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Thrusters

Influence of Thruster Response Time on DP Capability by Time-Domain Simulations

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Abstract

Due to their simplicity static approaches are a commonly used method of assessing the DP capability of offshore vessels. These static approaches are essentially based on a balance of forces and moments caused by environmental conditions, as well as the thruster forces. The ensuing DP plots usually come up with unrealistically high application limits regarding admissible environmental conditions for a given operation. This phenomenon is due to the fact that important influencing factors are being neglected. One example is the assumption that the vessel is at rest and another one is the fact that the responsiveness of thrusters is not considered.

With the Voith-Schneider-Propeller an alternative propulsion system for DP applications is available. It differs from conventional azimuth thrusters primarily because of its faster thrust variation and thrust change over zero position. Since static approaches completely ignore this factor, this paper intends to quantify the influences of the response time of a thruster on the wind envelope with the help of time-domain DP simulations and the ensuing capability plots.

For this purpose comprehensive simulations have been carried out for an offshore support vessel while varying the dynamic thruster characteristics. Relevant assessments show that the response time has a significant influence on the DP capability and thus the operational window. It was found that results that are exclusively based on static approaches lead to incorrect conclusions both qualitatively and quantitatively.

Additional efforts to back up the simulation-based results regarding thruster responsiveness were made towards a full-scale validation. A direct comparison of two vessels with different propulsion systems is only partially suitable for a validation due to different set-ups in terms of thruster configuration and weather conditions. Instead, a large number of platform supply vessels in the operating area North Sea were analyzed for their DP capability with the help of historical positioning and weather data. The statistical analysis based on this data confirms the trends discovered in the dynamic simulation in all relevant aspects.

1. Introduction

In many cases, the evaluation of the DP capability of offshore vessels is carried out by creating static capability plots. This process looks for the maximum possible environmental impact for each direction caused by waves, wind and current that can be balanced by the available thruster forces. Dynamic influences such as a decline in thrust due to inflow caused by vessel motions, ventilation or thruster response times are either not taken into consideration with this approach, or they are applied in unspecific safety factors regarding thruster saturation.

As a result of such simplifications, the assessment of limiting weather conditions, in which the vessel can still operate safely, becomes difficult. Wind envelopes on the basis of statistical analyses often present an operating window that cannot be used under realistic conditions.
Due to the neglected technical characteristics, a comparison of vessels with different thruster concepts may equally lead to misinterpretations. Examples for this are shown in the feedback from operators running offshore vessels with Voith Schneider Propellers (VSP) as well as ducted azimuth thrusters. Their operating experience shows that VSP vessels tend to have wider operating windows. Yet due to their higher static bollard pull of the ducted azimuth thrusters, the static capability plots of the vessels actually suggest an opposite trend.
This contradiction presented the motivation to perform time-domain DP simulations regarding the impact of thruster response times on the DP capability and to examine whether the results coincide with real-life observations.

2. Voith Schneider Propeller

The Voith Schneider Propeller, a controllable pitch propeller, generates thrust by means of profiled blades that protrude from the vessel hull and rotate around a vertical axis. The blades are mounted in a rotor casing which is flush with the hull of the vessel. A local oscillating motion of the individual propeller blades around their respective axis is superimposed on the rotary motion of the blades around the common vertical axis. Generation of this oscillating motion is done via a kinematic mechanism. This working principle enables the propeller to adjust thrust continuously, both in amplitude and in direction. More details on the VSP principle can be found in [1]. A technical detail that is relevant for DP applications lies in the inherent way of thrust variation. Unlike with Azimuth thrusters, the thrust control of the VSP occurs according to Cartesian coordinates, so that a thrust reversal takes place via the neutral position instead of turning the thrust vector in polar coordinates as performed by the azimuth thruster (Fig.2). Due to this fact, changing thrust demands can be implemented 3 – 4 times faster by the DP system. This paper intends to examine the impact of this characteristic on the DP behavior with the help of the following simulations.

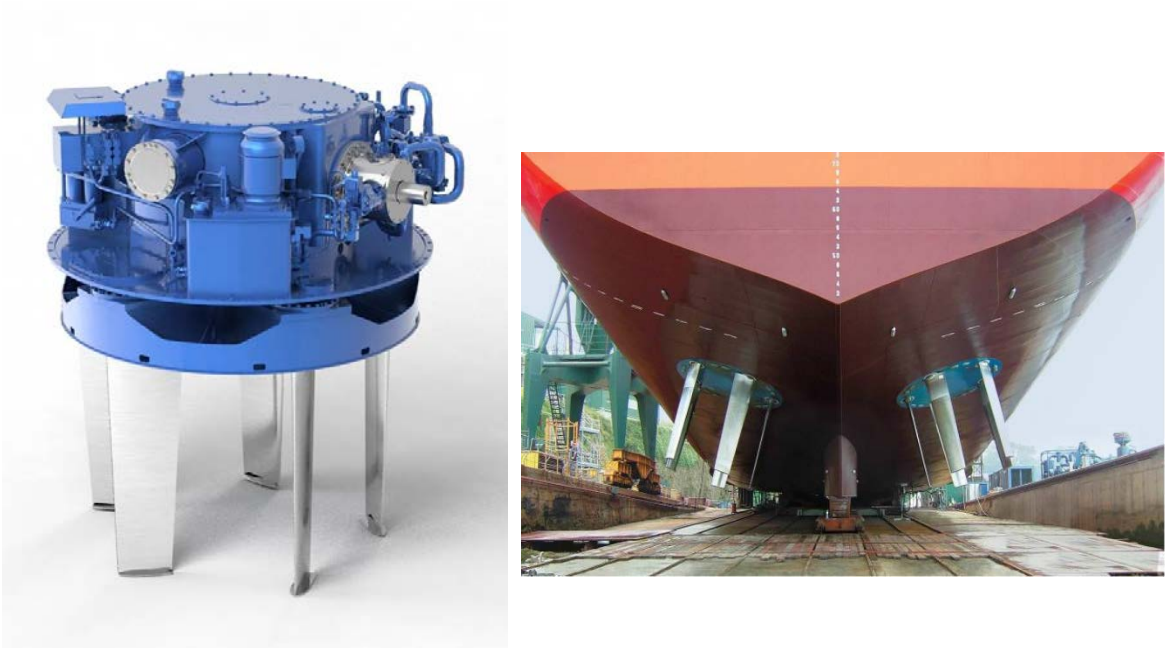

Fig. 1 Voith Schneider Propeller (VSP)

