Evacuating offshore structures

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“Evacuating Offshore Structures”

by

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1.0 INTRODUCTION

In the past two decades, offshore technology has advanced quickly, allowing operators to move into more challenging areas of exploration. Over the same period the number of lives lost on offshore platforms has increased dramatically, with most lives lost in emergency situations requiring evacuation.

The problems of safe evacuation of offshore personnel in high winds, poor visibility and rough seas were high-lighted with the capsizing of the accommodation rig Alexander Kielland, the explosion of the Piper Alpha platform and the sinking of the semisubmersible drilling unit Ocean Ranger.

A study designed to improve the understanding of the behaviour of offshore evacuation was conducted at the Institute for Marine Dynamics (IMD) during August and September 1996. Four evacuation systems, approved by the Canadian Coast Guard, (Davit, PrOD, Seascape and Freefall) were used to deploy a Motor Propelled Survival Craft (TEMPSC) from a semisubmersible rig in even keel, damage and extreme damage conditions. The objective of the study was to evaluate the smoothness of delivery of the TEMPSC to the water, the ability of the evacuation systems to work when the semisubmersible was in a damaged condition, and the ability of the TEMPSC to sail away from the rig area.

The aim of the study was to provide operators and regulators with a rational basis for comparison between systems thus, allowing for more realistic cost/risk tradeoff analysis.

2.0 PROJECT OBJECTIVE AND BENEFITS

The objective of the study was to provide a direct comparison between semisubmersible platform offshore evacuation systems, in which all the parameters were common except the means of launching the TEMPSC.

The most appropriate way to achieve this objective was:

- To develop a physical model test programme that used seastate, wind, wave direction, platform heel and trim angle as programme variables.
- To use the experimental results to observe the relative merits and weakness of the four offshore evacuation systems selected.

The benefits expected from conducting the comparative study were:

- An improved non-proprietary database upon which decisions concerning the choice of evacuation systems could be formulated.
- An understanding of offshore evacuation systems which may lead to further improvements.
- A physical model database suitable for validation of theoretical and numerical models.

3.0 SYSTEM EVALUATION CRITERIA

In order to evaluate the effectiveness of the evacuation systems the following criteria were proposed:

i. Relative smoothness of delivery of the TEMPSC to the water surface.

ii. Ability of the system to operate when the semisubmersible rig is in a damage condition.

iii. How the delivery system affected the ability of the TEMPSC to sail away from the rig area.

The following experiments and measurements were designed to compare the systems on these criteria:

<u>Experiments:</u>

a) Deployment from the semisubmersible in an even keel condition at two wave headings (i.e. head and quartering seas) with two regular waves.

b) Deployment from the semisubmersible with a combined angle of trim and heel of 15^{o}, damage condition, into two wave headings with two regular waves.

c) Deployment from the semisubmersible with a combined angle of trim and heel of 20^{o}, extreme damage condition, into quartering seas with one regular wave.

<u>Measurements:</u>

a) <u>Deployment Phase</u>: X-Y-Z motion of the TEMPSC, from the start of lowering to contact with the water surface.

b) Sail Away Phase: X-Y-Z motion of the TEMPSC, from contact with the water surface to within two wave periods.

c) Average speeds for the sail away phase.

4.0 PHYSICAL MODELS

Representative physical models (i.e. models that accurately predict one or more characteristics of the prototypes but not all of the characteristics) of the different components were, manufactured at a scale of 1:15. In the following sections a description of the semisubmersible unit, the Totally Enclosed Motor Propelled Survival Craft (TEMPSC) and deployment systems is presented.

4.1 Semisubmersible

The scale model designed and constructed for the study, M489, was a generic semisubmersible unit with geometrical and mass properties most similar to the semisubmersible drilling unit GVA 4000, of Gotaverken Arendal AB, Gothenberg, Sweden.

The change in semisubmersible condition from even keel to extreme damage (i.e. rig with a combined heel and trim angle of nominally 20^{o}) was attainable by flooding the aft starboard column with water. The semisubmersible model was of all welded steel construction. The pontoons were pressure tested to insure against leaks.

Each pontoon was fitted with permanent ballast, placed on the bottom along the centre line of the pontoon, and distributed fore and aft of the longitudinal centre of the pontoon. A mechanized ballast adjustment system was installed in each column to allow for the placement and vertical adjustment of ballast weights. The deck was fitted with ballast weights and trimming weights were added and placed on the top of the deck covers.

