



***'Case Study: An FPSO with DP for Deep Water Applications'***

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**ABSTRACT**

In the coming years, there will be a growing demand for Floating Production and Storage Units (FPSOs) for ultra deep waters (greater than 2000 m [6,000 feet]). In the Gulf of Mexico, the technical and economical limitations inherent to other type of concepts, the lack of pipeline infrastructure in such deep areas, and the wide acceptance of the FPSO concept by Shelf Authorities will accelerate this process.

One of the most critical issues in the design of FPSOs for ultra deep waters will be the selection of the most cost-efficient station keeping system for the specified operational requirements. Standard solutions based on internal turret and thruster assisted mooring systems are already being offered by the industry. However, beyond certain water depths, the technical and economical constraints associated with the use of mooring systems may favour other concepts potentially more attractive and cost-efficient, such as a fully dynamically positioned FPSO (DP-FPSO). This concept marries state-of-the-art FPSO technology and latest generation drill ship technology for dynamic positioning and operation in ultra deep waters. This system can either be utilised as an early production system or as a full-fledged field development solution. The areas most suited for this application will be the Gulf of Mexico, Brazil and West Africa.

The paper describes a joint study undertaken by the various companies represented by the authors to develop a design for a fully dynamically positioned FPSO for ultra deep waters. The various technical challenges and regulatory issues for a fully DP-FPSO will be identified and solutions to them provided. Detailed design information on the vessel design, the DP thruster, Power Generation and control systems, and the disconnectable turret and riser system shall be provided for a hypothetical field development in ultra deep water. The system performance shall be illustrated by the results from a comprehensive study involving state-of-the-art computer simulations and model test program. Results and conclusions from a reliability and safety study performed on the system shall also be presented, as well as those from a thorough power consumption analysis for the geographical areas of interest. Finally, a comparison is made between components associated with the stationkeeping system of the DP-FPSO and a conventionally turret moored FPSO, to provide input for CAPEX/OPEX estimates which in turn can be used to identify the range of water depths and field development scenarios for which the DP-FPSO is commercially feasible.

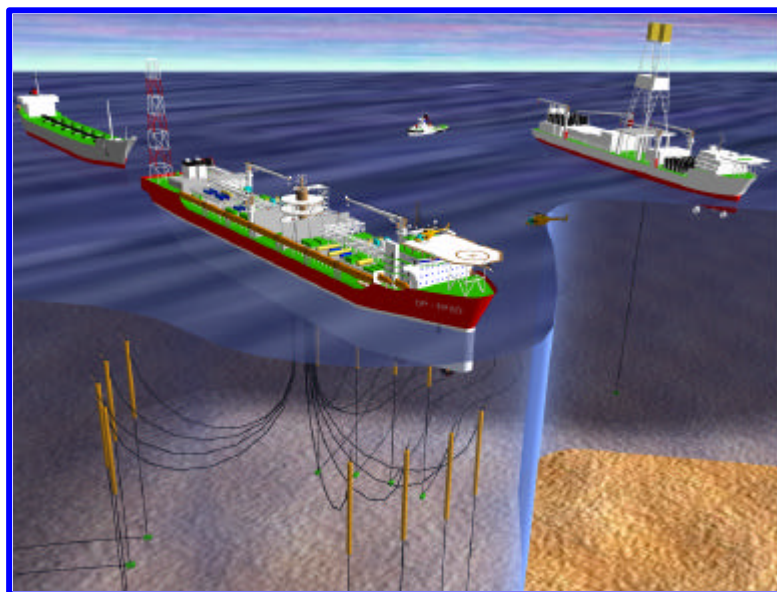
**KEY WORDS:** FPSO; Dynamic Positioning; Ultra Deep Water; Model Tests; Global Analysis, CAPEX/OPEX

## INTRODUCTION

There is a growing demand for cost-effective and reliable floating production system concepts for ultra-deep water depths (greater than 2,000 meters). Floating, Production, Storage and Offloading (FPSO) systems are a mature floating production technology that is readily adaptable to deep water and is one of the floating production systems of choice offshore Brazil and West Africa. Though there are currently no FPSOs in the deepwater Gulf of Mexico (GOM), the technical and economical limitations inherent to other type of concepts, the lack of pipeline infrastructure in ultra deep water, and the wide acceptance of the FPSO concept by Shelf Authorities should result in these systems being considered to be deployed in the near future.

There are a number of discoveries in ultra deepwater in the Gulf of Mexico alone that will require floating production units. Some examples are the Coulomb field in 2,320 meters (7,600 feet) water depth, the Vortex Field in 2,540 meters (8,334 feet), and the current world drilling record has been set by the Transocean Sedco Forex Drillship Discoverer Spirit in 2,965 meters (9,727 feet). This proves the high activity in ultra deep waters and the need for the industry to provide technical and economical solutions to face this challenge.

One of the critical issues in the design of FPSOs for ultra deep waters is the design of the most cost-efficient station keeping system for the specified operational requirements. The capital cost of the station-keeping system including its installation can increase dramatically with an increase in water depth. In addition, seafloor congestion, poor geotechnical conditions, or short field life may result in the traditional mooring system not being an optimum solution. Thus beyond certain water depths and for certain other conditions and applications, the technical and economical constraints associated with mooring systems may favour the fully dynamically positioned FPSO (DP-FPSO). This concept (see Figure 1) combines state-of-the-art FPSO technology and latest generation drill ship technology for dynamic positioning and operation in ultra deep waters. This system can either be utilised as an early production system or as a full-fledged field development solution. The areas most suited for this application are the Gulf of Mexico, Brazil and West Africa.



**Figure 1. The DP-FPSO Concept**

An early comprehensive study of dynamic positioning of large ships in ultra deepwater was conducted for a large ocean mining vessel in 6,000 meters of water (Brink and Chung, 1981). The development of the DP-FPSO builds from the experience obtained with the BP Seillian FPSO, disconnectable turret technology, and the latest generation of dynamically positioned Drillships specifically designed for water depths up to 3,000 meters. The BP Seillian operated in the North Sea for 8 years as a dynamically positioned production platform and was recently re-deployed in deep water offshore Brazil as an early production system for the Roncador field in 1,853 meter water depth. In Brazil the Seillian has remained on station while offloading to standard and DP shuttle tankers without incident (Henriques, 2000; and Gardner, 1999). The latest generation deepwater Drillships have been in operation almost 5 years in many deepwater regions world-wide and are designed to remain on station in sea states up to the 10-Year hurricane environment in the Gulf of Mexico. In addition many thruster-assisted turret-moored FPSOs are in operation in the North Sea and have been studied for the Gulf of Mexico (Wichers and van Dijk, 1999).

The paper describes a joint study undertaken by the various companies represented by the authors to develop a design for a fully dynamically positioned FPSO for ultra deep waters. Firstly, detailed design information for a hypothetical field development in ultra deep water on the vessel design (including the DP thruster, power generation and control systems), as well as the on the disconnectable turret and riser system is provided. Secondly, the system performance is illustrated by the results from a comprehensive study involving state-of-the-art computer simulations and model test program. This also includes the results from a thorough power consumption analysis for the geographical areas of interest. Regulatory aspects associated to this concept and results and conclusions from a reliability and safety study performed on the system are then presented. Finally, a comparison is made between components associated with the stationkeeping system of the DP-FPSO and a conventionally turret moored FPSO, to provide input for CAPEX/OPEX estimates which in turn can be used to identify the range of water depths and field development scenarios for which the DP-FPSO is commercially feasible. The main conclusions from the study are given at the end of the paper.

## THE 'DP-FPSO' CONCEPT

### DESIGN BASIS AND OPERATIONAL REQUIREMENTS

#### General

The DP-FPSO system has been developed and analysed based on a design basis developed for a hypothetical deep-water field in the Gulf of Mexico. The water depth selected was 2,500 meters, and the field was assumed to be produced from three drill centres. A total of twelve (12) risers and four (4) umbilicals were assumed to interface between the drill centres and the FPSO. The riser system consists of six (6) 12" pipe in pipe production risers, two (2) 10" water injection risers, one (1) 10" gas injection riser, one (1) 12" gas export riser, and two (2) additional 10" gas lift/injection risers. The production rate was assumed to be 125,000 barrels of oil per day, and the minimum storage capacity for the DP-FPSO was set to be 1 million barrels of oil.

The DP-FPSO system has been designed for the environmental conditions from the Gulf of Mexico. This allows the evaluation of the system stationkeeping performance in an extreme hurricane environment, and also in fairly mild operational conditions. This also covers a range of conditions anticipated in other regions of interest like offshore Brazil and West Africa. The results obtained for the Gulf of Mexico have been verified and calibrated against model test data. Results for other regions have been estimated using calibrated computer simulations.

