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Design

Model Tests for the DP System of a Drilling Semi-Submersible

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1. Introduction

As operators continue to explore and develop deepwater plays, demand for drilling units designed for deepwater operations has increased. Along with conventionally moored units, some operators are expressing a preference for Dynamically Positioned (DP) vessels for deepwater drilling projects. Among the reasons cited for this are subsurface conditions, such as pipelines or production equipment may make the use of DP vessels more active. Additionally, DP units may offer enhanced station keeping ability during extreme weather events, such as those found in the hurricane-prone Gulf of Mexico.

As a result of the demand and to meet market needs, Noble Drilling Services Inc (Noble) is converting its bare deck hulls to sixth generation semi-submersibles DP vessels. Noble developed an extensive upgrade program and it was decided that in line with established DP practices, and to satisfy client requirements, a process of DP capability based verification should be undertaken. These vessels will be outfitted with 8 azimuth thrusters, 2 at each corner of pontoon. This complex design accommodates several variables that affect the performance of thrusters and thus vessel's station keeping capability. Some of these variables are relative wave incidences and include interactions between thruster-thruster, thruster-hull.

An extensive model test program was developed to ensure that the vessel and the selected dynamic positioning system (DPS) would perform as expected. Model tests were conducted at a model test facility in California to assess the capability and reliability of the dynamic positioning system and the thrusters. The objectives of these tests were to investigate the capabilities of the selected DPS and thrusters to hold station during designed normal operating conditions in the Gulf of Mexico (GoM), Brazil, and West Africa (WA) or any other part of the world with similar metocean characteristics. The DP software and control system used during the test was a DP Class-3 system and it was designed especially for the purpose of the test and truly representative of the prototype system that will be installed on the semi-submersible.

This paper discusses the findings and benefits of the model tests, as well as the lessons learned. The paper also makes recommendations as to how they can be implemented in future projects.

2. Overview of the Semi-Submersible

Noble Drilling owns and operates a large number of offshore drilling rigs including several drill ships and semi-submersibles that are dynamically positioned. The majority of the current fleet of semi-submersibles is fully moored, while a limited number are dynamically positioned. Currently, several semi-submersibles are being upgraded with DP-3 systems to enhance the ability of the rigs to maintain position within specified locations during operations. The semi-submersible described in this paper is a twin hull semi-submersible. The semi-submersible will be equipped with eight thrusters arranged according to Figure 1.

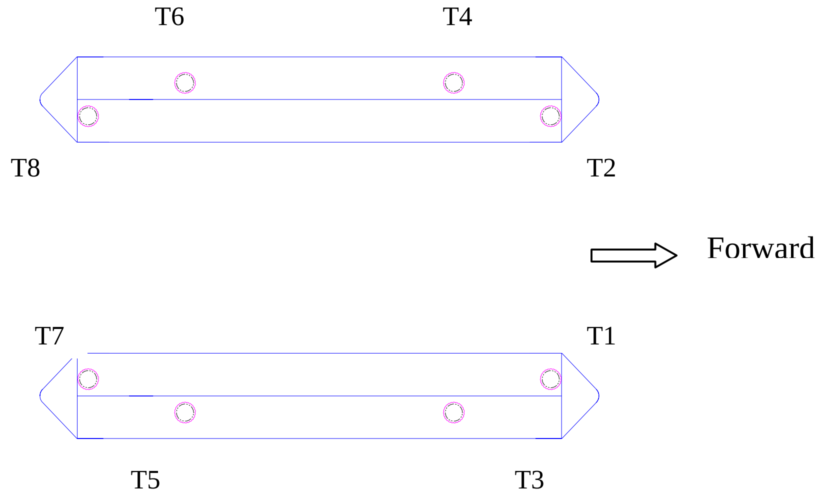

Figure 1: Thrusters Arrangement

The semi-submersible is designed to operate in the golden triangle areas (GoM, Brazil, WA) or other parts of the world with similar metocean characteristics. The transverse distance between the centerline of the pontoons is 55 m. Figure 2 shows a side view of the drilling semi.