The ballasted model, floating at a full scale equivalent draft of 20.5 m, was allowed to float freely in still water. Even keel was achieved by adjusting the deck trimming weights. An inclining experiment was performed to determine the transverse metacentric height (GM) of the unmoored semisubmersible model.

Natural periods of pitch and roll were measured for the semisubmersible model at even keel in both the unmoored and moored conditions. Heave natural periods were obtained for the model in the moored condition.

The semisubmersible model was moored in the Offshore Engineering Basin (OEB) in a water depth of 3.0 m, using a system that provided horizontal restoring forces only. In the 0^{o} heading (i.e. head seas) a four point mooring was used. Wire ropes were attached at the fairlead locations and extended horizontally from each column to the pulley locations on the basin walls. The wire ropes were turned around pulleys, and attached to springs. From the other end of the springs, wire rope extended vertically towards ceiling-mounted pulleys and then down towards the basin floor. Prior to testing the system was pretensioned and then restrained.

In the 45 ^{o} heading (i.e. quartering seas) the model mooring arrangement was somewhat different. From the forward port column and aft starboard column two wire ropes were extended from the fairlead locations to the wall-mounted pulleys. This method was used so that the ceiling-mounted pulleys used for the 0^{o} heading conditions could be utilized, thus reducing setup time between headings.

Static offset tests were carried out for the two mooring configurations and semisubmersible trim conditions (i.e. even keel and damage). The tests were performed to determine the global stiffness of the system.

Instrumentation on the model measured six-degrees-of-motion, wind speed and mooring line loads.

4.2 Totally Enclosed Motor Propelled Survival Craft (TEMPSC)

In the majority of marine situations, open lifeboats and more recently, Totally Enclosed Motor Propelled Survival Craft (TEMPS) are the principal means of evacuation.

In this study, two designs of TEMPSC with a occupant capacity of 50 persons were selected. The first was based on a general purpose TEMPSC and used with three of the evacuation systems, namely, Davit, PrOD and Seascape, while the second was based on a generic Freefall TEMPSC and was used with the Freefall evacuation system.

4.2.1 Conventional

The conventional TEMPSC model, M489A, was adapted from a 50-person Watercraft design. The baseline TEMPSC model was fitted with a twin falls release mechanism. For the PrOD System, an extra tagline hook bolted on to the bow of the TEMPSC forward of the release mechanism. The model was adapted for use with the Seascape system by inserting a tubular support in the canopy at the longitudinal centre of gravity (LCG). The loading remained approximately the same for all conditions.

The model was fabricated from Glass Reinforced Plastic (GRP) in two halves, canopy and hull. The canopy and hull mated along the gunwale with a rubberized gasket between to prevent water damage to instrumentation.

The hull portion of the model was fitted with a working rudder, a rudder servo, a three blade propeller, a DC motor, a motor controller, a receiver unit and a dry cell battery pack. The canopy half was fitted with the control boards for the release mechanism, and two solenoids connected to mechanical linkages to activate the forward and aft releases. Two waterproof toggle switches were fitted to the aft end of the canopy and six reflective hemispheres were glued to the outside of the canopy for use with the optical tracking system, Qualisys.

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

4.2.2 Freefall

The design of the Freefall TEMPSC model, M489B, was conceptualized from Harding and Verhoef brochures for freefall lifeboats and adapted for a 50-person capacity.

The freefall model was fabricated from Glass Reinforced Plastic (GRP) also in two halves, canopy and hull. The canopy and hull mated along an elevated gunwale with a rubberized gasket between to prevent water damage to the instrumentation. A rub rail was added to the model to prevent it from moving in the launch skid.

The hull portion of the model was fitted with a working rudder, a rudder servo, a three blade propeller, a DC motor, a motor controller, a receiver unit and a dry cell battery pack, and some ballast weights. No instrumentation or ballast weights were placed in the canopy half. One waterproof toggle switch was fitted to the aft end of the canopy. Six reflective hemispheres were glued to the outside of the canopy for use with the optical tracking system, Qualisys.

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

4.3 Deployment Systems

Emergency evacuation of personnel from offshore rigs/platforms can be classed into three general categories: dry, semi-wet, and wet systems.

Dry systems are associated with the emergency evacuation of personnel from a stricken platform to shore or to a temporary safe haven. They are the preferred method of evacuation in ideal conditions, however, they place total reliance on rescue crafts that are not under control of the people being rescued.

