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Design of the Dynamic Positioning System for the Drillship Glomar C. R. Luigs

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Abstract

Glomar C. R. Luigs is a state of the art, ultra-deep water, drillship, equipped with Nautronix ASK 5003 dynamic positioning controller, which controls the thrust vector from six (6), 5 MW each, azimuthing thrusters to provide superb stationkeeping capability. The system meets the ABS class requirements for DPS-3. The basic elements of a Dynamic Positioning System (DPS) are: (1) Sensor System, (2) Controller, (3) Thruster System, (4) Power System. The emphasis of this paper is on the thruster system. The thruster design has been optimized to satisfy the conflicting requirements for stationkeeping and propulsion.

The paper briefly discusses the preliminary analytical studies to estimate the DP power requirements and size the thruster system to satisfy the stationkeeping requirement for the specified metocean design criteria. This was followed by a full complement of scale model tests for stationkeeping, seakeeping, propulsion, and wind tunnel tests. The paper discusses how the results of the model tests were utilized to calibrate the analytical prediction model in order to predict the expected prototype performance.

The paper discusses the correction factors to the open water thruster performance for hull-thruster, thruster-thruster, and thruster-appendages interactions, in order to predict the in-service performance of the thrusters in the stationkeeping mode. The forbidden zones for thruster operation were developed from these interaction studies in order to provide input to the DP controller for optimum thruster performance. The influence on thrust of the cross-coupled side forces due an oblique inflow will also be discussed. The paper attempts to present a unified methodology for the thruster design in order to achieve optimum stationkeeping and propulsion performance.

1. Introduction

Global Marine pioneered drilling from a floater, particularly a drillship. A drillship's mobility, payload capacity, safety record, and ability to head into the weather, gave it a tremendous advantage to operate in almost all geographical regions of the world, albeit seasonal operation in harsh weather areas. After the advent of jackup and semisubmersible drilling units, the use of a drillship declined in comparison, as the former's unique design features found an optimum application for specific geographical areas.

However, the potential for finding large hydrocarbon reservoirs in ultra-deep waters has lead to a recent resurgence in the commissioning of ultra-deep water drillships, 3-5 times the size of the earlier designs. Glomar C. R. Luigs is a state of the art, ultra-deep water, drillship, equipped with Nautronix ASK 5003 dynamic positioning controller, which controls the thrust vector from six (6) azimuthing thrusters to provide superb stationkeeping capability. This paper discusses the design of the thruster system to satisfy the dual but conflicting requirements for stationkeeping and propulsion. The paper demonstrates that an optimum thruster design was achieved to satisfy these two requirements. The drillship is equipped with the latest in material handling and drilling equipment in order to maximize operational productivity (Reference 1).

2. Mission and Principal Particulars

Though initially equipped for drilling a 35,000 feet well (below sea level) in 9,000 feet of water depth, Glomar C. R. Luigs is capable of drilling in 12,000 feet water depth in metocean conditions equivalent to those listed in Table 1. The thruster arrangement and the principal particulars of the drillship are presented in Figure 1. The payload capacity, motion response, stationkeeping, mobility, vessel/power management systems, drilling system, material handling system, safety systems – all combine to produce an efficient drilling machine in the hands of a well trained crew. The drillship has a storage capacity for 130,000 barrels of crude oil for conducting Extended Well Testing operations.

3. Thruster System Design

Thruster system design consisted of the following steps:

- Preliminary estimate of total DP power requirements
- Number, placement, and sizing of thrusters
- Preliminary prediction of thruster system performance
- Model test verification of prediction
- Final thruster design

3.1 Preliminary DP Power Estimate. Preliminary estimate was made by the use of a thumb rule for DP stationkeeping performance in the Gulf of Mexico (GOM). The rule was developed by Howard Shatto and formally christened as HSSC (Howard Shatto Sanity Check) in Reference 2. The rule states that the wind load due to a 61-knot beam wind should not be greater than 80% of the total available thrust. Next, knowing the number of thrusters, one can estimate the power rating for one thruster. Reference 2 lists a companion formula for estimating the total installed power based on the power rating of one thruster. We found the estimates, based on these empirical rules, were confirmed by formal analytical studies.

The total DP power requirement was estimated at 30 MW (40,214 HP). The DP horsepower per ton of the operating displacement is another index of a DP vessel's stationkeeping capability. Glomar C. R. Luigs has 0.617 DP horsepower per ton displacement, which is substantially greater than that for any drillship of similar payload and water depth ratings. Therefore, this vessel and its sister vessel Glomar Jack Ryan are considered to be more capable in handling the situations such as hurricane, sudden squall, and eddy current.

3.2 Number, Placement, and Sizing of Thrusters. The thruster system power of 30 MW was divided equally divided into six (6) azimuthing thrusters, 5 MW each. Three (3) thrusters were arranged forward (CL & P/S) and the remaining three (3) were arranged aft (CL & P/S). See Figure 1. The criteria for the transverse and longitudinal placement of thrusters was to minimize the thrust degradation from thruster-thruster interaction. The thruster-hull interaction and frictional losses were minimized by tilting the nozzle outlet of the thrusters downward by 5 degrees. The arrangement allows continuous operation with one thruster off line. Other factors considered are listed below:

Mechanically simple and reliable in control. This led to the selection of fixed pitch thrusters.

Ease of repair and maintenance. This led to the design requirement that the thrusters be retrievable on the deck for repair and inspection. The result was a rack and pinion type jacking system, which can retrieve the thruster canister from the thruster well on to the deck.

Effective use of thrust. This led to the choice of azimuthing thrusters as compared to a combination of tunnel and azimuthing thrusters. The azimuthing thrusters allow an optimum use of thrust, especially when the vessel heading has an oblique angle with the resultant environmental load vector.

Harbor operation. The vessel can sail into a harbor or a shipyard without removing the thrusters, because the thrusters can be retracted inside the hull into the thruster wells.

All thrusters are identical. To minimize the cost of spare parts and the maintenance costs, it was decided to have all thrusters of identical design.

3.3 Preliminary Prediction of Thruster System Performance. IHC Gusto Engineering carried out the preliminary vessel design including the sizing of the power plant to support drilling, hotel and stationkeeping functions. Gusto utilized their proprietary software to conduct quasi-static and time domain simulations in order to determine the optimum size, number and placement of the thrusters for the DPS. The stationkeeping performance was predicted for the following GOM return period metocean conditions:

- 10-Year Winter Storm
- 100-Year Eddy Current
- 100-Year Hurricane
- Sudden Squall

3.4 Model Test Verification of Prediction. Following the above analytical studies, a comprehensive model test program was carried out for the above metocean conditions at MARIN and TNO:

- Resistance and Propulsion Tests (including various moonpool configurations)
- Dynamic Positioning Tests
- Seakeeping Tests
- Current Force Measurements
- Decay Tests
- Wave Drift Force Measurements
- Wind Tunnel Test (at TNO)

Four (4) configurations for the moonpool were tested to determine the hull resistance:

Configuration	Change in Resistance
A) Original, rectangular sides	0 %
B) Config. "A" with triangular cutoff at the trailing edge	-10 %
C) Config. "A" with triangular wedge at the leading edge	-10 %
D) Config. "A" with "B" and "C" combined	-25 %

Based on the above results, configuration "D" was selected for the propulsion tests. See Figure 2. The comparison between the calculations and the model test results for the wind tunnel, seakeeping, and DP tests indicated excellent correlation (Reference 3). It is beyond the scope of this paper to go into further details regarding the model tests.

