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VERIFICATION, TESTING AND TRIALS

Vessel Capability Sea Trials For Dynamically Positioned Mobile Offshore Drilling Units

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ABSTRACT

Over the last three years, Diamond Offshore Drilling, Inc. (DODI) commissioned the Dynamically Positioned (DP) semi-submersible Mobile Offshore Drilling Unit (MODU) **Ocean Confidence** and the DP ship-shaped MODU **Ocean Clipper** after upgrades to several systems on both vessels including propulsion and the dynamic position control system. This paper will compare and contrast the vessel capability trials (typically called sea trials on a ship) for the **Ocean Confidence** and the **Ocean Clipper**. Tests to characterize propulsion plant vibration behavior were conducted. Additionally, speed and maneuvering tests were performed to satisfy regulatory authority requirements (USCG) and to verify performance. Based on this experience, the authors would like to suggest a minimum required test plan for sea trials that can be used to commission and objectively evaluate the performance of the two types of DP MODUs.

INTRODUCTION

The ***Ocean Confidence*** is a semi-submersible type MODU and the ***Ocean Clipper*** is a ship shaped Mobile Offshore Drilling Unit (MODU). In the last three years, both vessels were upgraded by Diamond Offshore Drilling, Inc. (DODI) for deeper water drilling. Both vessels had propulsion and Dynamic Position (DP) control system upgrades or retrofits. This paper compare and contrast the vessel capability trials (typically called sea trials on a ship) required for commissioning these two types of drilling vessels. Tests to characterize propulsion plant vibration behavior were conducted. Additionally, speed and maneuvering tests were performed to satisfy regulatory authority requirements (USCG) and to verify performance. The Society of Naval Architects and Marine Engineers (SNAME) published the *Guide for Sea Trials* Ref [1] in 1989 as an update to the 1973 *Code for Sea Trials*. In general, this is a good planning tool for sea trials. The sorts of trials that are missed by this guide are those related to azimuthing thrusters and DP system checkout and commissioning.

In general, the sea trial objectives for both vessels were:

- Demonstration of operability,
- Demonstration of performance,
- Demonstration of economy,
- Demonstration of controllability,
- Provision of operating data.

Sea trials can mean many things to many people. The main tests outlined in this paper are related to vessel performance including:

- Propulsion and hull girder vibration trials,
- Speed trials,
- Maneuverability trials (where appropriate) including:
  - Stopping
  - Rotation

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- Turning circles
- Thruster assisted turning
- Pullout

Although important for commissioning, for the purposes of this paper we will not consider Failure Mode and Effect Analysis (FMEA) or the full Dynamic Positioning (DP) system trials.

VESSEL PARTICULARS

The *Ocean Confidence* semi-submersible drilling unit particulars are listed in Table 1. Figures 1, 2 and 3 are side elevation, forward elevation and pontoon plan views of the vessel, respectively. Table 2 lists the propulsion system particulars.

Table 1 *Ocean Confidence* Vessel Particulars

Description	Units	Value
Displacement Operational Draft (22.8m)	m. ton	47,063
Displacement Survival Draft (16.3m)	m. ton	40,670
Displacement Trials Transit Draft (10.5m)	m. ton	33,739
Displacement Light Transit Draft (7.9 m)	m. ton	30,918
Length of pontoons	meter	97.53
Distance between pontoons, C_L to C_L	meter	56.0
Pontoon breadth w/ sponsons	meter	23.2
Pontoon depth	meters	8.0
Number of pontoons	#	2
Number of columns per pontoon	#	4
Corner column diameter (Columns 1 & 4)	meter	11.3/ 11.9
Corner column sponsons	meter	7.8 x 3.45
Center column diameter (Columns 2 & 3)	meter	9.5
Center column sponsons	meter	9.4 x 2.45
Column spacing (transverse)	meter	56.0
Column spacing (longitudinally)	meter	23.5
Keel to cellar deck elevation	meter	35.3
Keel to center of cross bracing	meter	12.3

The thrusters on the *Ocean Confidence* are controllable pitch/azimuthing type thrusters. The propeller manufacturer was Rolls Royce/KaMeWa.

Table 2 *Ocean Confidence* Propulsion System Particulars

Description	Units	Value
Number of azimuthing thrusters	#	8
Propeller diameter	meters	2.8
Number of propeller blades	#	4
Thruster Motor power	kW	3,000
Thruster #'s 1,4,5,8 dual speed	RPM	145/ 219
Thruster #'s 2,3,6,7 single speed	RPM	219
Number of Diesel engines for propulsion plant	#	8
Max. thrust per propeller	m. ton	50.6

The ship shaped *Ocean Clipper* drilling unit particulars are listed in Table 3. Figures 4 and 5 are side elevation and plan views of the vessel, respectively. Table 4 lists the propulsion system particulars.