#### Environmental Criteria

The environmental conditions used for the design basis are derived from several sources and are considered to represent general conditions valid for the Gulf of Mexico. For this design effort it is assumed that the vessel is required to maintain station with risers attached for all extreme sea states including the 10-Year hurricane environment. For extreme sea states greater than this environment the vessel will disconnect from the riser system and sail away to avoid the storm. The DP-FPSO may also disconnect from the riser system in order to evacuate the crew from the remote site if that is an operational preference.

Table 1 below shows all combined environmental conditions that are considered in the current design basis document. In all conditions a NPD wind spectrum formulation is assumed. This data has been used for both the computer simulations and the model test program.

Sea State	Hs [ m ]	Tp [ s ]	$\gamma$ [ - ]	$\mu_{waves}$ [deg]	Vw [m/s]	$\mu_{wind}$ [deg]	Vc [m/s]	$\mu_{CUR}$ [deg]
90% exceedance. Collinear	2.0	6.0	1.0	180	10.0	210	0.35	180
90% exceedance. Cross	2.0	6.0	1.0	270	10.0	240	0.35	180
99% exceedance. Collinear	4.0	9.0	1.0	180	15.0	210	0.35	180
Loop current	3.8	9.0	1.0	270	15.0	240	2.13	180
10-Year winter storm	5.8	10.6	2.0	180	20.0	210	0.60	180
10-Year Hurricane	8.6	12.3	3.3	180	29.5	215	1.00	180
100-Year Hurricane	12.5	13.0	3.3	180	41.0	180	1.00	180

**Table 1: Environmental conditions assumed for DP-FPSO study**

To reduce the combination of environmental conditions to a manageable yet comprehensive set of cases an assumption was made on the relative directions of waves, wind and current. The following situations are considered:

- Wind direction is always at an angle of 30 degrees to the wave direction. The only exception is the 100-Year Hurricane condition, where wind and waves are considered to be parallel.
- Current is either in line (collinear) with the waves or perpendicular to the waves (crossed condition and loop current).

### Operational Requirements

From an operational standpoint, the conditions included in Table 2 have been considered, with respect to the simultaneous functions performed, the demand for the DP system and the limiting environmental conditions:

Operating Mode	Description	DP System	Reference Environmental Condition
Normal Operation	FPSO loading through the turret, processing and storing	Required thruster capacity low (one thruster forward and one aft)	Exceedance level in the range 90-95%
Extreme Operation	FPSO loading through the turret, processing and storing. Disconnection procedures ready.	Required thruster capacity moderate-high (two thrusters forward and two aft)	Exceedance level 99%
Offloading	FPSO loading through the turret, processing and storing. Simultaneous offloading to shuttle tanker	Required thruster capacity moderate-high (two thrusters forward and two aft)	Exceedance level 99%
Stand-by Condition	FPSO connected in stand-by mode. Production stopped. Disconnection procedures ready.	Required thruster capacity high (three thrusters forward and three aft)	10-year winter storm 100-year Loop current
Normal Disconnection Condition	FPSO connected in stand-by mode. Normal disconnection procedures executed.	Required thruster capacity high (three thrusters forward and three aft). About 4 to 12 hours disconnection time	10-year hurricane
Emergency Disconnection Condition	FPSO connected in stand-by mode. Emergency disconnection procedures executed.	Required thruster capacity high (three thrusters forward and three aft). Disconnection time about 5 minutes.	10-year hurricane or Abnormal Conditions
Reconnection Condition	Turret buoy retrieved by means of a winch	Required thruster capacity moderate-high (two thrusters forward and two aft)	Exceedance level 99%
Survival Condition	FPSO disconnected in heading control mode	Required thruster capacity high (three thrusters forward and three aft)	100-year hurricane

**Table 2. - Operational Conditions**

### DESCRIPTION OF THE 'DP-FPSO' SYSTEM

The DP-FPSO system consists of the hull and topsides, a thruster-based stationkeeping system, and a disconnectable riser turret that allows rapid disconnection from a large number of risers, when required. Figure 1 above provides a schematic of the DP-FPSO. The main components of the DP-FPSO system are:

- **DP-FPSO:** A 1,000,000 barrel storage vessel with production capacity for 125,000 barrels of oil per day. The FPSO has a DP-thruster stationkeeping system and offloads to a shuttle tanker connected in tandem.
- **Turret:** Allows for transfer of fluids between the riser system and the vessel. The turret is designed to allow rapid disconnection from the riser system, providing the ability to sail away from a hurricane. This also provides the means of disconnecting from the riser system in case of a blackout or scheduled maintenance at a shipyard.
- **Riser System:** The riser system provides transfer of product from the wellheads to the FPSO, and is specifically designed for use in this concept with the disconnectable turret system developed.
- **Offloading Tanker:** For transporting the stabilised oil to onshore refineries. Currently conventional tankers with a capacity of approximately 500,000 barrels are considered in this study.

### FPSO Vessel Hull Design

The FPSO has been designed with a crude oil storage capacity of one million barrels, and is double sided and has a double bottom to comply in full with MARPOL regulations (International Convention for the Prevention of Pollution from Ships). The vessel hull forms are typical for a new-built FPSO, with a prismatic mid-body, a sloped flat transom and triangular bow. The hull forms have been optimised to minimise wave drift forces and green water loading (Buchner and Cortijo, 2003). The turret is located amidships, to minimise the vessel motions affecting the riser system and the riser (dis)connection operations. A process plant weight of 15,000 tons is accounted for. Table 3 provides a summary of the main vessel particulars:

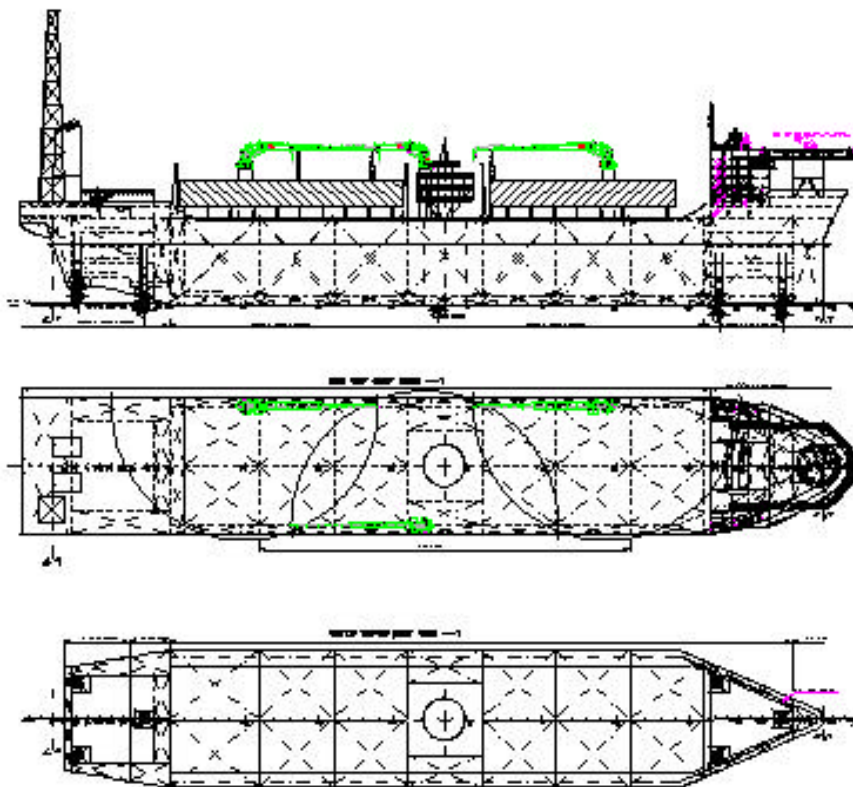
Parameter	Value	Units
Length b.p.p.	260	meters
Beam	46	meters
Depth	28	meters
Storage Capacity	1,000,000	Barrels
Topsides Weight	15,000	MT
Accommodation	100	p.o.b
Offloading Tanker	500,000	barrels

**Table 3. - DP-FPSO Main Particulars**

Cargo tanks are arranged forward and aft of the turret, as well as at both sides of the turret moonpool. Slop tanks are arranged aft of the cargo tank area. Ballast tanks are provided in the double hull, and fore and aft peaks. The power generation module is located on the aft main deck. Machinery spaces are located forward (underneath the accommodation block), and aft (under the power generation module).

The accommodation (and helideck) is located forward in order to provide adequate navigational capabilities, as it is envisaged that the FPSO will disconnect and sail away in extreme environmental conditions. The flare tower and the offloading equipment (hawser reel, hose reel, offloading station, etc.) are located at the stern.

