ABSTRACT

A Marine Simulator was developed for the Jack-St. Malo field located in approximately 7000 feet of water in the Gulf of Mexico Walker Ridge block. The simulator presented operational information in a form similar to that on the actual facility and provided operational personnel with extensive operational experience and training on scenarios as may be faced in the actual facility, prior to and subsequent to facility start-up.

The design of the ballast system for this Semi-Submersible Floating Production Unit (FPU) called for a comprehensive training procedure as an added operational safety measure for the marine operators. The Jack-St. Malo Marine Simulator utilizes process and safety control configurations that are the same as the facility. It includes a Load Management system and an Environment and Facilities Monitoring System (EFMS) integrated with a high fidelity dynamic model for the hull ballast and bilge systems. The simulator is an outstanding training tool that can be used during the life of the FPU to train operators for various operating scenarios and develop guidelines to handle emergency scenarios.

The simulator proved to be an effective tool to perform Control System check out during pre-commissioning. Lifts for production, generation, compression modules were first tested on the Marine Simulator before actual lifts were conducted in the yard. Naval architects were consulted to verify anticipated ballasting operations before actual operations. The simulator gave operators a feel of the Process Dynamics, Process Control, and Safety System and familiarity with the DCS Graphics well before start up. The simulator was successfully used as a dummy platform along with the Load Management Advisory Program to demonstrate the ballast procedure for the successive installation of three heavy modules onboard the actual platform. Scenarios simulated include hurricane shutdown and start-up, instrument failures, damaged mooring line situations and damaged compartment scenarios due to collision or inadvertent flooding, among many others.

Operator training to operate Jack-St. Malo Ballast and Bilge systems using facility Operator graphics and control system was thoroughly carried out using this Simulator and this contributed to the high level of confidence in Marine operations including lifts and ballasting operations. The simulator was a useful tool for validating Standard Operating Procedures before actual facility start-up.

Keywords: Jack St. Malo, Simulator, Marine
INTRODUCTION

Jack and St. Malo fields are located in the Gulf of Mexico Walker Ridge blocks situated in approximately 7000 feet of water. The Jack-St. Malo field development consists of 12 sub-sea wells connected to three sub-sea manifolds tied back to the Floating Production Unit with a production capacity in the range of 120,000 to 150,000 BPD of oil and 37.5 MMSCFD of natural gas. At approximately 54,000 tons hull weight supporting 25,000 tons topsides, Jack-St. Malo’s Hull is among the world’s largest oil production platforms to date to be operated at a draft of approximately 136 feet. The hull consists of a ring pontoon, four columns and a deck box below the lower deck level. The topsides modules are located on top of the hull at the main deck level of 230 feet above keel and in addition there is a process and subsea equipment located in the deck box. See Figure 1 for the Jack- St. Malo Field layout.

![Jack-St. Malo Field Layout](image)

Figure 1: Jack-St. Malo Field Layout

The high-complexity of the Jack-St. Malo (JSM) field development required a more effective training system for the operators. The design of the ballast system for this Semi-Submersible Floating Production Unit (FPU) is based on the principles of the GVA Sea-Loc System. This made it simple and easy-to-use, but called for a comprehensive training procedure as an added operational safety measure for the marine operators. Jack-St. Malo’s hull design has the following unique features as part of the Sea-Loc design -

- Ballast tanks are filled with water from deck level by submerged caisson type ballast/utility sea water lift pumps located outside the facility, hence there are no hull penetrations below the operational draft (closed hull philosophy).
- De-ballasting (emptying of tanks) is performed by conventional centrifugal pumps located in pontoon compartments. As an option all these pumps can be designed to operate submerged.
- Combined Ballast/Main bilge function, reducing the overall number of pumps simplifies operation
- All ballast tanks (except column ballast tanks above elevation 157 feet) are filled by gravity; hence there is no possibility to over-pressurize tanks.

The Marine Simulator presents operational information in a form similar to that on the actual facility and provides operational personnel with extensive operational experience and training on scenarios as may be faced in the actual facility, prior to and subsequent to plant start-up. A Lifecycle Simulator concept was applied such that the simulator grew and developed as the project progressed and was used in many phases of the project: from engineering studies, through control system check-out, operator training, commissioning support to possible future tie-backs engineering design and support functions. Similar simulators have been developed in the past for topsides (Dziubla et al, 2004), but the Marine Simulator for JSM was developed mainly for the Hull system.
The Jack St. Malo Marine Simulator was developed to provide an integrated simulator for the Jack St. Malo Marine facilities. This simulator provides marine operations personnel with a training environment, prior to and subsequent to facilities start-up. Transient response of the information provided accurately replicates that which would be observed on the actual platform when subject to the same or similar disturbances. To obtain a high-fidelity response to the disturbances, simulator scope includes most of the subsea, topsides and hull equipment, piping and instrumentation.