The thruster manufacturer for the *Ocean Clipper* is Rolls Royce/KaMeWa. The main propellers were manufactured by Bird-Johnson. All propellers on the *Ocean Clipper* are fixed pitch/variable speed types.

Table 3 *Ocean Clipper* Vessel Particulars

Description	Units	Value
Length Over All	meter	160.9
Breadth	meter	33.2
Depth to main deck	meter	12.2
Transit & Operating Draft	meter	7.3
Displacement	m. ton	26,100

Table 4 *Ocean Clipper* Propulsion System Particulars

Description	Units	Value
MAIN PROPELLERS		
No. of main propellers	#	2
Main propeller diameter	meter	3.3
No. of main propeller blades	#	4
Main propulsion power	kW	5,590
Main propeller max. thrust	m. ton	80
TUNNEL THRUSTERS		
No. of tunnel thrusters	#	5
Thruster propeller diameter	meter	2.4
No. propeller blades	#	4
Thruster motor power	kW	1,735
Tunnel thruster max. thrust	m. ton	25
AZIMUTHING THRUSTER		
No. of azimuthing thrusters	#	1
Thruster propeller diameter	Meter	2.7
No. propeller blades	#	4
Azimuth thruster power	kW	1,865
Azimuth thruster max. thrust	m. ton	32

PRE-TRIAL CAPABILITY PREDICTIONS

Pre-trial capability predictions were based on several model tests. The curve of Resistance vs. Speed in water and the curve of gross thruster vs. speed in water have been produced for the *Ocean Confidence* and are shown in Figure 8.

For each thruster on the *Ocean Confidence*, the motor power output for each thruster is 3000kw with thrust of 50.6 metric tons at 100%. Table 5 shows thrust and power requirements for thrust levels.

Table 5 *Ocean Confidence* Thrust & Power vs. %Thrust

%Thrust	60%	80%	100%
Motor Power kw	1599	2189	3000
Thrust in M-tons	30.4	40.5	50.6
Thrust in kips	66.9	89.2	111.5

At operating draft (22.8 meters) and at 5 knots speed, based on the model test, the resistance will be 315 metric tons (See Figure 8). At a speed of 5 knots, the total thrust force available is about 8 x 37 = 296 metric tons, less than the resistance force. Based on this, the predicted speed for the *Confidence* at operating draft should be less than 5.0 knots. In the sea trials, the speed obtained at operating draft (22.8 meters) was 4.2 knots.

MANEUVERING TRIALS

Maneuvering trials at transit draft were performed on both the *Ocean Clipper* and the *Ocean Confidence*. They included:

- Speed
- Stopping
- Turning circles
- Pullout

These sort of maneuvering trials are warranted for a ship shaped vessel that will transit within restricted waterways, like the *Ocean Clipper*. Figure 9 is a maneuvering placard developed for the *Ocean Clipper*. The *Ocean Confidence* by contrast cannot transit under its own power into port due to draft restrictions in all but the deepest fjords. It is the authors' opinion that maneuvering trials be performed on a DP semi-submersible consistent with the method that the vessel will operate. Figure 10 is a maneuvering placard for the *Ocean Confidence* that includes traditional turning circle and stopping information.

Speed Trials

The *Ocean Confidence* has various drafts at which it operates; transit (7.9m to 10.65m), survival (16.8m) and operating (22.8m). The *Ocean Clipper* has a single operating and transit draft (7.3m). Speed trials were conducted on the *Ocean Confidence* at both the transit and operating draft. The transit draft speed tests were used to verify cruising speed for future rig moves. The operating draft speed runs were used to compare to predictions and to update vessel capability plots. Vessel speed at transit draft is summarized in the maneuvering placard. Figure 7 is a plot of speed versus pitch setting for the Ocean Confidence at operational draft.

Stopping Trials

The *Ocean Confidence* is a semi-submersible with eight azimuthing thrusters. Even at transit draft and full speed it can stop within 1.5 ship lengths, whereas the ship shaped *Ocean Clipper* requires 6 ship lengths as can be determined from examination of Figure 9. This makes the *Ocean Confidence* a highly maneuverable vessel when underway.

Turning Circle Trials

It should be noted that a DP semi-submersible is not controlled in transit like a ship shaped vessel. When the *Ocean Confidence* is transiting the deck officers use the computer controlled "Thruster Control Station" (TCS).

Azimuthing thrusters do not behave like rudders when under TCS control. When a quick turn is requested all thrusters azimuth to give maximum yaw moment. The turning circles produced do not look like the classic turning diagrams shown on the maneuvering placard. Generally, the DP semi vessel can be stopped and turned to a new heading easier than trying to control the vessel like a ship shaped vessel and in essence this is what happens when a 90-degree turn command is executed on the TCS. Note the much smaller advance and transfer numbers compared to the ship shaped *Ocean Clipper*.