4. Final Thruster Design

A parametric analysis of the performance of the azimuthing thrusters was carried out with the propeller design point as variable. The scope of the analysis was:

- To establish the optimum propeller design point considering the results of the thruster performance calculations for stationkeeping and transit operations for several propeller design options (propeller design point at bollard pull, 2, 4, 6, or 13 knots inflow velocity). The final recommendation for the selection of the propeller design point (i.e., the pitch of the propeller) should yield an acceptable performance during both modes of operation - stationkeeping and transit - and an acceptable range of field weakening for the thruster drive system. Kamewa Aquamaster indicated a preference for keeping the field weakening range of the propeller drive (which is associated with a thruster rpm increase) within 10% of the nominal thruster design rpm.

- To predict the speed of the vessel in transit (using all six thrusters) and shallow water maneuvering (using the two stern thrusters only), for 100% as well as 80% power levels.

The available documentation for conducting this study is included in References 4 and 5. Reference 4 provided the resistance of the vessel. Reference 5 presented the performance of the thrusters from zero inflow velocity to 16 knots vessel speed, with the propeller design point (bollard pull, 8, and 13 knots inflow velocity) as parameter. Kamewa selected a propeller diameter of 4100 mm and RPM of 151 (nominal) and 166 (maximum). The challenge was to determine the propeller design point that results in an optimum performance in stationkeeping as well as propulsion, two conflicting requirements. For a fixed pitch propeller, the design point for the highest efficiency can either be the transit mode or the stationkeeping mode, but not for both. The reason is that the propeller pitch (for a given propeller diameter) to absorb 5 MW power with the maximum feasible forward speed (transit mode) is significantly different from that required to absorb the same power with zero forward speed (bollard pull or stationkeeping mode). However, it is possible to select the propeller design point in between these two limiting cases, and optimize the design for both stationkeeping and propulsion. This is discussed in Section 4.1.

4.1 Propeller Optimization. Computations were carried out for the performance of the thruster propeller at several design points with the inflow velocity as parameter (Reference 6):

- Bollard Pull (zero inflow velocity)
- Two (2) knots
- Four (4) knots
- Six (6) knots
- Eight (8) knots
- Thirteen (13) knots

The recommendation for the optimum propeller design point selection were based on the results of these calculations, considering the trade-off such as performance during stationkeeping, performance during transit, i.e., obtainable speed of the vessel, and thruster-specific parameters such as the required rpm range to yield optimum performance. The two extreme propeller design options are:

Bollard pull. A propeller designed for bollard pull yields the highest performance for stationkeeping. In order to apply full rated power to the propeller at increased inflow velocities including transit speed, the rpm of the propeller must be increased following the characteristic of the specific propeller. This rpm increase at rated power is feasible for thruster drive systems such as SCR controlled, shunt-field DC motors, or variable speed AC drives. A speed increase of 20% over the nominal rpm can be typically achieved from these drive systems. Kamewa Aquamaster, however, prefers to limit the rpm increase of their thrusters to approximately 10%. The required rpm range for the operation of a propeller from stationkeeping through transit speed depends on propeller parameters and, most of all, the transit speed of the vessel. Most of the applications fall within the 20% rpm range.

Transit speed. A propeller designed for transit speed yields the highest efficiency at this point; however, the stationkeeping capability is reduced. In the range from transit speed to zero speed, the drive system can only be operated at maximum torque level, which requires a reduction in rpm and reduces the power applied to the propeller and consequently the thrust output.

The results of the calculations indicate quantitative values for the performance of the propeller at the various design points. It must be noted that these calculations represent the theoretical performance of the propeller and the nozzle only. They do not account for any reduction in thrust or propeller/nozzle efficiency due to the presence of the thruster gear housing, support struts, etc. These factors are treated later on in this paper. Table 2 shows the summary of the results of the propeller optimization calculation:

- The highest bollard pull values can be achieved by designing the propeller for zero inflow. The thrust of this propeller at 14 knots is 10% lower than that of the propeller designed for 13 knots. An increase in the rpm of more than 15% is required.
- Designing the propeller for 13 knots yields the highest thrust at transit speed, but reduces the thrust available at bollard pull by 10%. RPM increase for 14 knots transit speed in negligible.
- The listed values for design points 2, 4, 6, and 8 knots indicate feasible compromise designs. Reviewing the results of the calculations, the inflow velocity of 6 knots was selected as the optimum propeller design point for propulsion as well as stationkeeping:
- Bollard pull is marginally reduced (approximately 1.5%)
- Thrust at 14 knots is 6% higher than that of a propeller designed for bollard pull
- RPM increase for full power at 14 knots is 12%, an increase which should be accommodated by Kamewa
- Maximum motor output at bollard pull is 4804 kW

5. Vessel Speed Prediction

The resistance of the vessel is documented in Reference 3. For the propeller designed for 6 knots inflow velocity (pitch/diameter ratio = 0.99), a series of calculations were carried out to predict the speed of the vessel during transit with six (6) thrusters and shallow water operation utilizing the two (2) stern thrusters only. The calculations were carried out for 100% power and 80% power (Reference 6). The following notes apply to these calculations (Tables 3 & 4 and Figures 3 & 4):

- The basic calculation procedure is similar to that applied for the propeller optimization calculations. However, the drag of the thruster was considered by introducing a thrust deduction factor of 0.9 through the entire range of calculations. This may lead to optimistic results in the higher velocity ranges.
- The resistance of the vessel was taken from Reference 3. The MARIN results indicate the resistance of the vessel at tank conditions, i.e., no wind, no waves, clean hull, etc. In order to yield more realistic results, we introduced a service allowance factor of 1.25 to the tank resistance value. The speed prediction graphs include this factor.
- The stern thrusters were treated in the calculations in the same way as the thruster mounted under the bottom of the hull. Factors such as wake fraction, thrust deduction fraction, and hull efficiency were neglected. Any thruster-hull or thruster-thruster interaction effects that may affect the results of these propulsion calculations are negligible and, therefore, were neglected.

Under above listed conditions, the speed prediction for the Glomar C. R. Luigs is approximately as follows:

- 100% power - all 6 thrusters 14.1 knots
- 100% power - 2 stern thrusters only 10.1 knots
- 80% power - all 6 thrusters 13.1 knots
- 80% power - 2 stern thrusters only 9.6 knots

6. Stationkeeping Performance

This section presents the stationkeeping capabilities of the vessel during drilling operations. It determines the required thruster loads at various environmental conditions (Table 1) - expressed in wind speed, current speed, and wave drift forces. The results are presented in polar plots indicating the required thrust levels as a fraction of the maximum available thrust as well as the required thruster torque as a fraction of the maximum allowable torque for the two groups of thrusters. Active thrusters as well as thrusters out of service are considered. The performance prediction is determined in accordance with the requirements of Reference 7. The DP stationkeeping capability plots are provided for the following operating modes:

- Intact System - all thrusters functional.
- Damaged System - DPS-2 (one thruster out) and DPS-3 (one main power plant/switchboard out).

For the DPS-3 mode, two forward thrusters and two aft thrusters are available. This was achieved by feeding the two portside thrusters (fwd & aft) from the port switchboard, two starboard thrusters (fwd & aft) from the starboard switchboard, and the two centerline thrusters (fwd & aft) from both the port and starboard switchboards. The latter pair can be switched between the port and starboard switchboards.

6.1 Thrust. The bollard pull thrust values in Table 2 have been corrected for hull-thruster interaction, thruster housing, and the thrust degradation due to current inflow velocities (Reference 8). These correction factors are presented in Table 5 and Figure 5. These data were incorporated into the calculations.

