>36.0</td>
<td>13.4</td>
<td>36.9</td>
<td>13.7</td>
</tr>
</tbody>
</table>

Figure 4  
Summary plots of untrained subject performance by age group and sex for the slide (top left), chute (top right), lifeboat (bottom left) and liferaft (bottom right).
Figure 5  Time to get seated inside a floating liferaft as a function of liferaft fullness

Trained and Untrained Personnel in a Vertical Chute

A small sample of 82 subjects were involved in these trials to compare abandonment time under controlled baseline conditions for trained and untrained subjects using a chute system. Population statistics are summarised in Table 2. Results are summarised in Figure 6 which indicate that, on average, trained subjects were able to abandon using the chute in less than half the time required by untrained personnel. The age range for both groups was very similar, however the proportion of male to female subjects was much higher for the trained group.

Table 2  Population statistics for trained and untrained subjects

<table>
<thead>
<tr>
<th></th>
<th>Trained</th>
<th>Untrained</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample Size</td>
<td>41</td>
<td>41</td>
</tr>
<tr>
<td>Mean Age</td>
<td>37.6</td>
<td>40.9</td>
</tr>
<tr>
<td>Std Dev Age</td>
<td>11.4</td>
<td>12.9</td>
</tr>
<tr>
<td>Males:Females</td>
<td>36:5</td>
<td>21:20</td>
</tr>
<tr>
<td>Mean Mass (kg)</td>
<td>90.6</td>
<td>73.5</td>
</tr>
<tr>
<td>Mean Height (m)</td>
<td>1.75</td>
<td>1.72</td>
</tr>
<tr>
<td>Mean Years Working Offshore</td>
<td>3.2</td>
<td>0</td>
</tr>
</tbody>
</table>
Abandonment for Non-Ambulatory (Stretcher) Cases

A series of tests was carried out to determine the efficacy of abandonment for non-ambulatory personnel using the slide and chute LSAs. It was assumed that the stretchers arrived at the LSAs ready for abandonment (i.e., times recorded did not include stretcher loading). Three types of stretchers (Table 3) and three mannequin masses (Table 4) were tested to determine if efficacy of evacuation depended on any combination of these factors.

Results for the slide tests indicate that mass of the stretcher did not affect the time required for abandonment, however abandonment times did vary with stretcher type. Times for the rigid solid plastic basket litter were, on average, 1.3s faster than the collapsible plastic litter and 5.3s faster than the rigid mesh basket litter. Overall results indicate that it will take on average 89.3s and a maximum of 129.8s for a loaded stretcher to descend the slide and be placed into its final position in the liferaft.

Results for chute tests indicate that rigid basket litters cannot be used in some chutes. It was not possible to move either of the rigid litters through the chute. It was possible to move a loaded collapsible plastic litter through the chute due to its flexible nature. However, doing so took more than 30 minutes and required two personnel to travel with the mannequin in the litter at all times. Throughout the trial, the handlers were required to turn the litter in a specific manner in order to move from one cell to the next and prevent striking or scraping the face of the mannequin (Figure 7).
### Table 3  Stretcher types tested

<table>
<thead>
<tr>
<th>Stretcher Type</th>
<th>Photograph</th>
<th>Mass – light (kg)</th>
<th>Construction Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rigid Solid Plastic Basket Litter</td>
<td><img src="image1.jpg" alt="Photograph" /></td>
<td>11.0</td>
<td>Rigid plastic construction</td>
</tr>
<tr>
<td>Collapsible Plastic Litter</td>
<td><img src="image2.jpg" alt="Photograph" /></td>
<td>5.9</td>
<td>Flexible plastic construction</td>
</tr>
<tr>
<td>Rigid Mesh Basket Litter</td>
<td><img src="image3.jpg" alt="Photograph" /></td>
<td>20.0</td>
<td>Stainless Steel Construction with moulded plastic basket</td>
</tr>
</tbody>
</table>

