PERFORMANCE OF TWIN FALLS DAVIT & LIFEBOAT EVACUATION SYSTEM IN EXTREME SEAS

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Performance of Twin Falls Davit & Lifeboat Evacuation System in Extreme Seas

by

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Abstract

Evacuation system performance deteriorates as weather conditions worsen. A research program based on model scale tests of a twin falls davit evacuation system has quantified how prevailing weather affects performance. To do this, several measures of performance were proposed and their utility confirmed. Specifically the research reported here investigated performance of a twin falls davit system in extreme weather conditions. In addition, performance effects on wave steepness and lifeboat orientation were determined. Results are presented and discussed in the context of goal-based decision making.

Acknowledgements

Financial support of this work was provided by several organizations: the Petroleum Research Atlantic Canada, the Government of Newfoundland and Labrador, Transport Canada, Natural Resources Canada, the Canadian Association of Petroleum Producers, and the National Research Council of Canada. Representatives of the supporting organizations helped to shape the research program, as did stakeholder organizations, particularly those at the Canada-Newfoundland Offshore Petroleum Board, Petro-Canada, and the Department of Mines and Energy. The author acknowledges with gratitude the contributions and financial support.

The author would like to thank Dr. Brian Veitch and Dr. Bruce Colbourne for their supervisory support in the preparation of this thesis. In addition, the author would also like to thank Antonio Simões Ré for his continued advice and mentorship and Dr. Leonard Lye for his assistance with the statistical analysis. A final thanks is extended to the technical staff of the model preparation shops, electronic shops, and the Ocean Engineering Basin at the Institute for Marine Dynamics, National Research Council.

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Section 1.0

1.0 Introduction

1.1 Background

In the past two decades there has been a growing concern about the safety of offshore oil workers, and in particular the relative operational safety of evacuation systems presently installed on offshore oil platforms. Some in the shipping industry have also raised similar concerns, but it has been the offshore oil industry that has taken the lead on this issue. With the growing offshore oil production activity off the east coast of Newfoundland and Labrador, and Nova Scotia, Canadian federal and provincial governments and regulators have deemed it necessary to re-examine safety systems on offshore platforms.

Many of the concerns about safety have been pushed to the forefront by offshore oil production accidents, which have resulted in the loss of many lives. Invariably, even after 20 years, it is the loss of the offshore drilling rig the *Ocean Ranger* that is still remembered by the Newfoundland people and Canadian offshore oil industry. This installation capsized in a storm on February 14, 1982 resulting in the deaths of the entire 84-man crew. The drilling platform was outfitted with four evacuation systems. Thirty-one members of the crew were able to successfully launch one of the totally enclosed motor propelled survival craft (TEMPSC). These crewmembers perished during a rescue attempt by a supply vessel. Two of the lifeboats were never found and the fourth was discovered floating up side down and damaged beyond usefulness.

After the incident, a Royal Commission (1984 –85) was formed to investigate the cause of the accident and subsequently made recommendations concerning deficiencies in the rig design and the safety and evacuation systems onboard. In general, the Royal Commission recommended that improvements be made to personnel safety training and that the evacuation process be researched.

In 1999, fifteen years after the *Ocean Ranger* disaster, the Institute for Marine Dynamics (IMD) organized an offshore safety workshop. The workshop discussions quickly drew consensus from all attendees that there was a strong need for more research into the areas of escape, evacuation, and rescue (EER). The necessity for more research was also strongly endorsed by the offshore regulators. Their need for information was driven by a move away from existing prescriptive regulations and toward a goal-setting regime or performance standards as recommended by the Royal Commission.

Prescriptive or compliance based regimes are generally set up such that the regulations or laws are described and implemented in technical detail. Prescribed regulations usually state specifically the type and numbers of equipment or standard procedures that operators and designers must adhere. Goal-setting regimes are more general in nature, specifying objectives and the assignment of responsibility for reaching them. The operator or duty holder has the responsibility to meet broadly stated goals, or expectations, and the opportunity to establish the most effective means by which to achieve or exceed them. To foster such a regime however, requires reliable scientific information to assist designers and operators in formulating strategies to meet these goals, and to provide guidance to regulators to judge whether the installed systems fulfill the goals. In the absence of this information it is impossible to make objective evaluations of systems either by the designers or regulators.

For example, a goal or performance based regulation for an EER process might be expressed as: "In circumstances that necessitate a marine evacuation, personnel must have access to an evacuation system, be able to embark and launch safely, clear the installation, and survive until rescued, and to have a reasonable expectation of successfully escaping harm in the environmental conditions that can reasonably be expected to prevail during operations" (Simões Ré & Veitch. (2001)). This definition was formulated based on recommendations of the Royal Commission on the *Ocean Ranger* but could quite easily have been derived from other marine accident inquiries.

The goal-based regime does not dictate the systems or processes that are to be used; instead the operators and designers are afforded some flexibility, including the ability to adopt the best available technology. More importantly they have the ability to select systems that are best suited to a specific situation, or *fit for purpose*. To select a system that is fit for purpose and that meets the goals set out in the regulations, a means is required of objectively evaluating the capabilities of the systems available.

In response to the offshore safety workshop and the need to develop reliable information to assist with the development of goal based regulations and to attempt to meet some of the challenges put forth by the Royal Commission on the *Ocean Ranger*, a new research project was initiated. The project involves research institutions, government departments, regulators, and industry. The primary goal of the research project is to explore possible measures of performance, or benchmarks, that could be used to evaluate the capabilities of evacuation systems.

The initial phase of this research consisted of a set of trial model scale experiments of lifeboat evacuations from a floating platform (Simões Ré & Veitch 2001). These tests demonstrated that model testing was an appropriate tool for the study of evacuation, particularly for investigating performance in rough environmental conditions. Further, a collection of performance indicators was found to have practical use for evaluating evacuation capabilities. The trial experiments provided guidance for the second phase of the research program.

The next phase of the research consisted of a set of model scale experiments using a twin-fall davit TEMPSC system launched from a fixed platform (Simões Ré et al. 2002a). Four test configuration parameters were varied: the weather conditions (calm water to Beaufort 8), the deployment height, the clearance from the platform, and the orientation of the TEMPSC with respect to the platform. These experiments confirmed that the performance measures adopted in the first phase of the project continued to show practical utility. Indeed, from these tests it was possible to show how the performance measures could be used as possible design tools (Simões Ré et al. (2002a, 2002b)). The goal of the third phase was to investigate the performance of the twin fall davit system in extreme weather conditions, which is the focus of this thesis.

1.2 Purpose

The primary purpose of this research is to establish the capabilities of a twin fall davit system in extreme weather conditions, using previously established measures of performance, and to critically examine the suitability of these measures. Additionally, the effects of wave steepness and orientation were also considered to be important parameters to be investigated, in terms of evacuation system performance.

1.3 Scope

This research consisted of a systematic series of model scale experiments. The type of evacuation system used was the twin-falls davit launched TEMPSC (see figure 1.1), deployed from a stationary platform. Of interest were the launching phases that consisted of deployment, splash down, and sail away of the lifeboat. The escape and rescue portions of the evacuation sequence were not considered.

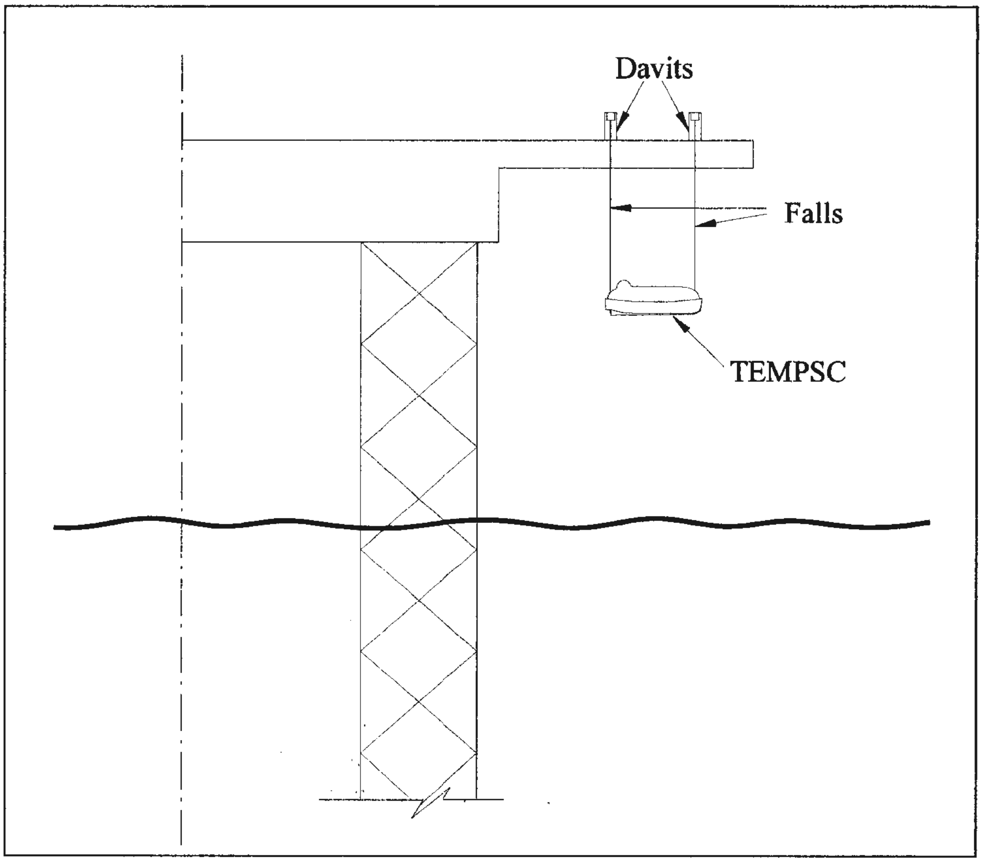


Figure 1.1: Typical twin falls davit launch illustration

Since the focus was on the extreme weather conditions, only Beaufort 6 to Beaufort 9 weather conditions were used during the testing. Some calm water tests were also performed to provide base line data. Due to the operating envelope of the Offshore Engineering Basin tank, in which the experiments were performed, two model scales were necessary. A 1:13 scale model was used in Beaufort 6 to Beaufort 7 weather conditions, and a 1:20 scale model was used for Beaufort 7 to Beaufort 9 conditions. The four variable test configuration parameters were wave steepness, orientation, deployment height, and regular and irregular wave types. The clearance of the TEMPSC was not a test variable. However, it was necessary to increase the clearance part way through the tests to ensure that the model was not damaged during testing.

Simões Ré & Veitch (2001) laid out the limitations of model testing safety systems at some length. No attempt was made to model the reliability of evacuation technology, nor account for the role of maintenance, although these are important. Likewise, human factors cannot be treated in physical model tests, so no account was taken of the effects of human behavior, training, or human physiology in the experiments, although the importance of these is recognized.

Section 2.0

2.0 Extreme Environmental Conditions

As discussed in section 1, the goal of this project is to investigate the performance of a twin-fall davit lifeboat system and determine and evaluate practical measures of performance in extreme weather. Although not necessarily restricted to one geographical area, the prevailing extreme weather off the east coast of Canada is of particular interest. Therefore an investigation of the prevailing weather conditions was performed with focus concentrated on the extremes. This section explains the statistical process and the results of this investigation.

2.1 Extremes

2.1.1 Extreme Conditions

There are many factors that influence the design of an offshore installation and selection of safety equipment. These factors broadly include, depth of water, size of the oil field, the nature of the oil and gas present, and the environmental conditions. It is the final factor, the combination of wind and waves that is of interest for this work, and more specifically the extreme weather conditions.

The term extreme weather, is a general term, and needs to be defined in more detail. Before defining the wave and wind components, some discussion of what is meant by an extreme weather condition is necessary.

When describing weather conditions at sea it is common to use a scaling system called the Beaufort scale. Also known as the Beaufort wind force scale, this system categorizes ranges of wind and wave conditions on a scale of zero to twelve, with zero as the least severe and twelve as the most severe. The scaling system is illustrated in Appendix A.

Extreme weather conditions could be defined objectively as any condition that reaches some high Beaufort condition. For instance, one might define a Beaufort 7 to be an extreme weather condition. Although a Beaufort 7 condition is a severe condition with winds in the range of 28 to 33 knots and a significant wave height of 18ft (5.5m) to 26ft (7.9m), it might not necessarily be an extreme condition for some localized area. Alternatively for a given local area an extreme condition may only be a Beaufort 5 condition. A more robust means of defining an extreme weather condition is necessary.

In the field of probabilistic statistics, there is a method of determining extremes. This method involves calculating the probability of individual random events. These probabilities can be either illustrated as a probability distribution function (pdf), or as a cumulative distribution function (cdf). The pdf and cdf give a complete description of the probability distribution of a random variable, which is in this case the environmental condition. The cdf is of particular interest when considering extremes. From the cdf, it is possible to determine the events that have a less than 10% probability of occurrence. So the severe weather conditions that have a less than 10% probability of occurring could be considered to be the extreme weather conditions. The 10% value is arbitrary and may be higher or lower depending on the probability of occurrence that is required.

2.1.2 Scope of Environmental Conditions

The scope includes the analysis of environmental data taken from the geographical areas described in section 2.1.4. The following information is synthesized and presented:

- ☐ Joint probability of significant wave height and wind as well as significant wave height and peak period.
- ☐ Significant wave height, peak period, and wind velocity probability distributions.
- ☐ Exceedance probability.
- ☐ Prediction models for significant wave height versus wind speed, and significant wave height versus peak period.

In addition, the entire data set was categorized into a standardized scale, which in this case is the Beaufort scale. Putting the data into the Beaufort scaling system is done to simplify the reporting of the weather condition.

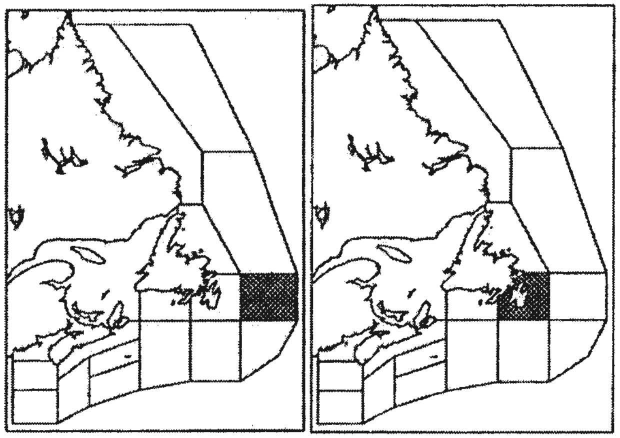
2.1.3 Data Source

All of the data was obtained from the Wind and Wave Climate Atlas Volume I, published by Transportation Development Center (MacLaren Plansearch (1991) Limited). This publication is not raw data from wave rider buoys or hind cast prediction analysis. Instead, the data is already compiled and prepared in data tables with mean values, standard deviations, monthly wind speeds, significant wave heights, and peak period distributions. More importantly, the joint probability observations are tabularized for the significant wave height – peak period, and the significant wave height – wind velocity.

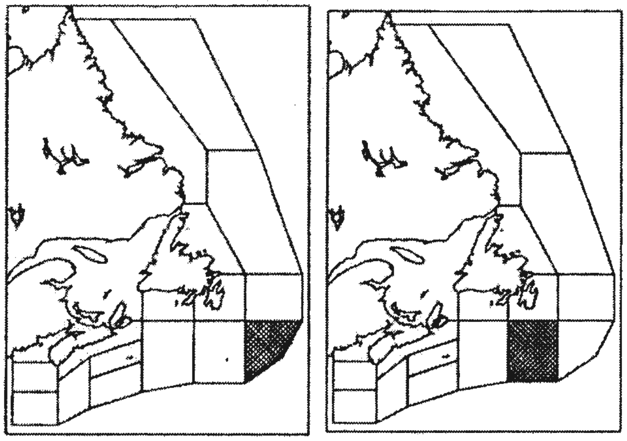
2.1.4 Geographical Region

The Grand Banks, cover approximately 45°N – 48°N latitude and 48°W- 52°W and encompass about 130,000 km^2. The bottom structure is a series of submarine planes or plateaus with water depths ranging from 36.5m to 185m.

The Environment Canada data is segmented into approximate rectangular areas and not all of these areas were included in the study. Only the areas important to the offshore oil industry were investigated. Graphical representation of the individual areas is shown in figure 2.1.



Northern Grand Banks South East Coast



South East Grand Bank South West Grand Banks

Figure 2.1: Geographical areas (Grand Banks)

2.2 Grand Banks Weather Conditions

To begin the investigation of environmental conditions, plots of the annual probability distributions for significant wave height, wind velocity, and peak period were prepared. The probability density distribution for the significant wave height is shown in figure 2.2 with the cumulative probability distribution shown in figure 2.3. The cumulative distribution plot shows the measured data and the fitted Rayleigh distribution indicated by the dashed line. The Rayleigh distribution is commonly used to describe wave distributions, and as shown, describes the significant wave distribution for the Grand Banks region very well.

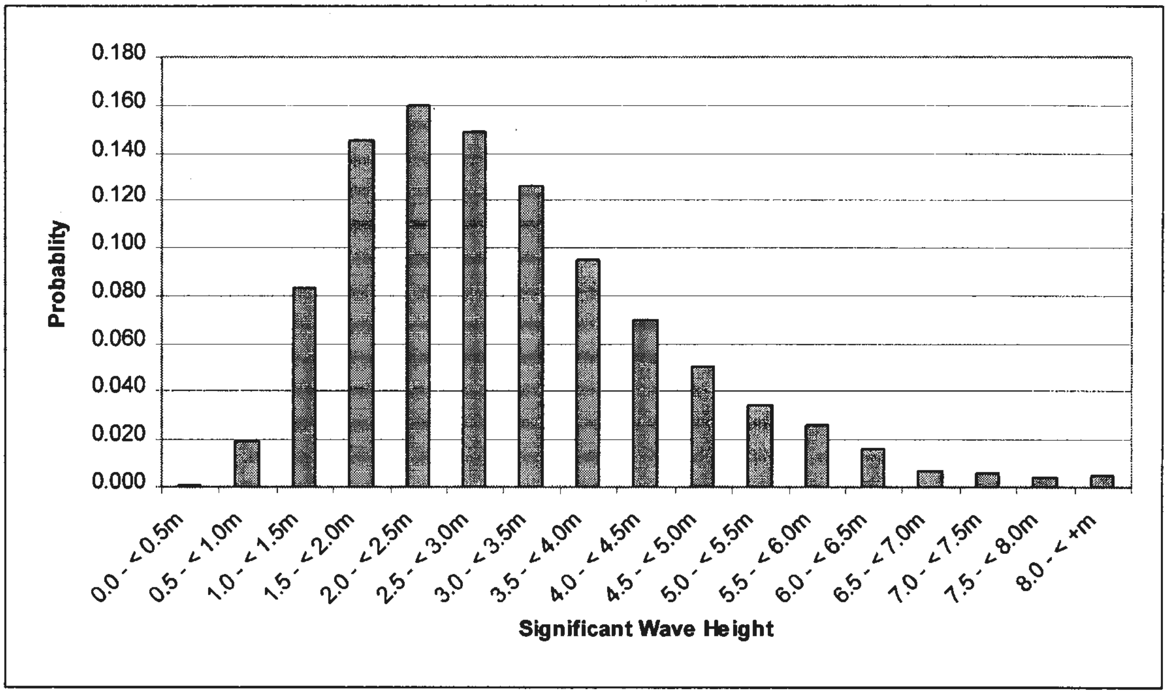


Figure 2.2: Probability distribution of significant wave height distribution

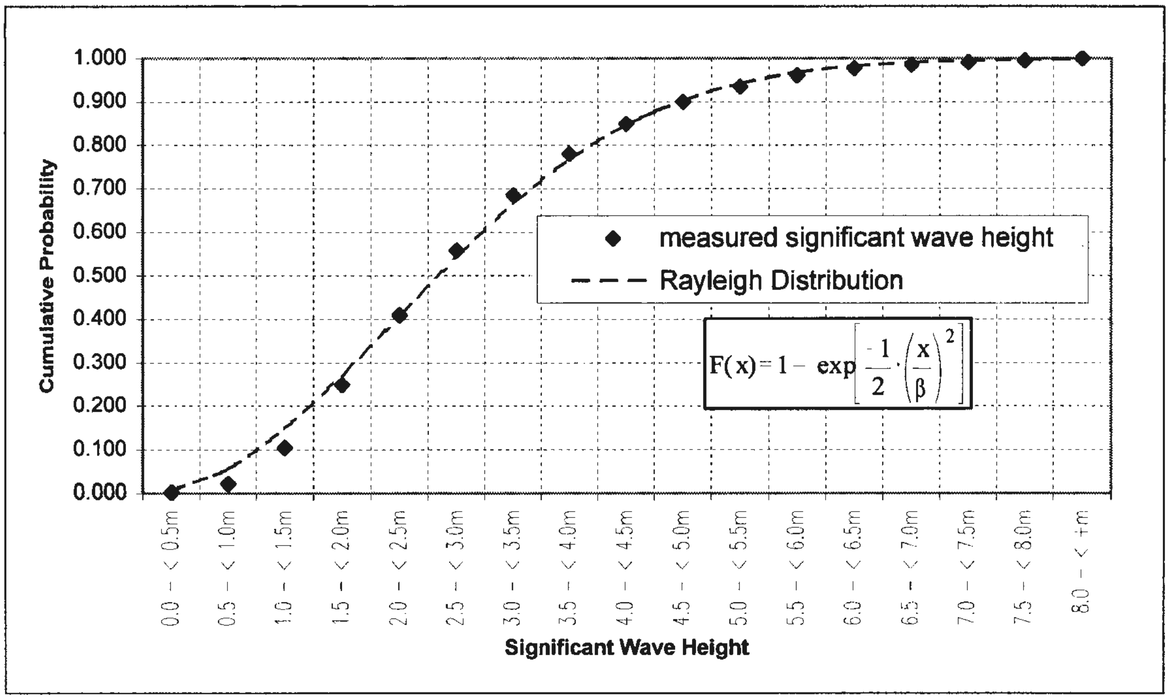


Figure 2.3: Cumulative distribution of significant wave height

The Rayleigh function for the cumulative distribution is shown in equation (2.1), with β= 2.20 for the significant wave height. The β value, a constant that adjusts the shape of the distribution, is determined through trial and error to provide the best fit to the data.

$$F(x)=1-\exp\left[\frac{-1}{2}\left(\frac{x}{\beta}\right)^2\right] \quad \text{-----}\ (2.1)$$

$$\beta=2.20$$

Figure 2.4 shows the probability density for the wind speed. The cumulative probability is shown in figure 2.5, and similar to the significant wave height distribution, the wind speed distribution also closely follows a Rayleigh distribution, having β=12.91.

The peak period probability density and the cumulative density distributions are shown in figure 2.6 and figure 2.7. Unlike the significant wave height and wind speed distributions, the peak period distribution appears to be very close to a normal distribution. As illustrated in the cumulative probability plot, the normal distribution matches very closely to the measured data, with a slight offset, which is a result of the slightly skewed measured data.

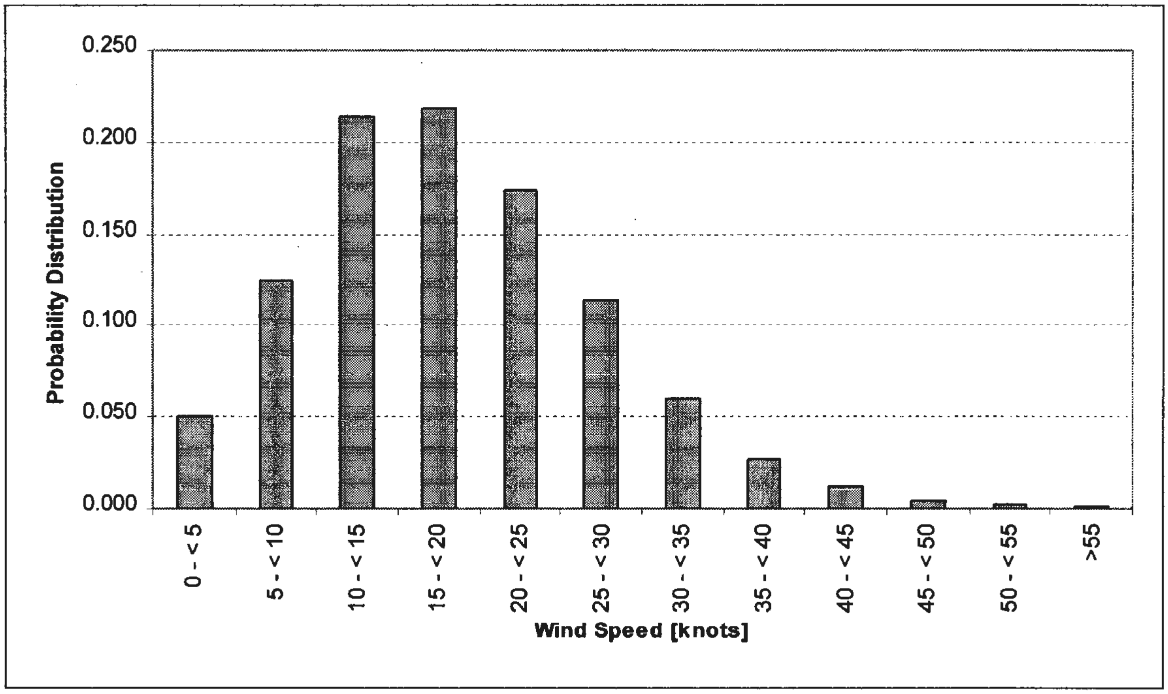


Figure 2.4: Probability distribution of wind speed

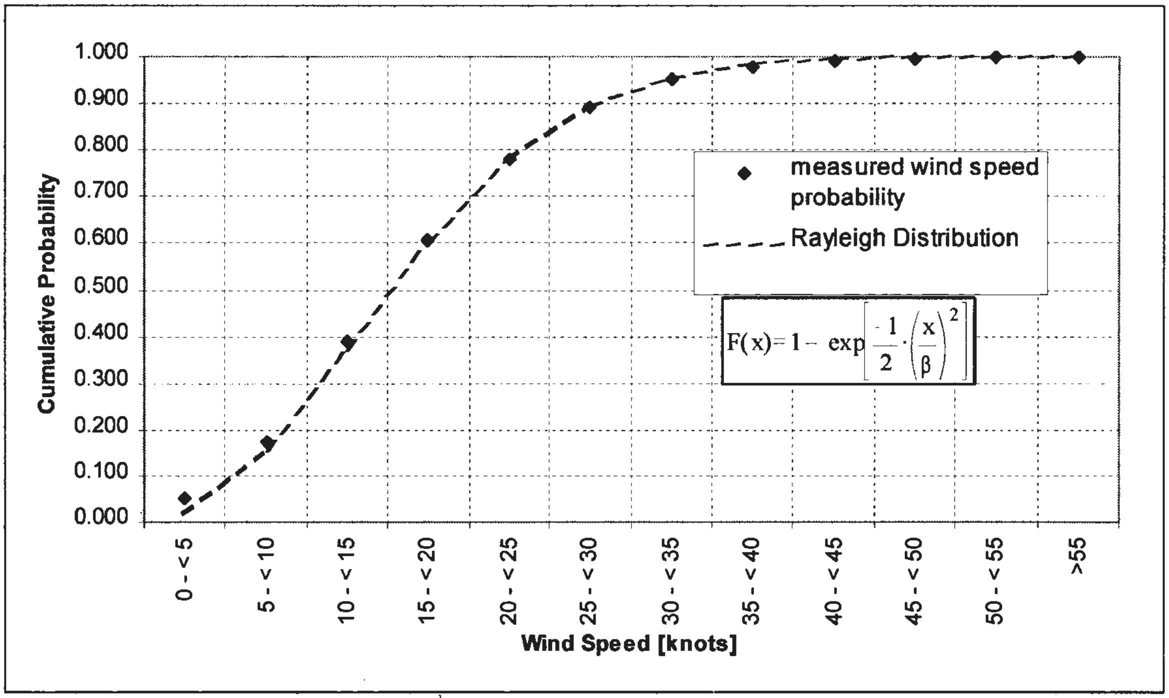


Figure 2.5: Cumulative distribution of wind speed

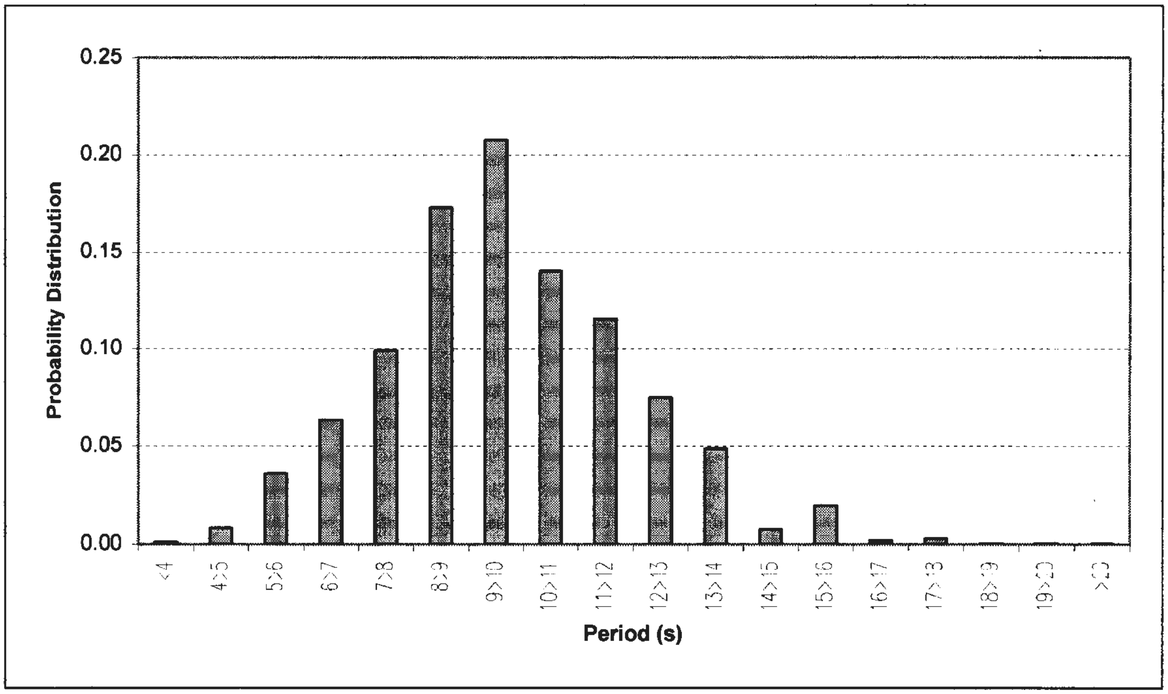


Figure 2.6: Probability distribution of peak period

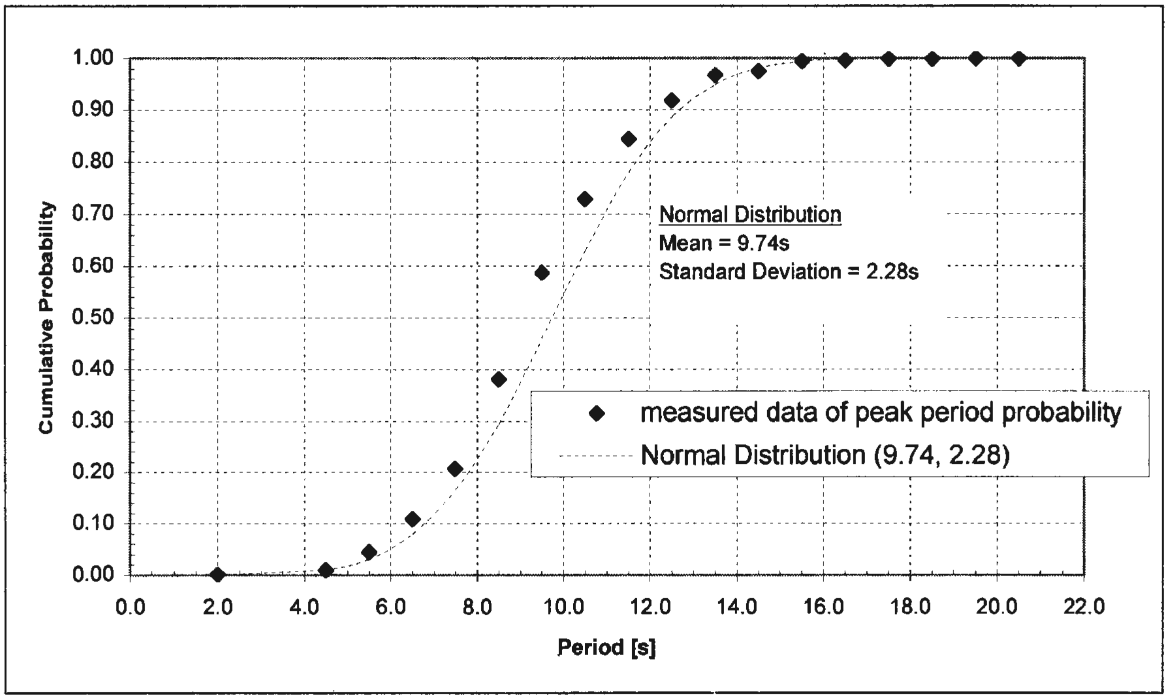


Figure 2.7: Cumulative distribution of peak period

With the distributions established, it is possible to determine mean values and standard deviations. These calculated parameters are listed in table 2.1. The complete table can be found in appendix B.

Table 2.1: Mean, variance, and standard deviation values

Item	Mean	Variance	Standard Distribution
Significant Wave Height [m]	3.094	1.994	1.41
Wind Velocity [knots]	18.44	84.44	9.19
Peak Period [s]	9.74	5.21	2.28

The next step in the analysis involved investigating the joint probability between the significant wave height and the wind velocity, as well as the significant wave height and the peak period. The legends for both the joint probability of significant wave height and wind speed and the joint probability of significant wave height and peak period are provided in figures 2.8 and 2.9. The joint probability of the significant wave height and wind speed is shown in figure 2.10 and the joint probability tables are provided in appendix B. The plot is a contour plot with the probability of occurrence indicated by the shaded regions. The numbered rectangular regions indicate the Beaufort scale ranges with respect to the significant wave height and the wind speed. The plot shows that there are large gaps within the scale especially near the highest probability sea conditions. This issue will be revisited later.

■ 0.0500-0.0600
■ 0.0400-0.0500
■ 0.0300-0.0400
■ 0.0200-0.0300
■ 0.0100-0.0200
□ 0.0000-0.0100

Figure 2.8: Legend for joint probability of significant wave height and wind speed plots

■ 0.035-0.04
□ 0.03-0.035
□ 0.025-0.03
■ 0.02-0.025
■ 0.015-0.02
■ 0.01-0.015
■ 0.005-0.01
□ 0-0.005

Figure 2.9: Legend for joint probability of significant wave height and peak period plots

A closer inspection of the contour plot shows that there is an identifiable trend indicated by the black line. The wave height probability increases linearly with the wind speed up to a value of 6.0m significant wave height, and 35 knots of wind. Beyond these levels the probability of occurrence drops below 0.5%. Also, drawing attention to the lower left portion of the graph, it is interesting to note that there is a 1% - 1.5% annual probability (4 – 5 days) that there is no wind, yet there is a significant wave height of 1.0m – 3.5m. In addition, by comparing this probability to the probability of both calm wind and wave conditions (less than 0.5% of the time (1-2 days) it can be concluded that there is almost always some wave action, whether there is wind or not. Taking into account the location of the Grand Banks, a possible reason for this could be due to the long fetch waves traveling from other regions. When these waves hit the shallow water, the waves increase in height due to bottom effects. Therefore, significant waves heights in the range of 1.0m to 3.5m can be experienced without the influence of wind.

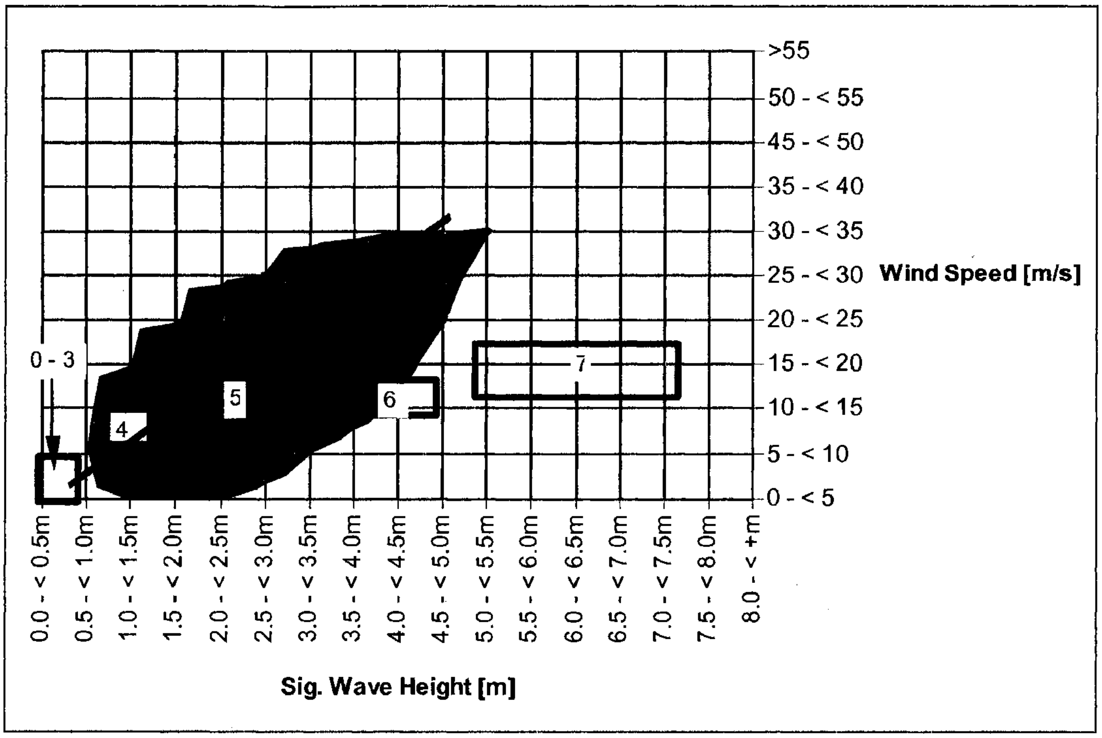


Figure 2.10: Joint probability of significant wave height & wind speed

The joint probability of the significant wave height and peak period is shown in figure 2.11. This joint probability plot indicates an increasing linear trend up to a peak period of about 12s to 13s. At 12s to 13s the peak period probability does not continue to increase with an increase in significant wave height. Instead, the peak period probability levels off, and from this, it can be concluded that there is some limiting factor (possibly the water depth) that keeps the peak period at or below 12s to 13s, even with significant wave heights of up to 8m.

Next, the annual exceedance probabilities are considered separately for each environmental parameter. The significant wave height probability of exceedance plot in figure 2.12, the wind speed probability of exceedance plot in figure 2.13, and the peak period plot in figure 2.14, are summarized below in table 2.2.

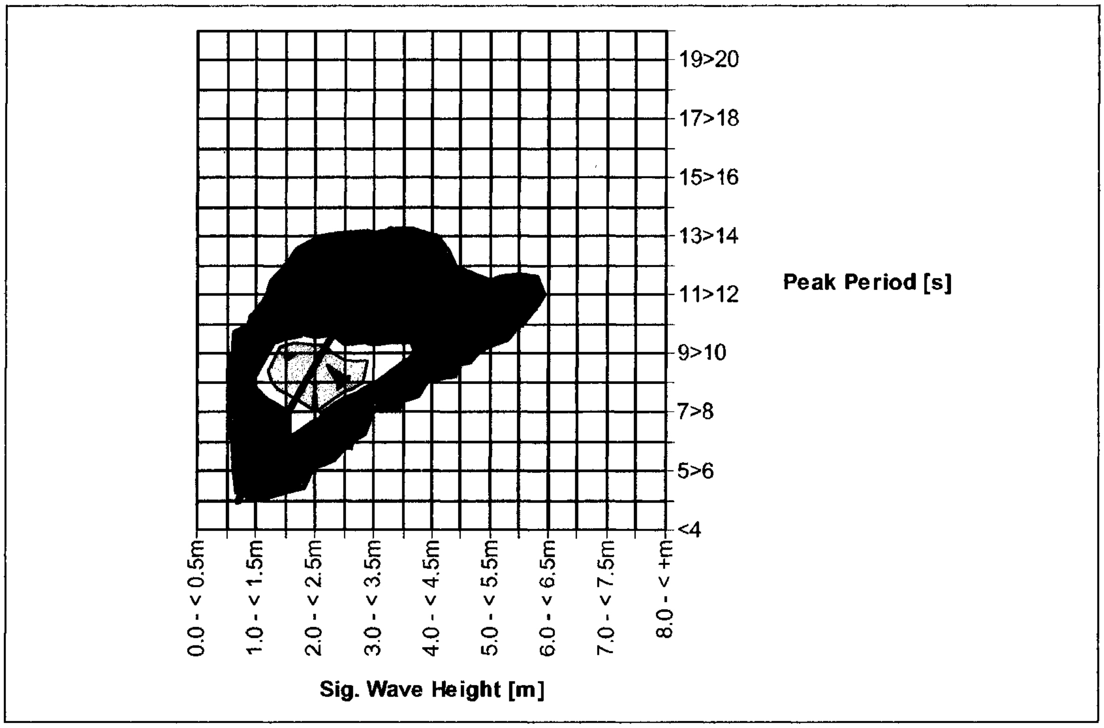


Figure 2.11: Joint probability of significant wave height & peak period

The annual exceedance plots are useful in that they indicate the probability of extremes. For example, using the information provided in table 2.2, one can conclude that for 90% of the year the significant wave height is less than 4.75m, the wind velocity is less than 28 knots, and the peak period is less than 12.5s. The extreme values then are all greater than this, depending on the percent exceedance considered.