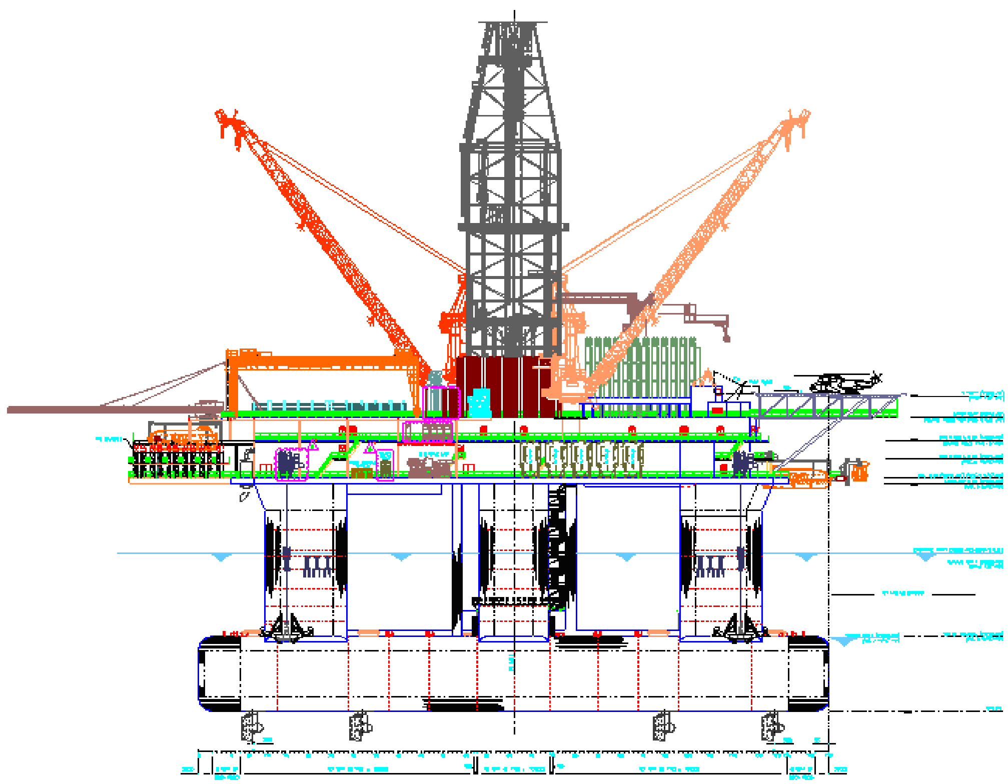

Figure 2: Drilling Semi-Submersible Elevation

The model tests were conducted at operating draft. At this draft the semi had a displacement of approximately 58,000 metric tons. The semi-submersible is equipped with fourable derrick with vertical riser storage and is designed to operate in 12,000 ft water depth.

3. Thrusters and DP System

The thrusters selected for this project are Rolls-Royce UUC 355 FP with a propeller diameter of 3.5 m and motor speed of 720 rpm. At this speed, each thruster has an input power of 3754 kW and delivers thrust of 646 kN. The Power Management System (PMS) and DPS control system are manufactured by Converteam (previously Alstom).

4. Model Test Overview

When selecting a DP system including thrusters, several factors must be considered. These factors include:

- operating conditions such as the vessels draft, displacement and water depth.
- areas of operation
- operating (environmental) conditions

To ensure that the system would perform as expected and to meet the contractual requirements, Noble performed a numerical analysis and then decided to perform physical model tests on the selected thrusters for various operating scenarios.

In a twin-hull drilling semi-submersible, the thrusters' efficiency and performance depend on several parameters:

- Thrusters location on the hull
- Thrusters location relative to each other
- Distance between pontoons
- Shape of pontoons

To investigate the effect of these design parameters on the thrusters' efficiency, several thruster-hull interaction tests and thruster-thruster interaction tests were performed. Also, thrust variations versus current speed were investigated. Finally, the holding capability of the system was tested for a series of environmental and operating conditions.