Pullout Trials

Pullout tests are used on ship shaped vessel to determine the dynamic stability of the vessel coming out of a turn when the rudders are commanded back amidships. Some ships' rate of turns never decay to zero and are deemed unstable. The eight-azimuthing thrusters make the *Ocean Confidence* dynamically stable coming out of a turn because the thrusters are always thrusting forward. The vessel must be stable under these conditions. Pullout tests are inappropriate for DP semis with azimuthing thrusters at each corner.

VIBRATION TRIALS

Vibration trials were conducted on both the *Ocean Confidence* and the *Ocean Clipper*. The *Ocean Confidence* is propelled by eight azimuthing thrusters. These thrusters are operated at a fairly high RPM and they are relatively low power compared to main propellers on a ship shaped vessel. Hull girder excitation is not generally expected to be a major problem. The *Ocean Confidence* is a symmetric vessel. To save cost only two thrusters were instrumented for vibrations and it was assumed that the other six thrusters would behave similarly. The USCG guideline Ref. [2] was followed and two tri-axial accelerometer packages were placed on each instrumented thruster, on top of the motor housing and on the thruster foundation. The accelerations were single integrated to give velocities that could be compared to the USCG guidelines. Under the conditions that the thrusters will be operated, they performed within the recommended limits of 0.3 inch/sec for the motor, 0.4 inch/sec (continuous) for the foundation and 0.7 inch/sec (intermittent) for the foundation. See Figure 6 as an example of the output used to summarize the vibration trials testing.

The objectives of the *Ocean Clipper* vibration trials were different compared to the *Ocean Confidence*. The Vessel had been upgraded by adding sponsons and weight. It was conjectured that the ship structural natural periods may have changed sufficiently to cause hull girder resonant excitation from the main propellers. With this in mind, the *Ocean Clipper* was instrumented to measure vibration at the following locations:

- Hull Girder at the Aft Perpendicular
- Port Thrust Bearing Top
- STBD Thrust Bearing Top
- Port Aft Crane Pedestal
- STBD Aft Crane Pedestal
- Drilling Derrick at Monkey Boards
- Tunnel thruster #1 foundation
- Tunnel thruster #2 foundation

None of the locations were measured to have excessive vibratory motions when compared to habitability or the USCG structural standards. Ref. [3] describes the methodology used to measure vibrations on a ship shaped vessel with main propulsion.

ECONOMY TRIALS

Typical strict ship Economy trials were not warranted since the ancillary loading of the drilling equipment and hotel loads during DP operations will constitute the largest loading of the system, rather than ship transit mode. There were concerns regarding transiting fuel consumption that were considered with abbreviated Economy trials on both the *Ocean Clipper* and *Ocean Confidence*. Objectives of endurance/ economy trials included:

- Demonstration of satisfactory operation of the propulsion plant for a specified period of time,
- Determination of the rate of fuel consumption of the plant when operating at specified power output,
- Determination of performance characteristics of the machinery plant or components.

The endurance tests were run and both vessels proved their ability to run for the prescribed period of time without maintenance. The results of the fuel economy trials for both vessels are summarized in Tables 6 and 7.

Table 6 *Ocean Clipper* fuel consumption rates

Avg. Total Power Output (kW)	Aft Azimuthing Thruster Installed?	Main Propeller RPM (RPM)	Fuel Consumption Rate (gal/hr / [m. ton/hr])
5,900	No	150	450 [1.45]
5,500	Yes	140	427 [1.37]

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Table 7 *Ocean Confidence* fuel consumption rates

Avg. Total Power Output (kW)	No. of Thrusters Running	Thruster Pitch Setting (%)	Fuel Consumption Rate (gal/hr / [m. ton/hr])
14,750	8	80%	1,162 [3.74]
11,450	8	67%	815 [2.62]

CONCLUSIONS

From comparing and contrasting the sea trials conducted on the *Ocean Clipper* and the *Ocean Confidence* we conclude the following:

- Vibration studies on a ship shape with a conventional twin propeller propulsion system are appropriate for ship shape drilling vessels. Special vibration studies that follow the USCG guideline for thrusters are appropriate for tunnel and azimuthing thruster sea trials on a both ship shaped and semi-submersible DP vessels.
- Speed trials at operating and transit draft on a ship shaped or semi-submersible DP drilling vessel are appropriate for operations, capability plots and planning purposes.
- Maneuvering trials are appropriate for ship shaped vessels that will transit under their own power in restricted waterways. A sub-set of traditional ship shaped maneuvering trials tailored for the modes of operation of a DP semi are appropriate.

ACKNOWLEDGEMENTS

The authors would like to thank our respective companies for supporting the effort to produce this paper, Diamond Offshore Drilling, Inc. and Scientific Marine Services Inc.

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[1] Society of Naval Architects and Marine Engineers, 1989, *Guide for Sea Trials*, Technical and Research Bulletin 3-47, Jersey City, New Jersey.