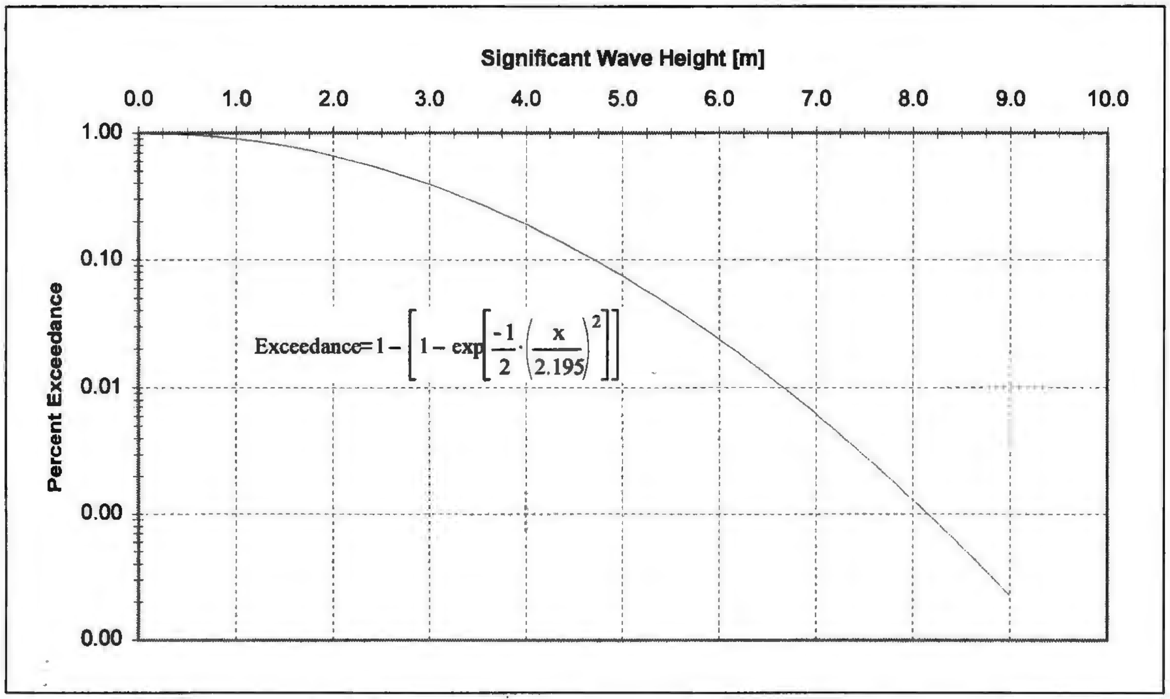


Figure 2.12: Significant wave height probability of exceedance

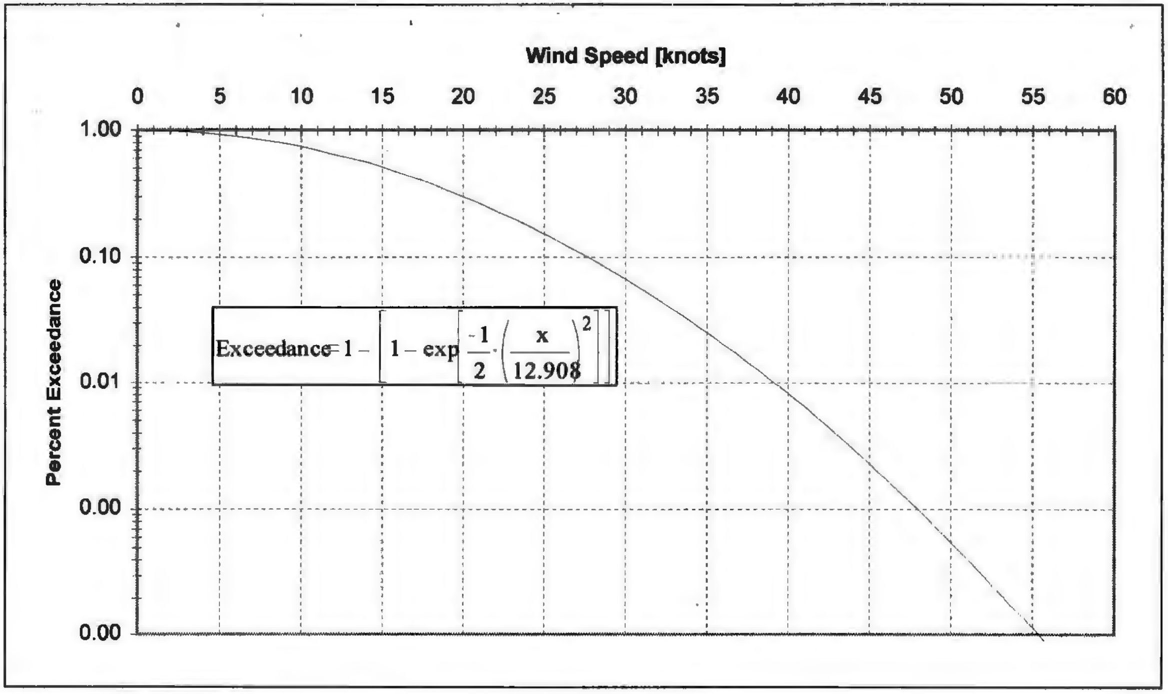


Figure 2.13: Wind speed probability of exceedance

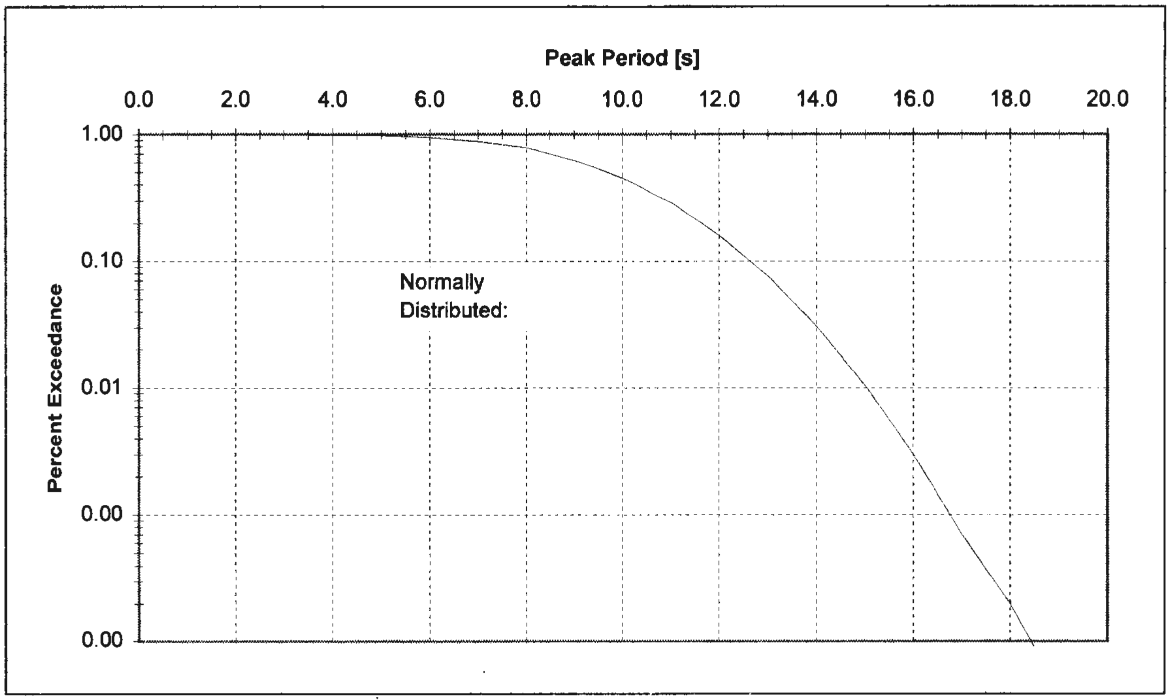


Figure 2.14: Peak period probability of exceedance

Table 2.2: Exceedance probabilities

Probability	Sig. Wave Height [m]	Wind Velocity [knots]	Peak Period [s]
10%	> 4.75	> 28	> 12.5
1%	> 6.6	> 39	> 15
0.1%	> 8.2	> 48	> 17

Environmental prediction models were generated using the joint probability data. These probability prediction models were created using the statistical theory of correlation values. The correlation value, r_{xy}, was calculated using equation (2.2) shown below.

$$r_{xy} = \frac{\sum_{i} \left[\left(x_i - x \right) \left(y_i - y \right) \right] \cdot p_{ij}}{S_x \cdot S_y} \qquad ....(2.2)$$

Where: x_i & y_j = i^{th} & j^{th} value
x & y = mean values
p_{ij} = joint probability of x_i & y_j
S_x = Standard Deviation of x
S_y = Standard Deviation of y

The correlation value is used to calculate the slope of a model prediction line using equation (2.3).

$$b = r \cdot \frac{S_y}{S_x} \qquad ...(2.3)$$

Where b = slope
r = correlation value
S_x = Standard Deviation of x
S_y = Standard Deviation of y

Using basic algebra, the intercept is calculated. The final prediction models are shown in figures 2.15 and 2.16. Both prediction models assume that the significant wave height is known. From the significant wave height, the corresponding most probable wind velocity and peak period can be derived. It is important to note that the corresponding values are the most probable values and in reality variations will be observed.

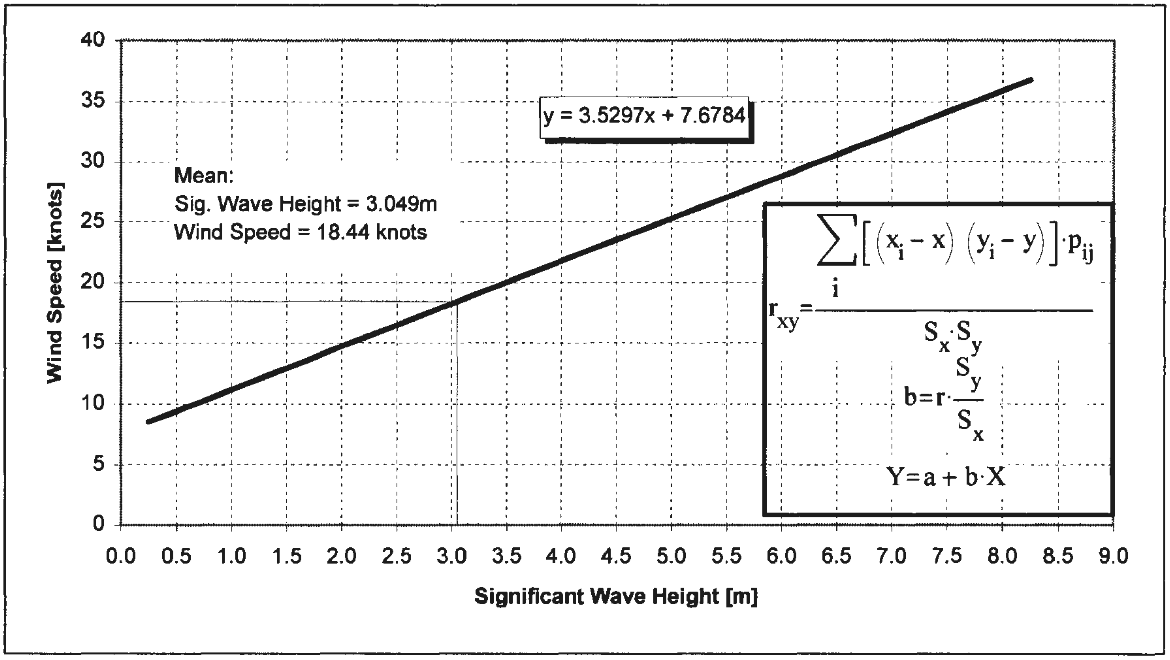


Figure 2.15: Wind speed versus significant wave height model

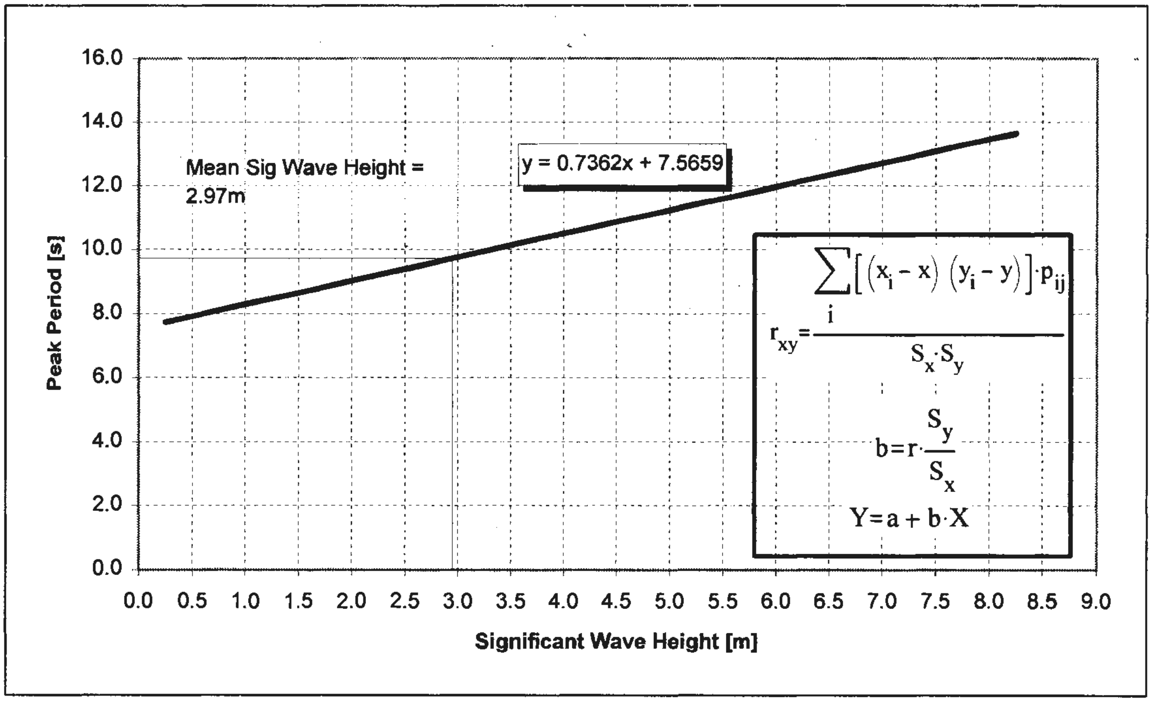


Figure 2.16: Peak period versus significant wave height model

As indicated earlier, using the Beaufort scale to describe the sea conditions in the region under consideration (see figure 2.8) results in large gaps. For example, if the prevailing sea condition at any given time has a significant wave height of 1.5m to 3.0m, a peak period of 7s to 8s, and a corresponding wind speed of 10 to 15 knots, it is impossible to categorize the sea condition with reference to the Beaufort scale. The sea condition would fall between Beaufort 4 and Beaufort 5. Yet this sea condition has the highest probability of occurrence in the region under consideration. It was therefore decided to create a new scale that would cover the range of highest probable sea conditions prevalent to the Grand Banks region. The new scale is shown graphically with the joint probability plots in figures 2.15 and 2.16. The new scale is also illustrated numerically in table 2.3.

The methodology used in determining the new scale was based entirely on the joint probabilities of the significant wave height – peak period, and the significant wave height – wind velocity. It was deemed important to use the joint probabilities to ensure that all the most probable conditions were included.

Table 2.3: Grand Banks scale

Grand Bank	Sig. Wave Height [m]	Peak Period [s]	Wind Speed [knots]
1	0 - 0.5	0 – 4	0 - 5
2	0.5 - 4.0	0 – 7	0 - 5
3	0.5 - 2.5	6 – 9	6 - 15
4	2.5 - 5.0	6 – 9	6 - 15
5	0.5 - 3.5	9 – 12	16 - 25
6	3.5 - 5.5	9 – 12	16 - 25
7	2.0 - 4.5	12 – 15	26 - 35
8	4.5 - 6.5	12 – 15	26 - 35
9	4.0 - 8.0	15 – 20	36 - 55
10	> 8.0	> 20	> 56

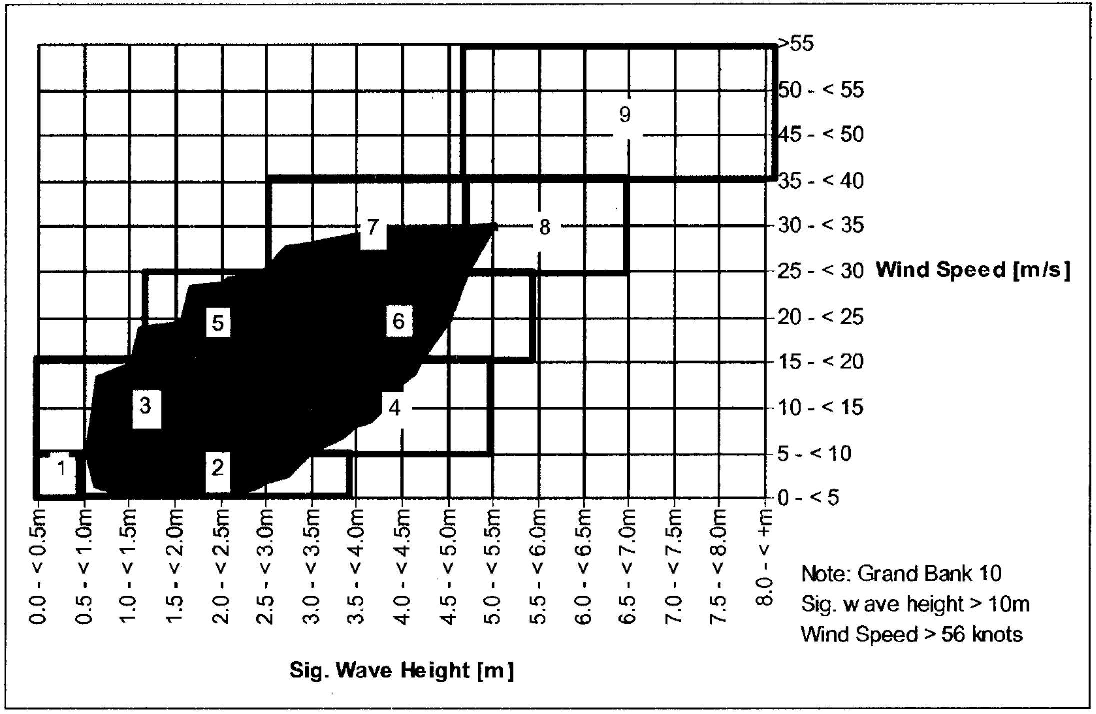


Figure 2.17: Grand Banks scale (significant wave height & wind speed)

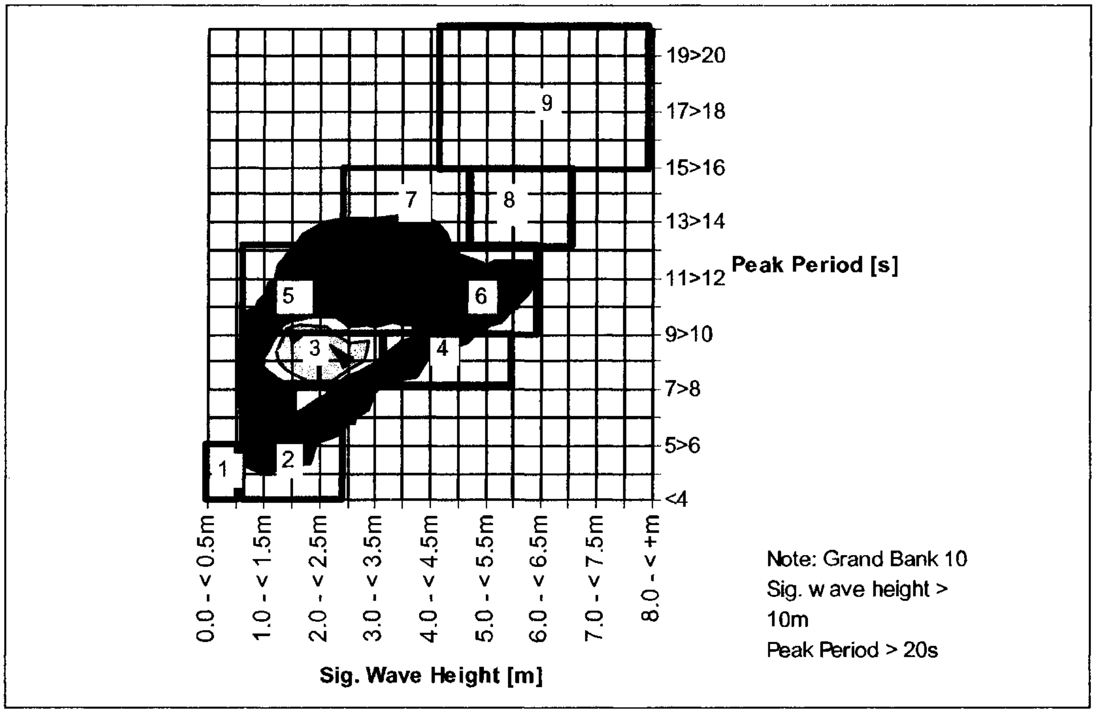


Figure 2.18: Grand Banks scale (significant wave height & peak period)

The significant wave height was common to both; therefore it was used as the basis for the new scale. The intervals used were determined arbitrarily, with an attempt to make them as equal as possible between the scales GB 3 to GB 8. The end values GB1, GB2, GB9, and GB10 had to be different due to the nature of the distribution of the environmental parameters. More wave parameters such as modal period, average wave height, and wind gust velocity could be incorporated into the scale if the observational data and joint probabilities were available.

2.3 Extreme Weather Conditions

2.3.1 Grand Banks Weather Conditions

The distributions of the significant wave height and wind velocity both follow Rayleigh distributions, which is common for wave and wind velocity distributions. The peak period is approximately normally distributed with a slight skew in the data.

The joint probabilities show well-defined linear trends across the contour plot. The significant wave height and wind velocity joint probabilities show that there is almost always some wave action even without the presence of wind. The significant wave height and peak period joint probability indicate a limiting factor that keeps the peak period from extending past 12s to 13s.

The probability of exceedance analysis provides clear information about the nature and values of the extreme conditions. On average, the significant wave height is not greater than 4.75m, the wind velocity is not greater than 28 knots, and the peak period is not greater than 12.5s.

The environmental model prediction charts were obtained using statistical analysis. These charts provide the ability to generate realistic environmental conditions that would be most probable in a region under consideration. Just by knowing or assigning a significant wave height, a researcher can quickly calculate the most probable corresponding peak period and wind velocity.

Using the Beaufort scale to categorize the Grand Banks region does not adequately identify the most probable conditions that one would observe. The scale fails because it is not specific to the conditions observed, but represent a broader average of world wide sea conditions. The proposed Grand Banks scale covers all of the most probable conditions to be encountered in that region. By using the joint probabilities, one would not expect to encounter a weather condition on the Grand Banks that could not be categorized within the Grand Banks scale.

2.3.2 Extreme Weather Conditions for Testing

The model experiments for this project were completed before the study of the extreme weather conditions was finished. Therefore, in the absence of this information and since it was important to define global boundaries for all oceanographic areas, the Beaufort scale was used to determine the extreme weather conditions. The weather conditions used are described in section 3.1.3. This information is still useful and should be considered when determining weather conditions for future evacuation system experiments.

Section 3.0

3.0 Test Setup

Experiments supporting this research were performed in the Offshore Engineering Basin (OEB) at the National Research Council of Canada, Institute for Marine Dynamics (NRC/IMD). The OEB has a 65m × 26m working area, and a maximum working depth of 3m. Individual hydraulically activated wave maker segments (168) cover two adjacent sides of the basin. Opposite to the wave makers, expanded sheet metal passive wave absorbers are fitted to reduce wave reflection in the wave basin. The water depth during the tests was set at 2.8m with all waves traveling in an unidirectional pattern from the bank of wave boards on the West side of the basin as shown in the installation setup in figure 3.1

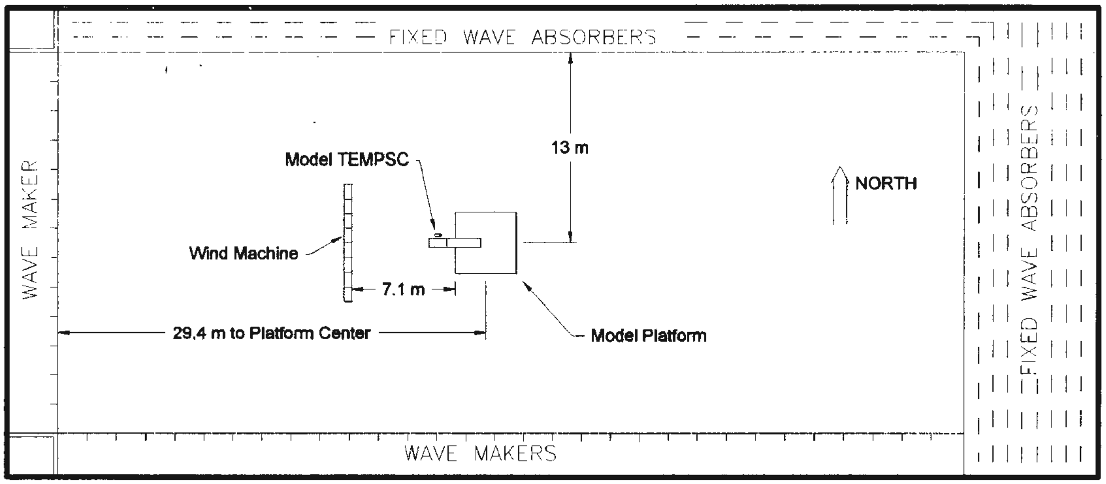


Figure 3.1: Plan general arrangement of the test setup in the OEB.

A platform was built and installed in the OEB specifically for the evacuation system experiments. The platform was a four-legged truss structure that was attached to the basin floor with concrete anchors. The legs of the platform were constructed with small diameter cylindrical members to minimize wave reflections. A fine mesh net was attached to the platform behind the TEMPSC's landing area to reduce damage to the model in the event it was pushed into or under the platform. These features are illustrated in figure 3.2.

The lifeboat station was designed and built in three modules. The davits, winches, and TEMPSC were mounted on a wooden deck, which was in turn fitted to a steel truss beam. The steel truss beam was attached to a lifting table (for vertical displacement settings) in a cantilevered arrangement, as illustrated in figure 3.2. The modular arrangement allowed rapid changes to be made to the configuration of the lifeboat station. All the setup arrangements are shown in appendix C.

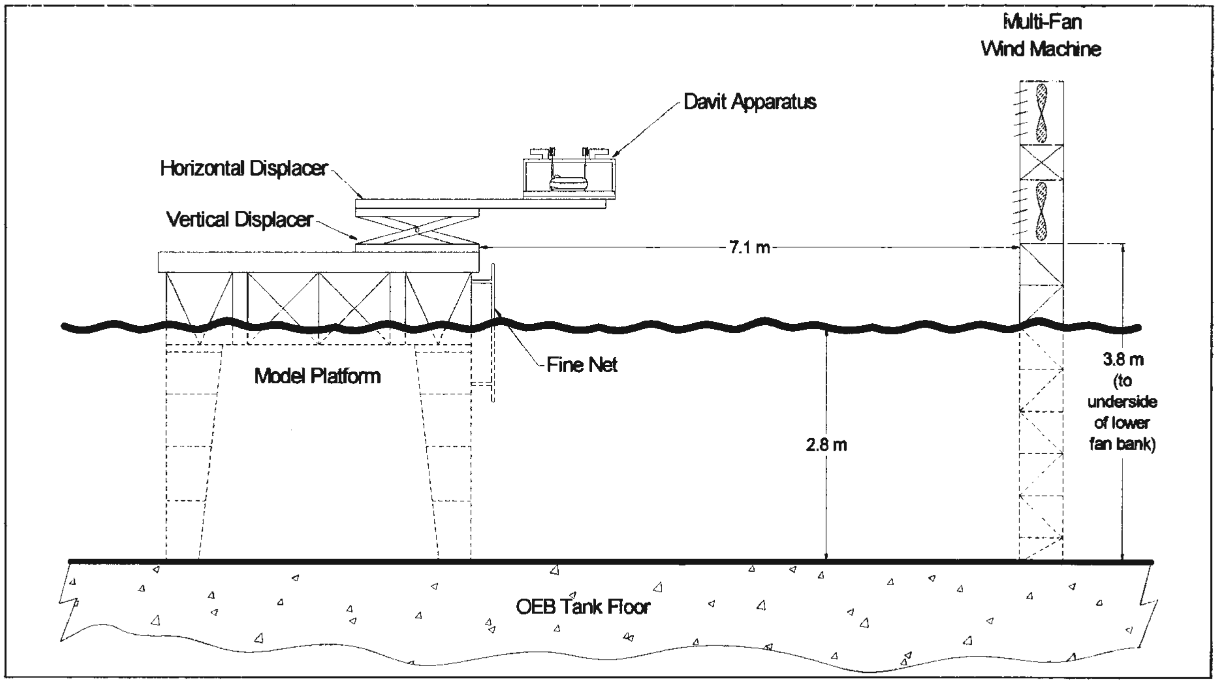


Figure 3.2: Elevation general arrangement of the test setup in the OEB.

Two different launch orientations were tested: one with the TEMPSC parallel to the platform, the second with the TEMPSC perpendicular to the platform. The configuration change, from perpendicular to parallel, was made by rotating the wooden deck through 90° and reconnecting it to the cantilever beam.

Similarly, changes in clearance between the platform and TEMPSC were made by moving the truss beam inboard or outboard as required, and reattaching it to the platform. Three different clearances were tested in the parallel and perpendicular orientations, corresponding approximately to $3.0\times B$, $4.0\times B$, and $6.5\text{x}B$, where B is the beam of the TEMPSC, which was nominally 3.7m (full-scale) in these tests. Figure 3.3 illustrates the clearance and the orientation configurations.

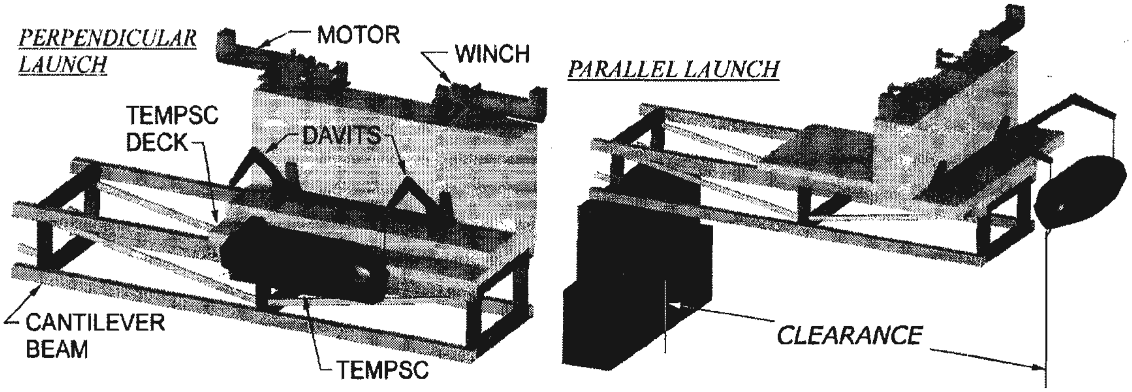


Figure 3.3: Perpendicular and parallel orientation setup.

3.1 Physical Models

3.1.1 Totally Enclosed Motor Propelled Survival Craft (TEMPSC)

Due to the operating envelope of the OEB facility, two scales for the TEMSPC were necessary: 1:13, and 1:20. Both scale models were representative of a typical 80-person craft.

1:13 Scale Model

The 1:13 scale model was constructed of glass–reinforced plastic, and had a displacement of 5.36kg. The TEMPSC model was fabricated in two halves: hull and canopy. The hull and canopy mated along the gunwale line. A rubberized gasket was used between the two to prevent water ingress.

A steerable nozzle, nozzle servo, 32mm four bladed propeller, shaft, DC motor, motor controller, receiver unit, rechargeable battery pack, accelerometers, and simulated hydrostatic interlock release unit were fitted to the hull half.

Two mechanical releases for the twin falls with interlocking mechanical release servos, a wireless video camera, and a water detection light emitting diode (LED) were fitted to the canopy half. The LED was used to signal that the hydrostatic interlock had been released so that the hooks could be released.

Styrofoam spheres covered with reflective tape were placed either on top of 75mm posts or directly attached to the canopy at several locations for use with the Qualisys Optical Tracking System (QOTS). The Styrofoam spheres had a diameter of approximately 38mm.

The TEMPSC velocity was determined by averaging the time required for the model to travel a distance of 20m. The TEMPSC model speed trials were conducted in the towing tank in calm water with the model in its test configuration and load condition.

An average speed of 6.01 knots (full scale) was achieved, which is slightly higher than the target of 6 knots that is required by international regulations (IMO 1997). The overall TEMPSC forward speed was programmed into the controller. Hydrostatics, and swing test data are provided in appendix D.

1:20 Scale Model

The 1:20 scale model was made with a thermal moulding process using styrene material. This allowed for a much lighter hull, which made it possible to put all of the instrumentation within the hull and still meet the displacement requirement of 1.5 kg. This model obtained a full-scale speed of 6.04 knots in calm water. Hydrostatic, propeller and swing data are provided in appendix D.

Similar to the 1:13 model, the 1:20 model was constructed in two halves (hull and canopy). The hull and canopy mated along the gunwale line. A rubberized gasket was used between the two to prevent water ingress.

The model was outfitted with an electric motor and shaft, a 25mm three bladed propeller, a working rudder, one rechargeable battery, a simulated hydrostatic release circuit with interlocking mechanical release servos, a radio transmitter, a wireless camera, and a water detection light emitting diode.

Styrofoam spheres covered in reflective tape were either placed on top of 75mm posts or directly attached to the canopy at several locations for use with the QOTS. The Styrofoam spheres had a diameter of 38mm.

3.1.2 Twin Falls Davit Deployment System

The deployment system was a twin falls davit system, with a totally enclosed motor propelled survival craft (TEMPSC) stowed and launched either parallel or perpendicular to the installation. The basic deployment setup is shown in figure 3.4.

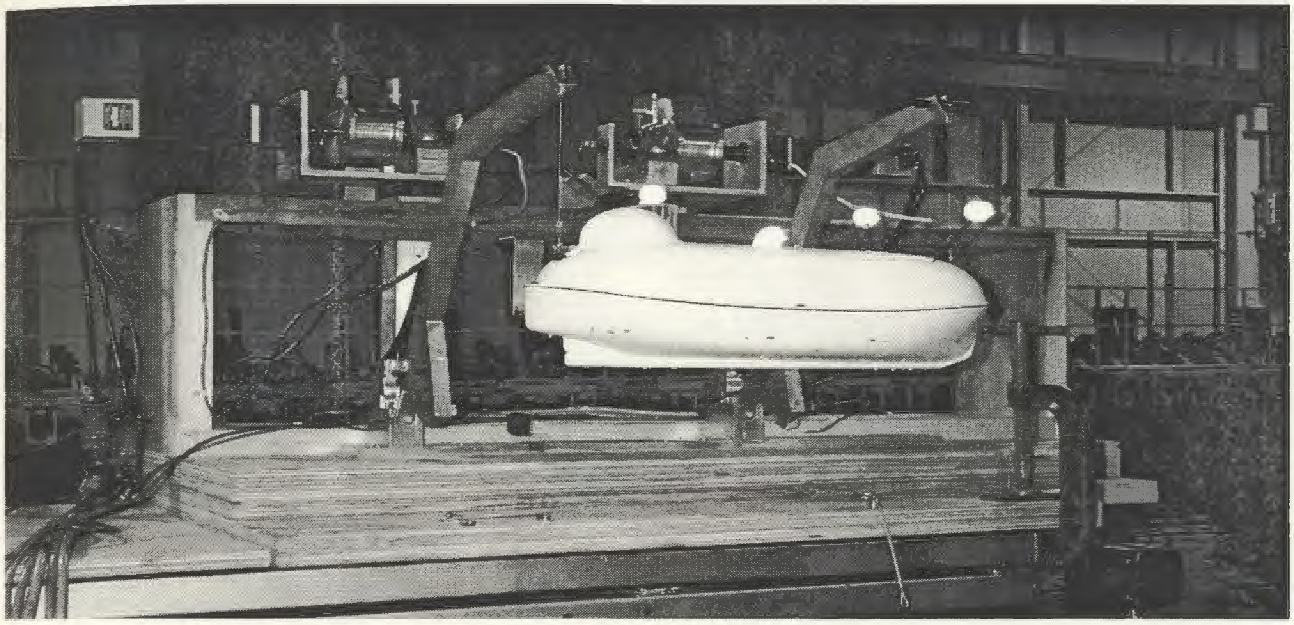


Figure 3.4: Twin falls davit system showing 1:20 scale TEMPSC model

The deployment clearances of the TEMPSC from the installation were set to 3.0x*B* (11.0m full-scale), 4.0x*B* (14.7m full scale), and 6.5×*B* (24.6m full-scale). These clearance changes were done to minimize the damage to the model due to collisions. The launch height was varied from 20m to 30m above the still water surface. Tests were done with the TEMPSC at 100% load condition.

The main components for the davit system are the winch drums for the cable storage, the winch brake for controlling the speed of decent, and the cables themselves. Cable length was modeled correctly. The other cable properties such as diameter, breaking strength, and stiffness were not modeled.

The rate of descent of the TEMPSC was controlled by programming the DC motor controller to spool out cable from the winch drums at full-scale rates ranging from 0.8m/s (deployment height of 20m) to 1.0m/s (deployment height of 30m). The lowering speed was obtained from IMO regulations.

Swivels were attached to the TEMPSC end of the davit cables. These were in turn fitted into the pins of the release blocks located at the bow and stern of the TEMPSC model. The pins of the release blocks were linked to a servomotor fitted in the TEMPSC canopy and activated from the side of the tank by a radio controller. Release of the forward and aft cables was simultaneous: no problems were encountered with the system.

3.1.3 Environmental Conditions

This series of experiments required the generation of five different environmental conditions for waves and wind (Beaufort 6 to Beaufort 9, and calm water). The nominal wave heights and wind speeds corresponding to each of the five conditions are given in table 3.1. Regular waves, and one irregular wave were used for these tests. All waves propagated normal to the platform. For the regular waves, the target wave height value was in the Beaufort scale range of significant wave height, rather than mean wave height.

The wave modeling concentrated on matching the wave height and period. The wind modeling concentrated on matching a mean wind speed. The wave matching was performed without the platform or TEMPSC model in the basin, while for the wind speed calibration the fixed installation model was secured to the basin floor in its testing configuration. The required quantities were adjusted by iteration to the desired settings and the control signals recorded for playback during the test.

The sizes of the 1:20 steepness waves and wind speeds are shown in figure 3.5, which for illustration also shows the relative size of the model TEMPSC.

Table 3.1. Target environmental conditions.

(Beaufort) Description	Mean Wind	Significant Wave	Peak Period
	[$m \cdot s^{-1}$]	[m]	[s]
(0) Calm water	0	0	0
(6) Strong breeze	12.62	3.96	7.1
(7) Moderate gale	15.60	6.71	9.3
(8) Fresh gale	17.44	9.14	10.8
(9) Strong gale	18.30	15.20	12.9

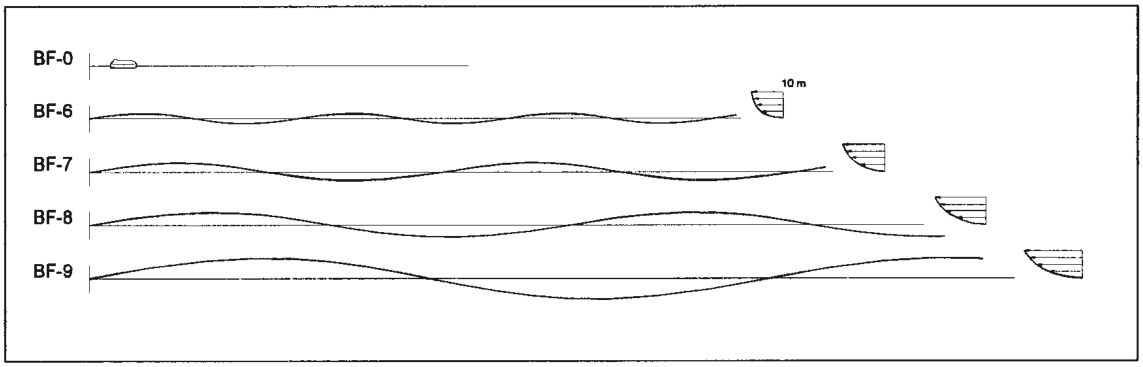


Figure 3.5: Wave profiles (1:20 wave steepness).

3.1.4 Regular Waves

Wave generation at IMD is provided by a multi-segmented hydraulically powered paddle type wavemaker. Regular waves can be generated as well as short crested or long crested irregular waves. Wave direction can be varied from 0° to 90° in the basin.

The test program required the generation of four regular waves divided into two sections according to the model scale used. This included three regular waves at the Beaufort 7 and 8 conditions at three wave steepnesses (1:20, 15, and 1:10). For each matched wave, a segment of 20 cycles was chosen to evaluate the wave parameters. The 20-cycle segment was selected by windowing through the entire time trace. The regular wave target conditions are provided in appendix E

3.1.5 Irregular Waves

The OEB facility has the ability to create irregular spectrums with a maximum wave height of 0.76m and wave directions varying from 0° to 90° degrees. The test program called for the creation of two of irregular waves with characteristics shown in table 3.2. The waves had a repeat period of 1 hour, full scale. To ensure repeatability between tests the complete spectrum was scanned for the most severe conditions. The most severe condition was then extracted from this file as a short segment called a snapshot. This snapshot segment was then used for each test. The waves were matched on significant wave height and peak period. All of the calibrations and naming conventions for both regular and irregular waves is reported in Pelley et al. (2002)

Table 3.2. Irregular waves.

Wave Type Spectrum	Significant Wave (m)	Peak Period (s)	Beaufort
JONSWAP Spectrum	10.0	12.3	8

3.1.6 Wind

Wind was simulated using a horizontal array of 12 analog-controlled fans mounted on support frames. The fans were positioned such that the wind direction was 180° to the installation at a distance of 7.10m from the front edge of the platform. Each fan had a blade diameter of 530 mm, and was powered by a DC motor capable of rotating at speeds of up to 5000 rpm. Horizontal louvers were attached to the front of the fans and were used to direct the flow in the vertical plane (i.e., wind could be directed downward/upward). The wind generator can produce winds of speed up to12 m/s at a reasonable distance to the measuring device.

The wind speed was calibrated prior to the test program with the platform model installed. The fans were run at a steady speed and adjusted so that at a distance of 7.10m, the mean wind speed was the one specified in the test program. The anemometer for calibration was 0.2m above the waterline. Figure 3.6 illustrates the setup of the wind fans in relation to the platform.

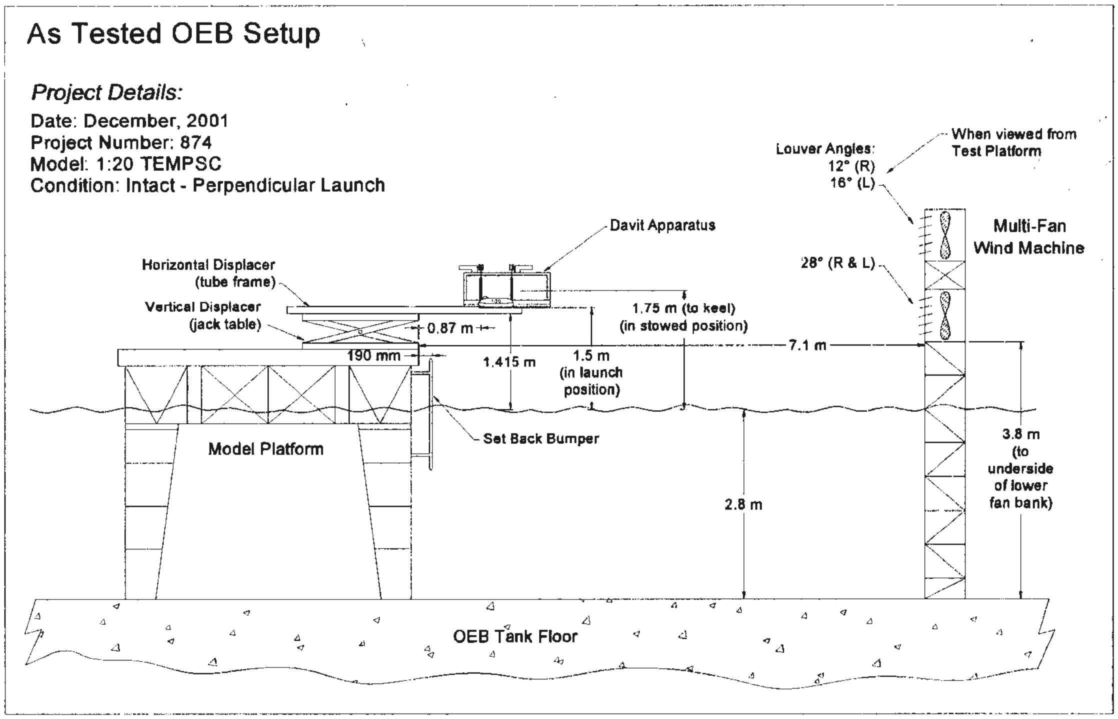


Figure 3.6: Typical setup showing location of fans.

3.1.7 Instrumentation

1:13 Model, and 1:20 Model

The instrumentation used for this series of tests consisted of the following.

1. Qualisys optical tracking system providing six degrees of freedom motions of the TEMPSC model with respect to the earth fixed coordinate system (see Section 3.1.11).
2. Four anemometers, one mounted at the lifeboat storage position, one mounted at the deployment position, one mounted just below the deployment position, and one mounted near the water line.
3. Three accelerometers to record TEMPSC longitudinal, lateral and vertical accelerations during lowering, splash down, and sail-away.
4. Two load cells to monitor line loads during deployment.
5. An electrical circuit mimicking a hydrostatic interlock release unit with LED to alert the operator that davit release could proceed.
6. Motor controller to provide accurate davit pay-out rates.
7. Electronic switch identifying davit release time.
8. Seven capacitance wave probes (one upstream between the wave makers and the wind fan structure, one on the port side in line with the geometrical centre of the installation, and five on the port side of the platform in line with the stern, midship and bow of the TEMPSC in its deployment ready position) to give feedback on the wave environment.

Radio telemetry was used to transmit data signals from the model to the acquisition system. A full description of the system is provided in Pelley et al. (2002)

Video records of the tests were recorded with three fixed video cameras and a hand-held one. Still photographs were taken with a 35 mm and digital cameras. The fixed video cameras were located in the following locations:

a) One camera mounted in the TEMPSC at the coxswain station providing the model operator with the same view as the TEMPSC coxswain from the start of TEMPSC descent to splash down and sail-away.
b) A ceiling mounted camera providing a bird's-eye view of the entire process.
c) A camera mounted on the side of the basin providing a profile view of the tests.
d) A tripod camera mounted on the side or end of the basin providing alternate views of the lowering, splash down and sail-away.

3.1.8 Wave Timer

A wave timer device, developed especially for these tests, was used in order to place the TEMPSC on either a trough/upslope or a crest during the launching phase of the experiments. The purpose for doing this is explained further in section 3.6.2 A complete description of the wave timer can be found in Finch et al. (2002).

The device's hardware and software was wired into the davit launching system and controlled the launch timing of the TEMSPC. By controlling the launch timing it was possible to launch the TEMSPC on either the trough/upslope or the crest of the wave. It was not possible to launch on the downslope because of the shadowing effect of the wave. With the descent rate fixed, it was impossible for the davit system to lower the TEMSPC fast enough to hit the downslope before the next wave impacted the TEMPSC (e.g. Soma *et al.* 1986, Finch *et al.* 2002).

3.1.9 Calibrations

All analog sensors were calibrated before the start of the experiments. The response of the sensor to a set of exciting loads was measured and a straight line fitted through the data points by means of a least squares technique.

The line is defined by two constants A and B, which relate the integer analog-to-digital (A/D) converter reading (counts) to the physical quantities being measured according to the following linear transformation:

$$X = A(k) \times (M - B(k)) \ldots\ldots\ldots\ldots (3.1)$$

Where:

X = physical value in physical units,

M = integer A/D converter reading,

A(k) = sensitivity of the sensor connected to the A/D channel k in physical units per count

B(k) = zero offset of the sensor connected to A/D channel k in counts.

The purpose of the calculation is to determine the constants A(k) and B(k), and to ensure that the sensor functions properly and has a linear response. The constant A(k) also represents the digital resolution of the measurement. All calibrations are reported in Pelley *et al.* (2002).

3.1.10 Data Acquisition

Data acquisition was made through three different systems, the Neff620-500, telemetry, and video, and at four sampling frequencies. The Neff data were sampled at 50Hz for all the channels except for the acceleration instruments, which were sampled at 100Hz. The telemetry data was transmitted at 472 Hz. The video data was sampled at a normal recording speed of 30 frames per second. The Neff system was shore based, while the telemetry was installed on the TEMPSC. The video was both TEMPSC and shore based.