For the purpose of the tests, scaled thruster models were built to a scale of 1:50 to match the model scale. The individual model thrusters were instrumented to measure the following:

- Azimuth angle feedback and command
- RPM feedback and command
- Electric current

The thrusters were calibrated to establish the relationship between the rpm and thrust, and electric current and thrust. The measured electric current was used to calculate the thrust. The thruster models were built with zero degree fixed tilt angle.

The results of these tests are presented in the following sections.

5. Thruster Interaction Tests

5.1 Background

When a thruster is attached to a hull, degradation in thrust is common based on the shape of the hull and the location of the thruster relative to the hull. The thrust loss is mainly due to:

- Frictional losses between the thruster race and the surface of the vessel
- Deflection of the thruster race around structural elements such as bilges

The frictional loss depends on the location of the thruster and on the geometry and draft of the hull. Typically a monohull vessel of 200m-length will experience a thrust loss of 20 to 25% if the race is blowing underneath the entire bottom of the vessel. Table 1 presents estimated values of frictional thrust loss underneath the hull:

Thruster Location	Direction of Propeller Race	Frictional Thrust Loss %
Bow	Aftward	20-25
Bow	Forward	0-5
Amidship	Forward/Aftward	10-20
Amidship	Sideways	0-5
Aft	Forward	20-25
Aft	Aft	5-10

Table 1: Frictional Losses of a Thruster underneath a Hull

The deflection of a propeller race is studied by Thon (1986) and Lehn (1981). The deflection of the thruster race due to the presence of structural objects or the hull is often referred to as the Coanda effect. The Coanda effect is the natural phenomenon that allows a stream of fluid to follow a slightly curved solid surface when the fluid is flowing along the surface (Ref.1).
The most serious consequence of the Coanda effect occurs if the thruster race is deflected and hits other parts of the hull, i.e. another thruster, or another pontoon in the case of a twin-hull semi-submersible. In this case, the thruster loss can be up to 40 to 50% as measured in some model tests. This thrust loss can be greatly reduced by directing the flow away from the opposing structure. This can be accomplished by tilting the thruster or by adding guiding fins to the nozzle.
Test results showed that thrust loss due to Coanda effect can be less than 5% if the thruster jet is directed to an area where there is no other structure in the path (Ref.3).

Table 2 provides typical values of various parameters for estimation of thruster-hull interaction for a twin hull semi-submersible.

PORT PONTOON, TWIN HULL					
Thruster Location	$\alpha 0$	β	a0	$a + \beta$	$a - \beta$
Forebody	0	20	0.25	0.02	0.1
	90	20	0.05	0.02	0.02
	180	20	0.02	0.02	0.02
	290	35	0.45	0.1	0.02
Midship	0	20	0.15	0.02	0.02
	90	20	0.02	0.02	0.02
	180	20	0.15	0.05	0.02
	270	35	0.45	0.02	0.05
Afterbody	0	20	0.02	0.02	0.02
	90	20	0.05	0.02	0.02
	180	20	0.25	0.1	0.02
	250	35	0.45	0.02	0.1

STARBOARD PONTOON, TWIN HULL					
Thruster Location	α_0	β	a_0	$a + \beta$	$a - \beta$
Forebody	0	20	0.25	0.02	0.02
	70	35	0.45	0.1	0.02
	180	20	0.02	0.02	0.1
	270	35	0.05	0.02	0.02
Midship	0	20	0.15	0.02	0.02
	90	20	0.45	0.05	0.02
	180	20	0.15	0.02	0.05
	270	35	0.02	0.02	0.02
Afterbody	0	20	0.02	0.02	0.02
	110	35	0.45	0.02	0.02
	180	20	0.25	0.1	0.02
	270	35	0.02	0.02	0.1