6.2 Control of Power and Torque. The design point of the propeller was selected for 6 knots inflow velocity. From zero inflow velocity to the design inflow velocity of 6 knots, the thrusters are controlled by varying the input voltage to the drive motor which regulates the rpm of the motor. The limitation for this operation of the thrusters is the maximum allowable torque (or maximum allowable current of the drive motor). For the operating range from 6 knots to the maximum transit speed, the thruster motor is controlled by field weakening, i.e., increasing the motor rpm beyond the nominal or base speed of the motor. The limitation for this operation is the maximum available power. Since the thrusters will be operated during stationkeeping operations from zero to maximum torque (at slightly reduced rpm and power), the stationkeeping capability polar plots (see below) for the propeller load also indicate the torque level as a fraction of the maximum allowable torque.

6.3 Cross-Coupled Side Force. During some DP operations, in particular when executing yaw maneuvers, the thrusters are pointed in a direction which deviates from the direction of the incoming current. The propellers then operate at oblique inflow angles. In this condition, in addition to the propeller thrust, a cross-coupled side force, orthogonal to the propeller axis, is generated. Table 6 and Figure 6 present the correction factors for the cross-coupled side force as a fraction of the bollard pull and a function of the inflow angle (Reference 8). This data was incorporated into the calculation procedure.

6.4 Forbidden Zones. The results presented in this paper do not incorporate the effect of thruster forbidden zones into the analysis (Reference 8). These forbidden zones are shown in Figures 7 and 8. The forbidden zones arise from thruster-thruster interaction and thruster – skeg interaction. The typical width of a forbidden zone for the Glomar C.R. Luigs thruster arrangement is ±15° for thruster-thruster interaction, and ±10° for thruster-skeg interaction. For example, if thrusters 2 and 3 are producing thrust to port beam, the downstream thruster (#2, in this case) would experience significant reduction in thrust within ±15° off the beam direction, due to the wake of thruster #3 blowing into thruster #2. However, Nautronix's ASK 5003 DP system controller incorporates these forbidden zones and would automatically steer the upstream thruster out of its forbidden zone. By steering the upstream thruster out of the forbidden zone by ±15°, the maximum reduction of effective thrust is about 3.4% (1-cos15°). If the forbidden zones were taken into account, the mathematical model for the calculations would have grown by a factor of three, but without altering the overall conclusions of the study. Therefore, the additional complications to the mathematical model were not justified and the forbidden zones were ignored in this study.

6.5 Methodology. The calculation method is based on the usage of MATHCAD Professional, Version 8 (Reference 8). The objective was to determine the thruster forces required to keep the vessel on location during various environmental conditions. The method determines the equilibrium between the steady state environmental forces acting upon the vessel and the forces generated by the thrusters. For this report the environmental forces due to wind, waves, and current are imposed on the vessel collinearly and concurrently, although the calculation procedure allows the selection of individual incident angles for the three environmental forces. First, the thrust forces required to balance the environmental forces are calculated. Next, the torque required from the thrusters to generate the required thrust, are calculated. The torque calculation considers the thruster propeller characteristic, including the thrust degradation due to the current velocity. Since the design point of the propellers is selected at 6 knots inflow velocity, the limiting load factor during stationkeeping (between bollard pull and six knots) is torque. Due to the interaction of the variable speed AC drive system with the propeller characteristics, the thrusters can be operated to the maximum allowable torque level during the stationkeeping mode. For the development of the calculation procedure, the vessel's six (6) thrusters were grouped into two groups as follows:

- Forward azimuthing thrusters, which includes thrusters 1, 2, and 3 (Figure 1)
- Aft azimuthing thrusters, which includes thruster 4, 5, and 6 (Figure 1)

In the polar plots, each of these thruster groups is represented by a separate trace for its combined thrust contribution as well as for the combined torque required to generate the thrust under the given conditions such as inflow velocity, inflow angle, etc. However, each thruster in the forward or aft group is treated separately with its individual coordinates in order to determine the polar plots for thrust and torque. For example, for the DPS-2 failure mode, any of the six thrusters can be deactivated. The total required thrust forces are equally allocated between the two thruster groups. The environmental forces acting against the vessel are the surge (X), sway (Y), and a yaw moment (M). The calculation procedure establishes the equilibrium of these known forces and moment with the unknown forces and moment generated by the thrusters. The three unknown values are the thrust generated by the forward and aft thruster group, the azimuthing angle of the forward thruster group, and the azimuthing angle of the aft thruster group. The results (thrust and torque of the forward and aft thruster groups) of the non-linear equation are plotted in a polar diagrams for 0–360 degrees in ten-degree intervals.

6.6 Stationkeeping Capability Polar Plots. The polar plots indicate the required thruster load as a function of the vessel heading (Reference 9). The required thruster load is represented as a fraction of the maximum available thrust and as a fraction of the corresponding maximum allowable torque for each group of thrusters. Each plot represents:

- a selected environmental condition
- a selected number of active thrusters (or plants powering the thrusters)
- a selected draft of the vessel

In addition, the cross-coupled side forces of the thrusters during oblique inflow angles are also considered. The input variables include the following:

- Current velocity and wind velocity, applied collinearly with the wave
- Significant wave height and peak period
- Selection of thrusters and /or power plants (on or off)
- Vessel draft, 7 m and 11 m (11 m is the loadline draft)

The following cases for the intact condition and failure modes were considered in the computations:

Case 1. This is the intact case. All thrusters are available at full load. This is the normal operating condition.

Case 2. Thruster No. 1 is out (DPS-2 condition). This mode considers failure of the thruster in the bow. Due to the longest moment arm, it is the most critical thruster for vessel heading control.

Case 3. Port power plant is out (DPS-3 condition). In this mode, thrusters 3 and 6 are out. Thruster 4, normally assigned to the port power plant, is switched to the starboard power plant. (Starboard power plant out, is treated similarly.)

In all, ninety-eight (98) polar plots were calculated, representing various combinations of operating modes, failure modes, vessel draft and environmental conditions. Only a few representative plots are shown in Figures 9, 10, and 11.

7. Results

The results of the stationkeeping capability plots lead to the following conclusions:

Intact Condition. The static holding calculations indicate that the vessel is capable of keeping position in all environmental conditions equivalent to those listed in Table 1, except the 100-year hurricane. The results for the intact cases are presented in Table 7.

DPS-2 Notation. The static holding calculations for the vessel indicate that the vessel is capable of keeping station and/or operating in the environmental conditions equivalent to those listed in Table 1 after loss of a critical thruster, except the 100-year hurricane. Hence it complies with the DPS-2 notation requirements of Reference 5.

DPS-3 Notation. The static holding calculations indicate that the vessel is capable of keeping position after loss of one power plant during the environmental conditions equivalent to those listed in Table 1, except the 100-year hurricane. Hence it complies with the DPS-3 notation requirements of Reference 5.

8. Conclusions

Main conclusions of this study are as follows:

- The thruster system propeller has been designed to provide optimum propulsion and stationkeeping performance, two inherently conflicting requirements.

- The vessel speed during transit is expected to be about 14 knots with all of the six (6) thrusters operating at 100% of power, and about 10 knots with only two aft thrusters operating at 100% power. At 80% of power, the respective speeds are expected to be 13 and 9.5 knots.
- For stationkeeping, the thrust output in the bollard pull condition (zero inflow velocity) is only 1.5% less than that would have been possible were the propeller designed for zero inflow velocity instead of 6 knots inflow velocity.
- Glomar C. R. Luigs complies with the ABS DPS-2 and DPS-3 requirements for all environmental conditions equivalent to those listed in Table 1, except the 100-year hurricane.

