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# Experimental Evaluation of Lifeboat Evacuation Performance

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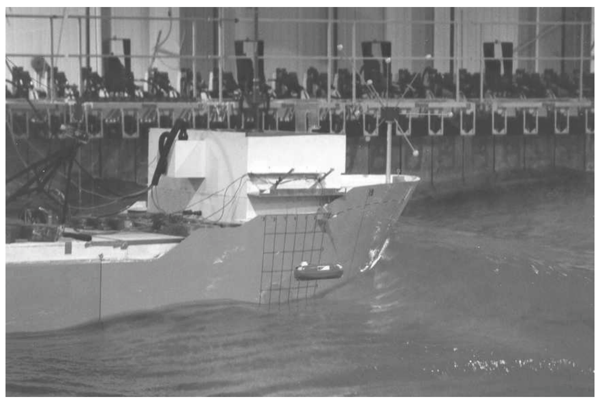

***ABSTRACT***

*Results are presented from a model tank test program designed to evaluate the performance of lifeboat evacuation in a range of environmental conditions. The aim of the program is to provide objective, reliable data concerning particular aspects of evacuation performance, which can be used by designers, regulators, and others in their decision-making. As the shipping industry follows the offshore oil and gas industry in requiring more rigorous management of safety, and as both industries and their regulators move increasingly toward performance standards rather than prescriptive rules, the availability of such information becomes a necessity for assessing and managing risk.*

## INTRODUCTION

A series of large scale model experiments of lifeboat evacuation from a floating platform was done at the National Research Council of Canada's Institute for Marine Dynamics (NRC/IMD). The main objective of the experiments was to measure evacuation performance as a function of environmental conditions. Results of these experiments can be useful for benchmark comparisons or for quantifying the risks associated with evacuation of offshore petroleum installations (Menarry 1996). Risk assessment is a design imperative and a regulatory requirement in many jurisdictions, but published quantitative data on lifeboat evacuation are sparse (Spouge 1999). This hampers the design process and attaches uncertainty to any regulatory goals. The results presented here help to close the knowledge gap. The present discussion is in the context of offshore petroleum installation safety, although the results are relevant to ship safety. Previous work on evacuation system evaluation using model tests has been reported by Rutgersson & Tsychkova (1999) for ships, for example, and by Campbell *et al.* (1983) and Simões Ré (1996) for offshore structures.

Evacuation of an offshore petroleum installation, or ship, can occur under a range of situations, from a routine training exercise, to a precautionary partial evacuation, to an emergency. The degree of stress and related human factors, and the degree of physical impairment of the installation and personnel will be related to the type of situation. An evacuation of healthy personnel carried out with well maintained equipment during a training exercise in good weather is likely to be more successful than an emergency evacuation of distressed and possibly injured personnel in foul weather with equipment that might be damaged by the event that caused the emergency.

Our interest here is in evacuation by lifeboats during emergencies, which must necessarily be done in prevailing weather conditions. Current regulations do not require operators, or duty holders, to demonstrate the capability of evacuation system performance as a function of weather conditions. Apart from their relevance to an overall safety assessment then, the results quantify performance at "*the interface between a realised event and its consequences*" (MacFarlane 1994) that is, when it is actually needed. Model experiments allow us to investigate evacuation performance and generate statistically reliable data that would otherwise be prohibitively dangerous to collect, if done with full scale manned equipment under controlled conditions, or relatively uncertain, due to the low frequency of occurrence of actual installation evacuations, which are not controlled in the experimental sense (Royal Society Study Group 1992, pp.19-20).

Evacuation is one part of the Escape-Evacuation-Rescue (EER) process, where escape refers to escape from the danger on the installation to an evacuation point, evacuation means a planned escape from the installation via lifeboats (or other means, such as helicopters), and rescue means reaching a level of safety comparable to that obtained before the emergency situation, which should include the availability of medical assistance. Escape can also be used to refer to an uncontrolled flight from the hazard, such as jumping into the sea (e.g. Cullen 1990, p.337). The EER process is only successful when the last phase is complete. The experimental work reported here deals only with the evacuation phase of EER, although the importance of the other phases is recognised.

There are limits to what can be accomplished in model tests. Failure in an evacuation process can occur before launch, during launch, or after launch. In the first case, a failure might be that some lifeboats are damaged due to the emergency initiating event, are undergoing maintenance, or are otherwise rendered unavailable. This limits the choice of lifeboat, which can impact on the launch scenario, but it is not explicitly dealt with in our experiments. Failure after launch, for example due to capsize after clearing the installation, is also not treated.

Our experiments model the launch and are particularly concerned with performance during launching and clearing. There are no generally accepted measures of performance in this context, but we explore several potential measures and discuss their practical utility. These include lifeboat motions and collisions with the installation during launching (lowering), and lifeboat set back, collision, and drift during splash-down and sail-away. Launch failures due to equipment failure, such as accidental release or inability to release, are not modelled.

This is an important point. Equipment failure is an important part of a risk assessment and we have made every reasonable effort to model the mechanical components of evacuation systems so that they perform in a physically accurate way. However, the reliability of the actual mechanical systems is a function of things like maintenance, which we cannot reproduce at model scale. Therefore, model launch failures attributed to launch equipment failure are not included in the results as this class of failure is not necessarily statistically representative of full scale. To address this aspect of launch failure, one might turn to a survival training facility, where relatively many launches are done, all in controlled conditions. Reliability data from such a source would complement the model data presented here. Otherwise, a starting point for this and other aspects of quantitative risk assessment of the evacuation process can be found in Spouge (1999), along with some data sources.

The scope of the experimental work in terms of the EER process and its relevance to performance assessment is illustrated in Figure 1.

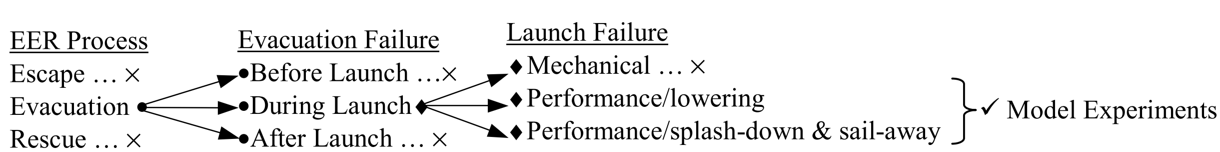


Figure 1. Scope of experimental work.

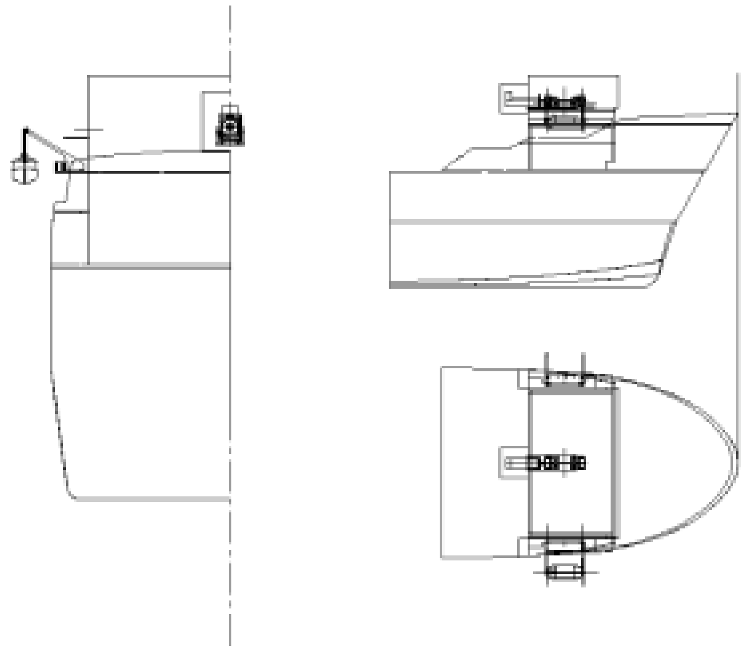

Figure 2. Basic test configuration.

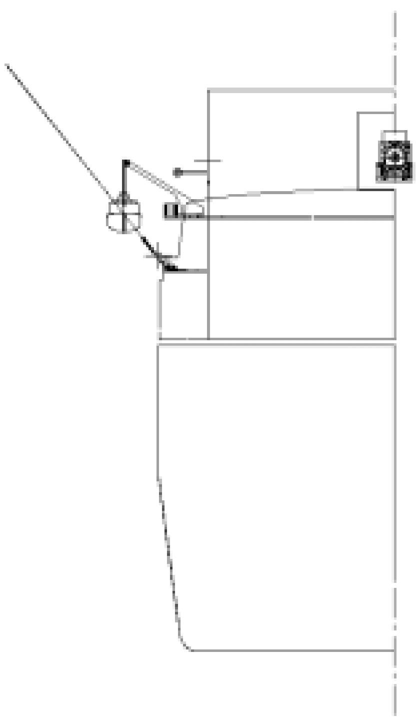

Figure 3. Modified test configuration.

## MODEL TESTS

### Test Design

A floating production, storage, and off-loading vessel (FPSO) was used as the platform for the evacuation tests. The FPSO was tested in its ballast, intact condition. No damage cases were investigated. The FPSO was arranged such that it had a 20° heading to the waves and a 57° heading to the wind. The lifeboat was deployed from the starboard (windward) side.

The evacuation system used for this set of experiments was the twin falls davit system. The system was of the straight fall double wire category with a totally enclosed motor propelled survival craft (TEMPSC) stowed and launched parallel to the hull. The basic test setup is shown in Figure 2. The deployment clearance of the lifeboat from the FPSO was 1.5 times the breadth of the lifeboat (5.5m full scale); the launch height was 26.9m above the still water surface. All tests were done with the TEMPSC in its 100% load condition. The model TEMPSC was launched at random positions with respect to incident waves, and propulsion power was available when the boat hit the water. In addition, a smaller set of comparative experiments were performed with a modified launch system. The modification consisted of the addition of a flexible boom. The modified test setup is shown in Figure 3.

