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Publisher's version / Version de l'éditeur:
https://doi.org/10.4224/8896241
Technical Report (National Research Council of Canada. Institute for Marine Dynamics); no. TR-2000-07, 2002

FPSO EVACUATION SYSTEM PERFORMANCE IN A RANGE OF ENVIRONMENTAL CONDITIONS

TR-2000-07

Prepared for:
Institute for Marine Dynamics

By
The National Research Council Canada
Institute for Marine Dynamics

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October 2000

SUMMARY

This report describes the results of a physical model study aimed at establishing a baseline performance profile of lifeboat evacuation capability as a function of environmental conditions.

The lifeboat evacuation experiments were performed from a Model Floating Production Storage and Offloading (FPSO) vessel, at the Institute for Marine Dynamics (IMD), Offshore Engineering Basin (OEB) during the month of February 2000.

A twin falls davit evacuation system was used to deploy a Totally Enclosed Motor Propelled Survival Craft (TEMPSC) from the FPSO into wave and wind conditions ranging from calm to Beaufort Scale 8. The system was of the straight fall double wire category with the TEMPSC stowed and launched parallel to the hull. A total of 120 deployments were originally projected for the twin falls davit system. The test program was expanded to include a flexible boom assisted launch arrangement. This brought the total number of deployments to over 180.

The FPSO was tested in its ballast, intact condition and was arranged such that it had a 20° heading to the waves and a 57° heading to the wind. The TEMPSC was deployed to the windward side. The model TEMPSC (100% load condition) was launched at random positions with respect to incident waves, and propulsion power was available when the boat hit the water.

Motions of the FPSO had a major effect on the launch and made it difficult to determine the specific effects of weather conditions on launch performance. Since it is evacuation system performance and the effects of configuration parameters, such as height of launch, clearance of TEMPSC at launch, orientation of the TEMPSC at launch, direction of the weather relative to launch, launch point on waves, and others that can be usefully evaluated by systematic model test series, a second phase of testing consisting of launches from a fixed platform are being considered.

Transport Canada, Canada-Newfoundland Offshore Petroleum Board, Offshore Safety and Survival Centre and other provincial government representatives witnessed a small but representative portion of the experiments.

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1.0 INTRODUCTION

This report covers a series of model scale experiments performed on a generic Floating Production and Offloading (FPSO) vessel fitted with a conventional twin fall davit evacuation system. The experiments were aimed at evaluating the performance capability of evacuation system as a function of environmental conditions.

As the offshore oil and gas industry and its regulators move increasingly toward performance, or goal based standards, rather than prescriptive rules, clearly defined performance measures and the means to quantify them become a necessity for assessing and managing safety.

Risk assessment is a design imperative and a regulatory requirement in many jurisdictions, but published quantitative data on lifeboat evacuation are sparse (Spouge 1999), which hampers the design process and attaches uncertainty to any regulatory goals. The results presented in this report help to close the knowledge gap.

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.

These experiments focused on 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. Systematic physical 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).

The experiments were conducted at the Institute for Marine Dynamics (IMD), Offshore Engineering Basin (OEB) during the month of February 2000. The experimental work reported here deals only with the evacuation phase of the Escape-Evacuation-Rescue (EER) process.

Launch failures due to equipment failure, such as accidental release or inability to release, were not modelled. However, every reasonable avenue was explored to model the mechanical components of evacuation systems so that they perform in a physically accurate way.

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.

2.0 PROJECT OBJECTIVES

The main objectives of the test program were quantification of evacuation system performance degradation as a function of environmental conditions and determination of the effect of evacuation system design variation on system performance. The objectives were met by a combination of individual experiments, evacuation scenario and component modeling:

1. Development of a physical model test program that uses waves and wind direction for a particular FPSO condition as program variables
2. Verification tests aimed at determining that the FPSO vessel motions were representative of similar vessels in similar environmental conditions.
3. Environmental conditions representative of East Coast of Canada.
4. FPSO and TEMPSC condition representative of a possible evacuation scenario.
5. Modeling of the complete twin falls davit system, associated TEMPSC and pay-out speed as well as the flexible boom system with regards to boom deflection characteristics
6. All these features are incorporated into the physical model experiments of the lowering, splashdown and sail-away of the TEMPSC.

The benefits of conducting these experiments were:

A. The quantification of evacuation system performance degradation as a function of environmental conditions.

B. Determination of the effect of evacuation system design variation on system performance.

C. Development of information that may be used by offshore platform managers in emergency evacuation situations.

D. Establishment of a non-proprietary database on evacuation system baseline performance that may be used by designers, operators and regulators to make rational decisions.

3.0 PROJECT EVALUATION CRITERIA

In order to evaluate the evacuation process, several parameters such as time from launch start to splashdown, time from splashdown to open sea, path length from splashdown to danger zone boundary, path length from danger zone boundary to safety zone boundary, distance from target to drop point, setback after splashdown, accelerations during lowering and sail-away, oscillations during lowering and collisions were directly measured and/or derived. Evaluation criteria are as follows for both the experiments and the actual measurements:

EXPERIMENTS

Twin falls davit deployments from the FPSO at 20^o heading to the waves and 57^o to the wind floating in an intact condition at the ballast draft and for six different environment conditions. Additional experiments for the modified evacuation system fitted with a flexible boom. All the experiments were performed from the windward side.

MEASUREMENTS

<u>Deployment Phase (from start of lowering to splashdown)</u>

X-Y-Z position of the TEMPSC, lateral acceleration of the TEMPSC, davit payout speed, flexible boom position and load, collisions

<u>Sail away Phase (from splashdown to outside the safe boundary zone)</u>

X-Y-Z position of the TEMPSC, relative position of the TEMPSC with the FPSO, time to cross danger and safe boundary zones, average sail away speed, lateral accelerations of the TEMPSC

4.0 PHYSICAL MODELS

Adequate physical models (i.e. models that accurately predict one or more characteristics of the prototype but not all the characteristics) of the FPSO vessel, TEMPSC and the flexible boom system and its components were designed and manufactured according to Froude scaling laws at a scale of 27.65. In the following sections a description of the vessel and the system is presented. Selected photographs of the different physical models and their components are incorporated in Appendix 11.

4.1 Floating Production Storage and Offloading (FPSO) Vessel

The FPSO hull included flat plate bilge keels, forecastle, bulwarks, and accommodation module and an enclosed main deck for water integrity. Remaining topside structures such as the process equipment module, helideck, flare tower, cranes and other above structures were left off. Provision for port and starboard TEMPSC launching systems were made but only the starboard side was used during the testing. It was determined that this would represent the worst-case scenario, since this was the windward side. Also from test program efficiency, observation and video recording considerations, deployment from one side was more advantageous.

Figure 4.1- FPSO Model

The model was further modified to carry an under-water rotatable mooring that was fitted at the centre of the moonpool and extended 310 mm below the cover of the moonpool. The moonpool cover was fitted at the same level as the bottom of the FPSO.

Figure 4.2- FPSO Model Mooring System

The model mooring was located below the FPSO bottom and was designed to have the modeled stiffness characteristics of full-scale mooring lines. Detailed drawings of the model mooring are located in Appendix 4. The mooring system consisted of a mooring post attached to the model. At the bottom end of the post a 200 mm turntable was mounted to which three mooring lines were attached in a 120 degrees radial spacing and extending under water to spring support posts on the side of the basin. The springs were tri-rated and provided an equivalent mooring line restoring force. Figure 4.3, compares the tri-rate springs linearized mooring characteristics to those of a typical FPSO non-linear single group mooring characteristics. The linearized spring system is a good representation of the actual mooring system but differences occur in large excursions. These are non-linear systems that in these tests were modeled linearly.

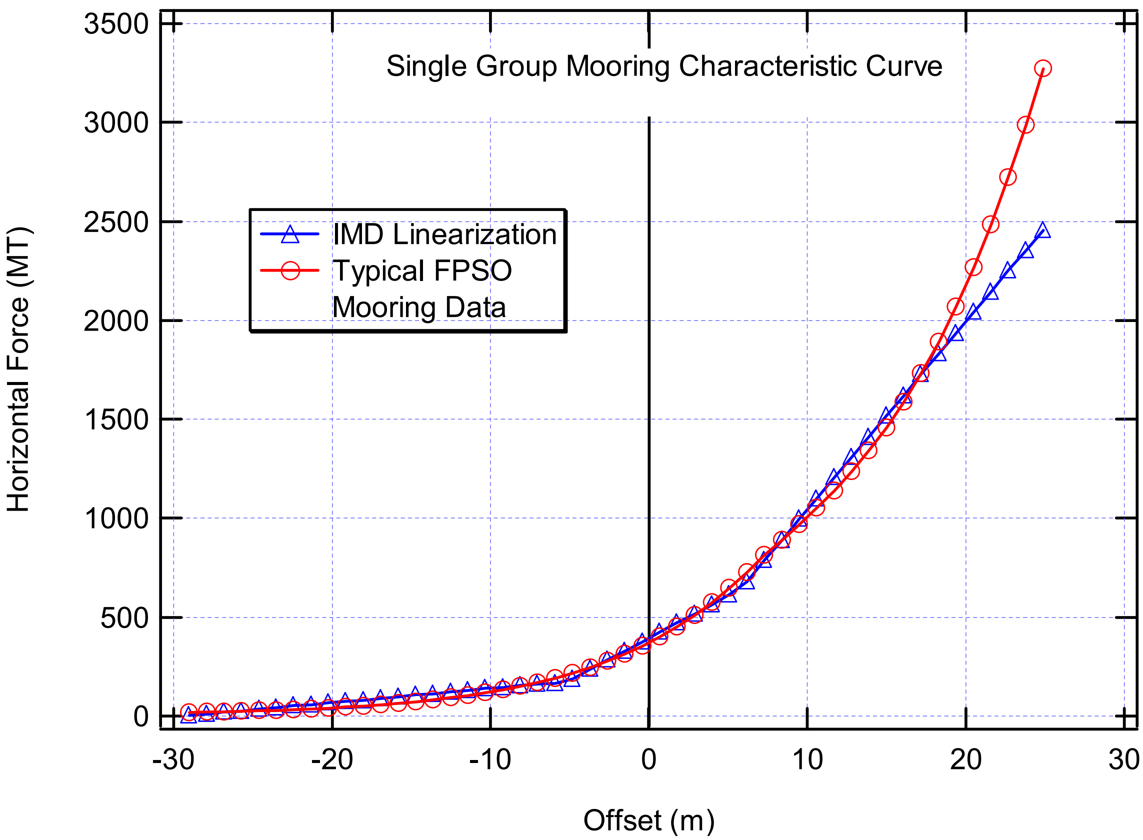

Figure 4.3 – FPSO Mooring Data Comparison

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 RenShape® (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 (5.1m) and the *z*-increments were the TEMPSC's overall height (3.5m).

The FPSO model was tested for the intact ballast load. The hydrostatics for the ballast load condition were calculated and the results are presented for both the model and full scale vessels in Appendix 2. 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 weights were moved port and starboard equal distances for the inclining experiment.

A summary of the hydrostatics and the mass properties is presented in Table 4.1.

below.

Table 4.1 – FPSO Hydrostatics & Mass Properties

Floating Production Storage Offloading (FPSO) Vessel			
Condition	BL		Ballast
Length Between Perpendiculars	L_{PP}	m	277.0
Length on Water Line	L_{WP}	m	273.5
Beam	B	m	44.7
Draft at After Perpendicular	T_{AP}	m	12.81
Draft at Forward Perpendicular	T_{FP}	m	11.87
Equivalent Level Keel Draft	T_{MEAN}	m	12.37
Trim by stern		deg.	0.19
Displacement	Δ	tonnes	122159
Centre Gravity Above baseline	CG	m	18.0
Transverse Metacentric Height	GM_T	m	3.34

The natural periods in heave, pitch and roll of the free-floating (unmoored) FPSO were measured. The natural surge, heave, pitch and roll periods of the moored model were also measured. All the natural periods were measured using the Qualisys Optical Tracking System (QOTS). The natural periods for the free-floating and moored FPSO model are summarized in Table 4.2. Appendix 8, Qualification and Decay Tests, contains the graphical presentation of the FPSO surge, heave, pitch and roll characteristics.

Table 4.2 – Summary of Natural Periods for Free-Floating and Moored FPSO

FPSO Condition	Natural Period	Free-Floating	Moored
BL	Heave	9.56	*
BL	Pitch	9.08	9.48
BL	Roll	23.72	22.20
BL	Surge	-	105.3

Note: * No valid data collected during testing.

4.2 Totally Enclosed Motor Propelled Survival Craft (TEMPSC)

The model TEMPSC was representative of a typical 80-person craft. 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 TEMPSC was tested in the equivalent full load condition. No attempt was made to model fenders and other associated equipment. The accelerometer was mounted on the keel and oriented such it recorded lateral accelerations. The canopy was fitted with a servomotor that activated the forward and aft falls release mechanism and opened the flexible boom hook safety.

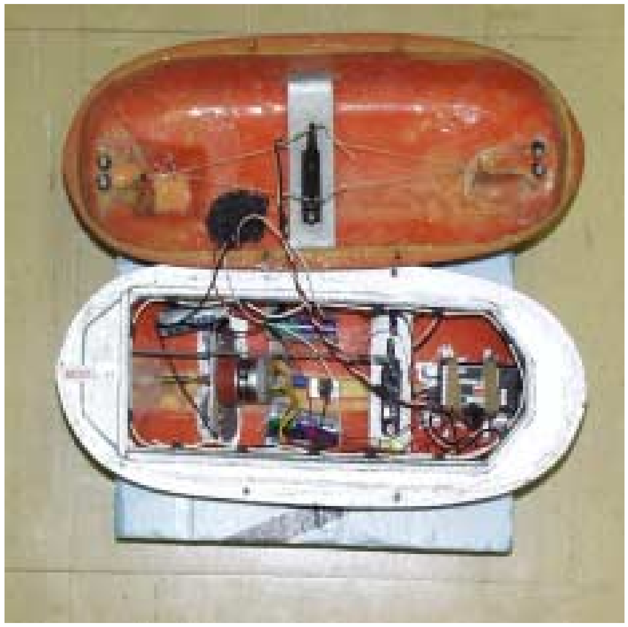

Figure 4.4 – TEMPSC Canopy and Hull

Figure 4.5 – Side View of the TEMPSC Model

Reflective tape was attached to the canopy at several locations for use with the QOTS. The instrumentation on the hull portion of the TEMPSC was used for the steering, propulsion and acceleration, while the instrumentation on the canopy was used to activate the flexible boom hook and release mechanisms. The complete systems are explained in detail in Appendix 3.

The TEMPSC 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). For repeatability purposes the calm water speed tests were repeated twice. The overall TEMPSC forward speed was programmed into the controller.

The hydrostatic properties and hull data are summarized in Appendix 3. The vertical centre of gravity (VCG) and radii of gyration were obtained by swinging the TEMPSC model hull on a frame in air. Results of the swinging are presented in Appendix 3.

Table 4.3 – TEMPSC Hydrostatics & Mass Properties

Tottaly Enclosed Motor Propoelled Survival Craft			
Condition	FL		100%
Length Overall	LOA	m	9.80
Length on Water Line	L_{WP}	m	9.80
Beam	B	m	3.30
Trim by stern		deg.	0.78
Displacement	Δ	tonnes	11.0
Centre Gravity Above baseline	CG	m	1.37
Transverse Metacentric Height	GM_T	m	0.71

4.3 Deployment System

The deployment system for the FPSO is classified as a semi-wet evacuation system and is characterized by two main components, namely, the evacuation craft and the system that launches it. Modifications were made to the launch system consisting of the addition of a flexible boom. Details of the modified system are described below.

4.3.1 Twin Fall Davit

The twin falls davit 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 4.6.

The deployment clearance of the TEMPSC from the FPSO was 1.5 times the breadth of the TEMPSC, ≈5.5m full-scale; the launch height was ≈27.0 m above the still water surface. All tests were done with the TEMPSC its 100% load condition. The davit system main components are the winch drum for the cable storage, the winch brake for controlling the speed of descent, and the cables themselves. Cable properties, such as diameter, breaking strength, stiffness etc. were not modeled, however, cable length was.

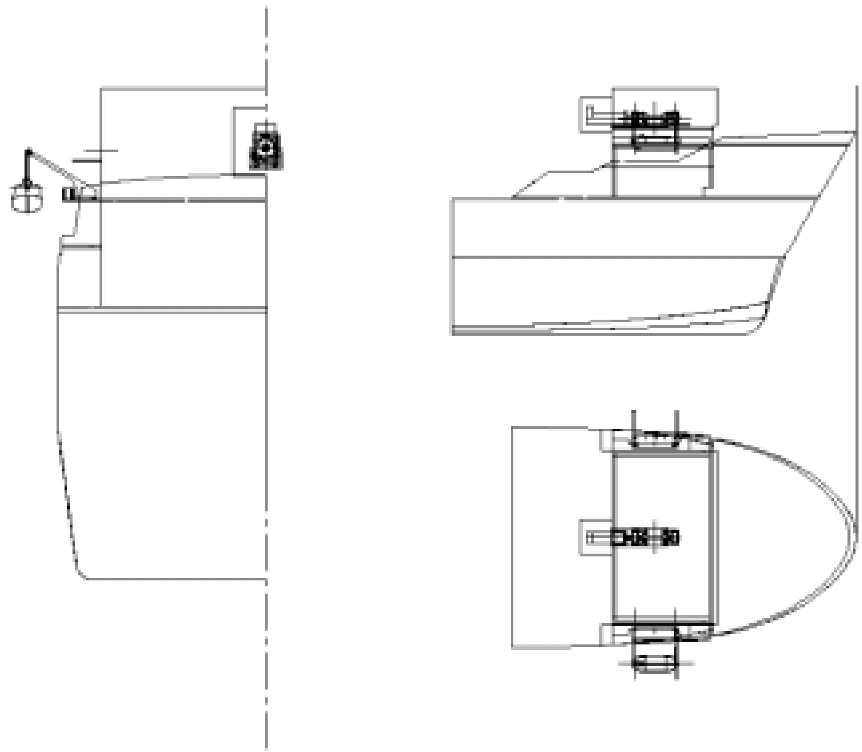

Figure 4.6 – Twin Falls Davit System Setup

The rate of descent of the TEMPSC 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.

4.3.2 Flexible Boom 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 modified test setup is shown below in Figure 4.7.

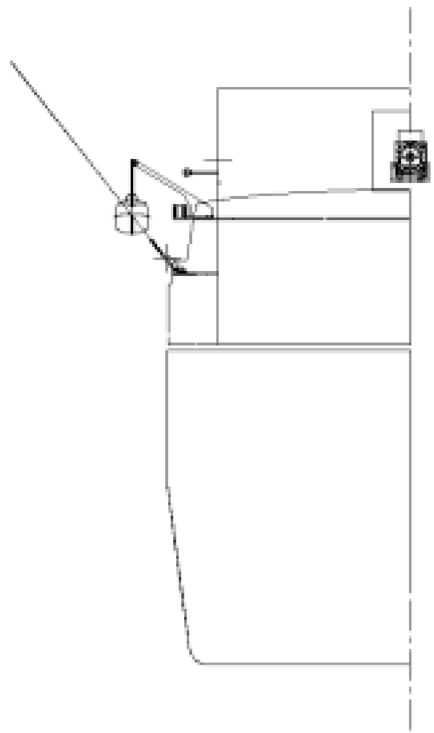

Figure 4.7 – Flexible Boom Deployment System Setup

The base plate was mounted approximately 2.5×TEMPSC height (316.5mm) below the embarkation deck, ⅛×TEMPSC length (45.6mm) forward of the forward davit arm, and ½×TEMPSC beam (66.5mm) 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 (≈868mm) 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 a controlled servo-motor 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.

Adequate scaling of the boom components was achieved. Boom tip deflection as well as ram extension and load were scaled according to information obtained from full scale. Tables 4.4 boom tip deflection, electronic spring extension versus load together with Figures 4.8 and 4.9 below show the modeled results. Boom deflection experiments were carried out with the boom in a horizontal position with loads applied at the 734.2 mm mark.

Table 4.4 – Flexible Boom Tip Deflection and Servo Motor Extension with Load

Applied Load (g)	Tip Deflection (mm)	Extension (mm)	Load (g)
9.5	238	5.72	795.1
18.9	392	10.47	1052.0
28.4	490	15.75	1256.9
37.8	550		
47.3	590		
56.8	615		
66.2	635		
75.7	652		
85.2	665		
94.6	675		

All the cables associated with the system (i.e. falls and tagline) did not have their properties such as stiffness, diameter, etc. scaled; however, the cable and tagline lengths were scaled.

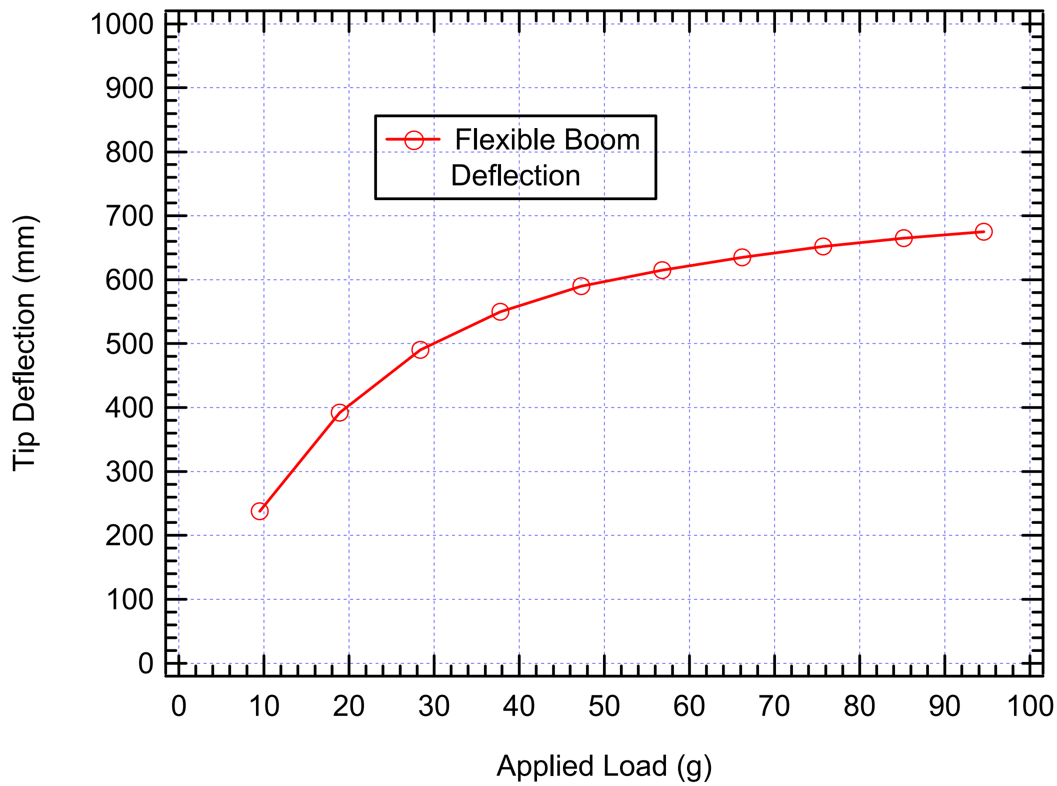

Figure 4.8– Flexible Boom Tip Deflection

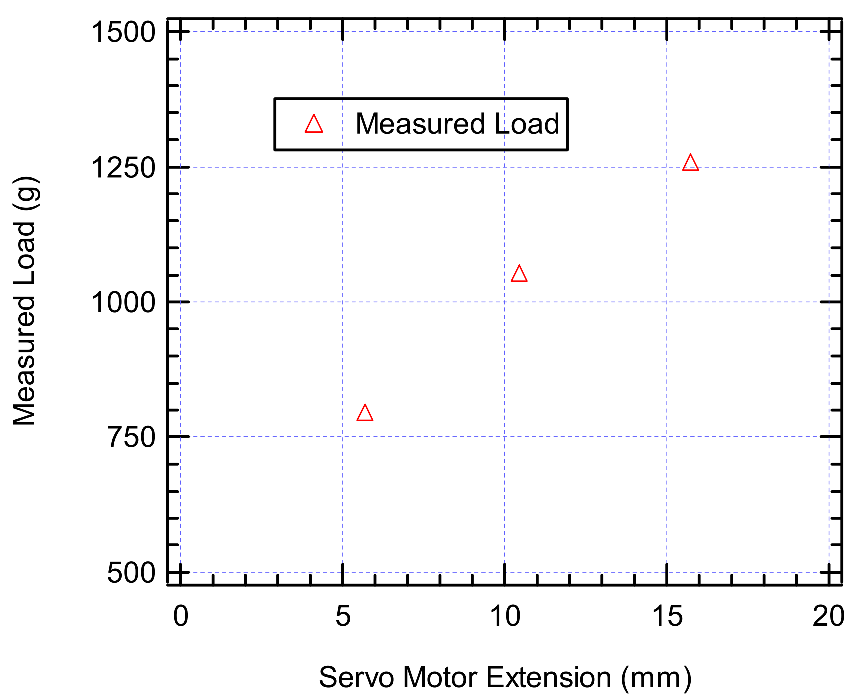

Figure 4.9 – Servo Motor Extension for Applied load

5.0 ENVIRONMENTAL MODELS

The Institute for Marine Dynamics (IMD) Offshore Engineering Basin (OEB) has a nominal working area of 65x26 m with a working depth of 3 m. The OEB 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. A general layout of the OEB is presented in Appendix 1.

A layout of the basin showing the direction of the waves, wind and the positioning of the FPSO is also presented in Appendix 1.

This series of experiments required the generation of different environments consisting of waves and wind. The wave modeling concentrated on the matching of the wave height and period while the wind concentrated matching a mean wind speed. The wave matching is performed without the model in the basin, while for the wind speed calibration the FPSO model was on its moorings. The required quantities are adjusted by iteration to the desired settings and the control signals recorded for playback during the test.

Table 5.1 below summarized the full-scale environmental conditions for the waves and wind. Appendix 6 contains the details and results of the environmental calibrations. The sections that follow discuss specific aspects of each environmental element.