### Table 4  Mannequin masses tested

<table>
<thead>
<tr>
<th>Weight Category</th>
<th>Demographic</th>
<th>Target Mass (kg) (Pheasant, 2003)</th>
<th>Actual Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Weight</td>
<td>50th Percentile, 12 year old British male</td>
<td>40.0</td>
<td>39.7</td>
</tr>
<tr>
<td>Medium Weight</td>
<td>50th Percentile British Female</td>
<td>63.0</td>
<td>62.7</td>
</tr>
<tr>
<td>Heavy Weight</td>
<td>95th Percentile British Male</td>
<td>94.0</td>
<td>86.2</td>
</tr>
</tbody>
</table>
In an effort determine if the required turns would actually be possible to perform with a real human, one of the investigators volunteered to be evacuated through the chute in the collapsible plastic litter (Figure 7). The mass of the volunteer was 89kg. The time required to perform this task again exceeded 30min. The subject indicated considerable concern for his safety at each turn in the chute and general discomfort resulting from the forces applied by the elastic members at the bottom of each cell in the chute. Based on the inability to move rigid litters through the chute and the difficulty of moving a collapsible litter safely through the chute, the project team assessment was that some chutes may be inappropriate for the evacuation of stretcher cases.

![Figure 7 Attempts at abandonment through the vertical chute](image)

Proper belay and rope systems were used for each trial of this study and operated by instructors trained in technical rope rescue. If such equipment is to be made available to a ship’s crew, training and regular drills must be provided to ensure correct usage.

These results identify 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 this study all evacuation personnel were in good health.

**Using Test Results in Simulation**

A simulation was setup with commercially available marine evacuation simulation software maritimeEXODUS. The representation of an MES within maritimeEXODUS is presented in Figure 8, which shows a portion of the embarkation deck and two liferafts attached to a collection platform; an arrangement similar to the test setup at OSSC.
The flow rates into the collection platform and the liferafts are defined as attributes of the equipment. Findings from the research trials described in this paper were incorporated within *maritime*EXODUS by appropriate definition of each attribute.

The simulation of evacuating stretcher cases may require an analysis separate from the main body of a ship evacuation simulation, unless an MES dedicated to the evacuation of only injured or physically impaired individuals is assumed. The main body of simulations would focus on the evacuation of able bodied personnel supplemented by stretcher case simulations. Figure 8 would represent a situation in which 10 individuals would require evacuation via stretcher using a 30m slide. Simulation results indicated that these 10 stretcher cases would increase the evacuation time of a ship by 12 to 23.5 minutes (Figure 9).

![Figure 8: *maritime*EXODUS representation of a MES](image)

**Figure 8**  *maritime*EXODUS representation of a MES

**Figure 9**  Distribution of simulated evacuation time for 10 stretcher cases on a slide
CONCLUSIONS

This paper has summarised results from several studies at the Offshore Safety and Survival Centre of Memorial University of Newfoundland to quantify human performance during the ship abandonment process. The focus of the research was abandonment of passenger vessels with the expected untrained and ambulatory subjects. A small number of tests were undertaken with trained subjects and non-ambulatory cases. Four types of life saving appliances were utilized – slide, chute, totally enclosed lifeboat and davit launched liferaft.

Results from the research indicate that:

- males are generally faster than females in abandonment for untrained persons,
- abandonment time increases with age for untrained persons,
- seating time in floating liferafts decreases as the liferaft becomes full,
- trained subjects are able to egress through vertical chute systems roughly twice as fast as untrained subjects,
- non-ambulatory passengers loaded in stretchers should not be evacuated through vertical chutes of the type used in this study, and
- non-ambulatory passengers loaded in stretchers can be evacuated on slides, however simulations indicate that the overall evacuation process will be slowed considerably.

Additional research is needed to properly define potential scenarios and quantify human abandonment performance for a wider spectrum of LSAs and environmental conditions. Such effort would permit accurate simulation of ship evacuation and suggest areas for additional crew training to ensure safe, effective and efficient response to emergencies at sea.

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REFERENCES