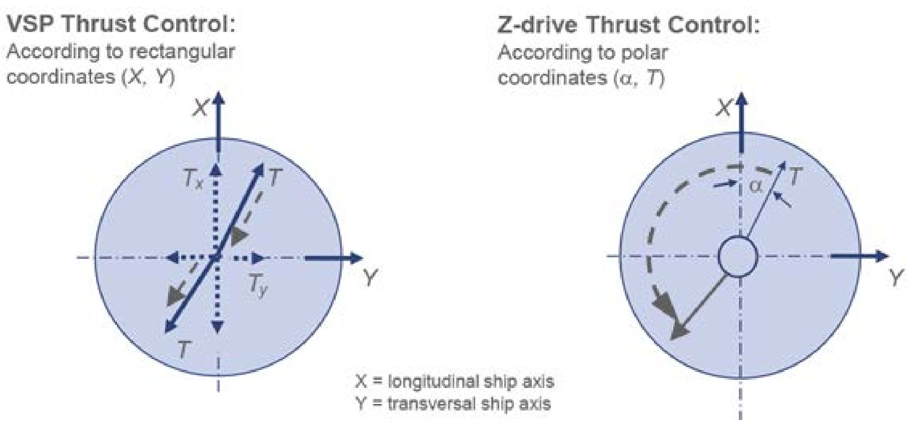

Fig. 2 Thrust control principles of VSP and Z-drive Thrusters

3. Time Domain DP Simulations

Against the background of the deficits of the static approach for determining the wind envelopes as indicated in Chapter 1, time domain DP simulations were performed as part of this paper. These simulations were carried out by DNV-GL Marine Cybernetics, which operate a closed-loop vessel simulator. It features a 6 DOF vessel motion module, taking dynamic wind, wave and current loads into consideration. In addition there is also a DP control system model, consisting of a DP controller including allocation, observer, sensors and position reference systems. The simulations also incorporate a power management system. The chain is closed by a propulsion system model for diverse propulsor types, where relevant effects such as inflow losses, interaction between thrusters, interaction between thrusters and hull or ventilation are being taken into account. Fig. 3 shows the structural scheme of the DP simulator. Further details regarding the setup of the simulator, as well as numerous results of different simulations are listed in [2], [3] and [4].

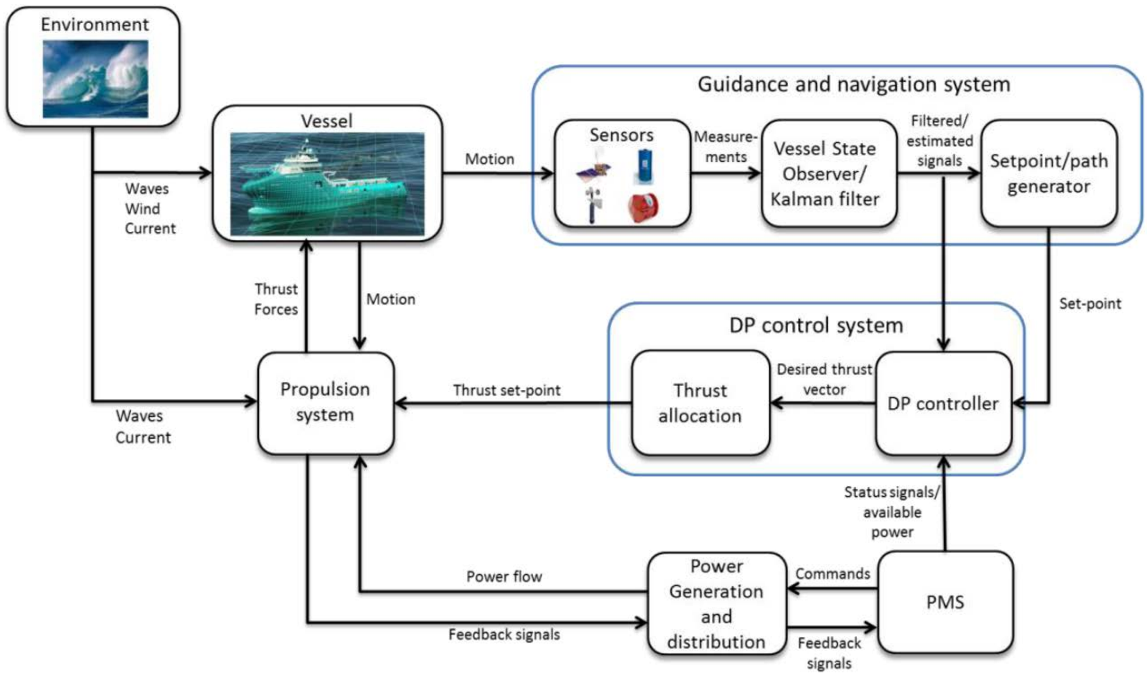

Fig. 3 DNV-GL Closed loop time-domain vessel simulator (figure taken from [1])

4. Case Study

The subject of the investigations was a Service Operation Vessel (SOV) with the following main particulars:

Length [m]:	80
Breadth [m]:	18
Displacement [t]:	6500

The following study distinguishes between two different configurations regarding thruster arrangements. The thruster layout is shown in Fig. 4.