[2] United States Coast Guard Engineering Logistics Center, 1999, *Design Standard For Evaluation Of Ship Propulsion Machinery Vibration*, Baltimore, MD

[3] Frank DeBord, Jr., William Hennessy and Joseph McDonald, 1998, "*Measurement and Analysis of Shipboard Vibrations*", Marine Technology and SNAME News, Vol. 35, Number 1, January, Jersey City, New Jersey.

[4] Ocean Confidence Operations Manual Rev. 2.

[5] Ocean Clipper Operations Manual Rev. 3.

[6] MARIN, 1998, "Current force, thruster hull interaction and thruster-thruster interaction tests".

Figure 1 *Ocean Confidence* side elevation view

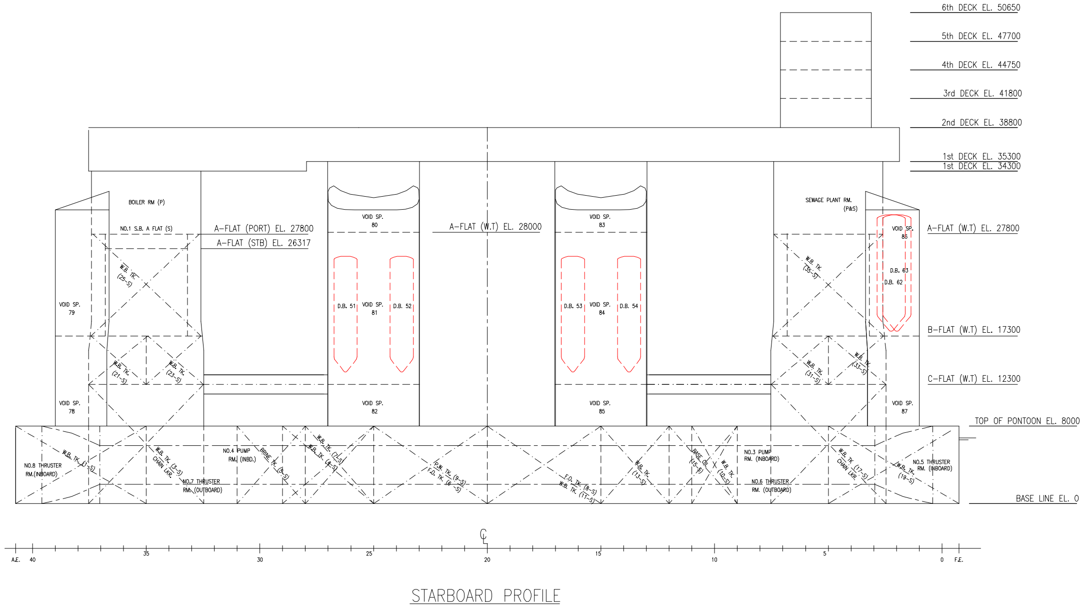

Figure 2 *Ocean Confidence* front elevation view

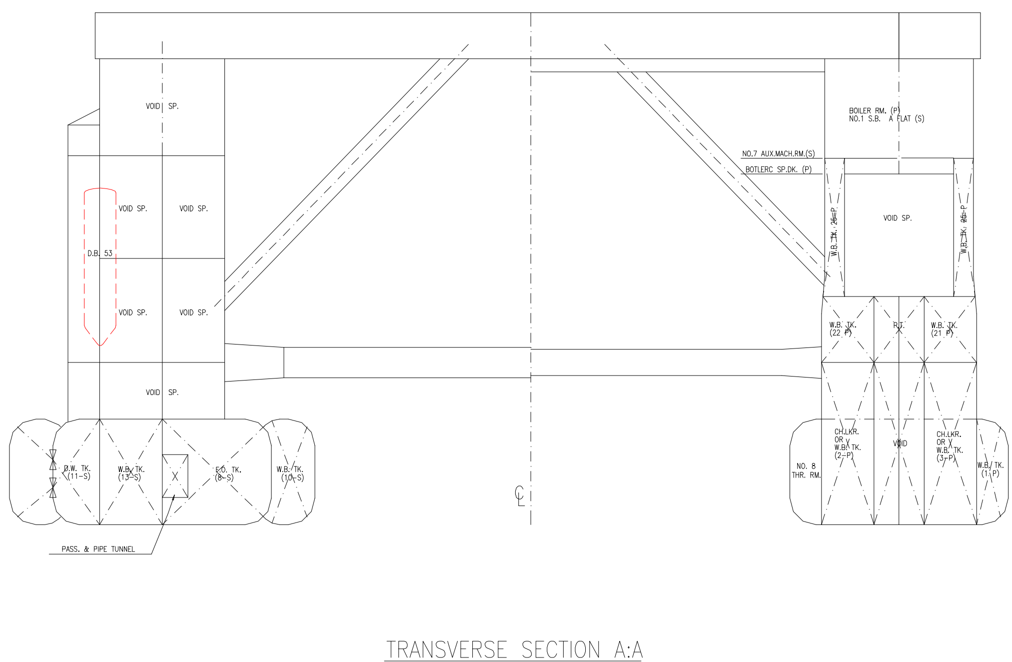

Figure 3 *Ocean Confidence* pontoon plan view

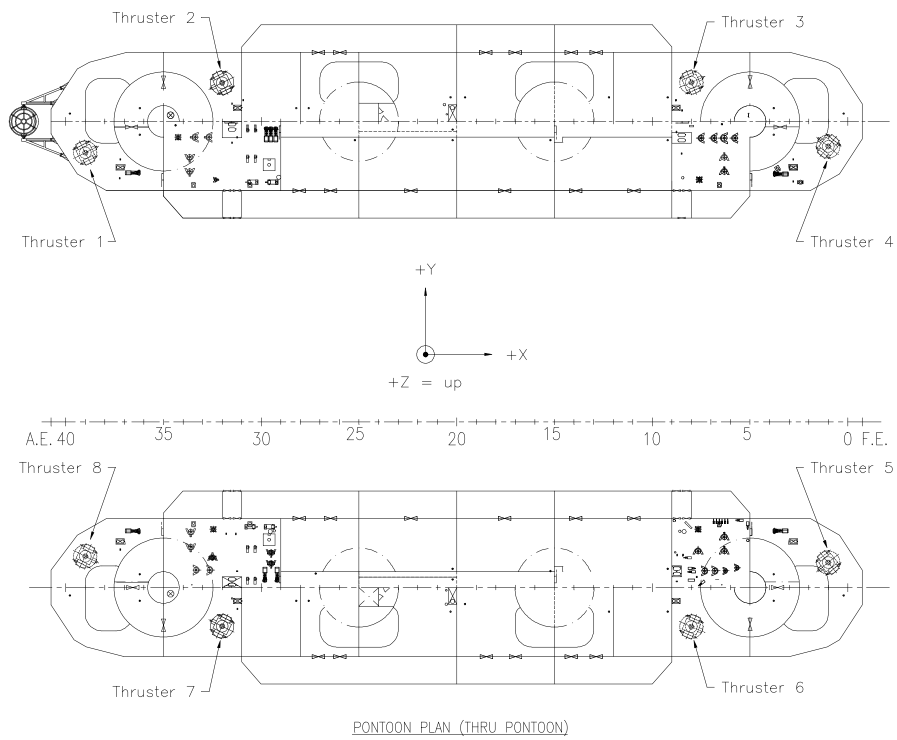