Whether the transfer is via helicopter, cable car, or articulated walkways to standby vessels, the weather conditions (i.e. wind, waves, visibility, icing), the presence of combustible gas and fire, and the motions at the platform, may impede the successful use of any of these systems.

Semi-wet systems are the primary method of offshore emergency transfer of personnel when dry systems are either unavailable or cannot be used due to weather, etc.. These systems are characterized by two components, namely, the evacuation craft and the system that launches it. Present-day systems use a combination of rigid and inflatable craft, which are gravity lowered or allowed to freefall to the surface of the water.

Wet systems, thermal immersion suits and floatation devices, are those associated with the evacuation of individuals directly into the ocean and are considered a last resort. In many cases these systems by themselves are perceived as being riskier than remaining on the unit being evacuated.

This study deals only with semi-wet systems in which rigid, totally enclosed motor propelled survival craft (TEMPSC) are either gravity lowered or freefall to the ocean surface. The systems selected for comparison are described briefly as follows:

4.3.1 Davit

The Davit system used in the present study was of the straight fall double wire category with the TEMPSC stowed perpendicular to the edge of the semisubmersible rig alongside a cantilevered platform.

The modelled components of the Davit system are the winch brake which controls the speed of descent, the release mechanism which disengages the falls, and the cables. The systems were adequately modelled, but no attempt was made to model the cable properties. However, cable length was modelled so that the TEMPSC could reach the water surface with the platform in a combined trim and heel angle of up to 20^{o} and in an unfavourable condition.

The rate of descent of the TEMPSC was modelled by programming a DC motor controller to spool out cable in the two drums at a full scale rate of 65 m/min - Reference 2 (1983 Amendments to SOLAS 1974, Volume I).

The ends of the cables were fitted with swivels which fitted into sliding pins in release blocks located at the bow and stern of the TEMPSC model. The pins of the release blocks were linked to solenoids fitted to the inside of the lifeboat model and activated from shore by a radio controller, adapted from a commercial garage door opener.

The release mechanisms were modelled as a simple positive release, as it was not possible to directly model, “Off-Load”, “On-Load” or “On-Load with hydrostatic interlock” systems.

The release of the forward and aft cables was intended to be simultaneous, with the exception of a few selected deployments in which the forward cable was released first and some 15-20 seconds (full scale) later the aft cable released. These cases were selected to approximate some known problems with release of such mechanisms.

4.3.2 Preferred Orientation and Displacement (PrOD)

The PrOD system consisted of an approximately 31 m (full scale) flexible boom held by a saddle support and a set of hinges attached to a base plate mounted along the centreline at the end of the TEMPSC evacuation station platform. The hinges had a horizontal axis which allowed the boom to move in a vertical plane with a swing of about 90^{o}. The boom was approximately the same length as the vertical distance from the TEMPSC launch station to the water surface at the semisubmersible’s light-ship draft (i.e. from the top of the deck to the top of the pontoons). The boom support was provided at the hinge by a spring and in its launching position, the boom rested at an angle of 45^{o}.

A fixed length of line,(the tagline) approximately equal to the boom length, attached at one end to the tip of the boom and at the other to a metal ring. In a deployment, as the TEMPSC was lowered by its regular launch cables, tension was generated in the tagline, causing the boom to bend like a large fishing rod until the falls were released. The TEMPSC was then pulled through the water by the tagline, away from the semisubmersible, and as it passed under the end of the boom it released.

It is important to note that, during a deployment and before release at the water surface, the tagline caused the TEMPSC to move about half to one boat length from the vertical, and the boom to bend approximately one boat height. Also, at no time is the PrOD boom supposed to support the weight of the TEMPSC. These observations were similar to those in Reference 3 (PrOD Evacuation System 1987).

PrOD boom stiffness reported in Reference 3 was modelled by selecting a model boom that had a tip deflection approximately equal to a boat height for a predetermined load of about 1 tonne (full scale).

The rate of descent of the TEMPSC was modelled by programming the DC motor controller to spool out cable in the two drums at a full scale rate of 46.5 m/min, which represented an average of all the deployment speeds reported in Reference 3. A few deployments were performed with a rate of descent equal to that used in the Davit system.

The falls and lifeboat release mechanisms were the same for the Davit and PrOD systems. As mentioned earlier, the release mechanisms did not directly model, “Off-Load”, “On-Load” or “On-Load with hydrostatic interlock” systems.