The video acquisition system consisted of four VHS and SVHS video cameras. All the cameras except the one on board the TEMPSC and the hand held were attached to pan and tilt mechanisms controlled from the OEB observation tower. These cameras had remotely controlled zoom and focusing. The wireless camera on board the TEMPSC was mounted on a lexan frame with a minimal degree of adjustment ability and no modifications to the focus. The hand held video was adjusted manually for focus and viewing area.

3.1.11 Co-ordinate System

The coordinate systems used in the analysis of this series of experiments can be defined as follows:

- Basin Coordinate System

The global right-handed system has its origin at the geometrical centre of the platform at the calm water level (i.e. 2.8m above basin floor). The X-axis is defined as up the basin in the direction of the west wall wave makers. The Y-axis is defined to port and the Z-axis upwards (i.e. typical right hand coordinate system). Wave probe, anemometer, lifeboat station, camera locations and wind machine locations are referenced to this system.

- TEMPSC Coordinate System

TEMPSC is fixed with its origin at the aft end of the keel along the centre line. This right-handed coordinate system is fixed to the TEMPSC and moves with it. It defines the location of equipment in the TEMPSC, the location of the release mechanisms, the wireless camera position, the accelerometers, brass pins for hydrostatic interlock simulation, and Qualisys markers.

3.1.12 Decay Tests

Decay tests were conducted on the free-floating TEMPSC model. Heave, pitch, and roll tests were conducted. These series of experiments were performed prior to the start of the test program. They were necessary to ensure that the periods for the

TEMPSC (i.e. heave, roll, and pitch) were realistic. Decay test data is provided in Pelley *et al* (2002).

3.2 Performance Measures

A set of twelve measures was used to quantify the performance of the twin-falls davit launched TEMPSC from a stationary platform. The measures reported here are based on work by Simões Ré & Veitch (2001) and have evolved further (Simões Ré *et al.* (2002a), Pelley et al.(2002), Simões Ré *et al.* (2002b). Some of the measures are considered in combination, whereas others can be interpreted alone. The performance measures are presented in table 3.3 and a brief description is given below.

Table 3.3. Performance measures.

Description of performance measure
Elapsed time from launch to splash down
Elapsed time from splash down to splash down border
Elapsed time from splash down to clear rescue zone border
Avoidance of collisions during lowering
Avoidance of collisions after launch
Accuracy of launch position relative to target point
Extent of setback
Path length from splash down to splash down border
Path length from splash down to clear rescue zone border
Accelerations during lowering
Accelerations during sail-away
Seaworthiness criteria, progressive setback

For the results presented in this thesis, not all of the performance measures were considered. Accelerations during lowering and sail-away were not considered because of problems with data collection. The accelerometer data was transmitted via radio link with the main data acquisition system, and due to radio frequency noise in the tank it was impossible to receive clean data traces from these instruments. In addition, the time from lowering to splash down was not considered since the lowering rate was fixed as described in section 3.1.2.

Several evacuation zones have been defined in figure 3.7 to provide a framework for the measurement of evacuation performance. The splash down zone is centered on the target launch point and is circumscribed by a boundary that is described as the area required by the TEMPSC to begin making way after launch. For this report, a size was set somewhat arbitrarily at a 15 meter radius.

The exclusion zone should encompass all collision hazards and should be large enough to accommodate launching in damaged conditions. For this analysis, the exclusion distance was chosen as 5 meters. The rescue zone boundary is defined as the distance from the installation that is considered safe for rescue operations. A distance of 25 meters was arbitrarily set in this case. The region between the exclusion and rescue zone boundaries is the clearing zone. The splash down, exclusion and rescue zones are, in practice, specific to every installation and lifeboat station arrangement. For example, the rescue zone could be the closest distance to the installation that a stand-by vessel is positioned in an emergency situation.

The first three performance measures are time measures for the three phases of evacuation. The first is the time required from launch start to splash down, or the lowering phase. It may appear that this should be minimized by maximum mechanical operation. However, it must be considered that in certain circumstances, a delay in lowering could aid in avoiding hazards, in particular, unfavorable approaching wave conditions. Prolonging lowering by timing the splash down might not necessarily be to the detriment of the evacuation. The second time measure gives the time elapsed for the TEMPSC to vacate the splash down zone. This reflects the time it takes for the lifeboat to be in control and start making way after splash down. The third time measure is the time required for the TEMPSC to clear to a rescue zone after splash down, which covers the entire sail-away phase of evacuation.

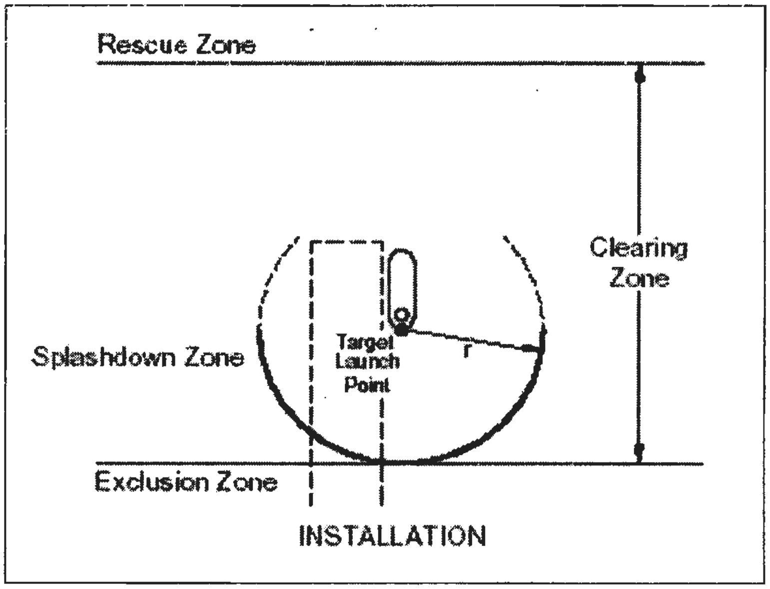


Figure 3.7: Evacuation zones

The fourth performance measure deals with collisions that may occur between the lifeboat and the installation during lowering. Collisions are hazardous and can lead to injuries, fatalities, or damage to the lifeboat. Collisions after splash down, which are referred to in the fifth performance measure, occur when the boat gets pushed into the exclusion zone and impacts the installation.

In the case of a TEMPSC lifeboat station with a simple davit, the point directly below the lifeboat in its deployed position is known as the launch target point. Since it is a target, the TEMPSC's launch accuracy is measured by how close the boat comes to it. This also illustrates the degree of control that the launch system has over the deployment of the boat during lowering. This is the sixth performance measure.

The success of the TEMPSC's escape also depends on the distance that the lifeboat is set back by waves, which is another performance measure. Set back is illustrated in figure 3.8 and is the magnitude of the vector in the $z = 0$ plane from the drop target to the point at which the lifeboat is pushed back by the first wave encounter. Set back was identified in earlier work by Simões Ré and Veitch (2001), but was also found by Campbell *et al.* (1983) and Hollobone (1984). All groups identified this set back of the lifeboat as one of the most important elements of a lifeboat launch sequence. The set back is also connected to the collision performance measure since excessive set back results in collisions.

The eighth and ninth performance measures are the path length distances as the lifeboat travels to the splash down and rescue zone boundaries and correspond to the second and third measures. They measure the directional control of the lifeboat and how far it veers from an ideal straight path as it clears both the splash down zone and the rescue zone.

The tenth and eleventh performance measures are the accelerations of the TEMPSC during lowering and sail-away. Accelerations during the sail-away phase are important when looking at the success of the evacuation process and the performance of the TEMPSC in rough weather. These performance measures are not investigated in this work.

If the model cannot make forward progress after the initial set back and is set back farther during the subsequent wave encounters, the TEMPSC is considered to have reached a weather limit. The weather limit is quantified further by the twelfth performance measure, called progressive setback. Evacuation systems should not be expected to function in weather conditions that go beyond the point at which progressive set back causes danger zone incursions or collisions. This performance measure should be added to the set back measure as the most important measures when evaluating the evacuation system performance.

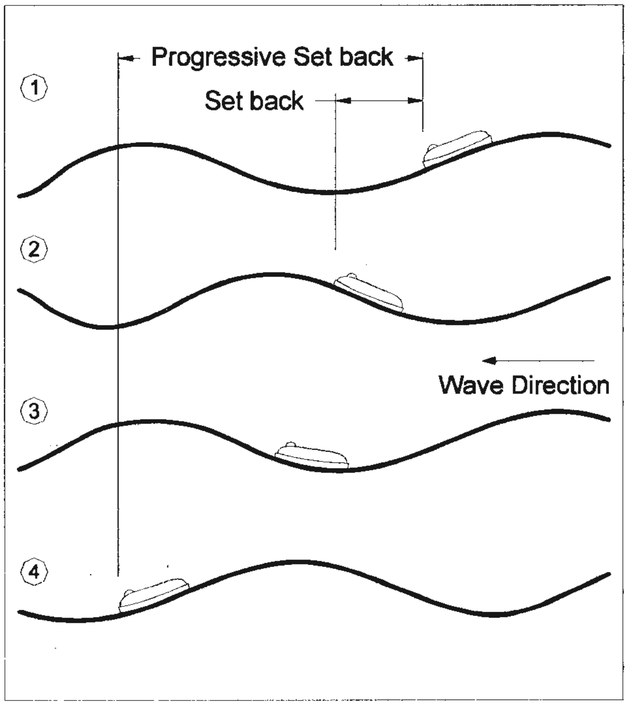


Figure 3.8. Set back.

3.3 Test Plan

The test plan focused on investigating effects of extreme weather, wave steepness, and orientation on TEMPSC performance. Each experiment series was divided up according to the scale of the model and the parameter settings. For example, the M20B series was a set of experiments using the 1:20 scale model launched from a perpendicular orientation and a wave steepness of 1:15. Series M13A was a set of experiments using the 1:13 scale model in the perpendicular orientation and wave steepness of 1:20. The test matrix is provided in appendix F.

The majority of experiments were performed using regular waves, with only a small number in irregular waves. The three nominal target values of wave steepness for regular waves that were used are 1:10, 1:15, and 1:20, where wave steepness is defined as the ratio of wave height to wave length (H/λ). The two launch orientations were perpendicular and parallel to the platform. The height of the TEMPSC, defined as the distance from the calm water mark to the bottom of the keel, was set at 30m or 20m full scale. The clearance of the TEMPSC, defined as the distance from the aft davit line to the outer edge of the platform, was set at three distances, 11.037m for the 1:13 model scale tests, 14.7m for the perpendicular 1:20 model scale tests, and 24.86m for the parallel 1:20 model scale tests. The clearance was not a test variable, however to avoid damage due to collisions, the clearance was increased for the 1:20 perpendicular tests, and then again for the 1:20 parallel tests.

The final parameter that was controlled for these experiments was the landing point of the TEMPSC, which was useful for exploring the effects on performance of the splash down point (relative to the wave phase angle). The wave timer provided the ability to set the TEMPSC down on either the trough/upslope or the crest of the wave. The wave timer device is described in section 3.1.8.

3.4 Test Methodology

Before the testing began on the main test matrix, decay tests on the TEMSPC were done to determine the natural roll, heave, and pitch frequencies. After the decay tests were completed, the actual systematic investigation of the performance of the twin-falls davit launched TEMPSC from the fixed installation in a range of weather environments and system configurations were performed. The procedure for both the decay tests and the systematic series experiments are provided in appendix G.

Successful runs were defined as those for which both the davit-line release mechanism and the TEMPSC functioned as intended. Runs where the davits released prematurely, or did not release at all were considered to be failed runs and were repeated.

3.5 Data Analysis and Techniques

Results from each test were recorded in model scale units and checked at the time of testing. Some basic analysis was performed with statistics generated for each channel. These results were treated as preliminary results.

Results were converted to full-scale values for salt water and analyzed to provide event statistics of wind and wave conditions, TEMPSC lowering time, TEMPSC immersion, falls release, winch payout rate, TEMPSC boundary crossing (both in time and distance) average speed, wave phase deployment, missed target, set back, accelerations, and collision avoidance.

The following section describes the techniques used to analyze the test data. In some cases packaged software was used, while in others, task specific software was developed for this experimental campaign.

3.5.1 Statistical Analysis

For each measured time series the following parameters were extracted:

- Mean value of the time series: $\overline{x} = \frac{1}{N}\sum_{i=1}^{N} X_i$
- Minimum value
- Maximum value
- Standard Deviation: $\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \overline{x})^2}$

where: N is the total number of samples in the time series,

X_I is a discrete sample of the time series,

- Variance: σ^2

3.5.2 Preliminary Analysis

This type of analysis was performed during the test program to ensure that the instrumentation was working properly. Data products from this type of analysis constituted time series and statistical summaries for the entire launching window as well as the following intervals: (S1) tare, (S2) stowed to embarkation (S3) deployment start to splash down (S4) splash down to sail-away and (S5) stowed to sail-away. Figure 3.9, below, illustrates the different intervals used in the analysis.

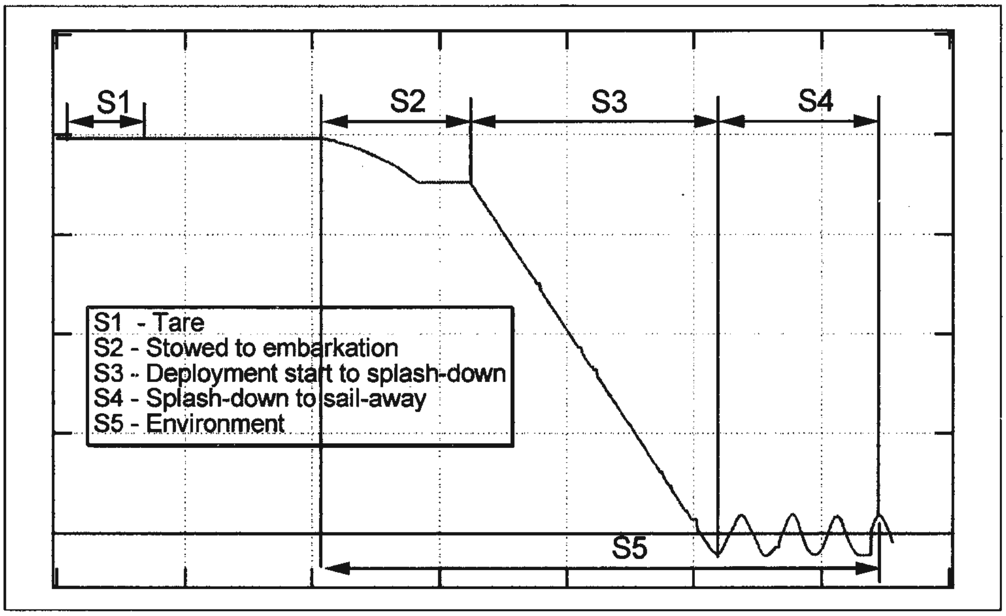


Figure 3.9: Analysis intervals.

In the tare interval, statistics were calculated for the wave probes to allow any small offset to be removed. In intervals S2 to S4 basic statistics were calculated for all channels collected. In interval S5 zero-crossing analysis and basic statistics were performed on the time series data for the environmental channels.

In the time series plots, the start of interval S3 represents the deployment start. Interval S4 captures all the data for the TEMPSC just after splash down to the point where it leaves the Qualisys field of view. Synchronization between the acquisition systems and the shifting due to condition changes were handled during this analysis. Synchronization between the data collected on the NEFF and the data collected on telemetry was accomplished through synchronization channels, one on each system.

3.5.3 Performance Measures Analysis

A software program called IGOR was used to perform the analysis of these performance measures. The program allows the user to extract the required information from the preliminary data for each particular performance measure. A detailed description of the analysis procedure using the IGOR software, as well plots showing the path of the TEMPSC for each test are provided in Pelley *et al.* (2002).

3.6 Application of Performance Measures

In summary, the analysis for this project took two stages. First, the raw data collected during the experiments was analyzed and formatted to correspond to the definitions of each performance measure. The data was then put into a format that facilitated the investigation of how configuration changes affected each performance measure, and the scrutinizing of these performance measures to determine their utility. It helps to recall that two of the main purposes of this work are to investigate the performance capabilities of a twin–fall davit system in extreme weather, and to evaluate reliable and practical measures that will provide guidance to designers and operators of offshore oil installations. These practical measures were established in previous work and are listed in section 3.2.

This following section uses the data from the two height configurations (H=30 & H=20) as an example to show how the data was plotted, and to provide additional understanding of the performance measures.

3.6.1 Typical Launch

Before continuing the discussion of how the performance measure data was plotted and interpreted, it is important to fist restate, through illustrations of an actual test, the phases of evacuation investigated. An example diagram is provided in figure 3.10, which shows one of the 1:20 scale model tests in a Beaufort 8 base line condition. The figure shows the launch in three views: elevation view (*xz*), plan view (*xy*), and centerline view (*yz*).

In the plan view, the platform is sketched at the left and the lifeboat station extends out perpendicular from it. The origin of the *xyz* coordinate system is located at the water surface vertically below the stern of the TEMPSC.

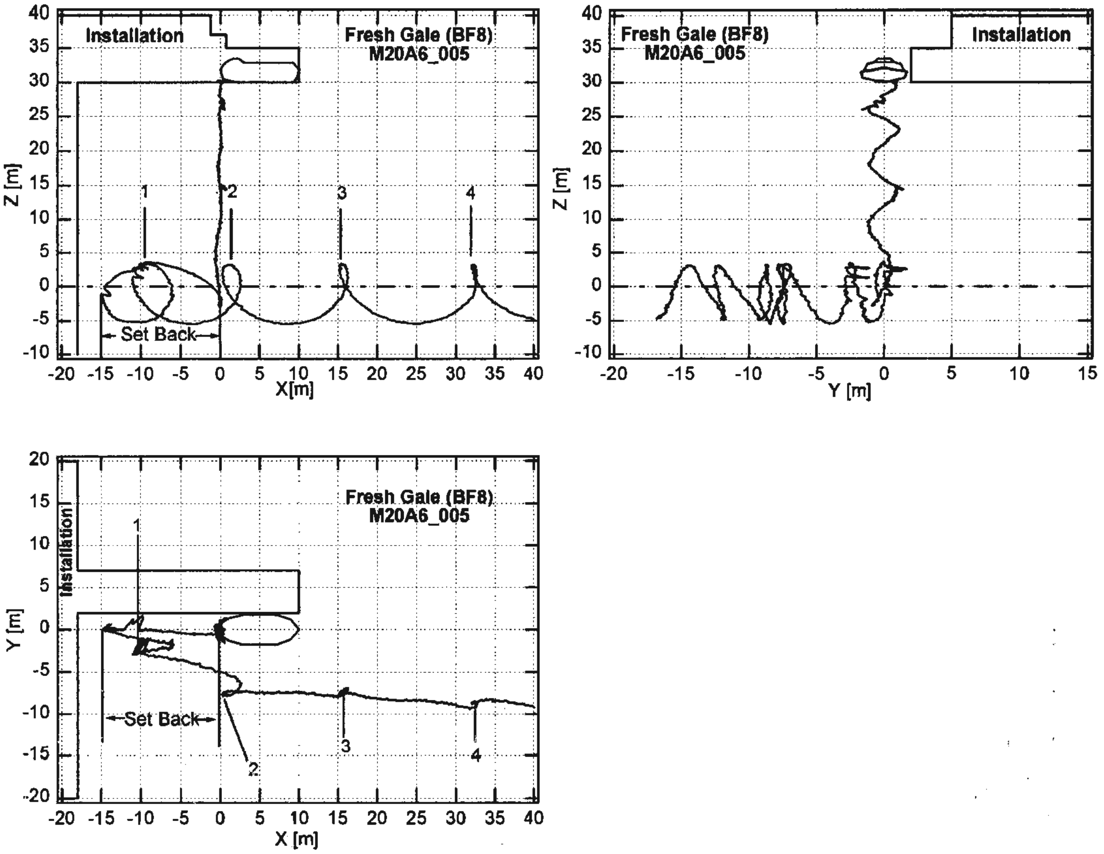


Figure 3.10: Evacuation path for a launch in Beaufort 8 (fresh gale) conditions.

The irregular line in all three views indicates the path taken by the model TEMPSC. First the model passes through the launching phase of the evacuation, which includes the lowering to the water, the splash down, and the set back if any. In this test, which was an upslope launch, the model missed the splash down target by a very small amount. Once the lifeboat landed it was set back by the first wave encounter by a distance of approximately 15 meters. Once the TEMPSC begins to make forward progress, the sail-away phase of the evacuation begins. The elevation view shows that during sail-away the TEMPSC crested 4 waves between its maximum set back point (at $x \approx -15$m) and $x \approx 35$m.

The elevation and centerline views show that during the lowering phase there was a small amount of wind induced oscillation in the *xz* plane (the plane of the twin-falls), and more, but not excessive, oscillation in the *yz* plane (which was perpendicular to the wind direction). Once in the water the lifeboat experienced some lateral (*y* direction) drift, but in general the evacuation proceeded successfully.

3.6.2 Performance Measure Application to Height Effects

The height of the TEMPSC above the waterline was varied from 20m to 30m as outlined in section 3.3. To determine the effects of performance the data is plotted predominately using the performance measures versus measured wave height. Other plots include performance versus phase angle, and *x*-coordinate versus *y*-coordinate graphs. The measures used to determine effects on performance are missed target, set back and progressive set back, the time and path length required to reach the splash down and rescue zone, collisions with the platform, and danger zone incursion. A performance measure that was not considered at the beginning of the project, but was added during the analysis of the performance measure data was the ability of the TEMPSC to reach the rescue zone.

In earlier experiments the TEMPSC was always able to reach the rescue zone. In extreme weather it was discovered that in some instances the TEMPSC was unable to reach the rescue zone. This performance measure was not included in section 3.2 because it was not one of the original measures.

Interpretation of the data was done using plotting routines instead of statistical distribution analysis because there were not enough runs for each configuration to allow for the creation of probability distributions.

The first measure to be considered is the missed target value. The missed target is the distance from the target drop point that the TEMPSC splashes down. In figure 3.11 the missed target is plotted versus the mean wave height for the deployment heights of 20m and 30m, from Beaufort 7 to Beaufort 9. The format of this graph provides a clear picture of the dependence of the measure on the weather condition. By plotting both configurations on the same plot it is also possible to determine if the weather has the same effect on each configuration. In this particular case, it is observed that there does not seem to be any dependence on weather for either deployment height. Observing more closely, it becomes clear that the amount of missed target is very small at both deployment heights. The missed target values vary between 0.2m and 1.6m, with mean values varying only as much as 0.3m. The standard deviations for each data set are also very similar. For example, the full-scale standard deviation value at the Beaufort 9 condition for the 30m height is 0.26m and the 20m height is 0.4m. In relative terms this is very small when it is considered that the TEMSPC beam is 3.67m. So the amount of variation in missed target for both heights in the perpendicular orientation, is only as much as 33% of the TEMPSC beam. This is an unexpected result since it was hypothesized that as the weather and especially the wind velocity increased, the missed target would increase due to large oscillations of the TEMPSC during lowering.

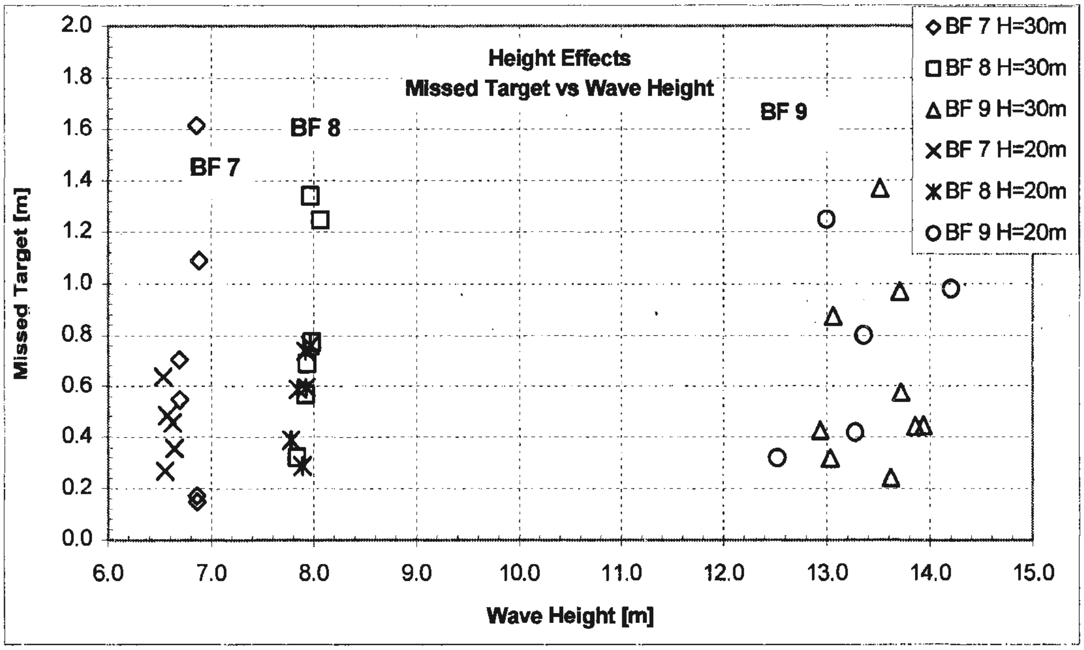


Figure 3.11: Missed target versus wave height

The set back results for the two deployment heights are shown in figure 3.12, which is plotted against wave height. As stated in section 3.2, the set back is the distance the TEMPSC is pushed back after the first wave encounter. At first glance, the results indicate that there are two distinct groupings of data points: a set of data below approximately 4m and a set that increases with wave height in the range of 8 to 18m.

This is due to the sensitivity of set back to the splash down position along the wave phase angle.

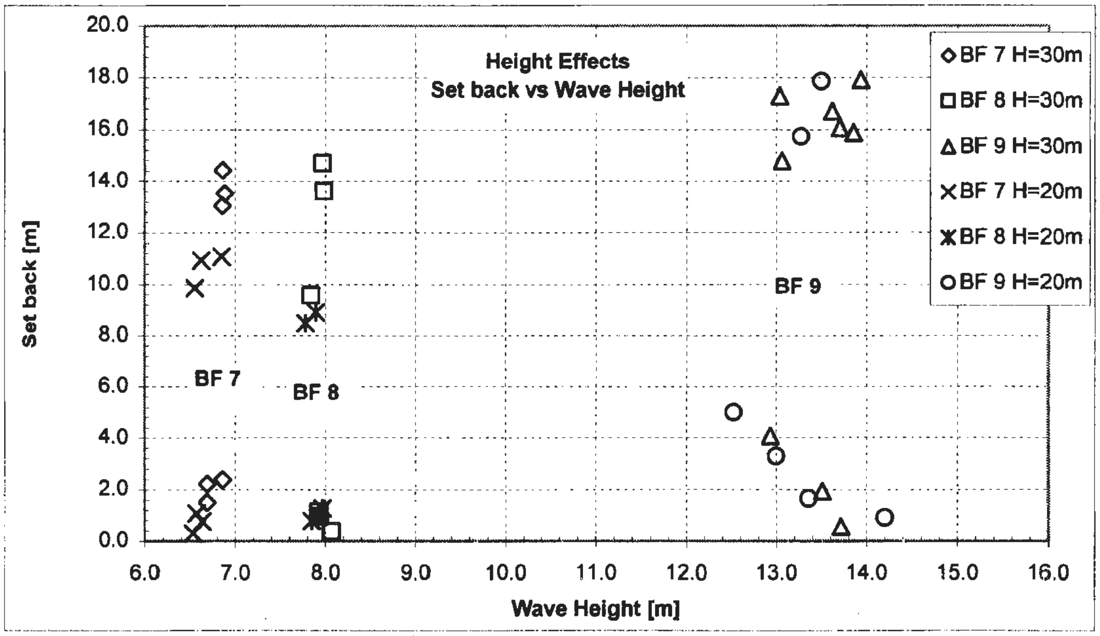


Figure 3.12: Set back versus wave height

For this reason there was an attempt to control the splash down point on the wave for these experiments. Using the wave timer device explained in section 3.1.8, the test matrix was set up with the splash down position as a test parameter. The wave timer was able to place the TEMSPC on either a crest or upslope, however it was not possible to land the lifeboat on a specific wave phase angle. Therefore during the analysis process the crest and upslope/trough portions of the wave cycle were segmented into phase angle ranges. The crest, upslope, and trough points were defined as +90°, 0°, and –90°, respectively. Then it was arbitrarily decided that a crest launch would be any launch that resulted in a phase angle splash down point of +40° to +120°, and an upslope/trough launch would range from –90° to +40° (figure 3.23). The downslope was not considered since none of the landings occurred along the downslope as stated in section 3.1.8.

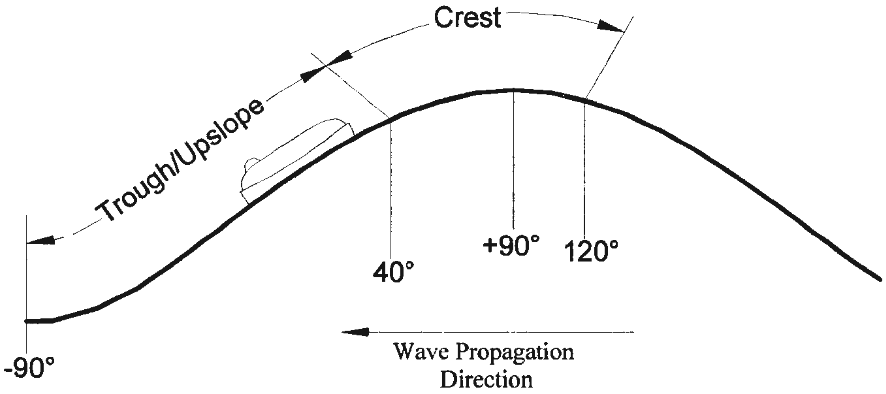


Figure 3.13: Splash down point phase angles

Returning to figure 3.12, the plotting format allows the observer to identify a number of important results. As indicated above, the amount of set back is dependent on the splash down position. For example, at the Beaufort 7 condition, the crest launches result in set back values between 0 and 2m. The upslope launches in that same weather condition range from 10m to 14.5m. It can also be observed that the upslope launches appear to increase with increasing weather conditions, whereas the crest launches do not. Finally, the deployment height does not appear to affect the amount of set back.

To investigate the crest and upslope launch phenomenon further, the set back is plotted versus the phase angle (figure 3.14). This plot clearly indicates the dependence of set back on launch splash down position. The crest launches are located in the lower right corner and demonstrate smaller set back magnitudes and less scatter than the upslope launches. At the crest location (40° to 120°) the set back ranges from 0 to 5m for all launches. For the upslope/trough launches (-90° to 40°) the set back ranges from 8.5m to 14.5m for Beaufort 7 and 8 conditions, and from 14.5m to 18m for Beaufort 9 condition.

The progressive set back occurs if the TEMPSC is unable to make forward progress after the first wave encounter. This progressive set back data is plotted with the set back data in an (*x*, *y*) coordinate plot. Figure 3.15 is shown as an example using the height effect data.

The time to reach the splash down zone border and the time to reach the rescue zone, as well as the corresponding path lengths are shown in figure 3.16, figure 3.17, figure 3.18, and figure 3.19. Again the data is plotted versus the wave height. This grouping of data does not appear to have the same strong dependence on splash down position as the set back values. Also as expected, the deployment height has no effect on these time and path length measures. These measures however, are very important when considering the other configuration changes which are discussed in section 4.0.

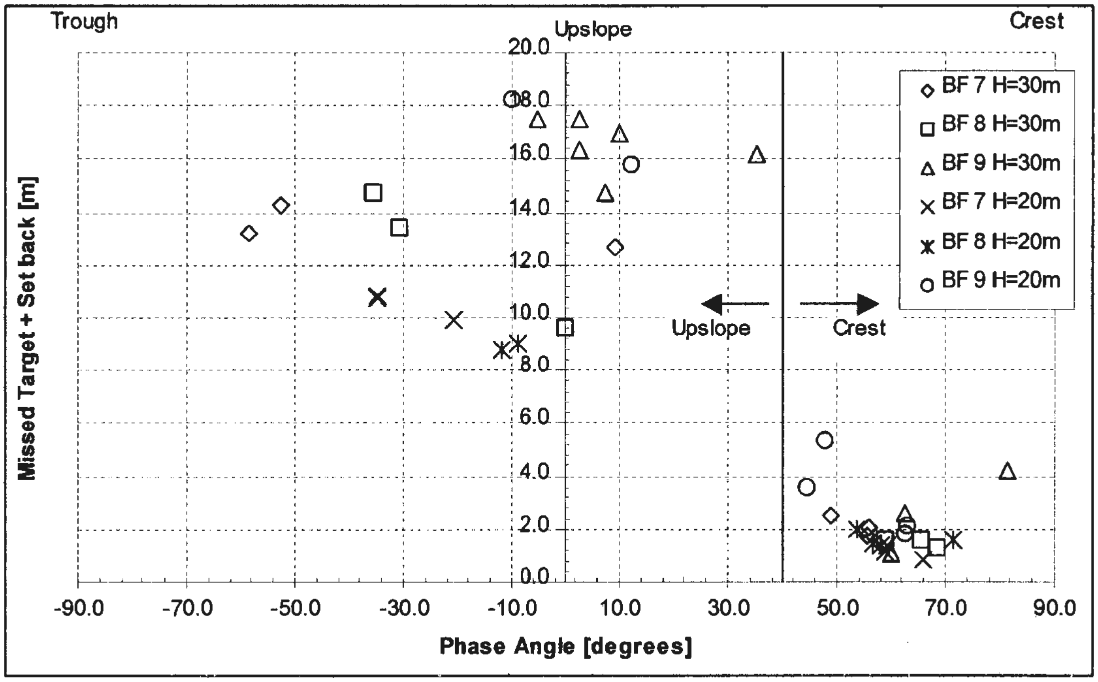


Figure 3.14: Missed target & set back versus phase angle

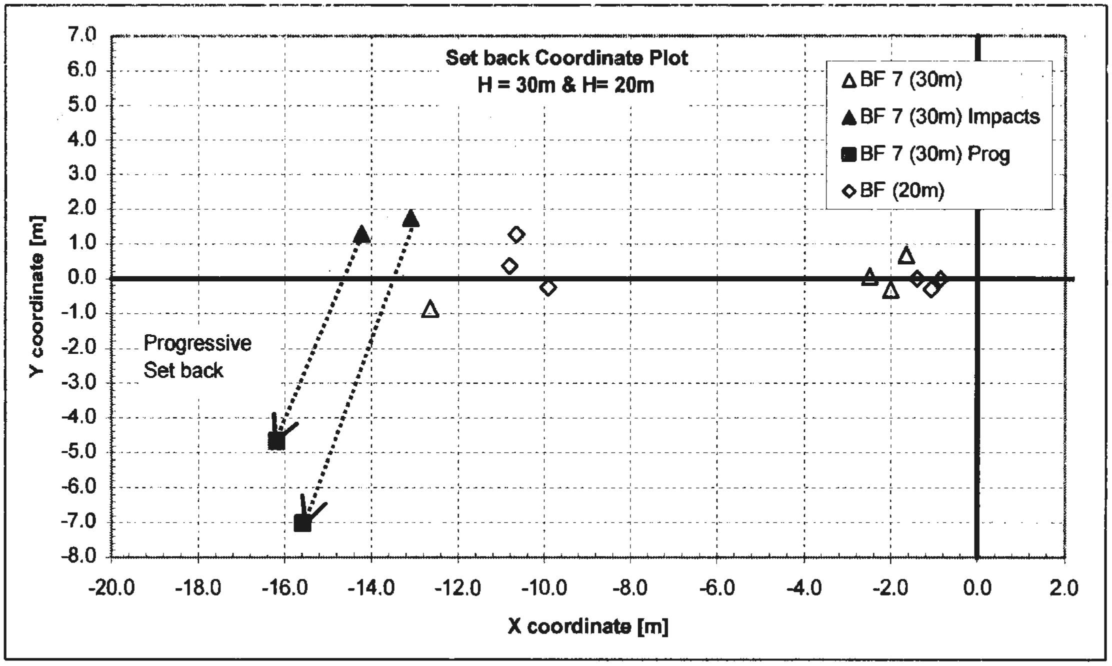


Figure 3.15: Set back and progressive set back coordinate plot

The last three performance measures are plotted differently than the ones described above. The number of collisions and danger zone incursions, and the ability to reach the rescue zone data are numbered events. It is also necessary to investigate the effect of two configuration changes, such as splash down position and wave steepness. Therefore this data is plotted as a 3-D bar graph. An example of this type of graph is shown in figure 3.20, which is the number of danger zone incursions observed as a function of sea condition, wave variation, and launch height.

This interpretation of the results discussed in section 4 will follow the same graphing procedures as illustrated here. It has also been determined that the deployment height does not influence any of the performance measures, except for the time from launch to splashdown. However this time measure is more dependent on the IMO regultations, which governed the deployment speed. The motions and subsequent possible collisions during lowering was expected with an increase in height but as the results indicate in figure 3.11 the missed target values of the lifeboat were small. This appears to indicate that the wind did not increase the lifeboat motions due to a higher deployment height. Similar findings were reported by Simões Ré et al (2002). Therefore the 20m deployment height data has been included with the 30m deployment height from this point forward.

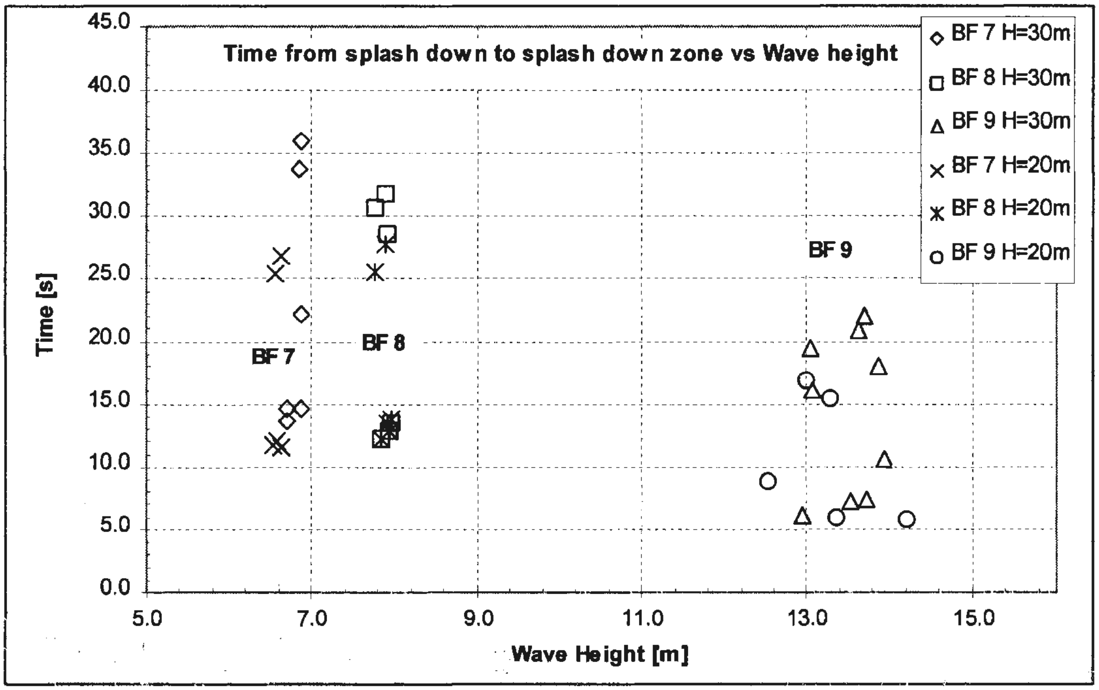


Figure 3.16: Time from splash down to splash down zone versus wave height

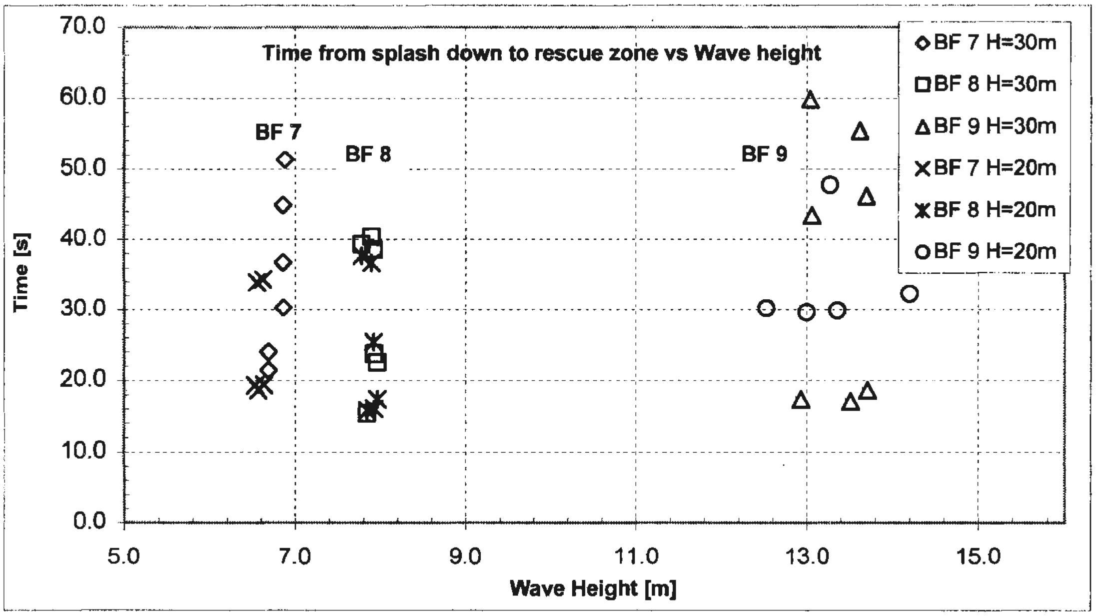


Figure 3.17: Time from splash down to rescue zone versus wave height

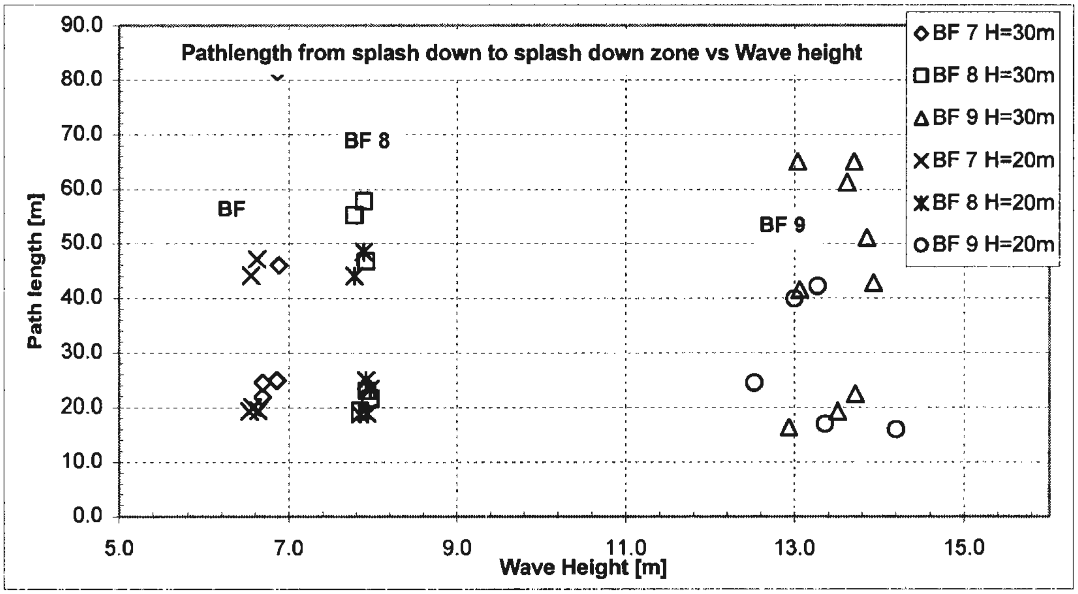


Figure 3.18: Path length from splash down to splash down zone versus wave height

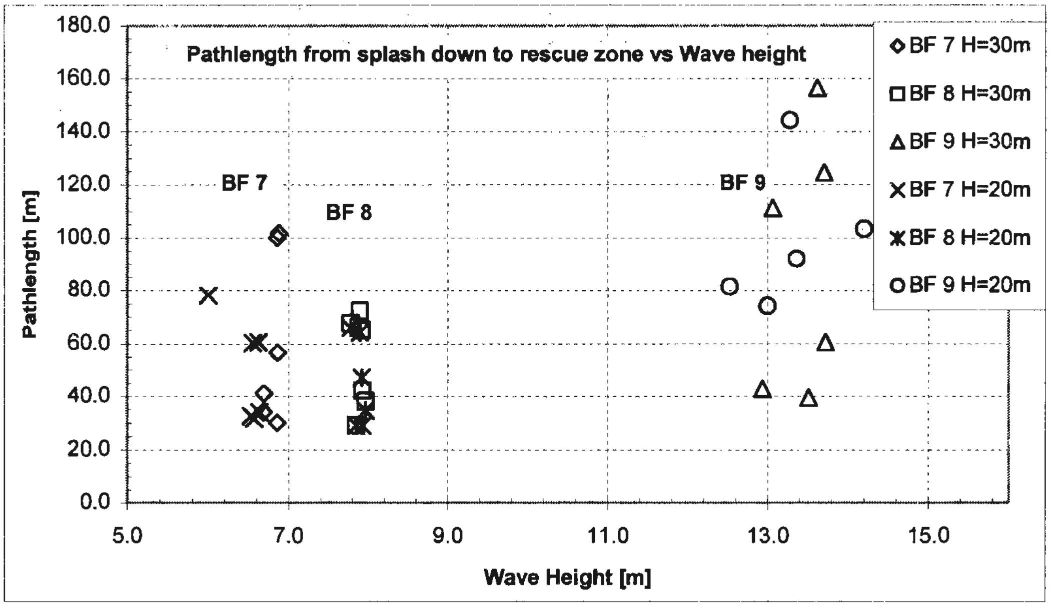


Figure 3.19: Path length from splash down to rescue zone versus wave height

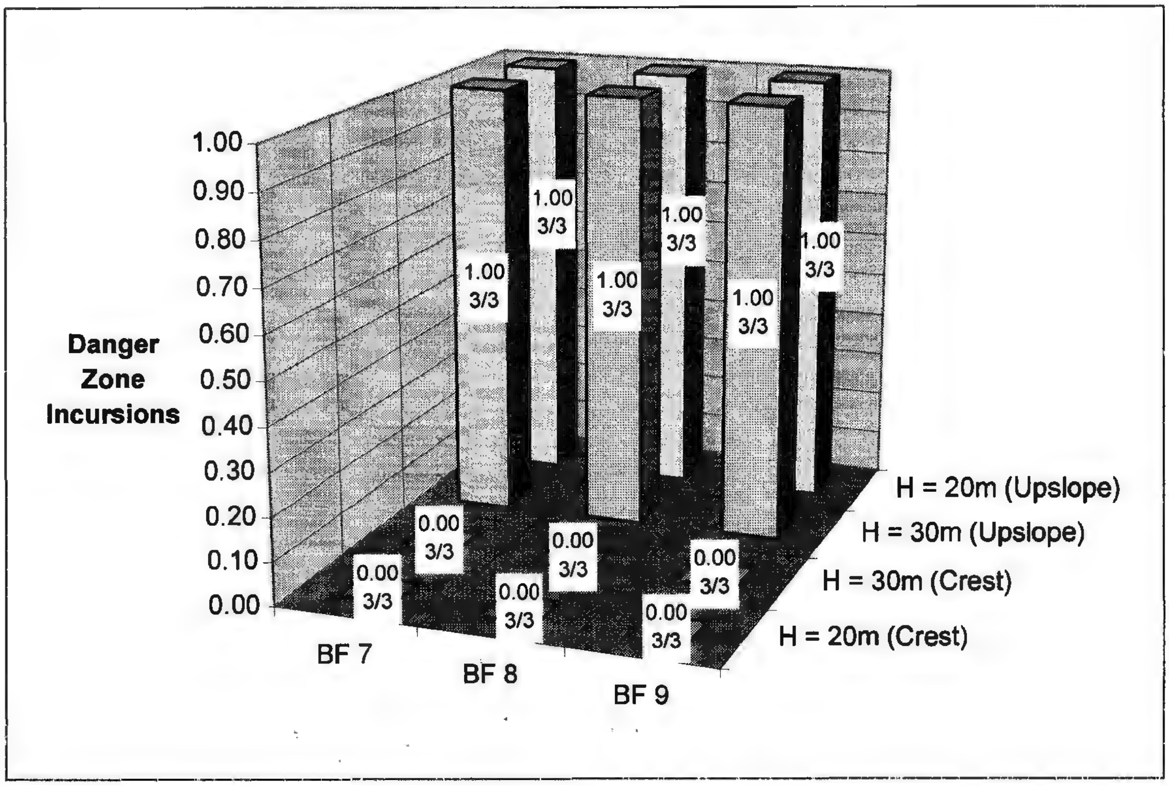


Figure 3.20: Number of danger zone incursions versus deployment height

Section 4.0

4.0 Discussion of Results

The following discussion focuses on the influence of weather, orientation, and wave steepness on the performance of the twin falls davit evacuation system using the following measures:

1. Time from splash down to splash down border.
2. Avoidance of collisions after splash down.
3. Distances from target drop point to splash down (missed target).
4. Set back of the lifeboat to oncoming waves.
5. Distance from target (missed target) to set back (missed target + set back)
6. Progressive set back of TEMPSC.
7. Path length from splash down to splash down border.
8. Path length from splash down to rescue zone border.