Table 5.1 – Environmental Conditions

		WAVES			WIND	
Environment	Beaufort Scale	H (m)	T (s)	Direction (Degrees)	Velocity (m/s)	Direction (Degrees)
A	(0) Calm Water	0.00	0.00	200	0.00	143
B	(4) Moderate Breeze	1.01	5.6	200	7.20	143
C	(5) Fresh Breeze	2.10	7.70	200	9.77	143
D	(6) Strong Breeze	3.96	9.90	200	12.60	143
E	(7) Moderate Gale	6.71	12.10	200	15.43	143
F	(8) Fresh Gale	11.28	14.90	200	19.03	143

5.1 Regular Waves

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

The test programme required the generation of five regular waves. The waves were initially matched on wave height and period without the FPSO model in the basin. For each matched wave, a segment of 20 cycles was chosen to evaluate the wave parameters. The 20-cycle segment was selected by windowing through the entire time trace.

The following criteria were applied to each segment selected:

A. $\text{Deviation from Height Target} = \dfrac{\left|\left(H_{Avg} - H_{Target}\right)\right|}{H_{Target}}$ <5%

B. $\text{Wave Height Stability} = \dfrac{\left(H_{Max} - H_{Min}\right)}{H_{Avg}}$ <5%

C. $\text{Wave Crest Stability} = \dfrac{\left(C_{Max} - C_{Min}\right)}{C_{Avg}}$ <2.5%

The selected segments were examined to ensure they were within the target tolerances. All five waves used in the test programme met the three criteria.

During testing the wave signal is also recorded but due to reflections from the model, this may not exactly mimic the calibrated wave.

The waves were regular waves run with the basin in flume mode and with a 160^0 direction (180^o -- head seas). The files were defined using the following naming convention:

REG_HαPα_TβPβ_00δ

Where:

REG - indicates regular waves

H - denotes wave height

T - denotes wave period

P - defines the decimal place

α - define the significant wave height in metres

β - defines the wave period in seconds

δ - defines the incremental matching attempt number

For example, the run designated:

"REG_H3P96_T9P90_002"

Defines a regular wave with a wave height of 3.96 metres, a period of 9.90 seconds and a matching attempt number of 2. The entire wave matching for the test series is contained in Appendix 6.

Table 5.2 – Summary of All Wave Files

			Wave Criteria		
	H	T	Height		Crest
Description	(m)	(s)	Target (5.0%)	Stability (5.0%)	Stability (2.5%)
REG_H1P01_T5P6_001	1.01	5.60	0.59	3.31	2.04
REG_H2P10_T7P7_002	2.10	7.70	1.79	2.34	1.39
REG_H3P96_T9P9_002	3.96	9.90	0.89	1.08	0.59
REG_H6P71_T12P1_002	6.71	12.1	0.67	1.78	0.81
REG_H11P28_T14P9_002	11.28	14.9	2.49	1.09	1.09

5.2 Wind

Wind was simulated using a horizontal array of 12 analog-controlled fans mounted on support frames. The fans were positioned such that the wind direction was 37^{o} to the FPSO heading and at a distance of 7.70m from the FPSO turret centre. 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 generator can produce a turbulent wind spectrum with a mean wind speed of 12 m/s. For installation and operating procedures refer to (Fudge & McKay 1995).

The wind speed was modeled in terms of mean speed and was calibrated prior to the test program with the FPSO model installed. The fans were run at a steady speed and adjusted so that at a distance of 7.70m, the mean wind speed was the one specified in the test program.

The accommodation module adjacent to the deployment zone was an accurate representation of a prototype, however the structures aft of this module were not modeled. The wind loading on these superstructures would not affect the TEMPSC deployment.

6.0 INSTRUMENTATION

Instrumentation for the models consisted of the following:

- Qualisys Optical tracking system (QOTS) to provide six degrees of freedom motions of the FPSO model with respect to the earth fixed coordinate system (see Section 6.2)
- One anemometer to provide information on wind speed in the area of TEMPSC deployment,
- A second QOTS to provide TEMPSC X-Y-Z motion during deployment and sail-away,
- One accelerometer to record TEMPSC lateral accelerations,

- A miniature load cell to provide feedback on the modeled hydraulic system load versus extension,
- A motor controller to provide accurate davit pay-out rates
- An electronic switch identifying the davit release time.
- Two capacitance wave probes (one upstream and one beam of the FPSO) to give feedback on the wave environment,

A summary of the instrumentation calibration used throughout the tests is presented in Appendix 7.

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

- One black and white camera mounted on the FPSO capturing the start of TEMPSC descent, splashdown and sail-away
- A ceiling mounted camera providing a birds-eye view of the entire process
- One camera mounted on the side of the basin providing a beam view of the tests
- One camera mounted on the wind machine looking into the FPSO and providing a view of the evacuation zone.

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.

6.1 Data Acquisition

Data acquisition was made through three different systems, namely, Neff620-500, telemetry and video and at two sampling frequencies. The Neff and telemetry data were sampled at 50 Hz. The video data was sampled at normal recording speed of 30 frames per second. The Neff system was shore based, while the telemetry was installed on the FPSO. The video was both FPSO and shore based.

The video acquisition system consisted of four VHS and SVHS video cameras. The cameras were installed at the locations stated in Section 6.0. All the cameras except the one on board of the FPSO were attached to pan and tilt mechanisms controlled from the observation tower. These cameras had remotely controlled zoom and focusing. The camera on the board of the FPSO was mounted on a tripod that provided for some degree of adjustment and any modifications to the focus had to be done manually. The video format of all the cameras was NTSC.

6.2 Co-Ordinate System

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

- Basin Coordinate System

  Global right-handed system with the origin at the centre of the turret at the main deck level at its rest position in calm water. The X-axis is defined as up the basin in the direction of the west wall wavemakers, Y-axis is defined to port and the Z-axis upwards. Wave probe locations and wind machine locations are referenced to this system.

- FPSO Coordinate Systems

  FPSO fixed with origin at the turret centre. This coordinate right-handed system is fixed to the FPSO and moves with it. It defines location of instruments on the FPSO, embarkation zone, flexible boom and davits locations, electronic spring load, and pay out.

- TEMPSC Coordinate Systems

  TEMPSC fixed with origin at the centre of gravity. This coordinate right-handed system is fixed to the TEMPSC and moves with it. It defines the location of the release mechanisms and other instruments, and lateral accelerations.

6.3 Measurement Error

Approximate measuring errors in model and full scale-scale units are summarized as follows:

Table 6.1 – Approximate Measuring Errors

DESCRIPTION	MODEL SCALE	FULL SCALE
Qualisys Linear Motions FPSO and TEMPSC	± 5 mm	±138.5 mm
Qualisys Angular Motions FPSO	± 0.5 degrees	± 0.5 degrees
Flexible boom electronic spring Load	± 0.05 N	± 1.06 kN
Lateral Accelerations	± 0.1 m/s^2	± 0.1 m/s^2

7.0 QUALIFICATION TESTS

Qualification tests consisted of instrumentation calibration, post-test calibrations, and decay tests in which the models were offset and allowed to oscillate in still water to determine the natural oscillation periods and the damping of the free-floating and moored FPSO. Also included in this section are the verification tests conducted to ensure that the conditions the evacuation system was being used was representative of similar hulls in similar environmental conditions.

7.1 Calibrations

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

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

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

Where:

X = physical value in physical units,

M = integer A/D converter reading,

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

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

The purpose of the calculation is to calculate the constants A(k) and B(k), ensure that the sensor functions properly and has a linear response. The constant A(k) also represents the digital resolution of the measurement. The calibrated sensors are presented in Appendix 7.

7.2 Decay Tests

Decay tests were conducted for the free-floating (unmoored) and moored FPSO model. Heave, pitch and roll tests were conducted for the free-floating FPSO. The same tests plus surge decay were conducted on the moored FPSO. These experiments were performed prior to the start of the individual runs and were necessary to ensure that the respective periods for the FPSO vessel (i.e. roll, pitch, and surge) were realistic. A discussion of all the decay test results is presented in section 10.1 while the individual results are contained in Appendix 8.

7.3 Verification Tests

Verification tests were conducted on FPSO model to ensure that the motions with the simplified mooring configuration setup were representative of an FPSO. The FPSO model was run through the five environments specified in section 5.1. With the waves, the aim was to match the wave height and period. Wind was matched for a specified mean speed at a nominal distance of 7.70m model scale (i.e. distance between the wind machine and the turret centre).

The verification experiments were conducted for the FPSO in its test configuration prior to the start of the evacuation system assessment. Results of the individual tests are contained in Appendix 8.

8.0 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 condition (i.e. waves & wind). Table 8.1 shows the nominal description of the environmental conditions, from calm water to fresh gale, and the planned and actual (full scale) mean wave heights and wind speed.

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 to be repeated 20 times. In actuality this number varied from 14 to 20. This provides an indication of the variability of the tests, which may help interpret the importance of particular random variables, such as the splashdown point on the wave (e.g. crest, trough).

Table 8.1 - Test program.

SERIES LABEL	NUMBER OF RUNS		BEAUFORT DESCRIPTION	MEAN WAVE (m/s)		MEAN WIND (m/s)	
	Plan	Actual		*Plan*	Actual	*Plan*	Actual
CONVENTIONAL TWIN FALLS DAVIT CONFIGURATION							
400	*20*	14	(0) Calm water	*0.00*	0.00	*0.00*	0.00
500	*20*	20	(4) Moderate breeze	*1.01*	0.88	*7.2*	6.27
525	*20*	19	(5) Fresh breeze	*2.10*	2.05	*9.77*	8.11
550	*20*	15	(6) Strong breeze	*3.96*	3.90	*12.6*	10.13
600	*20*	14	(7) Moderate gale	*6.71*	6.16	*15.43*	12.20
625	*20*	14	(8) Fresh gale	*11.28*	10.76	*19.03*	15.34
FLEXIBLE BOOM CONFIGURATION							
700	*20*	20	(0) Calm water	*0.00*	0.00	*0.00*	0.00
725	*20*	19	(5) Fresh breeze	*2.10*	1.93	*9.77*	8.32
800	*20*	19	(8) Fresh gale	*11.28*	10.84	*19.03*	16.15

8.1 Test Methodology

The methodology used throughout the nine different tests series can be summarized as follows:

Verification Tests

- Ballast the FPSO to the required load condition
- Perform inclining experiment to check the metacentric height of the FPSO

- Perform heave, pitch and roll decay experiments on the free-floating FPSO
- Attach the FPSO to the horizontal mooring
- Perform surge, heave, pitch and roll decay experiments on the moored FPSO
- Perform a check run, followed by the activation of the current.
- Start the data acquisition system followed by the wavemakers and the wind machine. Activate the video recording system. Run wind and waves continuously for 2-3 minutes.
- Stop the data acquisition, the waves, the wind and the video recording system.

Offshore Evacuation System Tests

These experiments were conducted after the verification tests, which meant that the FPSO load condition was set and the only variant was environment, and the TEMPSC deployment system.

- The moored and tethered FPSO was set according to the test matrix.
- The davit twin fall lines were winched-up to the bulwark deck level
- The TEMPSC was attached to the davit twin-falls. For the experiments with the flexible boom the tagline was attached to the TEMPSC flexible boom hook.
- The TEMPSC was winched-up to the proper launching height. This was accomplished by installing a limit switch that cut power to the winch when it was contacted by the TEMPSC.
- The member of the project team in charge of the TEMPSC setup, moved away from the test area to the north side of the basin
- The data acquisition was started, followed by the wavemakers, the video and the wind machine. After approximately 10-15 wave cycles passed the FPSO the command to start deployment was given. The basin operator tried to keep deployments as random as possible.
- After the signal was received, the deployment started. Half way between the TEMPSC launching rest position and the water surface the TEMPSC propulsion system was started remotely.
- After splashdown the davit releases were activated. For experiments using the flexible boom, the TEMPSC hook safety open and after tagline release the TEMPSC was sailed away from the FPSO. The rudder control was not activated during the TEMPSC sail away to the safe zone.
- The wavemakers, video and wind were stopped and the run considered terminated. At this time the TEMPSC was manoeuvred back to the FPSO for pickup.

- After a few minutes the members of the project team started preparation for the next run. The time between test runs was set to 10 minutes.

Successful runs were defined as those for which a release of both davit-lines and flexible boom tagline released and the TEMPSC sailed away from the FPSO. Deployments were such that splashdown occurred on different portions of the wave, i.e. wave trough, crest, up and down slope.

8.2 Test Matrix

The test program was conducted as per plan with last minute modifications as the tests proceeded. The tables below detail the tests conducted for the verification test series and the offshore evacuation systems test series.

The verification tests series was conducted on FPSO model to ensure that the motions with the simplified mooring configuration setup were representative of similar hull forms on a mooring. The experiments took place prior to the start of the evacuation system assessment. The test matrix is presented in Table 8.2 below:

Table 8.2 – Verification Tests Matrix

FPSO		WAVE CONDITION		
Condition	Test Name	H (m)	T (s)	Direction (deg.)
BL	T913_300_001	1.10	5.60	200
BL	T913_301_001	2.10	7.70	200
BL	T913_302_001	3.96	9.90	200
BL	T913_303_001	6.71	12.10	200
BL	T913_304_001	11.28	14.90	200

The test matrix for the evacuation system assessment was broken down into two major components. The first consisted of six test series for the basic twin falls davit launched system while the second consisted of three test series for the flexible boom. All of the launch configurations started with the TEMPSC parallel to the platform and the only variable was the environmental condition. Table 8.3 below presents the test matrix:

Table 8.3 – Offshore Evacuation System Test Matrix

FPSO	TEMPSC	SYSTEM	WAVE CONDITION		WIND	DESCRIPTION	
Condition	Condition		H (m)	T (s)	Veloc. (m/s)	Series Number & Name	**No. Tests**
BL, I, B20	W, P	Davit	0.00	0.00	0.00	400, Calm Water	20
BL, I, B20	W, P	Davit	1.01	5.60	7.20	500, Moderate Breeze	20
BL, I, B20	W, P	Davit	2.10	7.70	9.77	525, Fresh Breeze	20
BL, I, B20	W, P	Davit	3.96	9.90	12.60	550, Strong Breeze	20
BL, I, B20	W, P	Davit	6.71	12.1	15.43	600, Moderate Gale	20
BL, I, B20	W, P	Davit	11.28	14.9	19.03	625, Fresh Gale	20
BL, I, B20	W, P	Boom	0.00	0.00	0.00	700, Calm Water	20
BL, I, B20	W, P	Boom	2.10	7.70	9.77	725, Fresh Breeze	20
BL, I, B20	W, P	Boom	11.28	14.9	19.03	800, Fresh Gale	20

Definitions:

BL – Ballast Load,
I – Intact
B20 – 20^0 FPSO heading,
P – TEMPSC power
W – Windward deployment
Davit – Twin falls davit system
Boom – Flexible boom system

9.0 RESULTS

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

Results presented in this report have been translated to full-scale values for salt water and have been re-analyzed to provide event statistics for the FPSO motions, the TEMPSC deployment, falls and tagline release. Results of the verification experiments in addition to being translated to salt water and full-scale values were also re-analyzed to provide both detailed statistical results and response amplitude operators (RAO). The RAO's were obtained from the double amplitude of motion divided by the wave height.

Detailed results are presented in Appendix 9 for individual experiments. The individual tests contain the FPSO motions, TEMPSC deployment, falls and tagline release event statistics followed by detailed statistical and RAO results for the verification experiments. Throughout this Appendix tables are presented before figures.

9.1 Data Analysis and Techniques

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

9.1.1 Statistical Analysis

For each measured and calculated time series the following parameters are calculated and output:

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

where: N is the total number of samples in the time series,
X_I is a discrete sample of the time series,

9.1.2 Zero-Crossing Analysis

A zero-crossing analysis is performed on the time series data, using a GEDAP program, “ZCA”. The software checks the time spacing of the signal to ensure that the sampling rate is high enough to accurate perform zero crossing analysis. The software is designed primarily for wave elevation records but it may be used to analyze other types of data such motions and forces. The ZCA performs both zero up and down-crossings and calculates parameters that are defined for each individual cycle in the record as well as parameters that apply to the entire record.

9.1.3 Response Amplitude Operator

The FPSO motions are presented as Response Amplitude Operators (RAO’s) for the six-degrees-of-freedom. The average values of surge, sway, heave, yaw, pitch and roll are divided by the average wave height and the results plotted as functions of the respective wave period. In the case of the linear motions the RAO has units of $^{m}/_{m}$ while for the angular motions the units are $^{deg}/_{m}$.

9.1.4 Deployment Analysis

This type of analysis was performed during the test program to ensure that the instrumentation was working properly. Data products produced by this type of analysis constituted time series and statistical summaries for the entire launching window as well as the following intervals: (a) start of deployment to splashdown (b) splashdown to davit release/tagline release and (c) davit/tagline release to open sea. Environment data (i.e. wind and waves), FPSO motion data, electronic spring load, boom position, davit payout, TEMPSC release, lateral acceleration and X-Y-Z position data were analyzed. In the time series plots, the davit release along with the tagline release were clearly marked and used to determine the local conditions at the time of release. FPSO motions, wave conditions, TEMPSC X-Y-Z were extracted at the above referred times. Synchronization between the acquisition systems, the shifting due to condition changes, etc. were handled during this analysis. Synchronization between the FPSO motion channels (data collected on the NEFF) and flexible boom load, davit payout, etc. (data collected on Telemetry) was accomplished through synchronization channels, one on each system. The synchronization between the TEMPSC X-Y-Z data and the other data was accomplished with software and manual manipulation.

9.1.5 Event Analysis

This type of analysis as the name indicates, was used to determine the sequence of events from lowering, splashdown and sail-away phases of individual experiments. The data is transformed from an earth-fixed coordinate system to a FPSO fixed coordinate system with its origin at the center of gravity of the TEMPSC canopy. Generally speaking the data is presented in plan view, view along the centerline of the TEMPSC and an outboard profile view. In each view the path taken by the TEMPSC 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 somewhat arbitrarily but represent areas for which TEMPSC target drop point, davit falls release, flexible boom tagline release, sail away and others have measurable values.

This type of analysis allows for the estimation of TEMPSC lowering, sail track with respect to the FPSO and get-away time.

10.0 DISCUSSION AND RESULTS

This series of model experiments conducted on the evacuation systems installed on the FPSO, measured the motions of the FPSO, the X-Y-Z position of the TEMPSC and its relative position to the FPSO. In addition measurements of the TEMPSC lateral accelerations, flexible boom load, davit release, payout were made together with measurements of wave and wind.

Results from this test program are contained in the appendices and are grouped according to the following:

- System calibration tests (series 200),

- FPSO motion verification tests (series 300),
- TEMPSC deployment from FPSO in intact ballast load condition at 20^o heading to the waves and 57^o to the wind using the twin falls davit system (series 400, 500, 525, 550, 600,625)
- TEMPSC deployment from FPSO in intact ballast load condition at 20^o heading to the waves and 57^o to the wind using the flexible boom deployment system (series 700, 725, 800)

For each of the above test series the only variable was the environment. FPSO, TEMPSC and deployment conditions were kept constant. This section is structured to address general observations on the different types of experiments performed on the overall test program.

10.1 Systems Calibration (200 Series)

This series of tests were aimed at establishing the natural periods of the FPSO model in the free-floating and moored configurations. Inclining experiments for the FPSO in the ballast load condition as well as TEMPSC speed tests were also included in this series. The natural periods for the free-floating and moored FPSO are summarized in the table below.

Table 10.1 – Comparison of Natural Periods for Free-Floating and Moored FPSO

FPSO Condition	Natural Period (s)	Free-Floating	Moored
BL	Surge	-	105.3
BL	Heave	9.56	-
BL	Pitch	9.08	9.48
BL	Roll	23.72	22.20

The only periods for which a comparison can be made are the pitch and roll. They show that by mooring the vessel the pitch period increases slightly and the roll period decreases. The slight increase in pitch is an unexpected result, however, the values are close and the possibility of error in the decay analysis is large given that the values are attained from one or two cycles. A comparison is also made in the table below between the values attained for the FPSO used in this test programs and other similar vessels.

Table 10.2 – Comparison of Natural Periods for FPSO and Similar Vessels

Natural Period (s)	Generic FPSO	FSO	FPSO	Tanker
Surge	105.3	-	285.0	-
Heave	9.56	13.0	11.0	-
Pitch	9.08	12.0	10.0	8.3
Roll	23.72	14.0	11.0	9.4

The above values show that the generic FPSO used in the experiments had heave and pitch periods similar to other hulls, however, it is clear that the both the surge and roll periods are quite different. TEMPSC deployments are not expected to be adversely affected by the differences in either surge and roll natural periods.
The results of the inclining experiments for the generic FPSO used in the tests are compared to other GM values obtained from similar vessels. The results from the two FPSO's are comparable but the results from both the FSO and tanker are quite different. This may be explained by the difference in the types of operation and also from the fact that many of the current FSO's are in essence tankers converted. This is explains the similarity in the FSO and tanker metacentric height values.

Table 10.3 – Comparison of Metacentric Heights (GM_T)

	IMD FPSO	FSO	FPSO	Tanker
GM_T (m)	3.34	8.84	3.90	7.83

The TEMPSC speed calibration consisted of multiple runs in calm water over a 20 m distance (model scale). Once the proper speed was attained, a set point was established on the controller for speed repeatability purposes.

The vertical and longitudinal centre of gravity of the TEMPSC used throughout the tests series was estimated by swinging it in air. The TEMPSC was attached to the swinging beam at the location of the longitudinal centre of gravity and weights adjusted until it balanced in the forward and aft directions. This started the process to determine the VCG. The restoring moment and mass moment of inertia of the beam, TEMPSC and weight were determined and the VCG estimated. The TEMPSC displacement was approximately 100% of loaded condition. In table 10.4 below the values attained by swinging are compared to values from comparable designs. The TEMPSC and swinging beam are shown in Appendix 3.

Table 10.4 – Comparison of Non-Dimensional Longitudinal and Vertical Centre of Gravity

	TEMPSC IMD	TEMPSC RIT	TEMPSC Conventional	TEMPSC Freefall
LCG	0.42	0.48	0.42	0.49
VCG	0.39	0.35	0.36	0.34

Note: IMD – Institute for Marine Dynamics

RTI – Royal Institute of Technology

10.2 FPSO Motion Verification (300 Series)

FPSO motion verification tests were aimed at comparing the results of the FPSO model hull design and its setup used in this set of experiments to results of similar hull designs. The intent was also to demonstrate that the current model experiments produced realistic FPSO motions in the different environmental conditions for the evaluation of the offshore evacuation system.

Tests were conducted in five environments made up of waves and wind and for the FPSO in its ballast loading condition and with heading to the waves of 20^o and 57^o to the wind. The environments corresponded to those proposed for the test series.

The results from the small environment produce little or no motions on the FPSO. Also some of the data collected for this environment was very noisy which made analysis difficult and very unreliable. A decision was made to omit this environment from the comparisons. The fresh and strong breeze along with the moderate and fresh gales environments will be used for the comparison of the resulting motions of the FPSO in the current setup.

The parameters for comparison will be the FPSO linear and angular motions. The average values of all the motions together with the average wave height of the matched wave will be used in the comparison. The RAO's were calculated by dividing the average of the motions by the average of the wave height.

The comparison is made with results from the Offshore Engineering Handbook, OEH, FPSO-2 and IMD tanker. The results are tabulated below, (Table 10.5) and presented in Figures 10.1 and 10. 2. The OHE results are only for heave and pitch and there was no reference to the FPSO heading. The data for both the FPSO-2 and IMD tanker are for the same heading to the waves as the current tests but no reference is made of the wind direction. The comparison must therefore be made with the understanding that not all the parameters were the same, however, one can get a sense of the FPSO overall performance.