The environmental conditions were combinations of wind and waves, which were varied systematically over the (full scale) range from 1m to 11m in wave height, and from 7m·s$^{-1}$ to 19m·s$^{-1}$ wind speed. Only steady mean wind speeds were used. Regular waves were used, with periods ranging from 5.5s to 15s. Launches were also made in calm conditions to provide a performance baseline.

As the concern here was with the lowering, splash-down, and sail-away phases of evacuation, measures were established to quantify the system's performance during each phase. During lowering, the TEMPSC's motions (e.g. pendulum oscillations) and positions were measured, and collisions with the installation noted. The time taken to lower the lifeboat was also recorded. At splash-down, the position of the TEMPSC relative to its target drop point and its position on the incident wave were measured, as was its initial set back during the passage of the first wave encountered. The performance measures during sail-away were the lifeboat's accelerations and the time required to clear the installation. These measures, a few of which are illustrated in Figure 4, correspond to some of the performance objectives specified recently by Kingswood (2000).

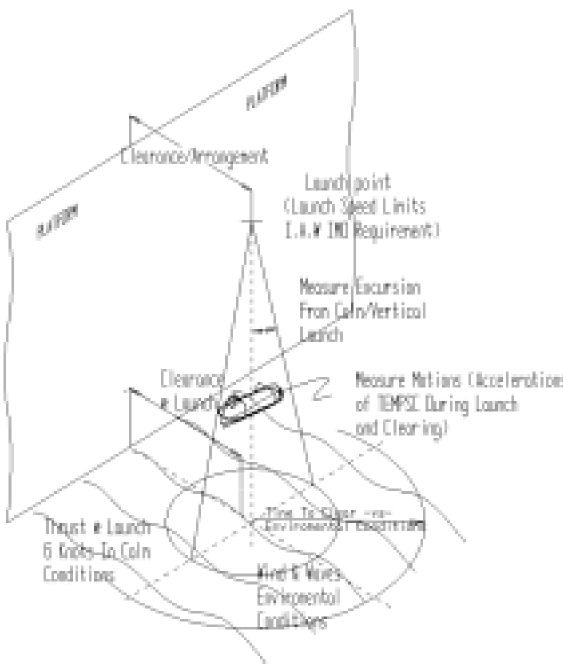


Figure 4. Measures of performance.

## Test Facilities

The experiments were done in the Ocean Engineering Basin (OEB) at the Institute for Marine Dynamics. The OEB has a nominal working area of 65m×26m with a maximum working depth of 3.2m. The basin is fitted with 168 individual wavemaker segments, hydraulically activated and distributed in a "L" shape around its perimeter. The segments are 2m high and 0.5m wide and are grouped four to a module. Each module can be adjusted vertically to accommodate water depths varying from 0.4m to 3.2m. Wave direction can be varied from 0° to 90° in the basin. Passive absorbers are fitted to the walls opposite the wave boards.

The regular waves were modeled in terms of wave height and period, and matched to specific target values without the model present.

Wind was simulated using a horizontal array of 12 analog-controlled fans mounted on support frames. Each fan had a blade diameter of 530mm and was powered by a DC motor capable of rotating at speeds of up to 5000 rpm. The wind generator can produce a turbulent wind spectrum with a mean wind speed of up to 12 m·s$^{-1}$.

Only mean wind speed was used in these tests; wind was calibrated prior to the test program with the model in place (Fudge & McKay 1995).

## Floating Platform Model: FPSO

Physical models of the FPSO, TEMPSC, twin falls davit deployment system, and its modified configuration components were designed and manufactured at a scale of 27.65.

The FPSO hull was an accurate geometric representation of a generic FPSO design. Accommodation modules, forecastle and bulwarks were modeled while the remaining topsides structures, such as the turret, process equipment module, helideck, flare tower, and cranes, were left off. The FPSO was decked over at the main deck level for water integrity.

The model hull was constructed of Styrofoam®, wood and glass reinforced plastic (GRP). The model's internal structure consisted of a plywood box supported by transverse and longitudinal frames. Foam strips roughly 100 mm wide and 51 mm thick were glued to the box and reinforced with a high density foam at the aft and forward thruster locations and in the moonpool area. The Institute's computer controlled milling machine milled the model FPSO hull shape with a ball-nose cutter. The tool paths compensated for the thickness of the fiberglass, gelcoat and paint. The model was hand finished, covered with two layers of 340 g/m$^2$ fiberglass cloth and epoxy resin and a layer of gelcoat that was faired smooth. The model hull surface was painted yellow; the accommodation module and deck covers were painted white.

Draft marks for the full and ballast loads were marked on both sides at stations 1, 2, 10, 19, 20 and at the longitudinal centre of the moonpool. A grid with its origin at the intersection of the midpoint between the davit arms and the keel of the TEMPSC in its launching position was marked on the side of the FPSO hull. The grid's *x*-increments were half the TEMPSC's overall length (5.05m) and the *z*-increments were the TEMPSC's overall height (3.5m).

The model was fitted with an underwater rotatable mooring that extended 310 mm below the cover of the moonpool. The moonpool cover was fitted at the same level as the bottom of the FPSO.

The model mooring was located below the FPSO bottom and was designed to have the modeled stiffness characteristics of full scale mooring lines. The mooring system consisted of a mooring post attached to the model. At the bottom end of the post a 200mm turntable was mounted, to which three mooring lines were attached in a 120° radial spacing interval. These extended under water to spring support posts on the side of the basin. The linearized spring system is a good representation of actual mooring systems, but differences occur in large excursions. These are non-linear systems that in these tests were modeled linearly.

The empty FPSO model was weighed and swung using a large steel frame in order to measure the model's radii of gyration. The inertia of the ballast weights, the accommodation module, and deck covers were included by calculation. An inclining experiment was performed to determine the transverse metacentric height (GM) of the free-floating model. Weights located on either side of midships at deck level were used as trimming weights.

The Qualisys Optical Tracking System (QOTS) tracked an irregular array of reflective spheres mounted on a vertical support at the bow of the FPSO model to measure the six-degrees of freedom motions of the model with respect to an inertial coordinate system. An anemometer was mounted just aft of the davit arms to provide wind speed information in the area of the TEMPSC location. Four video cameras were used to track the TEMPSC from start of descent to splashdown and sail-away.

**Lifeboat Model: TEMPSC**

The model lifeboat was representative of a typical 80 person TEMPSC. The model was fitted with two mechanical releases for the twin falls. For the modified system, a hook was added to the forward davit release block for attachment of the tagline ring.

The TEMPSC model was fabricated in two halves (hull and canopy) from glass reinforced plastic (GRP). The hull and canopy mated along the gunwale line. A rubberized gasket was used between the two to prevent water ingress. The model hull was fitted with a working rudder, rudder servo, 18mm three bladed propeller, shaft, DC motor, motor controller, receiver unit, rechargeable battery pack, accelerometer, and simulated hydrostatic interlock release unit. The hydrostatic release unit was modeled by inserting four brass pins (bow, stern, port and starboard at midships) at an equivalent full scale height above base line of approximately 0.5m. In order for the TEMPSC blocks to be given the open command, an electronic circuit had to sense that at least three of the pins were submerged. The circuit also activated a light positioned on the TEMPSC canopy that served as a visual trigger for the operator to open the block. This arrangement ensured that no accidental opening of the blocks was possible and modeled an "On-Load" system with hydrostatic interlock. The accelerometer was mounted on the keel and oriented such it recorded lateral accelerations.

The canopy half was fitted with a servomotor that activated the forward and aft davit falls release mechanism. The same servomotor was also used to activate the hook safety of the modified davit system. Reflective tape was attached to the canopy at several locations for use with the QOTS tracking system. The instrumentation on the hull portion of the TEMPSC was used for steering, propulsion and acceleration, while the instrumentation on the canopy was used to activate the release mechanisms and the tagline hook.

Prior to the launching tests, the TEMPSC's speed was determined by averaging the time required by 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 5.94 knots (full scale) was achieved, which is slightly below the target of 6 knots that is required by international regulations (IMO 1997a). The calm water speed tests were repeated twice.

The vertical centre of gravity (VCG) and the radii of gyration were obtained by swinging the TEMPSC hull model on a frame in air.

The evacuation system used for the majority of the tests was the twin falls davit launching system: this is a system that involves the emergency transfer of personnel by evacuation lifeboats that are stored on the offshore installation and are boarded before launching. This type of evacuation system typically incorporates two discrete components that work together to allow the evacuating personnel to escape the immediate vicinity of the offshore installation and await transfer to a place of safety. The two components of the system are the evacuation craft and the system that launches it.

The davit system was of the straight fall double wire category with the TEMPSC stowed parallel to the hull of the FPSO. In the deployed position, the davit arms positioned the TEMPSC centre line approximately 1.5 TEMPSC beams from the deck edge. The davit system's main components are the winch drum for the cable storage, the winch brake for controlling the speed of descent, the release mechanism that disengages the falls, and the cables themselves. The speed of descent and release mechanism were adequately modeled, but cable properties such as diameter, breaking strength, and stiffness were not modeled.

The rate of descent of the TEMPSC was modeled by programming the DC motor controller to spool out cable from the winch drums at a full scale rate of 53.6m·min$^{-1}$. The lowering speed was obtained from the following formula:

$$S = 0.4 + 0.02H \quad (1)$$

where $S$ is the lowering speed in meters per second and $H$ is the height in meters from the davit head to the still water line at the lightest seagoing condition (IMO 1997b, Regulation 41, General requirements for lifeboats, Lifeboat propulsion, page 342).

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.