4.3.3 Seascape

The Seascape deployment system consisted of an evacuation platform at deck height and a rotating arm 34.8 m long (full scale). The arm pivoted on two pins mounted on the semisubmersible’s cross member. The model deployment arm was an “A” frame manufactured from tubular aluminum with a mass to buoyancy ratio of 1.4:1 (Reference 4). At the hinge the frame had a width of 12.7 m while at the top its width was 3.4 m. At the top was a yoke, where the lifeboat, fitted with a horizontal tubular member rested. The attachment points for the lowering cable were located 4.95 m from the top of the arm.

The lowering and raising of the arm was controlled by a DC motor controller which spooled out cable from a single drum. The motor controller and drum were mounted on the evacuation platform. The lowering rate was set at 150 m/min (Reference 4).

All aspects of the Seascape system were modelled except for the cable stiffness and the acceleration at start of deployment. The latter induced a small rocking motion on the lifeboat as it started the descent towards the water surface.

The conventional 50-person model TEMPSC, modified to accommodate the tubular support and fitted with the reflective hemispheres, propulsion and manoeuvring instrumentation, was used as the deployment craft.

4.3.4 Freefall

The freefall system consisted of a launch ramp, inclined at an angle of 35^{o} in relation to the horizontal, (for the rig at even keel) attached to the forward end of the semisubmersible and a generic freefall lifeboat.

The launch ramp was 15 m long (full scale) and had bottom and side support rollers fitted to it. Both sets of rollers were equally spaced along the launch ramp with one at the start and one at the end.

The freefall TEMPSC was positioned in the launch ramp so that it had a launch offset of 3.1 m, a distance from the forward end of the ramp to its centre of gravity of

6.5 m, and a freefall height to the water surface of 14.9 m (for the rig at the level operating draft).

A swivel was fitted to the aft end of the lifeboat model near the ON-OFF power switch and the launch ramp was fitted with a release mechanism (solenoid activated linkage).

Some aspects of the freefall system, such as skid friction, release mechanisms, etc. were not modelled, however, the length of the ramp and its position were.

5.0 ENVIRONMENTAL MODELS

The Institute for Marine Dynamics (IMD) Offshore Engineering Basin (OEB) has a nominal working area of 65 × 26 m with a working depth of up to 3.5 m. The basin is fitted with 168 individual wavemaker segments, hydraulically activated and distributed in an "L" shape around its perimeter. The wavemakers are capable of generating multi-directional irregular waves of 0.5 m significant wave height.

The environments of waves and wind were calibrated separately. Conditions requiring simulation of both were achieved by generating the two individually calibrated environments simultaneously in the basin.

5.1 Regular Waves

The test programme on the comparison of offshore evacuation systems required the generation of two regular waves. The waves were modelled in terms of wave height and period and were calibrated prior to the test programme without the model installed. For each calibrated wave, a segment of 20 cycles was chosen to evaluate wave parameters. The 20-cycle segment was selected by windowing through the entire time trace.

5.2 Wind

Wind was simulated using a horizontal array of 12 analog-controlled fans mounted on support frames positioned ahead the west wall wavemakers. Each fan, with a blade diameter of 530 mm, was powered by a DC motor, capable of rotating at speeds of up to 5000 rpm.

The wind was modelled in terms of mean speed and was calibrated prior to the test programme without the model installed. The fans were run at steady speed so that the full scale mean wind speed was 30 knots at a height above the water surface of 10m.

6.0 EXPERIMENTAL STUDY

6.1 Experimental Setup

All the experiments described in this report were conducted in the Offshore Engineering Basin (OEB) at the Institute for Marine Dynamics (IMD) in St. John's, Newfoundland. The 1:15 scale semisubmersible rig model was installed on the basin's centre line approximately 9.5 m from the mean position of the wavemakers in a water depth of 3.0 m (model scale). The mooring lines were connected to the model at the fairlead location and then pretensioned and clamped. The individual deployment systems were then installed, one at the time, on the forward end of the deck between columns 1 and 2.

The test matrix is given in Table 6.1 indicating combinations of semisubmersible ballast conditions, semisubmersible orientation, wave height and period. In addition to the tests identified in the test matrix, static offset, decay tests, and TEMPSC speed tests were also conducted.