Table 10.5 – Response Amplitude Operators Comparison

ENVIRONMENT 1		**RESPONSE AMPLITUDE OPERATOR**					
Vessel	T (s)	Surge (m/m)	Sway (m/m)	Heave (m/m)	Yaw (deg/m)	Pitch (deg/m)	Roll (deg/m)
FPSO	7.71	0.045	0.081	0.082	0.027	0.028	0.043
OEH FPSO	7.50			0.030		0.030	
FPSO-2	7.50	0.024	0.024	0.125	0.024	0.060	0.054
IMD Tanker	7.75	0.152	0.303	0.273	0.042	0.026	0.048
ENVIRONMENT 2		**RESPONSE AMPLITUDE OPERATOR**					
Vessel	T (s)	Surge (m/m)	Sway (m/m)	Heave (m/m)	Yaw (deg/m)	Pitch (deg/m)	Roll (deg/m)
FPSO	9.91	0.099	0.246	0.240	0.076	0.252	0.101
OEH FPSO	9.90			0.160		0.170	
FPSO-2	10.0	0.073	0.048	0.357	0.050	0.120	0.107
IMD Tanker	9.95	0.182	0.288	0.136	0.048	0.324	0.133
ENVIRONMENT 3		**RESPONSE AMPLITUDE OPERATOR**					
Vessel	T (s)	Surge (m/m)	Sway (m/m)	Heave (m/m)	Yaw (deg/m)	Pitch (deg/m)	Roll (deg/m)
FPSO	12.10	0.067	0.081	0.289	0.118	0.486	0.225
OEH FPSO	12.00			0.130		0.220	
FPSO-2	12.00	0.20	0.182	0.580	0.170	0.430	0.134
IMD Tanker	12.00	0.091	0.121	0.409	0.164	0.618	0.333
ENVIRONMENT 4		**RESPONSE AMPLITUDE OPERATOR**					
Vessel	T (s)	Surge (m/m)	Sway (m/m)	Heave (m/m)	Yaw (deg/m)	Pitch (deg/m)	Roll (deg/m)
FPSO	14.91	0.415	0.058	0.412	0.182	0.597	0.197
OEH FPSO	15.00			0.330		0.440	
FPSO-2	15.00	0.521	0.242	0.804	0.206	0.600	0.161
IMD Tanker	15.00	0.348	0.106	0.606	0.267	0.647	0.204

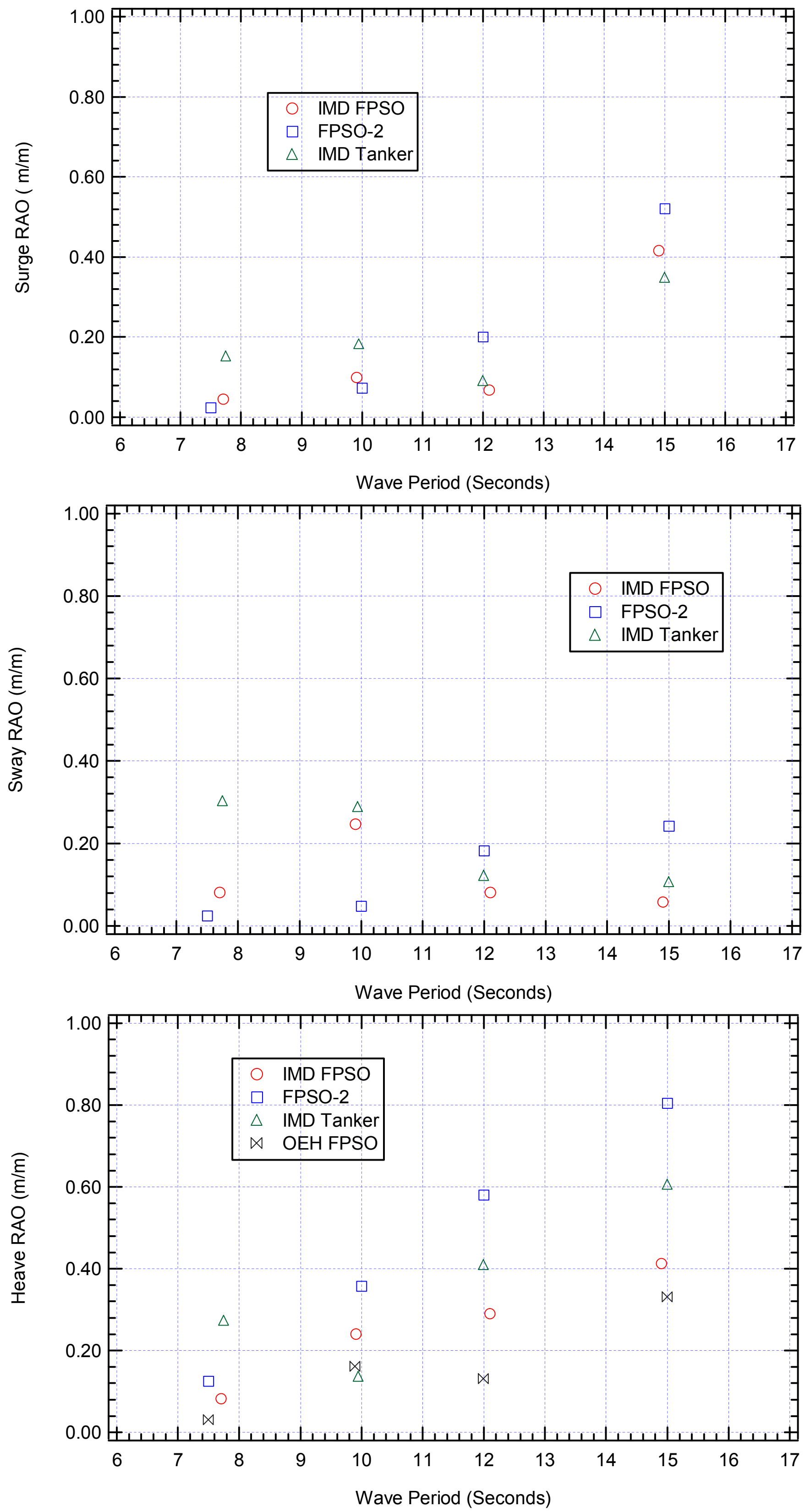

Figure 10.1 – Surge, Sway and Heave RAO Comparison

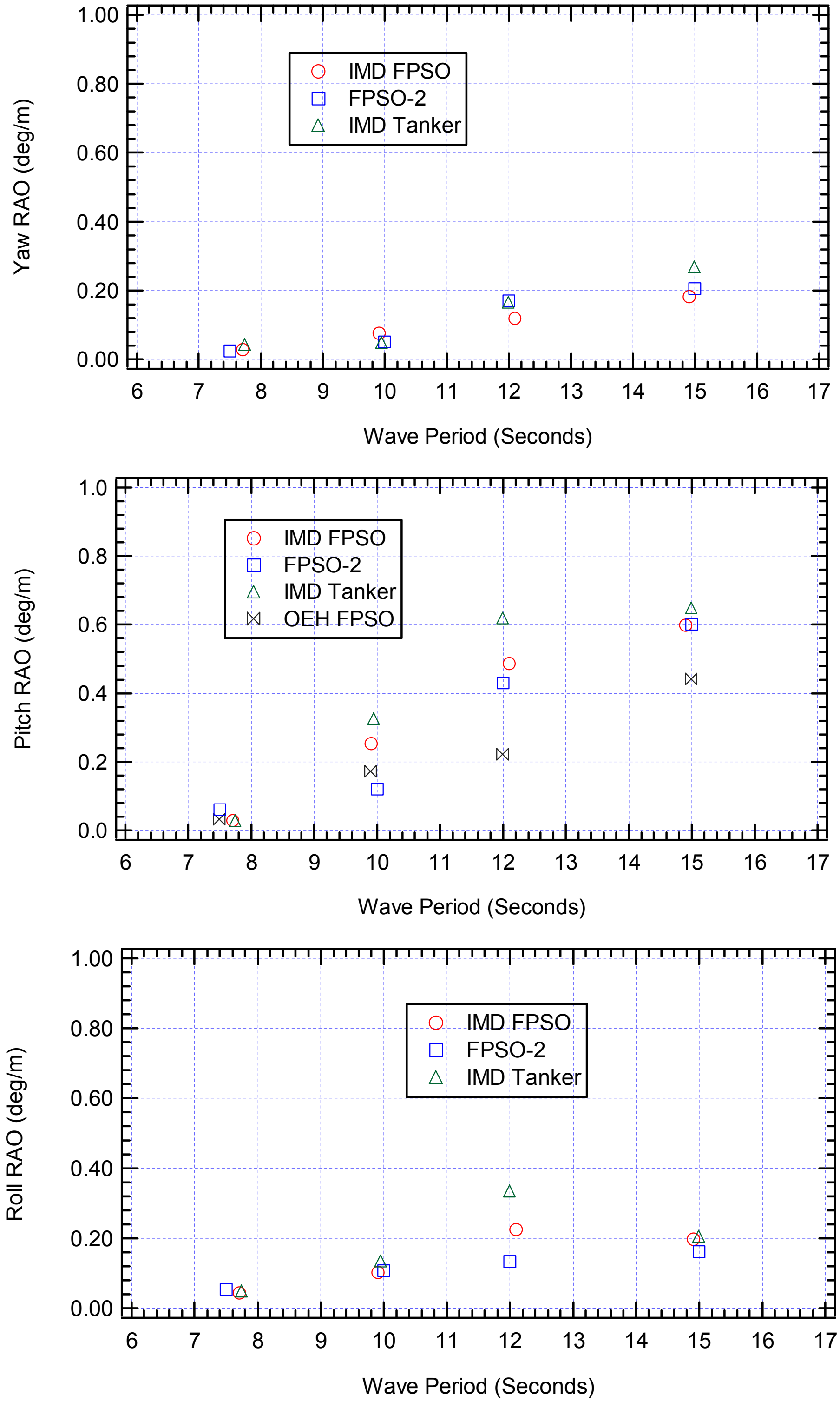

Figure 10.2 – Yaw, Pitch and Roll RAO Comparison

The results of the verification test indicate that the linear and angular motions of the FPSO are within the limits of similar hull forms. The IMD FPSO follows the same trends and in all the cases the recorded values are within the upper and lower limits presented for the other hull forms. This demonstrates that the FPSO hull form selected to conduct the offshore evacuation series of experiments is a valid platform representative of industry trends.

10.3 TEMPSC Deployment from FPSO - TWIN FALLS DAVIT SYSTEM (SERIES 400, 500, 525, 550, 600,625)

TEMPSC deployment from the FPSO with the twin falls davit evacuation system was one of the main objectives of the test program. Data collected for the FPSO, TEMPSC, evacuation system and environment conditions will be used to evaluate the overall performance of the system. The different series refer to TEMPSC deployments in:

400 series -- Calm Water, 14 runs

500 series -- Moderate Breeze, 20 runs

525 series -- Fresh Breeze, 19 runs

550 series – Strong Breeze, 15 runs

600 series – Moderate Gale, 14 runs

625 series – Fresh Gale, 14 runs

The test program for the TEMPSC twin falls davit deployment has a total of 96 runs analyzed of a projected total of 120. The 24 runs that were not analyzed represent runs for which data quality was poor, data channels failed to work, or mechanical failures due to low battery power occur.

The individual runs data for FPSO motions, TEMPSC location, wind and waves together with the detailed video analysis are presented in Appendix 9

10.3.1 400 Series -- CALM WATER TWIN FALLS DAVIT SYSTEM TEMPSC DEPLOYMENT

The 400 series – calm water -- deployments were performed for the FPSO in the intact condition. A total of 21 deployments were performed, however, the first seven were omitted from the presentation and analysis because the operator used excessive rudder angle. For these experiments no rudder angle data was collected so the radio controller was calibrated such that different notches on the controller corresponded to different rudder angles. This way the operator could consistently provide similar input to the rudder controller.

All of the tests were similar and can be described with reference to Figures 10.3 to 10.5, which illustrate the lowering, splashdown, and sail-away phases of a test in calm water. Figure 10.3 shows a plan view, Figure 10.4 is a view along the centreline of the TEMPSC, and the Figure 10.5 shows an outboard profile. In each view the path of the TEMPSC 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.

During the calm water deployments the path of the TEMPSC is simple: it goes straight down during lowering, as indicated in Figures 10.4 and 10.5; upon splashdown into the danger zone it sails straight ahead through the intermediate zone to safety, as illustrated in the Figure 10.3.

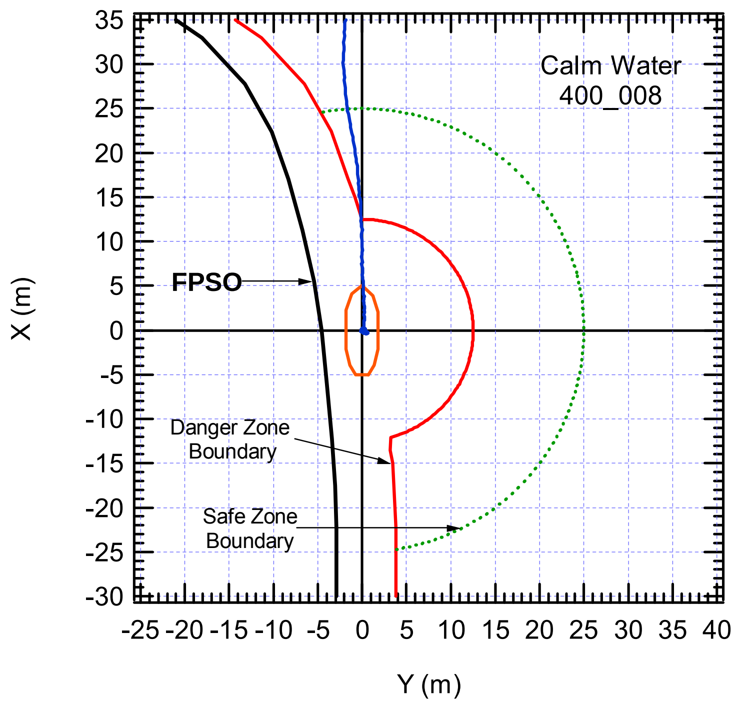

Figure 10.3 – Plan View of the of Deployment

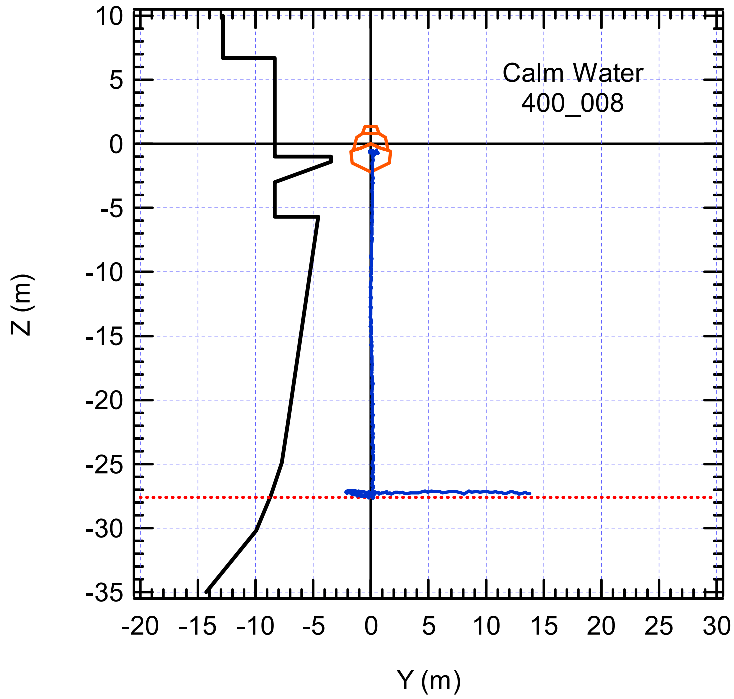

Figure 10.4 –View Along the Centre Line of the TEMPSC

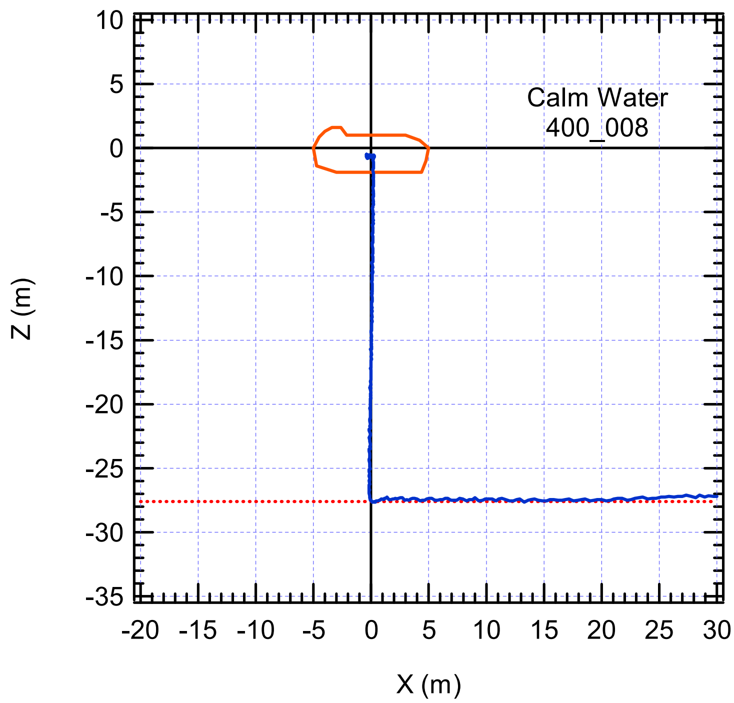

Figure 10.5 –Outboard Profile of the Deployment

During each individual deployment data were recorded as time required to process required activities (i.e. time from launch to splashdown, time from splashdown to davit falls release, time from splashdown to danger zone boundary, time from splashdown to safe zone boundary) and as trajectories taken by the TEMPSC during the deployment, splashdown and sail-away (i.e. path length from splashdown to danger zone boundary, path length from danger to safe zone boundary, distance from target to drop point, setback, deployment excursion). Table 10.6 presents the tabulated data for the entire test series while Figures 10.6 and 10.7 capture the overall effect on the control of the TEMPSC during the evacuation in calm water. In these figures an envelope is drawn that encompasses the path taken by the TEMPSC in all deployment runs. The paths are shown in two views, with the plan view showing sail-away and the outboard profile showing lowering, set back, and sail-away.

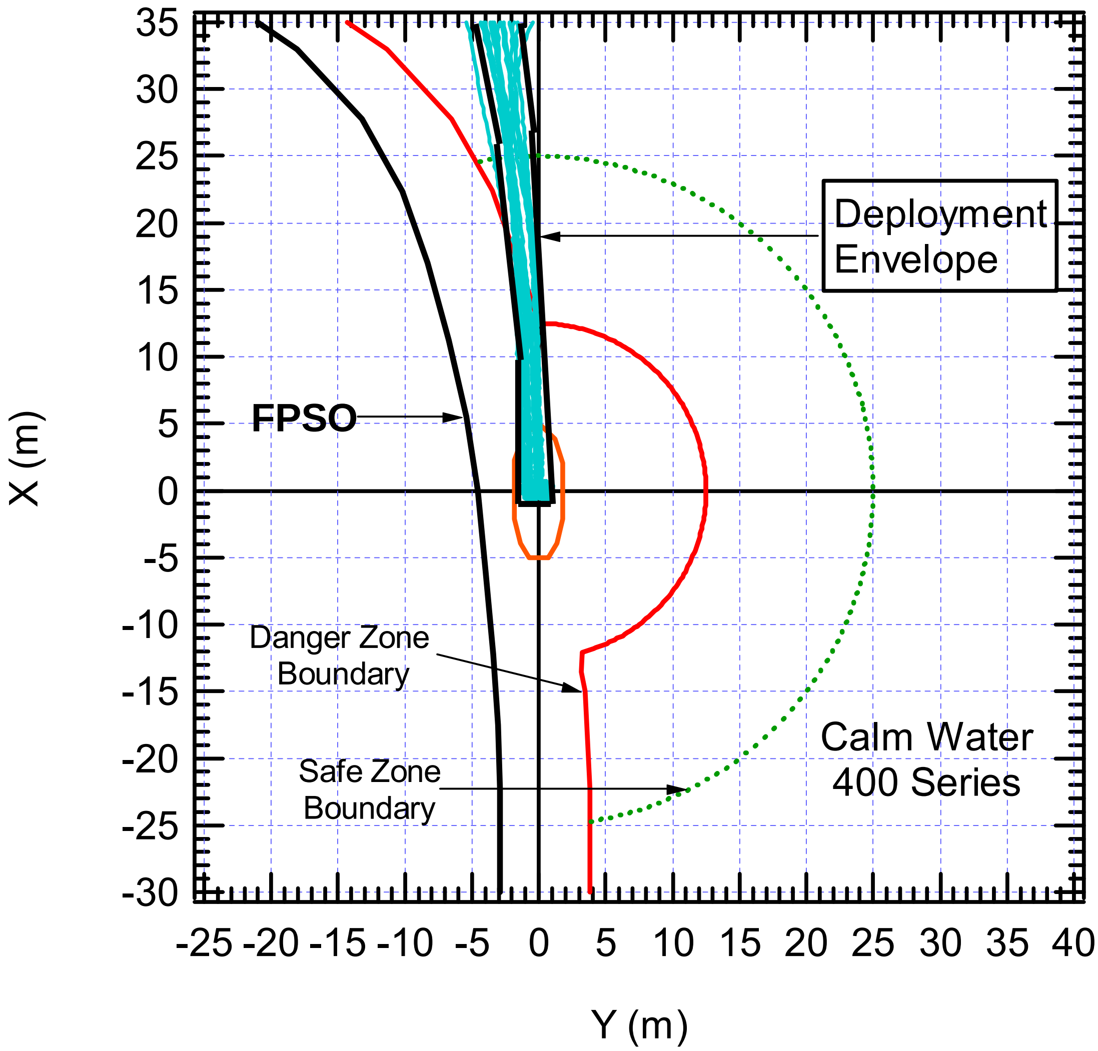

Figure 10.6 – Calm Water, Plan View of Deployment Envelope

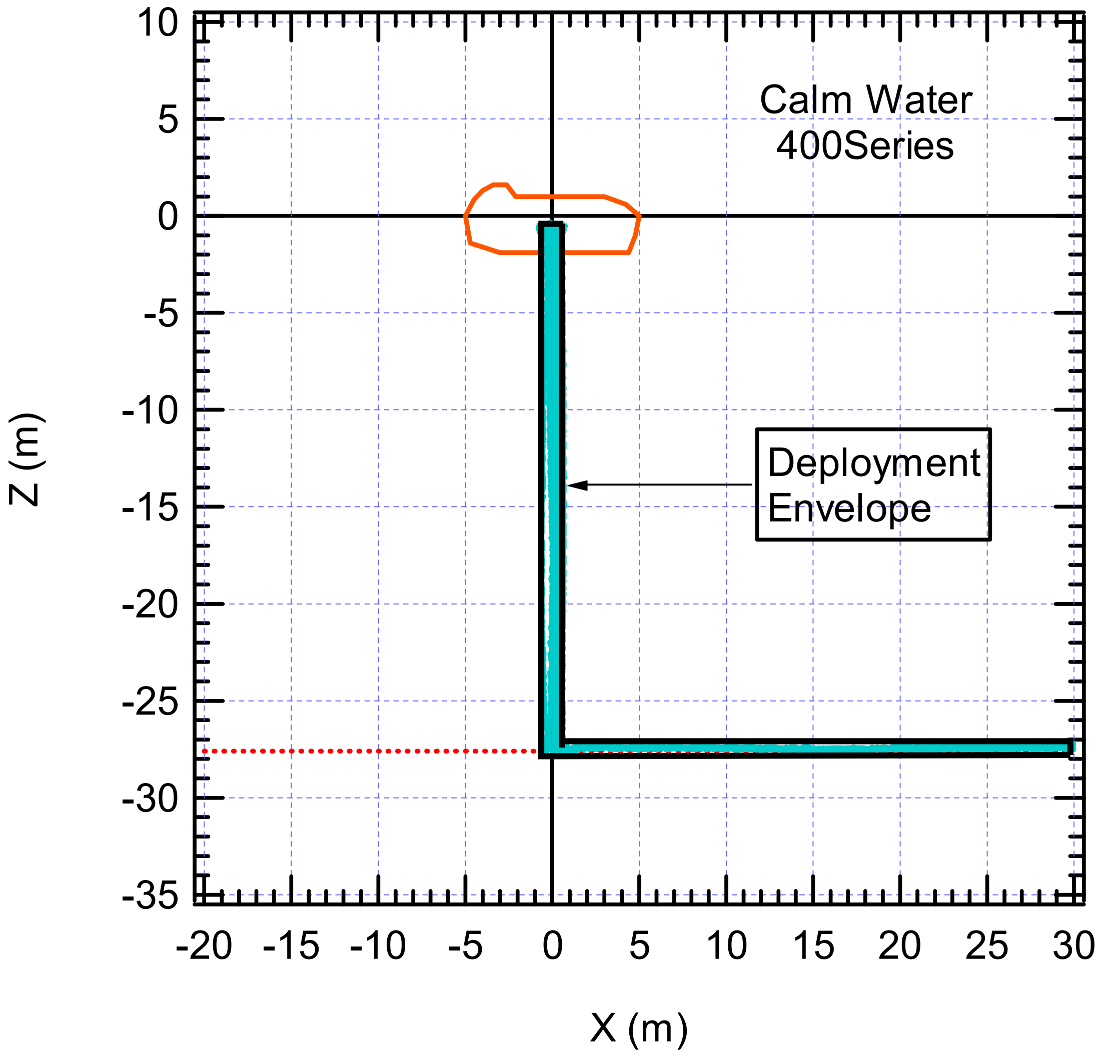

Figure 10.7 – Calm Water, Outboard Profile of Deployment Envelope

Table 10.6 – Summary of Calm Water Deployment Data for Twin Falls Davit System

Run Number	Deployment: Launch to Splash [s]	Deployment: Splash to Davit [s]	Deployment: Launch to Davit [s]	Boundary Crossing: Splash to Danger [s]	Boundary Crossing: Splash to Safe [s]	Boundary Crossing: Danger to Safe [s]	Boundary Crossing: Launch to Safe [s]	Travel Distance: Splash to Danger [m]	Travel Distance: Danger to Safe [m]	Average Speed: Danger Zone [knots]	Average Speed: Inter. zone [knots]	Average Speed: Open sea [knots]	Accelerations: Launch to Splash [g]	Accelerations: Sail away [g]	Splashdown: Missed Target [m]	Splashdown: Setback [m]	Splashdown: Combined miss/set [m]
400_008	27.52	4.18	31.70	9.40	13.08	3.68	40.60	13.00	12.00	2.69	6.34	7.00	0.96	0.29	0.332	0.000	0.332
400_009	27.87	3.93	31.80	9.69	12.32	2.63	40.19	18.75	8.25	3.76	6.10	7.00	0.89	0.25	0.540	0.000	0.540
400_010	28.04	3.86	31.90	9.91	12.33	2.42	40.37	16.00	8.25	3.14	6.63	6.60	0.93	0.23	0.210	0.000	0.210
400_011	29.10	5.20	34.30	8.99	11.93	2.94	41.03	15.00	9.50	3.25	6.27	6.80	0.39	0.58	0.743	0.000	0.743
400_012	28.57	3.33	31.90	8.43	11.05	2.63	39.62	15.00	9.50	3.46	7.02	7.60	0.89	0.43	0.706	0.000	0.706
400_013	28.75	3.45	32.20	10.36	11.94	1.58	40.69	19.25	5.25	3.61	6.47	7.00	0.83	0.81	1.166	0.000	1.166
400_014	27.87	4.33	32.20	9.13	12.60	3.47	40.47	13.25	11.25	2.82	6.30	7.00	1.26	1.30	0.686	0.000	0.686
400_015	29.62	5.68	35.30	7.55	10.92	3.36	40.54	13.50	11.00	3.48	6.35	6.60	0.89	0.21	0.324	0.000	0.324
400_016	27.87	3.13	31.00	10.59	12.80	2.21	40.67	16.00	8.00	2.94	7.04	7.00	0.95	0.21	1.103	0.000	1.103
400_017	27.87	3.83	31.70	10.02	12.64	2.63	40.51	16.00	8.50	3.11	6.29	7.30	1.15	0.97	0.858	0.000	0.858
400_018	28.22	0.38	28.60	8.17	11.96	3.79	40.18	13.00	11.25	3.09	5.78	7.60	0.95	0.33	0.619	0.000	0.619
400_019	28.57	2.33	30.90	9.93	11.93	2.00	40.50	17.50	7.00	3.43	6.81	7.00	0.51	1.68	0.622	0.000	0.622
400_020	27.87	3.83	31.70	8.17	11.43	3.26	39.30	13.00	11.50	3.09	6.86	7.10	0.95	0.32	0.330	0.000	0.330
400_021	29.10	1.30	30.40	7.49	10.22	2.73	39.32	14.50	10.00	3.77	7.11	7.80	0.95	0.51	1.232	0.000	1.232

10.3.2 500 Series – Moderate Breeze

Twin Falls Davit System TEMPSC Deployment

The 500 series – moderate breeze -- deployments were performed for the FPSO in the intact condition and for a heading of 20 degrees to the waves and 57 degrees to the wind. A total of 20 deployments were performed. All of the tests were similar and illustrate the lowering, splashdown, and sail-away phases of a test in a moderate breeze. The same three zones described in the previous section are used in this series

For individual deployments data were recorded as time required to process required activities and as trajectories taken by the TEMPSC during the deployment, splashdown and sail-away. The entire test series data is tabulated in Table 10.7 while the overall effect of the environment on the control of the TEMPSC during the evacuation is shown in Figures 10.8 and 10.9. Once again the figures show the envelope that encompasses the path taken by the TEMPSC in each deployment run.