The modified launch system consisted of a flexible boom held by a saddle support and a set of hinges attached to a base plate. The base plate was mounted approximately 2.5×TEMPSC height (8.75m) below the embarkation deck, ⅛×TEMPSC length (1.26m) forward of the forward davit arm, and ½×TEMPSC beam (1.84) from the bulwarks. The hinges had a horizontal axis, allowing the boom to move in a vertical plane with a swing of about 75°. The boom length (≈24m) was about the same as the vertical distance from the TEMPSC launching position to the calm water surface for the FPSO at the ballast draft. The boom support was provided by an electronic spring controlled by a feedback loop of ram extension versus load. The boom was parked at an angle of 40° with respect to the baseline. A fixed length of line, or tagline, was attached at one end to the tip of the boom and at the other end to a metal ring. The ring fitted over the boom hook attached at the bow of the TEMPSC forward of the davit release block. The length of the tagline was set at about the same length as the boom itself.

In a deployment, as the TEMPSC is lowered by the davit falls, tension is generated on the tagline, causing the boom to rotate at the base and bend throughout its length until the falls are released. The TEMPSC is then pulled through the water by the tagline away from the FPSO and as it passes under the boom tip the tagline releases. The pulling motion is generated by the hydraulic pressure build-up in the hydraulic cylinder attached to the saddle. In the model version, this was accomplished via the electronic spring that was calibrated to behave in the same fashion as the full scale system. The hydraulic cylinder pulls the boom upwards causing the TEMPSC to be pulled in an outward direction away from the FPSO. During deployment and prior to the release of the TEMPSC from the davit falls, the tagline changes the heading of the TEMPSC away from the FPSO and stabilizes the TEMPSC as it is being lowered to the water surface. The stabilization of the TEMPSC reduces the pendulum effect observed in traditional twin davit falls systems.

## Test Program

The experiment program consisted of nine series of tests. The basic twin falls davit launched system was used in the first six series; a flexible boom was used in the last three series. All of the launch configurations started with the TEMPSC parallel to the platform. The only variable in the test program was the environmental conditions. Table 1 shows the nominal description of the environmental conditions, from calm water to fresh gale, and the actual (full scale) mean wind speed and wave heights.

As one of the aims of the tests was to evaluate the use of model tests and experimental methods themselves, each type of test was repeated between 14 and 20 times. This provides an indication of the variability of the tests, which may help interpret the importance of particular random variables, such as the splash-down point on the wave (e.g. crest, trough).

Table 1. Test program.

| Series Label | # of repeats | (Beaufort) description | Mean wind | Mean wave |
|---|---|---|---|---|
| | | | [m·s$^{-1}$] | [m] |
| Conventional twin falls davit configuration | | | | |
| 400 | 14 | (0) calm water | 0 | 0 |
| 500 | 20 | (4) moderate breeze | 6.27 | 0.88 |
| 525 | 19 | (5) fresh breeze | 8.19 | 2.05 |
| 550 | 15 | (6) strong breeze | 10.13 | 3.90 |
| 600 | 14 | (7) moderate gale | 12.20 | 6.16 |
| 625 | 13 | (8) fresh gale | 15.34 | 10.76 |
| Flexible boom configuration | | | | |
| 700 | 20 | (0) calm water | 0 | 0 |
| 725 | 19 | (5) fresh breeze | 8.32 | 1.96 |
| 800 | 19 | (8) fresh gale | 16.15 | 10.84 |

## RESULTS & DISCUSSION

All of the tests were similar and can be described with reference to Figure 5, which illustrates the lowering, splash-down, and sail-away phases of a test in calm water. Three plots are shown in the figure. The top plot shows a plan view, the middle plot is a view along the centreline of the TEMPSC, and the bottom shows an outboard profile. In each view the path of the TEMPSC during lowering and sail-away is shown as an uneven line.

In the plan view, the outline of the TEMPSC is shown in its deployed position prior to lowering, which is used as a reference position. A pair of axes is centred at its midpoint. The waterline of the FPSO hull is also shown. Outboard of the FPSO the water surface is divided into 3 regions: a danger zone, an intermediate zone, and a safe zone. The danger zone is the area bounded by a 12.5m radius from the TEMPSC's reference position and extending 6.6m outboard from the FPSO's waterline. The region outside a 25m radius is the safe zone, and the circular band between the danger and safe zones is the intermediate zone.

These boundaries have been drawn rather arbitrarily at this stage and have specific weaknesses, not the least of which is that the danger zone encompasses the target drop point, which implies the danger zone used here is either too large, or the lifeboat ought to be launched farther away from the platform. A discussion of the boundaries is taken up further in the section on the utility of performance measures below.

During a calm water deployment the path of the TEMPSC is simple: it goes straight down during lowering, as indicated in the two lower plots; upon splash-down into the danger zone it sails straight ahead through the intermediate zone to safety, as illustrated in the plan view.

When the conditions are not calm, there are additional considerations and these can be understood with reference to Figure 6, which shows an example of a deployment in a fresh breeze. In this case, the effects of the vessel motions on the TEMPSC's path during lowering are indicated in the two lower plots.

Splash-down was made on a wave's up-slope, midway between the trough and oncoming crest, as can be seen best in the profile plot at the bottom of Figure 6. Measurements in the bottom plot show that no forward progress was made until the TEMPSC crested the next wave and motored down-slope. In fact, the TEMPSC moved backwards, or was set back, as it motored up-slope the first wave. These types of measurements were recorded for each of the 153 tests.

Further examples of evacuation path measurements are shown in Figures 7 to 11 for both the basic and modified system configurations in various weather conditions.

A comparison of the two systems' performance in fresh breeze conditions can be made by considering Figures 6 and 7. There are two significant points to compare. First, in the absence of the boom the lifeboat sails straight ahead after splash-down (see the plan views). With the boom, the lifeboat moves away from the platform. This is due to the steering effect of the tensioned tagline. Also, the set back experienced by the lifeboat with the boom is less than the set back with the basic configuration (see the profile views). In both regards, these results are typical of these series.

In general, platform motions do not appear to be significant in moderate and fresh breeze conditions, where the overall mean wave height and mean wind speed were about 0.9m and $6.3 m \cdot s^{-1}$ and 2.0m and $8.2 m \cdot s^{-1}$, respectively. In the fresh breeze cases shown in Figures 6 and 7, for example, small oscillations can be seen to have occurred during lowering as the lifeboat swung as a pendulum. Some of this oscillation may be attributable to the direct forcing by the wind, but it is mainly due to the motions set up in the platform by the waves.

Platform motions have a more noticeable effect in the strong breeze conditions, such as the case shown in Figure 8 where the mean wave height and mean wind speed were about 4.1m and $9.9 m \cdot s^{-1}$.

In moderate gale conditions, platform motions dominate the lowering phase. Figure 9 shows this clearly. A repeating elliptical orbit of the TEMPSC while in the deployed condition before lowering is visible in the *yz* view. The same oscillating path is visible in the *xz* view. During lowering, the oscillations continue.

As the lifeboat is arranged at the platform's side, roll motion is important, although in these tests, the lifeboat station was arranged near the bow, so pitch motions are also significant. The mean wave height and mean wind speed were 6.2m and $12.2 m \cdot s^{-1}$ in the example shown.

Figures 10 and 11 offer another comparison between the basic and modified launch configurations, this time in a fresh gale. Platform motions again dominate during the lowering phase, and again multiple orbits of the TEMPSC were recorded while the lifeboat was deployed in its suspended position prior to lowering. Close examination of the paths indicate, qualitatively at least, that the boom reduced oscillations during lowering and reduced set back and drift at splash-down.

The effects of platform motions in the more extreme weather conditions make it difficult to separate evacuation performance, at least until splash-down, from platform characteristics.

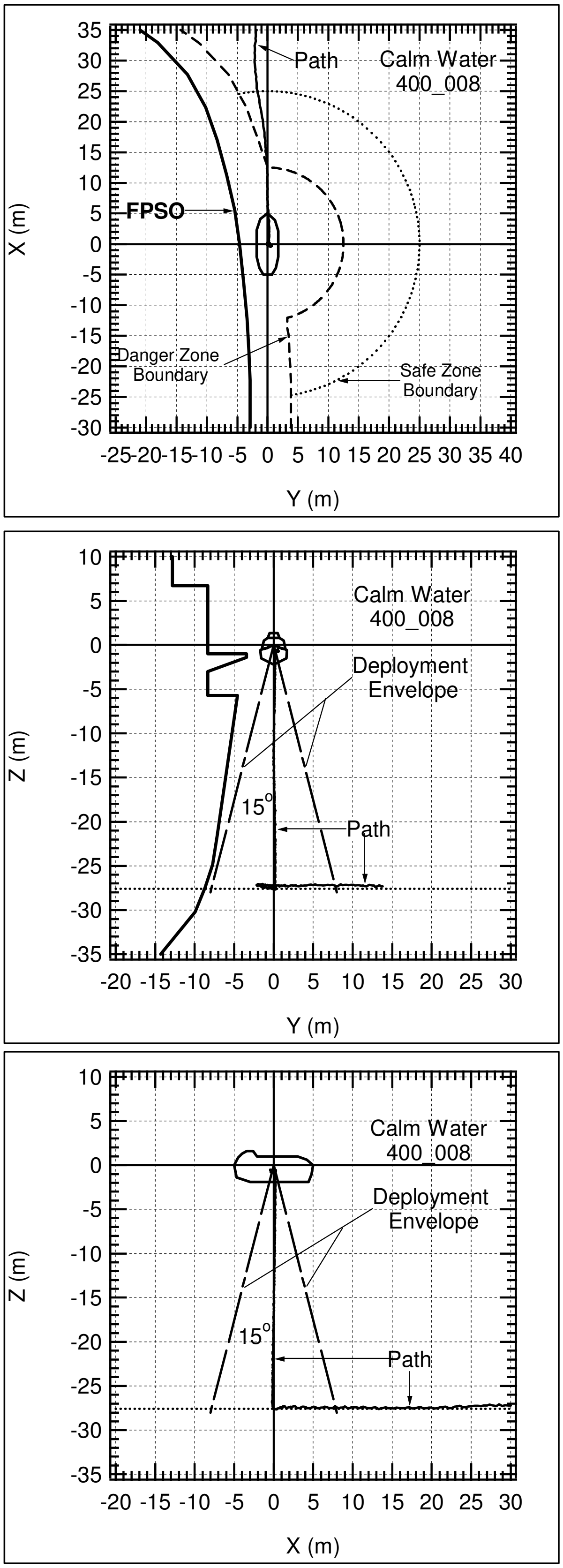


Figure 5. TEMPSC evacuation path in calm water.