Table 2: Typical Thruster - Hull Interaction/Thrust Loss on a Semi-Submersible

Where:

- α is the azimuth angle of the thruster
- α_0 is the azimuth angle at which the maximum thrust loss occurs
- a_0 is the maximum thrust loss at azimuth angle α_0
- $a + \beta$ is the thrust loss at outside the jet spread at azimuth angle $\alpha_0 + \beta$
- $a - \beta$ is the thrust loss at outside the jet spread at azimuth angle $\alpha_0 - \beta$
- β is half the width of the jet spread (i.e. thrust loss zone)

These parameters are defined in Figure 3.

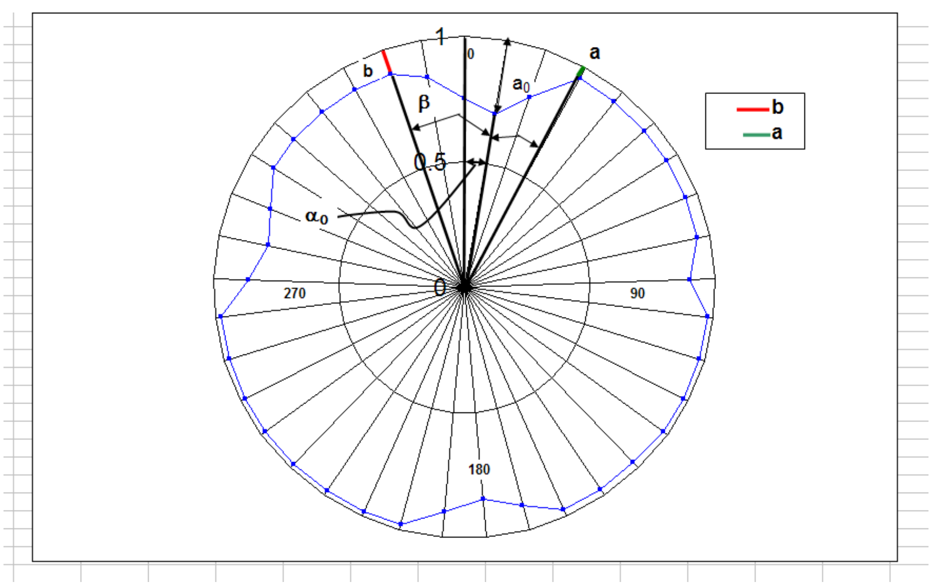

Figure 3: Thrust Loss Parameters Definitions

5.2 Test Set-up

For the purpose of the thruster-hull and thruster-thruster interaction tests, the model was rigidly attached to a stationary structure through three sets of dual axis load cells. These load cells were arranged as shown in Figure 4.

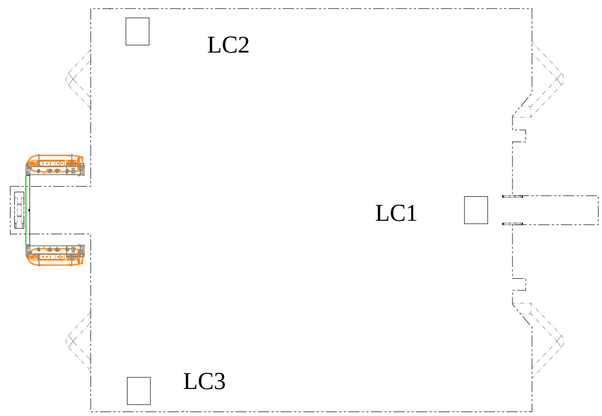

Figure 4: Load Cell Arrangement for Measuring Thrust

The summation of forces measured with these load cells was equal to the total force from the thruster(s).

5.3 Test Results

Thruster-hull interaction tests were performed to establish the interaction losses due to the drag from the opposite pontoon and Coanda effect. The tests were performed using thruster number 1 (only) and then thrusters 1 and 3 operating. The results are shown in Figures 5 and 6.