6.2 Instrumentation

The instrumentation package used during the experiments consisted of the following:

- two capacitance type wave probes,
- two anemometers,
- a system of eight accelerometers,
- one load cell per mooring line (total of 4)
- Qualisys optical motion measurement system

The waves and wind were measured using the wave probes, and the anemometers. Wave probes were placed, one forward, the other in line with the midships of the semisubmersible model at rest, while the anemometers were located, one upwind and the other at the forward end of the semisubmersible model.

Accelerations of the semisubmersible model in six degrees of freedom were measured by a system of eight accelerometers (four vertical and four horizontal, mounted at the corners of the rig at lower deck level). The semisubmersible model displacements were determined by integrating the measured accelerations.

Mooring loads were measured at the fairlead by waterproofed S-type load cells.

The Qualisys optical motion measurement system, composed of two Qualisys position sensors and video processors, was used together with an IMD computer running in-house software to track the X-Y-Z position of the TEMPSC, conventional and freefall. Six reflective hemispheres were attached to the canopies of the TEMPSC models.

To convert the image coordinates to TEMPSC global X-Y-Z position, the information from the two cameras, was processed by solving the photogrammetric equations for each marker's x-y-z coordinates. These data were then transformed into global X-Y-Z position for the lifeboat models.

6.3 Test Programme and Procedures

The comparative study of offshore evacuation systems was conducted in two regular waves, two orientations (head and quartering seas) and in level, damage, and extreme damage conditions. The waves, labeled, wave 1 and 2, had periods of 8 and 11.5 seconds and heights (double amplitude) of 7 and 10 metres, respectively. Damage and extreme damage conditions were defined as loss of buoyancy in one column, and were modelled by flooding one column. The combined angle of trim and heel was checked with a digital inclinometer along the model's diagonal. To produce the two angles, damage 15^o and extreme damage 20^o, approximately 500 and 1275 tonnes of water (full scale), respectively, were added to the aft starboard column. The added water inclined the semisubmersible model away from the waves.

The procedure employed for conducting the experiments identified in the test matrix (Table 6.1) is described below:

1) The moored semisubmersible rig was ballasted and oriented according to the test matrix.

2) The TEMPSC was fitted to the particular deployment system and the instrumentation turned ON.

3) The data acquisition was started, followed by wind machine and then by the wavemakers. A transition period of 45 seconds was established to allow the semisubmersible model to reach steady state. During the transition period the video recording system was activated. After the initial 45 seconds the deployment, release and manoeuvring commands were given. Just prior to splashdown the release and propulsion systems of the TEMPSC were activated via remote transmitters. All deployments were of a random nature and no attempt was made to launch the TEMPSC in any one particular area of the wave.

4) After the TEMPSC model cleared the splash-down area and was manoeuvred away from the semisubmersible, the wavemakers and the wind machine were stopped and the run considered complete.

5) After a few minutes the tank staff prepared for the next run. The time between runs was set at 15 minutes.

Each run was repeated at least once. Also, a successful run was defined as one in which a clean deployment took place. This criteria was necessary due to the technical problems associated with the release mechanisms (e.g. no release, premature release, etc.) used in both the Davit and PrOD evacuation systems. All data were sampled at 50 Hz.

6.4 Data Analysis and Techniques

The data analysis techniques were divided into three basic categories, namely, on-line, detailed and video analysis.

On-line analysis was performed during the test program to ensure that all the instrumentation was working properly. This type of analysis generated time series, statistical summaries and power spectra for examination.

The detailed analysis was used to determine average water entry speeds, average move away speed, X-Y-Z position of the TEMPSC models during and after deployment, motions of the semisubmersible model just prior to and during two incoming wave periods.

The semisubmersible motions at the lifeboat station were reduced to response amplitude operators (RAO) obtained from the double amplitude of motion divided by the wave height.

The video analysis consisted of examining each individual run at a slower than recorded speed to identify possible areas of concern with the individual systems. The analysis concentrated on areas such as the movement of the TEMPSC during the descent (e.g. pendulum effect, surge, rocking motions, etc.) the effectiveness and smoothness of the deployment to the water surface, the path of the TEMPSC just after splashdown and for at least two wave periods. The video analysis was also useful in the explanation of some of the detailed analysis results.

7.0 INDIVIDUAL SYSTEMS PERFORMANCES

The following observations are based on the analysis of the optical tracking systems(i.e. Qualisys) and video data.