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TABLE 1 – METOCEAN CONDITIONS

Sea State	Current Velocity Knots (m/s)	Wind Velocity (1 min.) Knots (m/s)	Significant Wave Height ft. (m)	Peak Period Sec (rad/sec)
1-Year Winter Storm	0.59 (0.30)	41.0 (21.1)	16.0 (4.9)	10.0 (0.628)
10-Year Eddy	2.72 (1.4)	34.4 (17.7)	11.5 (3.5)	9.0 (0.698)
Sudden Squall	0.59 (0.30)	61.0 (31.4)	4.9 (1.5)	5.9 (1.065)
10-Year Winter Storm	0.59 (0.30)	50.5 (26.0)	19.0 (5.8)	10.6 (0.593)
100-Year Eddy	3.89 (2.0)	34.4 (17.7)	11.5 (3.5)	9.0 (0.698)
100-Year Hurricane	1.94 (1.0)	103.2 (53.1)	41.0 (12.5)	15.0 (0.419)

TABLE 2 – SUMMARY OF PROPELLER OPTIMIZATION RESULTS

Propeller Design Point (Knots)	0	2	4	6	8	13
Max. BP thrust (kN) [1]	889.7	889.4	888.3	877.4	864.5	806.3
Max. power PD (kW) [2] at BP	4750	4724	4668	4564	4461	4009
Max. motor output (kW) at BP (at torque/current limit)	5000	4973	4914	4804	4696	4220
Propeller rpm at BP	151.0	150.2	148.5	145.1	141.9	127.5
BP thrust in % of BP thrust at BP design point	100.00	99.97	99.84	98.62	97.17	90.63
Thrust at 14 knots (kN)	347.0	355.0	362.5	368.5	373.0	383.0
Thrust at 14 knots in % of thrust at 14 knots at BP design point	100.0	102.3	104.5	106.2	107.5	110.4
Propeller rpm at 14 knots, full power	174.2	172.8	171.6	168.6	166.4	154.1
Required rpm increase at 14 knots and full power in % of design rpm (151 rpm)	115.4	115.0	113.6	111.7	110.2	102.1
Motor output power (kW) at design point	5000	5000	5000	5000	5000	5000
Power PD (kW) delivered to the propeller at design point	4750	4750	4750	4750	4750	4750
Propeller rpm at design point	151	151	151	151	151	151

NOTES: [1] BP = bollard pull or thrust at zero inflow velocity
[2] PD = power delivered to the propeller = 0.95 x motor output power

TABLE 3 – INTACT CONDITION STATIONKEEPING PERFORMANCE

Sea State	Draft (m)	Permissible Operating Sector at 80% Torque (Deg)	Permissible Operating Sector at 100% Torque (Deg)
1-Year Winter Storm	7 11	360 360	360 360
10-Year Eddy	7 11	95 76	360 98
Sudden Squall	7 11	72 86	93 121
10-Year Winter Storm	7 11	80 360	360 360
100-Year Eddy	7 11	68 53	82 64
100-Year Hurricane	7 11	None None	10 18
Maximum Wind	7 11	--- ---	360 at 60 knots 360 at 66 knots

DRILL SHIP "GLOMAR C.R. LUIGS"

PRINCIPAL PARTICULARS

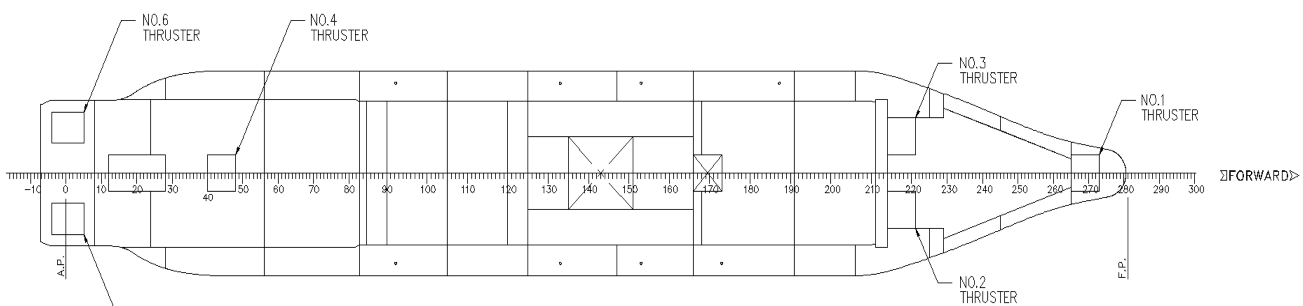
LENGTH OVERALL	231.3 m
LENGTH BETWEEN PERPENDICULARS (LBP)	210.0 m
BREADTH (MOLDED)	36.0 m
DEPTH TO MAIN DECK AT SIDE (MOLDED)	17.8 M
BLOCK COEFFICIENT (CB) AT 11.0-M (LOAD LINE) DRAFT	0.81
LOAD LINE DRAFT (MOLDED)	11.0 m
LOAD LINE DISPLACEMENT	68,043 TONNES
HEIGHT OF DRILL FLOOR ABOVE BASE LINE	34.1 m

ITEM	TRUSTER No.	DISTANCE TO A.P. (m)	DISTANCE TO ROTARY TABLE* (m)	DISTANCE TO HULL CENTERLINE* (m)
1	BOW	201.61	95.71	0.0
2	STARBOARD BOW	165.21	59.31	6.45
3	PORT BOW	165.21	59.31	-6.45
4	CENTERLINE STERN	30.51	-75.39	0.0
5	STARBOARD STERN	0.34	-105.56	7.76
6	PORT STERN	0.34	-105.56	-7.76

NOTE: MIDSHIP IS 105.0m FROM A.P. (A.P.= FRAME 0)
ROTARY TABLE CENTERLINE 105.9m FROM A.P. (A.P.= FRAME 0)

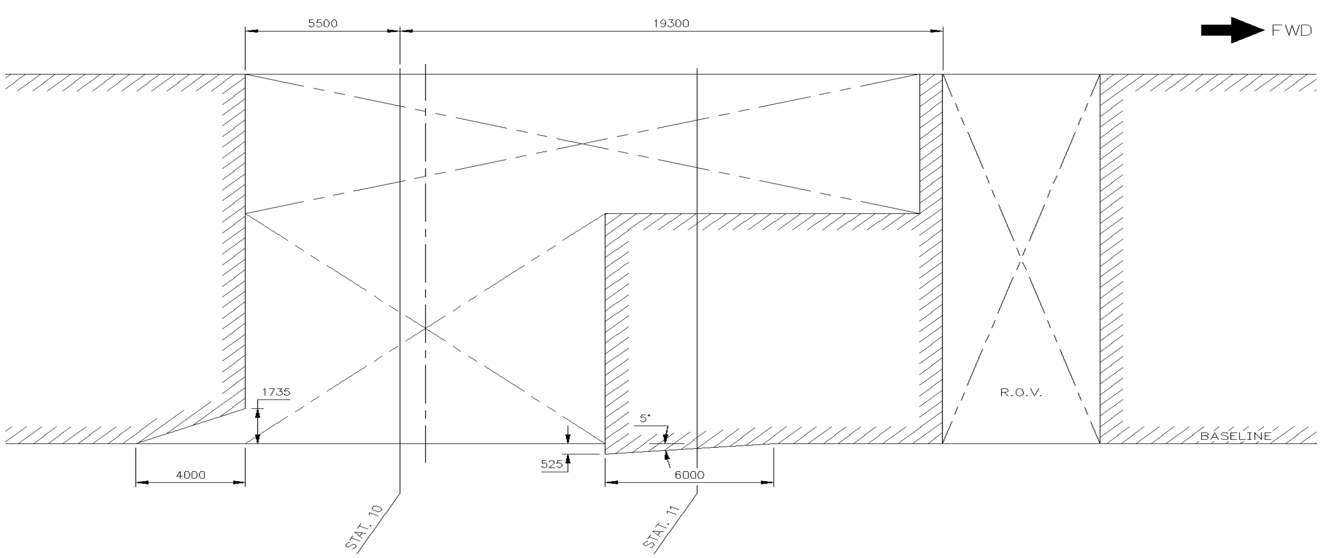
* (+) SIGN OF LONGITUDINAL DISTANCE INDICATES IT IS FORWARD OF ROTARY TABLE CENTERLINE.
* (-) SIGN OF LONGITUDINAL DISTANCE INDICATES IT IS AFT OF ROTARY TABLE CENTERLINE.