The process model for topsides, subsea and hull is connected to an emulation of facility control system, which has the exact same configuration for process logic and safety controllers and operator station screens as will be running on the facility. Location and elevation information for all the topsides and hull equipment and instrumentation is included in the simulator to accurately calculate platform inclination and draft under all scenarios.

The Jack-St. Malo Marine Simulator is built using Stimulated Control configuration which is the same as the Facility control configuration. Load Management system and an EFMS system are integrated with a high fidelity process model for the hull, topsides and subsea. The Simulator uses actual DCS graphics for Operator stations. Model Scope and control system scope is detailed in next section. Environment variables are set up by the Instructor in the Simulator to simulate environment as seen in Figure 3 below. Mooring Advisory System (MAS) and Ballast Advisory System (BAS) similar to those used in actual facility are provided to the student (Marine Operator) to aid in facility operation.
Process Model Scope

The Simulator process model is built using a multiphase subsea model, integrated together with a dynamic Simulation model built with K-Spice for topsides and hull. The Process model includes all the major equipment, pipe and fittings, and instrumentation. Topsides equipment was also included in the process model so that production fluid mass and movement will have an effect on the hull inclination and draft.

The main components of the model are:

- **Subsea**
  - 12 Subsea Wells
  - Three Subsea Manifolds
  - Three Subsea Boosting Pumps
  - Four 10” pipelines from Subsea Manifolds to Riser

- **Hull**
  - Ballast system – 38 Pontoon tanks, 28 Column tanks
  - Bilge System – Main and Daily
  - Hull Utility Sea Water Lift Pumps
  - Venting system

- **Topsides**
  - Oil Separation System
  - Cooling Medium System
  - Seawater Lift Pumps System
  - Heating Medium System
  - Waste Heat Recovery Unit
  - Produced Water System
  - Gas Compression System
  - Gas Dehydration System (including TEG Regeneration)
• Chemical Injection System – Low-Dosage Hydrate Inhibitor (LDHI) and Methanol
• HP and LP Flare System
• Fuel Gas System

Some of the Utility Systems like Seal Oil system, Lube Oil System, Nitrogen Production, Instrument Air System, Hydraulic Fluid Systems, Closed Drains and Open Drains were out of simulator scope. Figure 4 below shows an Operator overview screen for the Ballast system and includes heel, trim and four column draft information from the hydrostatic model and tank levels, pump and valve status from process model.

![Figure 4: Hull Ballast Overview Operator Screen](image)

**Control System Scope**

The Control System used on the Jack-St. Malo project is a Yokogawa Centum VP Distributed Control System (DCS). Yokogawa’s ProSafe controllers are used as Safety controllers. A Virtual Simulation of the Yokogawa Process Controllers (FCS) and Safety Controllers (SCS) was done by running the controllers in test function mode while controlled by Yokogawa’s Exatif link. A custom link was developed for the Marine Simulator to interface K-Spice Process model with Yokogawa’s Exatif Interface.

A total of 68 Controllers were included in the OTS system with the following split:
• Process Controllers (FCS) - 23 controllers
• Safety Controllers (SCS) – 45 controllers

Out of these 68 controllers, 23 controllers are used for Hull control - 11 for Process control and 12 for Safety control.
SYSTEM ARCHITECTURE

Figure 5 represents the hardware architecture for the complete Marine Simulator. Hardware used for Model server, Operator Stations and DCS Controller machines are all HP DL380 G7 servers. Figure 6 shows the software communication for the Marine Simulator.

The Simulation system has two instances of the hydrostatic model running – one represents the facility and other one is the advisory Load Management System (LMS) for the Marine Operators. The Advisory LMS can go online to get the live data from the facility hydrostatic model and the student/operator can then use the off-line LMS to move the fluids around to test a scenario before performing the operation on the facility.