The results revealed a number of interesting points. Three of these discoveries are key to the continued understanding of the performance of a twin fall evacuation system, and the process of generating effective performance based measures.

First, it was found that there are limitations to the definition of the splash down zone in the extreme seas. In extreme seas the TEMPSC's performance was degraded severely, with the craft becoming unseaworthy. However, the measure of time for the TEMPSC to reach the splash down boundary indicated that the performance of the

TEMPSC was improving. Secondly, progressive set back was found to be much higher in the parallel orientation leading to increased collision rates and degrading the ability of the TEMSPC to clear the platform area. This appears to be in contradiction to findings of earlier work performed by Simoes Re *et al.* (2002a).

Finally, wave steepness was shown to be very important when evaluating the performance of the TEMPSC evacuation system. When wave steepness increases to a point where the TEMPSC wave encounter distance is shorter than the TEMPSC boat length, the performance of the boat degrades rapidly. This is explained fully in section 4.3

4.1 Perpendicular Configuration (base line)

The base line setup for the experiments was done in the perpendicular orientation. Although the base line case was set at a deployment height of 30m, the 20m deployment height condition for the 1:20 model scale experiments has been included with this experimental set, as stated in section 3.6.2.

The missed target performance measure was found to be insignificant in the perpendicular orientation. As shown in figure 4.1, the majority of the missed target values range from 0.1m to 1.8m. These values are only about one half of the TEMPSC's beam. There are two data points corresponding to a calm water run and one Beaufort 7 condition run, with missed target points of 2.5m and 3.3m, respectively. These points are still less than the beam of the TEMSPC and are considered to be outliers. Missed target results are small and not strongly dependent on weather. This corresponds to earlier work performed by Simões Ré and Veitch (2001) and Simões Ré, et al (2002a).

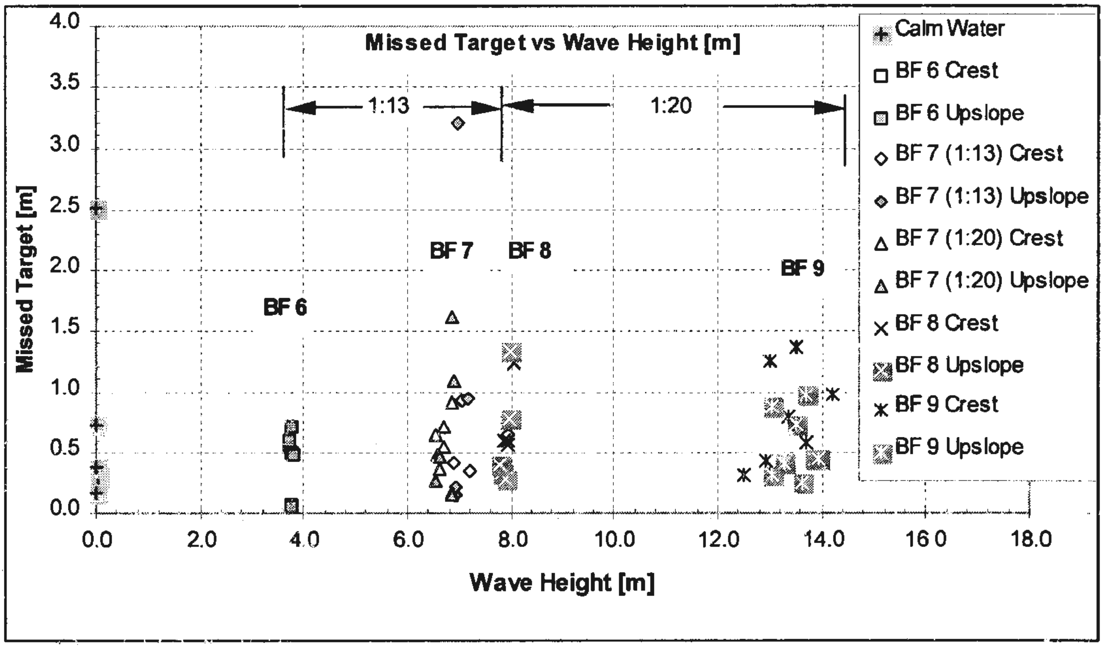


Figure 4.1: Missed target versus wave height (perpendicular orientation)

The set back results have a number of interesting features. Figure 4.2 shows set back distance plotted versus wave height. The first observation is that set back increases with increasing weather, but only for upslope wave landings. The set back for crest launches remain in the range of 0m to 8m. In previous work (Simões Ré et al. 2002a) the maximum set back was found to be approximately twice the wave height. For the results shown here this conclusion holds true for the Beaufort 6 condition. For example, the Beaufort 6 condition has a wave height of approximately 4m, and the maximum set back for upslope wave landings is approximately 7.5m. The trend appears to level off at the Beaufort 7 condition, but the leveling is related to the distance the TEMPSC is launched from the platform. The 1:13 model experiments had a clearance of 11.87m and the 1:20 model experiments had a clearance of 14.7m. So for the 1:13 model experiments the amount of set back was limited to 11.87m, which is confirmed by the collision points indicated on the graph for that set of data. For the 1:20 model scale experiments, the amount of set back is limited to 14.7m and again the collision points confirm this. The set back distance in some cases is greater than the allowable clearance. The reason for this is due to the definition of set back and to the physical setup of the experiments, which included the use of netting material as a 'backstop' for the model.

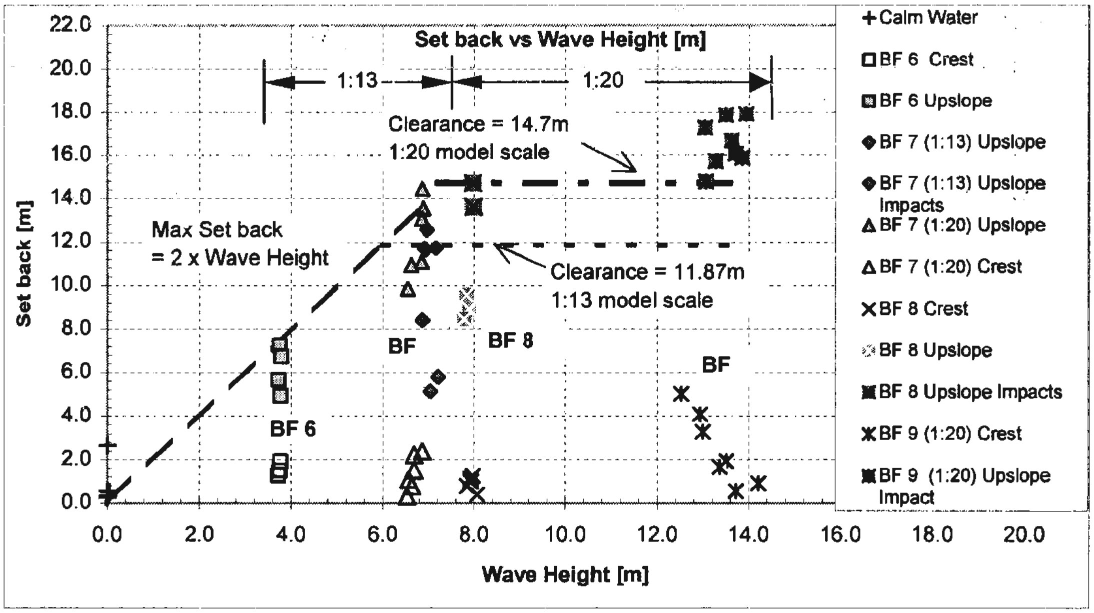


Figure 4.2: Set back versus wave height (perpendicular orientation)

As indicated in section 3.2, the set back is the magnitude of the vector in the $z = 0$ plane between the drop target and the point to which the model is pushed back by the first wave encounter. So the set back distance can be greater than the evacuation system clearance, which is the distance in the x-direction only. In addition, the platform was outfitted with a net to prevent damage to the model when it collided with the platform. It was impossible to make the net completely taut, so the 1:20 model scale experiments could result in set back values in the x-axis direction that were up to 2m higher than the allowable clearance.

To illustrate the dependence of set back on the splash down position on the wave, the set back data is plotted versus the phase angle of the wave. Figure 4.3 shows the plot of the data from the Beaufort 6 to the Beaufort 8 conditions. The plot demonstrates clearly that the crest splash downs, which are shown in the lower right corner, result in significantly less set back than the upslope splash down points. The amount of set back for crest launches remains about 0.5m to 2m, independent of the weather conditions. Set back for the upslope launches varies from 5m to 15m, with the maximums tending to increase with weather condition. The Beaufort 8 condition upslope launches range from approximately 8m to 15m of set back. Most of the Beaufort 9 condition upslope launches have approximately 14m to 18m of set back, resulting in collisions with the platform.

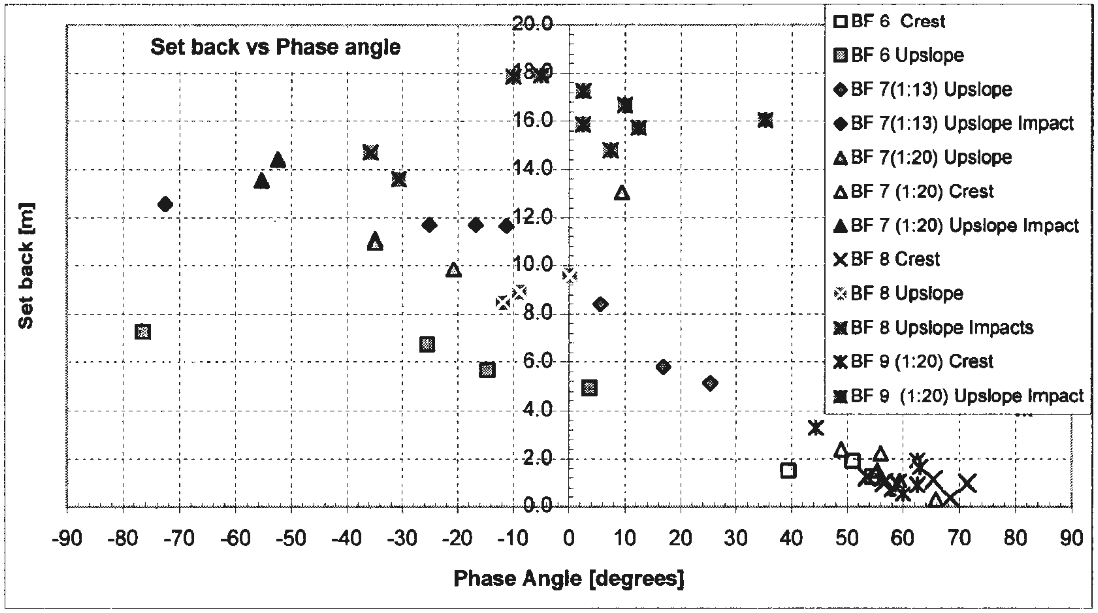


Figure 4.3: Set back versus phase angle (perpendicular orientation)

The *x* and *y* coordinate plots provide a map of the set back values for each weather condition. Plotting the data in this format is also useful for comparisons between configurations and weather conditions. At this point in the discussion, only the effects of weather will be considered. Figure 4.4, shows the set back coordinates. The circular lines represent the maximum set back value for the upslope launches for each Beaufort condition. These circles become very useful in developing boundaries of performance.

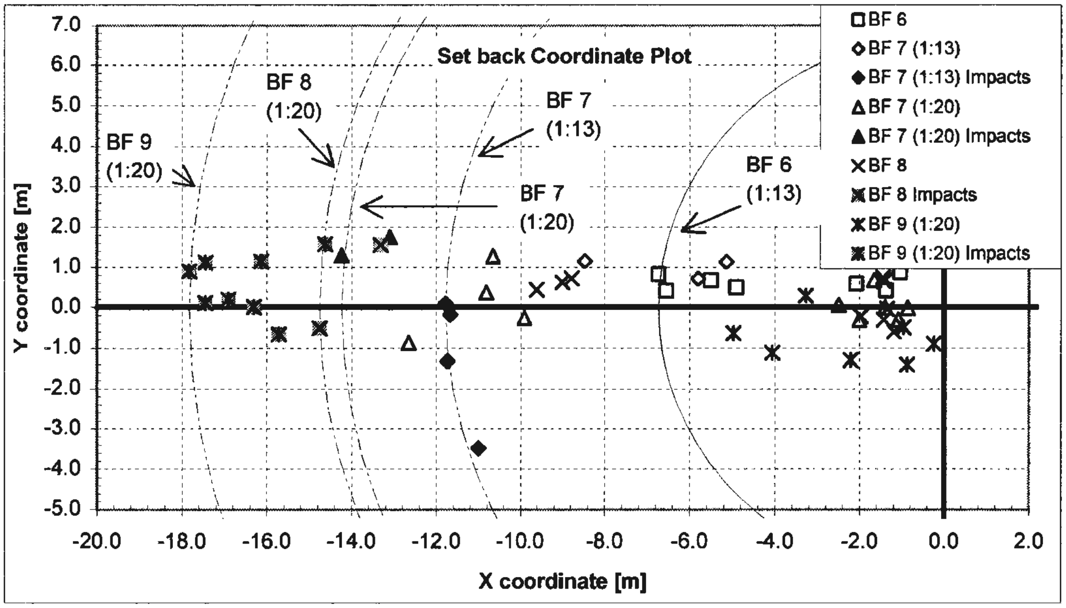


Figure 4.4: *x*-coordinate versus *y*-coordinate set back (perpendicular orientation)

The coordinate plot also appears to indicate that set back increases with increasing weather, however this is misleading. Similar to the results shown in figure 4.2, the platform, and in this case the netting material, provides a boundary that limits set back. The apparent increase in set back is related to the amount of slackness in the net only. There is an increase in set back from Beaufort 6 to Beaufort 7. However after Beaufort 7, it is impossible to say conclusively that there is an increase in set back with an increase in weather. It can be concluded here then that a clearance of 14.7m is not always sufficient to avoid collision with the platform for upslope wave landings in Beaufort 7 conditions and greater. The clearance must be increased to avoid such collisions, but there is no way to determine the distance from this set of experiments. It can be said that for a clearance of 11.87m (clearance for the 1:13 model), the maximum weather condition that the TEMPSC could be launched with 100% collision avoidance is Beaufort 6. For the clearance of 14.7m (1:20 model scale), 2/3 of the upslope launches in Beaufort 7 resulted in collisions. So even this amount of clearance is not sufficient to increase the allowable operating weather condition to Beaufort 7, and provide 100% collision avoidance.

The combination of set back and missed target for the perpendicular orientation experiments is the next performance measure considered. Due to the relatively small values for missed target distance, the combination of missed target and set back is very similar to the set back plot, and is shown in figure 4.5.

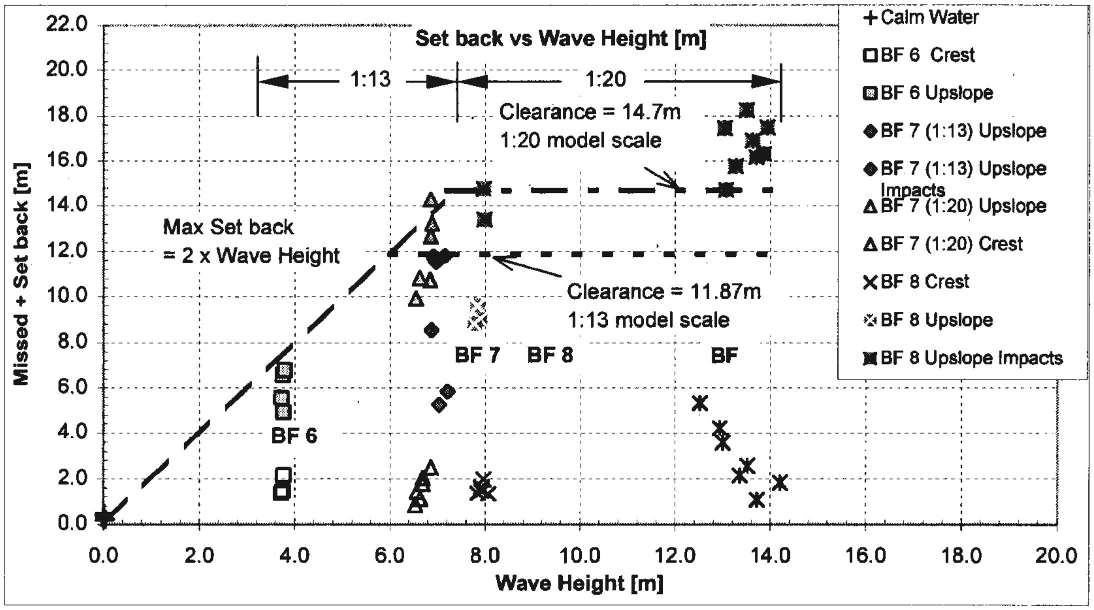


Figure 4.5: Missed & set back versus wave height (perpendicular orientation)

Progressive set back occurs if the TEMPSC is unable to make forward progress after the first wave encounter. Progressive set back was only observed for the Beaufort 7, 1:20 model scale tests and then only for two runs, which are shown in figure 4.6. One possible reason for this may be that the clearance restricted farther progressive set back. The TEMPSC could not be pushed back farther because it was stopped by the platform.

Times to reach the splash down zone and rescue zone boundaries are shown in figure 4.7 and figure 4.8. For both measures the Beaufort 6 condition shows less scatter than the other weather conditions and it appears that upslope launches require more time for the TEMPSC to exit the splash down zone. In the Beaufort 7 condition, for both model scale experiments, the difference between upslope launches and crest launches is not as obvious. The amount of variability for both time measures is also large, ranging from 11s to 36s for the time to exit the splash down zone, and 15s to 70s for the time to exit the rescue zone. In the Beaufort 8 condition, the time measure again shows some dependence on the landing position (upslope or crest), but the results fall within the same range as the Beaufort 7 condition.

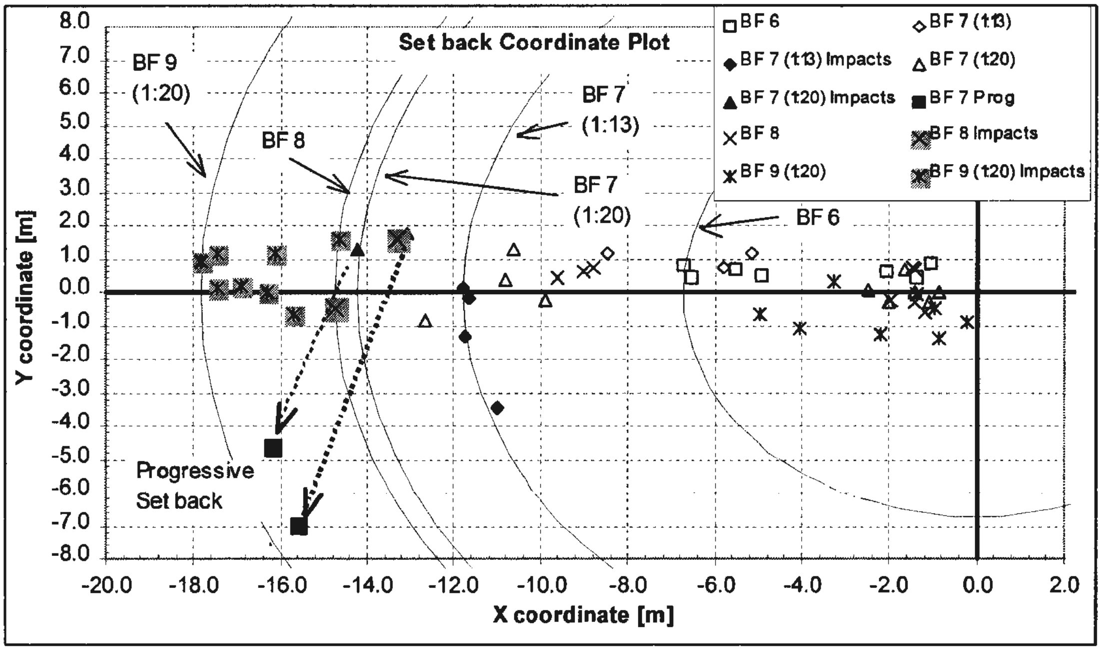


Figure 4.6: Set back and progressive set back coordinate plot

The 1:20 model scale results at the Beaufort 9 condition are interesting in that the time to exit the splash down zone decreases and the time to exit the rescue zone continues to increase. The maximum value for the time to exit the splash down zone decreases by approximately 14s from the maximum value for the Beaufort 7 and 8 conditions. This result poses two questions. First, why does the time to reach the splash down boundary decrease with increasing weather condition? Secondly, why does the time to reach the rescue zone boundary show an opposite trend and increase with increasing weather conditions?

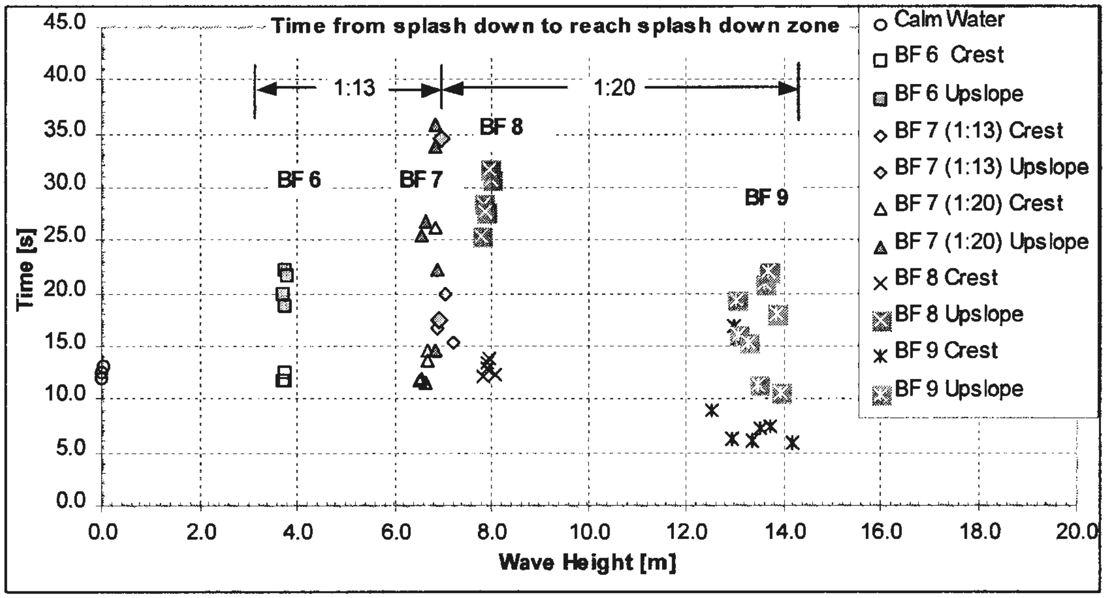


Figure 4.7: Time from splash down to splash down zone versus wave height

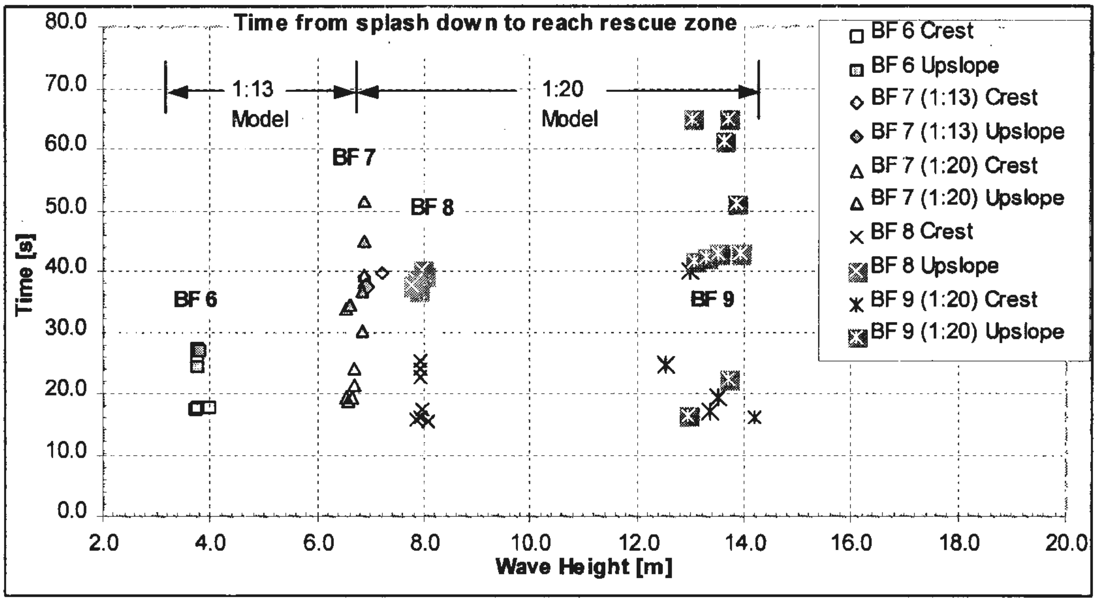


Figure 4.8: Time from splash down to rescue zone versus wave height

The answer to both questions is found in the influence of the waves on the TEMPSC motion, and the definition of the boundaries. At the lower weather conditions, the waves do not have much influence on the TEMPSC motion. As the weather conditions increase to Beaufort 7, the lifeboat is set back farther and farther, but manages to recover and make headway directly out of the splash down region, as shown in figure 4.9. At the Beaufort 9 condition the TEMPSC does not have enough power to maneuver under control. This results in the coxswain being unable to steer the TEMPSC in the direction intended. Two examples in figure 4.10 and figure 4.11 show this lack of control. In the first instance in figure 4.10 the lifeboat is pushed back into the platform after the first wave encounter. After the collision the TEMPSC surfs down the wave bringing it back near the splash down point. However, the next wave comes quickly and the lifeboat cannot power up the wave front. In fact, it gets turned around to about 45° to the platform. The lifeboat then surfs down the wave front in the direction of wave propagation, and gains speed. This is the point where the definition of splash down zone plays a part in the phenomenon of the decreasing time to exit the splash down zone. The splash down zone is circular so as the model travels quickly 45° to the platform, it exits the splash down region. So the TEMPSC was able to exit the splash down region by running with the waves more quickly than in the Beaufort 7 and 8 conditions where the lifeboat moved into and over the waves to reach the splash down zone. If the splash down zone was defined as a straight line parallel to the platform in the same manner as the rescue zone, then the time to reach the splash down zone might exhibit the same increasing trend. The intention of the splash down zone is to define an area in which the lifeboat is able to gain control and begin making way and as stated in section 3.2, the size of the zone was arbitrarily set at a value of 15m.

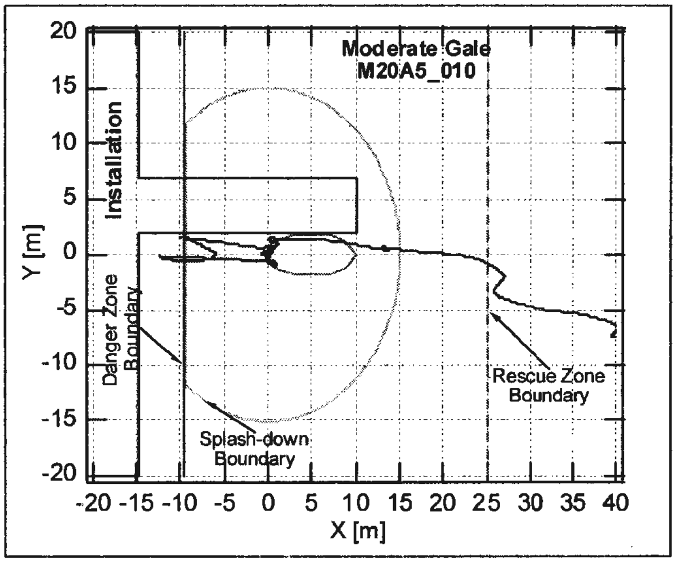


Figure 4.9: Beaufort 7 weather in perpendicular orientation

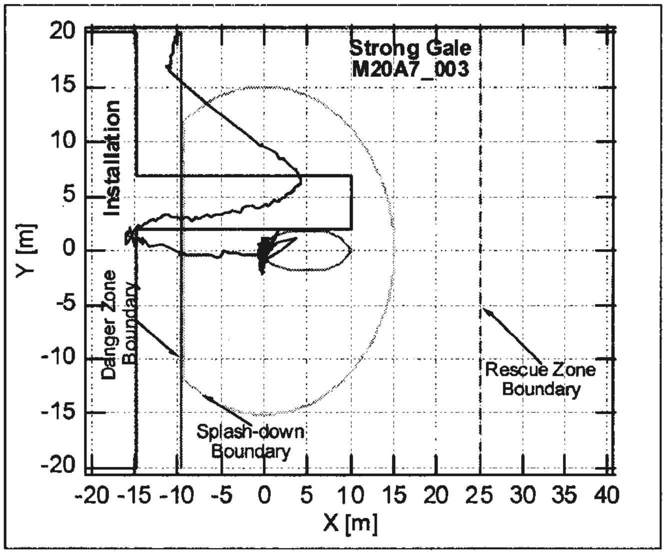


Figure 4.10: Beaufort 9 weather, TEMSPC turns back toward the platform

In the second instance (figure 4.11), the TEMPSC is pushed back by the first wave encounter, resulting in a collision. Next the TEMSPC surfs down the wave and instead of encountering the next wave upslope before reaching the splash down zone, the forward momentum results in the TEMPSC clearing the splash down zone. Taking the definition of the splash down zone into account, the results shown in figure 4.7 would indicate that the lifeboat performance is increasing with increasing weather conditions. However, in the Beaufort 9 condition, the lifeboat is not in control and in a number of launches it is not making progress away from the platform, and is in fact heading back to the platform. Therefore, the splash down may need to be re-defined or complemented to better reflect the performance of the evacuation system in extreme seas.

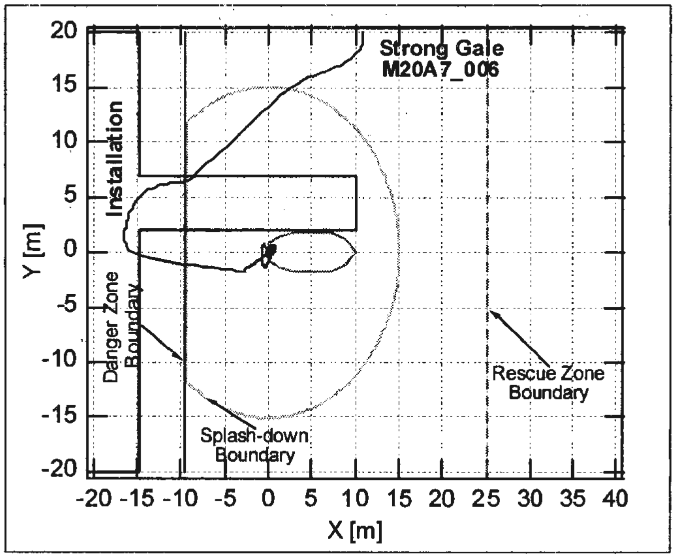


Figure 4.11: Beaufort 9 weather, TEMPSC surfs out of splash down zone

Both figures 4.7 and 4.8 also suggest that there is correlation between the time to reach a boundary and the wave landing position, especially in the Beaufort 6 and Beaufort 9 weather conditions. To investigate this further, the time measures are plotted versus wave phase angle and are shown in figure 4.12. The plots indicate that it takes slightly longer to exit each zone and there is more variability in the time for the upslope launches. There are a couple of runs with crest launches that are as high as the upslope launches. For instance, in figure 4.12 there is a point at a phase angle of 49° that required 27s to exit the splash down zone. However, the majority of crest launch times are equal to or less than the minimum upslope launch times. This is better illustrated by table 4.1, which shows the mean and standard deviation values for all weather conditions. For example, the mean time to exit the rescue zone for all crest launches is 22s, the mean value for the upslope launches is 39s. The variation in the time measure is indicated by the standard deviation, which shows a 3s higher variability in the upslope launches as compared to crest launches. Clearly the dependence of the time measures on phase angle is not as strong as seen for the set back measure, but there appears to be some dependence.

Table 4.1: Time measure statistics in perpendicular orientation

TIME TO SPLASHDOWN ZONE				TIME TO RESCUE ZONE			
Crest		Upslope		Crest		Upslope	
Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
11.96s	4.31s	22.58s	6.85s	22.03s	6.38s	39.03s	9.89s

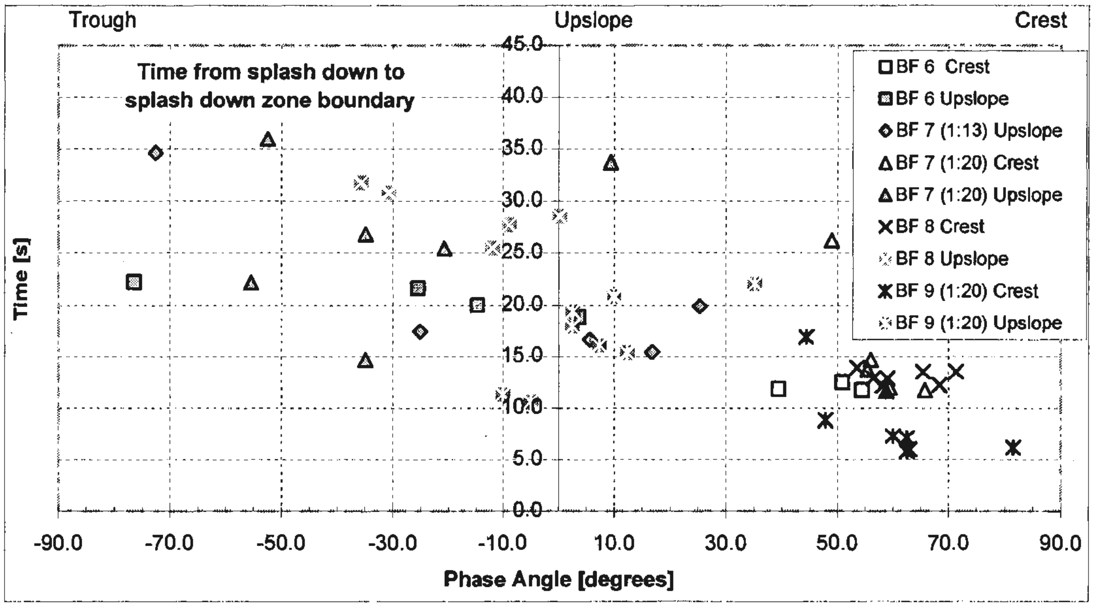


Figure 4.12: Time from splash down to splash down zone versus phase angle

Since this dependence was not found in earlier work, why is it appearing here? One plausible explanation relates to the set back measure. First of all, in previous work the clearance value was set to 11.037m (Simoes Re *et al.* (2002a)). This reduced the maximum amount of set back the TEMPSC could experience to 11.037m. Since it would be logical to assume that the farther the lifeboat was pushed back, the farther it would have to travel before it reached the boundary zones. It would then be logical to assume that if collisions occur for upslope launches at 11.037m, then increasing the clearance distance would result in higher set backs. As the weather conditions are then increased the set back would continue to increase and therefore increase the amount of time required to reach the boundary zones. For these experiments, the clearance was set to 11.87m for the 1:13 tests and 14.7m for the 1:20 scale tests, which would allow for higher set back values as compared to the 11.037m clearance. The weather conditions were also increased, which increased the amount of set back. As stated earlier, the amount of set back for crest launches was much less than the upslope launches, so using the logic outlined above, the crest launch runs should require less time to reach the boundary zones. In the smaller weather conditions however, the amount of difference is masked by the highly variable nature of the time measures. In more severe weather conditions, and with larger set back values due to increased clearance, the difference in the time measures between crest and upslope launches becomes easier to differentiate. The validity of this reasoning could be tested by performing experiments without a platform (i.e. infinite clearance). If the theory holds true, in the higher weather conditions the amount of time to reach the boundary zones should be infinitely longer than crest launches, if the TEMPSC continues to be pushed back until no forward progress is possible.

The path lengths or distances that the lifeboat travels to reach the splash down zone and rescue zone boundaries are shown in figure 4.13 and figure 4.14. The path lengths from splash down to splash down zone border show that the path length increases from Beaufort 6 to Beaufort 7 and 8. At the Beaufort 9 condition there is a slight reduction in the path length. This result is tied to the time measure results discussed above. The TEMPSC is not under control and is at the "mercy" of the waves. The wave pushes the TEMPSC back and it then surfs down the wave. In some cases the lifeboat gets turned around facing an angle of 45° from the platform and is pushed out of the splash down zone. In two other cases, the TEMPSC is pushed back and then surfs down the wave and out of the splash down zone. The path length results corresponding to these particular upslope launches are identified in the lower right of figure 4.13.

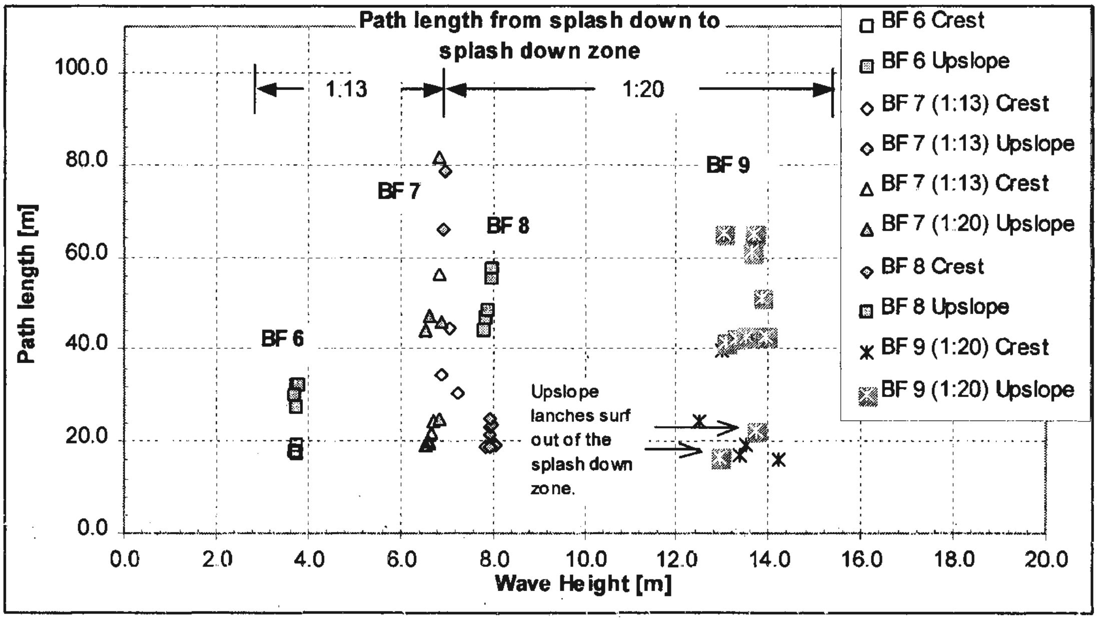


Figure 4.13: Path length from splash down to splash down zone

The distance to reach the rescue zone shows a similar trend, with an increased path length from Beaufort 6 up to Beaufort 7 and 8. At the Beaufort 9 weather condition, the TEMPSC must travel to a maximum of approximately 170m to reach a boundary line that is only 25m from the splash down point. The extra distance is attributable to the inability of the TEMPSC to make way in a direct path towards the rescue zone border. First there is set back and then after making some forward progress, the TEMPSC is continually yawing beam-on to the waves, heading parallel to the rescue zone. The TEMSPC then must recover to head back perpendicular to the rescue zone. This causes the path length to exceed the actual distance to the rescue zone.

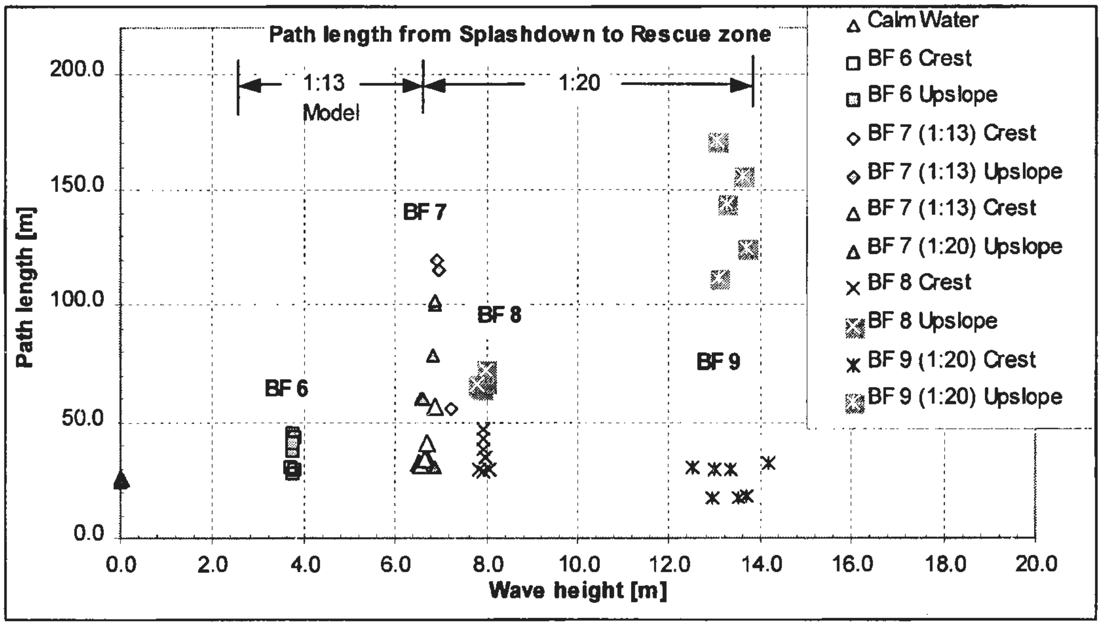


Figure 4.14: Path length from splash down to rescue zone

The ability of the TEMPSC to avoid incursions into the danger zone and collisions with the platform, as well as the ability to reach the rescue zone are crucial to the success of the evacuation sequence. These three measures are shown in figure 4.15 (the number of collisions with the platform), figure 4.16 (the number of danger zone incursions), and figure 4.16 (the ability to reach the rescue zone).