Figure 4 *Ocean Clipper* side elevation view

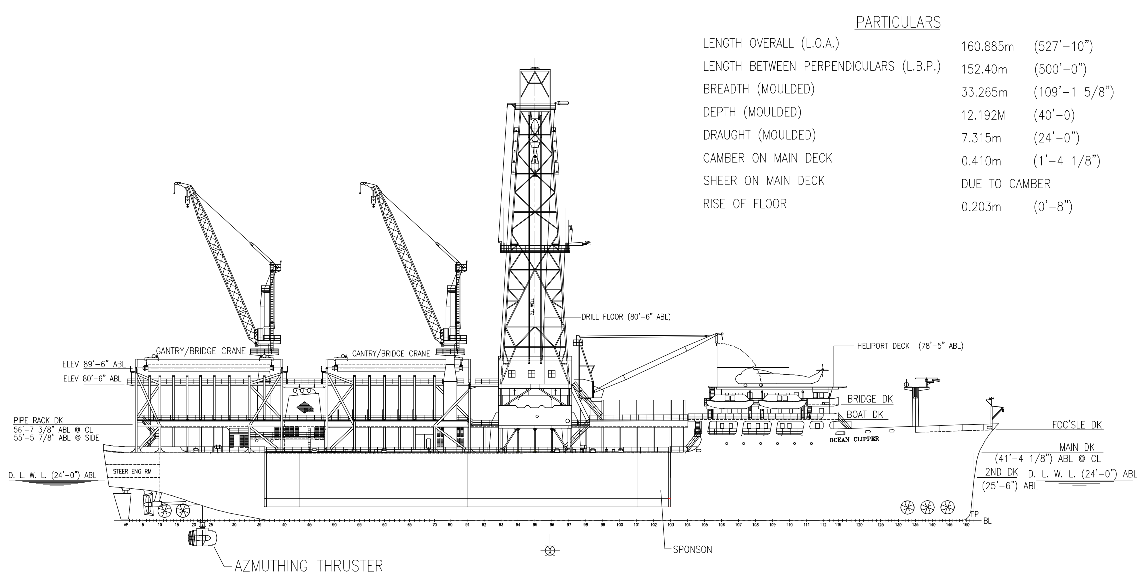

Figure 5 *Ocean Clipper* plan view

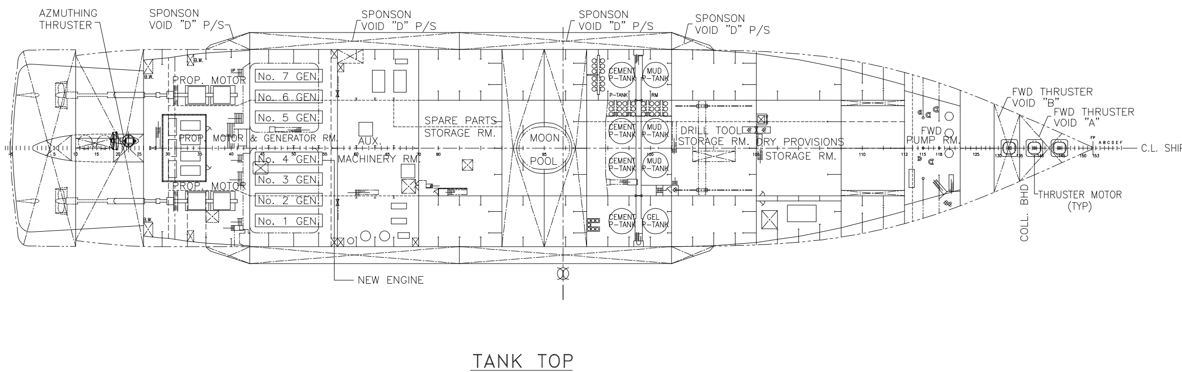

Figure 6 Example vibration summary on *Ocean Confidence* Thruster 5

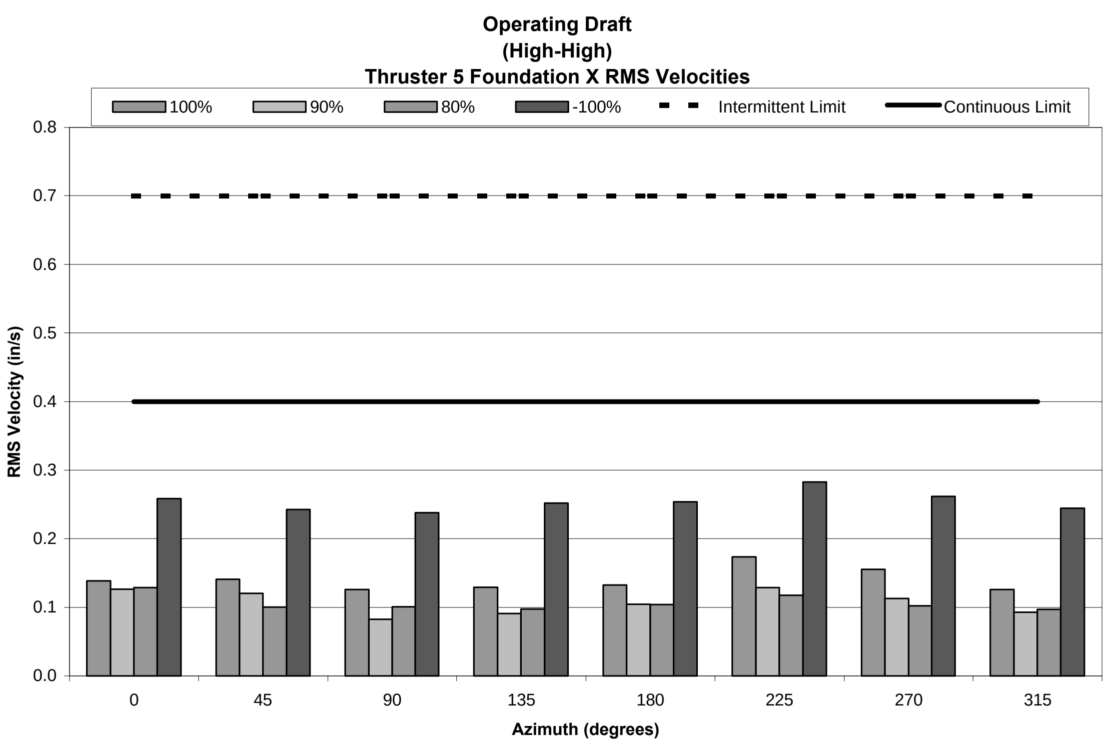

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Figure 7 Ocean Confidence operating draft speed versus azimuthing thruster propeller pitch setting