* (+) SIGN OF TRANSVERSE DISTANCE INDICATES IT IS ON THE STARBOARD SIDE OF CENTERLINE.
* (-) SIGN OF TRANSVERSE DISTANCE INDICATES IT IS ON THE PORT SIDE OF CENTERLINE.



GLOMAR C.R. LUIGS THRUSTER LOCATIONS
ABOVE TANK TOP

FIGURE 1



CROSS SECTION THRU MOONPOOL
LOOKING PORT

FIGURE 2

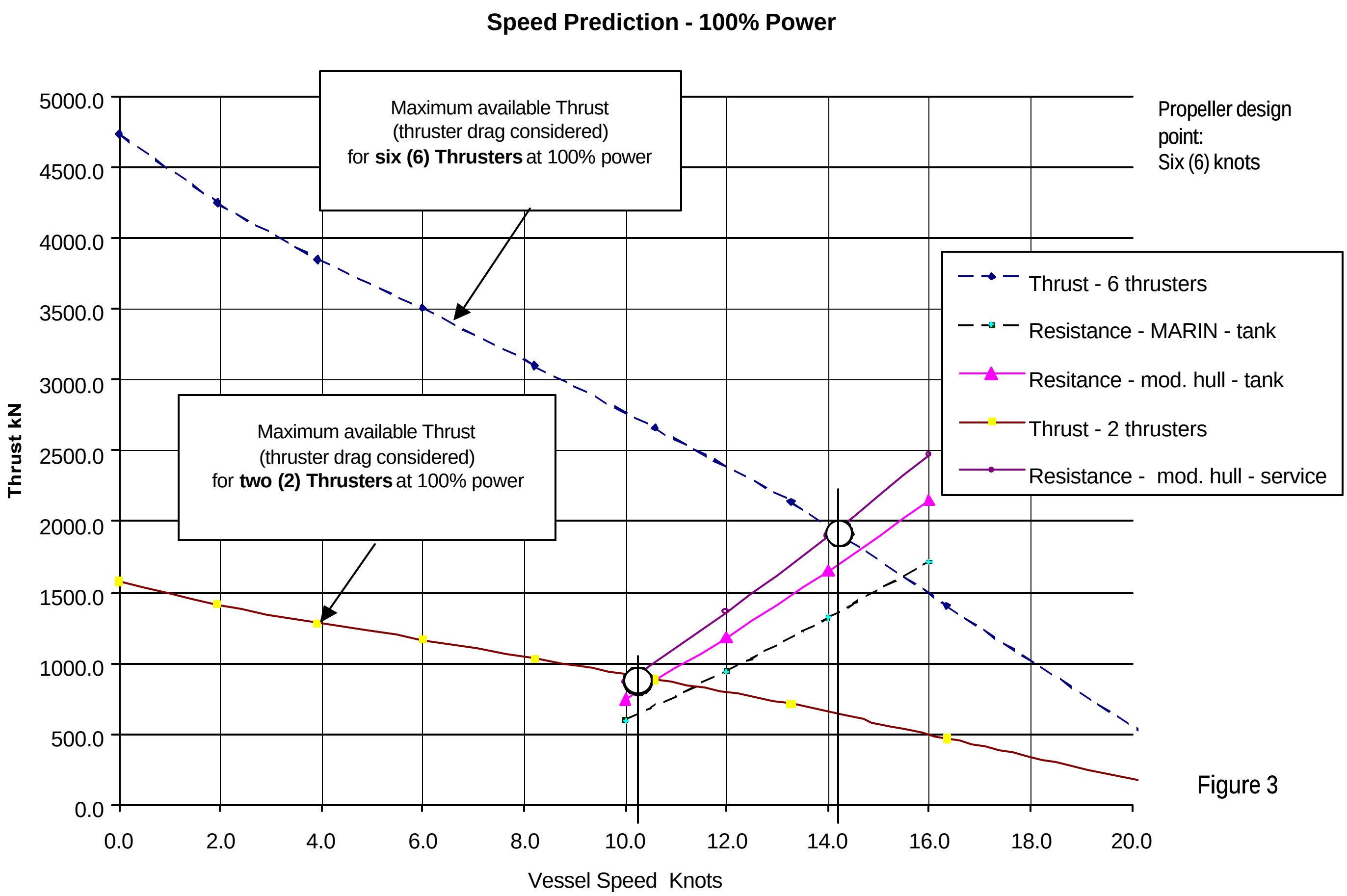


Figure 3

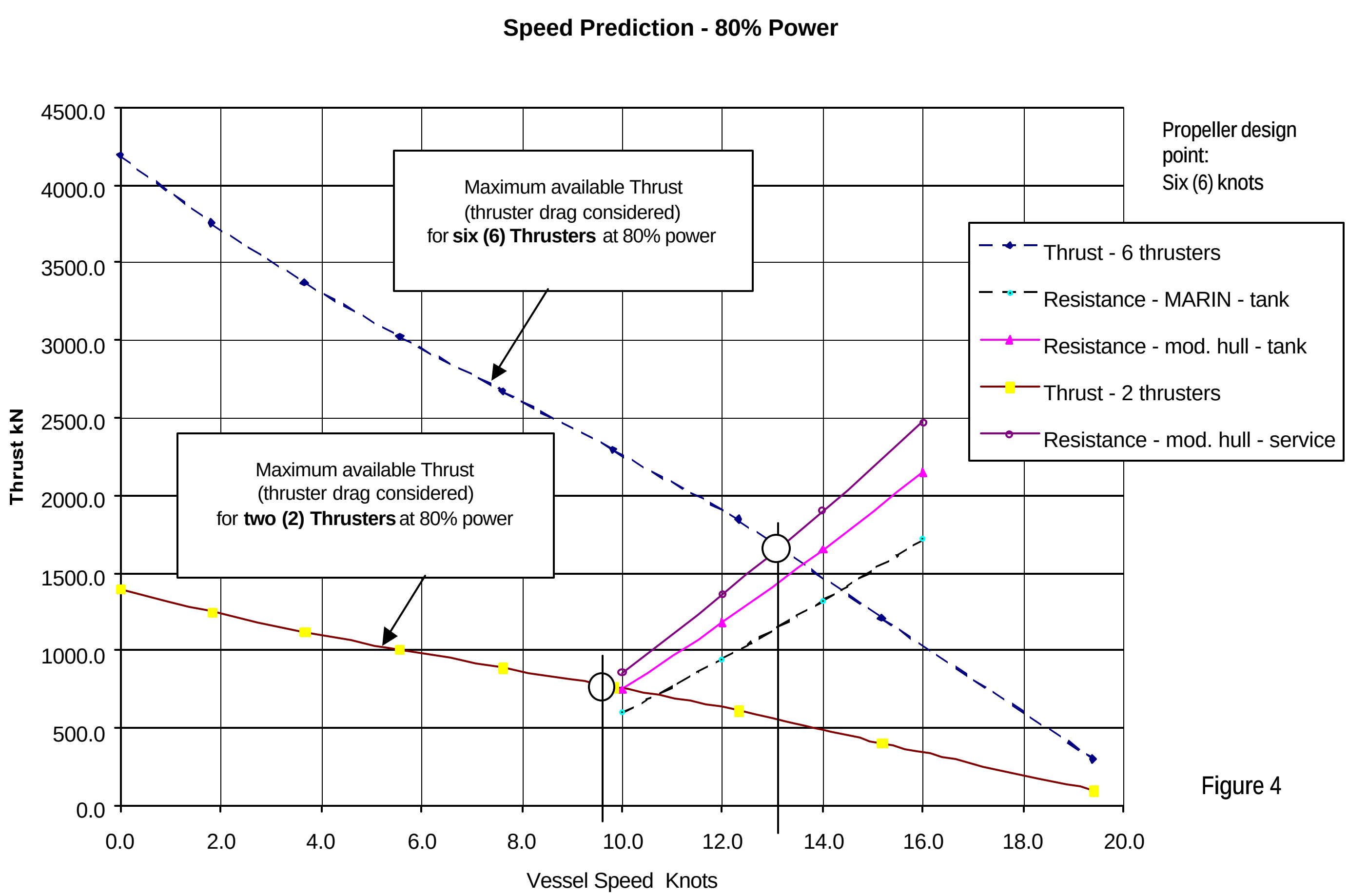


Figure 4

Thrust/Effectice Force Correction Factors
for Thruster-Hull Interaction, Current Inflow Velocities, and Thruster Housing

TDF1 = Thrust deduction factor: thruster housing
TDF2 = Thrust deduction factor: hull interaction for all azimuth angles