An enclosed gangway runs along one side of the vessel connecting the aft and forward vessel areas, with access from the main deck and process modules. This gangway is designed for safety of personnel in certain severe conditions, and to facilitate protecting piping and cabling. Blast walls are installed to provide a physical separation between the different areas and to avoid propagation of fire/explosion to adjacent areas in case of an accident. Transverse blast walls fore and aft of the turret, and a blast wall aft of the cargo tank area are also provided. Additionally, the aft accommodation bulkhead is designed to withstand the blast pressure and to protect the lifeboats. Cranes in adequate number and capacity will be spread throughout the deck to ensure proper handling of provisions, spares, equipment, etc. Figure 2 shows the general arrangement of the DP-FPSO.



**Figure 2. DP-FPSO General Arrangement**

The DP-FPSO is intended to operate permanently on site during the specified service life of 20 years without dry-docking. A high uptime of the installation is desired, similar to that of a conventional turret moored FPSO. For this purpose, the FPSO is provided with sufficient system robustness (redundancy of critical equipment, etc) to insure that operation can be made in a safe and efficient way for the conditions specified below. Adequate means for inspection and maintenance on site are provided. Special attention has been paid to thruster maintenance on location. A diverless procedure has been developed in co-operation with the thruster supplier to allow overhauling of all thruster components within the machinery spaces without the need of external means. Nevertheless, any thruster can be eventually removed with the help of an offshore crane if by any reason has to be repaired onshore or replaced by another one. The low utilisation of the thrusters (normally only one forward and one aft) allows for a proper scheduled maintenance of the thrusters during mild weather (overhauling is recommended every five years).

### **FPSO Station-keeping System**

The DP system is sized to provide the required stationkeeping performance governed by the riser system, in the extreme design environmental conditions. The maximum allowable riser system offset is approximately 10% of the water depth (250 meters) for the current design basis. The DP system is also sized to provide sufficient redundancy in case of thruster failure or is being out of service for maintenance.

The DP system is designed to be classified with DnV Notation DP AUTRO, equivalent to IMO Class 3. Class Requirements for such Notation are described in Section 'Regulatory Aspects' below.

The DP system consists of the following main subsystems: Thruster system, Power generation system, Control system and sensors. The Central Control Room is located within the accommodation block and is designated as the main control point of the unit. In the aft part of the FPSO an Engine Control Room is mounted adjacent to the engine room and is designated as the secondary control point of the vessel.

### **Thruster System**

For the present case study (GOM Area) the thruster system comprises six (6) azimuthing fixed pitch, frequency controlled thrusters with an anticipated capacity of 5 MW each. The thrusters are located three (3) aft and three (3) forward in individual compartments so as to fulfil the DNV AUTRO requirements. For Brazil and WOA regions, the thruster configuration would be retained (3 thrusters forward and 3 aft) for redundancy purposes, however the capacity of each thruster can be reduced to 3-4 MW.

### **Power Generation System**

Due to the criticality of the power generation system for a reliable and efficient operation of the DP and process systems, an optimisation study has been carried out to assess the features of alternative power generation plants. Table 4 and Figure 3 below show the three configurations that have been evaluated.

In all cases studied, the necessary redundancy required by the Class 3 Notation has been provided. The final rating of the generators will result from the electrical load balance where the following main scenarios will be considered and analysed:

- Normal operation (DP + Process + Hull utilities)
- Offloading operation (DP + Process + offloading + hull utilities)
- Stand by (DP + Hull utilities)
- Sail away (Heading control or navigation + Hull utilities)

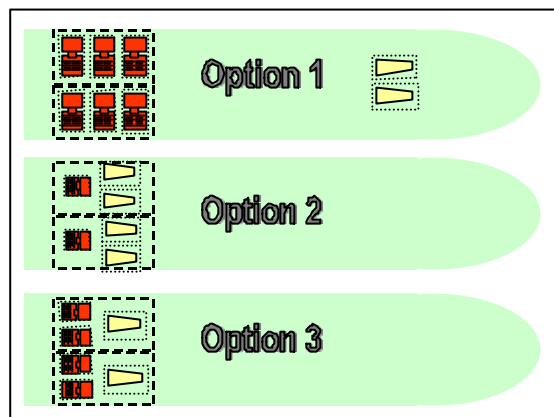
For each alternative, the following features have been evaluated: Reliability, Flexibility, CAPEX and OPEX. Although it is not possible to conclude which option is the best in absolute terms (theoretically Option 3 seems to be the optimum), as this depends on the record of decision of each Operator with respect to all these four parameters, some straightforward results from the comparison are:

- Option 1 is the most reliable, is quite flexible and has the highest total cost
- Option 2 has the lowest CAPEX/OPEX, is quite reliable but less flexible than the other two
- Option 3 is the most flexible, is highly reliable (especially after disconnection) and has a low CAPEX/OPEX

It must be stressed that for options 2 and 3 (i.e., unique power plant), the increase in power installed due to the DP system, compared to a passively turret moored system, is not that high (in the range of 20-30%). This is because the highest demand for the DP system (extreme weather conditions) is associated with the lowest demand from the process plant (production shutdown). In normal conditions, the electrical power required by both systems (DP and turret moored) is almost identical.

Option No.	Configuration	Characteristics	Total Power installed
1	Power Plant in Process area Redundant Power plant stern	2 Gas Turbines 40 MW each 2 x 3 Dual fuel DGs 7,8 MW each	126,8 MW
2	Integrated Redundant Power plant stern Based on turbines	4 Gas Turbines 30 MW each 2 x Dual fuel DGs 2,2 MW each	124,4 MW
3	Integrated Redundant Power plant stern Mixed turbines/generators	2 Gas Turbines 40 MW each 2 x 2 Dual fuel DGs 7,8 MW each	111,2 MW

**Table 4. – Alternative Power Generation Plants analysed**



**Figure 3. Alternative Power Generation Plants analysed**

**Control system and sensors**

The Control System and sensors for positioning required by the DP Class Notation are common to other conventional DP systems and have been described in previous papers (see e.g., Cortijo et al, 2003).

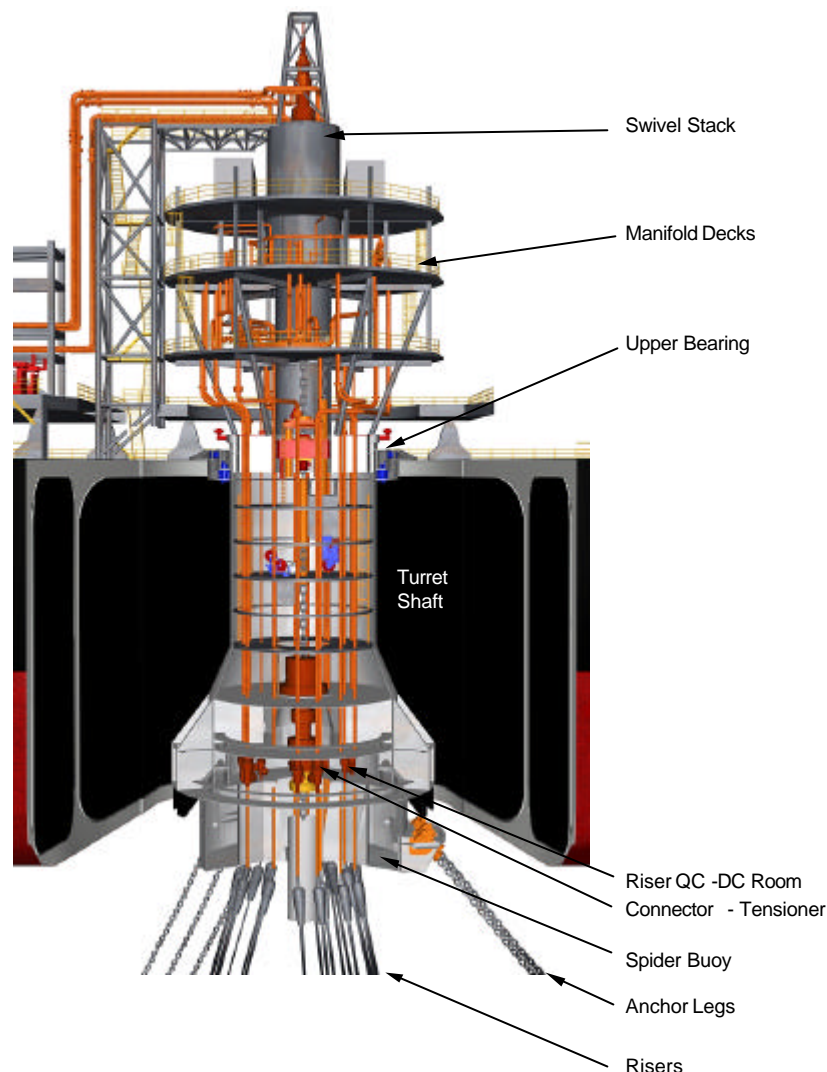
**Disconnectable Turret and Riser System**

The disconnectable turret and riser system is a very important component of the DP-FPSO. The turret allows the vessel to weathervane about a single point to minimise environmental loads and motions of the vessel as a function of the environment intensity and duration. This allows the optimisation of the thruster system, power consumption, and the motions of the vessel. The turret also allows fluid-transfer from the earth-fixed riser system to the ship-fixed production and storage system. Another important element of the turret-riser system is the ability to rapidly disconnect the vessel from the riser system when required.