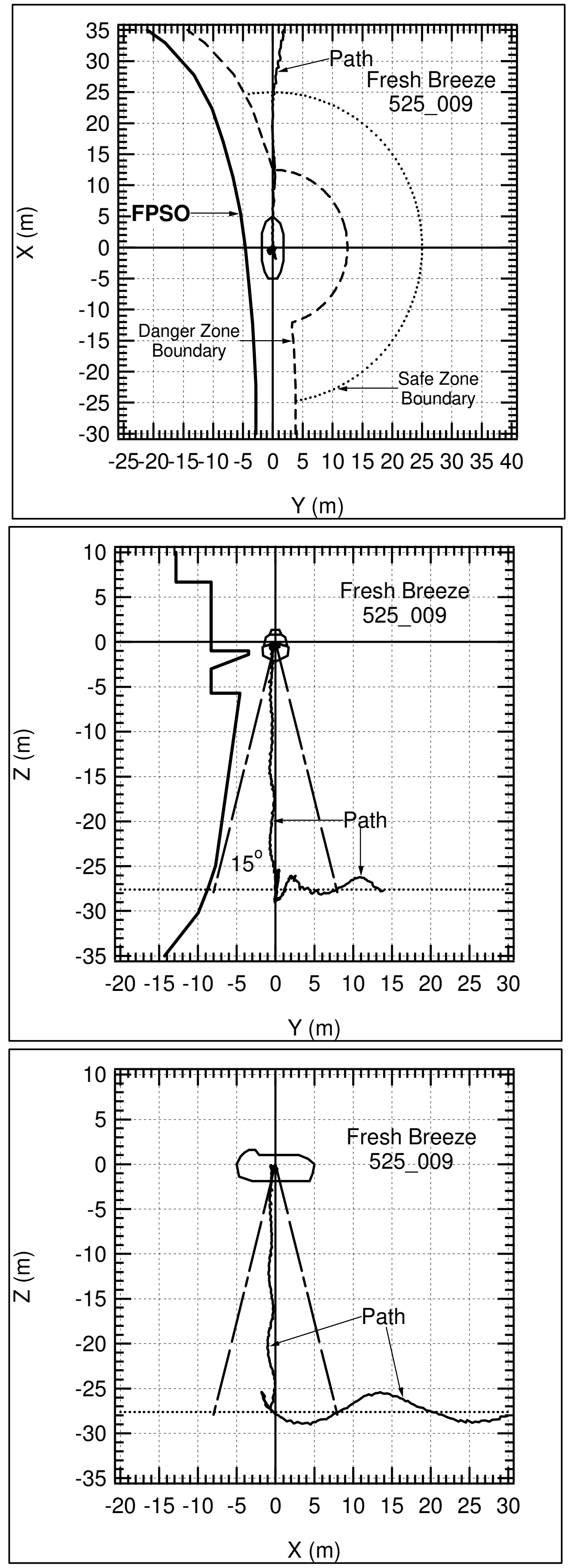


Figure 6. TEMPSC evacuation path in fresh breeze.

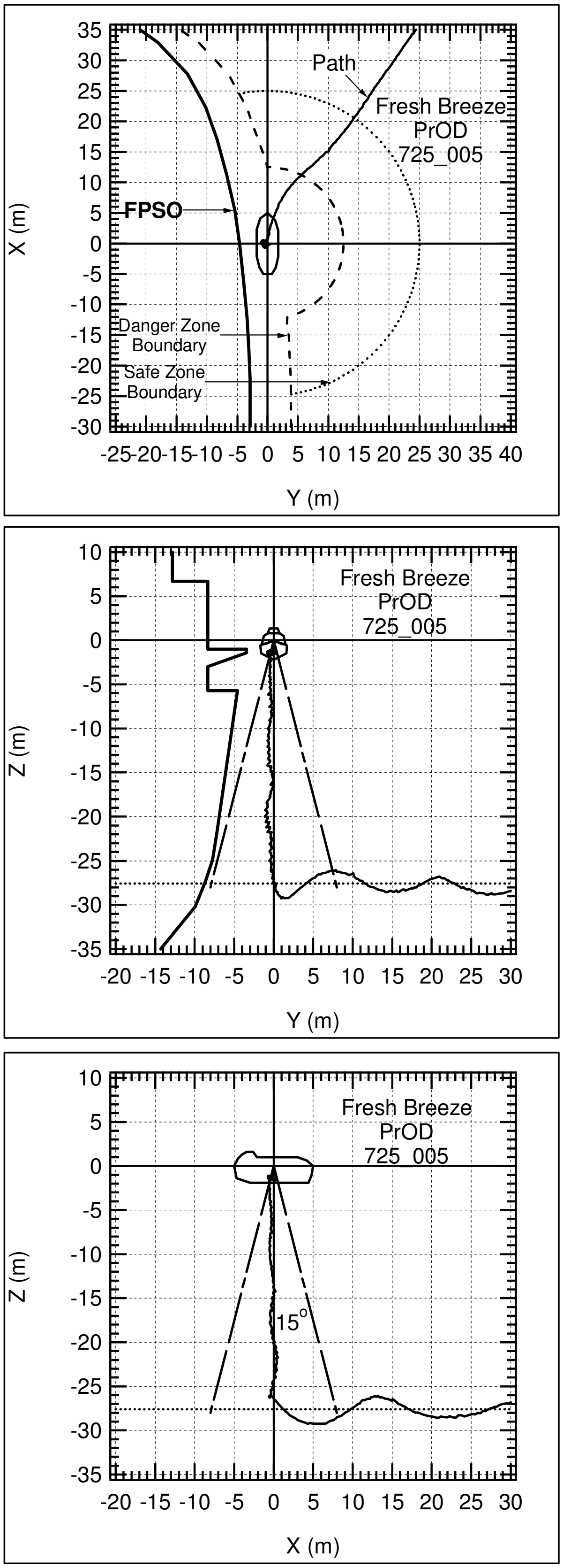


Figure 7. TEMPSC with boom: path in fresh breeze.

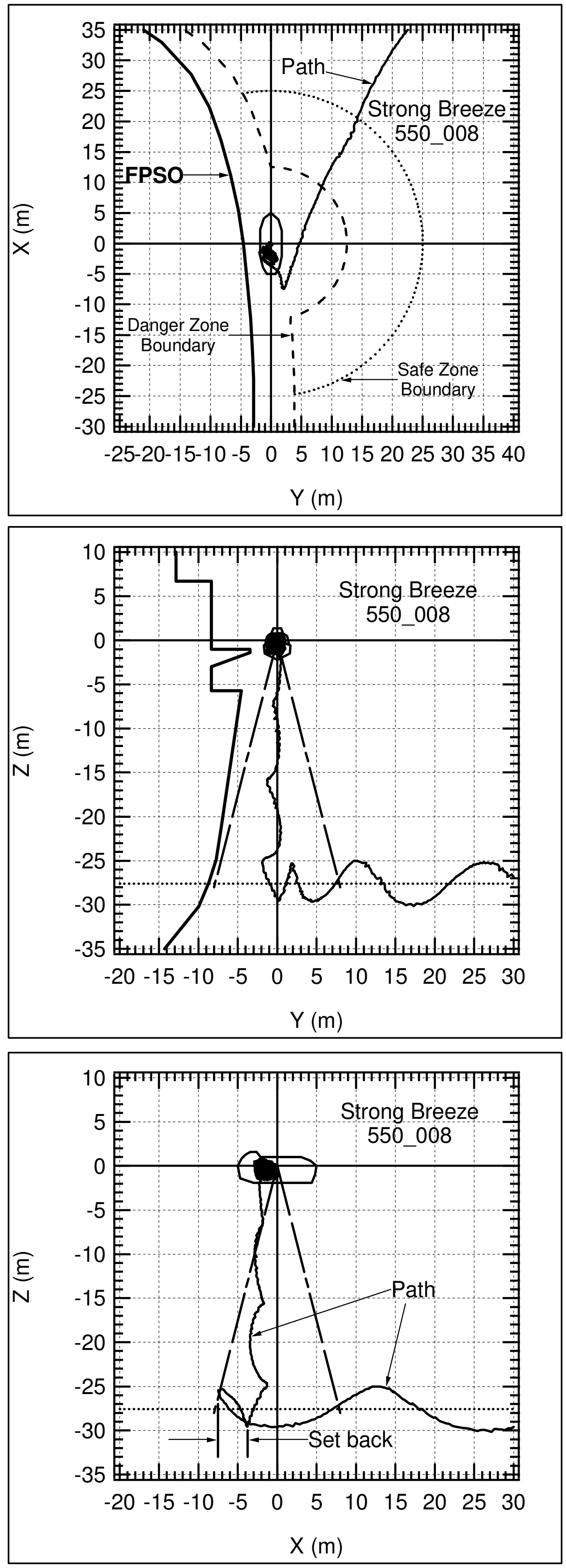


Figure 8. TEMPSC evacuation path in strong breeze.