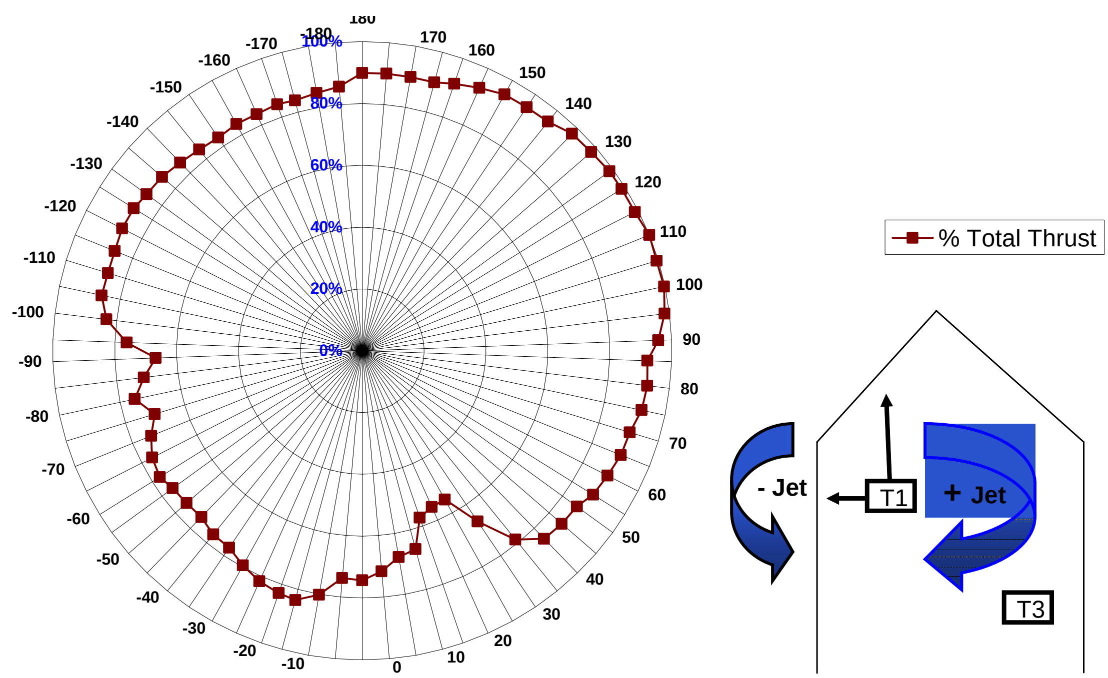

Figure 5: Thruster Hull Interaction, One Thruster Operating (T1)

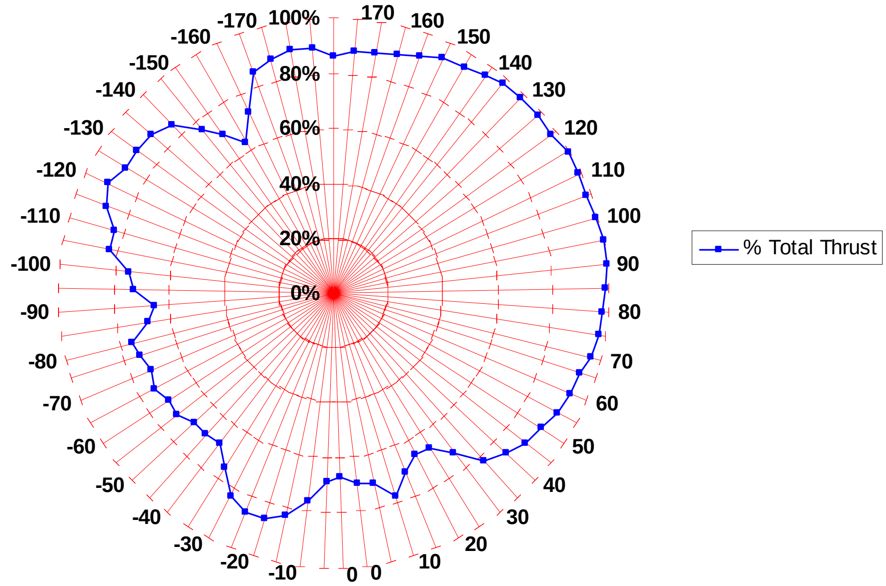

Figure 6: Thruster Hull Interaction, Two Thrusters Operating (T1 and T3)