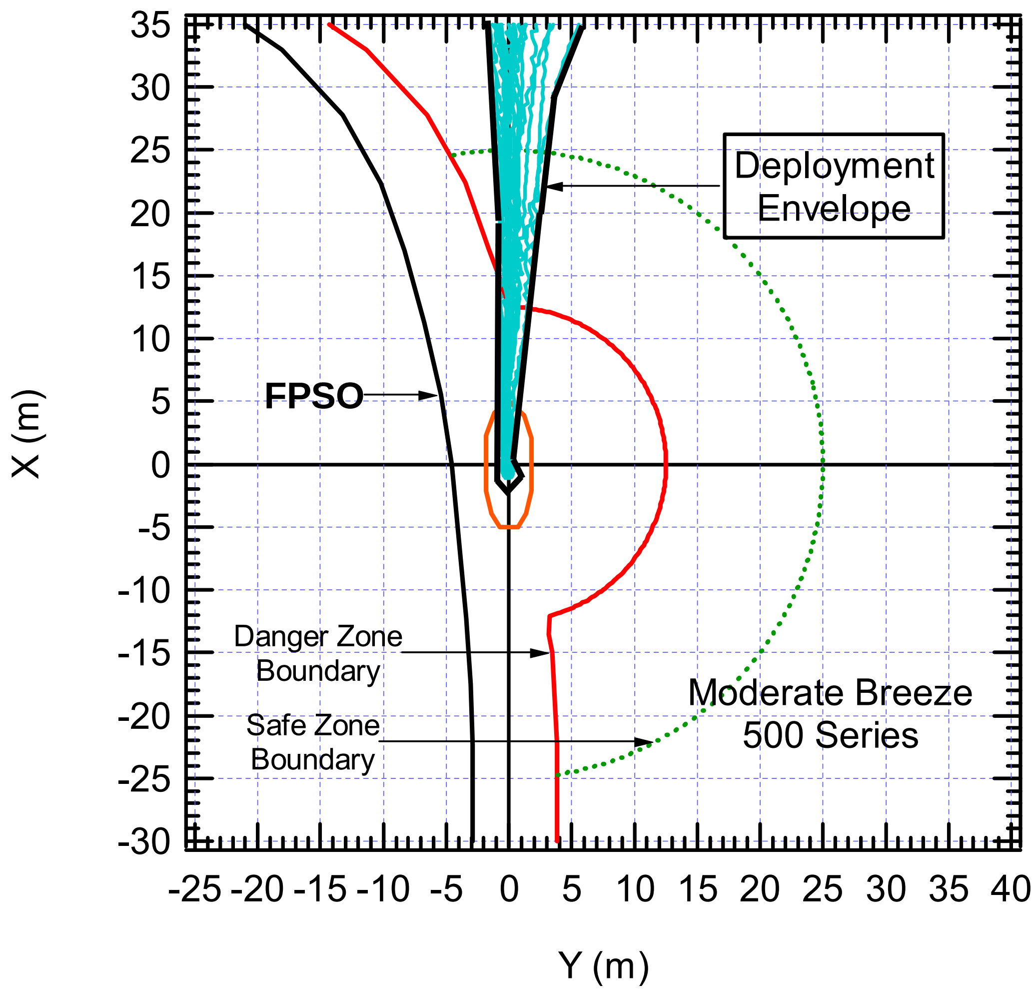

Figure 10.8 –Moderate Breeze - Plan View of Deployment Envelope

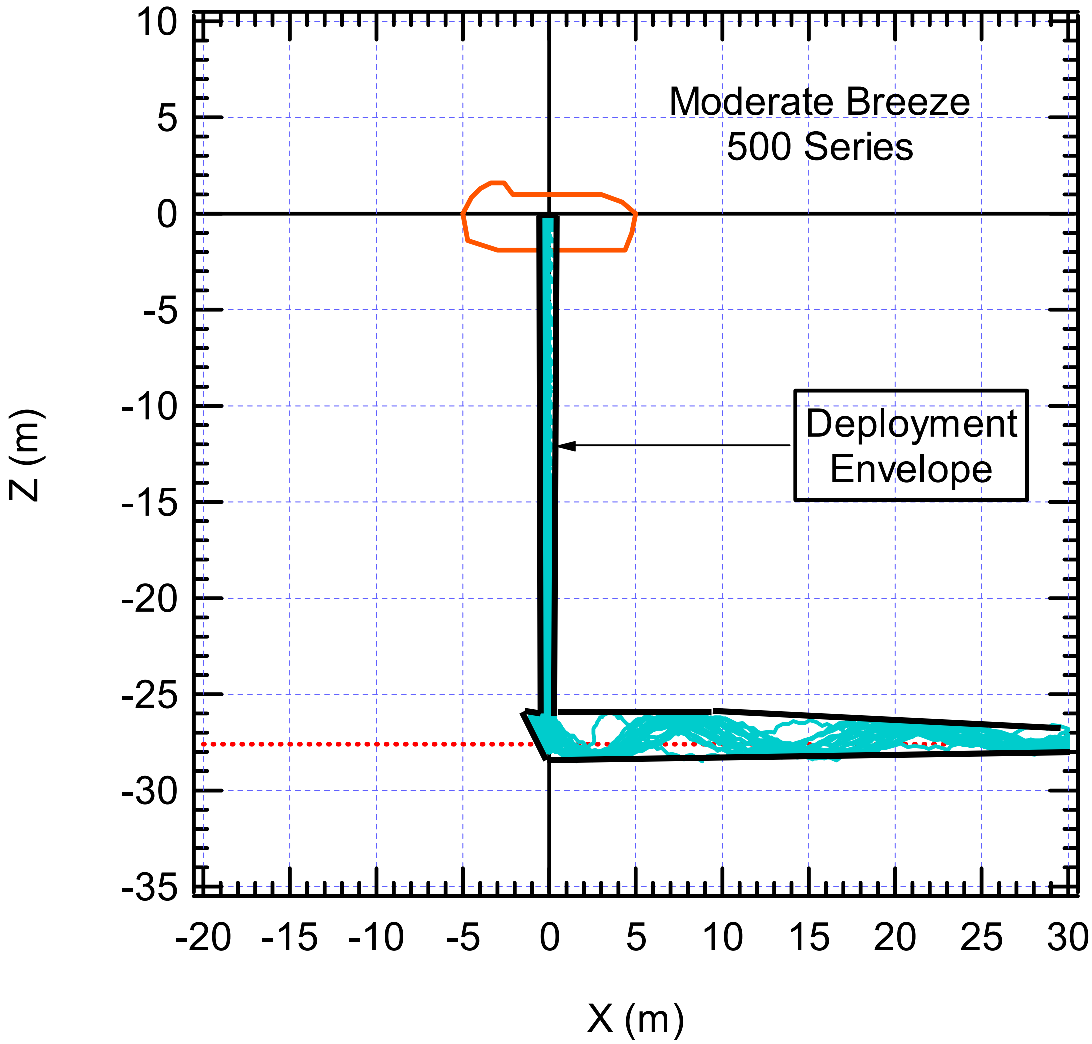

Figure 10.9 – Moderate Breeze, Outboard Profile of Deployment Envelope

When the conditions are not calm, as is the case here, there are additional considerations such as the effects of the vessel motions on the TEMPSC path during lowering and at splashdown. The splashdown point on the wave (i.e. crest, trough, up/down-slope) is important and it is directly connected to the ability of the TEMPSC to make way in the waves. There are instances in which the sail-away ability is hindered by the incoming wave while others the wave helps the sail away process.

These are examples of the splashdown point being up-slope, midway between the trough and oncoming crest. In these cases no forward progress is made until the TEMPSC crests the next wave and motors 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 this test series as well as all other series for which waves were present.

Table 10.7 – Summary of Moderate Breeze Deployment Data for Twin Falls Davit System

	Deployment			Boundary Crossing				Travel Distance		Average Speed			Accelerations		Splashdown			
Run Number	Launch to Splah [s]	Splash to Davit [s]	Launch to Davit [s]	Splash to Danger [s]	Splash to Safe [s]	Danger to Safe [s]	Launch to Safe [s]	Splash to Danger [m]	Danger to Safe [m]	Danger Zone [knots]	Inter. Zone [knots]	Open sea [knots]	Launch to Splash [g]	Sail away [g]	On Wave	Missed target [m]	Set Back [m]	Combined miss/set [m]
500_001	28.70	3.00	31.70	7.43	10.90	3.47	39.60	13.00	11.50	3.40	6.44	7.10	0.34	0.24	C	0.371	0.000	0.371
500_002	30.70	4.00	34.70	8.46	11.82	3.37	42.52	12.25	12.00	2.82	6.93	7.70	0.23	0.24	T	0.238	0.455	0.417
500_003	28.70	2.90	31.60	6.35	9.71	3.36	38.41	12.50	12.25	3.83	7.08	7.70	0.22	0.22	C	0.260	0.252	0.370
500_004	27.90	5.70	33.60	9.08	12.86	3.79	40.76	12.50	12.00	2.68	6.16	7.10	0.21	0.22	C	0.560	0.605	0.403
500_005	28.00	6.10	34.10	7.34	11.02	3.68	39.02	12.50	12.25	3.31	6.47	7.10	0.52	0.24	D	0.360	0.000	0.360
500_006	32.10	0.90	33.00	6.66	10.13	3.47	42.23	12.50	12.25	3.65	6.86	7.30	0.64	0.22	D	0.295	0.000	0.295
500_007	31.20	1.60	32.80	7.81	11.38	3.58	42.58	13.00	12.25	3.24	6.66	7.70	0.23	0.20	U	0.820	0.342	1.130
500_008	31.50	0.40	31.90	5.72	9.19	3.47	40.69	13.25	12.25	4.50	6.86	7.60	0.20	0.21	U	0.620	0.000	0.620
500_009	28.70	2.90	31.60	8.37	11.95	3.58	40.65	13.00	12.25	3.02	6.66	7.10	0.19	0.23	U	0.313	0.609	0.723
500_010	29.87	3.93	33.80	6.94	10.41	3.47	40.28	11.75	12.25	3.29	6.86	7.90	0.40	0.20	D	1.228	0.000	1.228
500_011	29.90	1.90	31.80	5.88	9.35	3.47	39.25	12.25	11.50	4.05	6.44	8.00	0.19	0.19	D	1.400	0.000	1.400
500_012	30.00	2.70	32.70	6.42	10.10	3.68	40.10	12.00	12.00	3.63	6.34	7.60	0.19	0.18	D	0.903	0.000	0.903
500_013	31.20	4.70	35.90	6.80	10.16	3.36	41.36	12.50	12.25	3.58	7.08	7.70	0.26	0.18	U	0.305	0.501	0.705
500_014	29.60	2.70	32.30	8.83	12.51	3.68	42.11	12.50	13.25	2.75	7.00	7.40	0.23	0.20	U	0.335	0.859	0.573
500_015	29.60	3.80	33.40	8.22	11.70	3.47	41.30	12.50	12.50	2.95	7.00	7.60	0.26	0.19	U	0.248	0.779	0.611
500_016	29.40	3.30	32.70	9.76	12.50	2.73	41.90	14.50	10.25	2.89	7.29	7.60	0.21	0.23	U	0.272	0.676	0.581
500_017	27.90	3.70	31.60	7.25	10.72	3.47	38.62	12.75	12.00	3.42	6.72	7.10	0.17	0.16	C	0.260	0.000	0.260
500_018	29.74	1.06	30.80	6.10	9.73	3.63	39.47	12.50	12.00	3.98	6.43	7.70	0.20	0.17	C	1.147	0.000	1.147
500_020	29.80	6.60	36.40	8.59	12.27	3.68	42.07	13.00	12.00	2.94	6.34	7.30	0.18	0.16	U	0.329	0.787	0.881
500_021	29.80	3.00	32.80	5.72	9.29	3.58	39.09	12.50	11.00	4.25	5.98	7.60	0.55	0.16	C	1.396	0.000	1.396

C - Crest T - Trough U - Up-slope D – Down-slope

10.3.3 **525 Series – Fresh Breeze**

Twin Falls Davit System TEMPSC Deployment

The 525 series – fresh breeze -- deployments were performed for the FPSO in the intact condition and for a heading of 20 degrees to the waves and 57 degrees to the wind. A total of 19 deployments were performed. The three zones, danger, intermediate and safe, defined in section 10.5.2 are used throughout this tests series. All of the individual experiments were run in similar manner and illustrate the twin falls davit system in operation in a fresh breeze.

Data were recorded as time necessary to perform activities such as lowering, safe boundary crossing, etc., and as path lengths taken by the TEMPSC after splashdown.

The entire test series data is tabulated in Table 10.8 while the overall effect of the environment on the control of the TEMPSC during the evacuation is shown in Figures 10.10 and 10.11. Once again the figures show the envelope that encompasses the path taken by the TEMPSC in each deployment run.

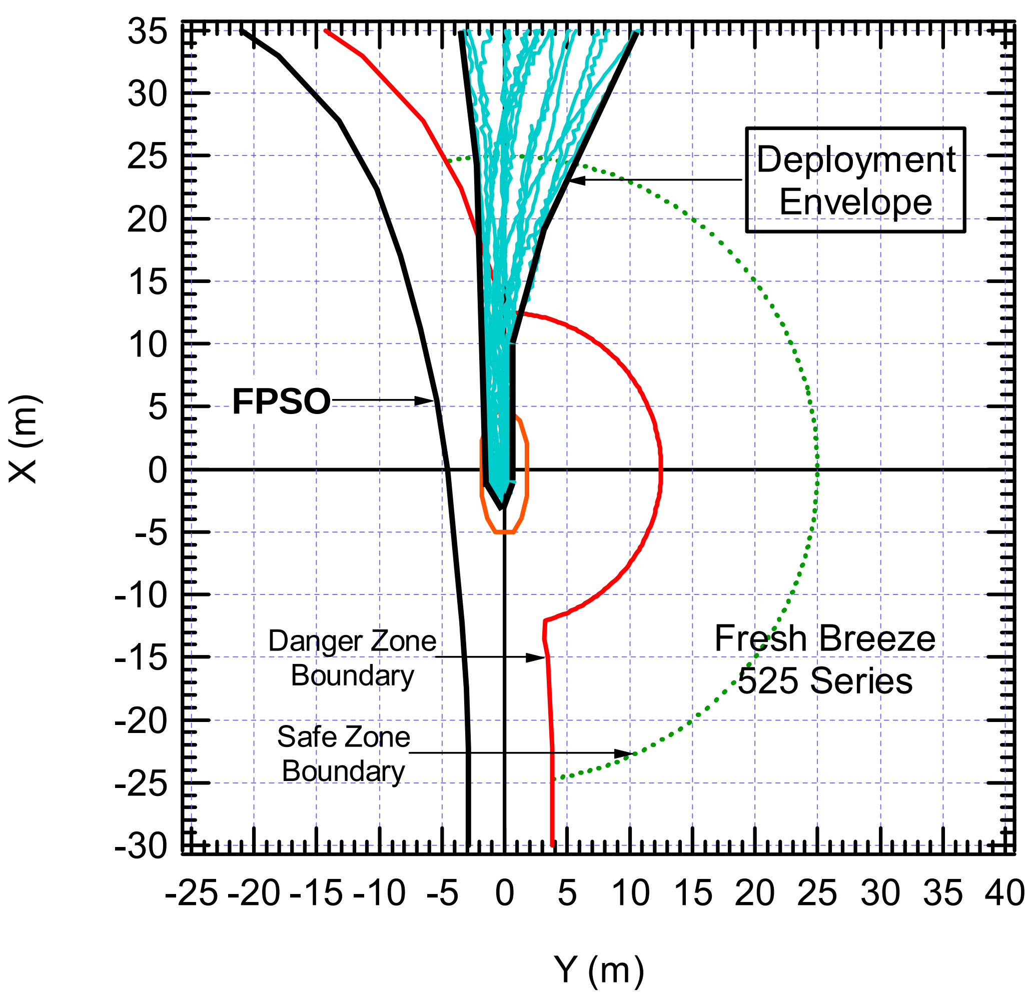

Figure 10.10 - Fresh Breeze - Plan View of Deployment Envelope

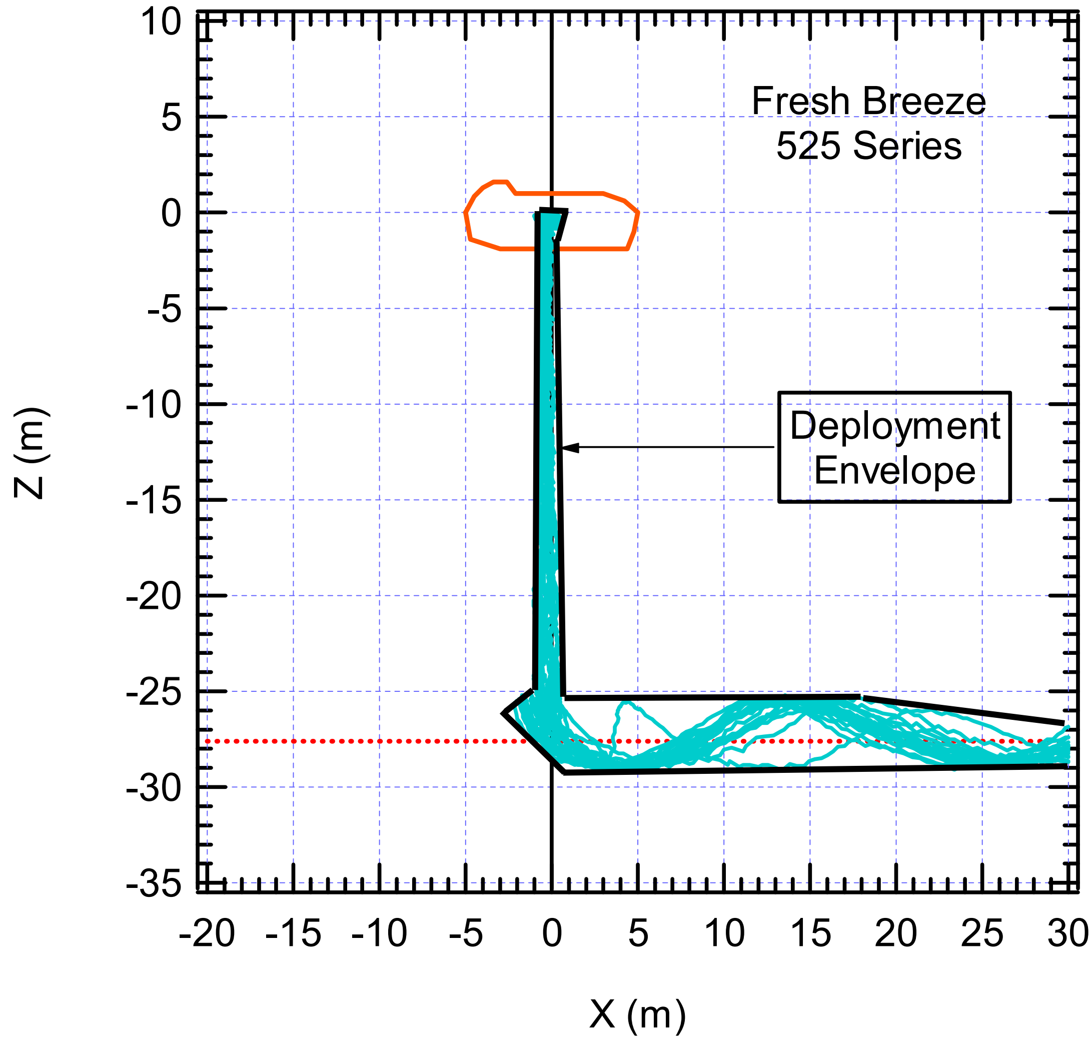

Figure 10.11 – Fresh Breeze, Outboard Profile of Deployment Envelope

In general, platform motions do not appear to be significant in this environmental condition. The individual deployments presented in Appendix 9, shown small oscillations during the 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.

The two figures above capture the overall effects of weather conditions on the control of the TEMPSC path during evacuation. The figures show envelopes that encompass the paths taken by the TEMPSC in the test series.

The most obvious trend demonstrated by the figures presented thus far, is that control deteriorates with increase in weather. 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.

Table 10.8 – Summary of Fresh Breeze Deployment Data for Twin Falls Davit System

	Deployment			Boundary Crossing				Travel Distance		Average Speed			Accelerations		Splashdown			
Run Number	Launch to Splash [s]	Splash to Davit [s]	Launch to Davit [s]	Splash to Danger [s]	Splash to Safe [s]	Danger to Safe [s]	Launch to Safe [s]	Splash to Danger [m]	Danger to Safe [m]	Danger Zone [knots]	Inter. Zone [knots]	Open sea [knots]	Launch to Splash [g]	Sail away [g]	On Wave	Missed target [m]	Set Back [m]	Combined miss/set [m]
525_001	28.60	3.00	31.60	10.42	12.52	2.10	41.12	19.00	8.25	3.55	7.62	7.70	0.10	0.10	C	0.681	1.390	2.064
525_002	30.50	2.60	33.10	10.57	13.51	2.94	44.01	15.50	11.00	2.85	7.26	7.70	0.12	0.18	U	0.544	1.780	1.662
525_003	28.90	3.90	32.80	10.98	12.87	1.89	41.77	18.00	8.25	3.19	8.47	8.70	0.15	0.13	C	0.497	1.189	0.892
525_005	28.70	4.90	33.60	8.04	11.09	3.05	39.79	16.00	10.75	3.87	6.85	8.50	0.12	0.14	C	0.036	0.526	0.549
525_006	30.50	1.50	32.00	8.60	11.97	3.37	42.47	14.00	12.25	3.16	7.08	9.00	0.12	0.14	U	0.103	1.285	1.323
525_007	31.00	2.00	33.00	8.46	12.14	3.68	43.14	15.50	12.25	3.56	6.47	8.00	0.11	0.15	T	1.544	0.769	1.536
525_008	29.40	1.90	31.30	8.89	12.36	3.47	41.76	15.00	12.50	3.28	7.00	8.70	0.12	0.13	U	0.164	1.511	1.500
525_009	29.30	2.70	32.00	9.22	12.74	3.52	42.04	14.50	12.50	3.06	6.90	8.40	0.12	0.15	U	0.577	1.269	1.622
525_010	27.00	2.30	29.30	11.43	14.90	3.47	41.90	15.75	11.25	2.68	6.30	6.50	0.09	0.12	T	0.644	0.000	0.644
525_013	28.90	1.90	30.80	8.38	11.65	3.26	40.55	14.50	12.50	3.36	7.45	8.70	0.13	0.19	C	0.346	0.991	1.131
525_015	30.10	2.10	32.20	9.05	12.42	3.36	42.52	14.00	12.00	3.01	6.93	8.70	0.09	0.11	U	0.465	1.106	0.792
525_016	28.20	1.50	29.70	8.61	11.45	2.84	39.65	16.25	12.00	3.67	8.21	8.70	0.14	0.13	C	0.334	0.943	1.260
525_017	25.90	2.00	27.90	8.36	10.63	2.26	36.53	17.50	9.25	4.07	7.95	8.60	0.09	0.07	D	0.572	0.000	0.572
525_018	30.00	2.20	32.20	9.23	11.96	2.73	41.96	16.00	10.50	3.37	7.47	8.40	0.07	0.10	D	0.465	1.160	1.310
525_019	29.60	0.40	30.00	9.40	12.45	3.05	42.05	15.50	11.00	3.20	7.01	8.60	0.35	0.35	C	0.121	1.254	1.338
525_020	34.20	-5.40	28.80	5.55	9.23	3.68	43.43	13.50	13.00	4.73	6.87	8.50	0.11	0.11	T	0.706	1.577	1.095
525_021	29.80	1.50	31.30	9.90	13.16	3.26	42.96	19.25	12.50	3.78	7.45	8.10	0.15	0.14	U	0.255	2.253	2.362
525_022	27.70	1.10	28.80	7.02	9.76	2.73	37.46	15.75	9.75	4.36	6.93	8.00	0.13	0.20	C	0.739	0.000	0.739
525_023	28.40	0.30	28.70	6.92	8.92	2.00	37.32	17.00	8.00	4.77	7.78	8.00	0.10	0.12	C	0.204	0.000	0.204

C - Crest T - Trough U - Up-slope D – Down-slope

10.3.4 550 Series –Strong Breeze

Twin Falls Davit System TEMPSC Deployment

The 550 series – strong breeze -- deployments were performed for the FPSO in the intact condition and for a heading of 20 degrees to the waves and 57 degrees to the wind. A total of 15 deployments were performed. Data presentation and analysis make use of the three zones identified in previous sections. All of the individual experiments were run in similar manner and illustrate the twin falls davit system in operation in a strong breeze.

The data recorded and presented in this report are for the time to lower the TEMPSC to the water surface, the time to move the TEMPSC from splashdown point to safe zone and the path length of the TEMPSC as it moved away to the safe zone from the original splashdown point. The entire test series data is tabulated in Table 10.9 while the overall effect of the environment on the control of the TEMPSC during the evacuation is shown as an envelope encompassing the paths taken by the TEMPSC in each deployment, in Figures 10.12 and 10.13.