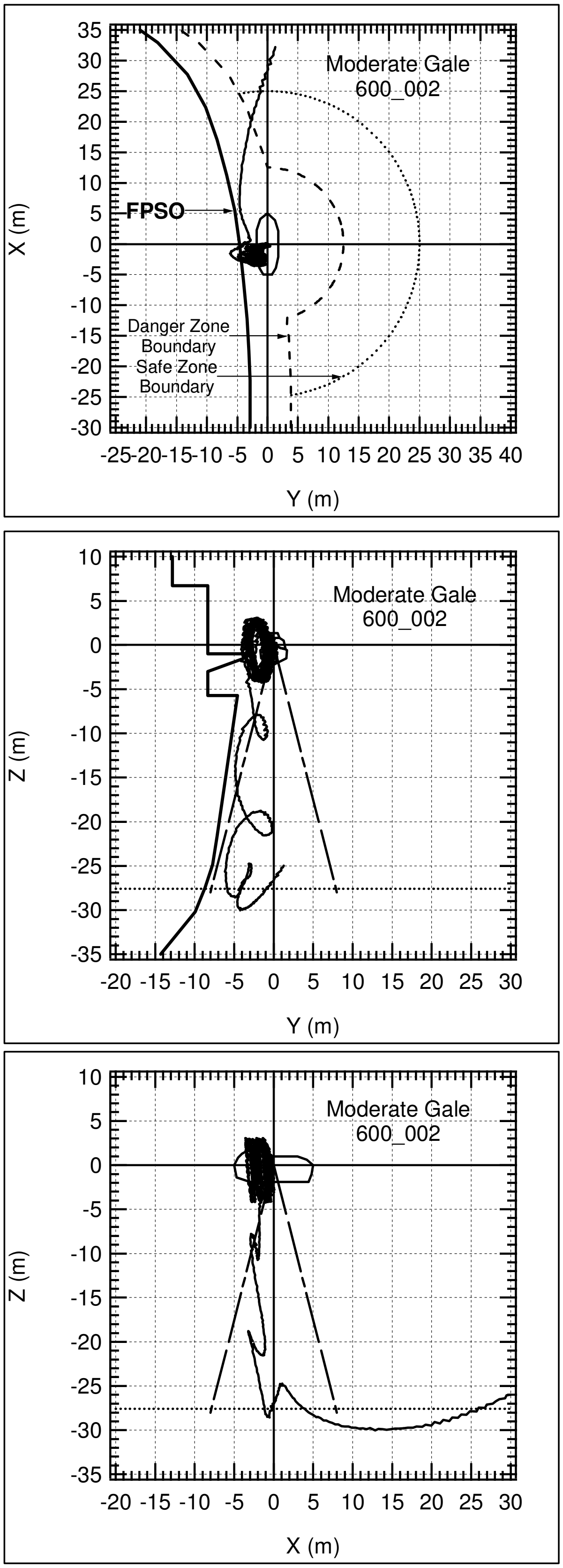


Figure 9. TEMPSC evacuation path in moderate gale.

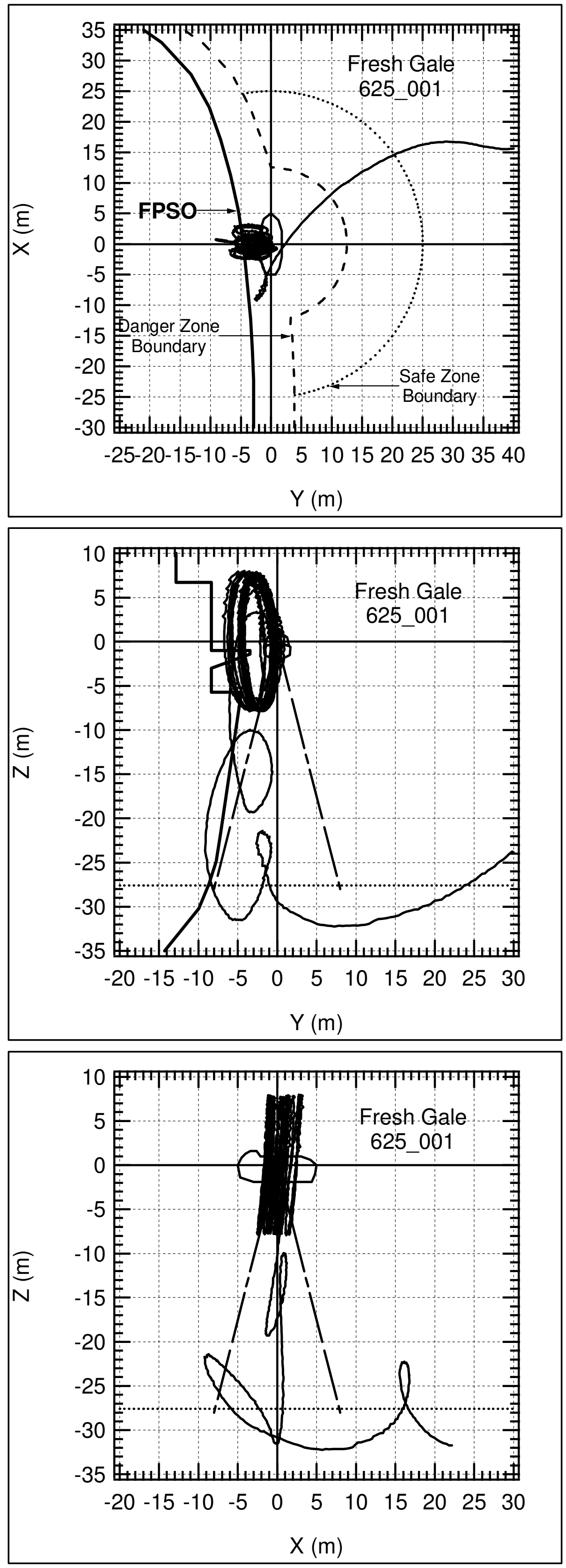


Figure 10. TEMPSC evacuation path in fresh gale.

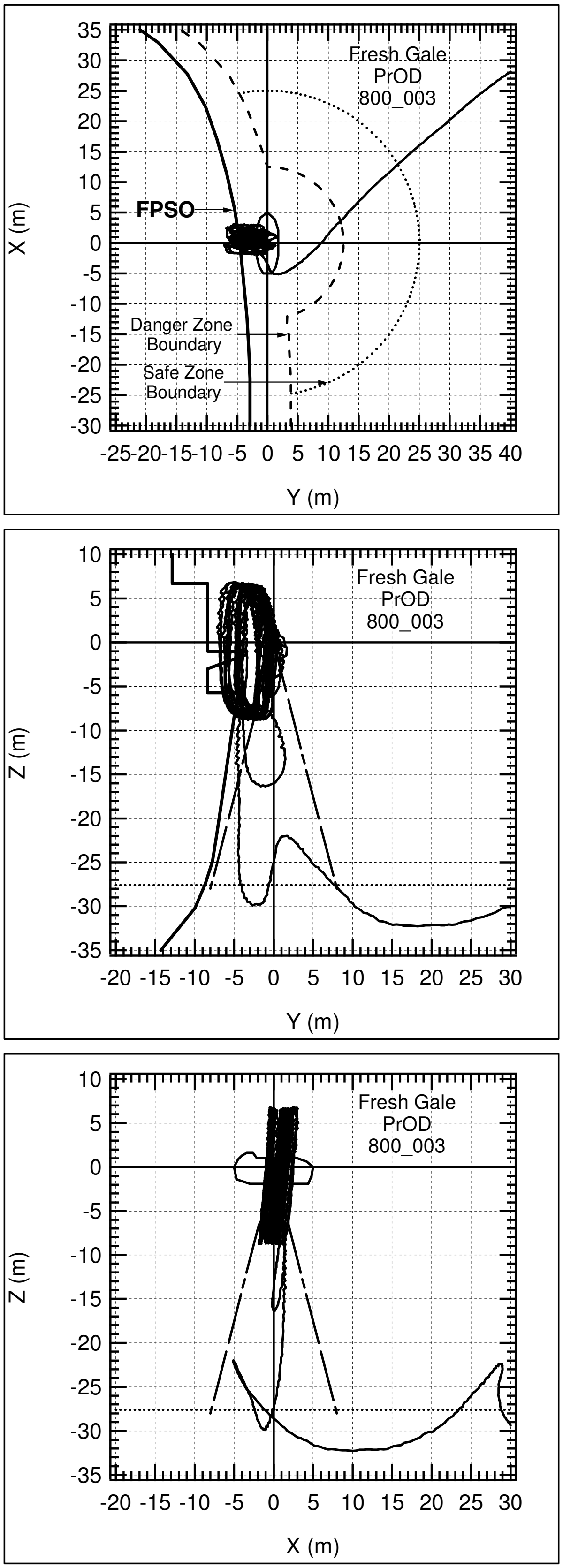


Figure 11. TEMPSC with boom: path in fresh gale.

**Measures of Performance**

Having looked at an example evacuation path from most of the nine test series, we can look at some possible performance measures versus weather conditions. In Figure 12 a performance measure is plotted against mean wave height for each of the tests done with the basic launch system. For example, the performance measure of the 14 tests done in Beaufort 7 conditions (about 6m wave heights) are all represented in the plot as crosses. Likewise, the 15 tests done in Beaufort 6 conditions are denoted by circles, and all the other test results are depicted as shown in the legend. Also shown in Figure 12 are a few basic trends in the data, specifically the line through the mean of each test series (the set of data at a given weather condition), and the lines through the series' mean ± 1 standard deviation.

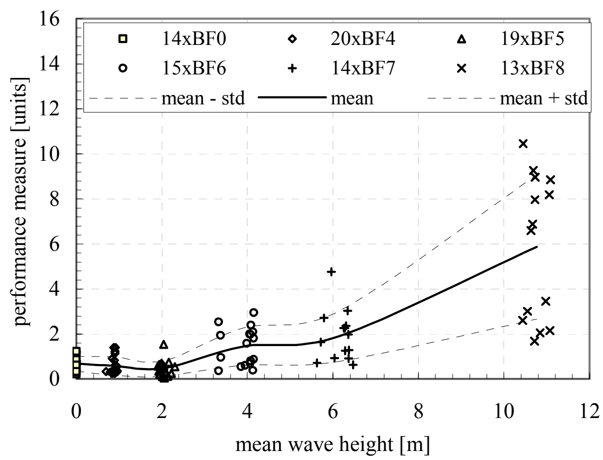


Figure 12. Presentation of results.

One performance measure is shown in each of the Figures 13 to 22. Figure 13 shows the mean time from the start of lowering to splash-down. As the lowering was done at a nominally constant rate for all the tests, this should be a flat line, independent of weather. This is not quite the case, as the time taken in rougher weather is slightly shorter than in light weather. This might be explained by the fact that most deployments occurred at wave crests, which would effectively reduce the lowering distance, and consequently the time.