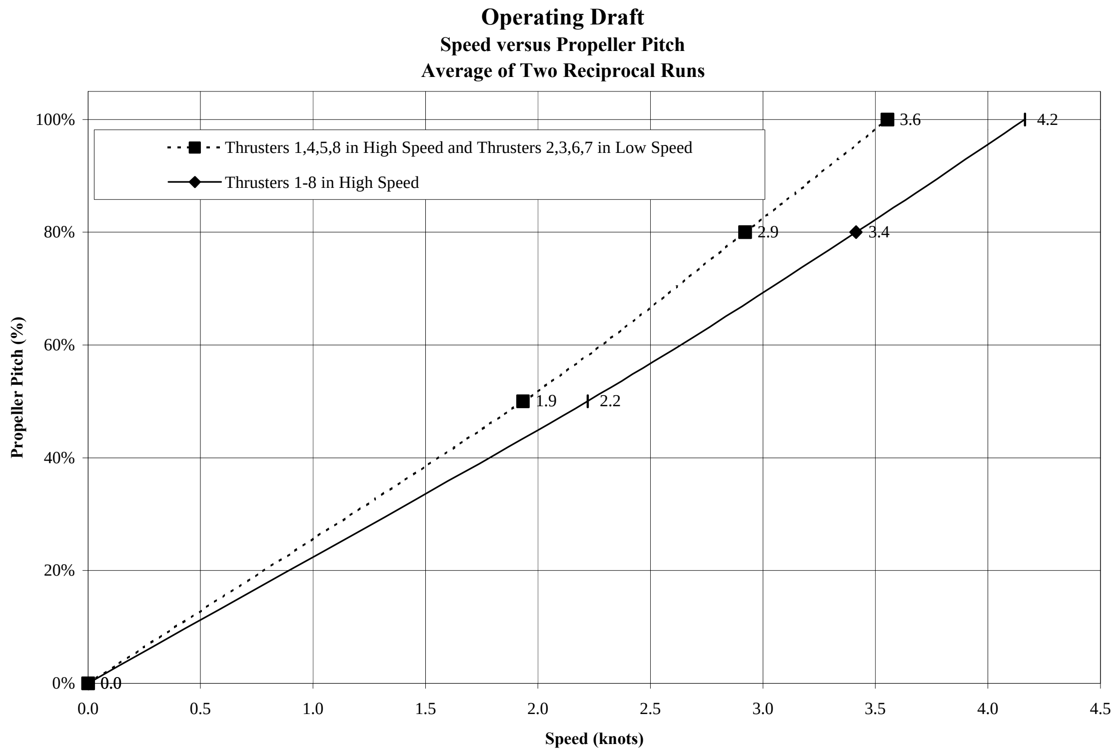
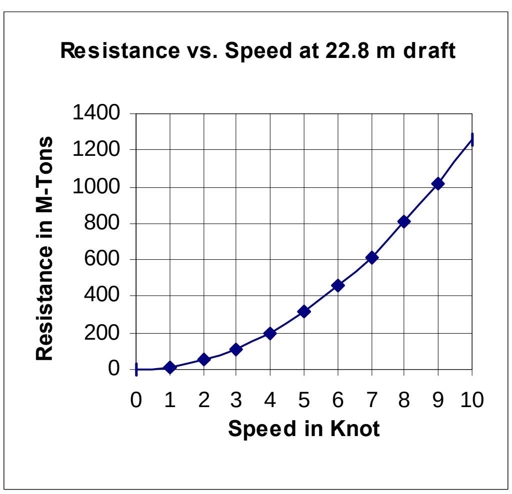


Figure 8 Ocean Confidence resistance vs. speed curve and gross thrust vs. speed curve



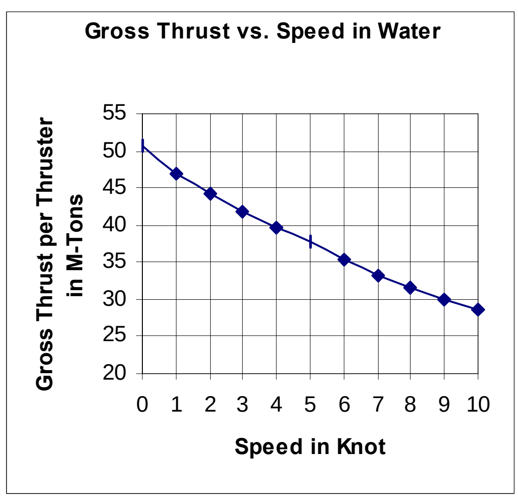


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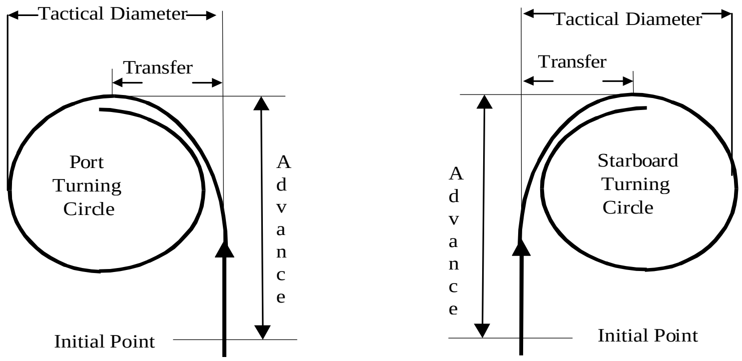
Figure 9 *Ocean Clipper* maneuvering placard