Va = Propeller inflow velocity

EF = Effective force = Tn xTDF1xTDF2
T0 = Thrust at Va = zero (bollard pull) = 877.4 kN
Tn = Thrust at inflow velocities

Va Knots	Thrust Tn kN	Tn/T0	TDF1	TDF2	EF kN
0	877.4	1.000	0.99	0.95	825.2
1.94	779	0.888	0.97	0.95	717.8
3.92	687	0.783	0.96	0.95	626.5
6	600	0.684	0.94	0.95	535.8

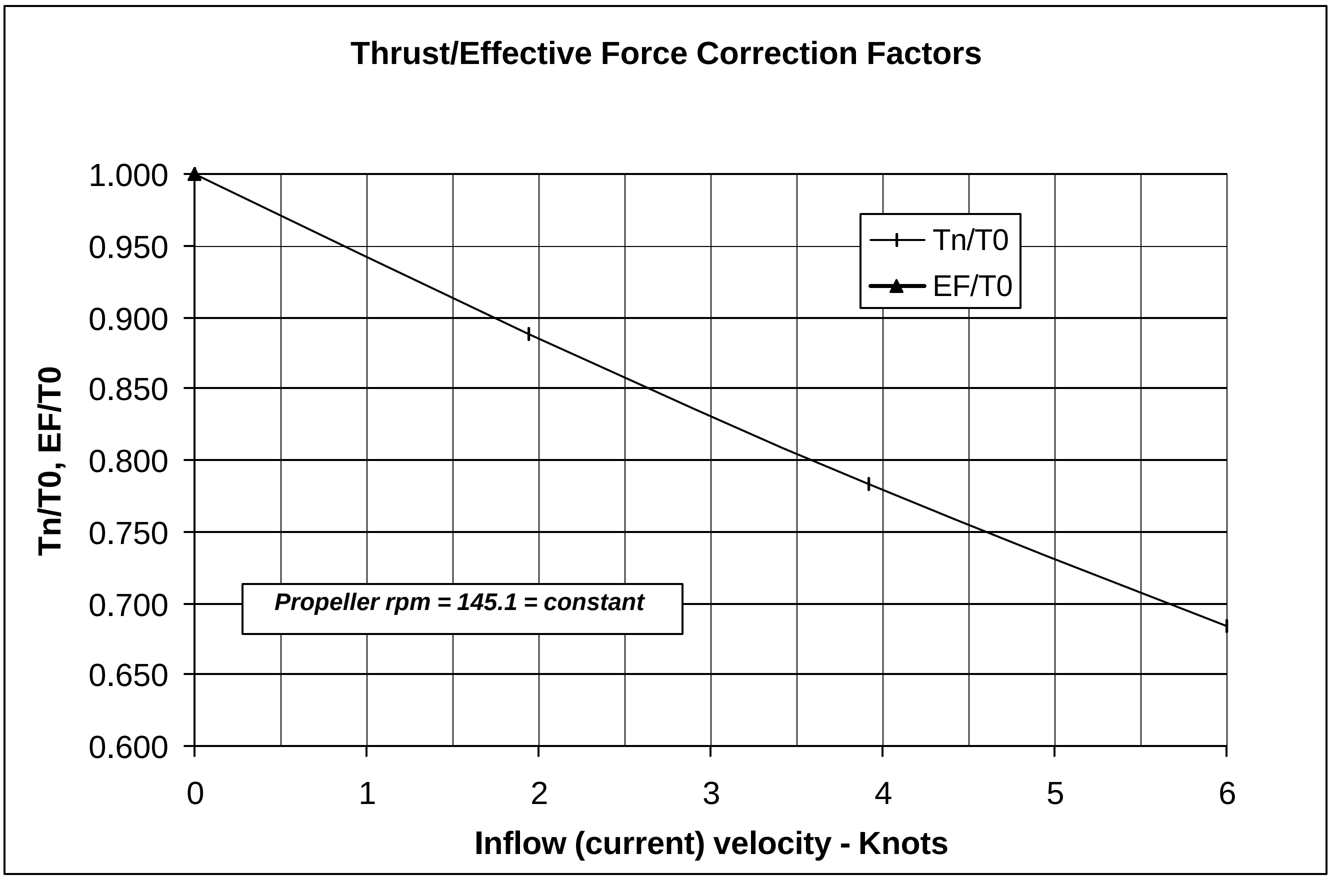


Figure 5

GMDC Hull 456 **H&W Hull 1739**
STATIONKEEPING

Azimuthing Thruster Performance Under Oblique Inflow Angles

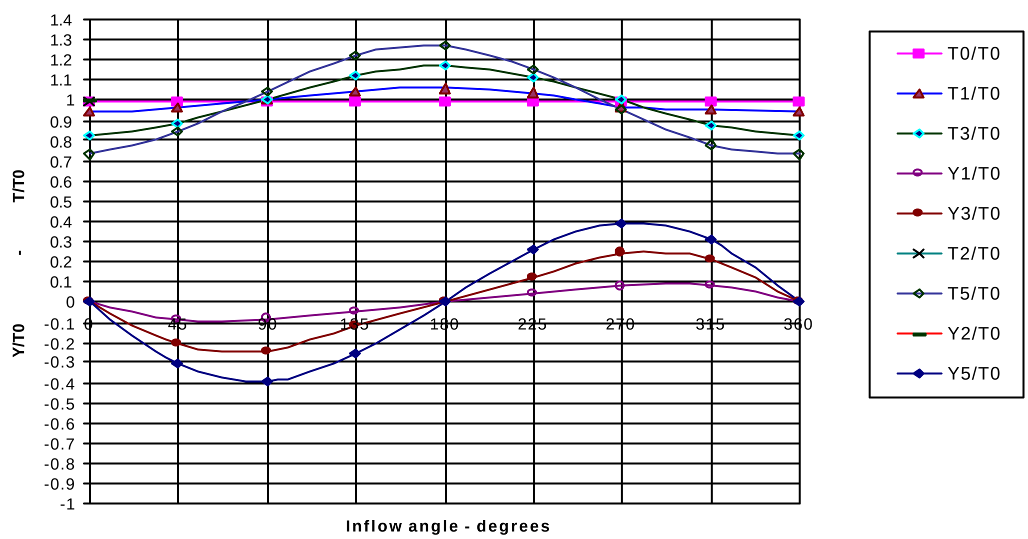
Thrust and (Cross-Coupled) Side Force as a Factor of Bollard Pull