Similarly, Figure 14 shows the time taken to release the falls after splashdown. As expected, weather appears to have little effect on this, although again, the release was executed slightly more quickly in rougher conditions than in calm water. A closer look at the figure shows that some of the times are actually negative, which means that the falls were released before splash-down. This occurred when the lifeboat was hit by a wave crest that released the falls, but then became air borne as the crest passed. There is a mechanical delay from the time that the hydrostatic release is activated and the blocks actually open. This delay is on the order of 2 to 3 seconds full scale. The significance here is that a wave may travel from half to a full TEMPSC length in one second. The combination of wave speed, platform motion, lowering speed, and mechanical delay results in these unique cases. The lifeboat subsequently dropped in free fall into a trough for splash-down.

The measure in Figure 15 also exhibits little weather dependence, although in this case – the time taken by the lifeboat to move clear to safety after splash-down – some might be expected. In fact, the speed of the lifeboat in rough weather conditions tended to increase compared to lighter conditions. Why this occurred is unclear, but it may be related to the surfing action of the TEMPSC on waves' down-slopes. A simpler explanation is that the propeller speed was poorly controlled. This latter is a model setup deficiency rather than a lifeboat weakness.

Figure 16 shows the distance covered by the lifeboat as it cleared the danger zone after splash-down. That it increases with weather indicates that there is some drift or loss of steerage during this phase. A look at the some of the path plots, say the strong breeze example in Figure 8, shows that this effect is most common just after splash-down when the lifeboat is accelerating. Once the lifeboat is at speed, the weather has less effect on its ability to make way. This interpretation is reinforced by the plot in Figure 17, which shows the distance covered by the lifeboat as it passed from the danger boundary to safety: during this phase it was typically at speed and making way without as much influence by the weather.

An effect of the boom can be seen in Figure 16. Compared with the basic system, the boom system's path lengths are shorter. This is due to the initial steerage provided by the boom, and the application of the tagline force, which mitigates the drift at splash-down. Any advantage of the boom over the basic system would be expected to be lost once the tagline is released. A comparison of the two systems in Figure 17 (path length from danger zone boundary to safety zone boundary) supports the expectation: the difference in path lengths from danger to safety is negligible. Such results give us more confidence in the utility of model testing as an effective tool for safety investigations.

Figure 18 shows how weather affected the launch performance in terms of splashing down on target, where the target is the point under the davit at the start of lowering. Ideally, the distance between the target and splash-down is zero. The figure shows that the extent that the target is missed increases with increasing weather. Further, the boom does not appear to reduce this.

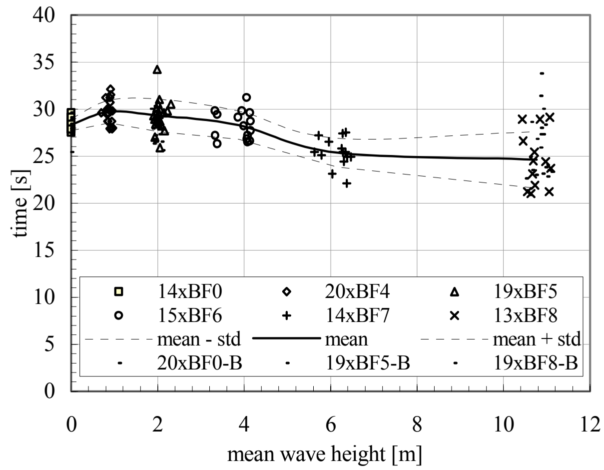


Figure 13. Time from launch start to splash-down.

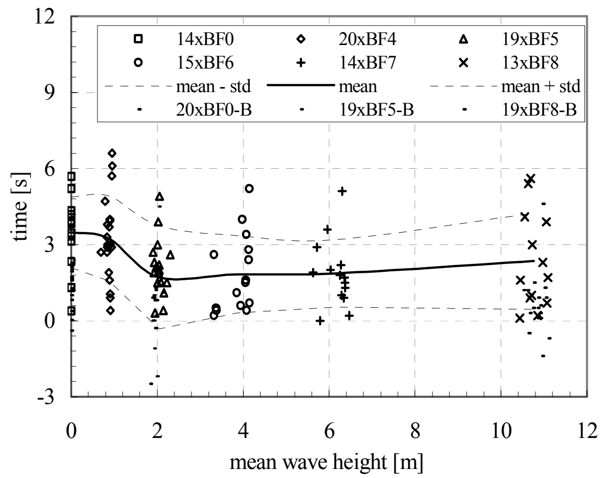


Figure 14. Time from splash-down to davit release.

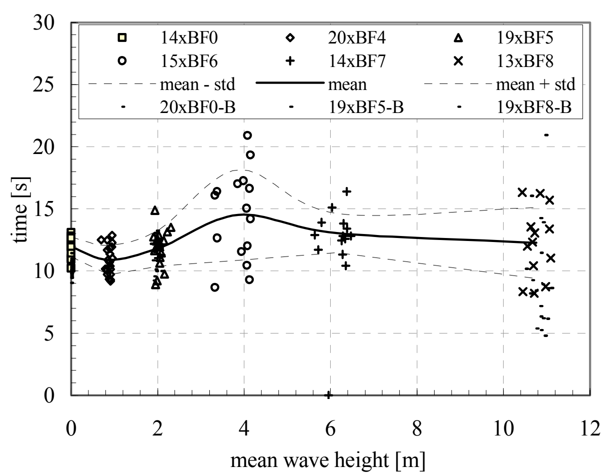


Figure 15. Time from splash-down to safety zone.

The boom has a significant role in reducing set back, as is illustrated in Figure 19. Set back generally increases with increasing weather, as might be expected, and is in practical terms to be avoided or mitigated, as excessive set back can result in collisions with the platform. The results presented in the figure are representative in general of all the tests in each respective series, but an important factor in the magnitude of the set back is not shown: the location on the wave of splash-down. This factor warrants further attention, but is not pursued here.

Figure 20 shows the combination of the missed target plus the set back, that is, the distance from the target drop point to the set back position. In each of the three measures shown in Figures 18 to 20, the distance is the distance in the *xy* plane.

Figure 21 shows the lateral accelerations measured in the TEMPSC during sail-away. As expected, accelerations increase with weather. The most interesting feature of Figure 21 is that the accelerations of the TEMPSC launched with the boom appear to be higher than those of the conventionally launched TEMPSC. This could be due to the fact that the boom orients the TEMPSC away from the FPSO, which coincides in this test setup with directing it towards beam seas.

Figure 22 shows the oscillation angles of the TEMPSC during deployment. These are derived from the measurements of the TEMPSC's motion and include all significant excursions due to pendulum motions during lowering. Only the means and maximums are shown for the basic system, both of which show a strong dependence on weather.

Figure 23 captures the overall effects of weather conditions on the control of the TEMPSC path during evacuation. The figure shows envelopes that encompass the paths taken by the TEMPSC in each set of tests. The paths in two views are shown: the plan view shows sail-away on top, and the outboard profile shows lowering, set back, and sail-away on bottom.

The first six pairs of envelopes (top and bottom) correspond to the basic davit launch configuration and the last three are for the boom assisted configuration. The most obvious trend is that control deteriorates radically with weather, regardless of the evacuation system used. This can be attributed to the weather alone in the sail-away phase, and to the combined effects of weather and platform motions in the lowering phase.

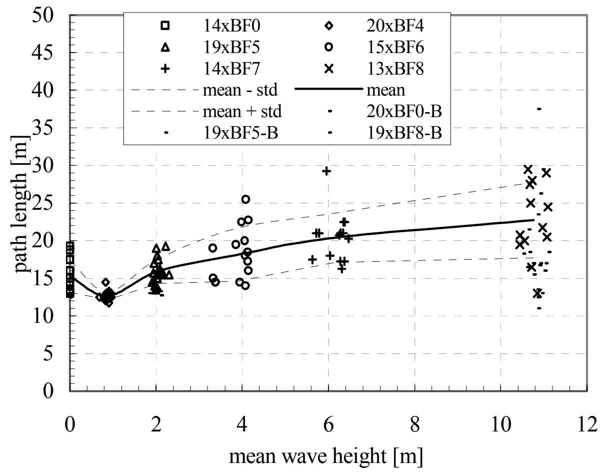


Figure 16. Lifeboat path length: splash-down to safety.

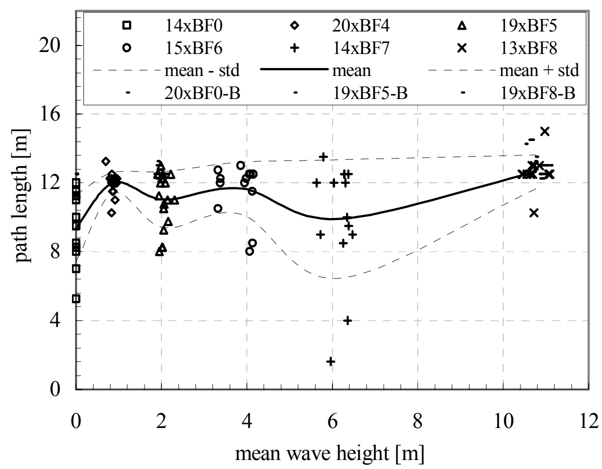


Figure 17. Lifeboat path length: danger zone to safety.

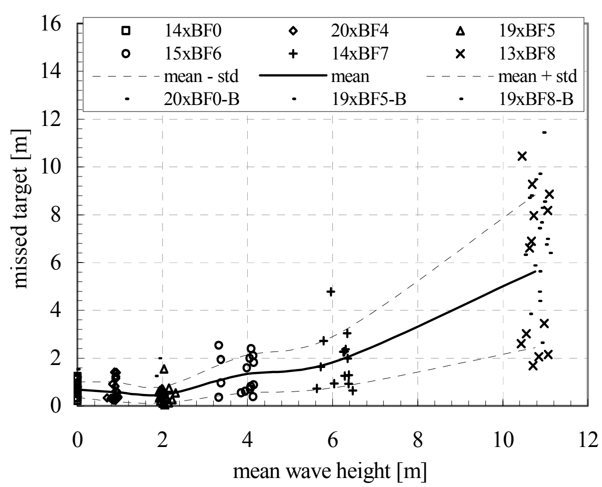


Figure 18. Missed target at splash-down.