TURNING CIRCLE

		RPM	Tactical Diameter (feet)	Advance (feet)	Transfer (feet)	Time to 90° heading change (min. : sec.)
Full Speed	**Port**	180	1115	1371	482	1:34
	Starboard	180	1115	1371	482	1:34
Half Speed	**Port**	90	1110	1305	477	2:57
	Starboard	90	1110	1305	477	2:57

DISTANCE AND TIME REQUIRED TO STOP VESSEL USING FULL ASTERN

	Distance (feet)	Time (min. : sec.)
Full Speed	3168	4:42
Half Speed	782	2:12

RPM versus Speed

Azimuthing Thruster Retracted

RPM	Speed
50	3.14
90	6.09
140	9.44
180	11.68

Speed is in knots

Vessel Condition

	Trials	Full Load	
Displacement	25,724	25,724	LT
Draft Forward	24.00	24.00	Feet
Draft Aft	24.00	24.00	Feet
Mean Draft	24.00	24.00	Feet
Trim	0.00	0.00	Feet
LOA	527.83	527.83	Feet
Beam	109.00	109.00	Feet
Depth (molded)	40.00	40.00	Feet

Thruster Effectiveness

Forward Speed (knots)	Thrusters Used	Time to turn 30° from Original Heading (seconds)
0	1 & 3	48
0	5 & 6	57.5
3	none	141.5
3	1 & 3	55
3	5 & 6	90
6	none	75
6	1 & 3	49
6	5 & 6	61
9	none	67
9	1 & 3	46.4
9	5 & 6	49.5

WARNING:

The response of OCEAN CLIPPER may be different from that listed above if any of the following conditions, upon which the maneuvering information is based, are varied: 1) Calm weather - seas calm wind 10 knots or less; 2) No current; 3) Water depth at least twice the vessel's draft; 4) Clean hull and; 5) Intermediate drafts or unusual trim

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Figure 10 *Ocean Confidence* maneuvering placard

TURNING CIRCLE

	Initial Speed (kts)	Pitch (%)	Advance (meter)	Transfer (meter)	Time to 90° heading change (min. : sec.)	Tactical Diameter (meter)
45° TCS Turn Control Thrusters 1-8 @ 219 RPM	6	80%	252	155	3 min 15 s	370
90° TCS Turn Control Thrusters 1-8 @ 219 RPM	6	80%	200	65	2 min 27 s	147
45° TCS Turn Control Thrusters 1,4,5,8 off, Thrusters 2,3,6,7 @ 219 RPM	4.1	80%	278	120	3 min 50 s	293
90° TCS Turn Control Thrusters 1,4,5,8 off, Thrusters 2,3,6,7 @ 219 RPM	3.8	80%	160	52	2 min 40 s	130

DISTANCE AND TIME REQUIRED TO STOP VESSEL AZIMUTHING THRUSTERS 180°, 100% PITCH

Propeller Pitch (%)	Thruster 1, 4, 5, 8 RPM	Thruster 2,3,5,7 RPM	Initial Speed (knots)	Elapsed Time to Stop (min., sec.)	Ahead Reach (meter)
50%	High	High	3.8	1 min 8 s	108
80%	High	High	5.6	1 min 10 s	141
100%	High	High	6.7	1 min 14 s	160
70%	Low	High	3.3	1 min 8 s	81
85%	Low	High	3.6	1 min 7 s	86
100%	Low	High	4.3	1 min 20 s	112

Stopping tests conducted at 10.5 m trials draft.

Propeller Pitch versus Speed

Thruster RPM Setting	Propeller Pitch Setting (%)	Measured Speed at 10.5m Draft (knots)	Predicted Speed at 7.9m Draft (knots)
High/High	50%	3.8	5.9
High/High	80%	5.6	8.7
High/High	100%	6.9	10.7
Low/High	70%	3.2	5
Low/High	85%	3.6	5.6
Low/High	100%	4.3	6.7

(High = 219 rpm, Low = 145 rpm)

Thrusters 1,4,5 and 8 are two speed controllable pitch thrusters.
Thrusters 2,3,6 and 7 are single speed controllable pitch thrusters.

VESSEL CONDITION

	Trials	Light Transit Condition	Units
Displacement	33,739	30,918	m. ton
Draft Forward	10.50	7.90	meter
Draft Aft	10.50	7.90	meter
Mean Draft	10.50	7.90	meter
Trim	0.00	0.00	meter
LOA	97.50	97.50	meter

WARNING:

The response of OCEAN CONFIDENCE may be different from that listed above if any of the following conditions, upon which the Maneuvering information is based, are varied: 1) Calm weather - seas calm wind 15 knots or less; 2) No current; 3) Water depth at least twice the vessel's draft; 4) Clean hull and; 5) Intermediate drafts or unusual trim