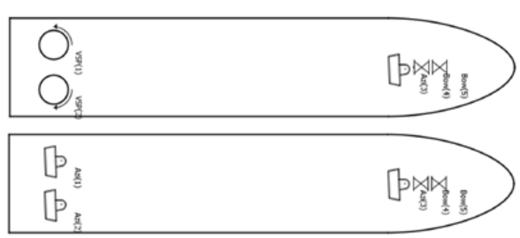

Fig. 4 thruster arrangement of the two examined variations

The arrangement in the bow is identical with both setups and consists of two tunnel thrusters and a retractable azimuth thruster with the following key data:

	D [m]	P [kW]
tunnel thruster	2.2	1200
retr. azimuth thruster	1.6	850

As main thrusters at the stern there are either two Voith Schneider Propellers or two ducted azimuth thrusters with an azimuth speed of 3rpm.

	D [m] / L [m]	P [kW]	BP [kN]
VSP	2.8 / 2.34	1850	255
azimuth thruster	2.4 / -	1500	258

For the environmental forces the wind-wave relationship shown in Fig. 5 was applied by DNV-GL. The current speed was 1.75kn and always collinear with wind and waves. Wind and current coefficients as well as transfer functions for wave-induced motion and forces have been determined by DNV-GL in a preprocessing stage.

Furthermore, the acceptance criteria for the vessel movement to determine the limiting weather conditions were defined as 1m set-point variation in surge and sway and ±2.5° in heading for the low-frequency motion of the vessel. The controller gains for each configuration have been tuned specifically in order to achieve optimal performance.

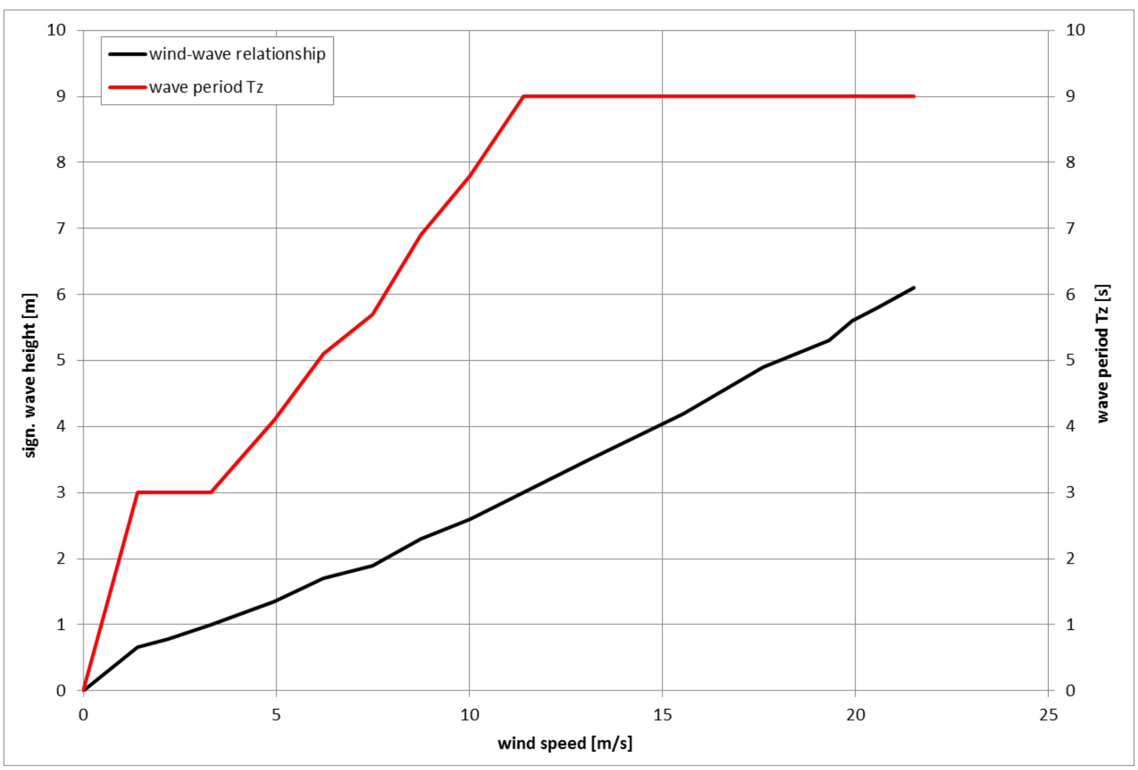

Fig. 5 wind-wave relationship

5. Simulation Results

For intact conditions the ensuing dynamic capability plot is shown in Fig. 6. Since the nominal bollard pull values of the two propeller types are nearly identical, the divergence in limiting wind speed can be attributed to the different responsiveness of the propellers.
In order to back up this thesis a further wind envelope was produced for the azimuth thruster configuration. In this envelope, the azimuth speeds of the system were reduced from 3rpm to 2rpm, that seems to be more common for such kind of vessels. The controller gains were then adapted to the modified thruster dynamics. All other simulation parameters remained unchanged. The red dotted wind envelope in Fig. 6 shows this scenario:

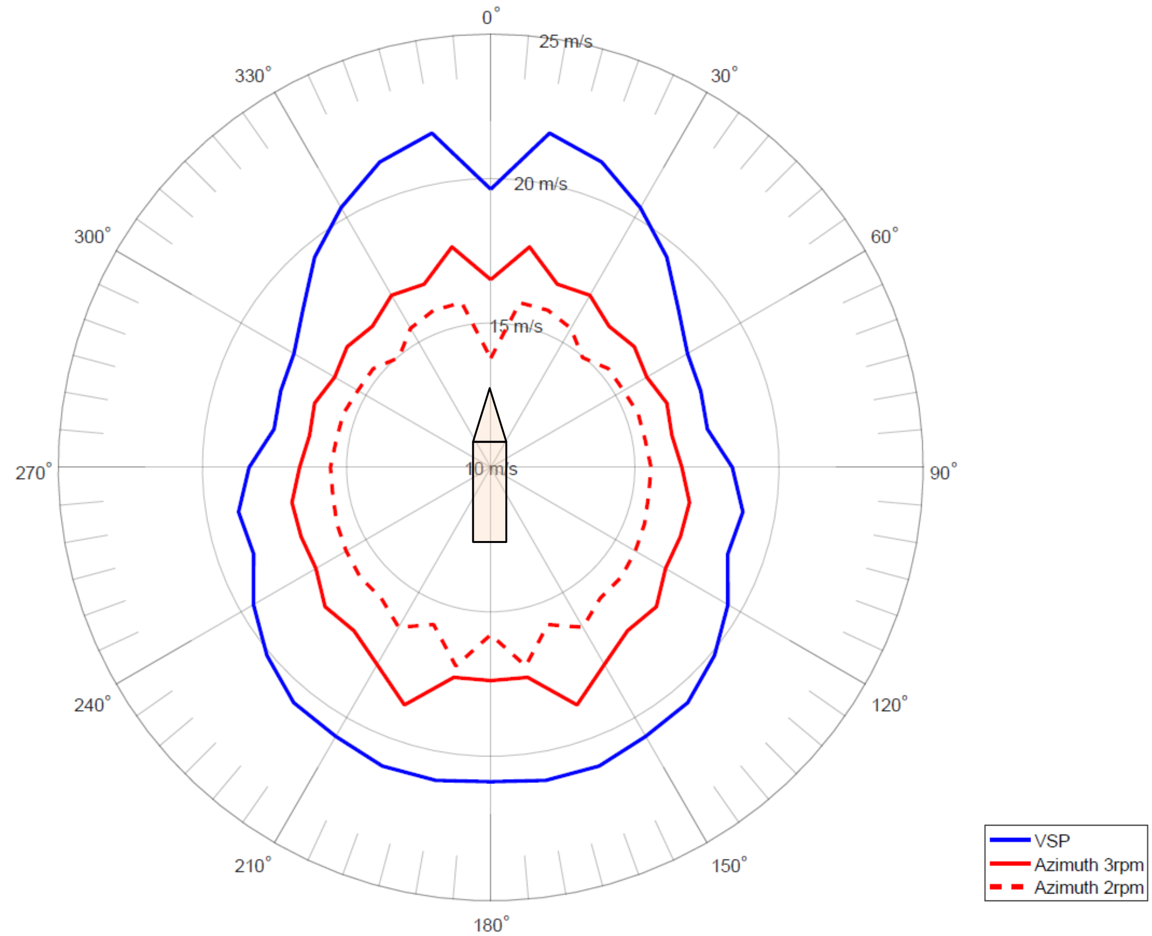

Fig. 6 dynamic capability plot

The reduced capability for all variants at weather from 0° can be explained by the effect of the dynamic wind forces. The wind amplitude as well as the wind direction is modeled as a spectral distribution around a specific mean value, such that the ensuing yaw moment on the vessel frequently changes the sign. The resulting demands for frequent thrust reversals cannot be perfectly met by the tunnel thrusters due to their slower response times. This leads to a local reduction of the capability. A similar trend can also be recognized at stern on weather. Here the

slower azimuth thrusters show a trend towards smaller limiting wind speeds due to the shortfall of the heading limit.
On average, the difference in limiting wind speeds between the VSP configuration and the fast azimuth variant is about 3m/s across all encounter angles. This corresponds to a difference of approx. one meter in significant wave height.
Fig. 7 shows exemplarily the vessel trajectories after six hours of simulation for stern on weather with a wind speed of 18m/s. According to Fig. 6, this point is just outside the wind envelope for the azimuth thruster configuration. The red circle marks the acceptance limit for horizontal motions.

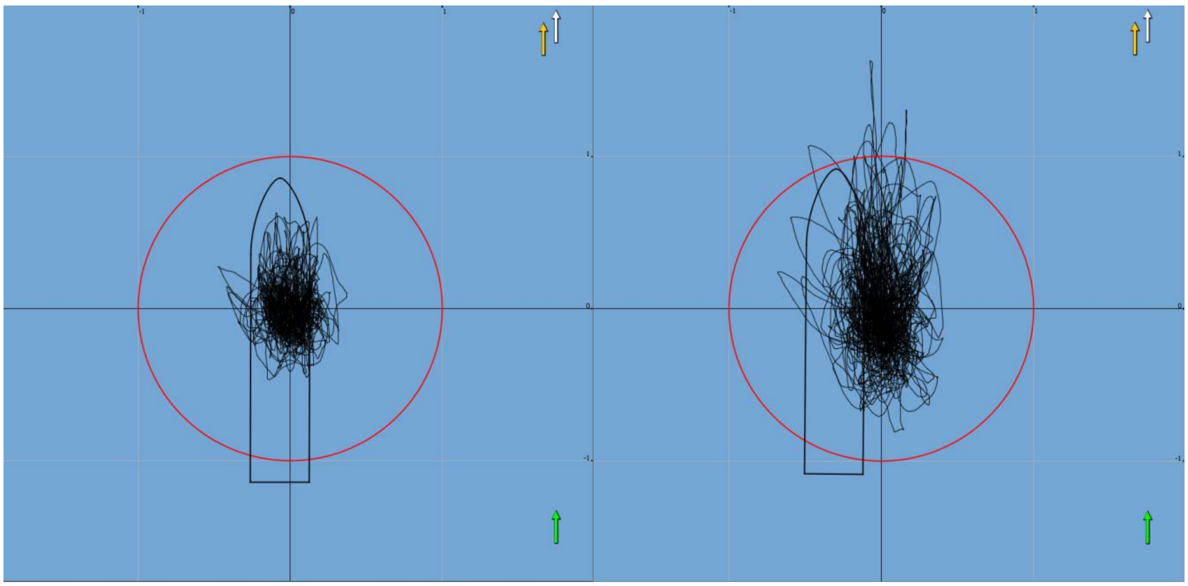

Fig. 7 vessel footprint for stern on weather (VSP left, Azimuth right, wind speed 18m/s, red circle indicates acceptance limit of R=1m)