Disconnectable turret mooring systems have been in use for many years, primarily in regions with frequent typhoons like the South China Sea and North-Western Australia. Most of these systems support a few risers and can be disconnected to allow the vessel to sail away and avoid a typhoon. The most sophisticated and complex disconnectable turret system to date has been installed in an FPSO on the Terra Nova field offshore Eastern Canada, (Duggal et al., 1999). This turret has been designed to support nineteen (19) risers and umbilicals, allow the vessel to stay moored in the severe 100-Year environment, and disconnect to avoid collision with icebergs. The vessel produces at a rate of 125,000 bbls/day, and has a storage capacity just under one million barrels of oil. The turret system is designed to disconnect from the riser system in a controlled manner with all risers depressurised and flushed in four (4) hours, and perform an emergency disconnect in less than fifteen (15) minutes. Figure 4 provides a schematic of the Terra Nova turret system. A detailed description of the turret and its operation are provided in Howell et al. (2000).

From the figure it is seen that the disconnectable turret consists of three major components:

- **Disconnectable Buoy and Associated Systems:** The “spider buoy” is connected to the lower part of the turret by means of a large hydraulically activated mechanical connector that is preloaded so that the connection acts as a bolted joint. Above the buoy each riser pipe is fitted with a quick connect – disconnect (QC-DC) valve and connector system that allows rapid shutdown and disconnection of each riser. The buoy is released by disengaging the mechanical connector and allowing it to freefall to its equilibrium depth. The buoy retrieval system is self-contained in the turret (winch and chain-jack system).
- **Turret Structure:** The turret structure provides the load-transfer interface between the mooring and riser systems, and the vessel. The turret structure is provided with a bearing system at its interface with the vessel to allow it to passively weathervane about the mooring centre. The turret structure also provides support for the fluid-transfer system.
- **Fluid-Transfer System:** The fluid-transfer system includes the piping above the riser QC-DCs, the manifolding, the pig launching and receiving systems, and the swivel stack that allows transfer of fluids and signals from an earth-fixed system to a ship-fixed system.



**Figure 4. The Terra Nova disconnectable turret mooring system**

The Terra Nova turret design forms the basis for the design of the turret system for the DP-FPSO concept. One major difference between the two systems is that no mooring loads are present for the DP-FPSO. This results in a much simpler lower turret load transfer system, a smaller disconnectable buoy, and a simpler connection mechanism. However, the lack of a mooring system for the DP-FPSO turret requires the riser system to support themselves when disconnected. This is a key feature of the disconnectable turret system designed for this application and requires the integrated design of the riser and turret systems.

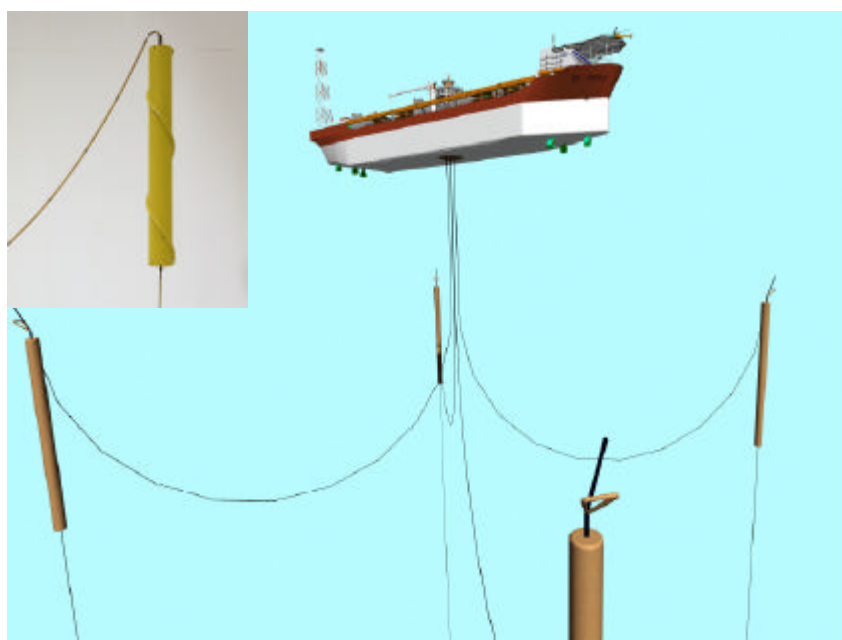


In order for the buoy to release and fall to a stable equilibrium position below the surface near FPSO centre, the riser system must be arranged so that the riser loads are distributed around FPSO centre. For most field development scenarios it is unlikely that the risers will approach the FPSO centre in this way. Thus the turret and riser system have to be designed in a way that allows such a system to disconnect and fall to a stable equilibrium position regardless of the field layout.

The solution developed for this application utilises single leg hybrid risers (Petruska et al., 2002), or multi-riser towers as used on the Girassol field, that can be arranged at the desired distance and orientation from FPSO centre to allow the system to be balanced, regardless of drill centre location, with very little economic and flow assurance impact. These risers consist of a vertical riser tower that is supported by a buoy near the surface. Flexible jumpers are used to interface between the FPSO and the riser as shown in Figure 5. Future risers can also be added in sequence to maintain this static equilibrium balance. These riser systems are well suited for ultra deep water and would most probably be used with a conventional turret-mooring system as well. Another important feature of this design is that the turret system is independent of water depth as the riser tower length is the water depth specific component. The length of the jumpers and the distance of the risers from the FPSO centre can be maintained to be the same for all applications if required.

For the current example in the Gulf of Mexico (2,500 meter water depth) the turret-riser system is designed with twelve (12) single leg hybrid risers arranged on a 250 meter radius from FPSO centre. Riser jumpers of length 425 meters are then used to connect the single leg hybrid risers to the buoy connected to the turret. For this application the buoy has a net buoyancy of 380 MT, and reaches a static equilibrium position approximately 200 - 250 meters below the water line, close to FPSO centre. For the Gulf of Mexico it is important for the buoy to drop below the region of high current (loop current) to prevent extreme offsets requiring a depth of greater than 200 meters. For other field locations this stable equilibrium depth can be optimised based on the current environment. This concept has been successfully verified in the model tests described in the following section.

The remainder of the turret arrangement will be based on a layout very similar to that of a conventional turret-moored system. The fluid-transfer equipment will be similar to that shown in Figure 4 with manifolding, pig launching and receiving capabilities, and a swivel stack designed for the various fluids to be transferred. Due to the lack of a mooring system to counteract the friction in the system, and to minimise the “twisting” of the risers, the turret shall be equipped with a turret drive mechanism that ensures that the turret heading is maintained with the earth-fixed riser system. The controlled disconnect (de-pressurizing and flushing risers) will take 4 – 12 hours, while the emergency disconnect is designed to allow total disconnection in under 5 minutes.



**Figure 5. Schematic of riser system for DP-FPSO**

## CONCEPT VALIDATION

### Computer Simulations

Prior to the model test program DP capability analyses and initial simulations were performed using the time domain simulation program DPSIM. DPSIM is used to study the behaviour of dynamically positioned vessels, exposed to wind, irregular waves and current. DPSIM predicts the mean and low frequency motions in the horizontal plane and provides mooring line loads (if used), thruster, propeller and rudder forces, and estimates of power consumption. Based on these simulation results the model test program was optimised and initial DP control settings were established.

Current loads were based on current load coefficients of a similar shaped FPSO and a constant current velocity. Wind loads were calculated using wind load coefficients of a FPSO with similar hull shape and topsides and assuming a NPD wind spectrum formulation. For the second order wave loads a diffraction analysis was performed on the DP-FPSO. All of this data, including thruster characteristics and positions, were used as input into DPSIM and simulations run for the various environmental conditions presented in Table 1.

A standard PID controller was used to calculate the required thrust. The initial control settings for surge, sway and yaw were determined as follows: Spring Coefficient: Maximum. Total thrust / max allowable excursion; Damping Coefficient: 70% of critical damping; and Integrating Coefficient: zero

With these settings a large number of simulations were performed to optimise the control coefficients. As sway and yaw are highly coupled, a good balance has to be found between these coefficients. The integrating coefficient was purposely set to zero as it only reduces the static offset and the main focus of the study was to study and optimise the motions of the DP-FPSO.

The calculated thrust by the controller was allocated over the available thrusters using a thruster allocation routine based on LaGrange multipliers and minimising the total consumed power. Three different allocations were used: Full DP, with all six thrusters active; Maximum single failure (CL fore and aft thrusters inactive); and Four thruster inactive (only CL fore and aft active)

The third allocation simulates a maximum single failure in light sea states, when only four thrusters are used to maintain position (and the other two are out of service, e.g. for maintenance).