In the case of two thrusters operating, thrusters 1 and 3 were operating at a maximum thrust and rotating at the same azimuth angle.

It is clear from Figure 6 the effect of the thrusters' performance due to thruster-to-thruster effect and the effect of the hull on the thrusters' performance.

The thrust degradation at 20^o and -160^o is the result of the jet stream from one thruster being directed to the other. The degradation in thrust between 0^o and -140^o occurs when the jet from both thrusters is directed towards the opposite pontoon (in this case, the portside).

It is worth noting that thruster-thruster interactions have been studied extensively by others in the past and the results are well documented. According to Lehn (1992) great losses occur when one thruster is mounted behind another, in tandem condition. At a distance of 6 times the propeller diameter, the thrust loss on the rear propeller will be approximately 45%, assuming equal pitch and RPM. However, by turning the front thruster 15 degrees, the rear thruster will operate at 95to 100%.

6. Sea Keeping Tests

6.1 Test Set-Up and Procedure

The sea-keeping test was conducted at a basin in California. The test was conducted in the sea-keeping and towing tank. The towing and sea-keeping basin is 91m long, 15 m wide and 4.5 m deep. On one end, there is a single wave flap that extends the entire width of the basin. It is operated by means of a hydraulic system with a servo controller. The wave absorber (beach) is located at the other end. The facility has a towing carriage driven by two AC motors. The carriage is capable of traveling at speeds up to 5.4 m/s.

During sea-keeping tests, an optical tracking system that measures the six degrees of freedom was mounted on the towing carriage, while the targets were mounted on the deck of the model. The position signal was provided to the DP control system using the output of the optical tracking system as a feedback. To simulate current, the towing carriage was driven at a speed equivalent to the desired current speed; the model followed using the feedback from the tracking system and pre-programmed parameters for position tolerances.

Wind was simulated using a servo-controlled winch. The wind spectra were converted to time history signal, which was provided as voltage to the servo-controller. A load cell was attached at the wind center of pressure. This load cell provided feedback to the controller at a rate of 200 Hz (model scale) to instantly correct for the wind force. A linear spring was introduced in the system to separate wave frequency from the simulated wind spectrum. Therefore, the wind forces were not affected by the higher frequency wave motions of the semi model. Figure7 illustrates this arrangement.