Starting with figure 4.15, the number of collisions shows that it is clear that the wave landing position is important. For all weather conditions, there were no collisions with the platform for crest launches (0/28). However, even at Beaufort 7, 33% (2/6) of the upslope launches resulted in a collision. For upslope launches the number of collisions does not increase between Beaufort 7 and 8. However, at Beaufort 9 the number of collisions increases to 100% (7/7).

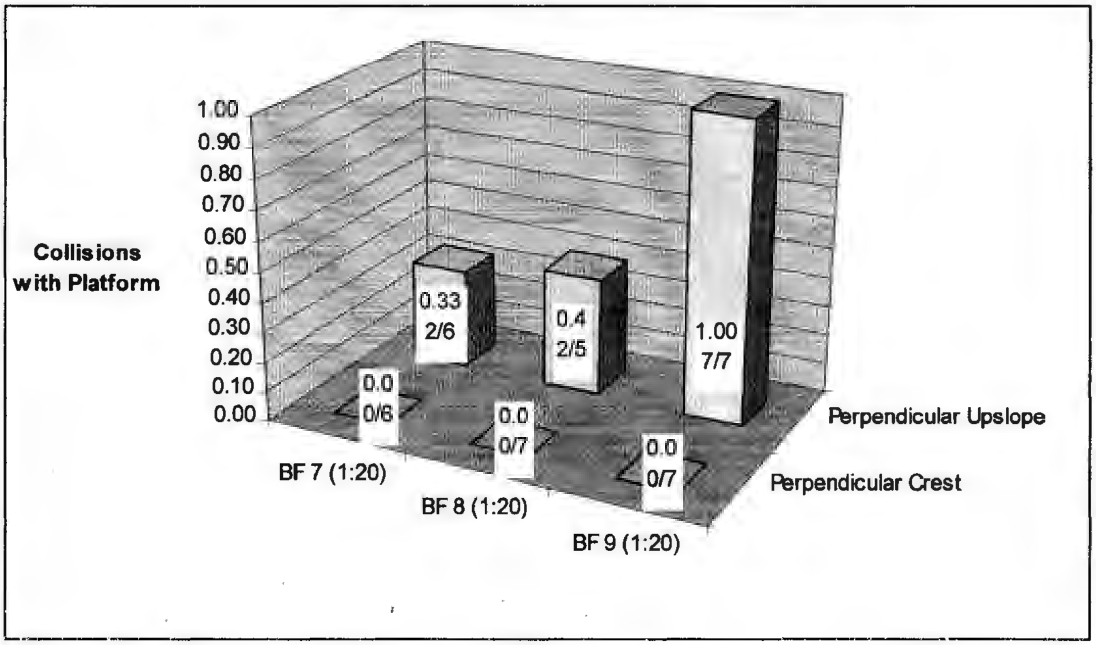


Figure 4.15: Number of collisions with platform (perpendicular orientation)

Danger zone incursion results are similar to the platform impact results and are shown in figure 4.16. None of the crest launch runs resulted in a danger zone incursion, but there are danger zone incursions occurring at the Beaufort 7 and 8 weather conditions for the upslope launches, 50% (2/4) and 53% (7/13) respectively. The proportion of incursions in Beaufort 8 condition increases to 60% (3/5). In Beaufort 9 condition the proportion of danger zone incursions is 100% (8/8).

Results showing the ability to reach the rescue zone in Figure 4.17, are relatively constant except for the 1:13 model at Beaufort 7 and 1:20 model at Beaufort 9. For the upslope launches at the Beaufort 7 condition, 23% (3/13) of runs were unable to reach the rescue zone. The Beaufort 9 condition resulted in 38% (3/8) of runs unable to reach the rescue zone.

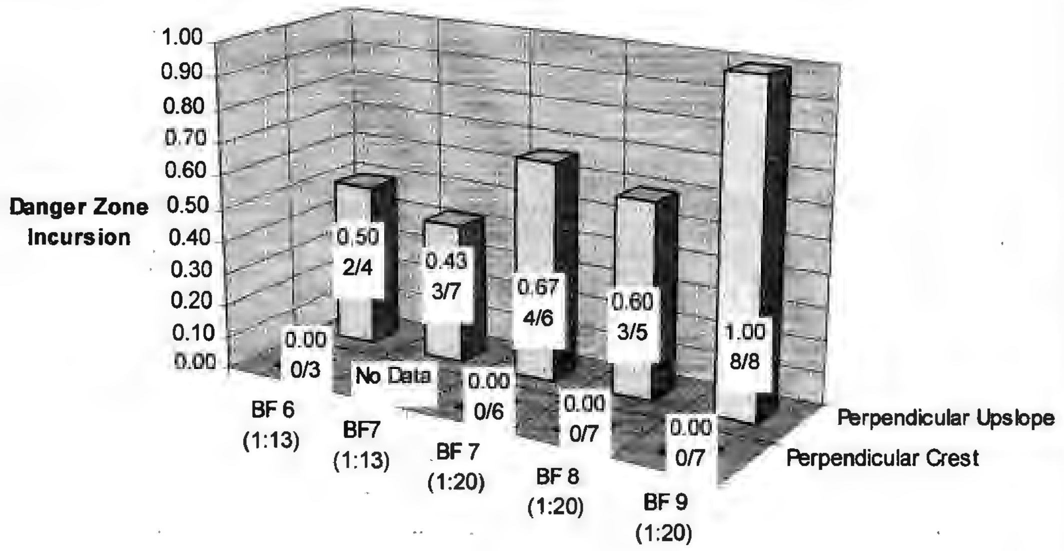


Figure 4.16: Number of danger zone incursions (perpendicular orientation)

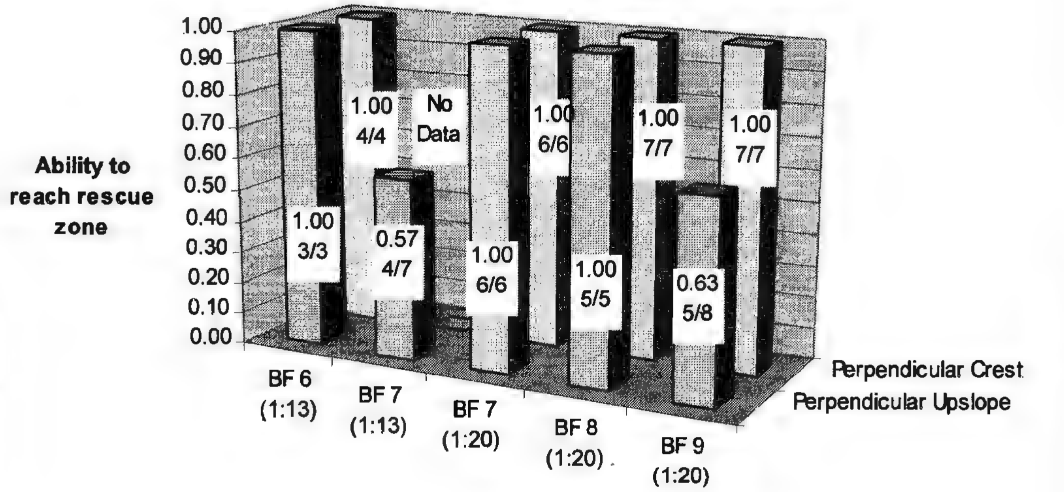


Figure 4.17: Ability to reach rescue zone (perpendicular orientation)

4.2 Parallel & Perpendicular Orientation Comparison

A series of experiments were performed with the TEMPSC parallel to the platform and weather. The purpose was to investigate the differences in performance of the evacuation system in the two orientations. Only the 1:20 model scale experiments were used for perpendicular and parallel orientation comparison. Recall from section 3.0 that the orientations are with reference to the platform and weather. The perpendicular condition is setup with bow facing into the weather, and the parallel condition is arranged with the lifeboat rotated 90° to starboard, facing beam on to the weather direction.

Figure 4.18 shows the perpendicular and parallel missed target results. The missed target results for the Beaufort 9 weather condition for both the perpendicular and parallel orientations are very similar, with maximum missed targets not exceeding 2m. The Beaufort 7 and 8 conditions resulted in two maximum missed target distances of 5.2m and 4.2m respectively. For similar weather conditions in the perpendicular orientation the maximum missed target values were less than 1.7m. Isolating these two Beaufort conditions in the parallel orientation and re-plotting the missed target results using the *x* and *y* coordinates confirms the difference in the data sets. Figure 4.19 shows the Beaufort 7 missed target results for perpendicular and parallel orientations. The maximum missed target for the parallel Beaufort 7 crest launches has two instances where the maximum missed target is larger than the parallel upslope and perpendicular crest launches. The Beaufort 8 condition shown in figure 4.20 shows similar results. With the TEMPSC oriented beam into the wind, the extra exposed wind area may be causing a higher force on the model and pushing the TEMPSC away from the target launch point. However if this was the case then the higher missed target results should occur independent of wave landing position.

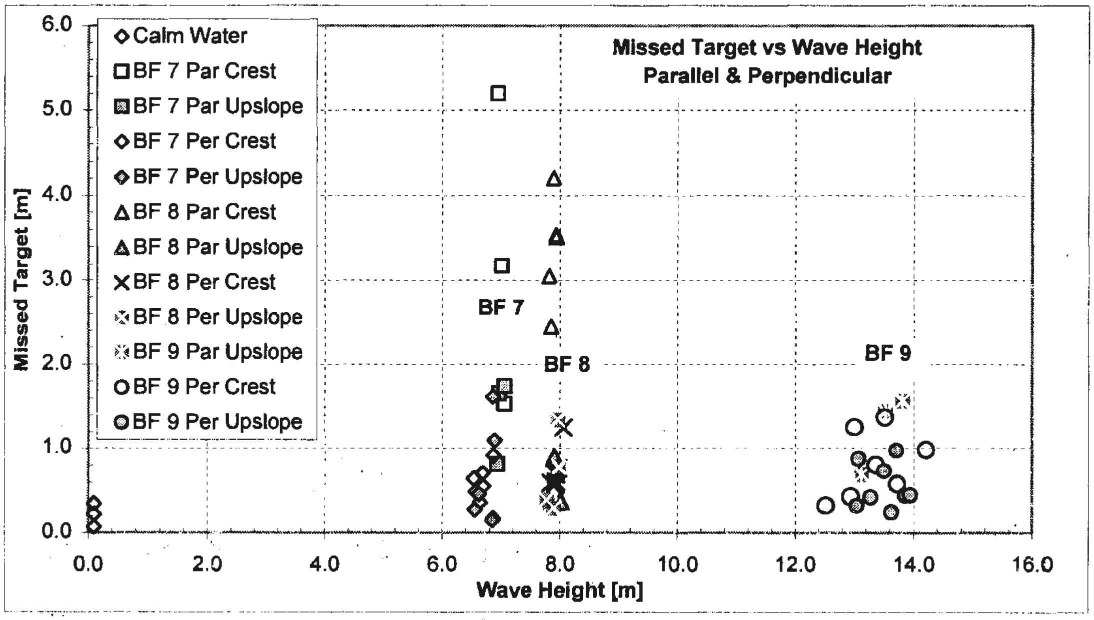


Figure 4.18: Missed target versus wave height

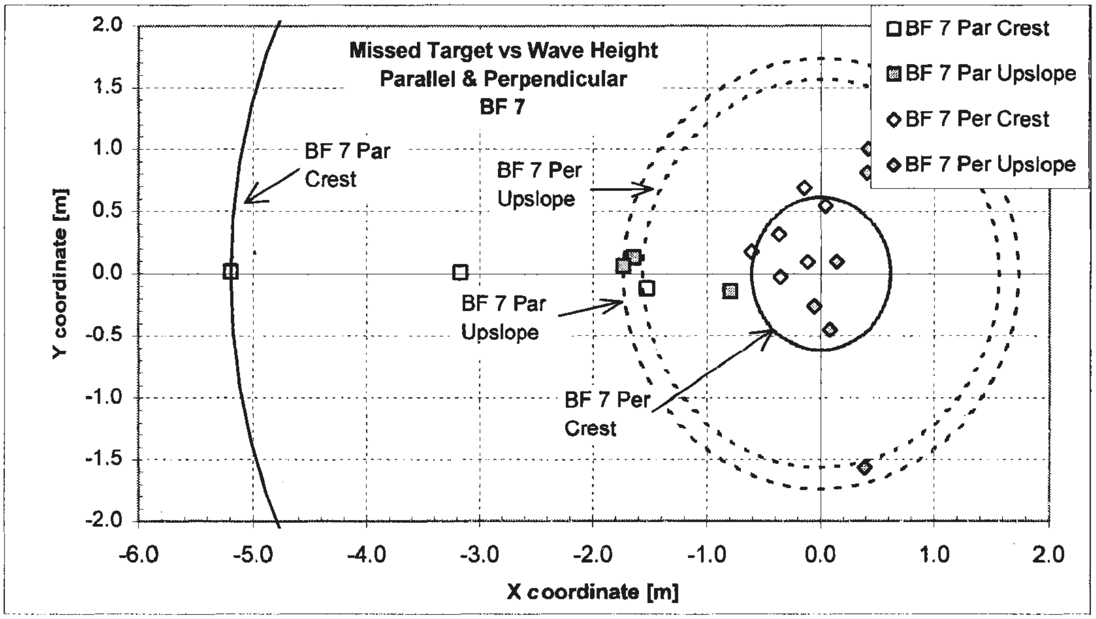


Figure 4.19: Missed target coordinate plot, Beaufort 7

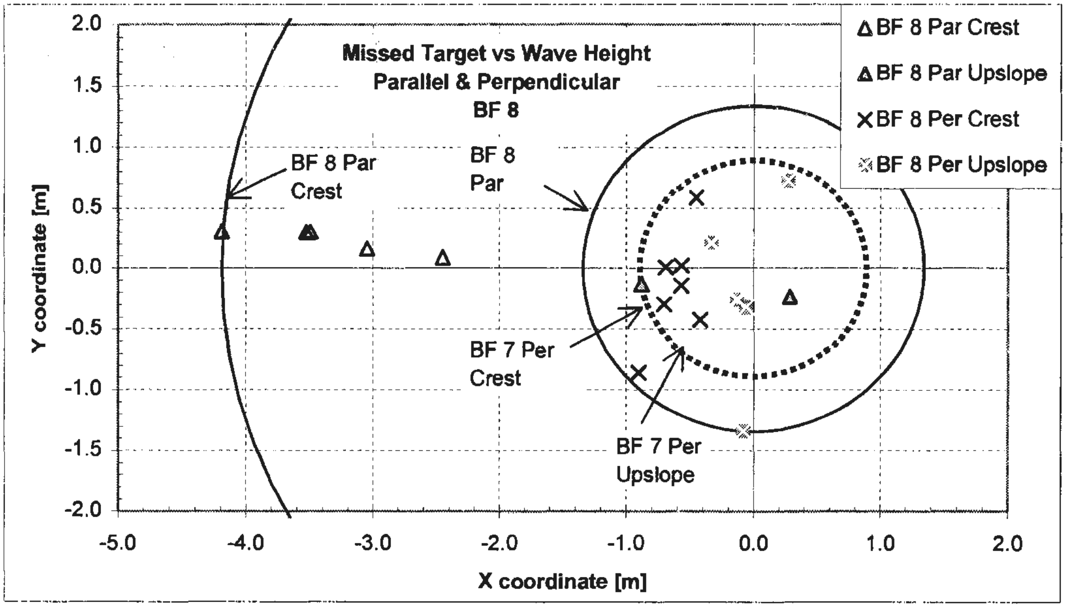


Figure 4.20: Missed target coordinate plot, Beaufort 8

The higher missed target results are due to the identification of the splash down position, which is illustrated in figure 4.21. When the TEMPSC touches down on the crest, a combination of the lowering speed and the wave celerity cause the boat to be pushed in the direction of the wave without decreasing the load on the davit lines and without activation of the hook release indicator. The time between splash down and release is relatively small but it is sufficient for the TEMPSC to travel 3m to 5m toward the platform. So it is a function of the splash down point definition and not the wind that is causing the missed target results. For analysis purposes, splash down point was identified as the point where either the davit load decreases or the immersion switch engages. In the parallel crest landing condition this does not occur until after the lifeboat touches the water and is pushed some distance pack toward the platform.

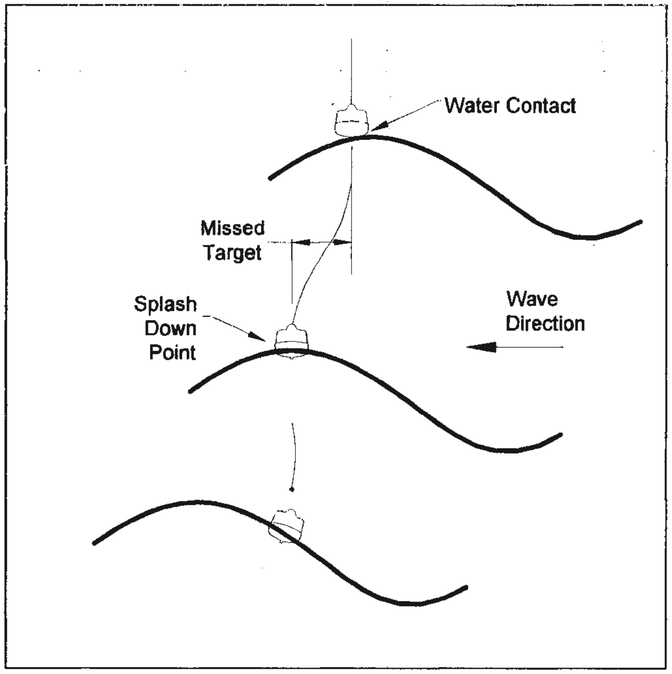


Figure 4.21: Missed target illustration

An example of a run in the Beaufort 7 parallel condition is shown in figure 4.22. During lowering there is some oscillation of the model but it is within the 2m maximum experienced in the perpendicular orientation. However, the maximum missed target for the run is not experienced until after the model touches the water and is pushed back before finally settling, reducing the davit load and engaging the immersion switch. The results then are a function of how the missed target was defined for the analysis.

The set back and the combination of missed target and set back are shown in figure 4.23 and figure 4.24. The set back for the parallel orientation is higher than the perpendicular condition. However, these results are misleading since the clearance for the parallel condition was increased to 25m full-scale for all weather conditions. In the parallel condition the TEMPSC was unable to turn into the waves and wind until outside the limits of the netting material. To avoid damaging the model, the clearance was increased to 25m full-scale. With two clearances, it is difficult to make comparisons about the amount of set back between the perpendicular and parallel orientations, since the perpendicular orientation was limited by the platform. However, it is important to note that at the Beaufort 9 condition, a clearance of 25m was not sufficient to eliminate collisions with the platform.

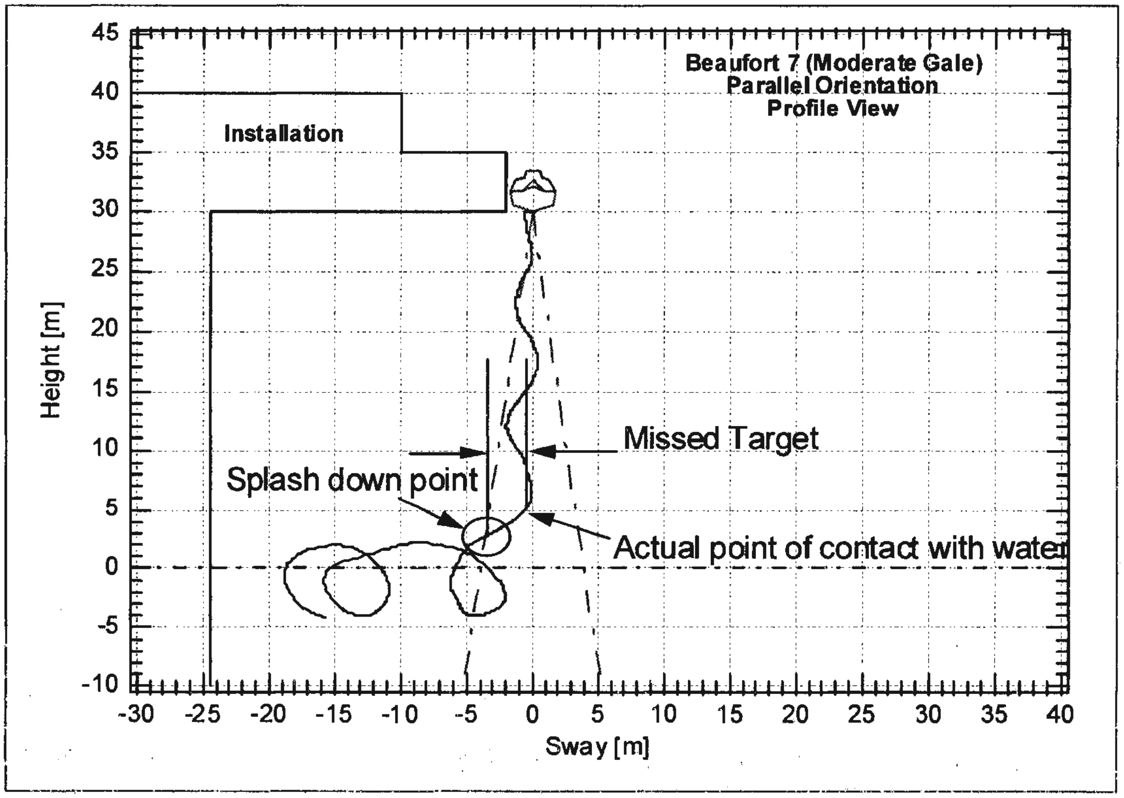


Figure 4.22: Beaufort 7 crest launch illustrating missed target

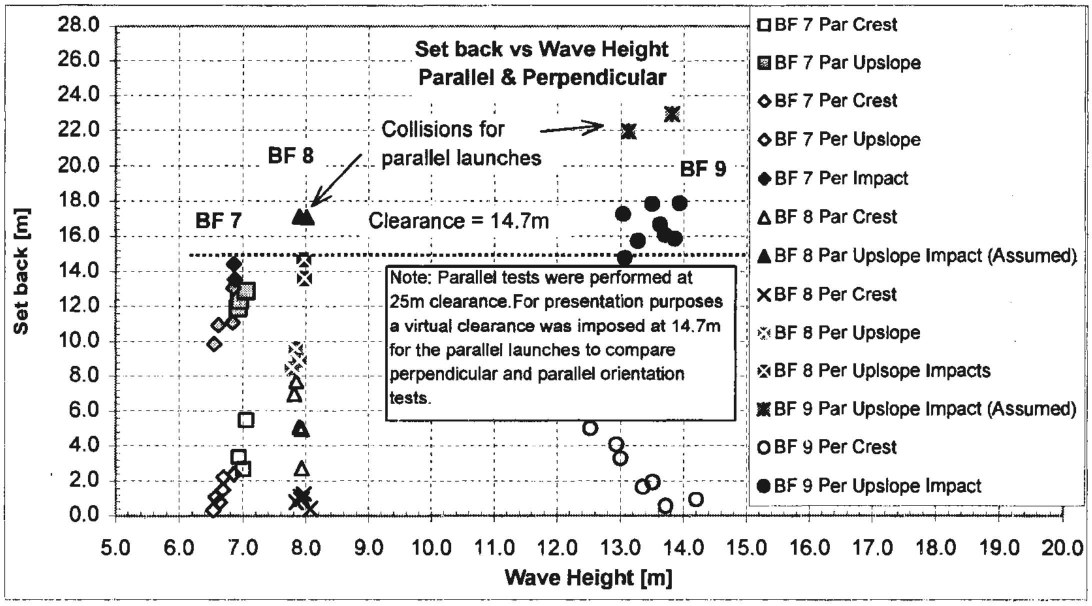


Figure 4.23: Set back versus wave height (perpendicular & parallel)

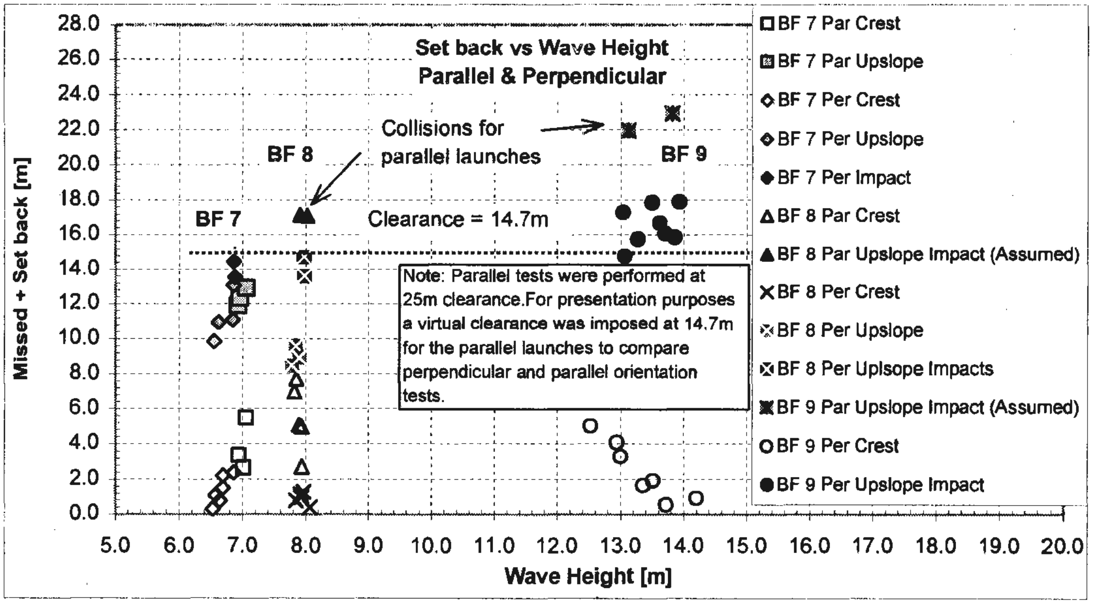


Figure 4.24: Missed target & set back versus wave height (perpendicular & parallel)

Figure 4.25 is a plot showing the missed target plus set back as well as the progressive set back, for the parallel orientation only. The TEMPSC experienced progressive set back for Beaufort 7, 8, and 9 conditions in the parallel orientation, whereas there were only two progressive set backs in the perpendicular condition for all three weathers. This was not surprising since the clearance was larger in the parallel orientation providing more space for the TEMSPC to experience progressive set back. What was surprising however was the occurrence of progressive set back during crest launches. In the perpendicular condition, there were no progressive set backs for any of the crest launches. Similar to set back, progressive set back is also a vector sum and can be plotted in the (x,y) coordinate plane. The purpose for doing this is to see if the large progressive set back is due to the TEMPSC traveling parallel to the platform some distance before it heads into the oncoming weather. A large y-component will result in a large vector sum for progressive set back. However, the amount the TEMSPC is pushed back in x-direction (i.e. toward the platform) may be small.

The coordinate plots for the Beaufort 7 and 8 conditions are shown in figure 4.26 and figure 4.27. Both plots show that some part of the progressive set back is due to TEMPSC traveling initially along the y–axis, but the larger component of the progressive set back comes from the x-direction component. The reason for the increase in the amount of progressive set back is a function of the TEMPSC's inability to turn into the weather and make forward progress away from the platform. It is possible that there could have been more progressive set back for the perpendicular condition if the clearance was set to 25m. However, this does not explain the progressive set back results observed for crest launches in the parallel condition. For the perpendicular crest launches, the set back was small enough that the TEMSPC could have experienced progressive set back but this was not observed. After the initial wave encounter the TEMPSC had no difficulties making forward progress away from the platform. These results suggest that landing on a crest in the parallel orientation does not provide the same advantage as landing on a crest in the perpendicular condition.

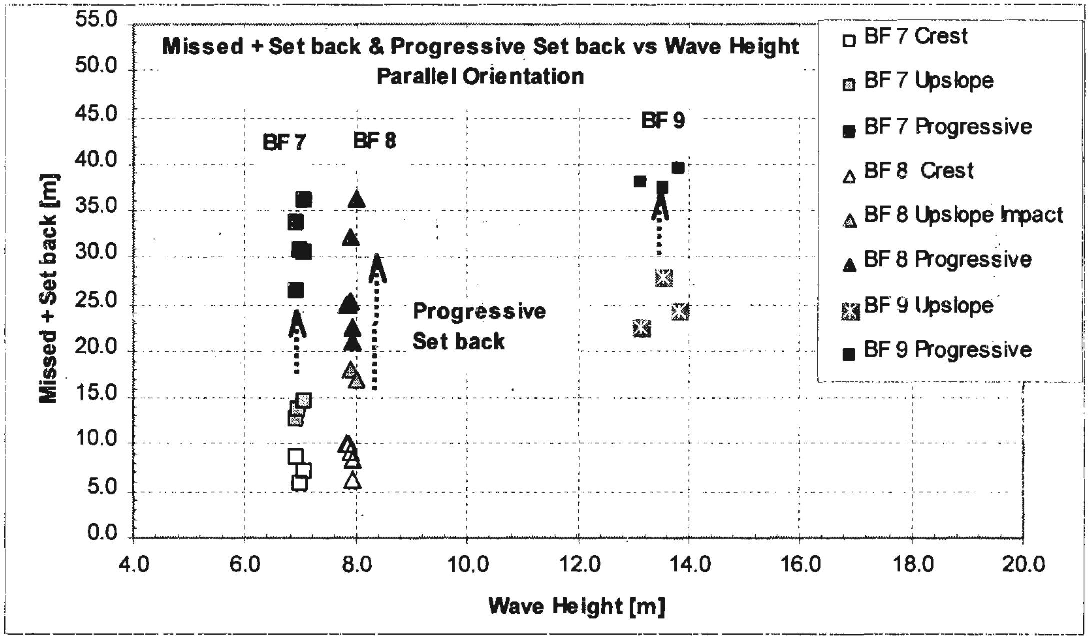


Figure 4.25: Set back & progressive set back versus wave height (perpendicular and parallel)

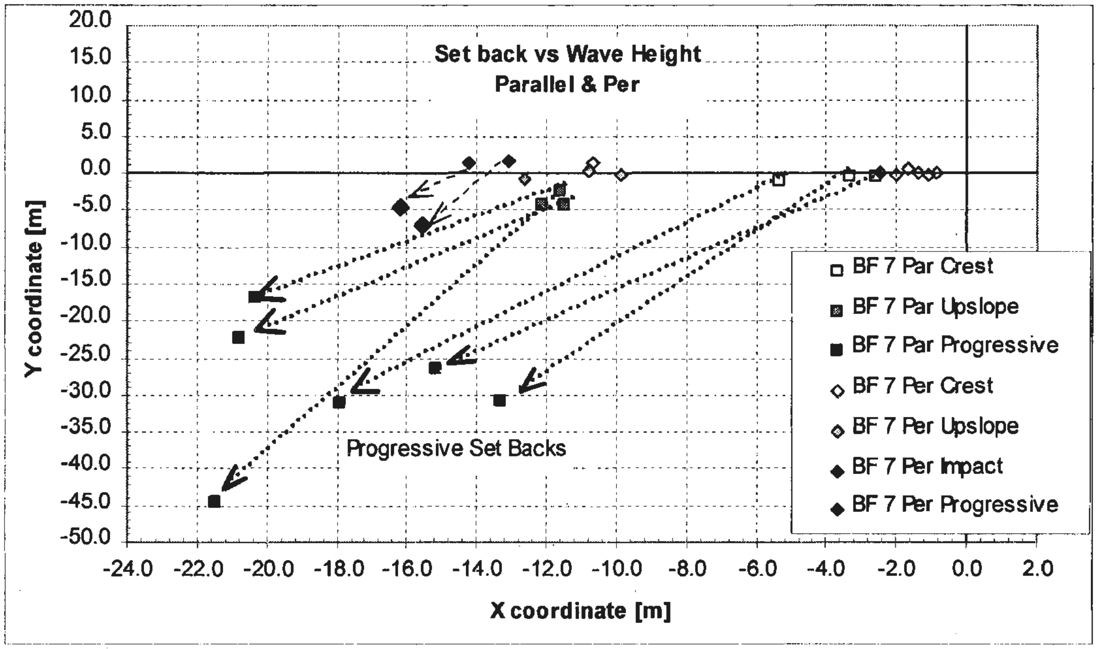


Figure 4.26: *x*-coordinate versus *y*-coordinate, progressive set back, Beaufort 7

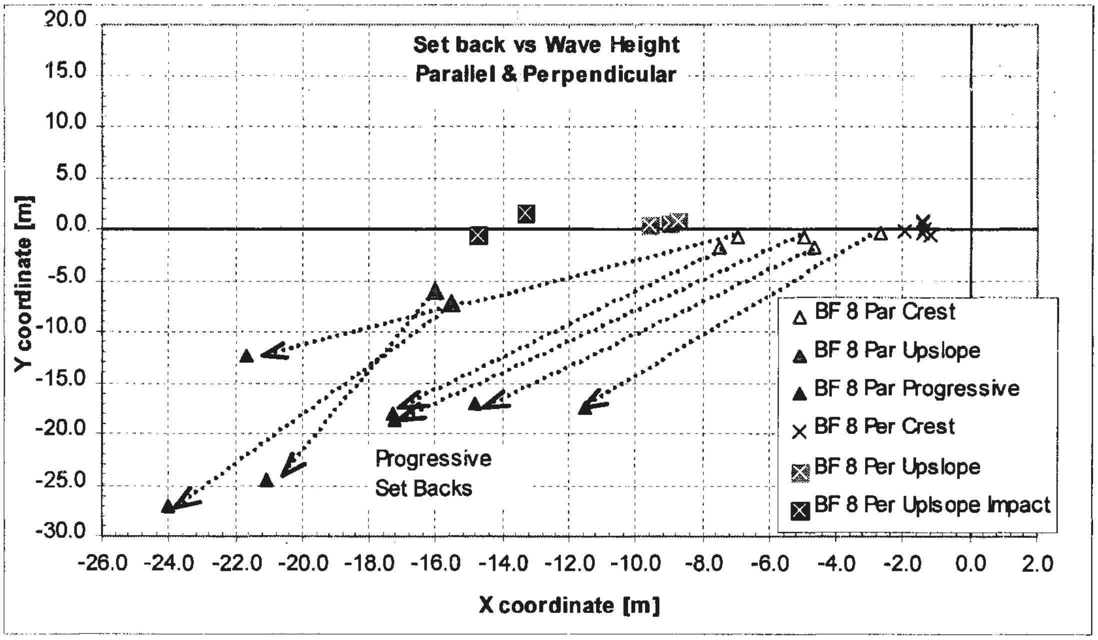


Figure 4.27: *x*-coordinate versus *y*-coordinate, progressive set back, Beaufort 8

The number of collisions for both the perpendicular and parallel orientations is shown in figure 4.28. As stated earlier, the clearance for the perpendicular orientation was 14.7m and 25m for the parallel condition. Therefore to make a comparison of the number of collisions an artificial clearance of 14.7m was used. Any run in the parallel condition, resulting in a set back or progressive set back that was greater than 14.7m in the x-direction, was considered to be a collision. When comparing the number of collisions it is apparent that the parallel orientation results in more collisions than the perpendicular orientation. For both crest and upslope launches, every run in all three Beaufort conditions resulted in a collision for the parallel orientation. The perpendicular upslope launches resulted in only 33% (2/6) and 40% (2/5) collision rates at Beaufort 7 and 8, before reaching 100% (8/8) at Beaufort 9. The crest launches show no collisions for the perpendicular orientation.

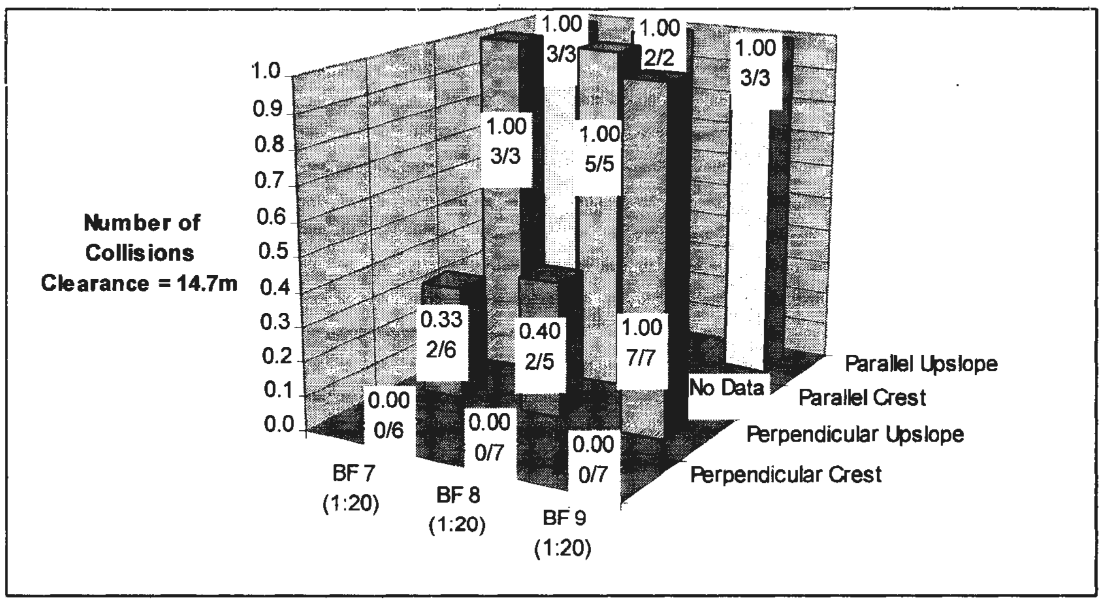


Figure 4.28: Number of collisions with platform (perpendicular & parallel)

Danger zone incursion for both orientations is illustrated in figure 4.29. The upslope launches resulted in approximately 40% fewer danger zone incursions in Beaufort 7 and 8 conditions for the perpendicular orientation as compared to parallel. In the Beaufort 9 weather condition, the number of danger zone incursions is 100% for upslope launches for both orientations. For the crest launches, 100% of runs resulted in danger zone incursions in the parallel orientation at Beaufort 7 and 8 weather conditions. This provides additional evidence that the parallel launch orientation decreases the performance of the evacuation system. Data for the crest launches with a parallel orientation in Beaufort 9 conditions would clarify the argument but crest launches were impossible for this weather condition. The deployment speed was not fast enough to land the TEMPSC on the crest. The wave was passing too quickly under the TEMPSC at the crest to allow the immersion switch to activate. The model would continue to be lowered and would impact the oncoming upslope.

The ability of the TEMSPC to reach the rescue zone is shown in figure 4.30. The TEMPSC was able to reach the rescue zone for all the crest launches in the Beaufort 7, 8, and 9, weather conditions in the perpendicular orientation. Crest launch tests were only performed for the Beaufort 7, and 8, weather condition in the parallel orientation, but in each of these weather conditions the TEMPSC had the ability to reach the rescue zone. In the upslope launch condition, the TEMSPC did not experience problems until the Beaufort 9 condition for the perpendicular orientation. The TEMPSC began to experience trouble at the Beaufort 8 condition in the parallel orientation, with only 50% successful launches.

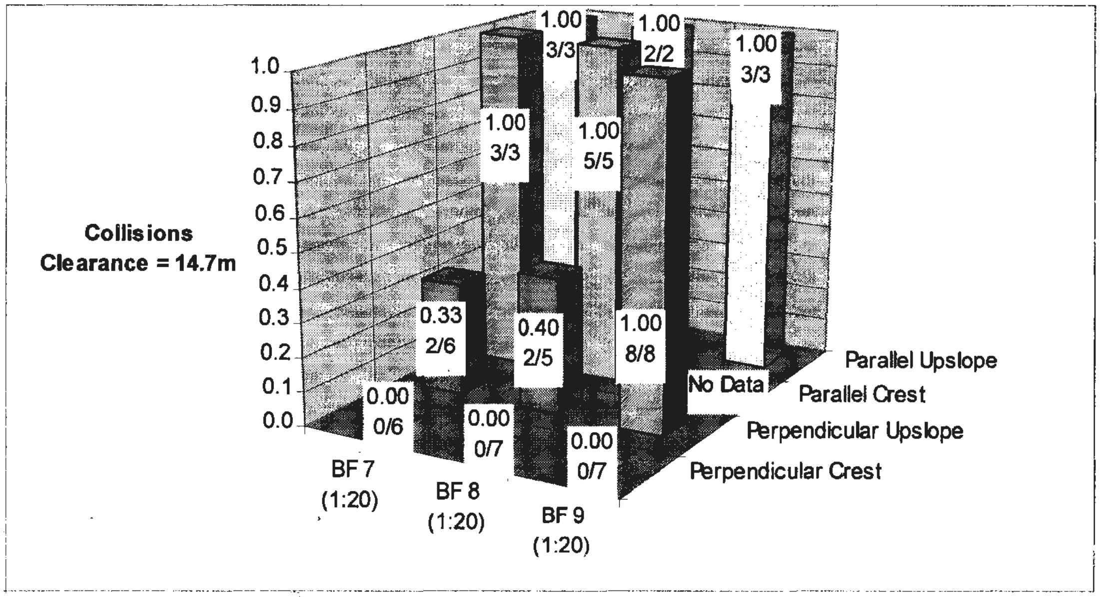


Figure 4.29: Danger zone incursions (perpendicular and parallel)

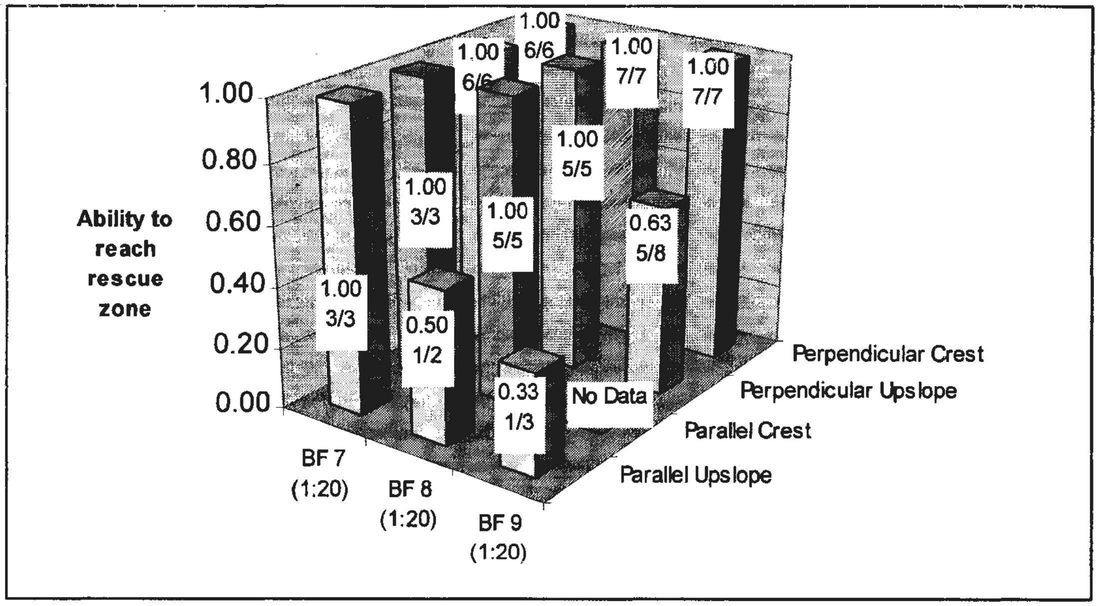


Figure 4.30: Ability to reach rescue zone (perpendicular and parallel)

In previous work by Simões Ré *et al.* (2002a), it was concluded that the parallel orientation resulted in improved performance of the evacuation system due to reduced set back and fewer collisions (see figure 4.31 and table 4.2), although those authors suggested further investigation of this was needed. The results of parallel launches shown here indicate that there is a higher probability of danger zone incursion and collisions with the platform even when the TEMSPC lands on the crest of the wave. For example, in Beaufort 8 conditions in the previous experiments, there were 0% (0/11) collisions reported for the parallel condition at a clearance of 11.037m. In the present set of tests with the clearance increased to 14.7m, the rate of collisions was 100% (7/7) for the parallel orientation. In addition, results show that there are larger progressive set back distances, due in part to the TEMPSC's inability to turn 90° into the weather and make forward progress toward the rescue zone. More importantly, the larger progressive set back in the parallel condition, even during crest launches, causes the TEMPSC to impact the platform, where it would not during crest launches under the same weather conditions in the perpendicular orientation.