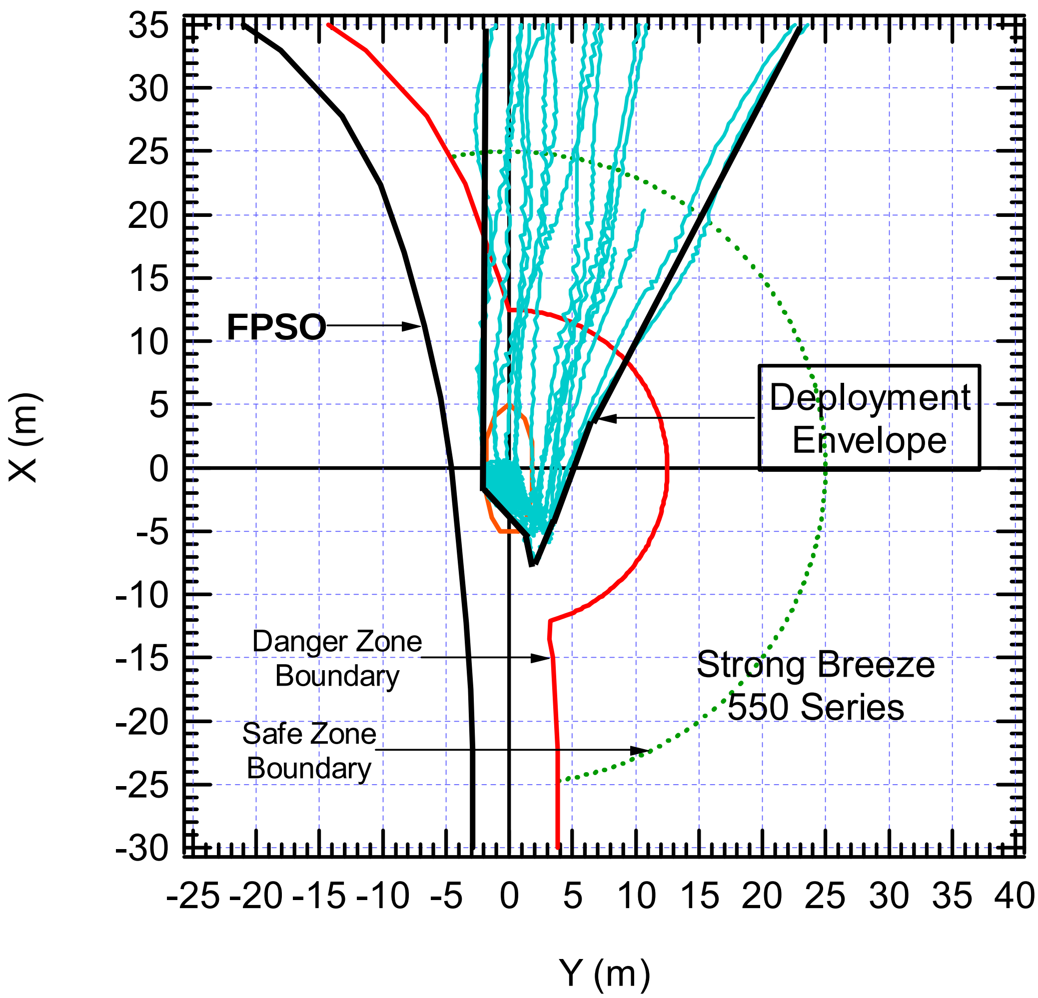

Figure 10.12 - Strong Breeze - Plan View of Deployment Envelope

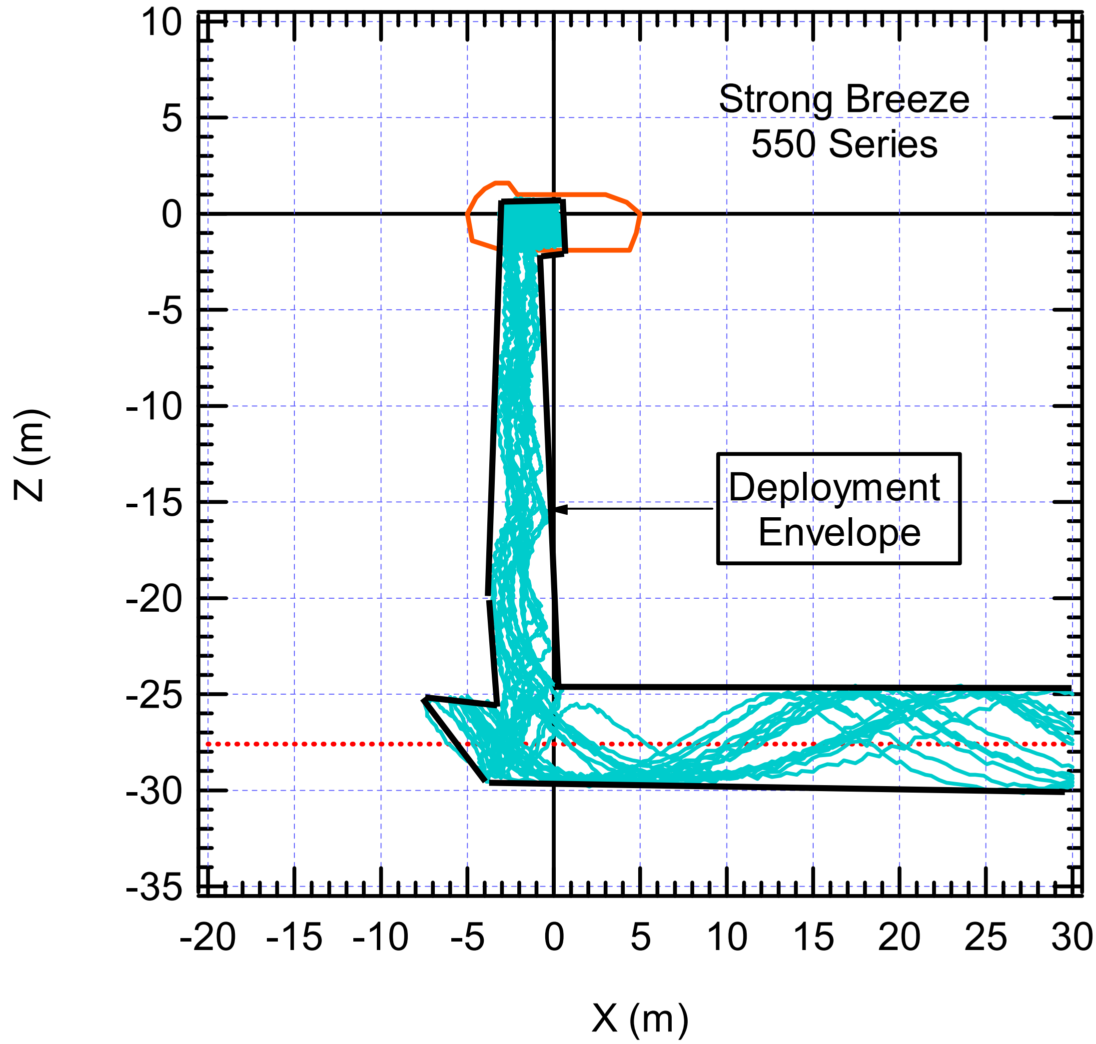

Figure 10.13 – Strong Breeze, Outboard Profile of Deployment Envelope

In general, platform motions start to be significant in this environmental condition. The individual deployments presented in Appendix 9, start to show oscillations in the z-axis of 3-4 meters prior to the lowering and oscillations of 3-4 m in the x-axis during the lowering, indicating that the TEMPSC swung as a pendulum. To some degree the oscillations are attributed to the wind force on the TEMPSC, but the majority of the oscillations are due to the motions set up in the platform by the waves.

The two figures above capture the overall effects of weather conditions on the control of the TEMPSC path during evacuation. The figures show envelopes that encompass the paths taken by the TEMPSC in the test series.

To reiterate the statement made in the last section, the most noticeable trend demonstrated by the deployment envelope figures, is that control deteriorates with increase in weather. In this test series this is attributed to the weather alone in the sail-away phase, and to the combined effects of weather and platform motions in the lowering phase.

Table 10.9 – Summary of Strong Breeze Deployment Data for Twin Falls Davit System

Run Number	Deployment: Launch to Splash [s]	Deployment: Splash to Davit [s]	Deployment: Launch to Davit [s]	Boundary Crossing: Splash to Danger [s]	Boundary Crossing: Splash to Safe [s]	Boundary Crossing: Danger to Safe [s]	Boundary Crossing: Launch to Safe [s]	Travel Distance: Splash to Danger [m]	Travel Distance: Danger to Safe [m]	Average Speed: Danger Zone [knots]	Average Speed: Inter. Zone [knots]	Average Speed: Open sea [knots]	Accelerations: Launch to Splash [g]	Accelerations: Sail away [g]	Splashdown: On Wave	Splashdown: Missed target [m]	Splashdown: Set Back [m]	Splashdown: Combined miss/set [m]
550_001	31.20	1.50	32.70	10.85	15.06	4.21	46.26	20.00	12.50	3.58	5.78	6.20	0.10	0.17	T	1.989	2.920	4.909
550_003	29.80	0.60	30.40	7.98	11.55	3.57	41.35	14.50	12.00	3.53	6.53	6.60	0.11	0.09	U	0.602	0.000	0.602
550_004	26.90	0.00	26.90	15.08	-	-	-	21.25	-	2.74	-	-	0.09	0.07	T	2.945	6.549	3.850
550_005	29.40	0.40	29.80	9.17	12.64	3.47	42.04	14.50	12.25	3.07	6.86	7.30	0.20	0.22	U	0.961	0.000	0.961
550_006	26.30	0.50	26.80	13.50	16.39	2.89	42.69	14.50	12.00	2.09	8.06	8.20	0.20	0.15	T	1.936	1.832	0.918
550_007	26.50	0.30	26.80	17.00	-	-	-	23.75	-	2.72	-	-	0.16	0.29	T	1.979	5.838	3.937
550_008	27.20	0.40	27.60	16.60	20.91	4.31	48.11	25.50	12.50	2.99	5.64	8.20	0.17	0.19	T	2.388	7.309	5.552
550_010	27.70	5.20	32.90	15.00	19.32	4.31	47.02	22.75	12.50	2.95	5.64	6.60	0.14	0.13	T	1.802	5.581	3.793
550_011	26.80	1.60	28.40	7.71	10.45	2.74	37.25	18.00	8.00	4.54	5.69	7.00	0.14	0.14	C	0.697	0.000	0.697
550_012	29.80	2.60	32.40	11.89	16.10	4.21	45.90	19.00	12.75	3.11	5.89	6.40	0.14	0.13	T	0.354	2.855	3.203
550_016	29.10	1.10	30.20	12.61	17.02	4.42	46.12	19.50	13.00	3.01	5.72	6.40	0.13	0.17	U	0.546	2.861	3.112
550_018	28.70	0.70	29.40	10.94	14.20	3.26	42.90	16.00	12.50	2.84	7.45	7.70	0.14	0.14	U	0.872	0.850	1.483
550_019	26.60	2.40	29.00	6.67	9.30	2.63	35.90	17.25	8.50	5.03	6.29	6.60	0.14	0.14	C	2.095	0.000	2.095
550_020	29.60	2.80	32.40	12.53	16.64	4.10	46.24	18.50	11.50	2.87	5.45	5.80	0.10	0.10	T	0.379	3.593	3.568
550_021	26.50	3.40	29.90	7.50	12.02	4.52	38.52	14.00	12.50	3.63	5.37	6.90	0.13	0.13	C	0.805	0.000	0.805
550_022	28.20	4.00	32.20	13.31	17.27	3.96	45.47	22.50	12.25	3.29	6.01	6.00	0.11	0.30	T	1.579	5.313	4.724
550_023	27.20	0.20	27.40	5.30	8.66	3.37	35.87	15.00	10.50	5.50	6.06	6.20	0.12	0.11	C	2.531	0.000	2.531

C - Crest T - Trough U - Up-slope D – Down-slope

10.3.5 **600 Series** – Moderate Gale

Twin Falls Davit System TEMPSC Deployment

The 600 series – moderate gale -- deployments were performed for the FPSO in the intact condition and for a heading of 20 degrees to the waves and 57 degrees to the wind. A total of 14 deployments were performed. All of the individual experiments were run in similar manner and illustrate the twin falls davit system in operation in a moderate gale. The data presented herein are for the time to lower the TEMPSC to the water surface, the time to move the TEMPSC from splashdown point to safe zone and the path length of the TEMPSC as it moves away towards the safe boundary zone from the original splashdown point. The series 600 data is tabulated in Table 10.10. The overall effect of the environment on the control of the TEMPSC during the evacuation is shown in Figures 10.14 and 10.15 as an envelope encompassing the paths taken by the TEMPSC in each deployment. The individual runs data for FPSO motions, TEMPSC location, wind and waves together with the detailed video analysis are presented in Appendix 9.

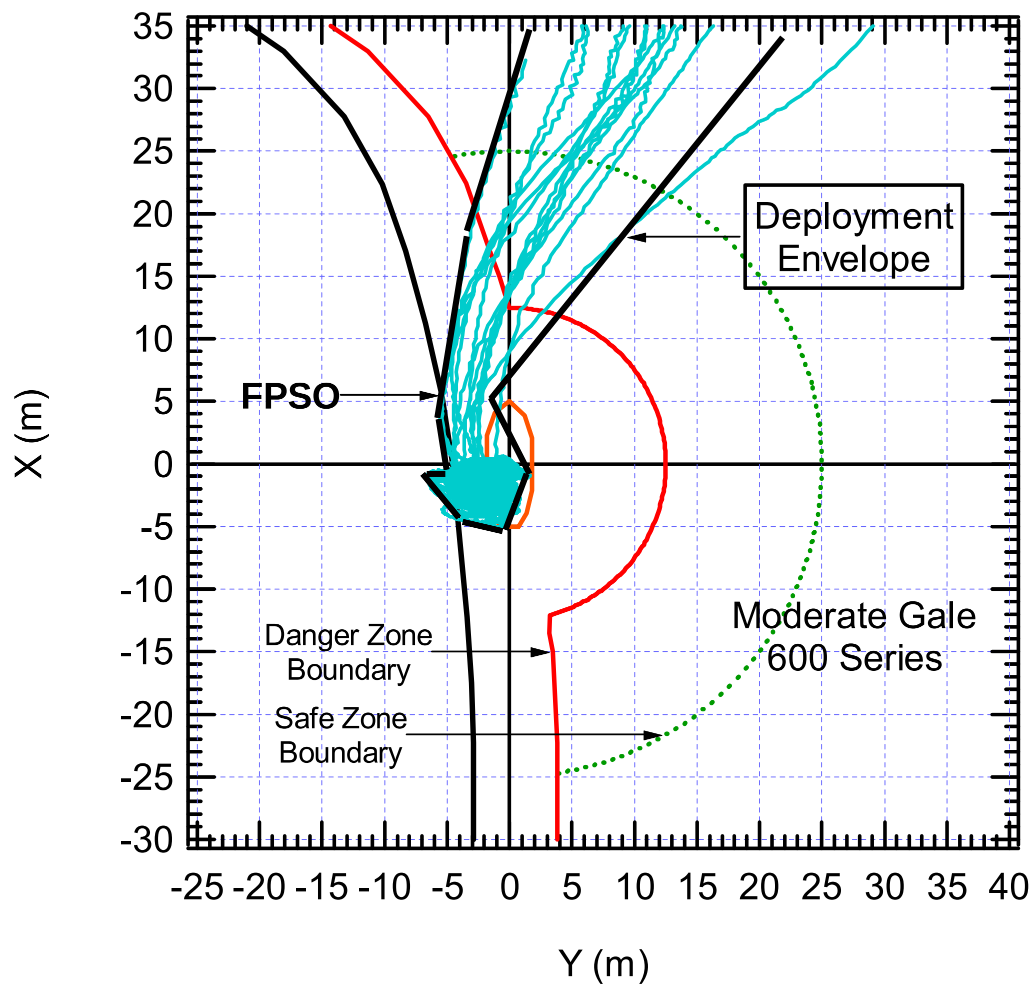

Figure 10.14 – Moderate Gale - Plan View of Deployment Envelope

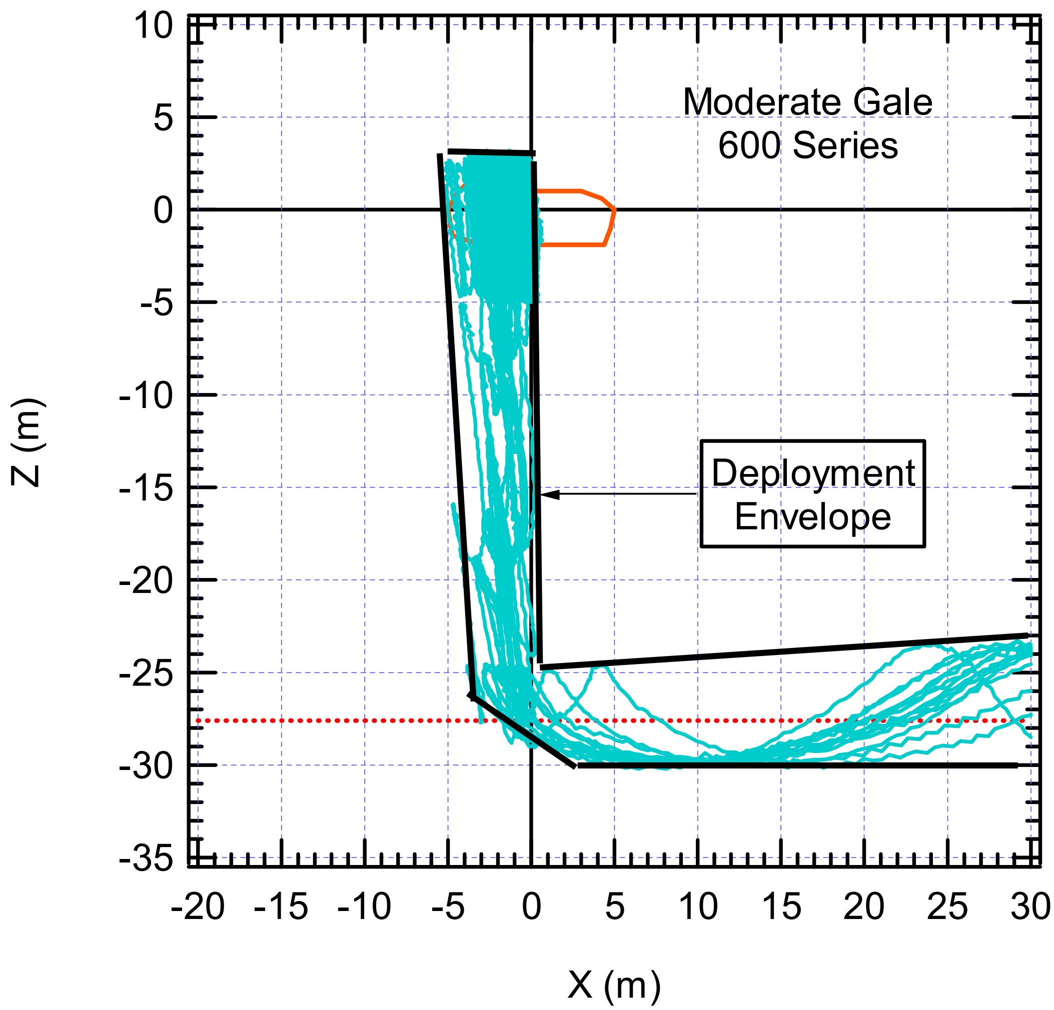

Figure 10.15 – Moderate Gale, Outboard Profile of Deployment Envelope

In general, platform motions are significant in this environmental condition. The individual deployments presented in Appendix 9, start to show oscillations in the z-axis in the range of 8 m prior to the lowering and oscillatory pendulum like motions of about 5 m amplitude in the x-axis during the lowering. The oscillatory motions are largely induced by the platform with the wind force contributing to a much smaller extent. Figures 10.14 and 10.15 show envelopes that encompass all the paths taken by the TEMPSC during the lowering and sailing away phases and capture the overall effects of weather conditions on the control of the TEMPSC path during evacuation.

The envelopes shape and size give a good indication of the degradation of TEMPSC deployment system with increase in environmental conditions and the reduction in TEMPSC control during sail-away.

Table 10.10 – Summary of Moderate Gale, Deployment Data for Twin Falls Davit System

Run Number	Deployment: Launch to Splash [s]	Deployment: Splash to Davit [s]	Deployment: Launch to Davit [s]	Boundary Crossing: Splash to Danger [s]	Boundary Crossing: Splash to Safe [s]	Boundary Crossing: Danger to Safe [s]	Boundary Crossing: Launch to Safe [s]	Travel Distance: Splash to Danger [m]	Travel Distance: Danger to Safe [m]	Average Speed: Danger Zone [knots]	Average Speed: Inter. Zone [knots]	Average Speed: Open Sea [knots]	Accelerations: Launch to Splash [g]	Accelerations: Sail away [g]	Splashdown: On Wave	Splashdown: Missed target [m]	Splashdown: Set Back [m]	Splashdown: Combined miss/set [m]
600_002	27.50	1.70	29.20	9.58	10.42	0.84	37.92	22.50	4.00	4.57	9.24	9.60	0.14	0.13	U	1.985	0.000	1.985
600_003	24.40	5.10	29.50	11.27	13.82	2.55	38.22	16.25	12.00	2.80	9.13	9.20	0.10	0.12	U	2.360	3.055	1.501
600_005	27.40	2.20	29.60	9.03	11.35	2.31	38.75	17.25	12.50	3.71	10.51	11.70	0.13	0.12	U	2.264	0.000	2.264
600_006	24.90	0.20	25.10	11.15	12.83	1.68	37.73	20.25	9.00	3.53	10.40	10.60	0.83	0.17	U	0.635	0.000	0.635
600_007	25.80	1.80	27.60	10.76	12.45	1.68	38.25	20.75	8.50	3.75	9.82	11.40	0.77	0.10	U	2.260	2.397	0.498
600_008	23.10	2.00	25.10	12.68	15.10	2.42	38.20	18.00	12.00	2.76	9.64	10.10	0.27	0.70	U	0.933	3.532	2.612
600_009	26.50	3.60	30.10	12.18	-	-	-	29.25	1.61	4.67	-	11.10	0.92	0.14	T	4.766	0.000	4.766
600_011	24.90	1.30	26.20	11.43	13.43	2.00	38.33	22.50	9.50	3.83	9.24	9.70	1.25	0.62	U	1.282	2.148	1.178
600_016	25.40	1.00	26.40	10.31	12.83	2.52	38.23	21.00	12.50	3.96	9.65	11.80	0.84	0.87	U	1.257	1.921	1.096
600_017	27.20	2.90	30.10	10.04	11.73	1.68	38.93	21.00	9.00	4.06	10.40	11.20	0.25	0.14	U	1.634	0.000	1.634
600_018	25.40	0.90	26.30	10.68	12.57	1.89	37.97	21.00	10.00	3.82	10.27	10.60	0.75	0.80	U	3.034	0.000	3.034
600_020	22.10	1.50	23.60	13.76	16.39	2.63	38.49	17.25	12.50	2.44	9.24	9.20	0.09	1.11	U	0.921	3.012	3.696
600_021	25.40	1.90	27.30	10.48	12.90	2.42	38.30	17.50	12.00	3.25	9.64	7.80	0.77	0.09	U	0.721	3.097	2.392
600_022	25.10	0.00	25.10	11.18	13.92	2.74	39.02	21.00	13.50	3.65	9.60	7.60	0.76	0.77	U	2.711	3.430	1.904

C - Crest T - Trough U - Up-slope D – Down-slope

10.3.6 **625 Series** – Fresh Gale

Twin Falls Davit System TEMPSC Deployment

The 620 series – fresh gale -- deployments were performed for the FPSO in the intact condition and for a heading of 20 degrees to the waves and 57 degrees to the wind. A total of 14 deployments were performed. The individual experiments were run following the same procedure and illustrate the twin falls davit evacuation system operation in a fresh gale. The data are for the lowering of the TEMPSC to the water surface and the sail-away to the safe boundary zone. The data collected are for both time to execute the process and the path length taken.

The fresh gale data is tabulated in Table 10.11 with the overall effect of the environment on the control of the TEMPSC during the evacuation shown in Figures 10.16 and 10.17. These are presented as envelopes encompassing the paths taken by the TEMPSC in each deployment from the lowering to the crossing of the safe boundary zone and beyond. The data for FPSO motions, TEMPSC location, wind and waves together with the detailed video analysis are presented in Appendix 9 for the individual test runs.