![Hardware Architecture Diagram]

The Simulator consists of a number of different servers running various components as outlined below:

- Model Server (one)
  - Dynamic Process Model for Ballast and Bilge System
  - Hydrostatic model for calculation of heel, trim and draft of the facility based on the condition in process model and instructor input for environment conditions
- OPC (Object Linking for Process Control) Server for communication between Hydrostatic model and Process model and for sensor simulation
- Environment and Facilities Monitoring System (EFMS) Simulator
- Instructor Station (one)
  - Running Kongsberg’s proprietary graphical interface software for controlling and monitoring the Simulator
  - Interface for setting environment (e.g. Wind speed, water current, deck loads)
- Operator Station/Engineering Work Station (one)
  - Interface with DCS Controllers
  - Running Operator Station Graphics and also acts as an engineering station to view control configuration and make changes to control configuration
- Student Advisory Hydrostatic Model
- EFMS Interface for Metocean data
- DCS Controller machines (two)
  - Running a total of 23 DCS Soft Controllers for Hull Safety and Process control system
- Historian Server (one)
  - Configuration and storage of historical data
- DCS OPC Server (one)
  - OPC server for DCS controller data.

There is an additional KVM (Keyboard Video Mouse) switch with LCD monitor which interfaces with all the servers located in the cabinet.

There are five software components of the system -

1. Hydrostatic Marine Model (supplied by Ocean Motions) – this model calculates the facility heel, trim and inclinations from deck loads, environment, ballast/bilge tanks levels and mooring line lengths. Figure 8 shows a sample output from hydrostatic model for JSM Stage 2 Operating Condition which has maximum topsides weight and maximum number of risers.

2. Ocean Motions Converter WinMon software (supplied by BMT) – this software converts the ten deck loads entered by Instructor to four equivalent fixed location deck loads in the Ocean Motions model. This is done since there is a limitation in the Ocean Motions model to be able to receive X & Y locations. This program runs in the background and there is no interaction with the user.

3. EFMS Sensor Simulator (supplied by BMT) – this software simulates any field sensors not available in Simulator e.g. Ambient temperature, pressure, humidity and other sensors. This program runs in the background and there is no interaction with the user. Figure 7 below shows a screen from EFMS system displaying wind

![Diagram](image-url)
and water current information along with weather data.

4. WinMon (supplied by BMT) – this software is the facility EFMS system which gets data from ICSS Yokogawa OPC server on the JSM facility but in the Simulator it gets data from K-Spice model via OPC server. This program runs in the background.

5. OPC Server (KEPServerEx5 Kepware OPC server supplied by BMT) – this is used for data transfer between Kongsberg’s OPC client and BMT software components.

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![Figure 7: EFMS Data Display Screen](image-url)
Figure 8: Sample Output from Hydrostatic Model Calculation
APPLICATIONS

The Marine Simulator for the Jack-St. Malo Facility integrates the process, control system and hull dynamics for the complete platform, and has proven to be an effective tool for training marine operations, control system I/O and configuration testing and for practicing various emergency and routine scenarios. It will be used as an Operator Assessment tool in the near future and during the life of the FPU.

Control System Check-out

The Marine Simulator presents operational information in a form similar to that on the actual facility since the Control system configuration and Operator graphics used were identical to the actual facility. The Simulator proved to be an effective tool to perform Control System Check out during pre-commissioning stage well before actual start up. This control system check-out detected configuration errors in the DCS logic and therefore improved the DCS implementation, reducing costly commissioning and start-up phases.

Input and output points were connected one at a time from Control system tags to the dynamic process model. More than 1500 I/O s were connected between the Control system and Dynamic process model. The data transfer between Control system and process model was done via a custom built link whereas the data transfer with hydrostatic model was done via OPC.

Control system check-out allowed the simulator to be used to:
- Check graphic displays and navigation
- Verify Alarm settings and trip set points
- Controller tuning
- Test motor start/stop logic
- Validate permissive logic
- Validate cause and effect matrices
- Test shut-down & start-up logic sequences
- Ballast/Bilge mode operation for pumps

Operator Training

Operator training to operate Jack-St. Malo Ballast and Bilge systems using facility Operator graphics and control system was thoroughly carried out using Marine Simulator and this contributed to the high level of confidence in Marine operations including lifts and ballasting operations. The Simulator was used to validate Standard Operating Procedures before actual facility start-up.