Parameter: Current Inflow Angle (Angle Relative to the Propeller Axis)

T0 = Bollard Pull = 877.47 kN

Inflow angle								
Deg.	T0/T0	T1/T0	T3/T0	T5/T0	Y0/T0	Y1/T0	Y3/T0	Y5/T0
0	1	0.940	0.830	0.733	0	0.000	0.000	0.000
45	1	0.960	0.883	0.843	0	-0.086	-0.207	-0.307
90	1	1.004	1.004	1.045	0	-0.079	-0.243	-0.393
135	1	1.045	1.123	1.221	0	-0.045	-0.117	-0.258
180	1	1.060	1.170	1.267	0	0.000	0.000	0.000
225	1	1.040	1.117	1.157	0	0.045	0.117	0.258
270	1	0.966	1.004	0.955	0	0.079	0.243	0.393
315	1	0.955	0.877	0.779	0	0.086	0.207	0.307
360	1	0.940	0.830	0.733	0	0.000	0.000	0.000

Thrust and Side Force vs. Inflow Angle



Reference: MARIN Report 0905-1-DC

T0	Thrust at zero current velocity		
T1	Thrust at one knot current velocity	Y1	Side force at one knot current velocity
T2	Thrust at two knots current velocity	Y2	Side force at two knots current velocity
T3	Thrust at three knots current velocity	Y3	Side force at three knots current velocity
T4	Thrust at four knots current velocity	Y4	Side force at four knots current velocity

Figure 6

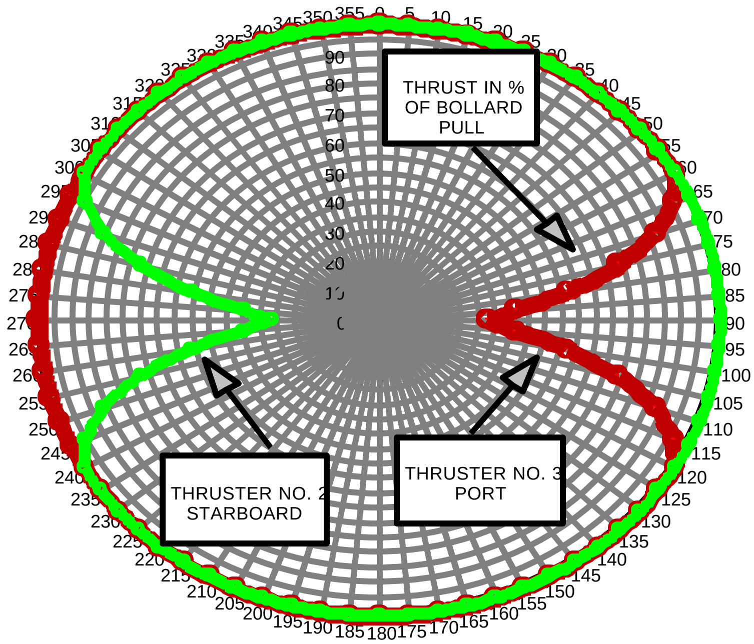


Figure 7

Thruster-Thruster interaction
For Thrusters No. 2 & 3

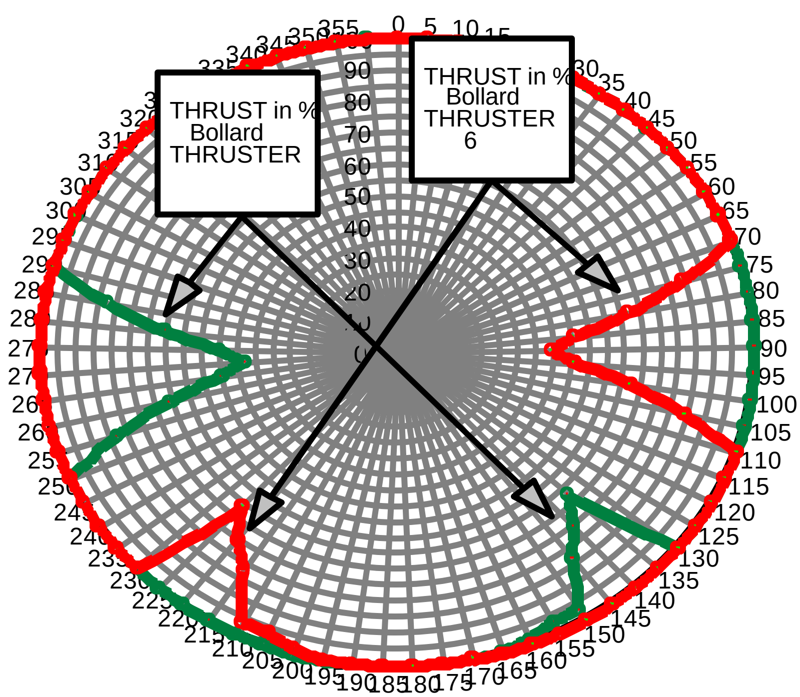


Figure 8

Thruster-Thruster and
Thruster-Skeg interaction
For Thrusters No. 5 &6

DP Drillship GLOMAR C. R. Luigs

Enviromental data :				**Incident angle with respect to south (bx = 0 [deg])**			
$v = 0.5$	[knots]	Current speed	**Input**	$\beta c = 180$	[deg]	Current	**Rounded data**
$w = 41$	[knots]	Wind speed	**Input**	$\beta w = 180$	[deg]	Wind angle	**Rounded data**
$df = 0.6$	[rad/s]	Wave frequ. (peak)	**Input**	$\beta d = 180$	[deg]	Wave angle	**Rounded data**
$Hs = 4.9$	[m]	Wave height	**Input**				
$Dft = 11$	[m]	Vessel draft	**Input**				

$\varepsilon_1 = 1$ $\varepsilon_2 = 1$ $\varepsilon_3 = 1$ $\varepsilon_4 = 1$ $\varepsilon_5 = 1$ $\varepsilon_6 = 1$ Thruster No in service = 1, out of service = 0

f the ship:

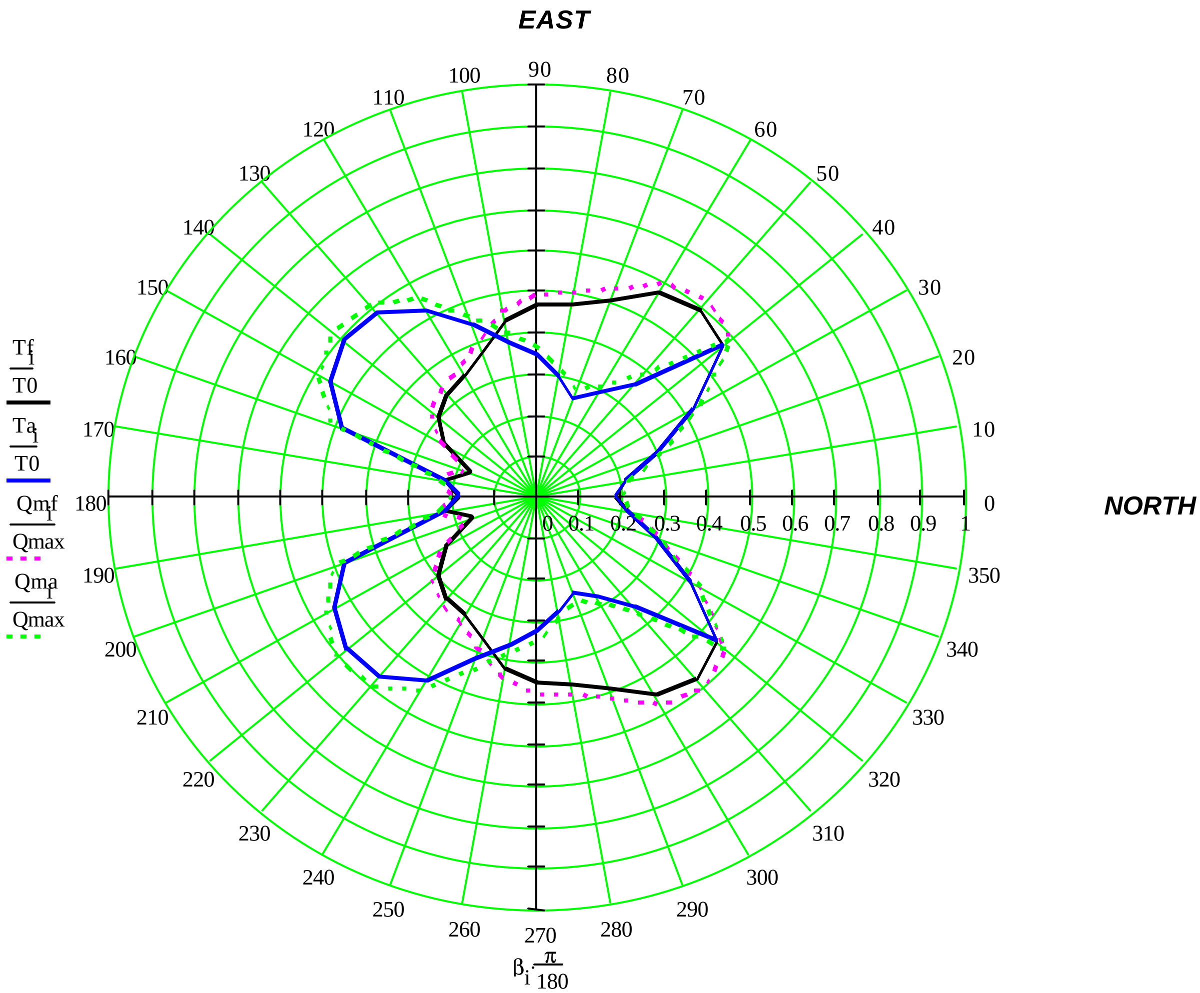


Figure 9

All Thrusters interact loadline Draft.
1- Year Winter Storm

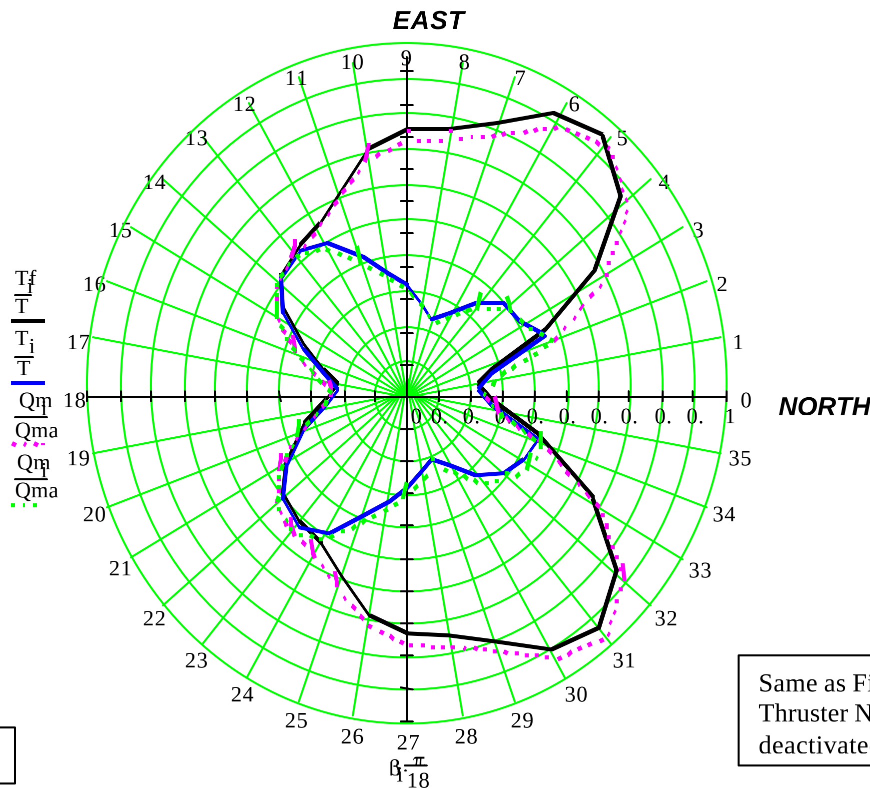


Fig. 10

Same as Figure 9 except Thruster No.1 deactivated. (DPS-2

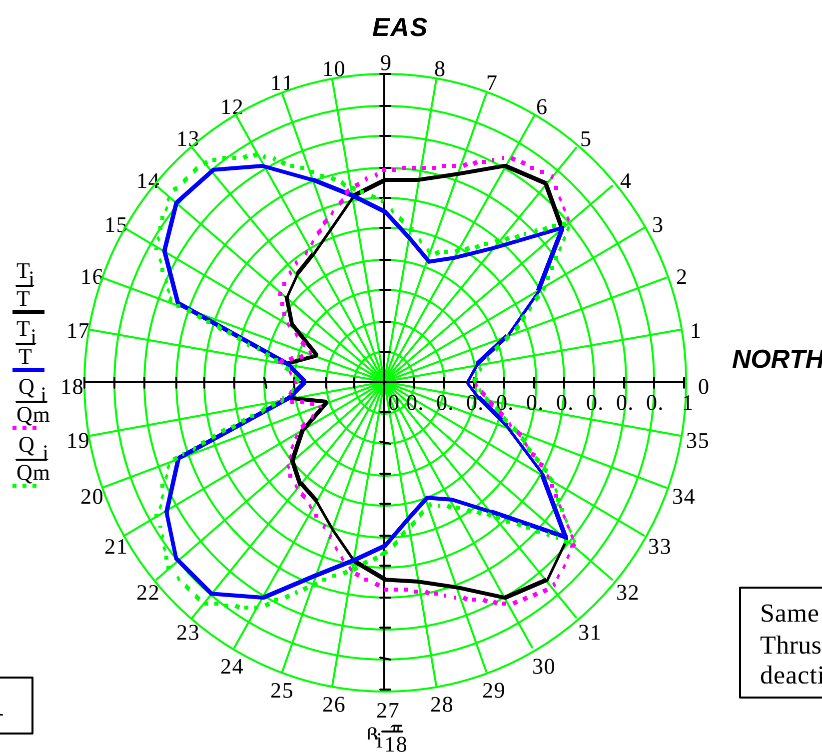


Figure 11

Same as Figure 9 except Thrusters No. 3 & 4 are deactivated. (DPS-3