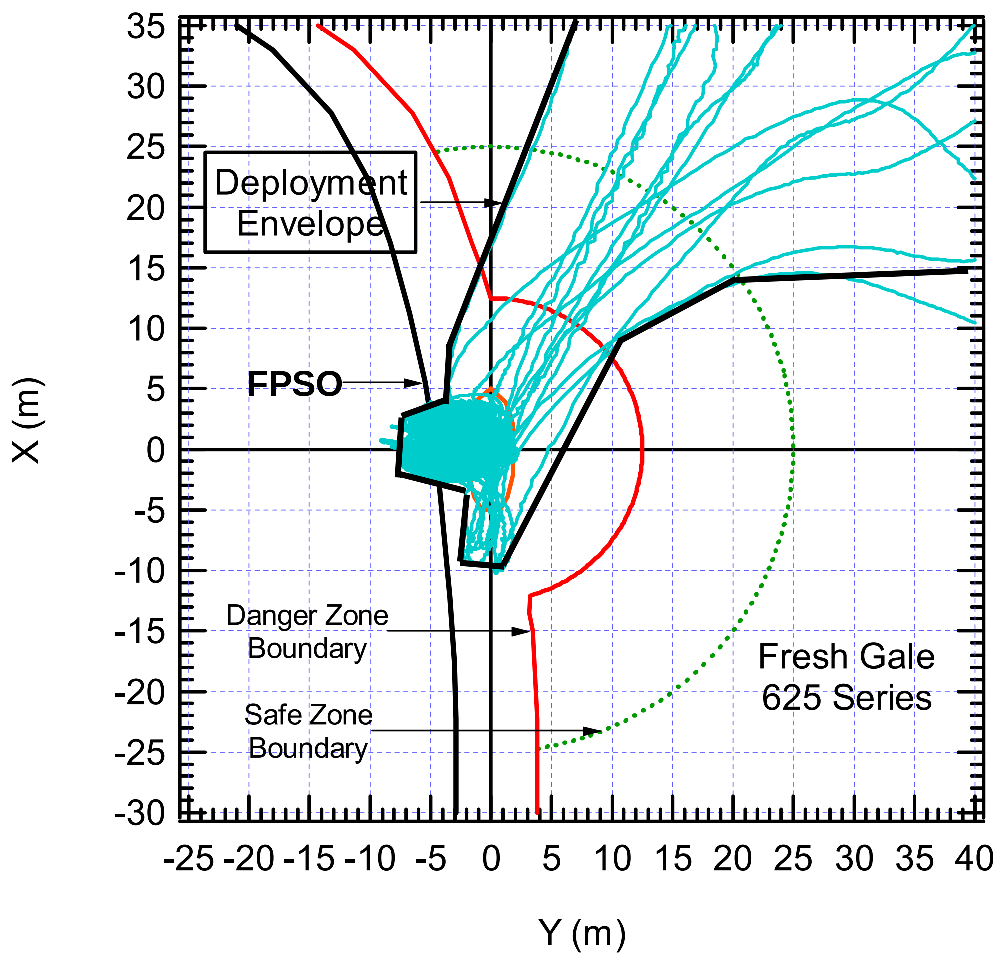

Figure 10.16 – Fresh Gale - Plan View of Deployment Envelope

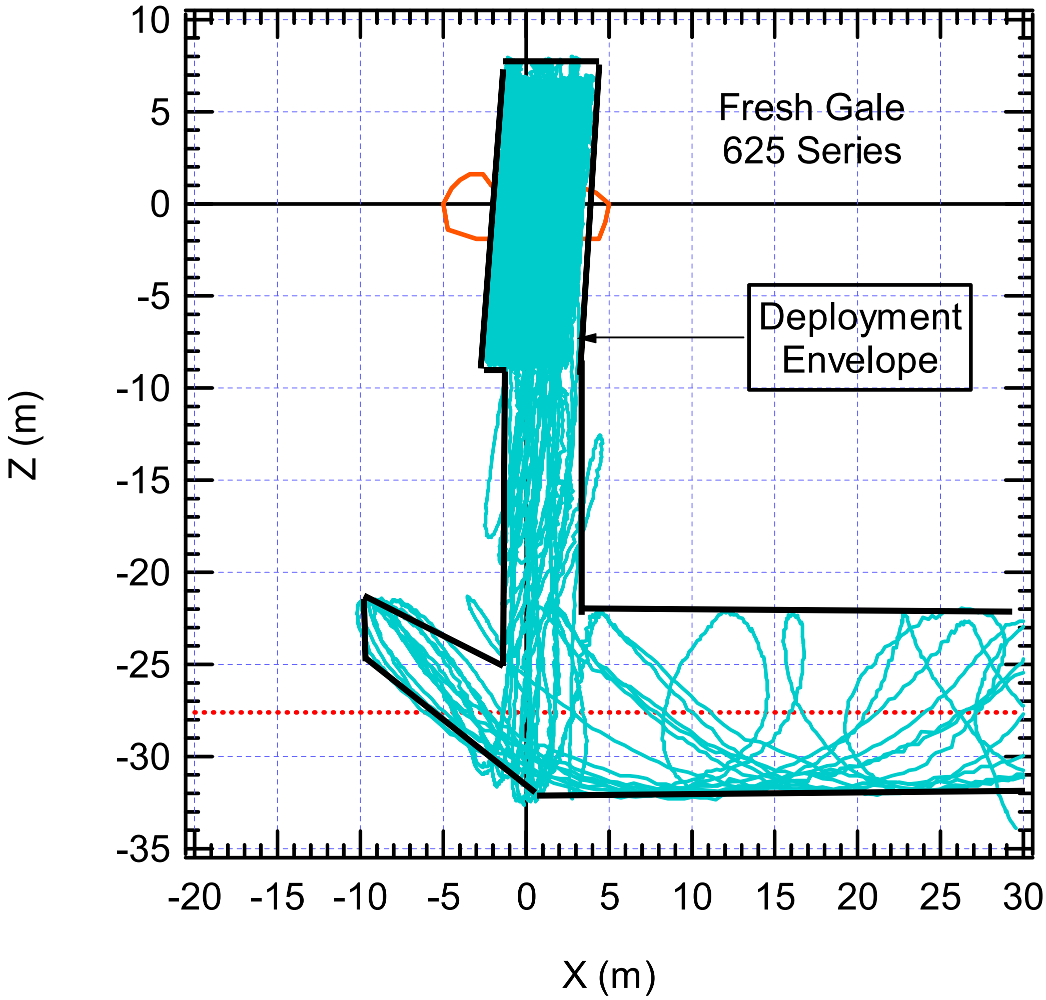

Figure 10.17 – Fresh Gale, Outboard Profile of Deployment Envelope

Platform motions are severe in this environmental condition. The individual deployments presented in Appendix 9, show oscillations in the z-axis in the range of ±8m prior to the lowering and oscillatory pendulum like motions of about 6 m or more of amplitude in the x-axis during the lowering. The oscillatory motions are induced by the FPSO with the wind force having a minor contribution. The envelopes that encompass all the paths taken by the TEMPSC during the lowering and sailing away phases are presented in Figures 10.16 and 10.17. These figures capture the overall effects of weather on the control path of the TEMPSC during evacuation. The envelopes irregular shape and size increase over the last weather series give a good indication of the rapid degradation of TEMPSC deployment system with increase in environmental conditions and the reduction in TEMPSC control during sail-away.

Table 10.11 – Summary of Fresh Gale, Deployment Data for Twin Falls Davit System

Run Number	Deployment: Launch to Splash [s]	Deployment: Splash to Davit [s]	Deployment: Launch to Davit [s]	Boundary Crossing: Splash to Danger [s]	Boundary Crossing: Splash to Safe [s]	Boundary Crossing: Danger to Safe [s]	Boundary Crossing: Launch to Safe [s]	Travel Distance: Splash to Danger [m]	Travel Distance: Danger to Safe [m]	Average Speed: Danger Zone [knots]	Average Speed: Inter. Zone [knots]	Average Speed: Open Sea [knots]	Accelerations: Launch to Splash [g]	Accelerations: Sail away [g]	Splashdown: On Wave	Splashdown: Missed target [m]	Splashdown: Set Back [m]	Splashdown: Combined miss/set [m]
625_001	26.60	1.60	28.20	6.14	8.34	2.21	34.95	20.75	12.50	6.57	11.00	11.60	0.91	1.35	T	10.456	0.000	10.456
625_004	21.00	5.40	26.40	11.35	13.56	2.21	34.56	29.50	12.50	5.05	11.01	8.50	0.32	0.26	U	6.596	6.472	11.404
625_005	24.40	2.30	26.70	6.32	8.74	2.42	33.14	21.75	15.00	6.69	12.05	10.20	1.25	0.06	T	3.448	1.423	2.392
625_006	21.90	3.00	24.90	10.66	13.08	2.42	34.98	28.00	13.00	5.11	10.45	9.60	0.51	1.30	U	7.960	13.480	10.068
625_007	25.20	0.00	25.20	23.67	33.34	9.67	58.54	44.50	19.00	3.65	3.82	4.80	0.75	0.72	T	8.963	0.000	8.963
625_008	28.90	0.10	29.00	14.23	16.33	2.10	45.23	19.50	12.50	2.66	11.55	12.30	0.17	1.48	T	2.601	0.000	2.601
625_009	24.50	5.60	30.10	8.22	10.43	2.21	34.93	25.00	12.50	5.91	11.00	9.50	0.10	0.09	T	9.265	14.062	8.644
625_011	23.10	0.90	24.00	10.13	12.34	2.21	35.44	27.50	13.00	5.28	11.45	11.00	0.04	1.45	U	6.881	6.212	11.379
625_012	21.20	3.90	25.10	11.28	13.38	2.10	34.58	29.00	12.50	5.00	11.55	7.80	0.04	1.02	U	8.175	7.886	14.687
625_013	29.10	0.70	29.80	13.40	15.71	2.31	44.81	20.50	12.50	2.97	10.51	12.70	1.17	0.12	T	2.144	0.000	2.144
625_014	23.70	1.70	25.40	8.95	11.05	2.10	34.75	24.50	12.50	5.32	11.55	13.00	0.04	0.11	T	8.853	3.556	11.074
625_017	21.20	4.10	25.30	10.00	12.00	2.00	33.20	20.00	12.50	3.89	12.16	13.10	0.02	0.05	T	3.015	4.465	6.307
625_018	25.40	1.00	26.40	6.52	8.20	1.68	33.60	16.50	10.25	4.92	11.85	13.10	0.02	0.07	T	1.682	0.744	1.307
625_019	28.90	0.20	29.10	13.84	16.25	2.41	45.15	13.00	13.00	1.83	10.47	11.40	0.68	0.98	T	2.055	0.867	2.865

C - Crest T - Trough U - Up-slope D – Down-slope

10.4 TEMPSC Deployment from FPSO – Flexible Boom System (Series 700, 725, 800)

TEMPSC deployment from the FPSO with the flexible boom evacuation system can be described as a subset, or secondary objective of the test program. Data collected for the FPSO, TEMPSC, evacuation system and environment conditions were used to evaluate the overall performance of the flexible boom system. The different series refer to TEMPSC deployments in:

700 series -- Calm Water, 20 runs

725 series -- Fresh Breeze, 19 runs

800 series – Fresh Gale, 19 runs

The test program for the TEMPSC flexible boom deployment system has a total of 58 runs analyzed of a projected total of 60. The 2 runs that were not analyzed represent runs for which data quality was poor mechanical failures due to low battery power occurred.

The data for FPSO motions, TEMPSC location, wind and waves together with the detailed video analysis are presented in Appendix 9 for the individual test runs.

10.4.3 700 Series -- Calm Water Flexible Boom TEMPSC Deployment

The 700 series – calm water -- deployments were performed for the FPSO in the intact condition and for the heading of 20 degrees to the waves and 57 degrees to the wind. A total of 20 deployments were performed. Instructions were relayed to the operator for minimal use of rudder during the initial sail-away. Compliance with this requirement insured that data for the flexible boom relating to time and path length and trajectory could be compared to the data collected for the twin falls davit system. As in the previous set of experiments no rudder angle data are available. The radio controller was calibrated such that different notches on the controller corresponded to different rudder angles. This allows the operator to consistently provide relatively similar rudder input.

The individual experiments were run following the same procedure and illustrate the flexible boom evacuation system operation in calm water. The evacuation system and TEMPSC data are for the lowering and sail-away. A plan view outlining the TEMPSC in its deployed position prior to lowering, together with the waterline of the FPSO hull and three demarked regions, (danger, intermediate and safe) are used to identify the trajectory of the TEMPSC and its path length. The figure is also used to obtain time related data for the TEMPSC crossing the different regions. An outboard profile view of the deployment is used to look at the TEMPSC oscillations during lowering and setback at splashdown.

The deployment data are summarized and tabulated in Table 10.12 with the path of the TEMPSC illustrated in Figures 10.18 and 10.19.

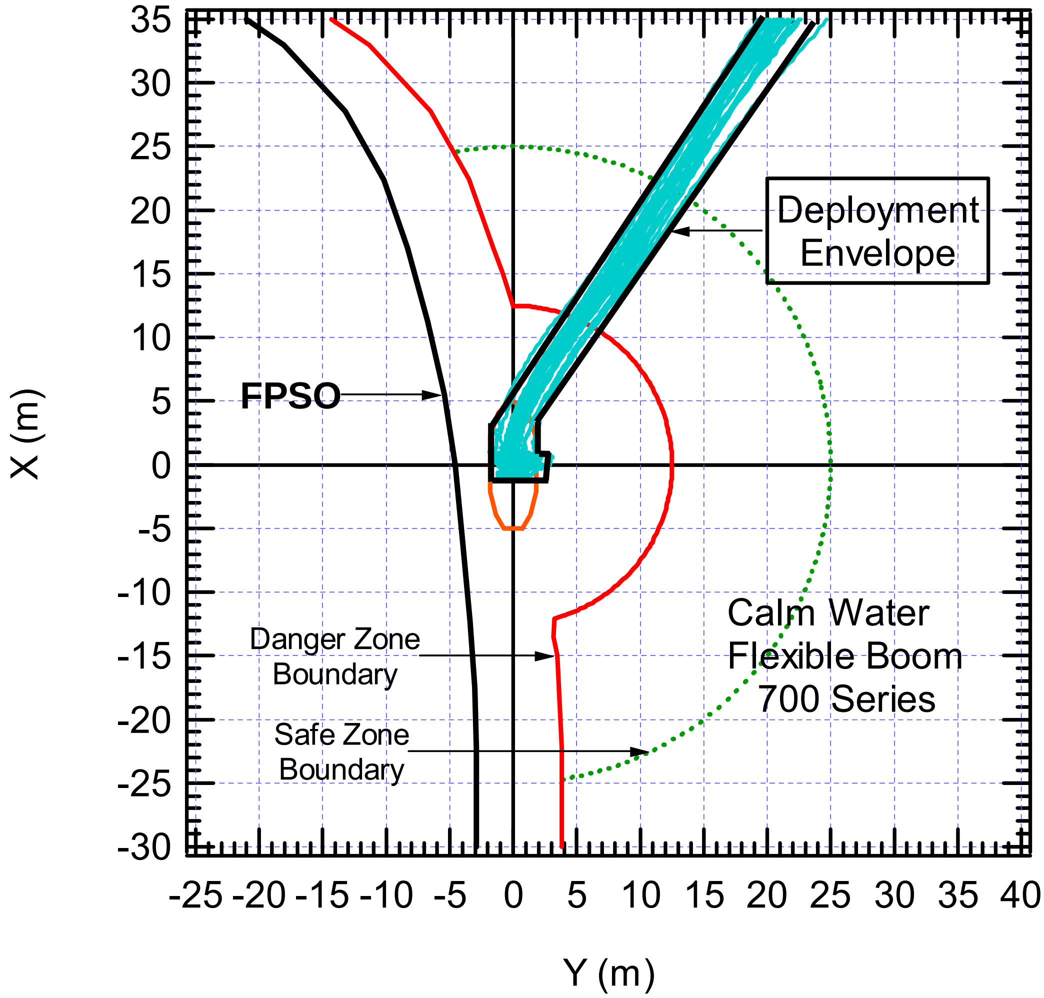

Figure 10.18 – Calm Water - Plan View of Deployment Envelope
Flexible Boom System

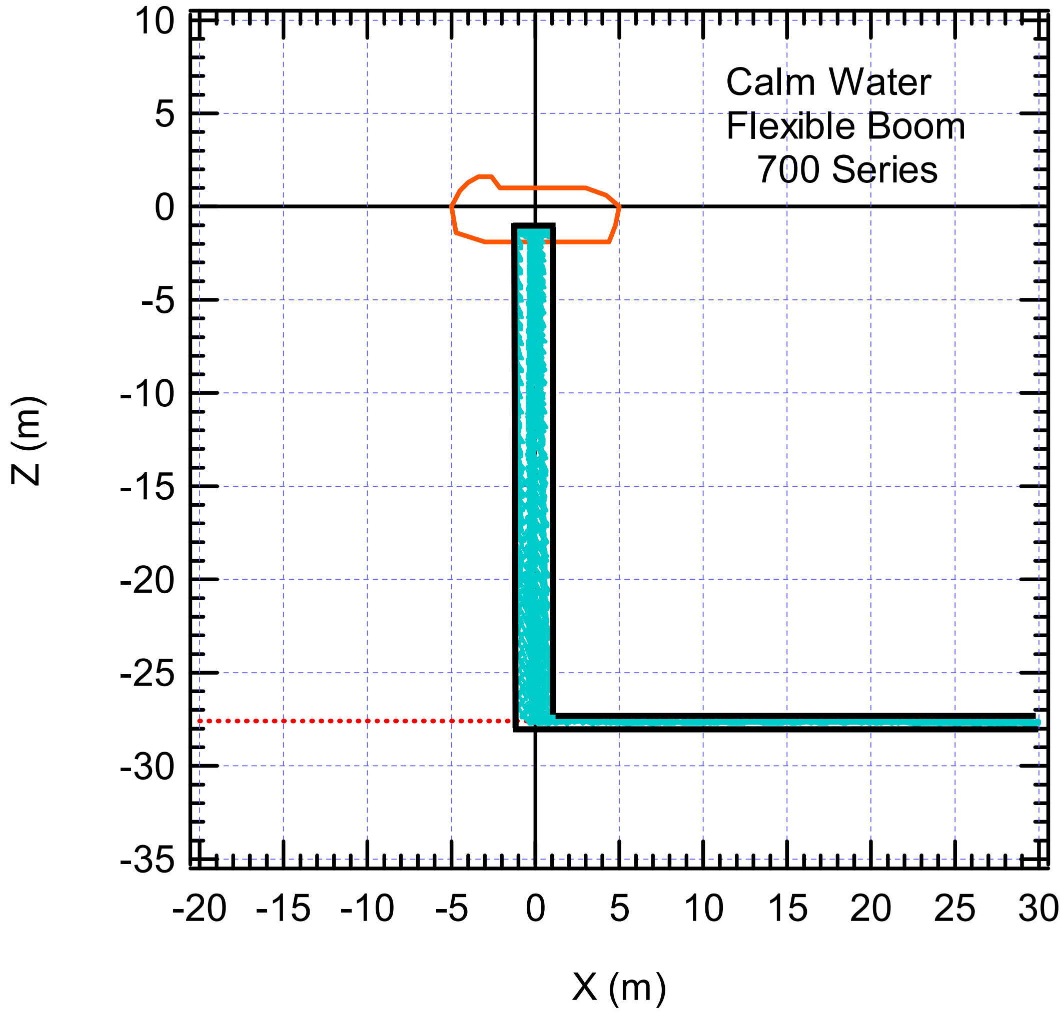

Figure 10.19 – Calm Water, Outboard Profile of Deployment Envelope

Flexible Boom System

During calm water deployments with the flexible boom system the path of the TEMPSC is simple: it goes straight down during lowering, as indicated in Figure 10.19; upon splashdown into the danger zone it sails at an angle of approximately 45^o the intermediate zone to safety, as illustrated in the Figure 10.18.

Table 10.12 – Summary of Calm Water, Deployment Data for Flexible Boom System

	Deployment						Boundary Crossing				Travel Distance		Average Speed			Accelerations		Splashdown		
Run Number	Launch to Splash [s]	Splash to Davit [s]	Splash to Tagline [s]	Davit to Tagline [s]	Launch to Davit [s]	Launch to Tagline [s]	Splash to Danger [s]	Splash to Safe [s]	Danger to Safe [s]	Launch to Safe [s]	Splash to Danger [m]	Danger to Safe [m]	Danger Zone [knots]	Inter. Zone [knots]	Open Sea [knots]	Launch to Splash [g]	Sail away [g]	Missed target [m]	Set Back [m]	Combined miss/set [m]
700_001	29.62	0.02	8.52	8.50	29.64	38.14	5.44	9.02	3.58	38.64	13.00	12.50	4.64	6.80	7.60	0.03	0.15	0.643	0.000	0.643
700_002	28.92	0.38	9.18	8.80	29.30	38.10	6.08	9.76	3.68	38.68	13.00	12.50	4.16	6.60	7.40	0.03	0.15	0.869	0.000	0.869
700_003	28.22	1.58	9.58	8.00	29.80	37.80	7.38	10.96	3.58	39.18	12.75	12.50	3.36	6.80	7.30	0.03	0.22	0.979	0.000	0.979
700_005	28.40	1.00	9.40	8.40	29.40	37.80	7.09	10.67	3.58	39.07	12.50	12.50	3.43	6.80	7.40	0.04	0.46	1.114	0.000	1.114
700_006	27.87	1.93	10.33	8.40	29.80	38.20	7.74	11.42	3.68	39.29	13.00	12.50	3.27	6.60	8.10	0.05	0.47	0.217	0.000	0.217
700_007	27.87	2.13	10.23	8.10	30.00	38.10	6.86	10.47	3.61	38.34	13.00	12.50	3.68	6.74	7.90	0.04	0.16	0.410	0.000	0.410
700_008	28.40	2.11	9.91	7.80	30.51	38.31	6.63	10.20	3.58	38.60	12.75	12.50	3.74	6.80	7.40	0.17	0.35	0.562	0.000	0.562
700_009	29.10	1.00	9.30	8.30	30.10	38.40	6.01	9.58	3.58	38.68	13.00	12.50	4.21	6.80	7.90	0.05	0.51	1.518	0.000	1.518
700_010	28.40	0.81	10.00	9.19	29.21	38.40	7.13	10.81	3.68	39.21	13.00	12.50	3.54	6.60	7.40	0.04	0.46	0.228	0.000	0.228
700_011	27.69	2.47	11.07	8.60	30.16	38.76	7.27	10.74	3.47	38.43	12.50	12.50	3.34	7.00	8.10	0.03	0.27	0.199	0.000	0.199
700_012	27.69	3.21	10.21	7.00	30.90	37.90	7.17	10.64	3.47	38.33	13.00	12.50	3.53	7.00	7.90	0.02	0.19	0.608	0.000	0.608
700_013	28.22	2.28	10.48	8.20	30.50	38.70	6.52	10.10	3.58	38.32	13.00	12.50	3.87	6.80	7.40	0.03	0.16	0.698	0.000	0.698
700_014	28.40	1.20	8.90	7.70	29.60	37.30	6.37	9.84	3.47	38.24	12.50	12.50	3.82	7.00	7.90	0.03	0.11	1.147	0.000	1.147
700_015	27.87	1.73	9.23	7.50	29.60	37.10	6.86	10.33	3.47	38.20	12.50	12.50	3.54	7.00	7.90	0.02	0.07	0.952	0.000	0.952
700_016	28.40	1.70	9.50	7.80	30.10	37.90	7.12	10.59	3.47	38.99	12.50	12.50	3.41	7.00	8.10	0.02	0.51	0.192	0.000	0.192
700_017	25.42	4.08	12.38	8.30	29.50	37.80	9.57	13.04	3.47	38.46	14.00	12.50	2.84	7.00	7.90	0.02	0.38	0.312	0.000	0.312
700_018	27.34	1.64	11.44	9.80	28.98	38.78	7.01	10.48	3.47	37.82	13.75	12.50	3.81	7.00	7.90	0.03	0.30	0.367	0.000	0.367
700_019	28.92	-0.40	8.70	9.10	28.52	37.62	5.97	9.44	3.47	38.36	13.00	12.50	4.23	7.00	7.70	0.01	0.39	0.537	0.000	0.537
700_020	28.04	1.26	10.46	9.20	29.30	38.50	6.62	10.09	3.47	38.13	13.50	12.50	3.96	7.00	7.90	0.02	0.38	0.200	0.000	0.200
700_021	27.87	2.01	9.81	7.80	29.88	37.68	7.35	10.82	3.47	38.69	14.00	12.50	3.70	7.00	7.90	0.02	0.51	1.024	0.000	1.024

10.4.3 725 Series – Fresh Breeze Flexible Boom TEMPSC Deployment

The 725 series – fresh breeze -- deployments for the flexible boom system were performed for the FPSO in the intact condition and with a heading of 20 degrees to the waves and 57 degrees to the wind. A total of 19 deployments were performed. The data is presented in plan and outboard profile views. 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. In the outboard profile view the lowering, splashdown and sail-away of the TEMPSC is illustrated. All of the individual experiments were run in similar manner and illustrate the operation of the flexible boom system in a fresh breeze.

The data presented herein are for the time to lower the TEMPSC to the water surface, the time to move the TEMPSC from splashdown point to safe zone and the path length of the TEMPSC as it moves away towards the safe boundary zone from the original splashdown point. The series 725 data is tabulated in Table 10.11. The overall effect of the environment on the control of the TEMPSC during the evacuation is shown in Figures 10.20 and 10.21 as envelopes encompassing the paths taken by the TEMPSC in each deployment. The two figures capture the overall effects of weather conditions on the control of the TEMPSC path during evacuation.