The narrower footprint of the VSP variant is consistent with its larger capability. In addition there is another interesting aspect due to the fact that the mean deviations from the set point for the VSP variation are always lower and thus reduce the average thrust demand on the propellers. A consequence of this scenario is evident, if the input power of all five propulsors is integrated over the duration of the simulation and thus provides a value for the respective energy consumption. A respective evaluation was carried out for three different encounter angles at a wind speed of 13m/s. The relative differences in overall consumption are represented in Fig. 8.
A reduction in consumption of about 10% occurred with encounter angles of 0° and 180°, while the encounter angle of 240°, which is characterized by higher thruster utilization, shows a difference of about 5%. This result leads to the question, to which degree the energy consumption of the VSP variant can be reduced further, if some of the DP capacity was sacrificed. In uncritical DP scenarios this consideration might be appropriate. For this purpose, DNV-GL adapted the controller gains in such a way that the dynamics of the VSP were reduced to a point where wind envelope becomes identical with the azimuth variant. Depending on the encounter angle this resulted in a further reduction of the energy consumption by up to 10%. This is illustrated by the light blue column in Fig. 8 named “VSP relaxed”.

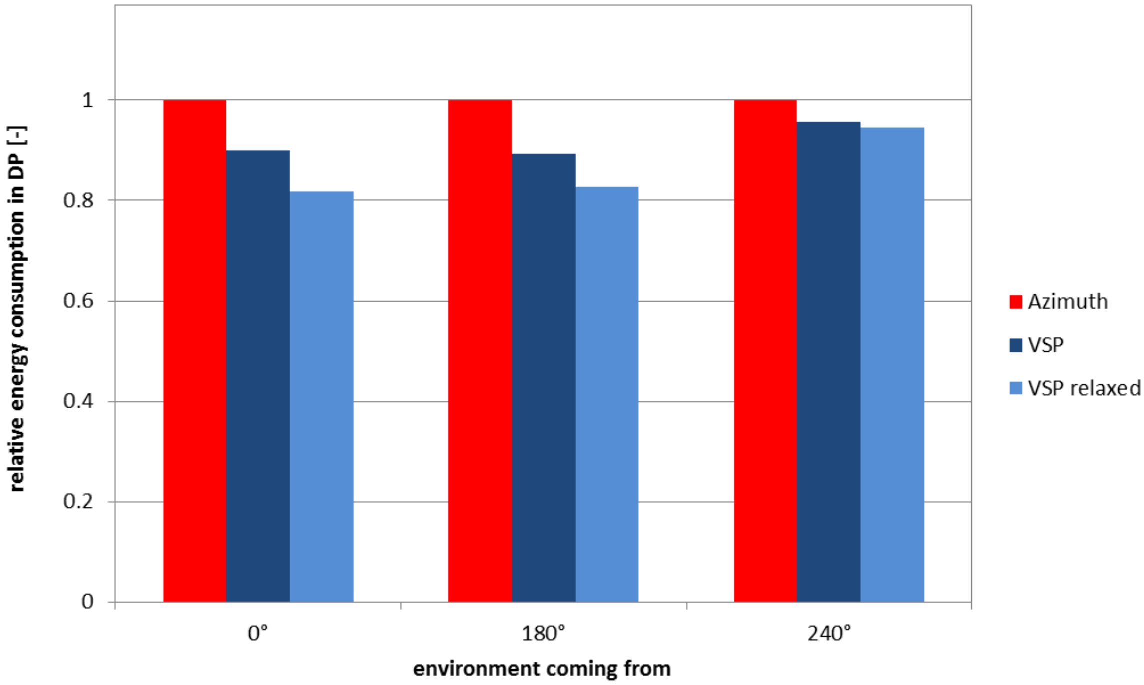

Fig. 8 relative energy consumption of all thrusters during DP

Another operating scenario that highlights that thruster responsiveness is relevant are worst case single failure (WCSF) conditions. Once these occur due to a switchboard failure, one tunnel thruster as well as one aft main propulsor will fail. Here, the main focus is, however, not on the DP capability in a stable condition long after the failure, but on the analysis of the positioning behavior in the transition phase between intact and WCSF conditions.
With a wind speed of 13 m/s stern on weather, the environmental conditions were chosen to represent a situation which is within the wind envelope of both thruster configurations for intact but also for WCSF conditions.
Fig. 9 shows the timeline of the distance to the point in the time window where WCSF conditions set in. One can recognize that both configurations are able to maintain the position within the acceptance limit of 1m for the prevailing weather situation at intact conditions as well as for a relatively long period after the WCSF event. Immediately after the failure of one bow and one main thruster, i.e. within the first 40 seconds, one can, however, observe a reduction of the station-keeping accuracy due to the required thrust reallocation on the remaining thrusters. With the azimuth variant, the acceptance limit is actually exceeded by as much as 70%.
In such a case, fast thruster response times can minimize the maximum positioning deviations and thus ensure an increased degree of safety for the operation that is currently carried out.