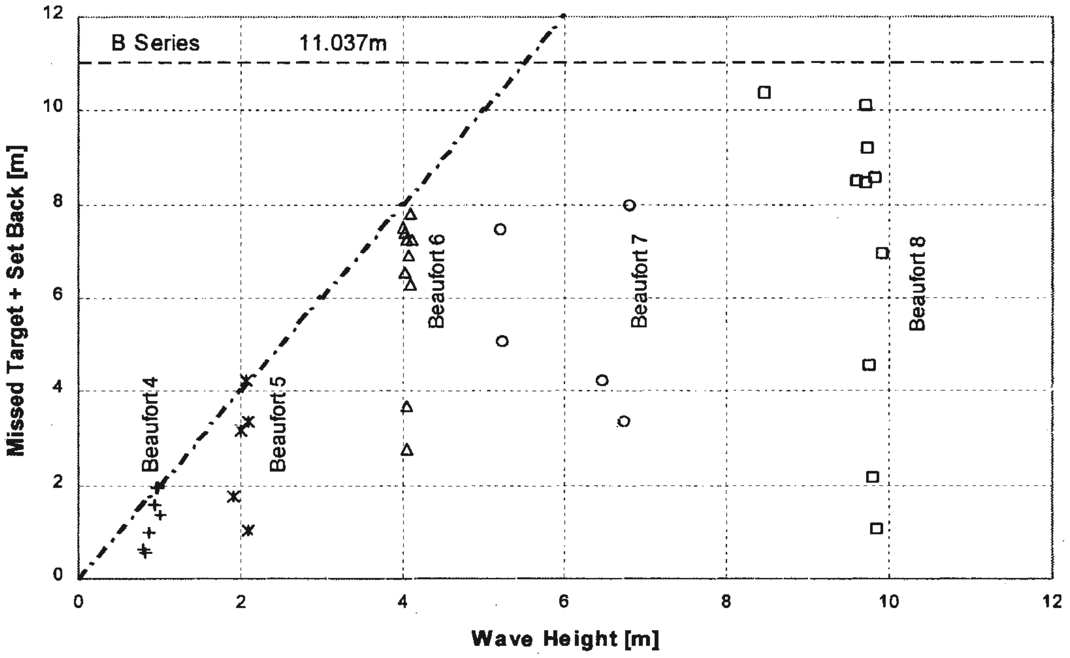


Figure 4.31: Set back for parallel launches (Simões Ré *et al.* (2002a), pg 15)

Table 4.2: Collisions in different configurations (Simões Ré *et al.* (2002a), pg 18)

	PER	PAR	PER	PAR	PER	PAR	PER	PAR	PER	PAR
C4	$\frac{0}{5}$		$\frac{0}{10}$		$\frac{0}{10}$	$\frac{0}{5}$	$\frac{5}{13}$		$\frac{9}{15}$	
C3	$\frac{0}{27}$	$\frac{0}{7}$	$\frac{0}{20}$	$\frac{0}{5}$	$\frac{0}{45}$	$\frac{0}{10}$	$\frac{9}{23}$	$\frac{0}{5}$	$\frac{17}{38}$	$\frac{0}{11}$
C2	$\frac{0}{5}$		$\frac{0}{9}$		$\frac{0}{10}$	$\frac{0}{10}$	$\frac{8}{12}$		$\frac{4}{5}$	
C1	$\frac{0}{5}$		$\frac{0}{10}$		$\frac{3}{8}$	$\frac{0}{9}$	$\frac{4}{5}$		$\frac{3}{5}$	$\frac{0}{5}$
	BF4		BF5		BF6		BF7		BF8	

4.3 Wave Steepness Effects

The majority of the experiments for this project were performed using regular waves at a nominal wave steepness of 1:20. To determine the effect wave steepness has on the performance of the TEMPSC, a set of experiments was performed using regular waves with nominal wave steepnesses of 1:15 and 1:10 in the Beaufort 7 weather condition in the perpendicular condition.

Wave steepness is defined as the wave height divided by the wave length. In these experiments the wave steepness was changed by holding the wave height constant and decreasing the wave period which in effect decreased the wave length, and therefore decreasing wave steepness. For example in the beaufort 7 condition with a wave height of 6.72m the wave period was 9.3s (wavelenght = 134.4m) resulting in a wave steepness of 1:20. To change this wave to a wave steepness of 1:15 the wave period was reduced 8.0s (wavelength = 100.8m).

The missed target versus the wave steepness for Beaufort 7 weather condition is shown in figure 4.32. The graph indicates that there is no influence due to an increase in wave steepness on the missed target. The values for the 1:15 wave steepness range from approximately 0.2m to 1.3m which is very similar to the 1:20 results. Only crest launches were performed at the 1:10 wave steepness, and these three values range from 0.2m to 0.6m.

The set back results shown in figure 4.33 indicate that there is no influence due to increase in wave steepness. Wave steepness did not affect the set back in tests reported by Campbell *et al.* (1983) either. The set back for the crest launches is not influenced by the change in wave steepness. It would also appear that changing the wave steepness does not affect the phenomenon that crest launches result in less set back than upslope launches. Set back during the upslope launches for the 1:15 wave steepness is similar to magnitude as the 1:20 wave steepness runs. This results are misleading since the set backs for the upslope launches are approximately equal to the clearance value. Indeed, some of the runs result in collisions. It may be that the influence of wave steepness is being masked by the lack of clearance.

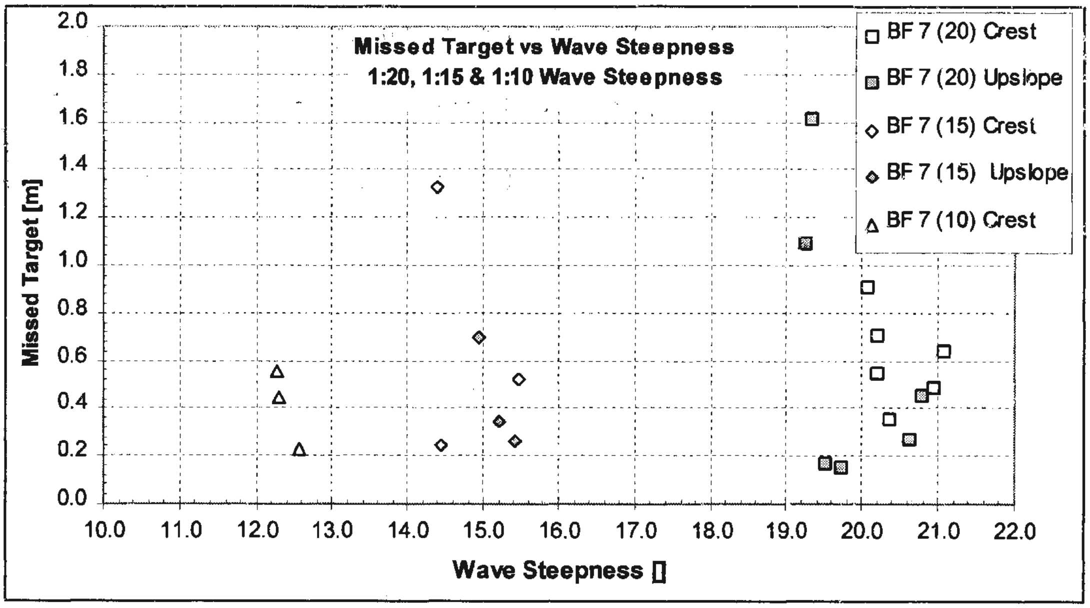


Figure 4.32: Missed target versus wave steepness (Beaufort 7)

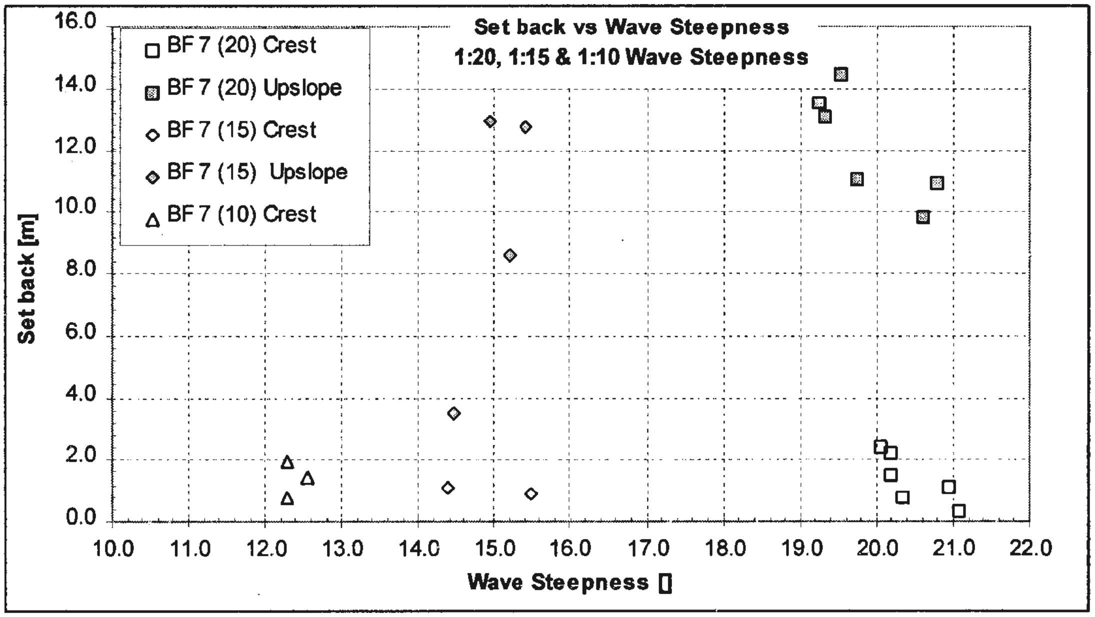


Figure 4.33: Set back versus wave steepness (Beaufort 7)

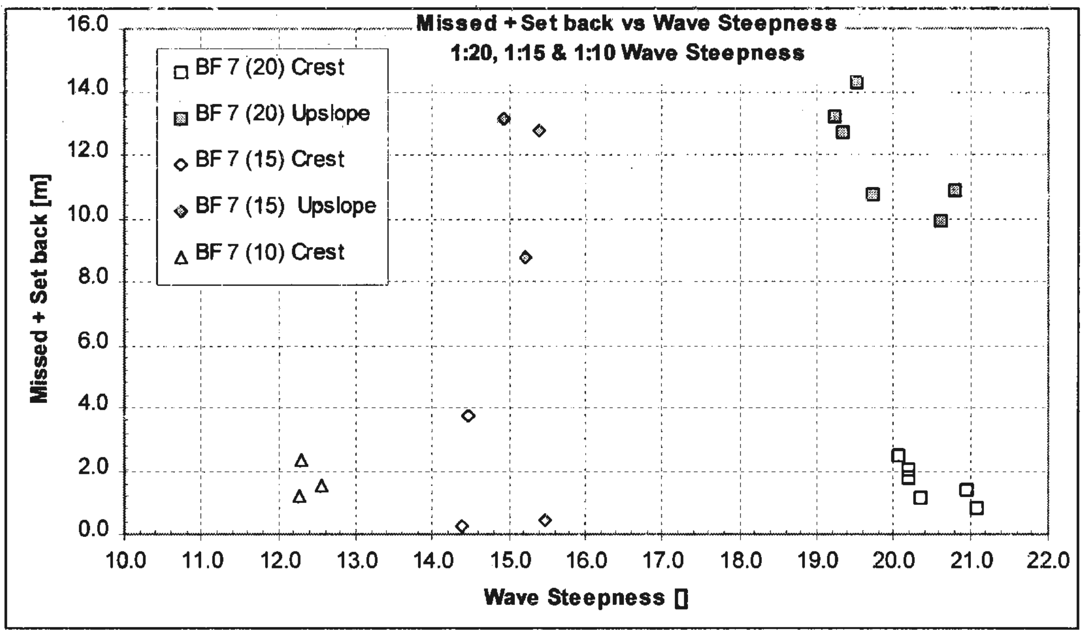


Figure 4.34: Missed target & set back versus wave steepness (Beaufort 7)

Figure 4.34, shows the combination of missed target and set back. Since the missed target values are small the results are very similar to the set back results shown in figure 4.33.

Missed target plus set back, and progressive set back are shown in figure 4.35. Wave steepness does have a strong influence on progressive set back. At the 1:20 wave steepness, there are only two out of twelve runs with progressive set back, and those are both amongst the six upslope launches. For the 1:15 wave steepness, no progressive set back is experienced for the three upslope launches or the three crest launches. The 1:10 wave steepness has no upslope launches. However, there is progressive set back on each of the three crest launches. This is shown again in figure 4.36, which is a (x, y) coordinate plot showing the progressive set back. This is the first indication that wave steepness influences the TEMPSC seaworthiness performance.

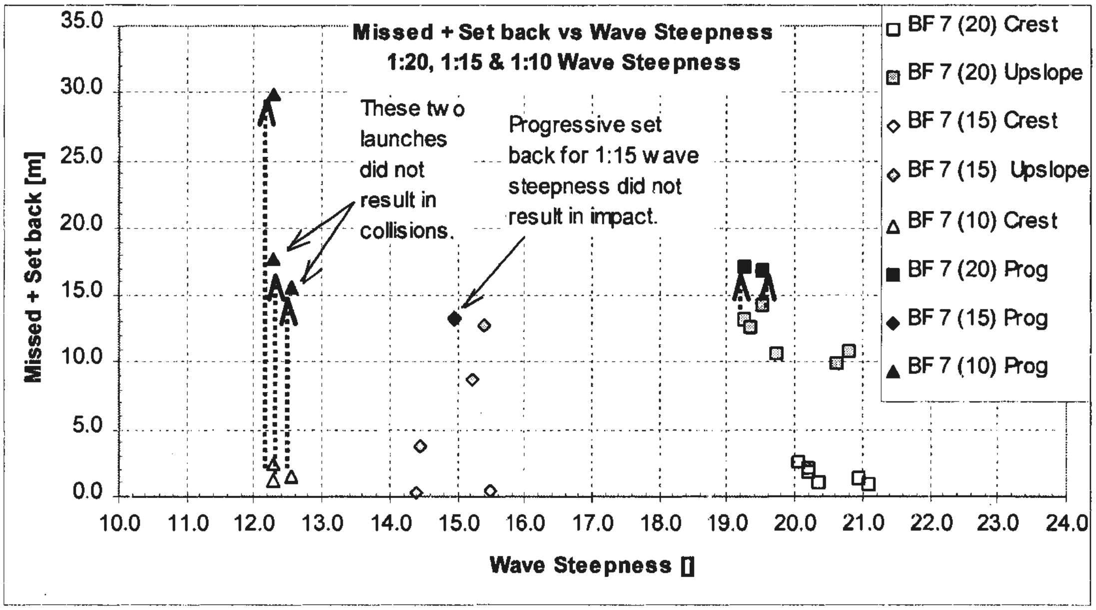


Figure 4.35: Progressive set back versus wave steepness (Beaufort 7)

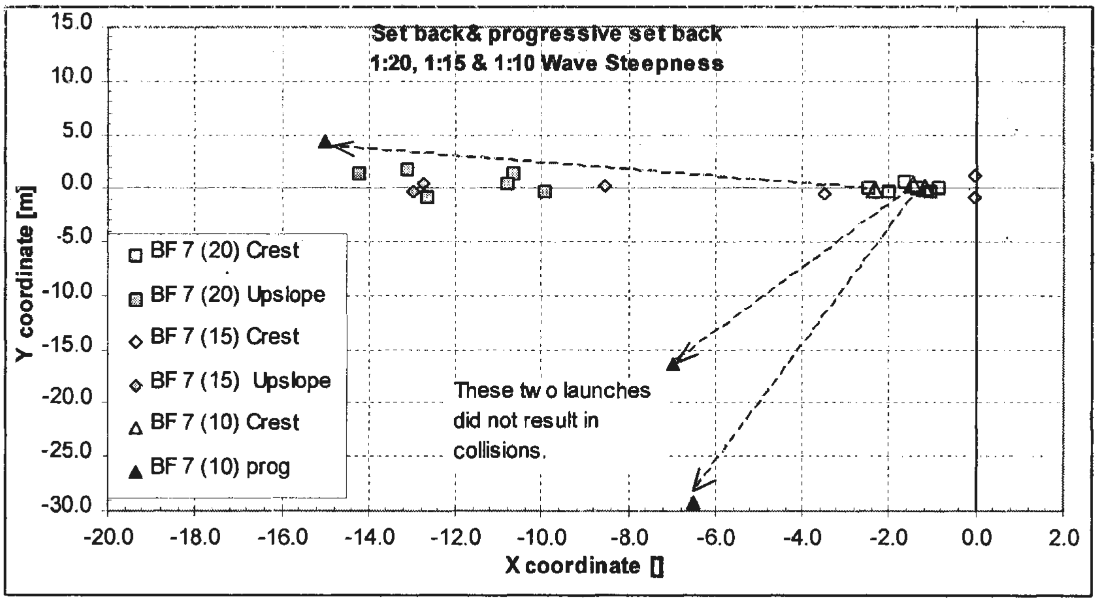


Figure 4.36: Progressive set back coordinate plot (Beaufort 7)

Further evidence is shown in figure 4.37, which illustrates the time to reach the splash down zone border. This plot clearly shows a very large effect at the 1:10 wave steepness. The time to exit the splash down zone increases dramatically from approximately 30s at the 1:20 and 1:15 wave steepnesses to a time of 100s to 700s at the 1:10 wave steepness. Figure 4.38 is a plot of the same data minus the 1:10 wave steepness results. The plot shows that the time to exit the splash down zone is relatively constant.

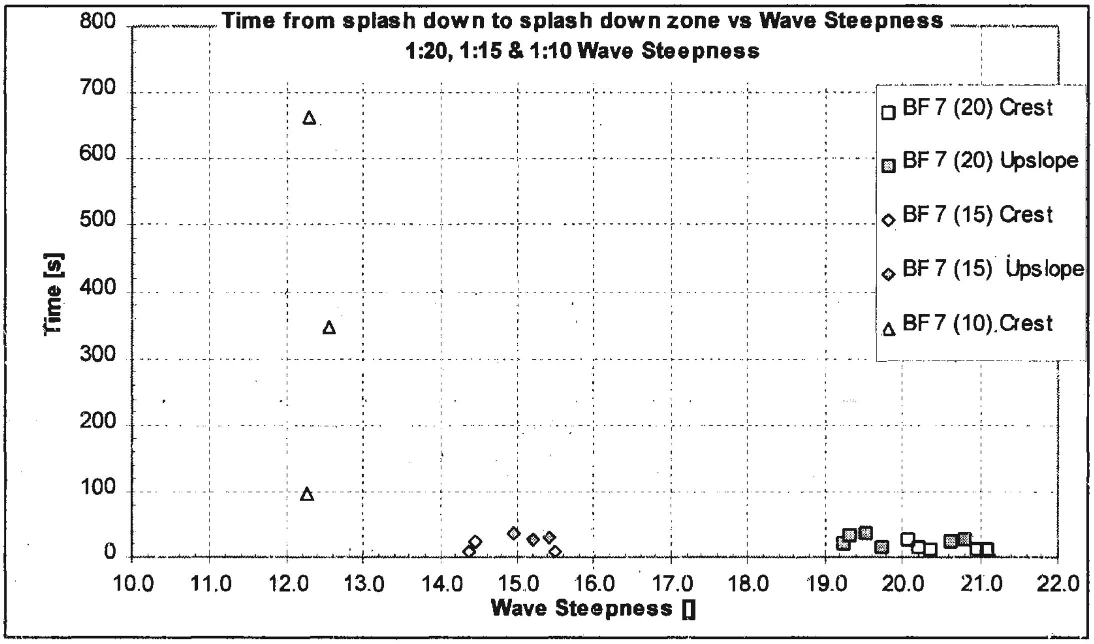


Figure 4.37: Time from splash down to splash down zone versus wave steepness

The time to reach the rescue zone, figure 4.39 shows the same phenomenon, with a dramatic increase in time to reach the rescue zone. In fact, of the three crest launches performed, only two resulted in the TEMPSC model actually reaching the rescue zone boundary. Figure 4.40, shows no influence of wave steepness between 1:20 and 1:15 wave steepness.

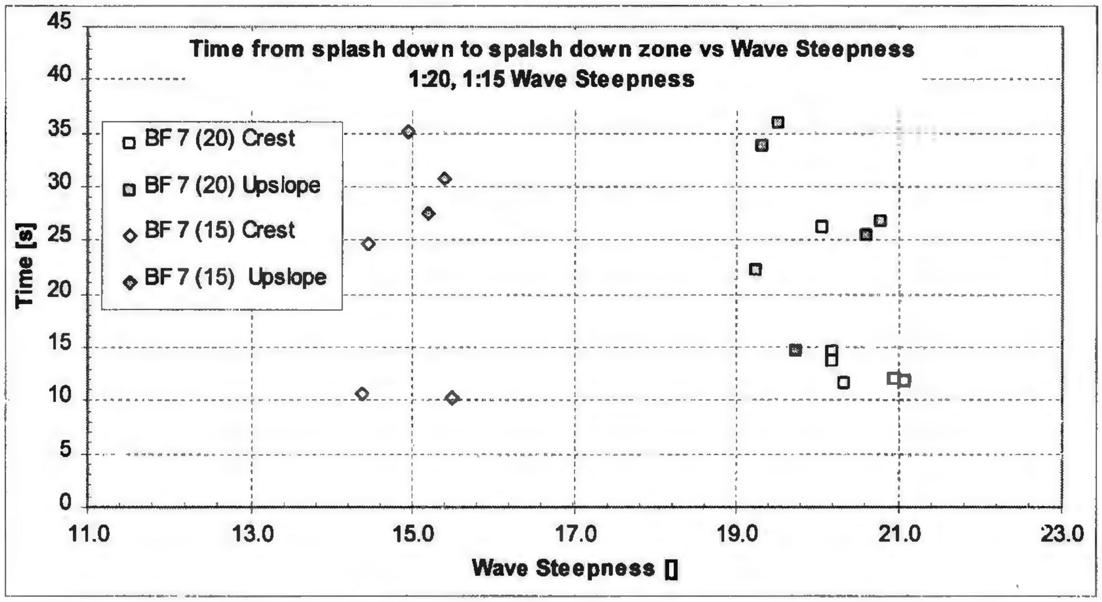


Figure 4.38: Time to splash down zone versus wave steepness (1:15 & 1:20)

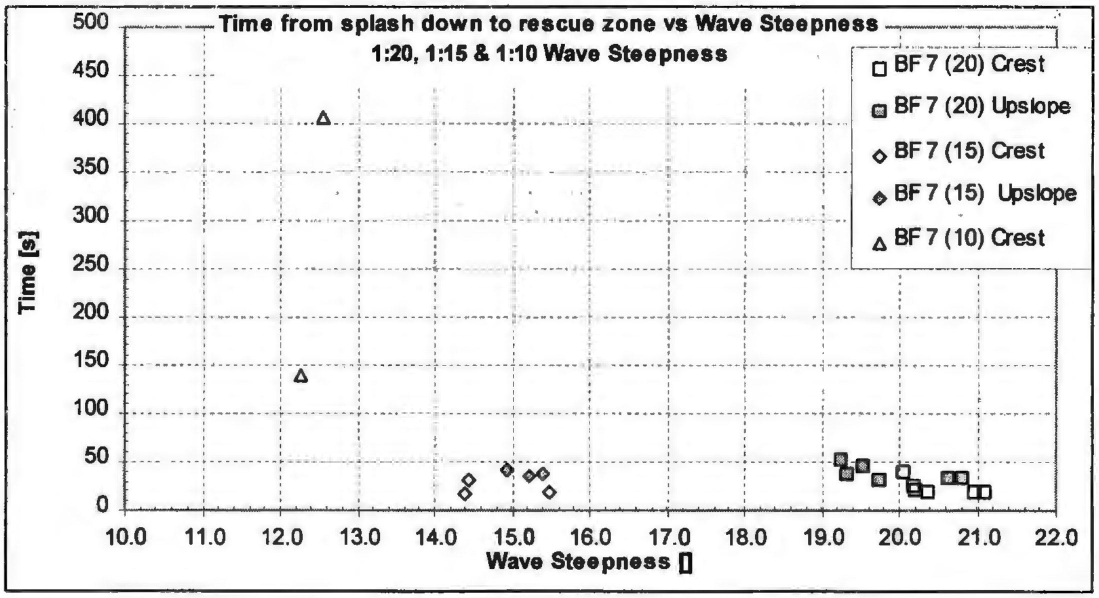


Figure 4.39: Time from splash down to rescue zone versus wave steepness

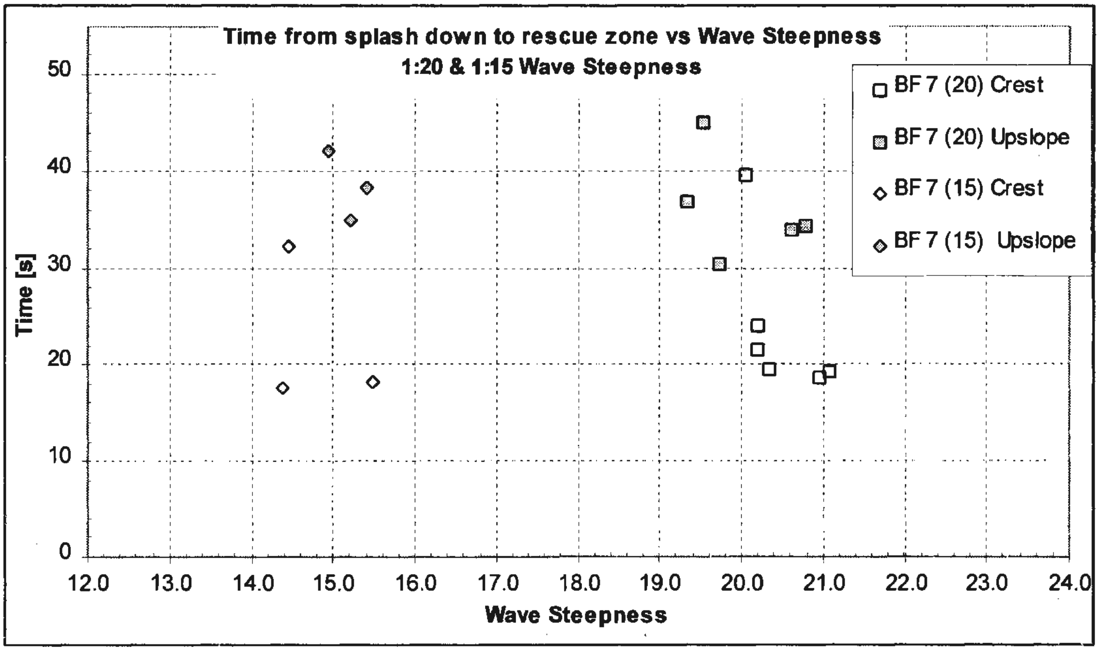


Figure 4.40: Time to rescue zone versus wave steepness (1:15 & 1:20)

Since the time and path length are related, the same trend should be seen for the path length graphs, which are shown in figure 4.41 and figure 4.42. Both show an enormous increase in the distance required to reach the respective zones. Figure 4.43 and figure 4.44 are the plots of the same data showing only the 1:20 and 1:15 data. Again there is little to no influence on the path length due to the increase in wave steepness between 1:20, and 1:15.

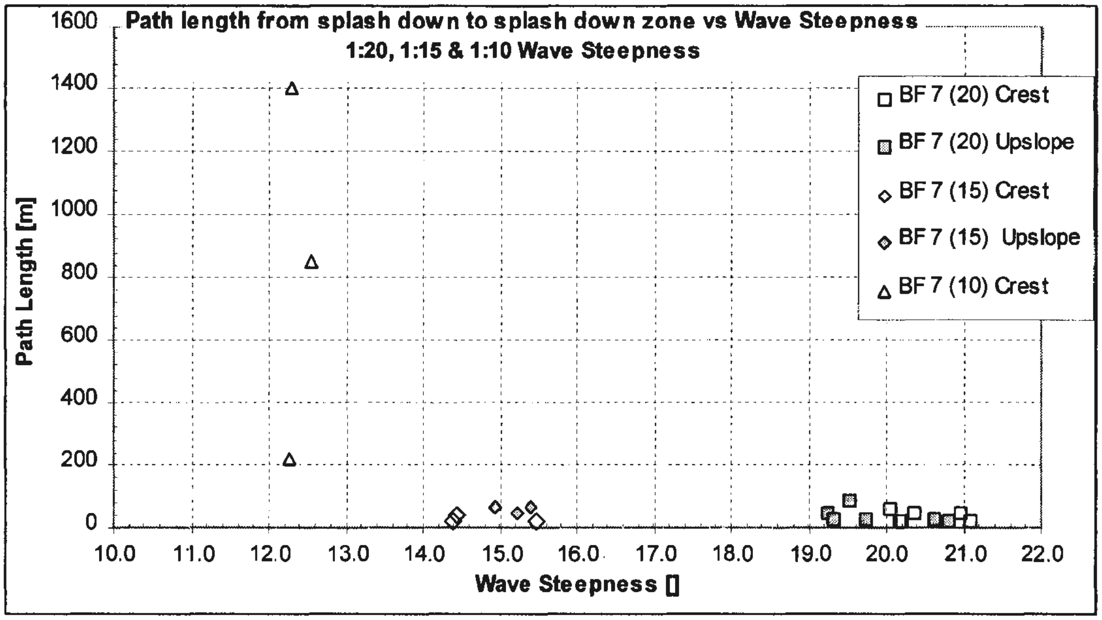


Figure 4.41: Path length from splash down to splash down zone versus wave steepness

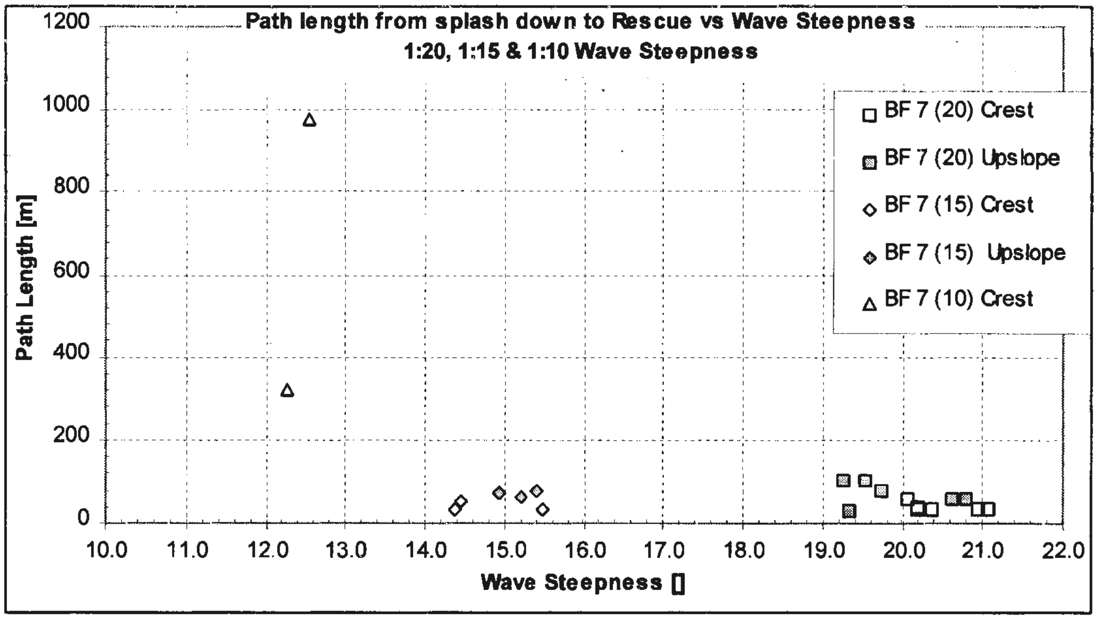


Figure 4.42: Path length from splash down to rescue zone versus wave steepness

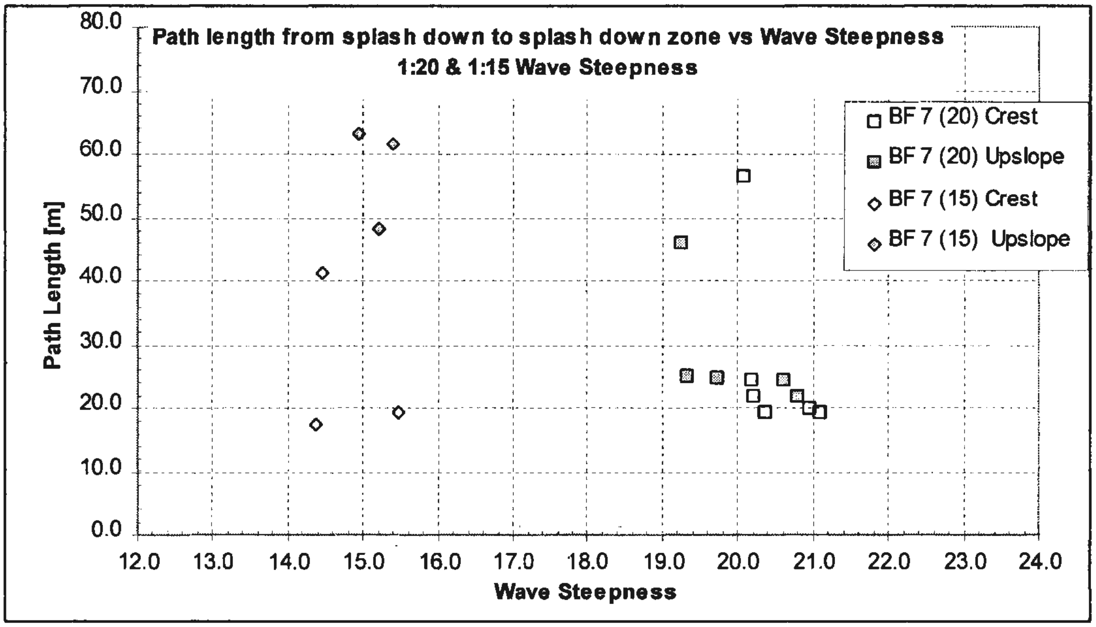


Figure 4.43: Path length from splash down to splash down zone versus wave steepness (1:20 & 1:15)

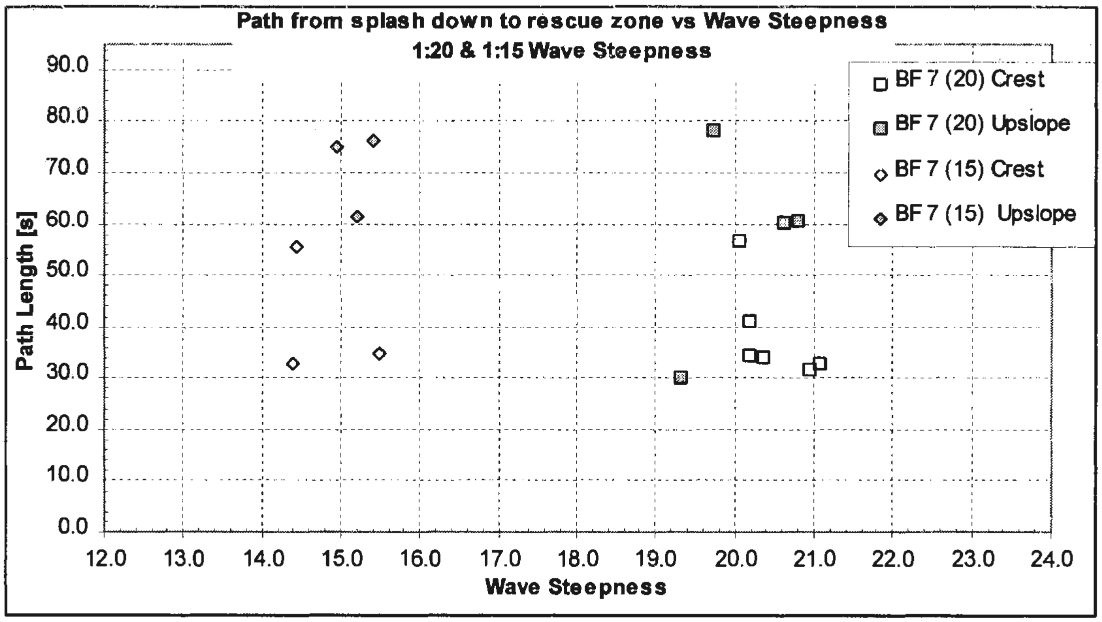


Figure 4.44: Path length from splash down to rescue zone versus wave steepness (1:20 & 1:15)

There is a noticeable difference in the progressive set back, time measures, and path lengths, between the 1:15 wave steepness and the 1:10 wave steepness experiments. The reason for the degradation in performance is related to the number of wave encounters experienced by the TEMPSC over a given time. As described on page 108, the wave steepness was changed by changing the wave period. So as the wave steepness decreases the wave encounter frequency of the lifeboat increases. At the 1:15 wave steepness the TEMPSC encounters a wave every 8s, where as it encounters a wave every 6.7s at the 1:10 wave steepness. To illustrate this further, plots of experiments in the 1:20, 1:15, and 1:10 wave steepness conditions are shown in figure 4.45, figure 4.46 and figure 4.47. Figure 4.45 and figure 4.46 show that in the 1:20 and 1:15 wave steepness, the TEMPSC reaches a crest, gets some forward momentum, is slowed down by the next upslope, but has enough forward momentum to reach the crest, where the boat picks up more momentum. Of particular interest here is that the TEMPSC encounters an upslope every 13m or more for the 1:20 wave steepness and 10m or more for the 1:15 wave steepness. In the 1:10 wave steepness (figure 4.47) the TEMPSC encounters a wave every 5m, which is one half of a boat length. So in the 1:20 and 1:15 wave steepnesses the TEMPSC is able to ride the wave, picking up forward momentum on the down slopes before reaching another upslope At the 1:10 wave steepness though, the TEMPSC is encountering a wave every half a boat length and doesn't have an opportunity to pitch down and ride the downslope. Instead, just as the nose is pitching down the bow encounters another upslope. The problem is compounded when the TEMSPC increases forward speed, which causes the number of wave encounters to increase, and in turn slows the boat down again. This makes it very difficult to make any forward progress and thus results in dramatically longer path length and time measures, even when launched on a crest.

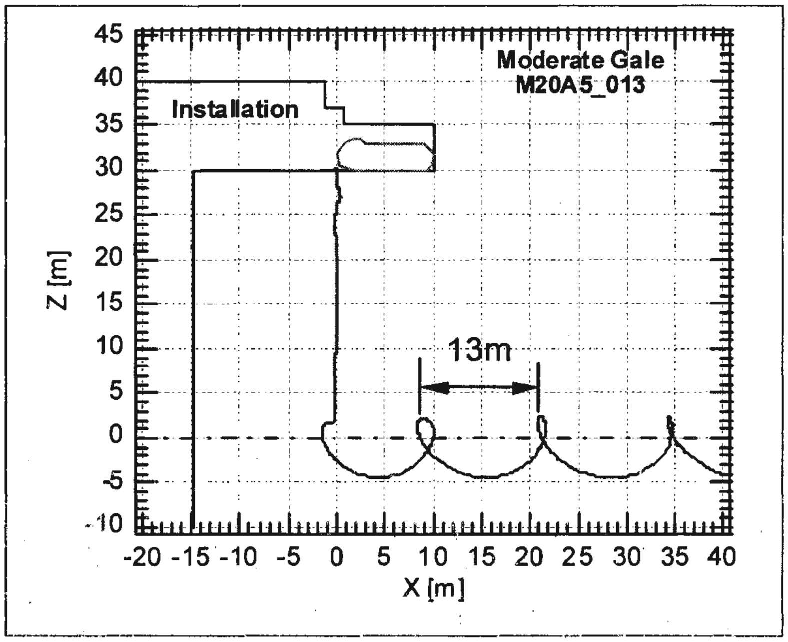


Figure 4.45: TEMPSC path through 1:20 wave steepness (Beaufort 7)

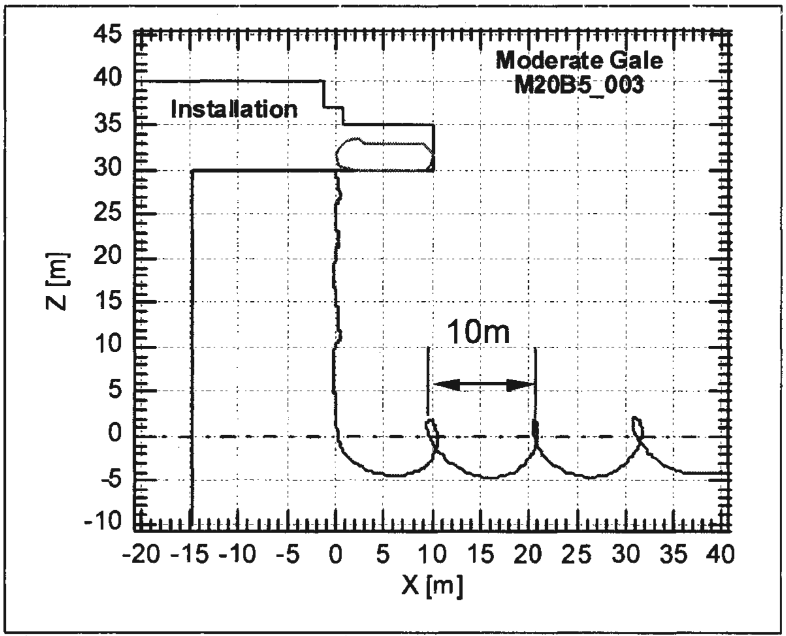


Figure 4.46: TEMPSC path through 1:15 wave steepness (Beaufort 7)

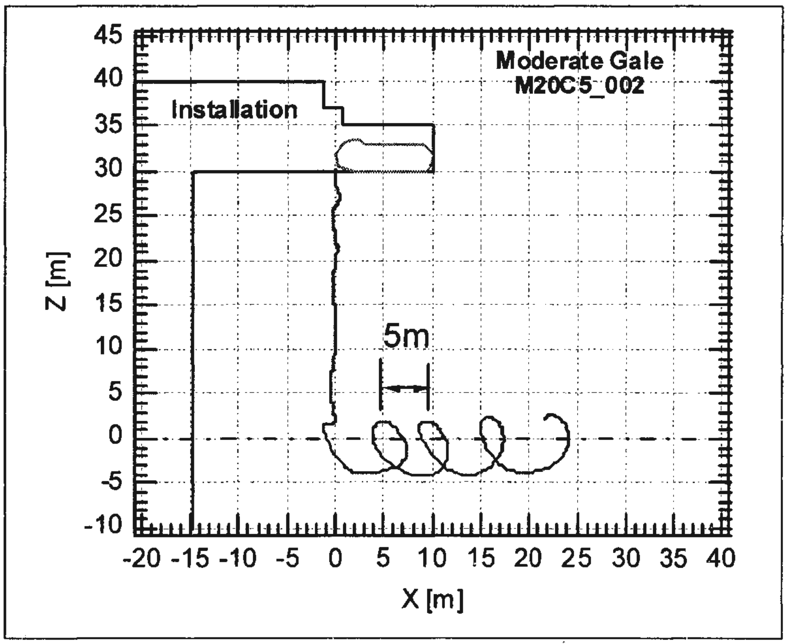


Figure 4.47: TEMPSC path through 1:10 wave steepness (Beaufort 7)

It is also reasonable to expect that the influence is directly related to the prevailing weather condition. As the wave height increases it will become more and more difficult for the lifeboat to make forward progress since the bow will always be "slamming" into larger and larger wave upslopes. Unfortunately, in this set of tests, no experiments were performed at the 1:10 wave steepness for weather conditions other than the Beaufort 7 condition.

4.4 Irregular Waves

As indicated earlier, the majority of the experiments were performed using regular waves. In real situations though, an evacuation system will be launched into an irregular wave field. Therefore, a small set of irregular wave launches in the Beaufort 8 conditions were performed. The data from these runs is compared to the data from the 1:20 wave steepness tests and the 1:15 wave steepness tests in the Beaufort 8 condition.

The missed target data, shown in figure 4.48 is comparable to the regular wave data. The missed target may be a poor comparison parameter since the results for all conditions have been similar up to this point.

Figure 4.49 and figure 4.50 show the data for set back, and missed target plus set back. The irregular wave data compares well with both sets of regular wave data. The irregular wave data was not separated into upslope and crest launches, however there seems to be some distinction in set back data points. Three irregular wave set back results compare well to the set back in regular wave crest launches, and at the high end, two points compare well to the regular wave upslope launches, averaging at about 14.7m and resulting in collisions.