A. Davit Evacuation System

The straight-fall Davit system deployment of the TEMPSC was not affected by the semisubmersible's ballast conditions and orientation changes in calm water. The system delivered the TEMPSC smoothly to the water surface and it got away easily after splash-down.

The semisubmersible's ballast and orientation greatly affected the effectiveness of the TEMPSC deployment in wind and waves. Generally speaking, the TEMPSC tended to get trapped in the column turbulence and was subjected to extreme pitch and roll motions. Occasionally, the TEMPSC was swept underneath the semisubmersible unit.

During descent, the motions of the semisubmersible caused the TEMPSC to oscillate as a pendulum. The deployment was heavily influenced by the splash-down point, and the success or failure of the deployment depended in what portion of the wave the TEMPSC was deployed. Trough and upslope splash-down resulted in deployment problems while crest and downslope deployments usually resulted in successful launches.

B. Preferred Orientation and Displacement Evacuation System (PrOD)

The PrOD calm water deployments were not affected by the semisubmersible's orientation, however, the ballast condition change from level through extreme damage had an affect. The tagline release became harder as the semisubmersible's angle of inclination increased to the point of no release at the combined angle of trim and heel of 20^o (i.e. extreme damage condition). It is important to note that the PrOD boom was not intended to support the weight of the TEMPSC, however, from the first to the last deployment it was seen that some degree of support was being provided by the boom (i.e. bow up angle). The effect of boom support became more obvious as the conditions of the semisubmersible were changed from level to damage and then to extreme damage. We believe this may be a modelling problem caused by excessive stiffness in the model boom for large deflections.

In wind and waves, the tagline reduced the TEMPSC pendulum motions during descent and pulled the TEMPSC away from the semisubmersible. Even in situations were the release of the falls was not ideal the tagline performed its job and pulled the TEMPSC away. The no-release problem experienced in calm water extreme damage condition was not present in the wind and waves.

The splash-down point on the wave did not have an influence on the success or failure of the deployment.

C. Seascape Evacuation System

The Seascape system performed well in calm water and the orientation of the semisubmersible did not affected the deployments. At the beginning of deployment, the TEMPSC experienced a small rocking motion induced by the winch at startup. At splash-down, the TEMPSC slight bow down angle provided for a cleaner get-away phase.

The motions of the semisubmersible did not affect the deployment, however, the orientation had a small affect. The A-frame remained visible longer after splash-down during the quartering seas than in the head seas case. The larger waves had a similar effect on the A-frame, manifested by the slacking of the deployment cable. The combination of orientation and wave indicated that the mass to buoyancy ratio of the modelled A-frame may be too small.

The ballast condition influenced the TEMPSC deployment. Analysis of video records showed that, in damage condition, at the start of cable payout the A-frame did not move, and that after a small period of time the frame lurched forward inducing a small rocking motion to the TEMPSC. The situation was attributed to the angle of the semisubmersible in damage condition which oriented the A-frame in a near vertical angle, placing the frame's centre of gravity directly above the hinge.

D. Freefall Evacuation System

The calm water freefall system delivery of the TEMPSC to the water surface was influenced by the semisubmersible's orientation change when in damage condition. The orientation change in damage condition increased the roll motion at the TEMPSC emergence after the initial splash-down. Similar observations were made for the wind and wave conditions.

The TEMPSC splash-down and subsequent emergence were not affected, to the same extent, by the portion of the wave on which it was deployed. However, an upslope deployment was not as smooth and clean as the others.

The freefall TEMPSC was developed from information found in the open literature and the main parameters are slightly outside those of the Harding and Verhoef designs. Also, a slight ballast change was made giving the TEMPSC a trim by stern. The new condition allowed the TEMPSC to maintain forward motion while under water. The size and surface finish of the TEMPSC contributed to the observed scale effects during water entry.

Overall the system performed well and the TEMPSC got away cleanly.

8.0 GENERAL OBSERVATIONS AND RECOMMENDATIONS

The present study documents the influence of wind and wave and the semisubmersible's ballast and orientation conditions on the ability of the four evacuation systems to deliver the TEMPSC to the water surface and its ability to sail away.

This section is structured to address general observations and recommendations on the overall study, followed by the study's recommendations.

8.1 General Observations

1. A total of 118 deployments were planned but due to technical problems and an expanded test programme a total of 182 deployments were performed.
2. All the deployments in wind and waves were performed on a random basis, without effort to deploy the TEMPSC on one particular section of the incoming wave (i.e. wave crest, trough, up or downslope).