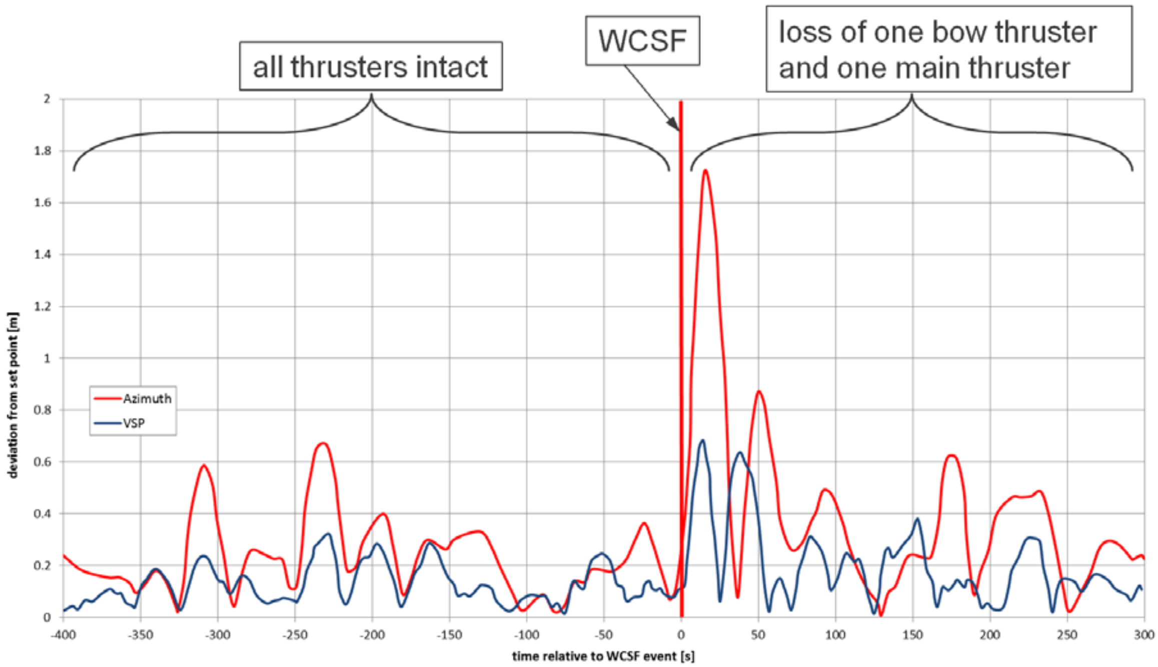

Fig. 9 deviation from set point at WCSF conditions

6. Statistical analysis of vessel positioning data

During the evaluation of the simulation results the question arose how the trend that suggests that thrusters with high responsiveness provide a relative improvement of the station keeping capability could be validated.

On the one hand, the validation at a single real vessel requires a complex structure of measuring sensors. On the other hand there are also countless challenges that present an obstacle to a direct comparison between simulation and actual measurements [4].

As an alternative to direct full-scale measurements an approach was chosen that correlates historical positioning and weather data for several vessels regarding their DP operation. Even though there might be inadequacies due to a certain amount of statistical vagueness, this approach was given preference over a direct validation due to the above aspects. The data procurement and analysis was carried out by German company Maritime Data Systems.

At the center of the investigation were the four oil platforms in the Brent oil field in the North Sea between the Shetland isles and the Norwegian coast. Among others, these platforms are served by three platform supply vessels with Voith Schneider Propellers. The selection of the region to be examined fell on these platforms, in order to ensure sufficient numbers of supply vessels with VSP and azimuth thrusters.

The investigations were based on historical vessel position data for the northern North Sea from October 2014 to October 2016, which were procured by marinetraffic.com. These data were initially filtered in such a way that only those vessels were considered, which were sighted during this time in quadrant 211/29 (location of the Brent field). Fig. 10 shows the trajectories of these vessels over the 25-month period.

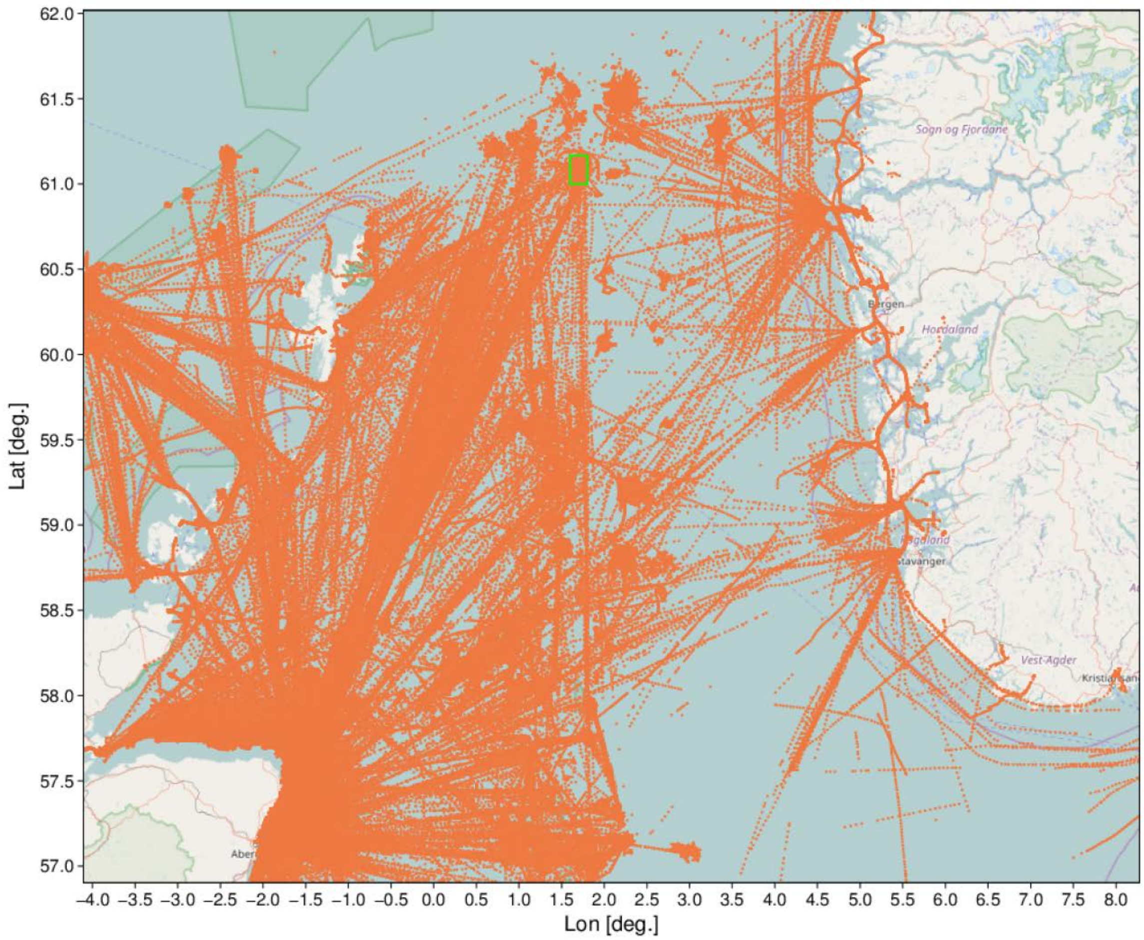

Fig.10 vessel trajectories of 29 vessels being spotted in quadrant 211/29 (green rectangle) where the Brent fields are located within the period from 1 Oct.2014 to 30 Oct.2016.