### Model Test Program

Early 2003 an extensive model test program on the DP-FPSO has been completed in MARIN's deep water Offshore Basin. The tests were performed at a scale of 1 to 60. The modelled water depth in the basin was 600 meters. The DP-FPSO model was equipped with a disconnectable buoy and six azimuthing thrusters, in a thruster layout with three thrusters both forward and aft. Figure 6 shows the model as used in the model tests.



**Figure 6. DP-FPSO model with disconnectable buoy**

The thrusters were controlled using a dedicated real-time full DP-system ('RUNSIM'), including an extended Kalman filter. Using this control system the DP-FPSO was free to choose any heading set point in order to minimise the motions

or power consumption. The turret was equipped with a heading control system, allowing the buoy to maintain its earth-fixed orientation independent of the DP-FPSO heading.

An equivalent riser system for 2,500 meters water depth was installed in the basin. The riser system consisted of four (4) truncated vertical riser towers (each modelling 3 individual risers), up to 250 meters below the water surface. Each riser had a cylindrical air can to obtain the required pretension. The connection between the top of the air can and the disconnectable buoy was made with flexible jumpers. The design of the riser system was such that after disconnection from the FPSO the buoy dropped to a depth of 250 meters below the water line, to avoid excessive current loads. Figure 5 shows a schematic view of the model test set-up, with the air can model in the inset.

The model test program focussed on Gulf of Mexico environmental conditions. The environments were simulated by generating waves, wind and current in the model basin. The test program considered the following sets of tests:

- ❖ Normal operational conditions
  - 90% exceedance (Hs 2 m / Tp 6 s)
  - 99% exceedance (Hs 4 m / Tp 9 s)
- ❖ Survival conditions
  - Loop current ( $V_c = 2.13$  m/s)
  - 10-Year winter storm (Hs 5.8 m / Tp 10.6 s)
  - 10-Year Hurricane (Hs 8.6 m / Tp 12.3 s)
- ❖ Squall conditions
  - Wind gusts to 30 m/s with change in direction
- ❖ Offloading to shuttle tanker
  - 90% & 99% exceedance sea states
- ❖ Disconnect and connect procedure
  - Disconnect in 10-Year hurricane conditions
  - Reconnect in 90% exceedance conditions
- ❖ Free drift or hovering tests
  - 100-Year hurricane conditions (Hs 12.5 m / Tp 13 s)

For each condition the range of headings was determined where position keeping is possible. This was done by performing short tests at 5-degree heading intervals. For the heading with the lowest thrust requirement a 3-hour test was performed to obtain statistics on power consumption and position accuracy.

### Model Test and Numerical Results

The first step was to assess the DP capability of the FPSO based on mean environmental loads. DP-capability plots were made for all selected sea states, loading conditions and thruster allocations. A typical example is shown in Figure 7 for the 10-Year winter storm condition and allocation for six thrusters (blue), four thrusters (red) and two thrusters (green). In these calculations a margin for dynamics has been used to account for the fact that a quasi-static approach is used to predict the dynamic behaviour of the vessel.

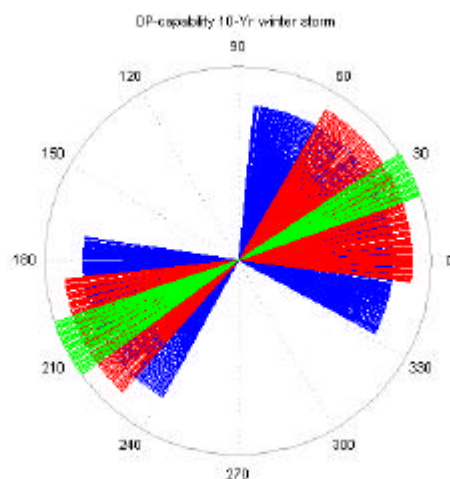
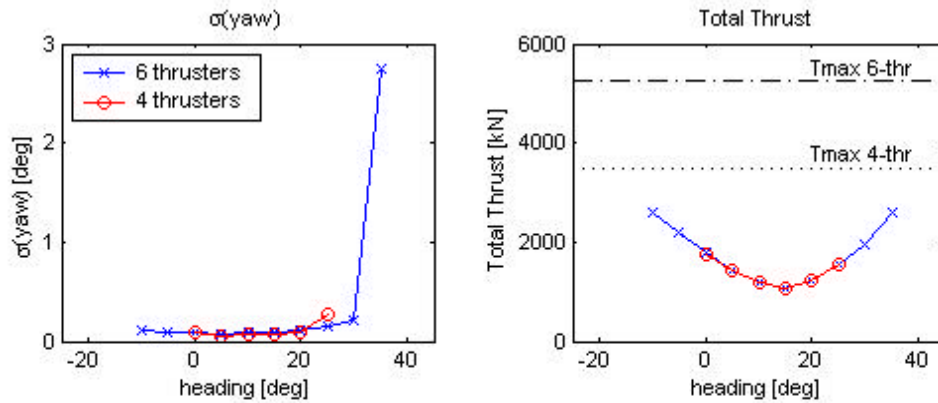


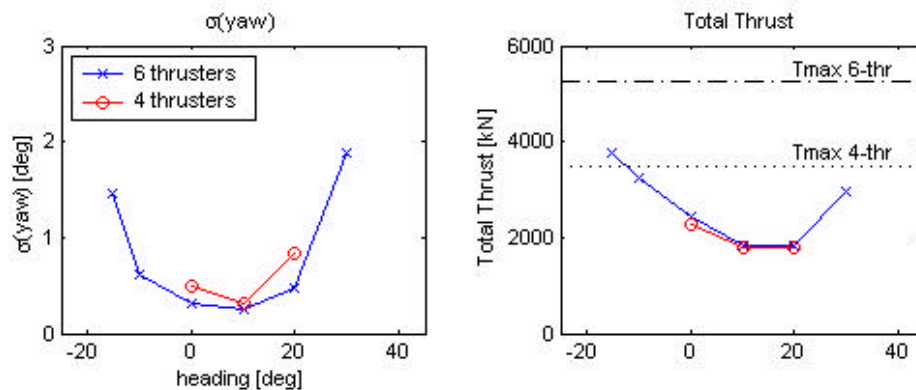
Figure 7. DP-capability plot for 10-Year winter storm condition

It is obvious that the use of six thrusters results in a higher capability than with four or two thrusters. Use of only two thrusters resulted in a marginal DP capability and was not further investigated for this 10-Year winter storm sea state. Figure 8 shows the results of the time domain simulations for the same condition. The simulations were done in 5-degree intervals until a drift off was observed. The trend in capability is the same, but the range of headings where the FPSO is able to maintain position is smaller. Apparently the dynamic effects are higher in this sea state than anticipated in the quasi-static approach.



**Figure 8. Results of DP simulations in 10-Year winter storm condition**

Based on the time domain simulations a heading range of -15 to +10 degrees is predicted. Figure 9 shows the model test results plotted on the same scale. The motions in the model tests are larger due to the wave frequency motions (which are not included in the time domain simulations) and the effect of the Kalman filter. However, the range of allowable headings for both simulations and model tests are identical. Total power consumption for simulations and model test shows the same trend, but the required power in the model tests is somewhat higher.



**Figure 9. Results of DP model tests in 10-Year winter storm condition**

The results of the model test program show that the DP-FPSO concept is very encouraging. The main findings are:

- In the 90% exceedance sea state only two thrusters are required to maintain position. This allows maintenance on the thrusters for most of the year while still having sufficient redundancy. Based on the required thruster power in these tests it can be concluded that the fuel consumption most of the time is very small.
- In the 99% exceedance sea state position keeping with four (4) thrusters is excellent. This means that even with a maximum single failure position keeping will still be good.
- The test in squall conditions show that the DP-FPSO can maintain its position provided the vessel heading is turned into the direction of the squall wind in time. It is not possible to maintain position with a squall beam-on, however this is the case for conventionally moored vessels. As the DP-FPSO is equipped with a turret amidships, it is not weathervaning and turning the vessel into the wind requires the DP operator to react on the

squall. Figure 10 shows a typical squall manoeuvre where the vessel turns into the wind before the maximum wind speed is reached.