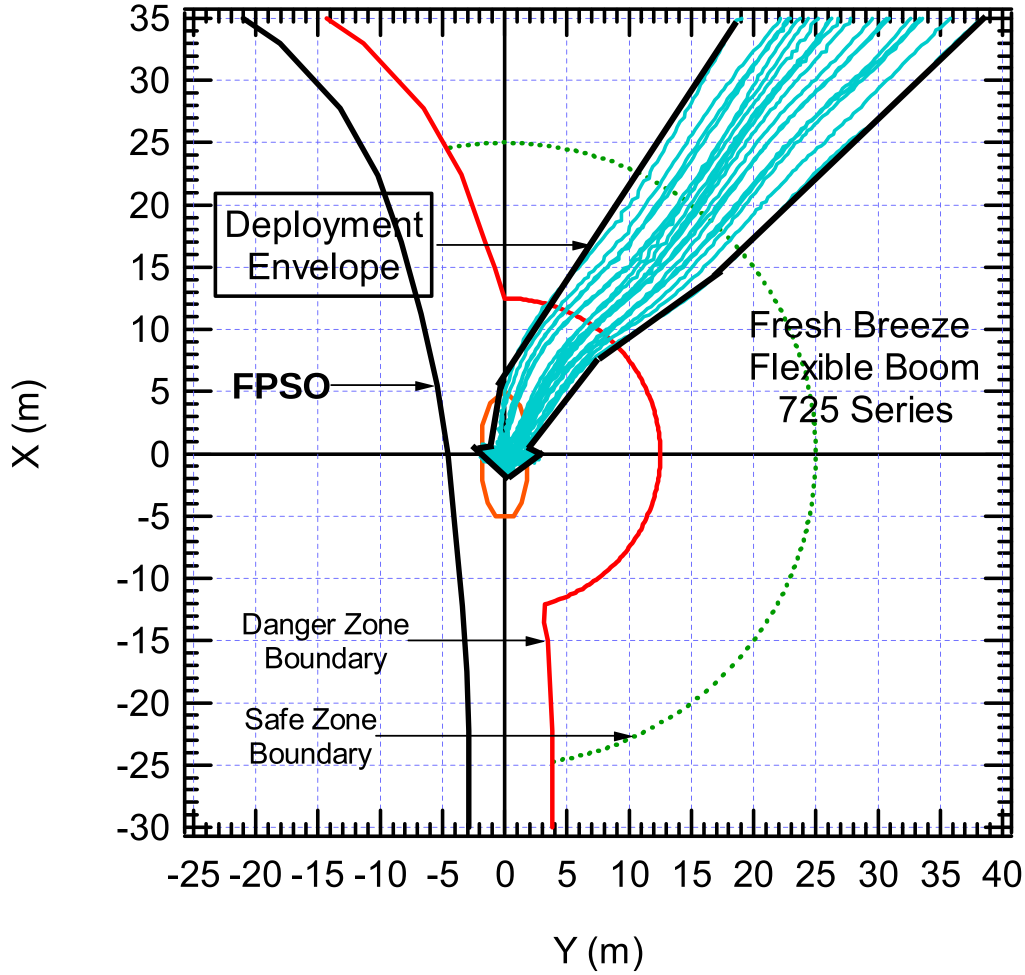

Figure 10.20 – Fresh Breeze- Plan View of Deployment Envelope
Flexible Boom System

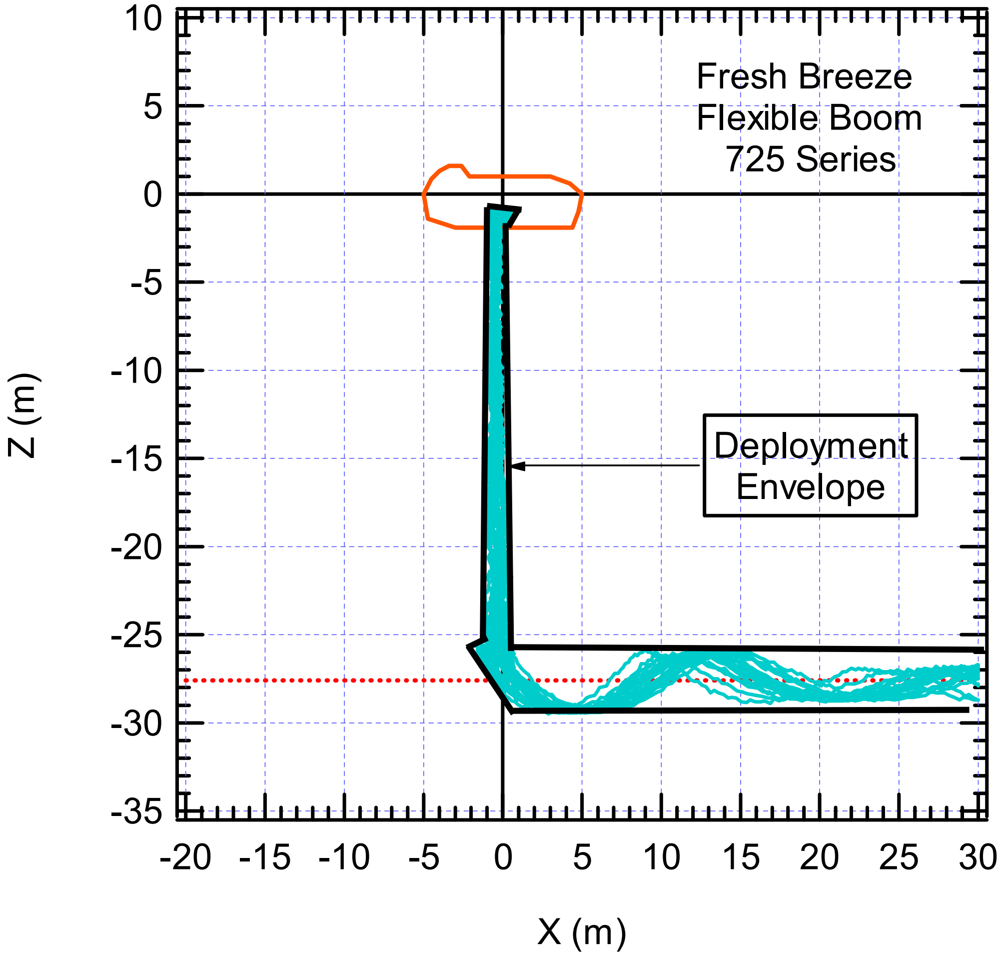

Figure 10.21 – Fresh Breeze, Outboard Profile of Deployment Envelope Flexible Boom System

In general, platform motions do not appear to be significant in this environmental condition. The individual deployments presented in Appendix 9, shown minimal oscillations during the lowering as the TEMPSC 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.

During the fresh breeze deployments with the flexible boom system the path of the TEMPSC is simple: straight down with minimal motion during lowering, as indicated in Figure 10.21; upon splashdown into the danger zone it sails at an angle of approximately 45^{o} the intermediate zone to safety, as illustrated in the Figure 10.20. The increase in weather from calm to fresh breeze manifest itself in the increased with of the plan view deployment envelope which indicates reduction of TEMPSC control during sail-away.

Table 10.13 – Summary of Fresh Breeze, Deployment Data for Flexible Boom System

	Deployment						Boundary Crossing				Travel Distance		Average Speed			Accelerations		Splashdown			
Run Number	Launch to Splash [s]	Splash to Davit [s]	Splash to Tagline [s]	Davit to Tagline [s]	Launch to Davit [s]	Launch to Tagline [s]	Splash to Danger [s]	Splash to Safe [s]	Danger to Safe [s]	Launch to Safe [s]	Splash to Danger [m]	Danger to Safe [m]	Danger Zone [knots]	Inter. Zone [knots]	Open Sea [knots]	Launch to Splash [g]	Sail away [g]	On Wave	Missed target [m]	Set Back [m]	Combined miss/set [m]
725_002	27.90	0.90	11.60	10.70	28.80	39.50	9.33	12.90	3.58	40.80	14.50	12.25	3.02	6.66	5.90	0.08	0.22	C	0.564	0.813	1.339
725_003	26.50	0.00	9.00	9.00	26.50	35.50	5.88	9.56	3.68	36.06	13.50	12.75	4.47	6.73	9.50	0.04	0.09	C	0.303	0.000	0.303
725_004	29.40	1.50	7.80	6.30	30.90	37.20	8.97	12.65	3.68	42.05	13.00	12.25	2.82	6.47	7.40	0.06	0.14	C	0.632	0.000	0.632
725_005	26.80	0.00	8.60	8.60	26.80	35.40	7.27	10.85	3.58	37.65	13.50	13.00	3.61	7.07	8.40	0.02	0.11	C	0.261	0.000	0.261
725_006	25.60	1.10	9.80	8.70	26.70	35.40	7.70	11.27	3.58	36.87	12.75	12.50	3.22	6.80	8.50	0.12	0.51	C	0.297	0.000	0.297
725_007	30.00	-2.50	11.90	14.40	27.50	41.90	8.39	12.18	3.79	42.18	13.00	12.50	3.01	6.42	8.20	0.12	0.27	T	1.243	0.000	1.243
725_008	29.80	-0.30	10.30	10.60	29.50	40.10	8.01	11.59	3.58	41.39	14.75	12.50	3.58	6.80	8.80	0.07	0.11	U	0.706	0.987	0.340
725_009	28.70	1.00	11.60	10.60	29.70	40.30	8.17	11.54	3.37	40.24	14.25	12.50	3.39	7.22	8.10	0.10	0.13	U	0.454	0.561	0.982
725_010	28.20	0.80	10.60	9.80	29.00	38.80	8.50	12.07	3.58	40.27	14.00	12.50	3.20	6.80	8.10	0.11	0.11	C	0.506	0.833	1.170
725_011	29.30	-2.20	11.10	13.30	27.10	40.40	9.55	13.23	3.68	42.53	13.25	12.50	2.70	6.60	7.70	0.06	0.17	T	0.627	1.047	0.763
725_013	30.30	-1.10	12.20	13.30	29.20	42.50	9.47	13.05	3.58	43.35	13.00	12.75	2.67	6.93	7.50	0.06	0.38	T	1.987	0.000	1.987
725_014	26.50	1.40	9.70	8.30	27.90	36.20	6.41	9.99	3.57	36.49	13.25	12.50	4.02	6.80	9.00	0.08	0.14	C	0.151	0.000	0.151
725_016	28.00	1.70	10.50	8.80	29.70	38.50	7.69	11.06	3.36	39.06	13.50	12.50	3.41	7.22	8.40	0.09	0.09	C	0.470	0.237	0.626
725_017	26.80	1.30	9.20	7.90	28.10	36.00	6.54	10.12	3.58	36.92	14.00	13.00	4.16	7.07	8.70	0.08	0.02	C	0.421	0.000	0.421
725_018	27.20	0.80	11.20	10.40	28.00	38.40	7.67	11.03	3.37	38.23	14.25	12.50	3.61	7.22	8.40	0.11	0.06	C	0.349	0.537	0.886
725_019	28.90	1.20	10.90	9.70	30.10	39.80	9.38	12.85	3.47	41.75	13.75	12.50	2.85	7.00	8.00	0.06	0.11	U	0.349	1.454	1.253
725_020	27.30	4.50	11.30	6.80	31.80	38.60	7.71	11.29	3.58	38.59	13.50	12.50	3.40	6.80	8.40	0.08	0.06	C	0.196	0.454	0.457
725_021	26.30	0.90	8.80	7.90	27.20	35.10	5.56	9.24	3.68	35.54	13.50	13.25	4.72	7.00	8.60	0.11	0.09	D	0.292	0.000	0.292
725_022	26.50	0.20	9.60	9.40	26.70	36.10	6.41	9.99	3.58	36.49	13.25	13.00	4.02	7.07	8.40	0.12	0.42	C	0.036	0.000	0.036

C - Crest T - Trough U - Up-slope D – Down-slope

10.4.3 800 Series – Fresh Gale

Flexible Boom TEMPSC Deployment

The 800 series – fresh gale -- deployments for the flexible boom system were performed for the FPSO in the intact condition and with a heading of 20 degrees to the waves and 57 degrees to the wind. A total of 19 deployments were performed. The individual experiments were run following the same procedure and illustrate the flexible boom evacuation system operation in a fresh gale. The data are for the lowering of the TEMPSC to the water surface and the sail-away to the safe boundary zone. The data collected are for both the time to carry out the process and the path length taken to accomplish it.

The fresh gale data is tabulated in Table 10.14 with the overall effect of the environment on the control of the TEMPSC during the evacuation shown in Figures 10.22 and 10.23. These are presented as envelopes encompassing the paths taken by the TEMPSC in each deployment from the lowering to the crossing of the safe boundary zone and beyond. The data for FPSO motions, TEMPSC location, wind and waves together with the detailed video analysis are presented in Appendix 9 for the individual test runs.

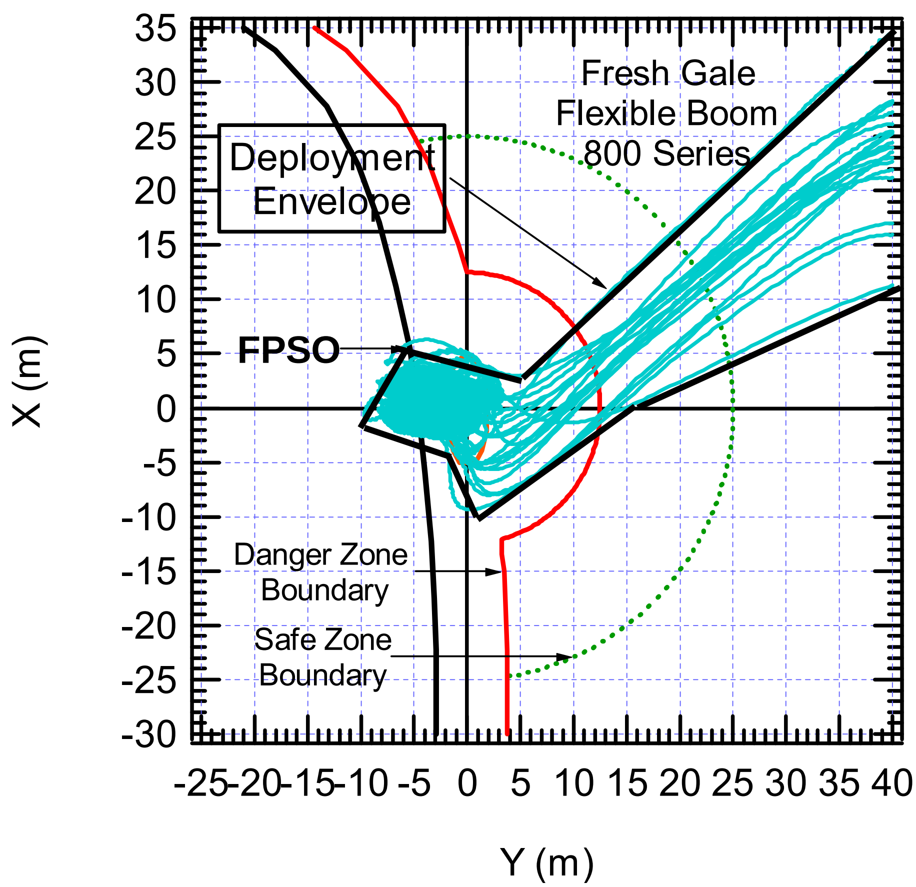

Figure 10.22 – Fresh Gale, Plan View of Deployment Envelope, Flexible Boom System

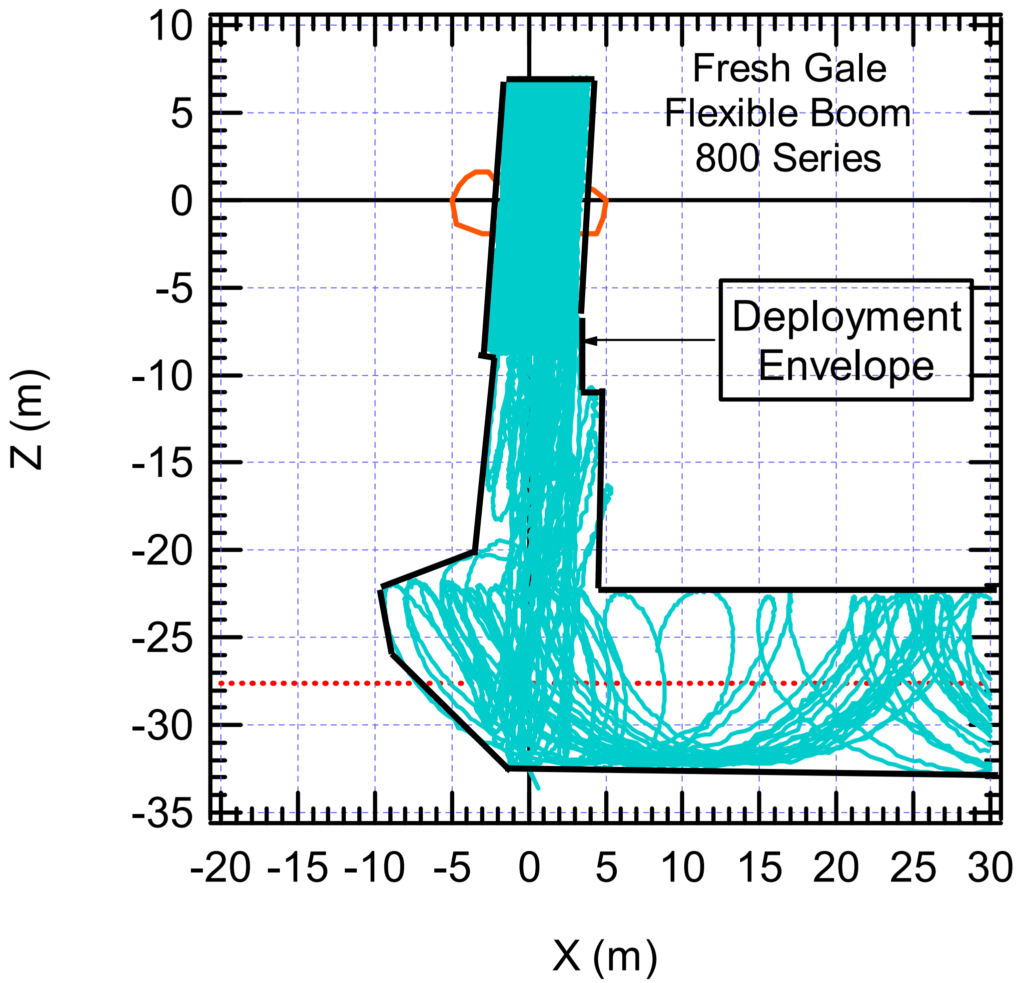

Figure 10.23 – Fresh Gale, Outboard Profile of Deployment Envelope

Flexible Boom System

Platform motions are severe in this environmental condition. The individual deployments presented in Appendix 9, show oscillations in the z-axis in the range of ±8m prior to the lowering and oscillatory pendulum like motions of about 5 m or more of amplitude in the x-axis during the lowering. The oscillatory motions are induced by the FPSO with the wind force having a minor contribution.

Table 10.14 – Summary of Fresh Gale, Deployment Data for Flexible Boom System

Run Number	Deployment: Launch to Splash [s]	Deployment: Splash to Davit [s]	Deployment: Splash to Tagline [s]	Deployment: Davit to Tagline [s]	Deployment: Launch to Davit [s]	Deployment: Launch to Tagline [s]	Boundary Crossing: Splash to Danger [s]	Boundary Crossing: Splash to Safe [s]	Boundary Crossing: Danger to Safe [s]	Boundary Crossing: Launch to Safe [s]	Travel Distance: Splash to Danger [m]	Travel Distance: Danger to Safe [m]	Average Speed: Danger Zone [knots]	Average Speed: Inter. Zone [knots]	Average Speed: Open Sea [knots]	Accelerations: Launch to Splash [g]	Accelerations: Sail away [g]	Splashdown: On Wave	Splashdown: Missed target [m]	Splashdown: Set Back [m]	Splashdown: Combined miss/set [m]
800_001	22.60	1.20	11.90	10.70	23.80	34.50	7.75	10.17	2.42	32.77	18.25	14.25	4.58	11.45	12.80	0.08	1.41	U	6.321	5.443	11.578
800_002	26.80	1.50	8.40	6.90	28.30	35.20	2.64	5.37	3.80	32.17	15.50	13.50	11.43	6.91	11.80	0.09	1.12	U	9.471	0.086	9.418
800_003	22.80	1.30	10.70	9.40	24.10	33.50	6.14	6.14	6.30	28.94	16.00	13.00	5.07	4.01	12.80	0.09	0.97	U	6.738	1.937	8.611
800_005	28.60	-0.50	12.80	13.30	28.10	41.40	13.74	16.05	2.31	44.65	21.50	12.50	3.04	10.50	13.30	0.60	1.08	T	3.837	6.635	4.030
800_006	24.90	1.20	11.30	10.10	26.10	36.20	2.94	8.19	5.70	33.10	16.50	14.50	10.93	4.95	10.80	0.08	0.70	U	8.700	3.305	11.982
800_007	23.30	-0.70	10.60	11.30	22.60	33.90	6.32	8.64	2.31	31.94	18.50	13.00	5.69	10.92	13.00	0.04	0.97	U	6.386	3.545	9.664
800_008	31.40	0.20	13.80	13.60	31.60	45.20	11.10	14.25	3.16	45.65	23.50	12.50	4.12	7.70	10.30	0.17	0.94	T	4.776	0.463	5.131
800_009	27.30	0.10	11.80	11.70	27.40	39.10	4.21	6.32	2.10	33.62	12.50	12.50	5.77	11.55	13.70	0.91	0.17	T	4.375	0.000	4.375
800_010	25.90	0.50	12.80	12.30	26.40	38.70	4.64	7.16	3.90	33.06	13.50	13.00	5.66	6.48	13.30	0.62	0.85	T	7.429	2.708	9.991
800_011	30.00	0.10	13.20	13.10	30.10	43.20	10.85	13.90	3.05	43.90	26.25	12.25	4.70	7.81	9.60	0.12	0.96	T	2.631	0.000	2.631
800_012	27.30	0.60	13.00	12.40	27.90	40.30	3.13	6.18	3.80	33.48	17.00	12.50	10.56	6.39	10.90	0.81	0.16	U	8.279	0.464	8.727
800_013	33.65	0.52	13.85	13.32	34.18	47.50	8.61	11.55	2.94	45.21	37.50	12.25	8.47	8.09	10.60	0.21	1.21	T	5.623	0.194	5.776
800_014	28.00	0.90	12.80	11.90	28.90	40.80	2.81	5.23	3.10	33.23	11.00	12.50	7.60	7.84	12.30	0.97	0.06	T	9.711	0.140	9.624
800_015	23.80	4.60	23.90	19.30	28.40	47.70	17.55	20.92	3.37	44.72	29.50	12.50	3.27	7.22	10.50	0.06	0.90	T	8.540	0.084	8.623
800_016	23.50	0.90	9.80	8.90	24.40	33.30	5.88	8.61	2.73	32.11	17.00	12.50	5.62	8.88	9.70	0.09	1.36	U	6.979	1.561	8.537
800_017	23.10	0.30	9.90	9.60	23.40	33.00	6.71	8.92	2.21	32.02	16.75	13.00	4.85	11.44	12.90	0.08	1.05	U	7.658	2.184	9.833
800_018	23.50	0.30	11.20	10.90	23.80	34.70	5.57	9.26	3.68	32.76	18.50	14.50	6.45	7.66	12.30	0.08	0.94	U	8.800	4.057	12.857
800_020	28.30	-1.40	10.30	11.70	26.90	38.60	1.95	4.79	4.50	33.09	13.00	13.00	12.97	5.62	12.90	0.69	1.05	T	11.429	0.000	11.429
800_021	23.00	0.50	11.70	11.20	23.50	34.70	5.78	8.41	2.63	31.41	17.00	13.25	5.72	9.80	11.80	0.04	1.09	T	5.865	2.939	8.752
900_006	23.10	3.20	11.40	8.20	26.30	34.50	6.62	8.72	2.10	31.83	12.75	13.25	3.74	12.25	12.80	0.07	1.07	U	6.284	2.694	8.915

C - Crest T - Trough U - Up-slope D – Down-slope

11.0 CONCLUSIONS

The work presented in this report has two main concerns: to evaluate TEMPSC evacuation capabilities as a function of weather conditions; evaluate the use of model testing as a tool for such safety studies.

The model experiment program was carried out using a 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. The evacuation systems were adequate model of the prototypes as every effort was made to scale as many components as possible for the tests.

The FPSO was set with heading of 20 degrees to the waves and 57 degrees to the wind for environmental conditions ranging from calm to Beaufort 8. The davit and the boom-assisted systems were tested over the above range of weather conditions and their performance found to deteriorate as weather conditions worsened.

The motion characteristics of the FPSO selected for these series of experiments compare well to those of other similar hull designs thus ensuring that the TEMPSC deployments were performed from a realistic platform.

Model tests proved to be a suitable tool for the investigation. Indeed, where extreme weather events are of interest, physical 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 will 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 would 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.

Several measures of performance are proposed and these are used to quantify the relationship between weather and the evacuation system's capabilities.

The test results for each series are summarized as the minimum, maximum, mean, and mean $\pm$ 1 standard deviation for different performance measures and plotted against the corresponding mean weather conditions.

The twin falls evacuation missed target data from all six-test series is plotted against mean wave height and illustrated in Figure 11.1. Also shown in this figure 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. One performance measure is shown in each of the next 10 figures.

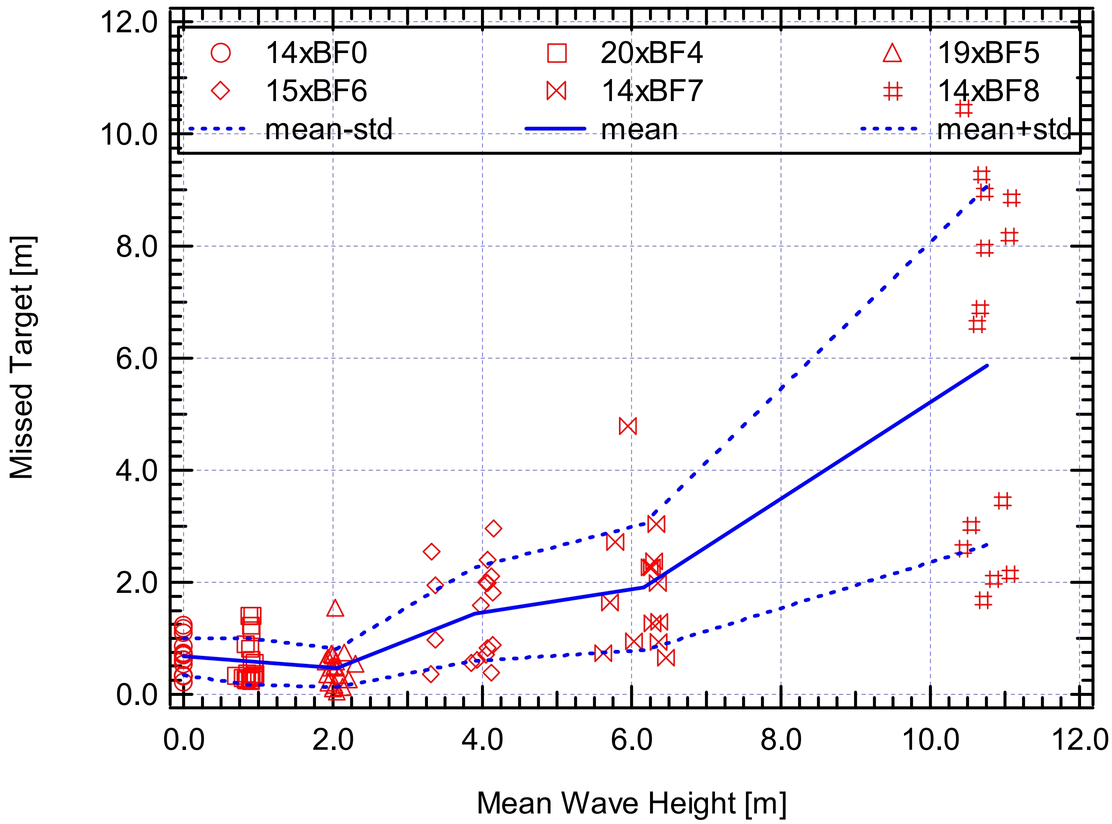

Figure 11.1 – Missed Target in Different Environments

The mean time from the start of lowering to splashdown is shown on Figure 11.2. Since 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 either wave up-slopes or wave crests, in matter of fact, of the 120 deployments in waves 80 took place at either wave up-slope or wave crest. This would effectively reduce the lowering distance, and consequently the time.