Additionally, weather data for the relevant period were obtained from European Center for Medium-Range Weather Forecasts (ECMWF). Fig.11 shows the local distribution of the significant wave heights in the northern North Sea for 20 March 2014 at 18:00 hrs. Using these data as a basis, Fig. 12 shows the distribution of the significant wave height in the Brent field area in a time interval of three hours projected over the entire timeframe.

Basing upon these key data, the positions of all vessels situated within a distance of less than 250m away from the four Brent platforms and with a speed close to zero were now identified. For these states the vessels were assumed to be in DP mode.

In this process, 11 vessels were found that spent a significant time share in this mode across the 25-month observation period.
These filtered position data were correlated with the weather data for the same timeframe, so that the overall time in DP mode at the platform could be classified in line with the prevailing wave height.

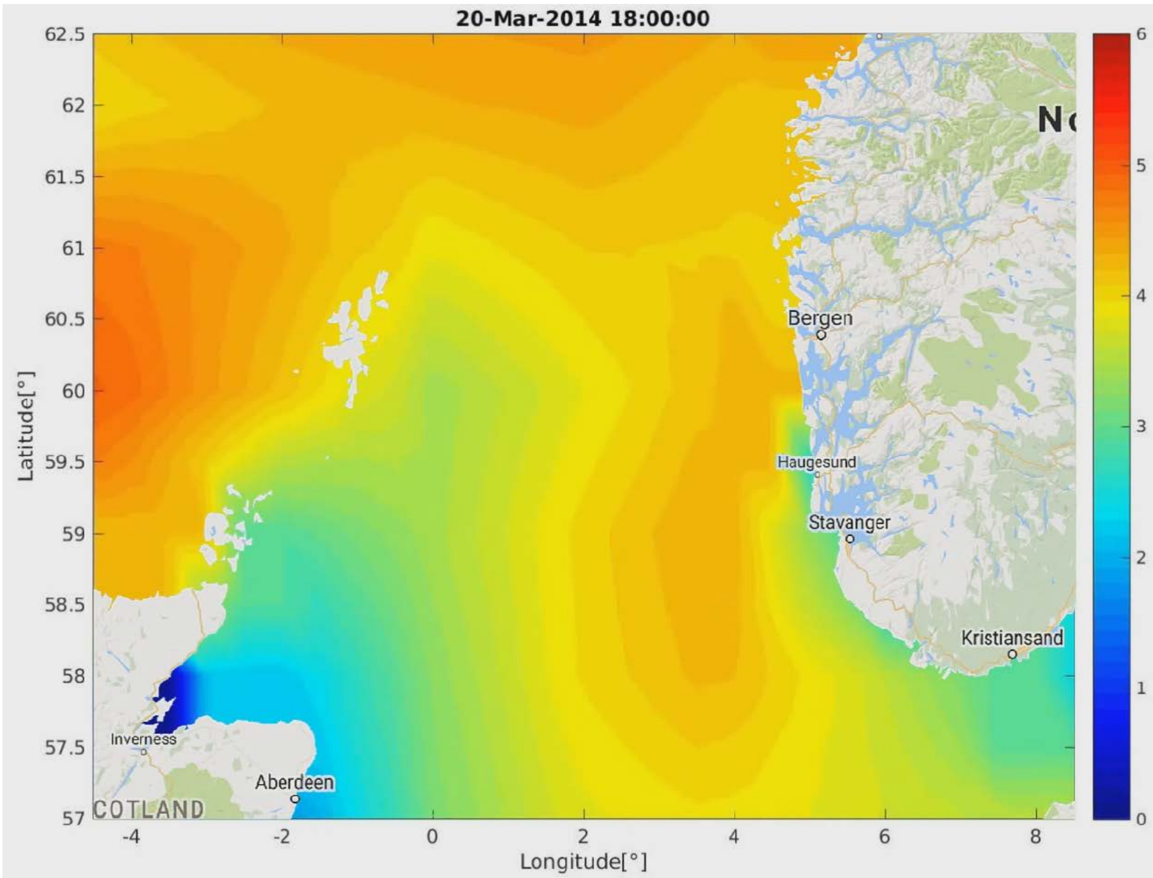

Fig.11 significant wave height in the northern North sea on March 20th 2014 - 6 pm