Other than the routine ballasting and de-ballasting operations, listed below are some of the special scenarios planned for extensive operator training during the life of the FPU –

- Environment changes – Wind/Current speed, Wind/Wave/Current direction, Wave height
- Damaged compartments due to collision
- Inadvertent Flooding of tanks
- Mooring line breakage
- Transmitter failure
- Variable Deck loads
- Hurricane Shutdown and Startup
Commissioning and Module Lifts Support

A total of three topsides module lifts were performed on the Jack-St. Malo hull at the Kiewit Offshore Services (KOS) integration yard in Ingleside, Texas – Compression module, Production module and Generation module. Table 1 below lists the weight for all the three topsides modules and also the cumulative load transfer that was planned using Kongsberg’s Simulator and GVA’s Load Management Stability Advisory Program for successive installation of the modules. Figure 9 shows a picture of the generation module lift being performed at the yard. The planned ballast operations are depicted in Figure 10, Figure 11 and Figure 12. These module lifts were performed in a very controlled manner at a constant draft of approximately 36 feet following a procedure which helped minimizing all relevant risks. This involved meeting a positive freeboard over the pontoon at all times of the load transfer operation, a not-to-exceed trim/heel inclination angle of 1 degree, a maximum allowed 3 feet elevation change at the fender, a minimum bottom clearance to seabed of 3 feet and a minimum 3 feet clearance for the module footings to any part of the FPU including guides. Ballast procedures were developed to minimize the time under which the Heavy Lift Device (HLD) was connected to the module. Marine Simulator was used during the three module lifts to validate the procedure for following items:

- Verify feasibility of the module installation with regard to ballast capacity, draft and displacement
- Identify tanks to be used during load transfer
- Quantify ballast steps and sequences
- Compute floating conditions and stability
- Estimate ballasting times for given pump rates

Table 1 Module Lift Installation Data

<table>
<thead>
<tr>
<th>Module</th>
<th>Weight (LT)</th>
<th>Cumulative Load Transfer (LT)</th>
<th>Ballasting Time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>6366</td>
<td>6366</td>
<td>6.2</td>
</tr>
<tr>
<td>Generation</td>
<td>2864</td>
<td>9230</td>
<td>2.4</td>
</tr>
<tr>
<td>Compression</td>
<td>5622</td>
<td>14852</td>
<td>6.2</td>
</tr>
</tbody>
</table>

Prior to actual ballast compensation the marine operators used the Load Management System in conjunction with the Marine Simulator to restore the Facility responding with a proposal of actions, e.g.

- Fill x tons of water in tank y
- Start pump z
- Open valves a, b, and c

The ballast operations were supervised from the Central Control Room (CCR) onboard the FPU and the execution of each ballast step was controlled using the Load Management System. A total of 15 tanks were involved in the ballast operations. Two seawater utility ballast pumps and eight de-ballast pumps operating at approximately 1900 GPM were used for the module lift phase. The Simulator helped the marine operators to practice operating the flow control valves at pump discharge to achieve a desired flow rate in order to optimize operational performance.
Figure 9: Generation Module Lift at KOS yard
Figure 10: End of Production Module Installation

Figure 11: End of Generation Module Installation
The OTS in conjunction with the Load Management Stability program will be used as an educational guide, engineering tool and training platform to practice handling of routine and emergency situations that could occur during the operational (30-year) life of the FPU. It will also be installed onboard the FPU to assist in the following marine operational phases:

- Inclining Test at quayside (KOS)
- Wet Tow to offshore site (Walker Ridge block 718)
- Mooring Line Installation at site (Walker Ridge block 718)
- Riser & Umbilical Installation at site (Walker Ridge block 718)
- Handling daily Ballast and Bilge Operations
- Handling flooding situations due to damaged tank, pipe leakage
- Monitoring and managing level alarms and trips due to instrument malfunction
- Handling Damaged Mooring Line Scenarios
- Hurricane Shutdown and Startup Scenarios
- Engineering support and training for future tie-backs and Stage 2 additions to the FPU

The Simulator will be used as an assessment tool for new and experienced Marine Operators.
CONCLUSIONS

The development and implementation of the Jack-St. Malo high fidelity Lifecycle Marine Simulator was a key contributing factor to the successful accomplishment of following:

- Hull Design and lay-out familiarization
- Validation of the design intent, integration and operability of the control system
- Validation of the Marine Standard Operating Procedures
- Familiarization of Marine Operators to the new control system
- Developing Operator skills in a safe and risk-free environment
- Pre-startup Trouble Shooting
- Improving coordination between Topsides and Marine operations
- Assistance during topsides module lifts at the commissioning yard

The above mentioned benefits prove that the Marine Simulator is an effective tool to develop and sustain operations skills and provide unique safe environment for “hands on” training and engineering support.

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REFERENCES