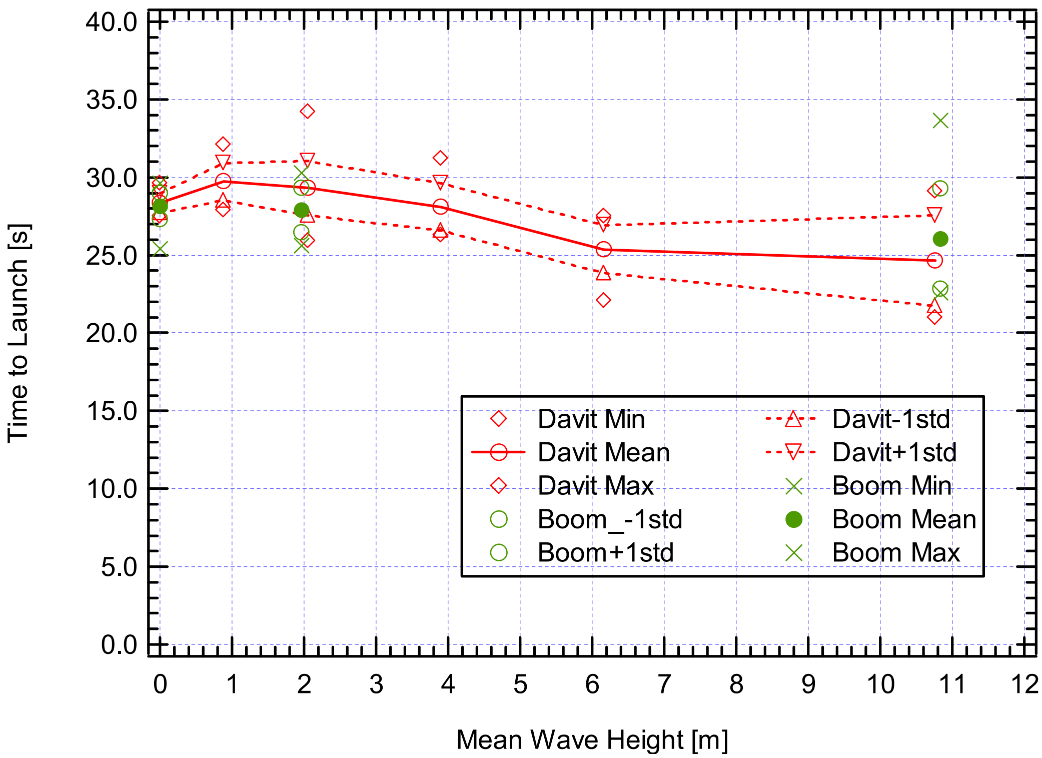

Figure 11.2 – Mean Time from Start of Launch to Splashdown

The time taken to release the falls after splashdown is presented in Figure 11.3. 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 prior to splashdown. This situation developed when a wave crest hit the TEMPSC. This sent a signal to the falls to be released, but as the wave crest passed the TEMPSC became air borne once again. There is a mechanical delay from the time 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 incoming wave speed, platform motion, TEMPSC lowering speed, and falls mechanical delay results in these unique cases. The TEMPSC subsequently dropped in free fall into a trough for splashdown.

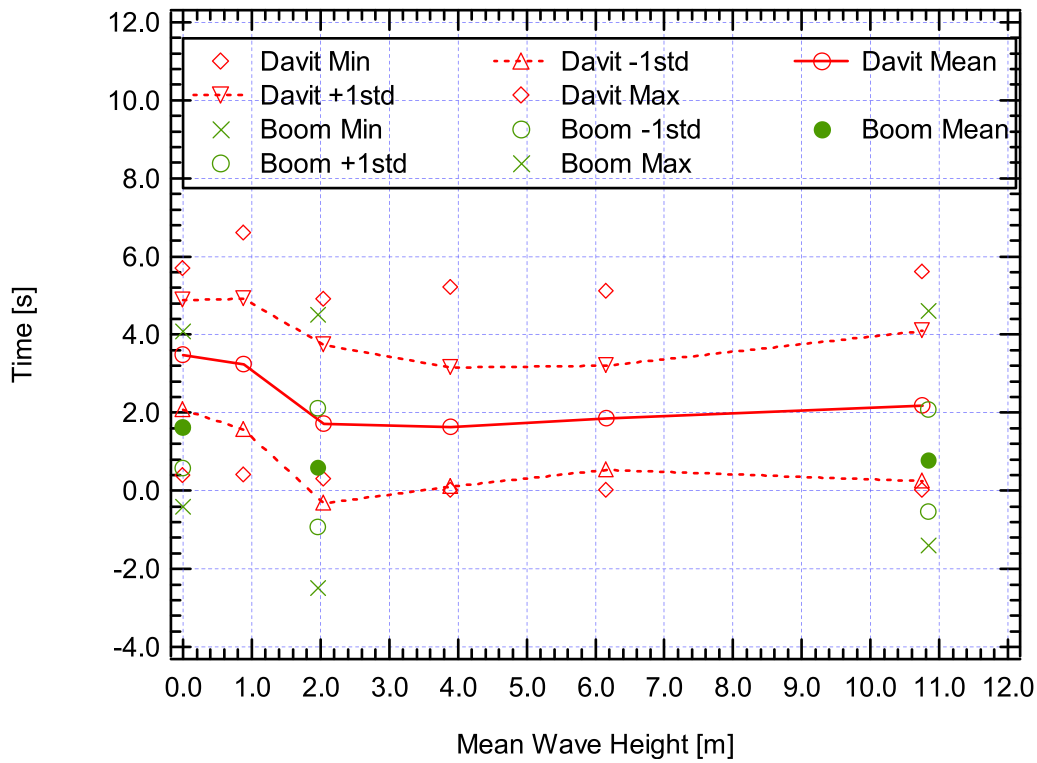

Figure 11.3 – Time from Splashdown to Davit Release

In this next figure, Figure 11.4, the time taken by the TEMPSC to cross the safe boundary zone from the splashdown is studied. It is clear that there is little weather dependency, and 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 wave's down-slopes. A simpler explanation may be that the propeller speed control was coarse and provided poor rpm control. This is a model setup deficiency rather than a TEMPSC weakness.

The distance covered by the TEMPSC as it cleared the danger zone after splashdown is presented in Figure 11.5. That distance traveled increase 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 in Appendix 9, shows that this effect is most common just after splashdown when the TEMPSC is accelerating. Once the TEMPSC is at speed, the weather has less effect on its ability to make way. This interpretation is reinforced by the plot in Figure 11.6, which shows the distance covered by the TEMPSC 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.

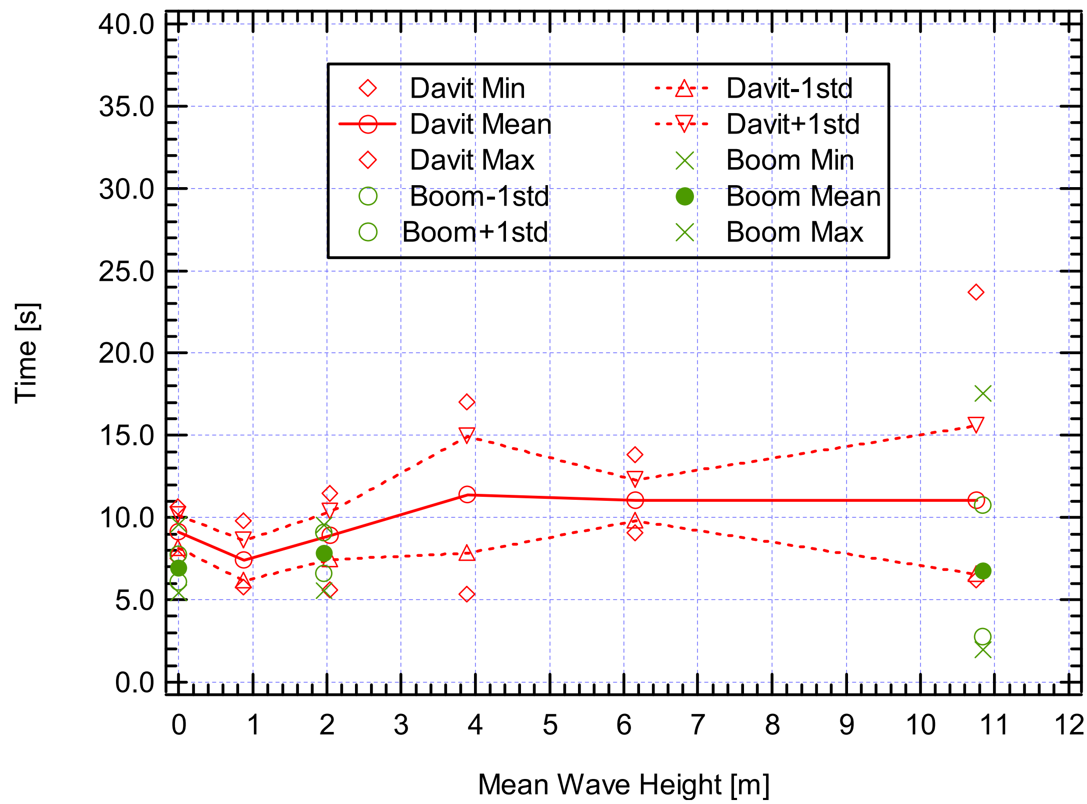

Figure 11.4 - Time from Splashdown to Safety zone

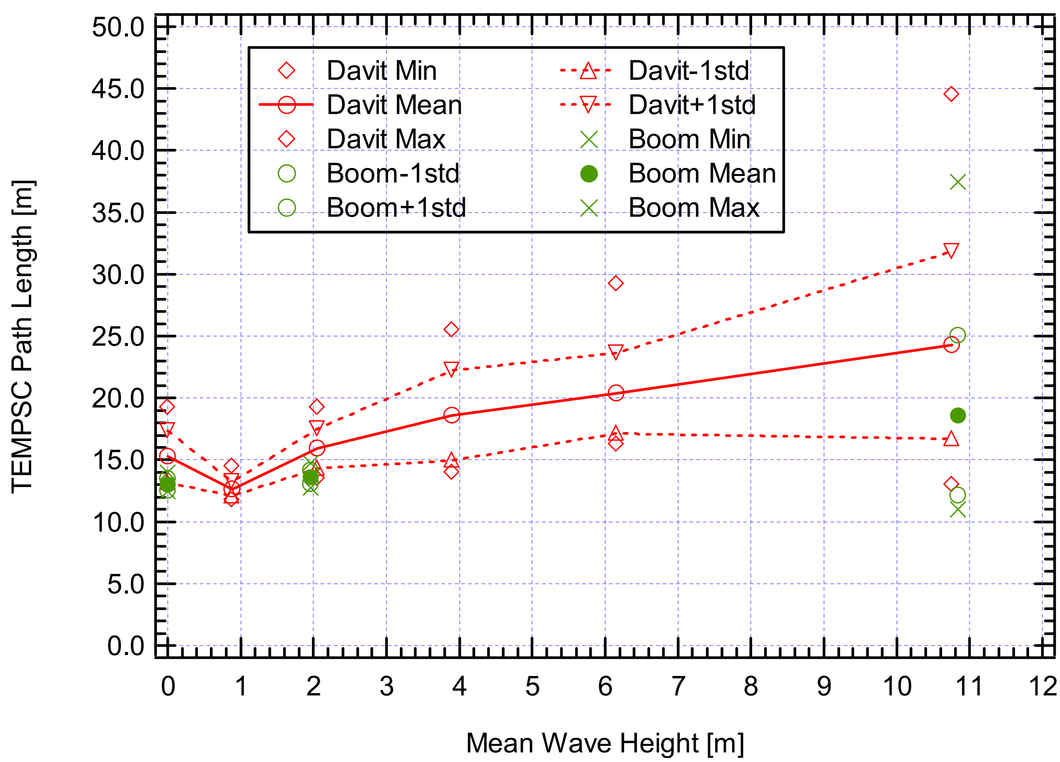

Figure 11.5 - TEMPSC Path Length from Splashdown to Safety Boundary Zone

The effect of the boom can be seen in Figure 11.5. 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 splashdown. Any advantage of the boom over the basic system is lost once the tagline is released.

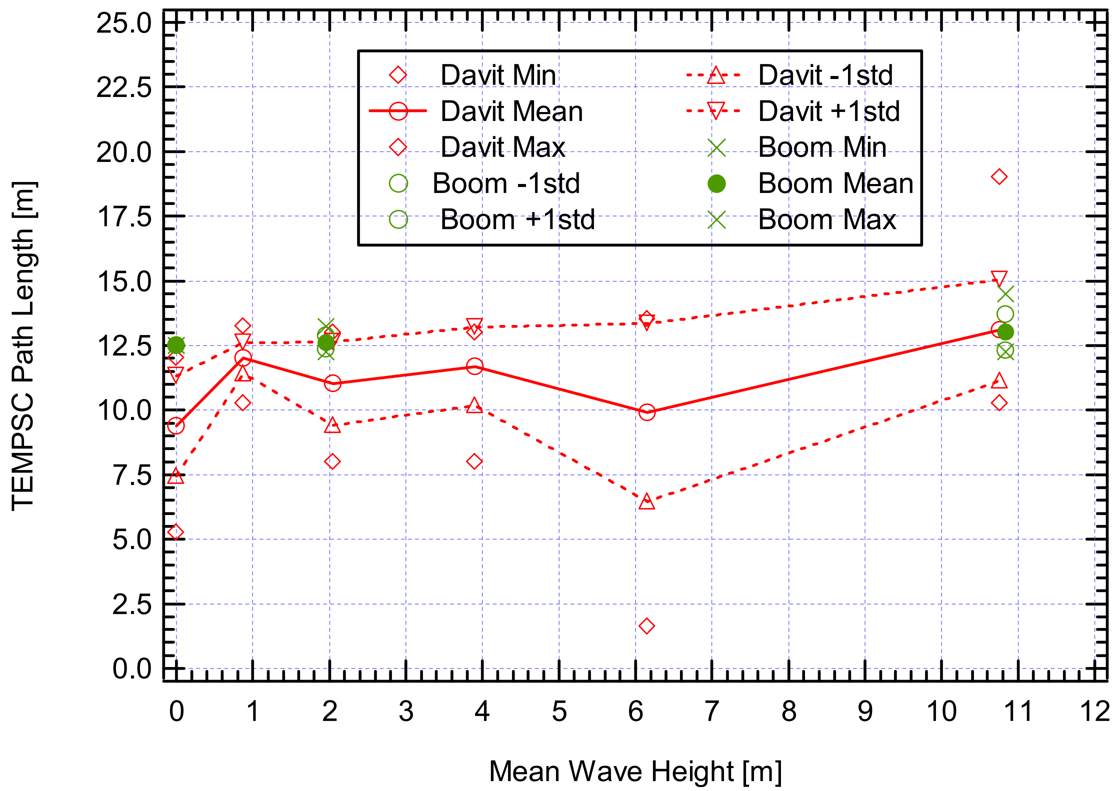

Figure 11.6 - TEMPSC Path Length from Danger to Safety Zone.

A comparison of the two systems in the figure above (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.

The weather effect on the launch performance in terms of the combination of missed target plus setback position is illustrated in Figure 11.7. Target here is defined as the point under the davit at the start of lowering and setback as the backwards movement of the TEMPSC after splashdown due to the incoming wave. Ideally, the distance between the target and splashdown is zero. The figure shows that the extent that the target is missed and the TEMPSC is setback increases with increasing weather, as might be expected. In practical terms this is to be avoided or mitigated, as excessive movement of the TEMPSC towards the FPSO can result in collisions. The combination of missed target plus setback position is presented in terms of distance in the XY plane.

In the figure it seems that the boom does not reduce missed target but plays a significant role in reducing set back. 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.

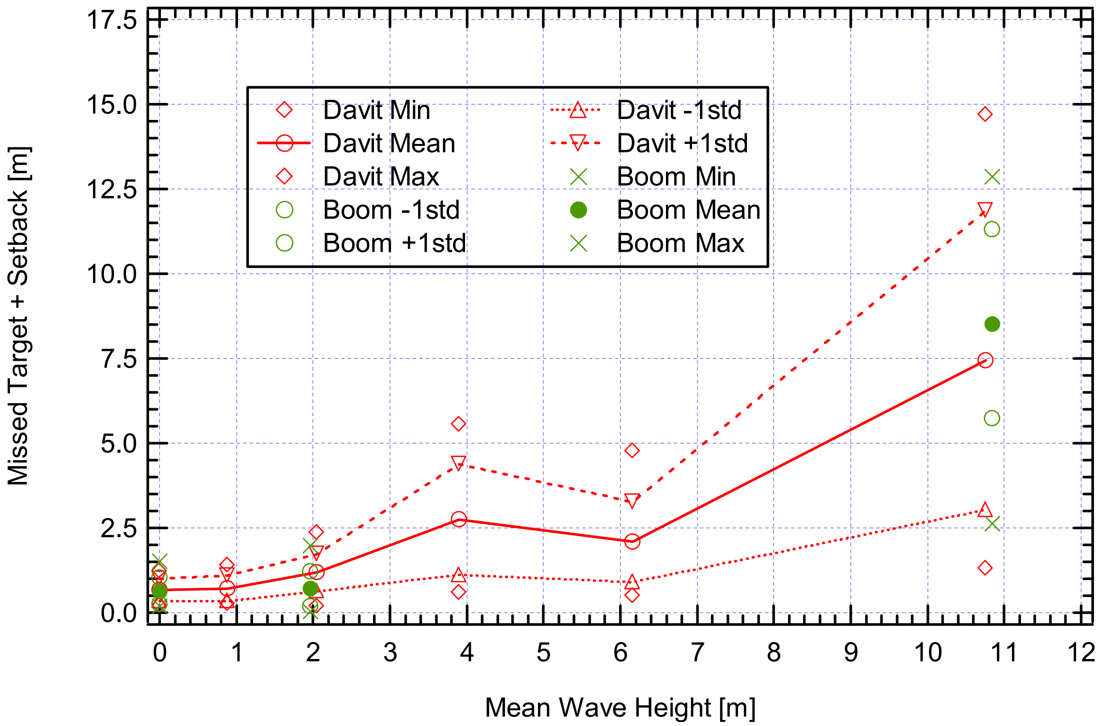

Figure 11.7 - Missed Target + Setback

The lateral accelerations measured in the TEMPSC during sail away are summarized in Figure 11.8. As expected, accelerations increase with weather. The most interesting feature of this figure 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.

The oscillation angles of the TEMPSC during deployment are shown in Figure 11.9. 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.

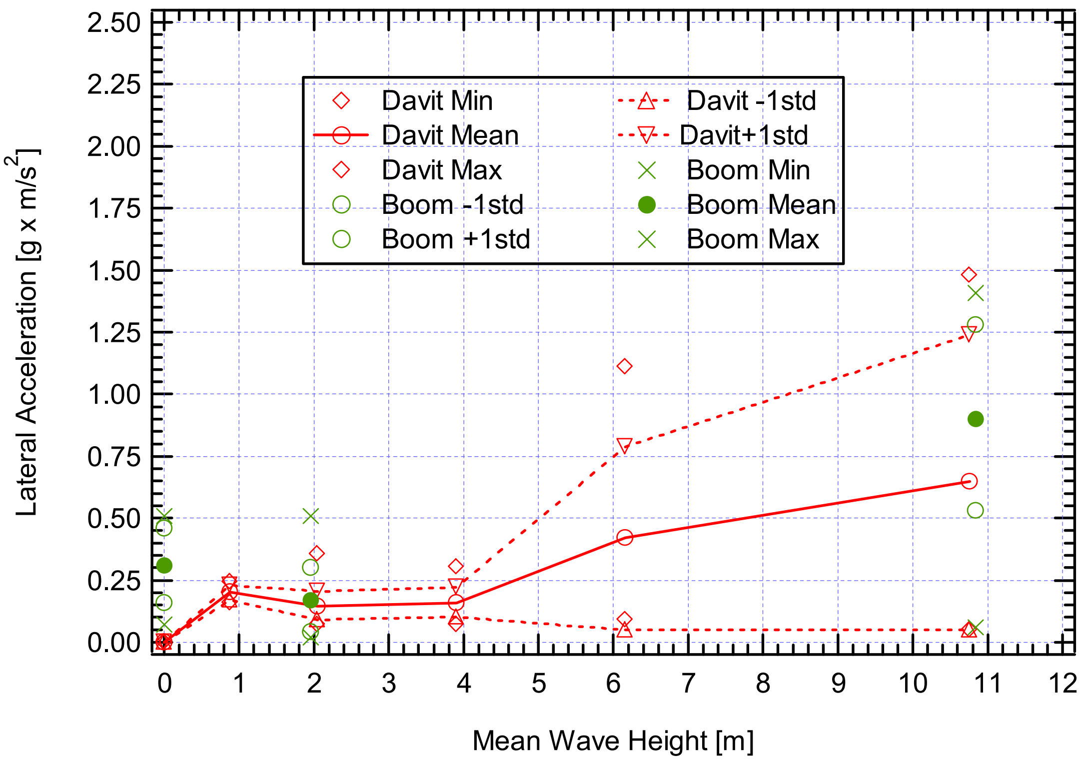

Figure 11.8 – Lateral Accelerations During Sail-away

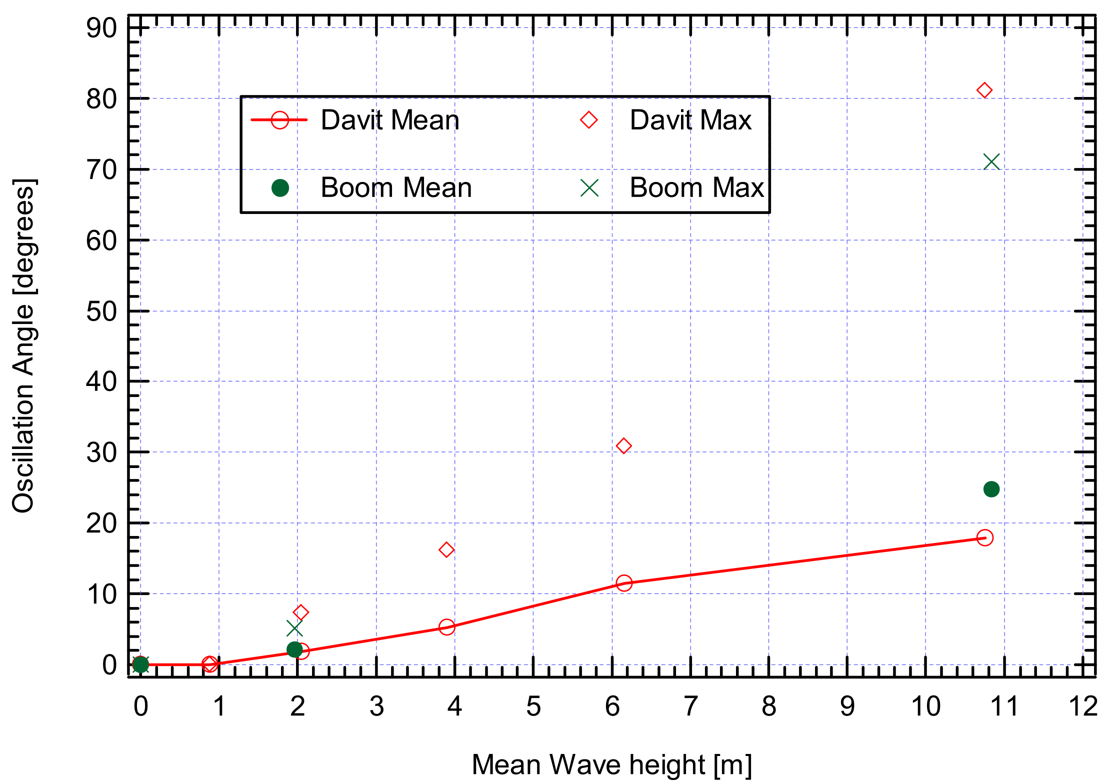

Figure 11.9 – Oscillation Angles During TEMPSC Lowering

The overall effects of weather conditions on the control of the TEMPSC path during evacuation are summarized in Figure 11.10. The figure shows generalized envelopes that encompass the paths taken by the TEMPSC in each set of tests. Figure 11.10 is a summary of Figures 10.1 to 10.23. 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 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.

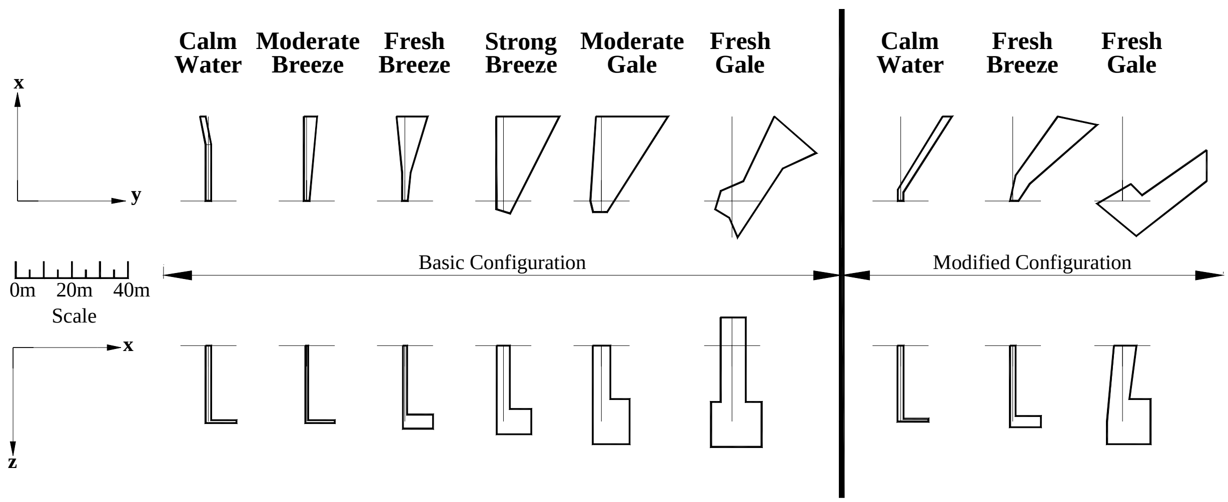

Figure 11.10 - Path Envelopes in Sail-away phase (plan view at top) and lowering and sail-away phases (outboard profile).

12.0 ACKNOWLEDGEMENTS

This test program was a collaborative initiative between the National Research Council’s Institute for Marine Dynamics, Petro-Canada and Memorial University.

A consortium consisting of Transport Canada, the Canadian Association of Petroleum Producers, Natural Resources Canada, and the National Research council provided subsequent funding for a broader evacuation performance research program, of which the work reported here is the first part.

The authors thank the people at IMD/NRC who contributed to the fabrication and instrumentation of the models, and helped carry out the experiments.

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