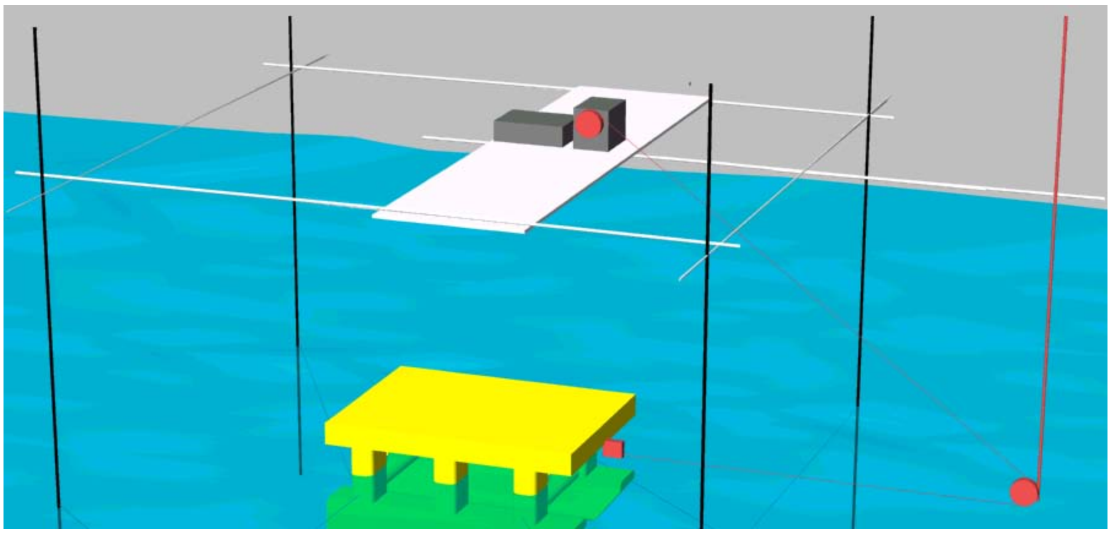

Figure 7: Wind Simulation Arrangement

6.2 Test Results

The tests were conducted for two representative operating environmental conditions in the Gulf of Mexico and in Brazil. They represented 10-year winter storm (GoM) and 1-year storm (Brazil) respectively. These tests were conducted at the vessel's operating draft. Although the semi-submersible will be allowed to weathervane, Noble elected to conduct the tests at several headings that cover the entire range from head to beam seas. All the environments (wind, wave and current) were assumed to be collinear. Where the required full-scale duration exceeded the test duration due to the current speed and limited tank length, the test was conducted over several runs to accumulate enough data for statistical analysis. The results of these tests are presented in Figure 8.

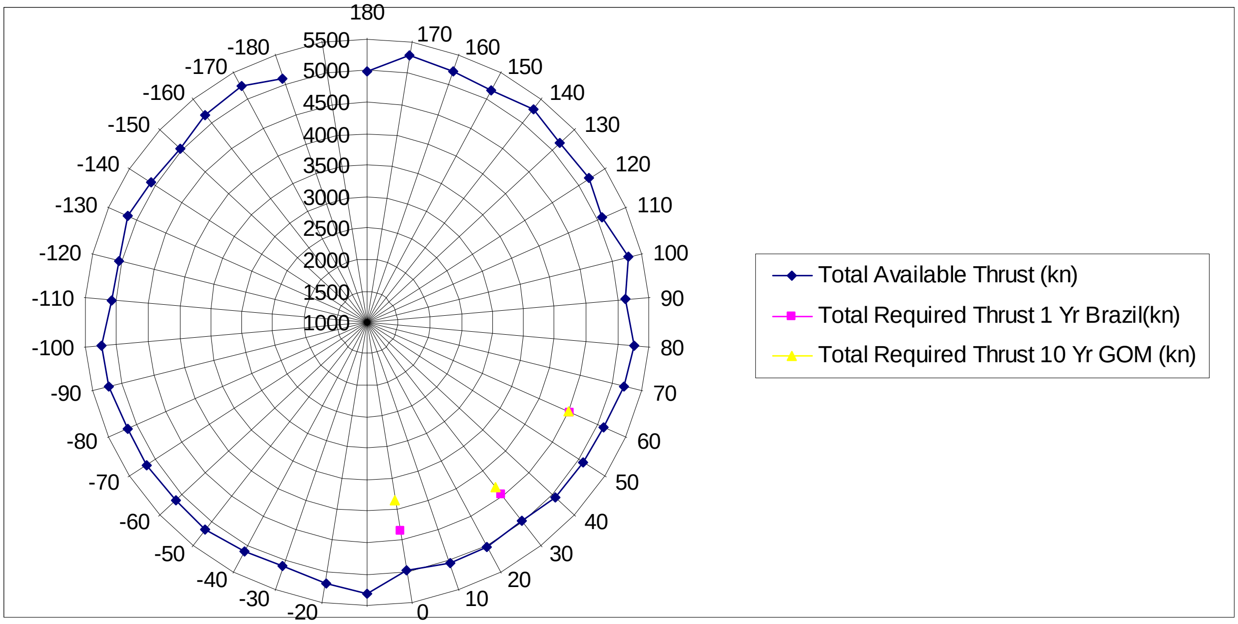

Figure 8: Holding Capability Plot from Model Test

As shown in the Figure 8, the available thrust in three of the four headings tested is larger than the required thrust for both environmental conditions.