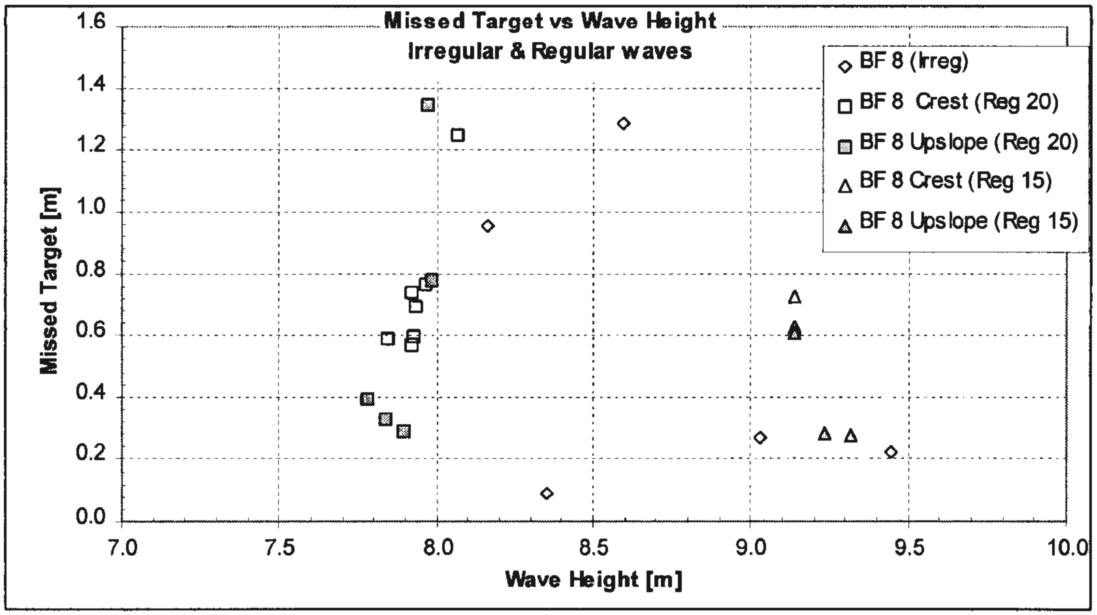


Figure 4.48: Missed Target versus wave height (irregular and regular waves)

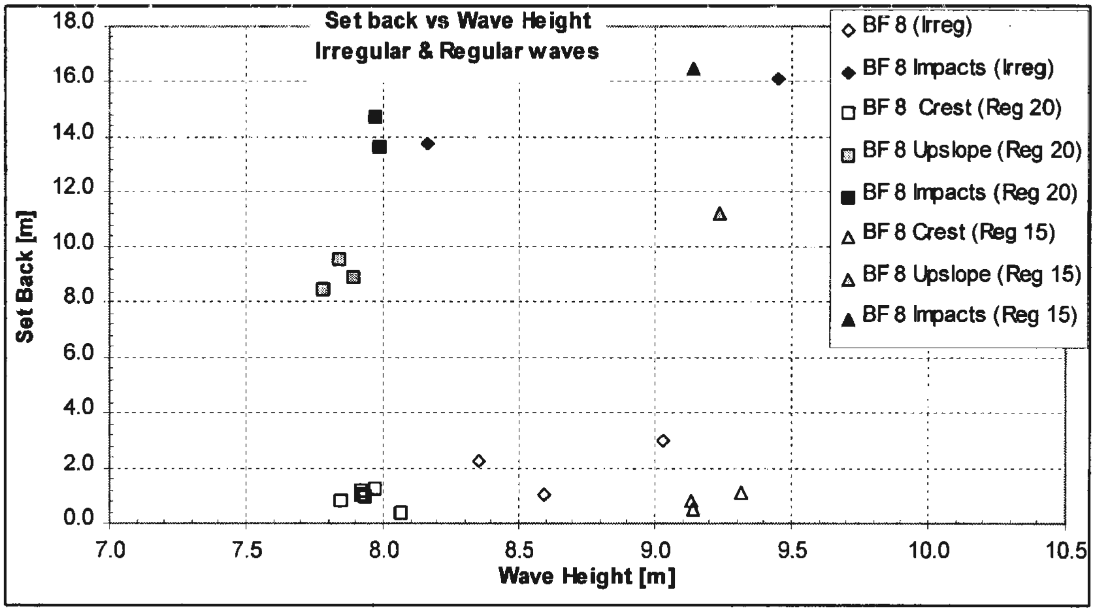


Figure 4.49: Set back versus wave height (irregular and regular waves)

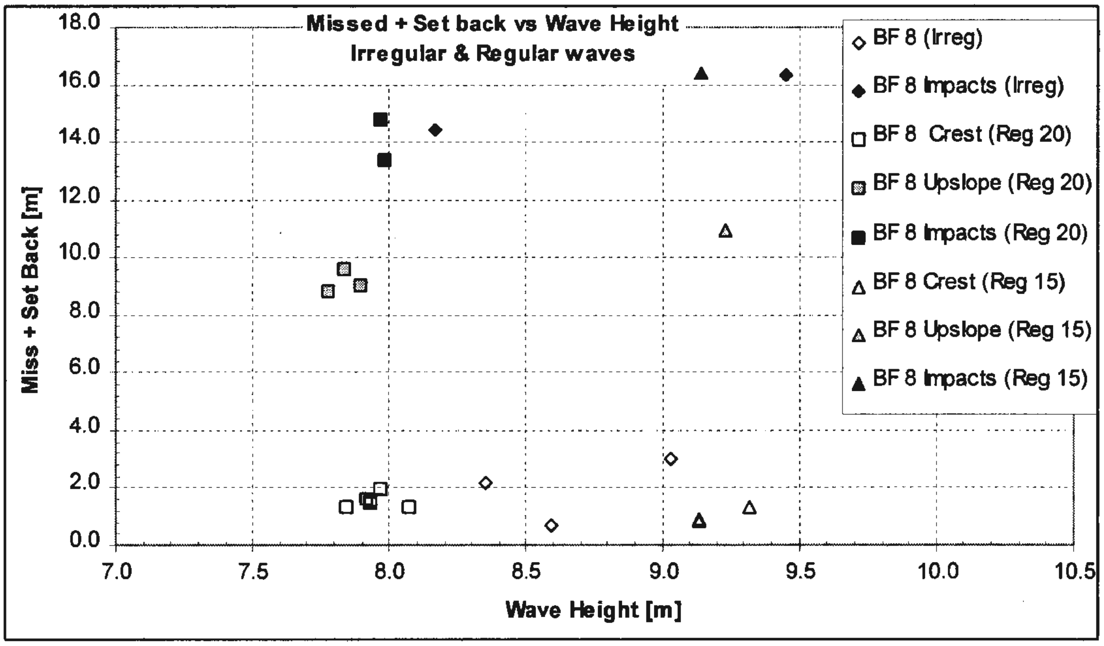


Figure 4.50: Missed target + set back versus wave height (irregular & regular waves)

Both time measures and path length measures for the irregular waves and regular waves also compare very well and are shown in figure 4.51, figure 4.52, figure 4.53, and figure 4.54.

A comparison of the number of impacts, danger zone incursions, and ability to reach the rescue zone is tabulated and shown in figure 4.55. The results indicate that danger zone incursions and impacts with the platform at a clearance of 14.7m occur approximately 50% of the time for the irregular and regular weather conditions. In each condition, the TEMPSC was also able to reach the rescue zone 100% of the time. Although the data set is small, the results indicate that there is little difference between experiments using regular and irregular wave patterns. However, an irregular spectrum can have significant variations in individual wave heights and periods whereas one evacuation system test will only see a few waves out of a large number. Therefore, results can be easily skewed depending on what part of the irregular spectrum is used. As stated in section 3.1.5, the portion of the irregular wave that was used for this set of tests had significant wave height of 8.7m and a peak period of 11.99s. The full-length spectrum had a significant wave height of 10m and a peak period of 12.3s.

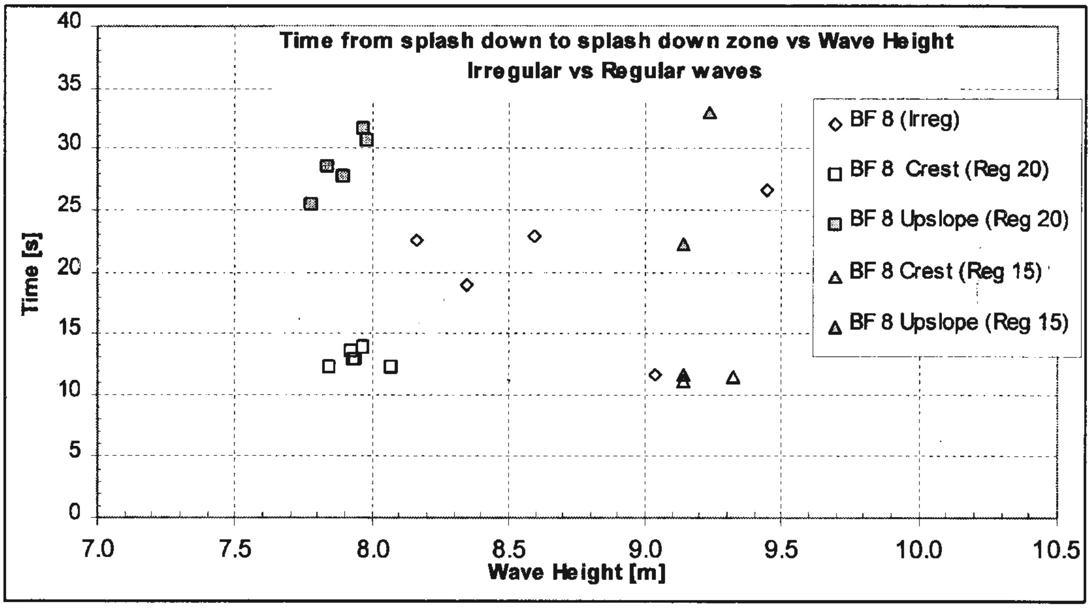


Figure 4.51: Time from splash down to splash down zone versus wave height (irregular and regular waves)

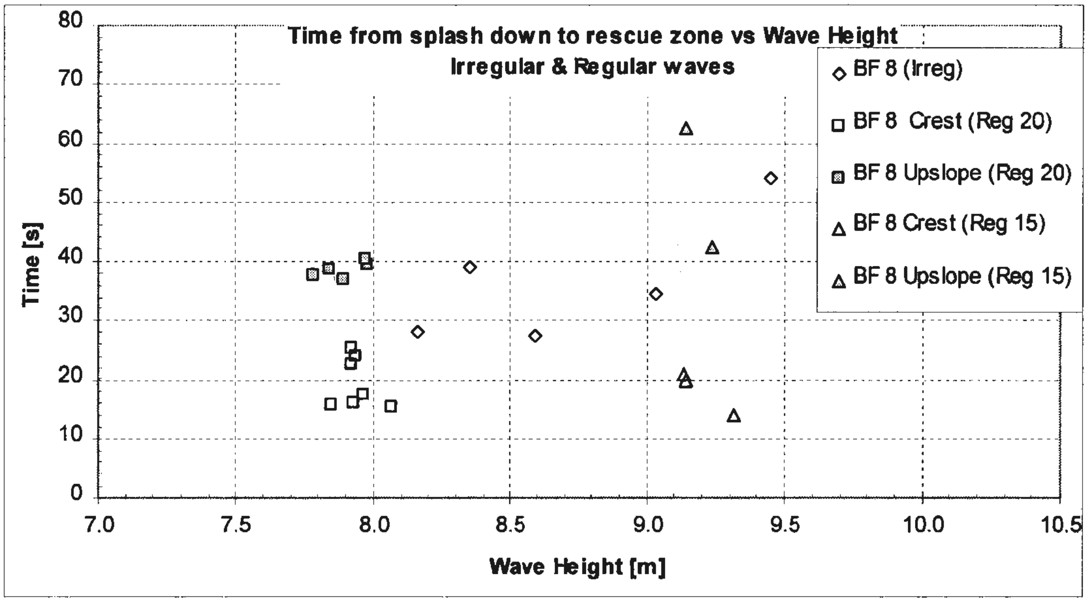


Figure 4.52: Time from splash down to rescue zone versus wave height (irregular & regular waves)

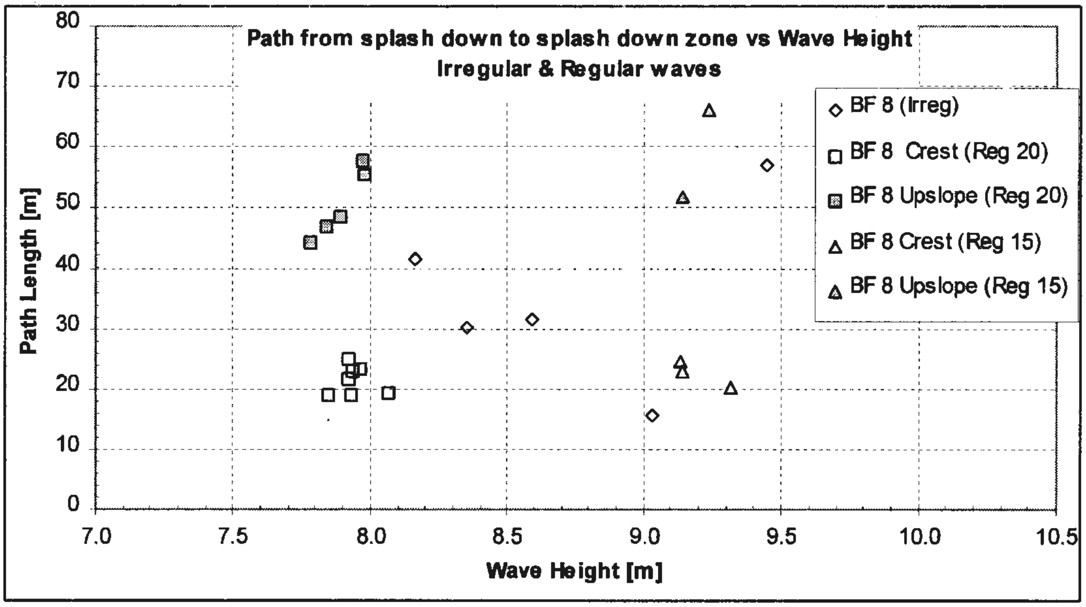


Figure 4.53: Path length from splash down to splash down zone versus wave height (irregular and regular waves)

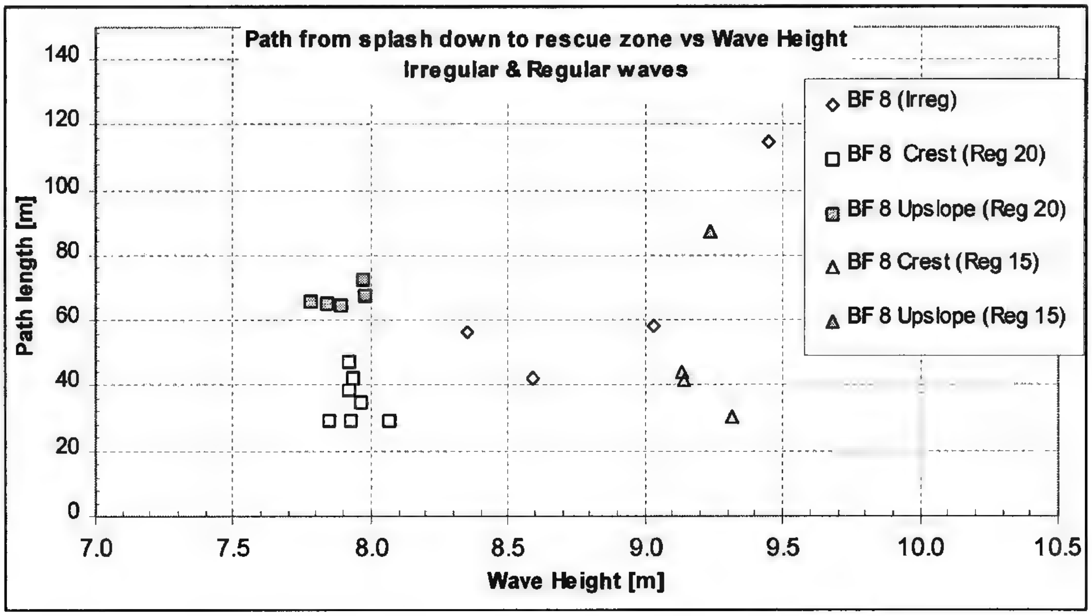


Figure 4.54: Path length from splash down to splash down zone versus wave height (irregular and regular waves)

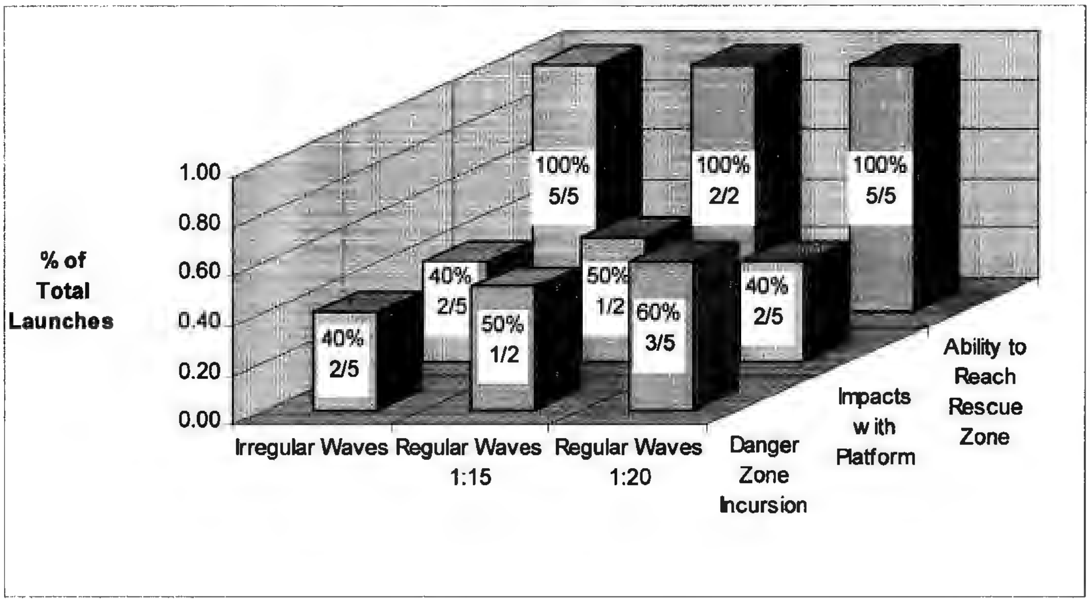


Figure 4.55: Danger zone incursion, collisions, and ability to reach rescue comparison (irregular and regular waves)

4.5 Experimental Uncertainty

A detailed study (Lindroth (2001) was performed on the uncertainty for the test set up used for these experiments and reports the instrumentation errors. Much of the information and methodology presented here is based on this study and is cited accordingly.

4.5.1 Model Characteristics

The moulds for both models were constructed at the Institute for Marine Dynamics using a five axis milling machine. Using the standard procedures for milling a model results in a general precision of ± 0.127mm. The actual main dimensions were measured using a tape measure. According to these measurements the models are to within 2mm to 3mm of the target dimension. The accuracy of the dimension is limited here by the measuring device (tape measure) and not the actual model dimension. The remaining model errors are shown in table 4.3

Table 4.3: TEMPSC model errors

Characteristic	**Target**	**Actual**	**Error**
Scale	1:13		
LOA	776mm		± 0.127mm
Beam	283mm		± 0.127mm
Height	269mm		± 0.127mm
Displacement (Full)	5.262 kg	5.275 kg	+0.25%
LCG	-7.7mm	0mm	+1.98%
VCG	105mm	110mm	+4.5%
Max Speed	0.856m/s	0.850m/s	-0.7%
Scale	1:20		
LOA	0.505mm		± 0.127mm
Beam	0.184mm		± 0.127mm
Height	0.175mm		± 0.127mm
Displacement (Full)	1.44 kg	1.52kg	+5.26%
LCG	-7.7mm	0mm	+1.98%
VCG	68mm	77mm	+11.68%
Max Speed	0.690m/s	0.695	+0.719%

4.5.2 Instrumentation Uncertainty

The total uncertainty of the instrumentation is a combination of the instrumentation acquisition error, calibration error, and for some channels the radio transmition error. The acquisition error and radio transmition errors are presented by Lindroth (2001), and remain the same for this experimental set. The calibration errors are provided in Pelley *et al*. (2002). A summary of all the errors is provided in table 4.4.

Table 4.4: Instrumentation errors

CHANNEL	ACQUISITION ERRORS (%)	CALIBRATION ERROR (%)	RADIO & NEFF TRANSMITION ERROR (%)	TOTAL ERROR (%)
Beam Wave Probe	0.018	2.69×10^{-4}	0.106	0.124
Upstream Wave Probe	0.018	1.86×10^{-4}	0.106	0.124
Wave Array 1	0.018	4.44×10^{-5}	0.106	0.124
Wave Array 2	0.018	1.53×10^{-5}	0.106	0.124
Wave Array 3	0.018	1.09×10^{-5}	0.106	0.124
Wave Array 4	0.018	4.89×10^{-5}	0.106	0.124
Wave Array 5	0.018	2.35×10^{-5}	0.106	0.124
Surge (X)	0.025	2.93×10^{-7}	0.106	0.131
Heave (Z)	0.025	6.60×10^{-9}	0.106	0.131
Sway (Y)	0.025	9.65×10^{-8}	0.106	0.131
Yaw	0.374	3.56×10^{-4}	0.106	0.480
Roll	0.374	1.98×10^{-5}	0.106	0.480
Pitch	0.374	5.60×10^{-6}	0.106	0.480
rms (Qualisys)	0	3.93×10^{-7}	0.106	0.106
Wind 1	0.5	7.40×10^{-4}	0.106	0.606
Wind 2	0.5	5.48×10^{-4}	0.106	0.606
Wind 3	0.5	8.37×10^{-4}	0.106	0.606
Wind 4	0.5	5.89×10^{-4}	0.106	0.606
Wind 5	0.5	6.18×10^{-4}	0.106	0.606
Lifeboat Immersion	0	1.96	1.726	3.688
Davit Release	0.75	0.00	0.106	0.856
Rudder Angle	18.5	2.36	1.73	22.590
Outboard Davit Load	1.024	1.21×10^{-3}	0.136	1.161
Inboard Davit Load	1.024	7.99×10^{-4}	0.136	1.161
Davit Payout	0.428	1.62×10^{-3}	0.106	0.535

Typically, similar instruments have the same amount of acquisition uncertainty. For example, all of the wave probes have an acquisition uncertainty level of 0.124%.

The largest total uncertainty value is on the rudder angle channel with an error of 22.6%, and is considered to be unreliable. This data stream was not used during the analysis. The remaining channels are well within reasonable reliability levels having uncertainty levels of approximately 1% or less.

4.5.3 Other Sources of Error

There are always sources of error that cannot be put into numerical format. Some of these errors are listed here.

Radio frequency noise in the tank sometimes caused dropouts of the data that was transmitted from the model to the shore side acquisition system. These drop outs were substantial on the acceleration instrumentation, which caused it to be discarded. The dropouts were not as severe on the rudder angle or lifeboat immersion channels.

The wireless camera feed from the model was also susceptible to this radio frequency noise. At times this made it difficult for the model operator to see and to navigate consistently.

The consistency of the model operator was also affected by a “learning curve”. The ability of the model operator to drive the model increased as the tests progressed. It is uncertain to what extent this has on the data collected. As much as was practical, the same person drove the model over the course of the tests. There were however times when another operator was necessary. The change in operator may also affect the consistency in lifeboat model navigation.

Section 5.0

5.0 Conclusions

5.1 Seaworthiness of the TEMPSC

In the perpendicular orientation, the time to exit the splash down zone decreases from the Beaufort 7 to Beaufort 9 weather condition. A decrease in time to exit this or any zone is normally interpreted as an increase in the performance of the TEMPSC. In this case the TEMPSC is not in control and exits the zone but is headed back toward the platform, which is a decrease in performance. It appears then that the time to exit the splash down zone is not accurately representing the relative performance of the evacuation system. In fact, this illustrates that the splash down zone when defined as a circle, does not capture all the performance limitations of the TEMSPC. This may suggest that a new measure of performance, which defines the seaworthiness of the TEMPSC, is necessary.

Possible solutions include re-defining the splash down zone as a border that runs parallel to the exclusion zone and passes through the target splash down point. The distance from the exclusion zone would be considered to be the clearance distance. The zone boundary would be labeled as positive on the forward side and negative on the side closest to the installation, as shown in figure 5.1. The TEMPSC would be in a positive position on the forward side, and negative position on the back side relative to the target splash down point. Set back and progressive set back would cause a negative position relative to the missed target point. When the TEMPSC crosses the boundary zone line and stays on that side of the line, then it is considered to be making forward progress. This is not to say that the lifeboat would not be making actual forward progress on the negative side of the line. Instead, the lifeboat would not be considered to be in a forward position relative to the splash down point until it was on the positive side of the set back zone boundary. If the TEMPSC crosses the boundary, but is subsequently pushed back, or re-enters the set back zone then, the TEMPSC is still not under control and is not making forward progress away from the installation.

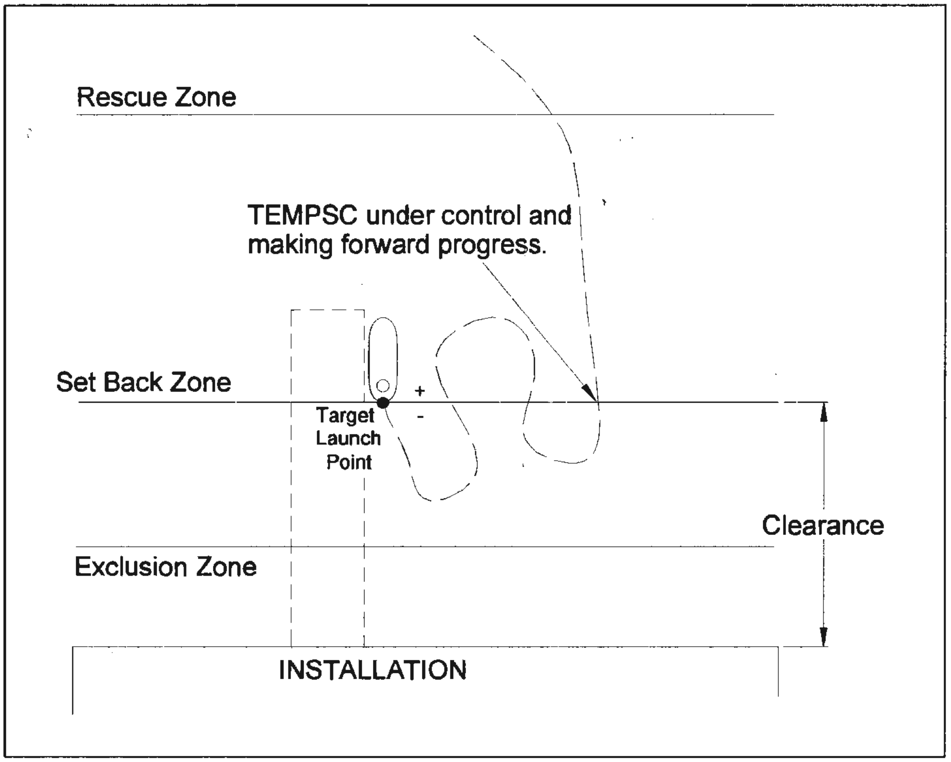


Figure 5.1: Set back zone

Defining the splash down zone in this way has advantages. In extreme seas, when the lifeboat is unable to maneuver in a controlled way, the boundary becomes the point of reference for forward progress. Defining the splash down zone as a circle in the parallel orientation is also problematic. In this orientation, the TEMPSC may exit the zone but still be traveling parallel or toward the platform (progressive set back). With the splash down border defined as a parallel line to the excursion zone/platform, the ability or inability of the lifeboat to turn perpendicular to the platform will be captured (figure 5.2).

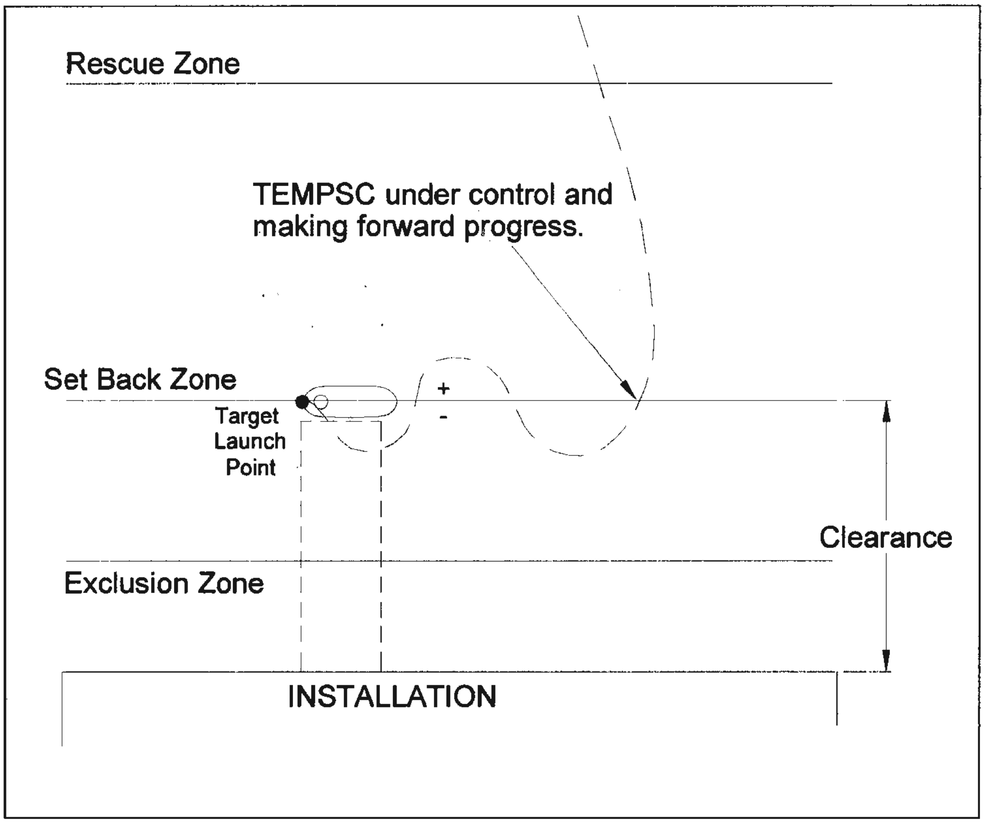


Figure 5.2: Parallel orientation showing set back zone

After exiting the new splash down boundary zone, the TEMPSC may continue to be pushed back temporarily, however as long as it remains on the positive side of the set back zone boundary it is considered to be making forward progress. The inability of the TEMPSC to make further forward progress is captured by the rescue zone performance measures.

One criticism of a parallel boundary is that it must be installation specific. However, if the evacuation system installed on an installation is to be fit for purpose then it will have to be site specific. It is proposed here that the geometrical shape of the zone be modified to suit an installation. Although illustrated as a straight line parallel to the platform for these tests, it can be changed to conform to the geometry of any installation. The set back zone should be traced out with reference points equal to the clearance distance from a point perpendicular to the installation edge. For example, for a spar installation the set back zone would be circular in shape (figure 5.3).

Another possible solution to the seaworthiness issue is to define a performance measure as the amount of set back for each wave encounter. For example, in light weather conditions the TEMPSC is able to ride the waves and is always making forward progress. As the wave height increases though, the TEMPSC begins to be pushed back slightly as it climbs each wave upslope. At the highest wave heights the TEMSPC is forced to follow the motion of the wave and travels in an elliptical pattern. This is illustrated in figures 5.4, figure 5.5, and figure 5.6.

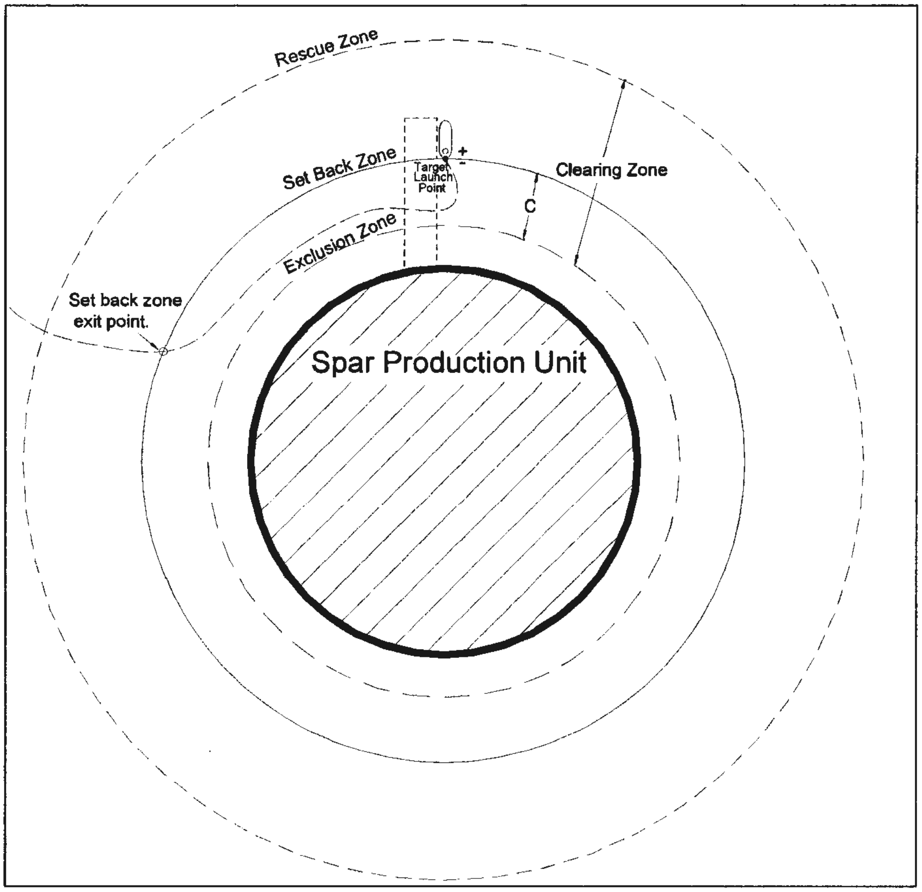


Figure 5.3: Spar with set back zone

It could be possible to assign the set back during each wave encounter as a seaworthy performance measure called *wave encounter set back.* For example in figure 5.4, the wave encounter set back is zero. In figure 5.5 the wave encounter set back is approximately 3m, and finally in figure 5.6, the wave encounter set back is approximately 7m. Further, the diameter then can be set as a scale, with larger numbers becoming a measure of reduced seaworthiness.

For demonstration purposes, the scale could be constructed as shown in table 5.1. To make the measure applicable to any evacuation system, the sail away set back could be converted to a function of the length of the lifeboat.

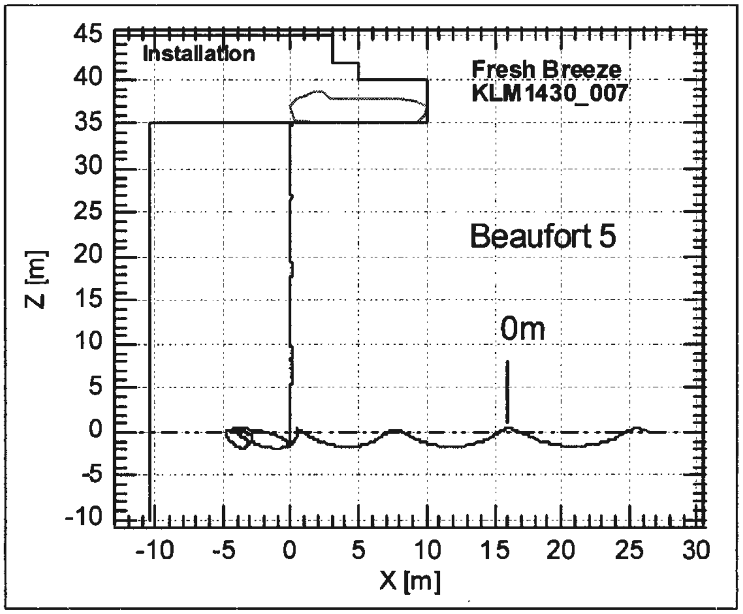


Figure 5.4: No sail away set back (Beaufort 5)

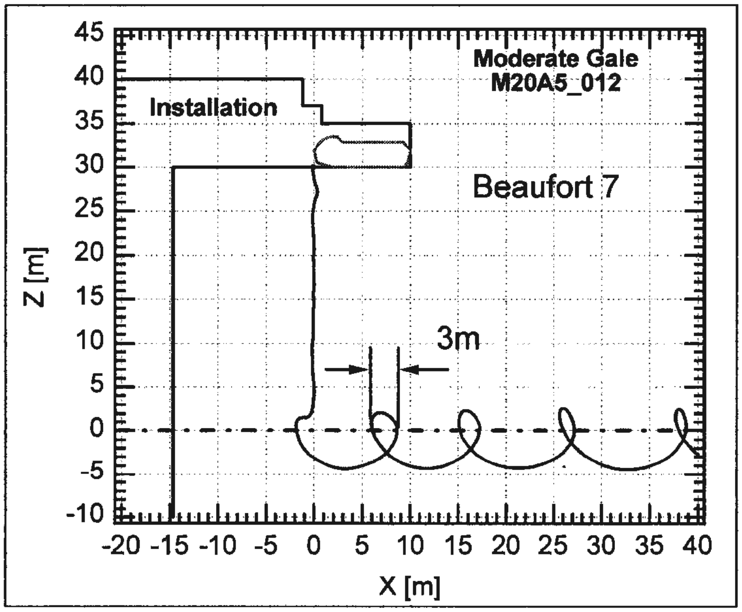


Figure 5.5: Sail away set back ≈ 3m (Beaufort 7)

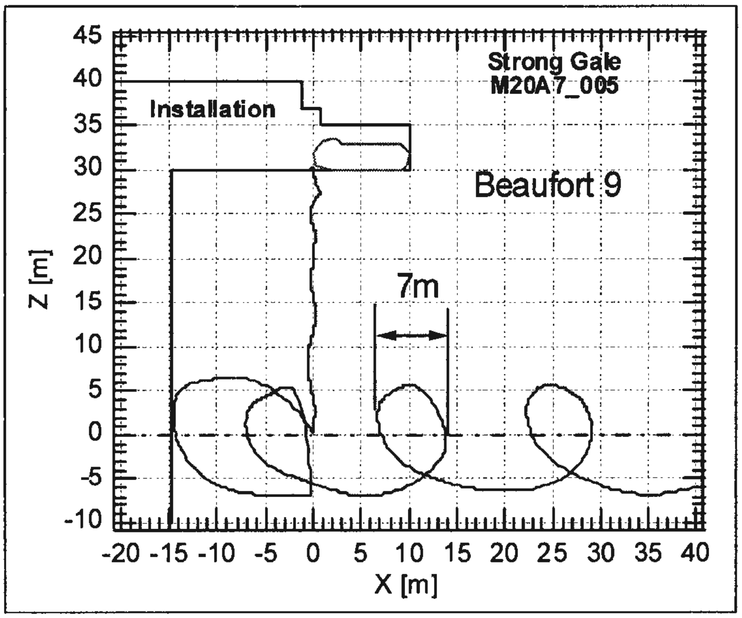


Figure 5.6: Sail away set back ≈ 7m (Beaufort 9)

Table 5.1: Seaworthiness scale

SEAWORTHINESS	SCALE (BASED ON ELLIPSE DIAMETER)
Maximum	0 – 0.2L
Moderate	0.2L – 0.7L m
Minimum	0.7L – 1.0L
Unseaworthy	1.0L >

This measure would have to be refined further. For example, would the wave encounter set back be the maximum set back during the sail way phase, or would it be the mean value for all of the set backs during a wave encounter? This measure is proposed here as one possible solution.

There may be other solutions, but the important point to make here is that the splash down zone has limitations and is not a good indication of the seaworthiness of the TEMPSC. Therefore another measure is necessary to complement it.

5.2 Parallel Orientation Set Back and Progressive Setback

In work presented by Simões Ré *et al.* (2002a), it was concluded that the parallel orientation provided better performance than the perpendicular orientation. Both set back and progressive set back values were smaller in the parallel orientation, which resulted in fewer collisions. The results presented here show the opposite trend. In the parallel condition there is more set back and progressive set back, as well as a higher incidence of collisions.

A possible reason for the difference in results may be due to the difference in the way the wind was set up. In the first set of tests the wind machines were set up side by side, as shown in figure 5.7. The wind velocity was set to the correct value but the wind was not evenly distributed over the entire test area. For this set of experiments, the two wind machines were stacked with one on top of the other, shown in figure 5.8. Adjustable louvers were also attached which made it possible to direct the flow of air more evenly over the test area. The parallel orientation would be more sensitive to any changes in the wind due to the increase in exposed frontal area as opposed to the perpendicular orientation.

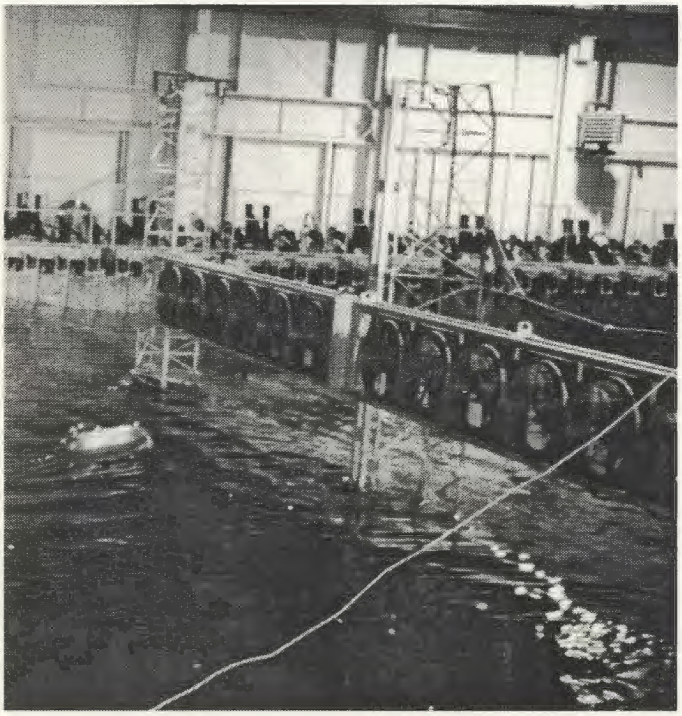


Figure 5.7: Original wind machine setup for tests reported in 2002

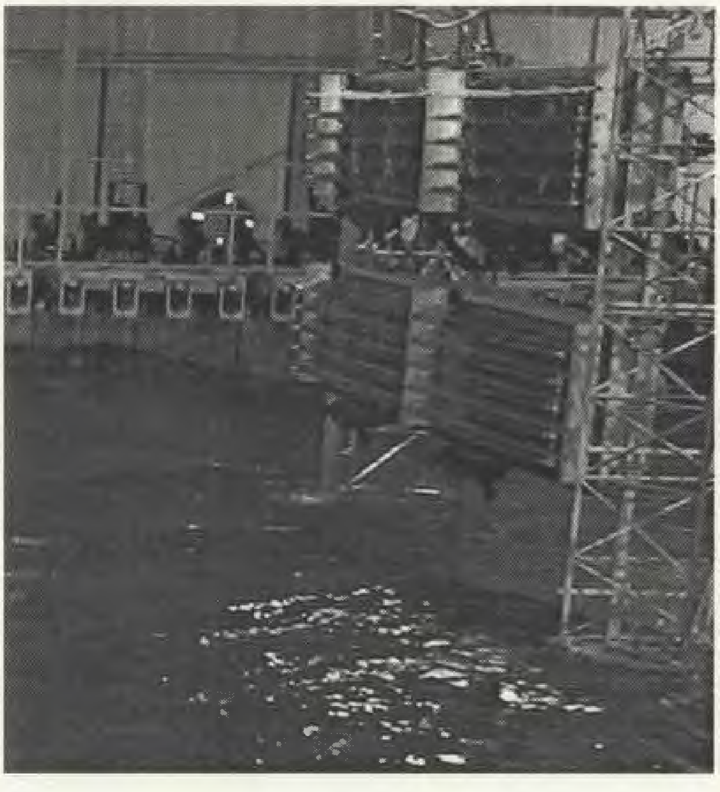


Figure 5.8: Revised wind machine set up

This is important, especially in the context of a new regulatory regime. Presently, some regulations recommend perpendicular orientation, which appears to be confirmed from the results presented in this work. However, the conflicting results presented by Simões Ré *et al.* (2002a) must be addressed before confirmation of a preferred orientation can be made. This might involve more experiments over the entire weather range in the perpendicular and parallel orientation with the revised wind set up. The clearance for these tests should also be set to an infinite value (i.e. no platform behind the TEMPSC launching device). Launching the TEMPSC on the side of the platform instead of in front of the platform would achieve this goal. In addition, other orientation angles to the waves and wind should be performed. Changes in incident angle may result in wide variations in performance.

In Campbell *et al.* (1983) the most important parameter in a lifeboat launch was identified as the amount of set back experienced by the lifeboat. The results of the experiments reported here show that set back in combination with progressive set back are the most important measures of performance. Both measures are strongly dependent on weather and orientation. If the set back or progressive set back is large enough the lifeboat will collide with the installation, drastically reducing the probability of a successful evacuation.

How does a designer overcome the problem of set back and progressive set back? In some cases it may be enough to increase the clearance from the platform. However in the extreme weather cases, Beaufort 6 to Beaufort 9, increased clearance may not provide a solution. Instead, something must be done to the evacuation system.

5.2.1 Survival Craft Improvements

More installed power and a better propulsion system can increase the TEMPSC's ability to make forward progress. It may also be necessary to redesign the hull to provide better motion and maneuvering characteristics. Present lifeboats are designed as full round bilge displacement hull forms. This works well for maximizing buoyancy, but it also increases the responsiveness of the hull in terms of heave, surge, sway, roll, pitch, and yaw to wave interaction. The hull form could be designed to increase its ability to maneuver in waves by making it less susceptible to wave action.

5.2.2 Launching System Improvements

The introduction of a flexible boom has been shown to improve evacuation system success by reducing set back (Leafloor & Yeo (1987)). The flexible boom is a large composite boom attached to the installation with a "tag" line attached to the lifeboat. As the lifeboat is launched the flexible boom bends down storing potential energy. When the lifeboat hits the water the flexible boom begins to bend back up and in doing so pulls the lifeboat away from the hull. This device has been installed with conventional twin fall davit systems on a number of installations including the Terra Nova FPSO off the coast of Newfoundland.