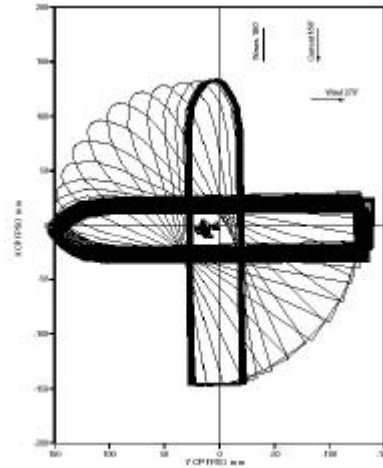


Figure 10. Squall manoeuvre

- The offloading tests were done with a traditional shuttle tanker connected to the FPSO by a bow hawser. Back thrust was applied to avoid fish tailing of the shuttle. Due to the hawser load this can be considered a worse case for the DP-FPSO. It is most likely that shuttle tankers in the GOM will be DP operated; however, in West Africa and Brazil they will most probably be conventional trading tankers. Therefore the offloading tests are considered to be conservative. The position keeping during offloading in 90% and 99% exceedance sea states was excellent, using only four thrusters. This means that even in offloading conditions a maximum single failure can be dealt with. Figure 11 shows a typical plot of the offloading of the DP-FPSO in 90% exceedance crossed condition ( $H_s = 2$  m). The DP-FPSO has virtually no motions, whereas the shuttle tanker shows some fishtailing.

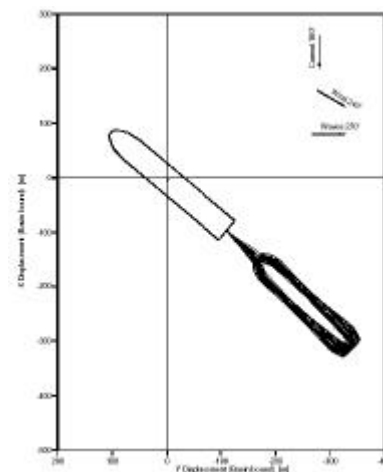
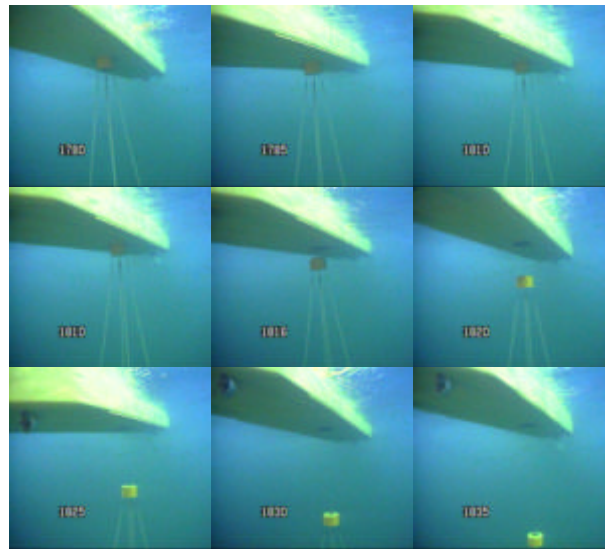


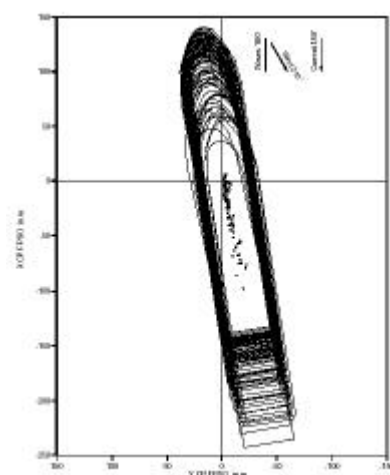
Figure 11. Offloading of DP-FPSO to a conventional shuttle tanker.

- To show feasibility of the disconnect procedure tests were performed in the 10-Year hurricane condition, where the disconnectable buoy was released from the turret. These tests were repeated at different times in the wave sequence and the behaviour of the buoy was observed with an underwater camera. The buoy showed a very predictable behaviour and dropped quickly from the FPSO. No impacts were observed between buoy and keel of the FPSO. The photo sequence in Figure 12 shows how the buoy is released during the disconnect procedure in 10-Year hurricane conditions.



**Figure 12. Disconnection of the riser buoy from the turret**

- Tests of the reconnect procedure in the 99% exceedance sea state showed no difficulties either.
- In survival sea states (loop current and 10-Year Hurricane) all six thrusters are needed to maintain position. Figure 13 below shows the DP performance in the 10-Year hurricane condition. The excursions of the DP-FPSO are mainly in surge direction. Although the range of headings where position keeping is possible is limited in these conditions, position accuracy is still very good and well within the limits of the riser system.



**Figure 13. DP positioning in 10-Year hurricane conditions**

- The free drift tests were performed in 100-Year Hurricane conditions, with the buoy disconnected. In this condition the vessel is able to maintain its heading, but not able to maintain position above the riser pattern. Based on these tests the drift speed was determined in order to calculate the time available for an emergency disconnection procedure.

Based on the model test results the numerical model was tuned. With this tuned numerical model more accurate simulations were performed for other environments than those tested in the model test program. Table 5 compares results from the model tests and the tuned time domain simulations for two environmental conditions.

There is reasonable agreement between simulations and model tests. A complicating factor in the comparison between model tests and time domain is the presence of the disconnectable buoy and the riser system that is not completely

modelled in the DPSIM simulations. The current loads on the riser system and the contribution to damping are fairly large and difficult to predict and have not been accounted completely in the preliminary engineering of the system.

Environment	90% exceedance		99% exceedance		10-Yr winter storm	
	DPSIM	model test	DPSIM	model test	DPSIM	Model test
mean X	-3.3	-5.8	-5.4	-4.0	-15.8	-9.8
stdev X	0.2	0.4	0.6	1.2	1.8	3.3
mean $\psi$	16.3	16.0	10.2	10.2	10.3	10.1
stdev $\psi$	0.1	0.2	0.1	0.2	0.2	0.3
mean power	957	755	2173	2954	4813	6699
stdev power	126	367	571	1440	1384	3501

Table 5. Comparison between simulation and model test results

**DP Power Consumption Analysis**

Using the tuned simulation results, an analysis was made of the power consumption of the DP-FPSO for a variety of sea states. These sea states were defined by:

- Wave height and period according to scatter diagrams for the Gulf of Mexico, West of Africa and Brazil areas
- A wave spectrum peak enhancement factor '  $\gamma$  ' as function of stage of development of the wind waves
- A wind speed based on the Kruseman relation ( $V_w = 372 * H_s^{1.829} / T_p^{2.66}$ )
- A current composed of a steady component and a wind driven component (2% of the wind speed)

For each sea state the DP-FPSO heading was selected based on the lowest mean environmental loads. A typical result of this analysis can be found in Figure 14, where the mean power consumption of the DP-FPSO is plotted in the scatter diagram. These analyses have been performed for both fully loaded and ballast conditions of the Unit, and for GoM, WoA and Brazil areas.

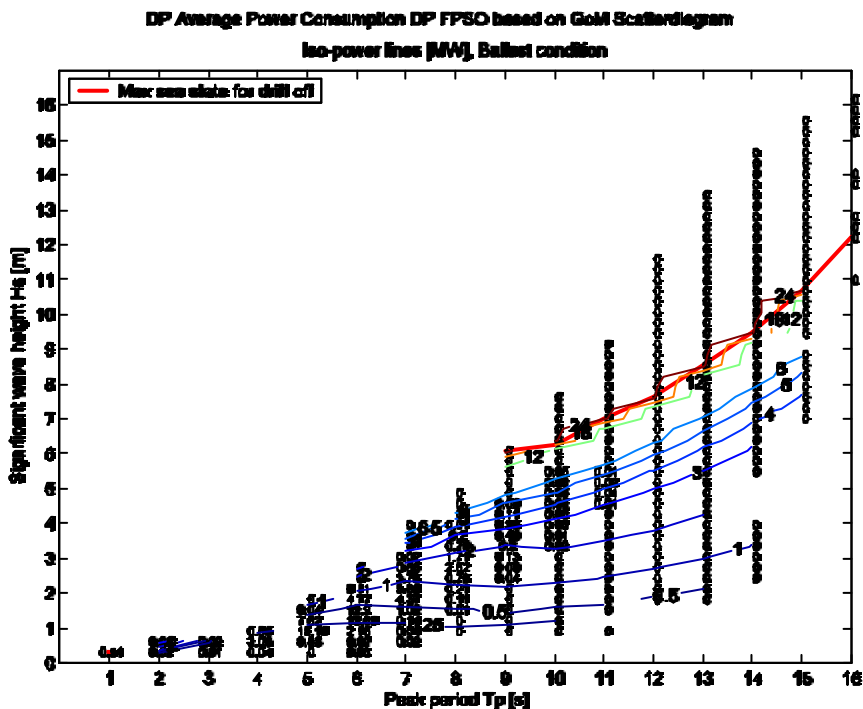


Figure 14. Mean power consumption for Gulf of Mexico scatter diagram

This figure shows that a mean power consumption of about 1 MW is sufficient to maintain position in sea states up to 2 m significant (90% probability sea state). For the 99% probability sea state (Hs 4 m) the mean power consumption is approximately 4 MW, i.e. less than 15% of the available thruster power. For higher sea states the total environmental loads increase rapidly. From tests and simulations it is observed that position keeping can be maintained until the mean power consumption exceeds approximately 80% of the available thruster power. In Figure 14 the limit for position keeping is shown. For these sea states the lines of mean power consumption are spaced closely together and even doubling the amount of power will result in only a marginal increase of workability. The scatter diagram shows that sea states above this limit do occur, but their probability is very low.