Concurrently with the model tests, a numerical DP simulation was carried out using a proprietary program owned by a consulting company in Houston. This simulation considered different environmental conditions in the Gulf of Mexico. Some failure modes were investigated as well. One case of the DP simulation is presented in Figure 9.

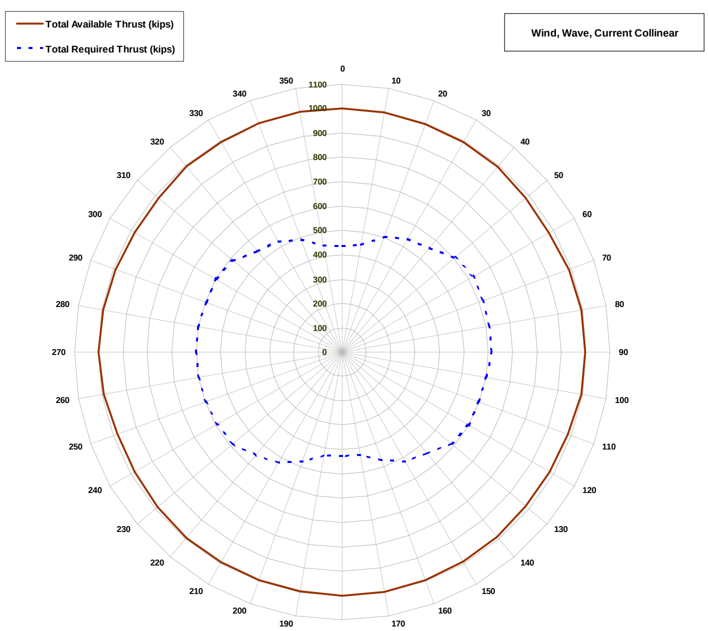

Figure 9: DP Simulation Program, 10-Year WS GoM

Figure 9 shows the results of the DP simulation for the 10-year winter storm in the Gulf of Mexico. The same condition is shown in Figure 8. Both plots show that the available thrust is greater than the required thrust. The variation in the values at the same headings can be explained in terms of differences in thrust losses assumptions in the computer model. In the computer model, assumptions are made to estimate the losses due to thrusters and hull interactions. These assumptions are based on typical values from previous research and model tests of similar hulls. As mentioned in previous sections, these losses depend greatly on design parameters and hull shape. Also, due to scaling effect and other physical limitations during the model test, the actual results may vary slightly from the measured values.

7. Lessons Learned and Challenges

Some of the challenges faced during the project are presented below:

- Scaling effect: In this case, the model scale was 1:50 due to limitations of the testing facility. A typical DP model test is usually conducted at a scale of 25 to 30. Due to the large scale, which translates to smaller model, the DPS used for the model test had to be modified so the clock rate of the controller was about 7 times faster than normal. This presented some challenges for the DPS manufacturer.

- Also, because of the size of the thrusters, physical load cells to measure the individual thrust on each thruster could not be implemented. Instead, electric current was measure for each thruster, and during the calibration phase, the relation between thrust and electric current was established and used to assess the individual thrust during the test.

- Although the test results and the computer simulation show that the available thrust is greater than the required for most of the operational cases using non-tilted thrusters, it was decided to use tilted thrusters to enhance the thrusters' performance and increase efficiency.

8. References

[1] "A thruster system which improves positioning power by reducing interaction losses", L. Vartdal and R. Garen, Dynamic Positioning Conference, September 2001.

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