5.3 Influence of Wave Steepness

The results for the 1:20 and 1:15 wave steepness indicate very little influence due to wave steepness. The 1:10 results indicate a large degradation in performance. The cause is due to the wave encounter interaction with the TEMPSC. In the less steep waves the wavelength is long enough to allow the TEMPSC to surf down the down slope building up enough momentum to climb the next up slope. At the 1:10 wave steepness the wavelength is short enough that the TEMPSC encounters a wave approximately every 5m of travel distance, which is only half a boat length for this particular model prototype. The lifeboat is then unable to build up any momentum on the down slopes to assist it in gaining forward motion. When the TEMPSC finally does make any forward progress the wave encounter frequency increases and compounds the problem slowing the model down again. The constant bow slamming also makes it difficult for the coxswain to control the lifeboat, making it difficult to keep on a heading away from the platform.

Experiments by Campbell *et al.* (1983) reported that there was no discernable dependence of set back on wave steepness. Although limited to one weather condition, the experimental results here also indicate no dependence of set back on wave steepness. This result may be misleading though since the clearance limited the amount of set back.

The use of one weather condition made it impossible to make any conclusions about the interaction between wave steepness and weather condition on the performance of the TEMSPC. To properly investigate the effects of wave steepness smaller weather conditions and the addition of a wave steepness value between the 1:15 and 1:10 should be performed.

5.4 Boundaries of Performance

The original goal of the project was to determine some boundaries of performance. Based on the results, qualitative graphical descriptions of the boundaries of performance have been extrapolated and are shown in figures 5.9 and figure 5.10.

Figure 5.9 shows the performance ability of the TEMPSC relative to the Beaufort 7 condition when launched in the perpendicular and parallel orientations, and is based on set back and progressive set back. The best launching condition for all weather conditions is crest launches in the perpendicular orientation. Launching on an upslope reduces the performance of the TEMPSC. Surprisingly, launching on a crest in the parallel orientation is not better than a perpendicular upslope launch. The progressive set back in the parallel condition results in high collision rates with the installation in the parallel orientation. The worst scenario involves launching on an upslope in the parallel condition. It should be noted that these statements are based on a relatively small number of runs and further experiments are necessary to confirm this conclusion.

Figure 5.10, shows the performance envelope based on weather and wave steepness. In this graphical representation it is assumed that performance of the lifeboat follows the same decrease in performance with increase in weather for all wave steepnesses. The experimental results presented earlier indicated no appreciable difference in performance between the 1:20 and 1:15 wave steepness. At the 1:10 wave steepness the performance ability of the TEMSPC quickly degrades.

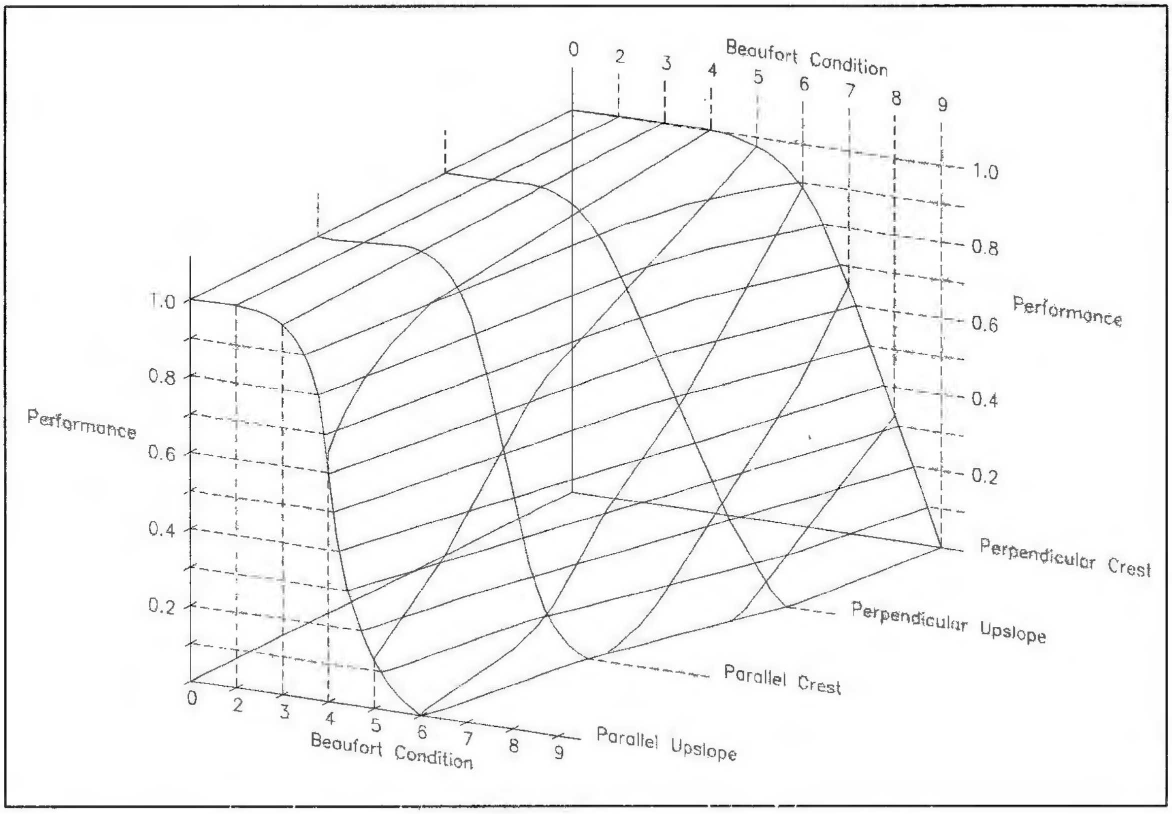


Figure 5.9: Orientation performance map

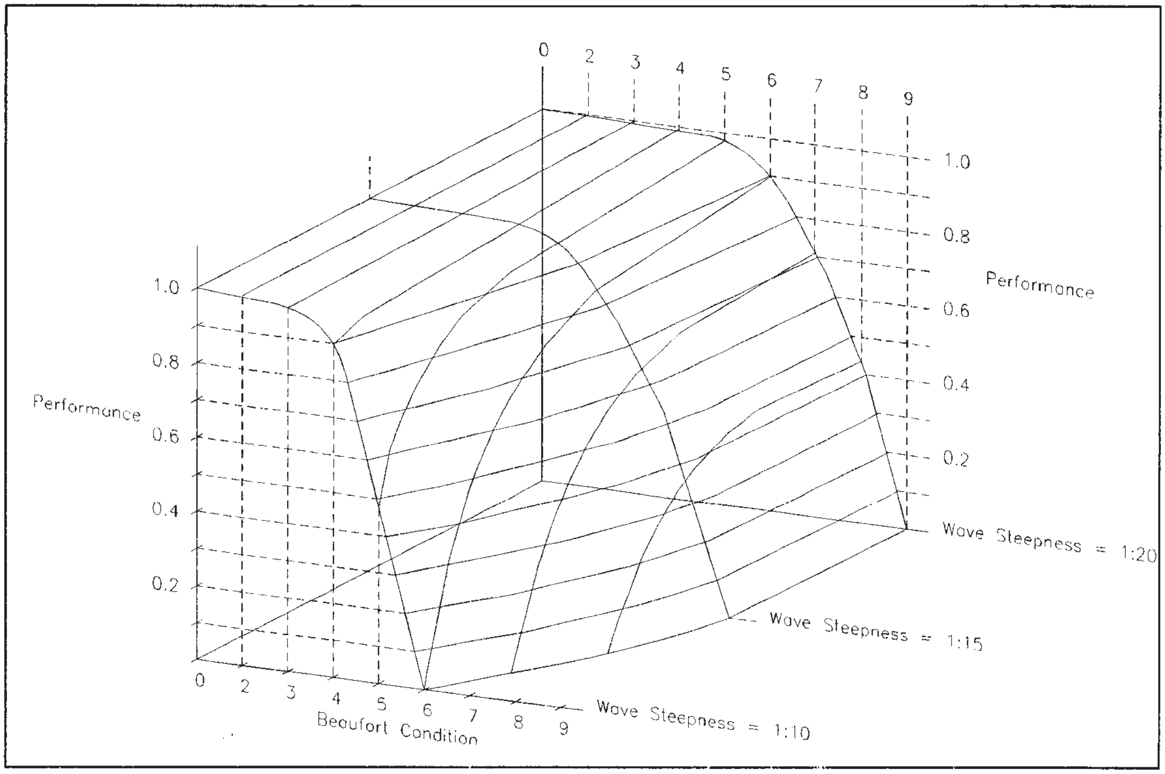


Figure 5.10: Wave steepness performance map

5.5 Limitations of the Experiments

The original plan involved investigating wave steepness, orientation, extreme weather boundaries, irregular and regular wave comparison, and scaling effects. With amount of time provided in the Ocean Engineering Basin, the number of launches per configuration was reduced to ensure there was enough time to cover all of the configurations. The small number of runs made it difficult to determine boundaries of performance. In retrospect, the test matrix should have been flexible enough to allow for investigation of boundaries of performance due to extreme and moderate weather and wave steepness. The moderate and lower weather would have provided a complete set of results for this particular set up and model. Earlier work could have been used but the experiments were done with a different wind machine set up and a relatively small clearance (11.04m). Also during these tests the experiments were halted when an apparent observed boundary limit was reached. For instance, at the 1:10 wave steepness in Beaufort 7 condition it was observed that the model could not make forward progress and was done to protect the sensitive instrumentation in the model. Therefore only 3 crest launches were performed and due to the large scatter in this data it was difficult to define the performance boundaries.

The clearance should have been set at much higher value initially. From previous experiments it was known that the amount of set back was twice the wave height. The clearance minimum should have been 26m for all tests. Further, some launches at the higher weather conditions should have been performed without the platform behind the TEMPSC (i.e. infinite clearance). This would have provided better information about the maximum set back and more importantly the points of progressive set back.

To model the wind accurately requires the use of Reynold's scaling. For these tests Froude scaling was used. This is standard practice in the Ocean Engineering Basin at the Institute for Marine Dynamics. It is impractical to use Reynolds scaling since the required velocities are beyond the capacity of the wind machines used there. An attempt was made to calibrate the wind velocities based on the induced force on the TEMPSC. The TEMPSC was placed in a specially designed calibration apparatus that measured the force of the wind on the model. A number of problems were encountered. The stiffness of in the calibration apparatus and the small scale of the model (small target forces) did not allow for the collection of clean data traces. It was impossible to distinguish the differences in force due to a change in wind velocity.

It is recommended that further investigation into the influence of wind velocity be performed. As discussed earlier, changes to the wind machine setup seem to have made significant changes in the results. The present method of modeling the wind may also explain the lack of oscillation of the model as it descends, resulting in small missed target values. In less severe weather conditions the influence of the wind is probably less noticeable. When testing in weather condition with full scale wind speeds of 40 knots, the influence of the wind may be higher.

5.6 Summary of Conclusions

The main purpose of this work was to establish the capabilities of a twin fall davit system in extreme weather conditions, using previously established measures of performance, and to critically examine the suitability of these measures. Additionally, the effects of wave steepness and orientation were also considered. With reference to this aim, the results of the research determined three main points.

1. The performance of the twin falls davit and TEMPSC system in extreme seas is directly related to the orientation to the weather direction and the splash down point on the wave. The performance limit of the system in the perpendicular orientation with a crest splash down point is the Beaufort 8 weather condition. This limit is reduced to Beaufort 6 when launched on an upslope. In the parallel orientation, the performance limit is Beaufort 6, regardless of splash down position. (See figure 5.9). Further tests are required to determine this conclusion decisively. The performance limit in the parallel orientation may be less than Beaufort 6.
2. The time to exit the splash down zone measure has limitations, especially at the extreme weather conditions. The measure must be complemented with a new measure to capture the unseaworthiness of the lifeboat in these extreme seas.
3. It was determined that wave steepness is an important parameter when determining the ability of the TEMPSC to make sustained forward progress away from the installation. (See figure 5.10)

Section 6.0

6.0 References

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Appendix A

Wind and Sea Scale for Fully-Arisen Sea

Sea state	Direction	Wind				Sea								
						Wave height, ft								
		Beaufort wind force	Description	Range, knots	Wind velocity knots†	Average	Significant	Average 1/10th highest	Significant range of periods, sec	*Imax*, period of maximum energy of spectrum, sec	*T* average period, sec	*L* average wavelength, ft	Minimum fetch, nm	Minimum duration, hr
	Sea like a mirror	0	Calm	Less than 1	0	0	0	0						
0	Ripples with the appearance of scales are formed, but without foam crests.	1	Light airs	1 to 3	2	0.05	0.08	0.10	up to 1.2 sec	0.7	0.5	10 inch	5	18 min
1	Small wavelets, still short but more pronounced; crests have a glassy appearance, but do not break	2	Light breeze	4 to 6	5	0.18	0.29	0.37	0.4 - 2.8	2.0	1.4	6.7 ft	8	39 min
	Large wavelets, crests begin to break. Foam of glassy appearance. Perhaps scattered white horses	3	Gentle breeze	7 to 10	8.5	0.6	1.0	1.2	0.8 - 5.0	3.4	2.4	20	9.8	1.7 hr
					10	0.88	1.4	1.8	1.0 - 6.0	4	2.9	27	10	2.4
2	Small waves, becoming larger; frequent white horses	4	Moderate breeze	11 to 16	12	1.4	2.2	2.8	1.0 - 7.0	4.8	3.4	40	18	3.8
					13.5	1.8	2.9	3.7	1.4 - 7.6	5.4	3.9	52	24	4.8
3					14	2.0	3.3	4.2	1.5 - 7.8	5.6	4.0	59	28	5.2
					16	2.9	4.6	5.8	2.0 - 8.8	6.5	4.6	71	40	6.6
	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray).	5	Fresh breeze	17 to 21	18	3.8	6.1	7.8	2.5 - 10.0	7.2	5.1	90	55	8.3
4					19	4.3	6.9	8.7	2.8 - 10.6	7.7	5.4	99	65	9.2
					20	5.0	8.0	10	3.0 - 11.1	8.1	5.7	111	75	10
5	Large waves begin to foam; the white foam crests are more extensive everywhere (probably some spray).	6	Strong breeze	22 to 27	22	6.4	10	13	3.4 - 12.2	8.9	6.3	134	100	12
					24	7.9	12	16	3.7 - 13.5	9.7	6.8	160	130	14
					24.5	8.2	13	17	3.8 - 13.6	9.9	7.0	164	140	15
6					26	9.6	15	20	4.0 - 14.5	10 .5	7.4	188	180	17
	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind (spindrift begins to be seen).	7	Moderate gale	28 to 33	28	11	18	23	4.5 - 15.5	11.3	7.9	212	230	20
					30	14	22	28	4.7 - 16.7	12.1	8.6	250	280	23
					30.5	14	23	29	4.8 - 17.0	12.4	8.7	258	290	24
					32	16	26	33	5.0 - 17.5	12.9	9.1	285	340	27

7	Moderately high waves of great length; edges of crests break into spindrift. The foam is blown in well-marked streaks along the direction of the wind. Spray affects visibility.	8	Fresh gale	34 to 40	34	19	30	38	5.5 - 18.5	13.6	9.7	322	420	30
					36	21	35	44	5.8 - 19.7	14.3	10.3	363	500	34
					37	23	37	46.7	6 - 20.5	14.9	10.5	376	530	37
					38	25	40	50	6.2 - 20.8	15.4	10.7	392	600	38
					40	28	45	58	6.5 - 21.7	16.1	11.4	444	710	42
8	High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Visibility affected	9	Strong gale	41 to 47	42	31	50	64	7 - 23	17.0	12.0	492	830	47
					44	36	58	73	7 - 24.2	17.7	12.5	534	960	52
					46	40	64	81	7 - 25	18.6	13.1	590	1110	57
9	Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind. On the whole, the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shocklike. Visibility is affected.	10	Whole gale*	48 to 55	48	44	71	90	7.5 - 26	19.4	13.8	650	1250	63
					50	49	78	99	7.5 - 27	20.2	14.3	700	1420	69
					51.5	52	83	106	8 - 28.2	20.8	14.7	736	1560	73
					52	54	87	110	8 - 28.5	21.0	14.8	750	1610	75
					54	59	95	121	8 - 29.5	21.8	15.4	810	1800	81
	Exceptionally high waves (small and medium-sized ships might for a long time be lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into froth. Visibility affected.	11	Storm*	56 to 63	56	64	103	130	8.5 - 31	22.6	16.3	910	2100	88
					59.5	73	116	148	10 - 32	24	17.0	985	2500	101
	Air filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	12	Hurricane*	64 to 71	>64	>80‡	>128‡	>164‡	10 - (35)	(26)	(18)	~	~	~

* For hurricane winds (and often whole gale and storm winds) required durations and fetches are rarely attained. Seas are therefore not fully arisen.

† A heavy box around this value means that the values tabulated are at the centre of the Beaufort range.

‡ For such high winds, the seas are confused. The wave crests blow off, and the water and the air mix.

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Appendix B

Significant Wave Height

Waves	South East Coast Observations	South Western Grand Banks Observations	South Eastern Grand Banks Observations	Northern Grand Banks Observations	Totals	PDF	CDF		Mean	Variance	SD
0.0 - < 0.5m	5	5	5	5	20	0.001	0.001	0.25	0.000	0.009	
0.5 - < 1.0m	106	60	69	106	341	0.019	0.021	0.75	0.015	0.103	
1.0 - < 1.5m	405	310	341	405	1461	0.083	0.104	1.25	0.104	0.270	
1.5 - < 2.0m	650	617	629	650	2546	0.145	0.249	1.75	0.254	0.245	
2.0 - < 2.5m	700	686	721	700	2807	0.160	0.409	2.25	0.360	0.102	
2.5 - < 3.0m	628	696	657	628	2609	0.149	0.558	2.75	0.409	0.013	
3.0 - < 3.5m	548	559	561	548	2216	0.126	0.684	3.25	0.411	0.005	
3.5 - < 4.0m	405	431	430	405	1671	0.095	0.780	3.75	0.357	0.047	
4.0 - < 4.5m	290	337	311	290	1228	0.070	0.850	4.25	0.298	0.101	
4.5 - < 5.0m	224	220	221	224	889	0.051	0.900	4.75	0.241	0.147	
5.0 - < 5.5m	158	149	145	158	610	0.035	0.935	5.25	0.183	0.169	
5.5 - < 6.0m	104	127	129	104	464	0.026	0.962	5.75	0.152	0.193	
6.0 - < 6.5m	72	69	72	72	285	0.016	0.978	6.25	0.102	0.167	
6.5 - < 7.0m	22	47	33	22	124	0.007	0.985	6.75	0.048	0.097	
7.0 - < 7.5m	27	29	27	27	110	0.006	0.991	7.25	0.045	0.111	
7.5 - < 8.0m	17	19	15	17	68	0.004	0.995	7.75	0.030	0.086	
8.0 - < +m	22	23	18	22	85	0.005	1.000	8.25	0.040	0.131	
	4383	4384	4384	4383	17534	1.0			3.049	1.994	1.412

Wind Velocity

Wind	South East Coast Observations	South Western Grand Banks Observations	South Eastern Grand Banks Observations	Northern Grand Banks Observations	Totals	PDF	CDF		Mean	Variance	SD
0 - < 5	216	222	229	207	874	0.050	0.050	2.5	0.125	12.664	
5 - < 10	509	534	623	516	2182	0.124	0.174	7.5	0.933	14.893	
10 - < 15	898	919	973	965	3755	0.214	0.388	12.5	2.677	7.555	
15 - < 20	942	949	1013	916	3820	0.218	0.606	17.5	3.812	0.192	
20 - < 25	778	759	742	767	3046	0.174	0.780	22.5	3.908	2.864	
25 - < 30	513	516	427	531	1987	0.113	0.893	27.5	3.116	9.302	
30 - < 35	285	282	230	248	1045	0.060	0.953	32.5	1.937	11.781	
35 - < 40	138	115	80	143	476	0.027	0.980	37.5	1.018	9.862	
40 - < 45	60	49	42	59	210	0.012	0.992	42.5	0.509	6.933	
45 - < 50	28	22	10	19	79	0.005	0.997	47.5	0.214	3.805	
50 - < 55	10	10	9	5	34	0.002	0.998	52.5	0.102	2.249	
>55	6	7	6	8	27	0.002	1.000	57.5	0.089	2.349	
Totals	4383	4384	4384	4384	17535	1.00			18.440	84.449	9.190

Peak Period

Period	South Western Grand Banks	South Eastern Grand Banks	Northern Grand Banks	South East Coast	PDF	CDF	Period	Mean	Variance	SD
<4	2	3	24	29	0.0010	0.0010	2	0.0020	0.05974	
4>5	54	42	142	238	0.0082	0.0092	4.5	0.0369	0.22458	
5>6	227	181	638	1046	0.0360	0.0452	5.5	0.1981	0.64595	
6>7	313	275	1256	1844	0.0635	0.1087	6.5	0.4127	0.66448	
7>8	574	570	1731	2875	0.0990	0.2077	7.5	0.7424	0.49453	
8>9	1059	1010	2945	5014	0.1726	0.3803	8.5	1.4673	0.26339	
9>10	931	990	4108	6029	0.2076	0.5879	9.5	1.9719	0.01149	
10>11	662	676	2739	4077	0.1404	0.7282	10.5	1.4738	0.08209	
11>12	323	365	2668	3356	0.1155	0.8438	11.5	1.3287	0.35984	
12>13	133	169	1874	2176	0.0749	0.9187	12.5	0.9364	0.57265	
13>14	79	74	1264	1417	0.0488	0.9675	13.5	0.6586	0.69145	
14>15	14	18	190	222	0.0076	0.9751	14.5	0.1108	0.17352	
15>16	10	8	552	570	0.0196	0.9947	15.5	0.3042	0.65216	
16>17	2	3	48	53	0.0018	0.9966	16.5	0.0301	0.08350	
17>18	0	0	81	81	0.0028	0.9993	17.5	0.0488	0.16813	
18>19	0	0	7	7	0.0002	0.9996	18.5	0.0045	0.01851	
19>20	0	0	9	9	0.0003	0.9999	19.5	0.0060	0.02954	
>20	1	1	1	3	0.0001	1.0000	20.5	0.0021	0.01197	
Totals	4384	4385	20277	29046	1.0000		Mean	9.7352	5.2075	2.2820

	Periods																		Totals
Waves	<4	4>5	5>6	6>7	7>8	8>9	9>10	10>11	11>12	12>13	13>14	14>15	15>16	16>17	17>18	18>19	19>20	>20	
0.0 - < 0.5m	0.00031	0.00000	0.00000	0.00003	0.00003	0.00024	0.00014	0.00003	0.00003	0.00007	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00024	0.00024
0.5 - < 1.0m	0.00041	0.00141	0.00207	0.00344	0.00420	0.00310	0.00275	0.00124	0.00038	0.00028	0.00034	0.00000	0.00000	0.00000	0.00003	0.00000	0.00000	0.00003	0.01969
1.0 - < 1.5m	0.00028	0.00510	0.01508	0.01301	0.01863	0.02627	0.01780	0.00640	0.00324	0.00176	0.00096	0.00034	0.00048	0.00003	0.00021	0.00000	0.00000	0.00000	0.10958
1.5 - < 2.0m	0.00000	0.00165	0.01398	0.02413	0.02410	0.03353	0.03560	0.01398	0.00868	0.00523	0.00220	0.00028	0.00103	0.00003	0.00024	0.00000	0.00000	0.00000	0.16467
2.0 - < 2.5m	0.00000	0.00003	0.00392	0.01394	0.02975	0.02992	0.03408	0.01883	0.01563	0.00923	0.00489	0.00062	0.00110	0.00021	0.00007	0.00007	0.00007	0.00000	0.16236
2.5 - < 3.0m	0.00000	0.00000	0.00079	0.00633	0.01401	0.03646	0.02730	0.01897	0.01460	0.00926	0.00565	0.00072	0.00189	0.00003	0.00003	0.00000	0.00000	0.00000	0.13606
3.0 - < 3.5m	0.00000	0.00000	0.00014	0.00182	0.00513	0.02613	0.02806	0.01715	0.01601	0.01054	0.00602	0.00069	0.00248	0.00014	0.00010	0.00007	0.00007	0.00000	0.11454
3.5 - < 4.0m	0.00000	0.00000	0.00000	0.00055	0.00241	0.00981	0.02988	0.01487	0.01343	0.00940	0.00658	0.00103	0.00361	0.00017	0.00028	0.00000	0.00000	0.00000	0.09203
4.0 - < 4.5m	0.00000	0.00000	0.00000	0.00017	0.00055	0.00417	0.01804	0.01553	0.00961	0.00682	0.00534	0.00110	0.00196	0.00031	0.00055	0.00000	0.00000	0.00000	0.06414
4.5 - < 5.0m	0.00000	0.00000	0.00003	0.00000	0.00014	0.00193	0.00695	0.01387	0.00806	0.00461	0.00358	0.00069	0.00145	0.00017	0.00031	0.00000	0.00000	0.00000	0.04180
5.0 - < 5.5m	0.00000	0.00000	0.00000	0.00000	0.00000	0.00076	0.00372	0.00936	0.00633	0.00348	0.00334	0.00038	0.00138	0.00021	0.00017	0.00003	0.00003	0.00000	0.02920
5.5 - < 6.0m	0.00000	0.00000	0.00000	0.00000	0.00000	0.00017	0.00162	0.00537	0.00806	0.00355	0.00244	0.00034	0.00093	0.00007	0.00028	0.00000	0.00000	0.00003	0.02286
6.0 - < 6.5m	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00103	0.00227	0.00461	0.00317	0.00200	0.00017	0.00110	0.00010	0.00021	0.00003	0.00003	0.00000	0.01484
8.5 - < 7.0m	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00045	0.00120	0.00337	0.00286	0.00100	0.00017	0.00072	0.00003	0.00010	0.00003	0.00003	0.00000	0.00998
7.0 - < 7.5m	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00010	0.00034	0.00165	0.00186	0.00103	0.00024	0.00038	0.00014	0.00000	0.00000	0.00000	0.00000	0.00575
7.5 - < 8.0m	0.00000	0.00000	0.00000	0.00000	0.00000	0.00003	0.00003	0.00048	0.00100	0.00131	0.00086	0.00017	0.00041	0.00007	0.00000	0.00000	0.00000	0.00000	0.00437
8.0 - < +m	0.00000	0.00000	0.00000	0.00003	0.00003	0.00000	0.00000	0.00045	0.00086	0.00151	0.00255	0.00069	0.00069	0.00010	0.00021	0.00000	0.00000	0.00000	0.00713
	0.00100	0.00819	0.03601	0.06349	0.09898	0.17262	0.20757	0.14036	0.11554	0.07492	0.04878	0.00764	0.01962	0.00182	0.00279	0.00024	0.00024	0.00031	0.99924

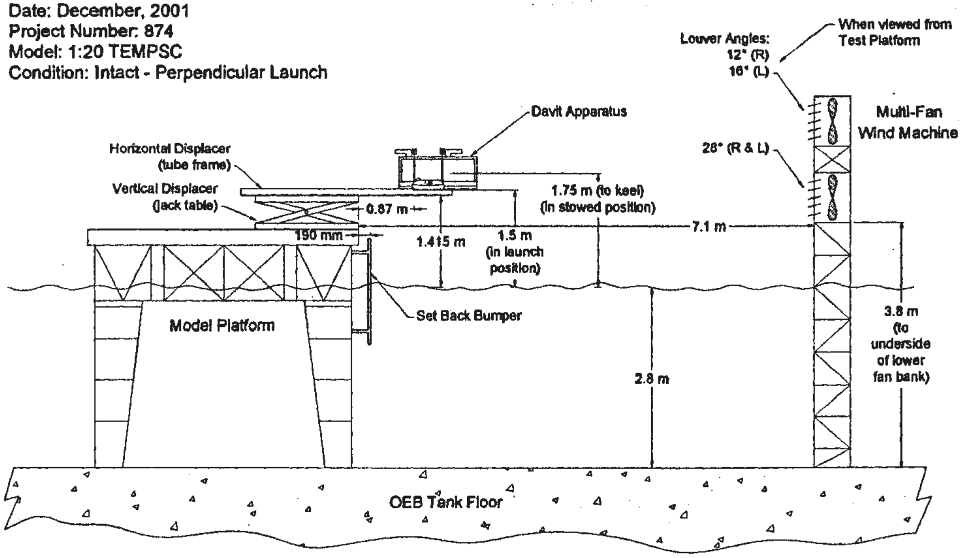
	Wind												
Waves	0 - < 5	5 - < 10	10 - < 15	15 - < 20	20 - < 25	25 - < 30	30 - < 35	35 - < 40	40 - < 45	45 - < 50	50 - < 55	>55	Totals
0.0 - < 0.5m	0.0007	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010
0.5 - < 1.0m	0.0048	0.0087	0.0047	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0184
1.0 - < 1.5m	0.0100	0.0254	0.0340	0.0095	0.0011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0800
1.5 - < 2.0m	0.0102	0.0306	0.0516	0.0423	0.0070	0.0014	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.1431
2.0 - < 2.5m	0.0100	0.0222	0.0430	0.0479	0.0291	0.0045	0.0013	0.0001	0.0000	0.0000	0.0000	0.0000	0.1580
2.5 - < 3.0m	0.0066	0.0164	0.0317	0.0401	0.0410	0.0106	0.0023	0.0009	0.0002	0.0000	0.0000	0.0000	0.1499
3.0 - < 3.5m	0.0033	0.0099	0.0200	0.0309	0.0367	0.0205	0.0043	0.0011	0.0003	0.0000	0.0000	0.0000	0.1269
3.5 - < 4.0m	0.0021	0.0052	0.0134	0.0195	0.0225	0.0244	0.0068	0.0024	0.0006	0.0001	0.0000	0.0000	0.0969
4.0 - < 4.5m	0.0008	0.0025	0.0078	0.0120	0.0148	0.0213	0.0100	0.0026	0.0009	0.0003	0.0001	0.0000	0.0730
4.5 - < 5.0m	0.0005	0.0018	0.0040	0.0071	0.0103	0.0124	0.0098	0.0034	0.0007	0.0003	0.0001	0.0001	0.0505
5.0 - < 5.5m	0.0004	0.0006	0.0019	0.0049	0.0046	0.0072	0.0103	0.0039	0.0018	0.0003	0.0001	0.0001	0.0361
5.5 - < 6.0m	0.0001	0.0006	0.0011	0.0018	0.0043	0.0055	0.0067	0.0040	0.0017	0.0006	0.0002	0.0001	0.0266
6.0 - < 6.5m	0.0003	0.0002	0.0007	0.0007	0.0013	0.0029	0.0043	0.0031	0.0015	0.0004	0.0001	0.0002	0.0159
6.5 - < 7.0m	0.0001	0.0001	0.0001	0.0002	0.0006	0.0011	0.0014	0.0031	0.0010	0.0002	0.0001	0.0001	0.0080
7.0 - < 7.5m	0.0000	0.0001	0.0000	0.0003	0.0005	0.0009	0.0010	0.0012	0.0013	0.0007	0.0002	0.0005	0.0066
7.5 - < 8.0m	0.0001	0.0001	0.0001	0.0001	0.0001	0.0005	0.0005	0.0007	0.0007	0.0006	0.0002	0.0001	0.0038
8.0 - < +m	0.0000	0.0000	0.0001	0.0001	0.0001	0.0001	0.0008	0.0006	0.0013	0.0011	0.0007	0.0005	0.0052
	0.0498	0.1244	0.2141	0.2179	0.1737	0.1133	0.0596	0.0271	0.0120	0.0045	0.0019	0.0015	1.0000

Appendix C

As Tested OEB Setup

Project Details:

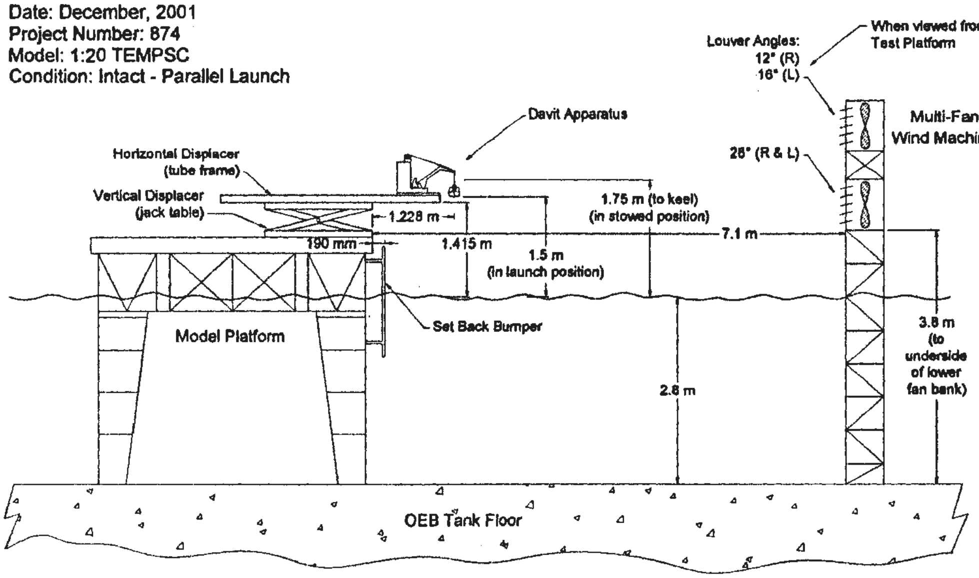
Date: December, 2001
Project Number: 874
Model: 1:20 TEMPSC
Condition: Intact - Perpendicular Launch



As Tested OEB Setup

Project Details:

Date: December, 2001
Project Number: 874
Model: 1:20 TEMPSC
Condition: Intact - Parallel Launch



Appendix D

1:13

Model # 543

Hydrostatic Properties

Draft is from Baseline.
No Trim, No heel, VCG = 0.000

LCF Draft (m)	Displ (MT)	LCB (m)	VCB (m)	LCF (m)	TPcm (MT/cm)	MTcm (MT-m /deg)	GML (m)	GM(Solid) (m)
0.860	11.469	* 0.076f	0.593	0.081a	0.25	2.59	12.949	2.066

Water Specific Gravity = 1.025.

Hull Data (with appendages)

Ap = 4.9629 m aft of ⌀.

Baseline Draft: 0.860
Trim: zero
Heel: zero

DIMENSIONS
Length Overall: 9.980 m LWL: 9.666 m Beam: 3.300 m BWL: 3.195 m
Volume: 11.189 m^3 Displacement: 11.469 MT

COEFFICIENTS
Prismatic: 0.706 Block: 0.422 Midship: 0.598 Waterplane: 0.792

RATIOS
Length/Beam: 3.024 Displacement/length: 353.869 Beam/Depth: 3.845
MT/ cm Immersion: 0.251

AREAS
Waterplane: 24.472 m^2 Wetted Surface: 32.050 m^2
Under Water Lateral Plane: 7.468 m^2 Above Water Lateral Plane: 6.572 m^2

CENTROIDS (Meters)
Buoyancy: LCB = 0.076 fwd TCB =0.000 port VCB = 0.593
Flotation: LCF = 0.081 aft
Under Water LP: 0.036 fwd of Origin, 0.396 below waterline.
Above Water LP: 0.007 fwd of Origin, 0.349 above waterline.

Note: Coefficients calculated based on waterline length at given draft

PARAMETER		PROTOTYPE	1/13 SCALE MODEL
Length Overall	LOA	10.0 m	769 mm
Beam Overall	BOA	3.7 m	285 mm
Height Overall	HOA	3.6 m	277 mm
Draft	T	0.894 m	69 mm
Displacement	Δ	12, 135 kg	5.38 kg
Wetted Surface Area	S	32.1 m	0.19 m
Block Coefficient	C_B	0.422	
Midship Coefficient	C_X	0.598	
Prismatic Coefficient	C_P	0.709	
Waterplane Coefficient	C_W	0.799	
Length to Beam Ratio	L/B	2.703	
Beam to Draft Ratio	B/T	4.302	
NOZZLE			
Outside Diameter	OD	500 mm	46 mm
Length	L	300 mm	25 mm
PROPELLER			
Diameter	D	450 mm	37 mm

	Target	Actual	Percent Error
VCG wrt Baseline (m)	105 mm	124 mm	15.3 %
Pitch Radius of Gyration (m)	234 mm	288 mm	18.8 %
Roll Radius of Gyration (m)	89 mm	62.7 mm	29.6 %

Hydrostatic Properties

1:20

Draft is from Baseline.
No Trim, No heel, VCG = 0.000

LCF Draft (m)	Displ (MT)	LCB (m)	VCB (m)	LCF (m)	TPcm (MT/cm)	MTcm (MT-m /deg)	GML (m)	GM(Solid) (m)
0.860	11.176	0.115f	0.594	0.074a	0.25	2.51	12.888	2.068

Water Specific Gravity = 1.025.

Hull Data (with appendages)

Baseline Draft: 0.860
Trim: zero
Heel: zero

DIMENSIONS
Length Overall: 9.980 m LWL: 9.644 m Beam: 3.300 m BWL: 3.177 m
Volume: 10.904 m^3 Displacement: 11.176 MT

COEFFICIENTS
Prismatic: 0.701 Block: 0.415 Midship: 0.592 Waterplane: 0.788

RATIOS
Length/Beam: 3.024 Displacement/length: 347.198 Beam/Depth: 3.845
MT/ cm Immersion: 0.247

AREAS
Waterplane: 24.132 m^2 Wetted Surface: 31.655 m^2
Under Water Lateral Plane: 7.414 m^2 Above Water Lateral Plane: 6.599 m^2

CENTROIDS (Meters)
Buoyancy: LCB = 0.115 fwd TCB =0.000 port VCB = 0.594
Flotation: LCF = 0.074 aft
Under Water LP: 0.071 fwd of Origin, 0.397 below waterline.
Above Water LP: 0.004 fwd of Origin, 0.351 above waterline.

Note: Coefficients calculated based on waterline length at given draft

PARAMETER		PROTOTYPE	1/20 SCALE MODEL
Length Overall	LOA	10.0 m	500 mm
Beam Overall	BOA	3.7 m	185 mm
Height Overall	HOA	3.6 m	180 mm
Draft	T	0.894 m	43 mm
Displacement	Δ	12,640 kg	1.58 kg
Wetted Surface Area	S	32.1 m	0.08 m
Block Coefficient	C_B		
Midship Coefficient	C_X	0.422	
Prismatic Coefficient	C_P	0.598	
Waterplane Coefficient	C_W	0.709	
Length to Beam Ratio	L/B	0.799	
Beam to Draft Ratio	B/T	2.703	
		4.302	
NOZZLE			
Outside Diameter	OD	500 mm	27 mm
Length	L	300 mm	20 mm
PROPELLER			
Diameter	D	450 mm	25 mm

	Target	Actual	Percent Error
VCG wrt Baseline (m)	68 mm	78 mm	15.4 %

Appendix E

OFFSHORE EVACUATION SYSTEM PERFORMACE

PHASE II

VERSION 6 / SEPT 25 ,2001 Prepared by: Dean Pelley

Weather	Full Scale			Equivalent Beaufort	
	Waveheight [m]	Period [s]	Wave Length [m]	[]	
W5_20_20	6.72	9.28	134.40	Beaufort 7	Scale 1:20
W5_20_15	6.72	8.03	100.80	Beaufort 7	
W5_20_10	6.72	6.72	70.56	Beaufort 7	
W6_20_20	9.14	10.82	182.80	Beaufort 8	
W6_20_15	9.14	9.37	137.10	Beaufort 8	
W6_20_10	9.14	7.84	95.97	Beaufort 8	
W6.5_20_20	12.17	12.49	243.40	Beaufort 8+	
W6.5_20_15	12.17	10.81	182.55	Beaufort 8+	
W6.5_20_10	12.17	9.05	127.79	Beaufort 8+	
W7_20_20	15.20	12.86	258.40	Beaufort 9	
W7_20_15	15.20	12.08	228.00	Beaufort 9	
W7_20_10	15.20	10.58	174.80	Beaufort 9	

Weather	Full Scale			Equivalent Beaufort	
	Waveheight [m]	Period [s]	Wave Length [m]	[]	
W1	0	0.00	0.00	Calm	Scale 1:13
W2_13_20	1.01	3.60	20.20	Beaufort 4	
W2_13_15	1.01	3.12	15.15	Beaufort 4	
W2_13_10	1.01	2.73	11.62	Beaufort 4	
W3_13_20	2.1	5.19	42.00	Beaufort 5	
W3_13_15	2.1	4.49	31.50	Beaufort 5	
W3_13_10	2.1	3.93	24.15	Beaufort 5	
W4_13_20	3.96	7.12	79.20	Beaufort 6	
W4_13_15	3.96	6.17	59.40	Beaufort 6	
W4_13_10	3.96	5.28	43.56	Beaufort 6	
W5_13_20	6.71	9.27	134.20	Beaufort 7	
W5_13_15	6.71	8.03	100.65	Beaufort 7	
W5_13_10	6.71	6.88	73.81	Beaufort 7	
W6_13_20	9.14	10.82	182.80	Beaufort 8	
W6_13_15	9.14	9.37	137.10	Beaufort 8	
W6_13_10	9.14	8.02	100.54	Beaufort 8	

Appendix F

Set up codes

Weather [Beaufort Scale]	**W1** (BF0)	**W4** (BF6)	**W5** (BF7)	**W6 & W6+** (BF8)	**W7** (BF9)
Wave Steepness [-]	**S10**		**S15**	**S20**	
Wave Type [-]	**REG** (Regular)		**IRREG** (Irregular)		
Orientation [-]	**PER** (Perpendicular)		**PAR** (Parallel)		
Clearance [m]	**C3** (11.037)		**C5** (14.7)	**C6** (24.56)	
Height [m]	**H2** (30)		**H4** (20)		

Series 13A: Weather effects on performance – baseline case.
[W1 W4-W5] in configuration [REG, PER, C3, H2]

Series Label	# of runs	Beaufort description	Mean Wind [m/s]	Mean Wave [m]
A1	6	(0) Calm water	0	0
A4	5	(6) Strong breeze	18.23	3.76
A5	7	(7) Moderate gale	24.38	7.07

Series 20A: Weather effects on performance – baseline case.
[W1 W5-W7] in configuration [REG, PER, C5, H2]

Series Label	# of runs	Beaufort description	Mean Wind [m/s]	Mean Wave [m]
A1	5	(0) Calm water	0	0
A5	6	(7) Moderate gale	15.43	6.75
A6	6	(8) Fresh Gale	27.63	7.93
A7	9	(9) Strong Gale	20.30	13.53

Series 20B: Wave Steepness effects on performance.
[W1 W5-W6+] in configuration [REG, PER, S15, C5, H2]

Series Label	# of runs	Beaufort description	Mean Wind [m/s]	Mean Wave [m]
B1	3	(0) Calm water	0	0
B5	6	(7) Moderate gale	16.79	6.63
B6	6	(8) Fresh Gale	18.82	9.20
B6+	5	(8) Fresh Gale	19.23	11.15

Series 20C: Wave Steepness effects on performance.
[W1 W5-W6+] in configuration [COLL, PER, S10, C5, H2]

Series Label	# of runs	Beaufort description	Mean Wind [m/s]	Mean Wave [m]
C1	3	(0) Calm water	0	0
C5	3	(7) Moderate gale	17.00	5.72

Series 20D: Parallel orientation effects on performance.
[W1 W5-W7] in configuration [REG, PAR, S20, C5, H2]

Series Label	# of runs	Beaufort description	Mean Wind [m/s]	Mean Wave [m]
D1	3	(0) Calm water	0	0
D5	6	(7) Moderate gale	16.5	6.99
D6	6	(8) Fresh Gale	18.58	7.91
D7	5	(9) Strong Gale	21.61	13.49

Series 20E: Height effects on performance.
[W1 W5-W7] in configuration [REG, PER, S20, C5, H4]

Series Label	# of runs	Beaufort description	Mean Wind [m/s]	Mean Wave [m]
E1	5	(0) Calm water	0	0
E5	6	(7) Moderate gale	16.23	6.63
E6	7	(8) Fresh Gale	18.58	7.91
E7	6	(9) Strong Gale	21.03	13.31

Series 20F: Irregular Wave spectrum.
[W1 W6] in configuration [REG, PER, S20, C5, H4]

Series Label	# of runs	Beaufort description	Mean Wind [m/s]	Sig Wave Height [m]
F1	5	(0) Calm water	0	0
F6	7	(8) Fresh Gale	16.24	8.72

Appendix G

Decay Tests

- Perform swing test of the TEMPSC in air. Adjust ballast weights as necessary.
- Place TEMPSC in basin and check for trim and heel. Adjust as necessary.
- Perform heave, pitch and roll decay experiments on the free-floating TEMPSC.

Systematic Experiment Series

- Clean wave probes every morning prior to acquiring data.
- Perform calm check runs at the start of each day with the wind fans and wavemakers turned off.
- The test configuration was set according to the test matrix.
- The member of the project team in charge of the TEMPSC setup entered the tank and moved to an area underneath the TEMPSC station.
- The operator lowered the davit twin fall lines down to the water surface and the TEMPSC was attached to the lines.
- The TEMPSC was winched-up to the proper launching height. This was accomplished by installing a limit switch that cut power to the winch when it was contacted by the TEMPSC.
- The member of the project team in charge of the TEMPSC setup moved away from the test area.
- The data acquisition was started, followed by the wavemakers, the video and the wind machine. After approximately 15-20 wave cycles passed the installation the command to start deployment was given.