Using the associated probability of the sea states in the scatter diagram the Probability of Exceedance plots and Probability Density Functions were also derived. The Probability Density Function associated with the above scatter diagram is shown in Figure 15.

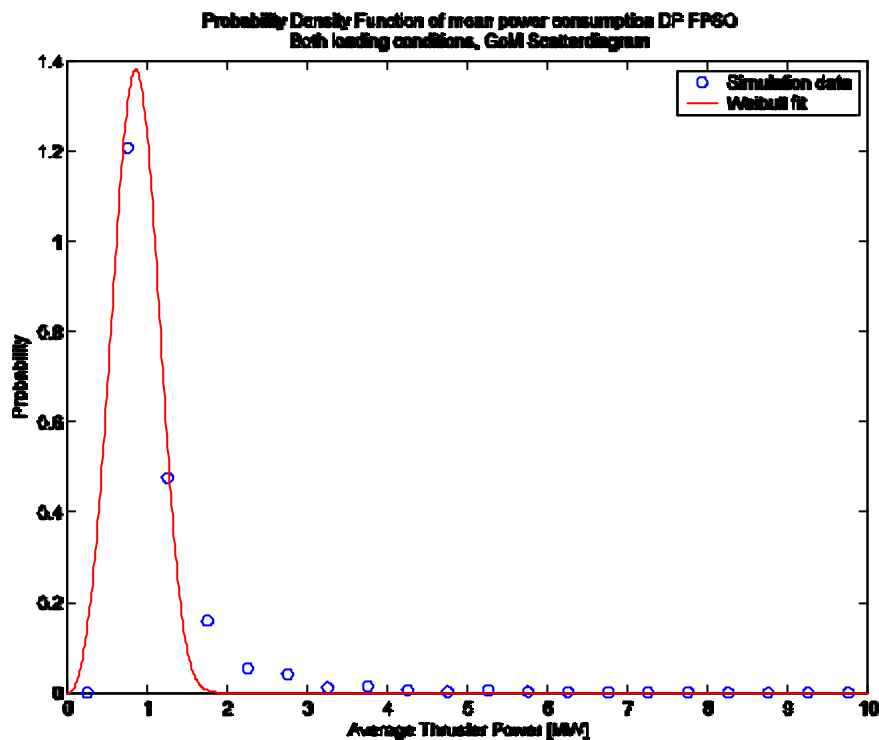


Figure 15. Probability Density Function for Gulf of Mexico scatter diagram

This figure shows that for most of the time the mean power consumption of the DP-FPSO is well below 2 MW.

A comparison between ballast and fully loaded condition shows that in general the DP performance is comparable for the two loading conditions. For hurricane conditions the wind load on the DP-FPSO is dominant and the loaded condition performs somewhat better. In loop current conditions the current load dominates and the ballasted condition is to be preferred.

**RELIABILITY AND RISK EVALUATION**

The DP system has been reviewed through a detailed Failure Mode and Effect Analysis (FMEA), developed to address the specific class requirement in addition to providing input to a reliability prediction model for the DP based FPSO. The FMEA evaluation is made relative to the DNV class notation: DYNPOS AUTRO, ref. DNV (2001), which corresponds with the IMO equipment class 3 requirements.



No major issues have been identified in the FMEA which potentially could jeopardise DP 3 class approval; however some smaller issues were identified which might need to be considered in more detail when further developing this concept. Some of the important issues include:

- Clarification on the fire rating requirements which separate the two engine rooms, a more detailed study of the possible fire scenarios to assure the passive fire protection is sufficient and in compliance with the A-60 requirements would possibly have to be performed.
- Two redundant power cables are currently routed in the same enclosed gangway, it was recommended that these cables be separated and protected to minimise the potential for simultaneous damage of the redundant cables.
- The current power distribution system requires quick and reliable activation of bus-ties and possibly redistribution of loads following a failure in the switchboards or in the engine rooms. These solutions are however normal and should not be a hinder the class approval if dealt with appropriately

The results from the FMEA were also used to develop a reliability prediction model. Reliability data was retrieved from available industry databases for the relevant components and industry experience from DP based vessels, mainly drilling vessels, was reviewed and evaluated. The reliability predictions performed indicate that an expected "maximum" failure, loss of one thruster forward and one aft will occur every second year. The evaluation of the potential for a "critical" failure, loss of more than one thruster forward and one aft, was performed and estimated to 14 years. If a "critical" failure occurs in weather and sea state close to the design conditions, loss of positioning may occur.

The risk for loss of position is higher than for a moored FPSO, and a coarse qualitative risk evaluation was performed. Fires and explosions are expected to be higher due to the increased activity and equipment in the machinery space on the DP-FPSO. However, there are some interesting advantages related to the DP based concept related to the ability to disconnect and abandon the site in case of subsea blow-outs and leaks as well as errant vessels on collision course. The DP based FPSOs ability to control heading and avoiding fishtailing are also important to reduce risk for shuttle tanker collisions during offloading. Better control on the FPSO will enable fewer thruster actions on the shuttle tankers, and hence less risk for shuttle tanker drive offs. A more detailed comparison of the risk exposure between a moored and a DP-FPSO should be evaluated to capture and qualitatively measure and balance all risk differences.

The general conclusion from this reliability evaluation is that the JIP has developed a reliable DP concept, with an acceptable weather window to compete with a more conventional moored system. Equipment failure could however result in some additional downtime, as production might have to be stopped in case of a failure of the DP system, and it is important that specific recommendations are implemented into the operating procedures to assure safe and reliable production from a DP based FPSO. Human factors and operational procedures have not been addressed in any detail in this assessment and should also be considered at a more detailed level.

## REGULATORY ASPECTS

The DP-FPSO concept builds on three main proven technology components: processing and storage of hydrocarbons on a floating facility, a ship-shaped floater and a dynamic positioning system. The industry experience with these technologies is discussed below.

The technology of floating production has been around for decades and today there are more than one hundred ship-shaped floaters in operation, in addition to other types of floating production systems. These technologies are regulated at the National level by Shelf State Authorities and by the International Maritime Organisation (IMO) for units that relocate across territorial waters. In addition to SOLAS and MODU Code, the IMO issued Guidelines (July 2003) for mandatory application of MARPOL Annex 1 to floating production and storage units. New purpose-built units must comply with MARPOL requirements for hazards similar to those of oil tankers but are not required to have double bottom tanks. The technologies employed on the DP-FPSO for processing and storage of hydrocarbons and for the ship-shaped hull are the same used elsewhere by industry.

Dynamic positioning systems have been used in the offshore industry since the early 1980's and today there are hundreds of vessels that rely on such systems for drilling, pipelaying, offshore installation, well stimulation, anchor handling and many other operations. This technology is well regulated by IMO and the systems are normally certified by Classification Societies. The DP system proposed for the DP-FPSO reflects the state-of-the-art technology in use by industry.

As the experience with hydrocarbon production on DP is relatively recent and limited to a single well tie-back, the regulatory compliance approach for the DP-FPSO will apply classification and statutory certification supplemented with risk assessment of issues specific to a floating production unit on DP.

The DP-FPSO DP system will be classified with DP AUTRO notation according DNV rules for ships Part 6 Ch. 7. This means basically that an automatic positioning keeping system with redundancy in technical design and physical arrangement will be achieved. The main principle is that a single failure shall not cause loss of position or heading that leads to critical situations. In this case a failure is defined as an occurrence in a component or system causing one or both of the following effects:

- Loss of component or system function
- Deterioration of functional capability to such an extent that the safety of the vessel, personnel or environment is significant reduced.

For the case of a DP-FPSO with DP notation AUTRO, the definition of single failure has no exceptions and shall include incidents of fire and flooding, and all technical breakdowns of system and components, including all technical and mechanical parts.

The operational mode of work will be the Automatic Mode that involves automatic position and heading control that will be the selected mode when the unit is in operation. In addition manual mode for each thruster will be made available. For periods where the unit is not in operation the provision of a Transit/Navigation Mode system is considered utilizing the aft port and starboard thruster for steering purpose and the remaining thruster in the zero position for propulsion. A full reliability study will verify the redundancy and the independence of the system.

In addition to classification and statutory certification the following specific issues will be investigated using risk assessment: DP system failure implications such as disconnection arrangement and philosophy for the turret/risers (e.g. ESD and gas release scenarios), tandem offloading with both FPSO and shuttle tanker on DP, vessel capability to stay/escape from approaching hurricanes, and emissions. Other issues that will require regulatory compliance attention are the submersible turret, the offloading/export arrangement and arrangements for inspection and maintenance of hull and thrusters.