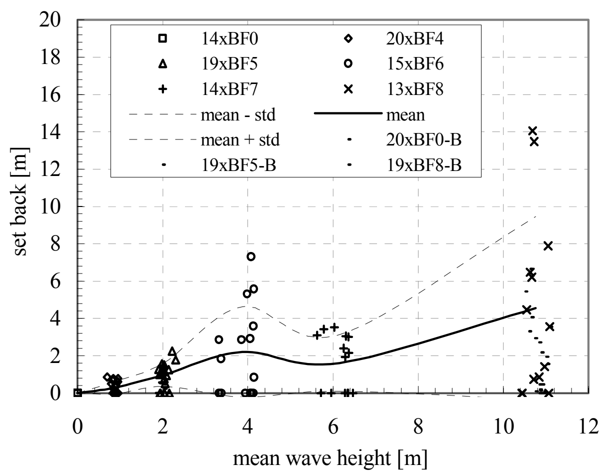


Figure 19. Set back.

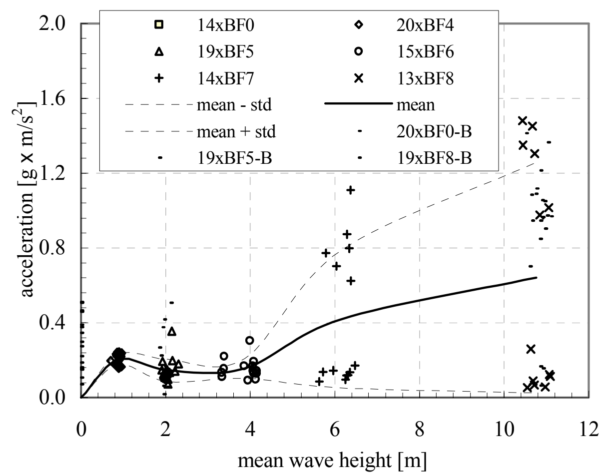


Figure 21. Lateral accelerations during sail-away.

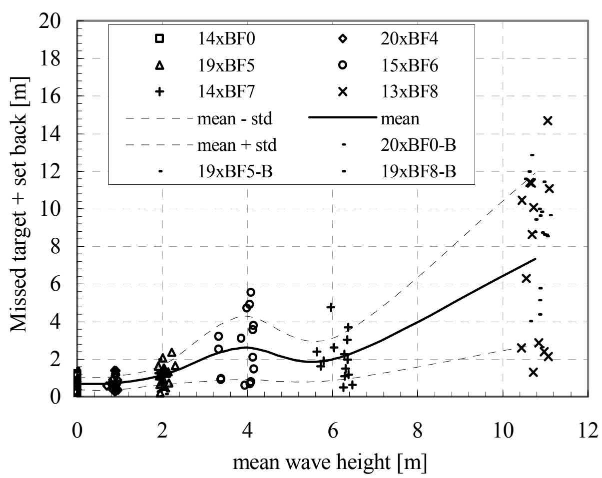


Figure 20. Missed target + set back.

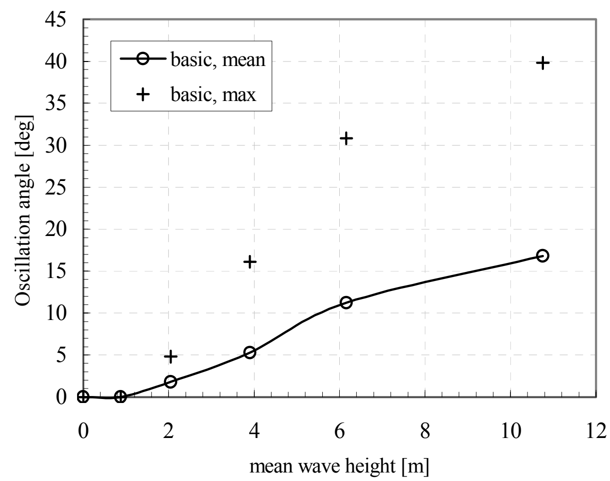


Figure 22. Oscillation angles during lowering.

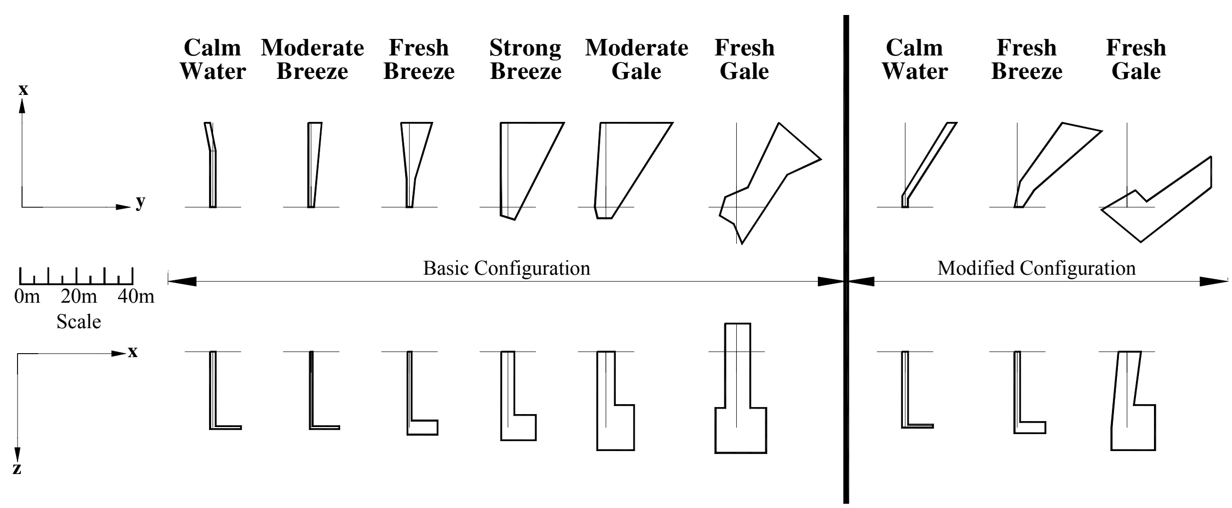


Figure 23. Path envelopes of all the tests: Plan view along top shows the envelope of the sail-away phase. Outboard profile view along bottom shows the envelope of both the lowering and sail-away phases.

**Utility of Performance Measures**

One of the key aims of this work is to explore possible performance measures, an aim motivated in part by the move away from prescribed specification standards and toward goal-setting regimes by both the shipping and offshore petroleum industries and their regulators. Under a goal-setting environment, the duty holder is given the opportunity and responsibility to achieve or exceed broadly stated goals, or expectations. The goals, and sometimes the means of achieving the goals, may be restated by the duty holder in terms of more specific performance targets. How these targets are reached in practice is a matter of concern.

In the present context, a reasonable goal might be stated as follows: 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. The preceding is our restatement as a goal of some of the findings of the Royal Commission on the *Ocean Ranger* Marine Disaster (1985). One might formulate a similar statement based on Cullen's inquiry (1990).

Many engineering and operational issues are covered by codes of practice, guidelines, or other accepted norms. In these circumstances, the goal-setting regime affords some flexibility to the stakeholders, including a mechanism to facilitate the incorporation of changes in best industry practice without the delays associated with explicit changes in legislation.

The absence of acceptable standards of performance, or performance benchmarks, becomes more problematic under a goal-setting regime because the absence must be addressed, or managed in some way. Recognition of and appropriate response to this responsibility is critical to the success of implementing goal-setting regulatory regimes, whether in the offshore petroleum or shipping industries.

To address this, we have considered several possible measures of performance for an evacuation system and reported eleven of these that appear to have some potential practical utility. Some of the eleven can be interpreted alone, others have to be considered in combination. The measures are listed in Table 2 below. There are other things that could have been included, but were not treated in these tests, such as the speed of deployment and the loads in the cables.

It is not the intention of our research to set performance criteria. Rather, our intention is to provide some means by which decision makers can reasonably and defensibly judge various options based on the regulatory goals and performance standards that obtain in a given context.

Table 2. Measures of performance.

| item | Description of performance measure |
|---|---|
| 1 | Time from launch start to splash-down |
| 2 | Time from splash-down to davit release |
| 3 | Time from splash-down to open sea |
| 4 | Path length from splash-down to danger zone boundary |
| 5 | Path length from danger zone to safety zone |
| 6 | Distance from target drop point to splash-down (missed target) |
| 7 | Set back of lifeboat due to oncoming waves |
| 8 | Distance from target to set back (6+7) |
| 9 | Accelerations during sail-away |
| 10 | Deployment excursion cone (oscillations) |
| 11 | Collision avoidance. |

That said, it is worth discussing how useful the measures presented above are. A performance standard might be as simple as a time limit by which evacuation must be complete. This would effectively be the sum of items 1 and 3 above, which encompass the lowering and sail-away phases of evacuation. Such a criterion is useful and might be adequate for the evaluation of a specific system, but if used alone, it would certainly ignore other relevant factors, and might be considered inappropriate or insufficient for comparative purposes. The other time measure, item 2 above, is rather too restrictive, specifying as it does davit release. Further, it is not immediately obvious whether short or long times would constitute "good" times for measure 2.

The next two items in Table 2 are path lengths during sail-away. Both are meant to be measures of the directional control of the lifeboat and both were shown to be useful in this regard, although the definitions of danger and safe zones used above were not ideal.