In future work special care must be taken to ensure that all the deployments are in the same area of the wave. This will facilitate the comparison process. Also, the number of deployments per condition should be increased to numbers which will permit statistical analysis.

3. The semisubmersible model was similar in geometry and mass properties to existing prototype and provided six degrees-of-freedom responses for two regular waves at level, damage and extreme damage conditions for 0^o and 45^o headings.
4. A good overall agreement was observed between the semisubermsible's response amplitude operators obtained in the study and published ones.
5. The unusual mooring configuration used in the 45^o heading had some degree of influence on the semisubmersible's motions. The mooring arrangement was a compromise brought up by time and setup constraints. It would be advisable in future work to maintain the mooring characteristics for all the conditions tested. This will make comparisons easier.
6. The conventional and freefall TEMPSCs were on the small side from an instrumentation layout and modelling point of views, respectively. In the conventional TEMPSC the size made it impossible to adjust any ballast, while in the freefall TEMPSC, the size might have been responsible for some scale effects. A small change in ballast distribution was necessary to ensure the freefall TEMPSC had a forward motion while submerged. In future studies larger TEMPSC models should be used. Also, it may be advisable to increase the roughness of the models surface in order to minimize viscous effects.
7. The Davit and PrOD release mechanisms were not model versions of any existing in the market. The activation of the release mechanisms was made via

a radio controller which in turn powered up solenoids. The system was inefficient and at times required several attempts to work properly.

It is recommended that in future studies the release mechanism be more representative of the ones used in industry. Also, the triggering of the mechanisms must be performed on a more reliable manner. This may be accomplished by using a higher quality radio control system such as the one used in the TEMPSC propulsion and steering systems.

8. The four offshore evacuation systems were adequately modelled, but not all of their individual components were. The information on the systems was obtained from the open literature due to the lack of response from the systems' manufactures. The one exception was the Seascape System for which all the modelling information required was provided by company.

It is recommended that in future studies, more effort be put in getting the collaboration of the different systems manufacturers. This will lead to a more comprehensive database which can provide designers, operators and regulatory agencies with tools to formulate decisions concerning the choice of evacuation systems.

9. The deployment cables (i.e. steel wire) were too stiff, causing them to unwrap from the drums after TEMPSC splash-down.

It is recommended that wires not be used, and that the stiffness of the deployment cables be modelled by thin ropes.

10. The PrOD boom induced a bowup angle to the TEMPSC during deployment, which increased as the inclination angle of the semisubmersible increased. This suggests that the model boom had a higher stiffness than the prototype.

Proper boom characteristics will be necessary in future studies. It is suggested that the builders of the boom be involved and develop the model boom.

11. The winch payout rates for the different systems were accurately modelled, however, the ramp up and down were not. It is recommended that better winch control be provided, especially at startup.

12. No attempt was made to properly model the ramp system friction in the freefall evacuation system.

13. For the most part the instrumentation worked reasonably well, however the optical tracking system (i.e. Qualisys) effectiveness decreased considerably as the semisubmersible's orientation and attitude changed. In future studies larger models will alleviate some of these problems, however, a secondary

system, must be available. Also, future work should include the measurement of accelerations in the model.

14. The speed of the TEMPSC was modelled. However, it would be better in the future to model the thrust available rather than the speed. This may lead to new information in the get-away phase of the deployment.
15. The average get-way speed of the conventional and freefall TEMPSCs was not greatly affected by either the orientation and/or the inclination of the semisubmersible. On average, the sail-away speed was between five and six knots.

8.2 Recommendations

1. Designers, operators and regulatory agencies should consider combining their efforts in order to create non-proprietary databases from which evacuation systems could be selected with some degree of confidence.
2. Future work on the effects of different semisubmersible orientations and inclinations other than those studied should be carried out. The number of deployments should be increased so statistical data manipulation may be used.
3. Work in areas dealing with the presence of ice could be included in future work.
4. Work with larger scale models should be considered in order to be able to model more details of the different systems, and to measure accelerations, motions and get-away speeds with more confidence.
5. Additional work with physical models can be used as input and/or validation of theoretical and numerical models, which are used in the selection of offshore evacuation systems.
6. Field work should be conducted to validate some of the model and theoretical studies. Also, some of the results may serve as input to further model tests.

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