### COST COMPARISON BETWEEN A DP-FPSO AND A PASSIVELY MOORED FPSO

The paper has demonstrated the technical feasibility of the DP-FPSO concept, evaluation of its stationkeeping performance for a variety of environmental conditions, and detailed the engineering philosophy and design to have acceptable reliability when compared to a passive turret moored system in ultra deep water.

The main objective of this section is to compare a DP and a conventional turret-moored FPSO developed using the same design basis to allow the estimation of the relative CAPEX and OPEX for each system. This is done by identifying and analysing the specific sub-systems that are different due to the system requirements. Based on these estimates the difference in life of field costs can be evaluated as a function of field development scenario and water depth, and thus the commercial feasibility of the DP FPSO can be established.

It is fairly clear that for water depths around 1,000 meters that a conventional turret-moored FPSO would be the preferred option based on both technical and commercial basis for most field development scenarios. However, the conventional system costs increase rapidly with water depth. On the other hand the DP-FPSO costs should be fairly independent of water depth, and therefore situations should exist where the costs of the two systems intersect as illustrated in Figure 16.

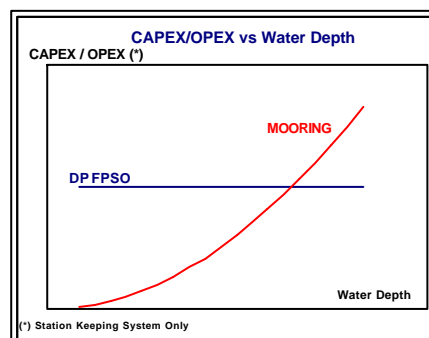


Figure 16. Generic Comparison between Turret Moored and DP FPSO Stationkeeping Costs

The objective of the comparison between the two FPSO systems is to identify this crossover point as a function of field development scenario and water depth.

The large number of variables associated with the two systems and possible field development scenarios make this very complex to analyse. However, as a starting point the design basis described in this paper will be used to compare the two alternatives. Once this baseline is established, the analysis shall be extended to determine the water depth crossover point for the large production scenario. Future work will focus on better identifying the situations (field development scenario, field life, production rates, water depth) that would be suited for the DP-FPSO concept.

For the baseline comparison between the conventional and DP-FPSO, the following assumptions have been made regarding the two systems:

- The design basis defined in this paper for a hypothetical field in the GOM is used for the design of both systems
- The conventional turret mooring utilises a taut-leg polyester rope anchor leg system with suction piles
- The same riser system (single leg hybrid risers) would be used for both systems
- The topsides production equipment is the same for both systems (excluding power generation)
- The upper turret (structure, manifolding, swivel stack, etc.) is the same for both systems
- No impact on accommodation block and vessel manning except marine crew for DP-FPSO
- Overall downtime (life of field) is the same for both systems

Based on these assumptions, the main differences between the two systems are outlined in Table 6 below. Based on the differences the following groups have been identified to estimate the relative costs for each system including engineering, management, fabrication/assembly costs, and operational expenses over the life of the field.

- **Hull Systems Group:** This group includes the modifications that need to be made to the hull for the DP FPSO option (thruster support systems, maintenance, etc. etc.) and the turret system for both systems.
- **Stationkeeping Group:** This includes the off-vessel anchor leg components for the conventional turret mooring system, and the DP-thruster system for the DP FPSO.
- **Lower Turret Group:** This includes all components of the turret system from chaintable to the upper bearing. For the DP FPSO this also includes the costs of the riser buoy, the retrieval system, the QC-DC system for the risers, and related piping.
- **Power Generation and Control Group:** This includes the additional power generation requirements and redundancy required for the DP FPSO as compared to a conventionally moored FPSO.
- **Commissioning and Installation Group:** This includes concept specific commissioning costs and the installation and hook-up of the anchor leg system for the conventional turret moored system.
- **Services and Administration Group:** This includes all engineering, management, procurement and mark-up costs associated with the conventional or DP FPSO specific items described above.
- **Maintenance and Inspection Group:** This includes the inspection and maintenance costs for the conventional anchor leg system and the DP-thruster systems.
- **Other System Specific Operational Expenses:** This category covers all other concept specific operational costs like fuel for thruster system, additional marine crew for DP FPSO option, etc.

Once the relative CAPEX and OPEX are estimated for these groups, a Present Value (PV) estimate of the total cost is computed for both systems on the same time reference, accounting for inflation and the present value of future expenses. This allows a simple comparison of expected life of field costs for both systems and thus a means of comparing commercial feasibility of a DP FPSO to a conventional turret moored FPSO in ultra deep water.

*The estimation of CAPEX and OPEX data for the case study described above was not available before the date of submittal of the paper so the final results of the study cannot be presented at this time (but will be presented during the oral presentation). The paper will be updated with this information and re-submitted to the DOT for distribution if possible.*

Table 6 presents the differences between the components for the passive and DP-FPSOs in terms of the stationkeeping and associated systems. The CAPEX and OPEX estimates will then be combined and a life of field cost estimated from the data by estimating the Present Value at the time of first oil.

	<b>TURRET MOORED OPTION</b>	<b>DP OPTION</b>
<b>CAPEX</b>		
Hull System Segregation	Not Required	To provide required system redundancy (DP Class 3), segregation of equipment/systems is required
Thruster System	Not Required Assumed Fully Passive	Thrusters forward and aft, including conditioning units, ancillary equipment, etc.
Power Generation System	One power generation plant in the process area, plus 2 small DGs for essential services in the machinery space	One integrated power plant for process and vessel systems of larger capacity and additional redundancy
Control & Instrumentation	Integrated control system for process and vessel systems	Same plus DP hardware/software Sensors
Turret Moonpool (Hull)	Moonpool of adequate diameter and load capacity	Same with reduced load capacity
Lower Turret System	Conventional, including: Turret Shaft, bearing system, chainable, chain stoppers, pull-in equipment, upper turret structure, swivel stack and associated piping.	Same upper turret structure, swivel stack and associated piping. Reduced load capacity for bearing and turret structure
Riser Buoy	Not required	Turret buoy including riser disconnection/reconnection system
Turret Heading Control	Not required – provided by mooring system	Required due to lack of mooring system
Mooring System	Anchor leg components including foundations	Not Required
Mooring System Installation	Installation of foundations, mooring lines and hook-up to the FPSO	Not Required
	<b>TURRET MOORED OPTION</b>	<b>DP OPTION</b>
<b>OPEX</b>		
Inspection and maintenance	All anchor leg components	Thrusters , power generation and DP control system
Fuel	None required	Fuel for power generation
Marine crew	Standard	Additional crew to support DP thruster system

**Table 6. DP-FPSO vs. Turret Moored FPSO - Comparison of specific sub-systems.**

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## SUMMARY AND CONCLUSIONS

The DP-FPSO concept proposed in this paper provides an innovative and cost effective solution to meet the challenges of ultra deepwater production by utilising existing and proven technology in the offshore industry. The paper demonstrates the technical feasibility of the concept by analysis, model testing, detailed engineering of the various sub-systems, and risk and reliability studies.

The development project is organised in as a JIP project which aims to address the key issues related to offshore production on DP, including the reliability of the DP system and the regulatory compliance (J.L.Cortijo, A.Duggal, R.V.Dijk, S.Matos, 2002 and 2003). The JIP is still in progress but already has demonstrated the feasibility of maintaining a large FPSO on position in extreme conditions in the Gulf of Mexico using a DP thruster system. The feasibility of the disconnectable turret riser system has also been demonstrated in the model test program. Preliminary results for Brazil and WOA regions show similar results than those for the GOM, however the milder extreme conditions allow for reduction in the capacity of the thruster and power generation systems.

Power consumption analyses have proved that most of the time the power required by the DP system represents a small fraction of the total power required by the process plant and vessel systems. The average thruster power required for the GOM area is of about 1 to 2 MW which is small compared to the peak power requirements of approximately 60 – 80 MW for a floating production system.

A reliability and risk evaluation has been performed on the DP-FPSO. The main conclusion is that the concept can be considered to have sufficient reliability. Although the risk for loss of position is higher than for a moored FPSO, the ability to disconnect and abandon the site together with the better control of the heading during offloading, provides unique advantages to this concept compared to a conventional turret moored FPSO.

Current work focuses on the completion of the engineering of the FPSO vessel, and the disconnectable turret riser systems. Work is also underway in ensuring compliance with the regulations in the various target regions. The Life of Field cost estimates for the present case study is in progress. Once this phase of the work is complete additional cases will be studied to cover a range of water depths and field development scenarios to evaluate the commercial feasibility of a DP-FPSO for use as an early production system to a full-fledged production system.

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