Items 6 to 8, were found to be both important and practical. Item 6 is a measure of how in control the launch system is in terms of its delivery to the water. The closer the splash-down point is to the target drop point, the more in control is the launch system. Item 7 – the set back of the lifeboat due to its first wave encounter (or until it begins to make way) – is a measure of how well the evacuation system can make way immediately after splash-down. Both 6 and 7 and their vector sum, (which is item 8), have a strong influence on collision avoidance after splash-down.

At this point it is useful to consider some modifications to the definitions of the performance measures, which is done here with reference to Figures 24 and 25.

A *danger zone* should be an exclusion zone. That is, the lifeboat should never enter it at or after splash-down. The distance from the installation to the danger zone boundary is the *exclusion distance*, the size of which might possibly be defined as the buffer needed to accommodate launching in damaged conditions, as illustrated in Figure 25.

The *splash-down zone* centers on the target launch point and is circumscribed by a boundary defined by the larger of the missed target measure (item 6) and the measure that combines the missed target and set back (item 8), as depicted in Figure 24 by points A and B respectively. The *drop target* is the position of the planned launch relative to the installation. It is located by putting the splash zone boundary tangent to the danger zone boundary. Together, the danger zone and splash-down zone are arranged to prevent collisions between the TEMPSC and the platform.

Some distance away from the installation may be considered "safe" for rescue operations. The region beyond this is the *rescue zone*. It is not clear how this should be delineated, but it might be the closest distance to the installation that a stand by vessel can come in an emergency situation, for example. The region between the danger and rescue zone boundaries is the *clearing zone*.

We can imagine that the planned splash-down zone will grow as the weather conditions in which evacuation is a planned contingency worsen. If there is an upper weather limit for planned evacuation by lifeboat (perhaps defined by the lifeboat seaworthiness, or some other limiting factors), then it would also define the splash-down zone size limit and thereby define the drop target position relative to the installation. This in turn sets the clearance requirement for the evacuation system's configuration. In this example, system capabilities as defined in terms of performance measures have been translated into a specific, rational design requirement.

Returning to Table 2, the next measure in the list is item 9, the acceleration during sail-away, which has nothing to do with the evacuation system. It depends on the weather conditions and the lifeboat's seaworthiness, for which it is a proxy measure. Acceleration can also be used to gauge human performance in terms of the likelihood of injury (e.g. Brinkley 1985) and seasickness (Landolt *et al.* 1992, Lawther & Griffin 1987). In the tests reported here, only lateral acceleration was measured; accelerations in all three components would be more useful.

Similarly, the oscillation angles during lowering (item 10) is a proxy measure of the evacuation system's control during lowering (see Figure 26). Accelerations might equally well fill this role, although it was not used in the present tests. As the missed target measure is also a measure of the evacuation system's ability to control the lowering process (at least at the end of the process), it might be argued that another measure is unnecessary, or redundant. However, neither accelerations nor oscillation angles (which are admittedly specific to suspended falls systems) are redundant, but rather are complementary to the splash-down measure of control. Further, both are relevant to the final item on the list, collision avoidance, which is discussed in more detail below under modeling issues.

In addition to the individual measures above, an overall performance indicator, or index, that captured the strengths and weaknesses of an evacuation system could be useful. A performance index might consist of a group of performance measures. The relative importance of specific performance measures might be reflected in the index by a weighting scheme of some sort, although further pursuit of this idea is beyond the scope of this paper.

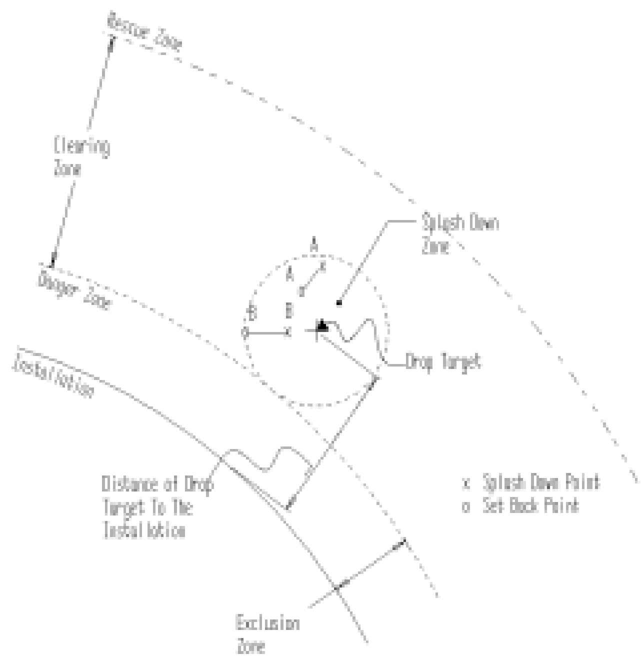


Figure 24. Modified performance zones and measures.

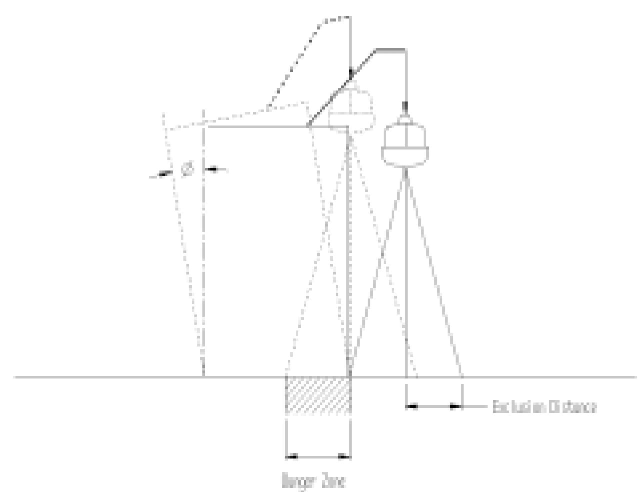


Figure 25. Buffer for launch in damaged conditions.

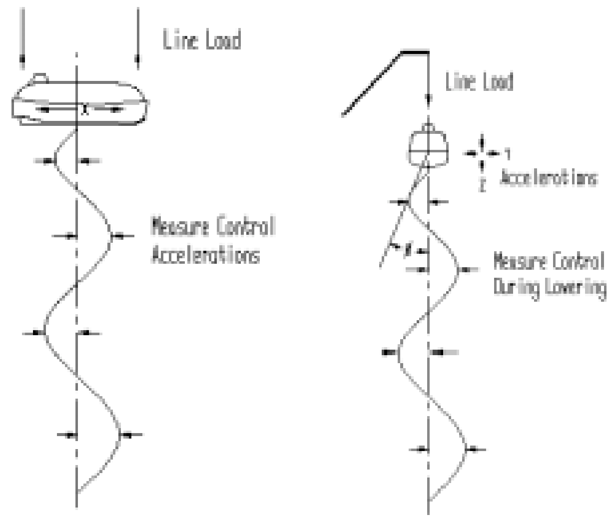


Figure 26. Measures of control during lowering.

**Modeling Issues**

One of the most anticipated events during the testing was collision between the lifeboat and platform. Prior to testing, there was concern that collisions might occur during lowering, due to pendulum oscillations of the TEMPSC, or after splash-down, due to wave set back or excessive drift. The latter was a particular concern as the clearance at launch deployment between the TEMPSC and the platform was only 1.5 times the lifeboat's beam. There were no collisions between the TEMPSC and platform in any tests.

This is a remarkable result and warrants further discussion. After splash-down, the waves reflected by the FPSO helped to reduce the likelihood of collision. In addition to reflected waves, the FPSO generated its own waves during large amplitude motions. These radiated waves may also have contributed to the absence of collisions.

Another factor relates to the type of waves used in the tests. The large amplitude waves generated in the model basin for these tests were less steep than one might expect to see in nature. This is particularly relevant for heavier weather, say above Beaufort 7, where breaking waves would be expected to occur. There were no breaking waves in the experiments. Breaking waves would constitute a greater danger to a lifeboat than regular waves of the same nominal amplitude. The greater danger is in the form of more excessive motions, loss of steerage and drift, capsizing, and wave impacts. Wave steepness effects could be considered more closely in future tests.

The probability of collisions might be expected to increase when lifeboats are launched from a damaged installation, particularly if deployments were from the high side of an inclined platform. Launching in damaged conditions was not investigated in the tests reported here, although as mentioned above, it might help define the exclusion zone around an installation.

## CONCLUSIONS

The work presented above has three main concerns: to evaluate lifeboat evacuation capabilities as a function of weather conditions; to evaluate the use of model testing as a tool for such safety studies; and to explore performance measures and examine their practical utility in the context of performance standards and goal-based regulations.

As further systematic experiments are envisioned in this research program, the focus of the conclusions below is on identifying where improvements might be made.

The model experiment program was carried out using an FPSO as a platform from which evacuation by lifeboat was tested. A total of 153 launches were made using two evacuation systems: a conventional twin falls davit launched TEMPSC, and the same system with the addition of a flexible boom. Both systems were tested in a range of weather conditions between calm and Beaufort 8. The performance of the evacuation systems was found to deteriorate as weather conditions worsened.

Several measures of performance were proposed and these were used to quantify the relationship between weather and the evacuation system's capabilities. Discussion of their practical use in a goal based regulatory regime lead to some refinements to the definitions, which could be useful in future work. In addition, a safety index that combined various individual performance measures in a weighted sum was discussed as being a potentially useful means to summarize overall launch system capabilities.

Model tests proved to be a suitable tool for the investigation. Indeed, where extreme weather events are of interest, model testing offers a reliable and safe means of performance evaluation. Several modeling issues were raised in the course of the work, specifically relating to the effects of wave steepness, and the relationship between set back and the drop point on the wave. The former could be investigated in future experiments; more insight into the latter might be gained from a closer look at the current test data and statistics. The test program did not include launches from the installation in any damaged conditions, which wold be worthwhile to consider in future. The motions of the platform were found to have a major influence on the motion of the TEMPSC during launching and while the analysis still showed clear trends in many of the proposed performance measures, it would be easier to discern launch system effects from platform effects if the platform was fixed, rather than floating. To this list of modeling issues can be added scale effects, which are always a concern in experimental modeling.

## ACKNOWLEDGEMENTS

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