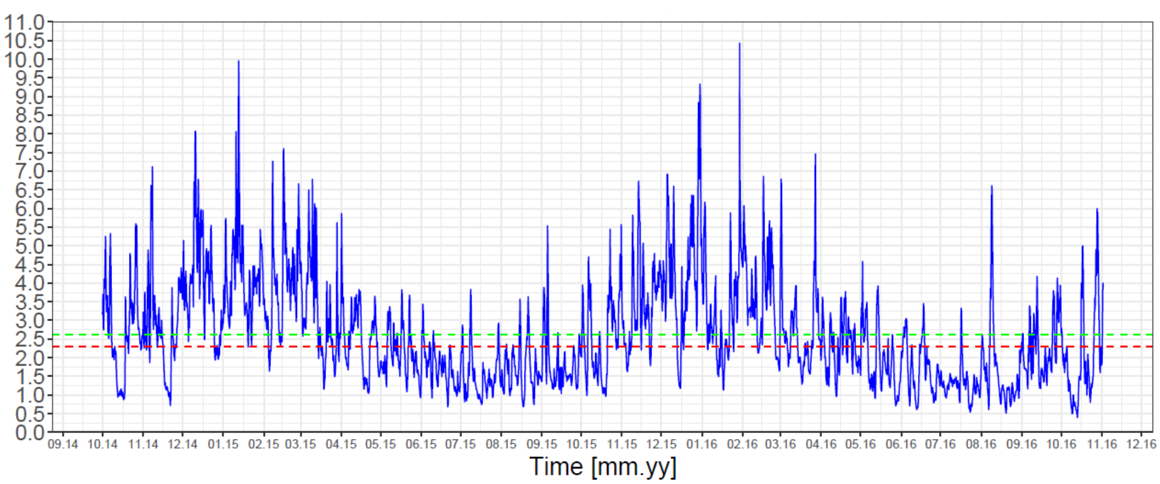

Fig. 12 sign. wave height in quadrant 211/29 (Brent field) over time (green=mean, red=median)

Fig. 13 shows the result of this evaluation for the 11 selected vessels. Regarding their thruster responsiveness, these vessels represent three different propulsion concepts. The main propulsion systems of Siem Opal and Olympic Hera consist of two screw propellers on a fixed shaft. Edda Fram, Edda Frende and Edda Ferd are each fitted with two Voith Schneider Propellers. The remaining vessels are all propelled by two azimuth thrusters.
It is interesting to recognize that, as expected, the statistical analysis assigns the lowest maximum wave heights to the two vessels with the fixed propeller shafts.
DP events of vessels that are fitted with azimuth thrusters were detected up to a wave height interval of 3.0 to 3.5m and thus present an increased weather window.
Wave heights above 3.5m could only be assigned to the three VSP vessels; for Edda Ferd wave heights as much as the 4.5 – 5.0m were identified.
In conclusion it can be stated that the order of weather windows of the vessels corresponds with the responsiveness of their main propulsion systems and is thus confirm the trends detected within the DP simulations.

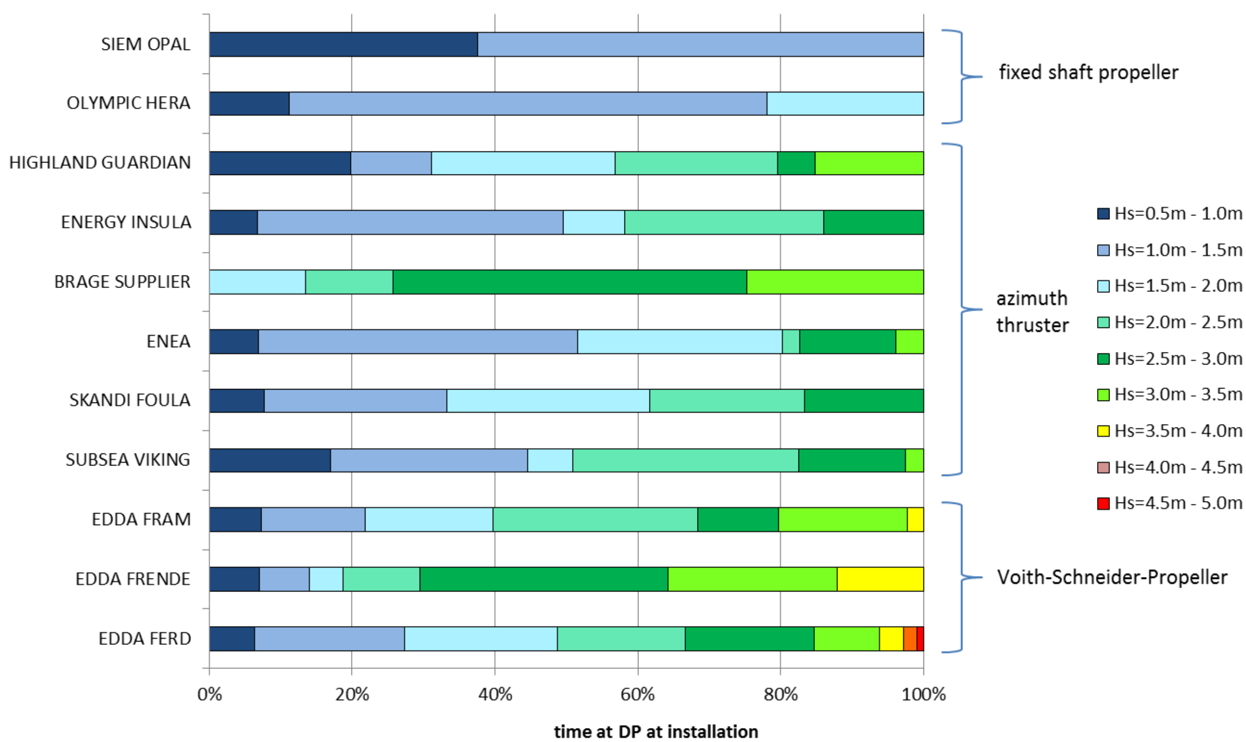

Fig.13 Percentage of DP time at the platform during different significant wave heights

7. Conclusion

The traditional way of creating DP capability plots on the basis of a static approach presents inadequacies regarding the modelled effects. This scenario often results in limiting weather conditions that are too optimistic. In addition, the results from the dynamic simulations presented in this paper have demonstrated that the disregard of thruster dynamics may lead to a reversal of trends regarding DP capabilities. While the time domain simulations have shown a clear dependence of the limiting weather on the thruster responsiveness, the statements made on the basis of static approaches would result in a contradictory classification of the different propulsors.

With the help of statistical evaluations of historical position and weather data for DP operations at oil platforms, it was possible to mirror the trend that emerged from the simulations regarding thruster responsiveness.

These aspects support the recommendation to carry out a valid classification of vessels in terms of their real DP capability based on dynamic time domain simulations.

Literature

[1] Jürgens D., Palm M., Voith Schneider Propeller - An efficient propulsion system for DP controlled vessels, Dynamic Positioning Conference, Houston, 2009

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