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DESIGN SESSION 2

DynCap – Full scale validation of a vessel's station-keeping capability analysis

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Abstract

With the steady growth of the number of DP vessels, increasingly complex designs and operations, and a decreasing number of experienced DP operators, effective Operational risk management tools are key for safer and more efficient operations as addressed by the recent MTS guidelines.

The vessel station-keeping capability (or DP capability) is one of the key aspects to consider when addressing the operational risk as many operations rely on accurate positioning. Loss of position can lead to dramatic consequences and significant downtime. An example is given by diving vessels, where in case of loss of position the vessel can drag the diving bell away from the diving site leading to interruption of air supply to the divers. Another critical operation is oil and gas offshore loading where loss of position can lead to collision between the production platform and the shuttle tanker. Similarly a platform supply vessel could collide with an installation in case of loss of position. For drilling units loss of position may lead to disconnection of the drilling riser with related consequences.

One of the key aspects when looking at the operational risks is the estimation of the vessel position and heading after the worst case single failure and also in the transient period after the failure has occurred. This cannot be obtained from the traditional quasi-static capability analysis but it is possible by running comprehensive capability studies employing simulation tools based on accurate vessel modelling and time-domain simulations. Such a tool, DynCap, was presented in the 2013 MTS DP conferences. A case study of a diving vessel, for understanding the vessel's performance and limitations, was the topic in the 2014 MTS DP conference.

One open question still remains to be answered. *How accurate is DynCap compared to reality?*

The aim of this paper is to present results from full-scale trials performed with the platform supply vessel Island Condor.Island Condor is a 97 meter long platform supply vessel with azimuth thrusters as main prolusion, two tunnel thrusters and a bow retractable azimuth. It is equipped with a DP control system and data logging capability. Waves were measured by a buoy while wind speed and direction were measured by wind sensors onboard the vessel. Current speed and direction was estimated by the crew. The trials were conducted with both calm and harsh sea conditions outside Norway on different locations.

The results show that the DynCap simulations can be quite accurate compared to the full-scale measurements, provided that the models of the vessel and its equipment are sufficiently accurate.

Contents

Introduction and History

With the steady growth of the number of DP vessels, increasingly complex designs and operations, and a decreasing number of experienced DP operators, effective Operational risk management tools are key for safer and more efficient operations as addressed by the recent MTS guidelines.

The vessel station-keeping capability (or DP capability) is one of the key aspects to consider when addressing the operational risk as many operations rely on accurate positioning. Loss of position can lead to dramatic consequences and significant downtime. The traditional quasi-static DP Capability Analysis (DPCap) as described in IMCA M140 [4] is the current industrial standard for analyzing a vessel's station-keeping capability. These analyses are used for vessel design, charter agreements and operational planning.

Due to shortcomings in the quasi-static DPCap approach, the Dynamic Capability (DynCap) concept based on time-domain simulations has been introduced in recent years. Employing time-domain simulations to assess complex marine operations is not new – this approach has been used for decades, and a number of simulation tools exist. However, the results are mostly presented in terms of time series and statistics. The novel feature of the DynCap concept is the way it combines extensive series of systematic time-domain simulations with intuitive and simple presentation of the results.

The terms "Dynamic Capability" and "DynCap" were – to the best of our knowledge – first introduced in the "FlexShuttle" Joint Industry Project including shuttle tanker operator Teekay, oil company Det norske, training center Ship Modeling and Simulation Center (SMSC) and Marine Cybernetics. The project was finalized in 2011 and supported by the Research Council of Norway. Key results were presented at the IMCA Annual Seminar in 2010 [1]. Since then, the DynCap concept has matured through a series of commercial projects and publications. At the MTS DP conference, the DynCap concept was first introduced in 2013, including analysis comparisons of three different vessel types, a case study on operability and fuel consumption, and experimental verification employing a 1:30 scale model PSV type vessel design [5]. This was followed by a case study with a single stern tunnel thruster diving support vessel in 2014, where focus was put on the transient response and excursion immediately after a failure [6]. The work presented in this paper is the next step and the result of a challenge from last year's MTS DP Conference audience: *what about full scale validation of the results*? In addition to the MTS publications, a DynCap study for a offshore windmill service vessel including optimization of positioning strategy with a motion compensated gangway has been presented at DP Brasil in 2015 [7].

As a consequence of the weaknesses in existing DP Capability standards, DNV GL is currently running the project "DP Capability Assessment" with a range of industrial participants encompassing designers, equipment manufacturers, vessel owners and oil companies [11]. The project aims to deliver a new standard for DP Capability studies in 2016, including a future replacement for the existinig ERN (Environmental Regularity Number) scheme as well as new standards for advanced quasi-static analyses and dynamic capability analyses based on time-domain simulations.

This paper presents the DynCap concept in brief including some of our recent experiences in running these analyses, the SimVal project where the full-scale trials were conducted, the approach taken to the validation, and finally the full-scale validation results for the platform supply vessel.

The Dynamic Capability Concept

DynCap is based on systematic time-domain simulations with a complete 6 DOF closed loop vessel model. This includes dynamic wind and current loads, 1st and 2nd order wave loads including slowly-varying wave drift, as well as the dynamics of the propulsion system and power system. A model of the Power Management System (PMS) is also included to simulate relevant functionality for DP operations such as black-out prevention, load limitation and sharing, and auto-start and auto-stop of generators. To close the loop, a model of the full DP control system is included with observer (Kalman filter), DP controller and thrust allocation, sensors, and position reference systems. The complete propulsion system model includes actuator rate limits and computation of dynamic thrust loss effects such as the interaction between thrusters, interaction between thrusters and hull, ventilation, out-of-water effects, and transversal losses based on empirical models. External loads from e.g. mooring lines, risers, hawsers and similar can easily be included in the analysis, including time-varying and motion dependent forces. More details on the vessel model can be found in [4]. The DynCap analysis can be performed for collinear environmental loads (wind, current and waves attacking from the same direction) or non-collinear loads, and any desired combination of wind, waves and current directions.

One of the advantages of the DynCap analysis, compared to a traditional DPCap, is that the limiting operating condition can be computed by applying a set of user defined acceptance criteria. The position and heading excursion limits can be set to allow a wide or narrow footprint, or the acceptance criteria can be based on other vessel performance characteristics such as sea keeping, motion of a crane tip or other critical point, dynamic power load, or tension and/or angle of a hawser or riser. In this way the acceptance criteria can be tailored to the requirements for each vessel and operation. An example of position and heading acceptance criteria is shown in Figure 1. In this case, the station-keeping capability is found by searching for the maximum operational condition in which the vessel footprint stays within the predefined position and heading limits.

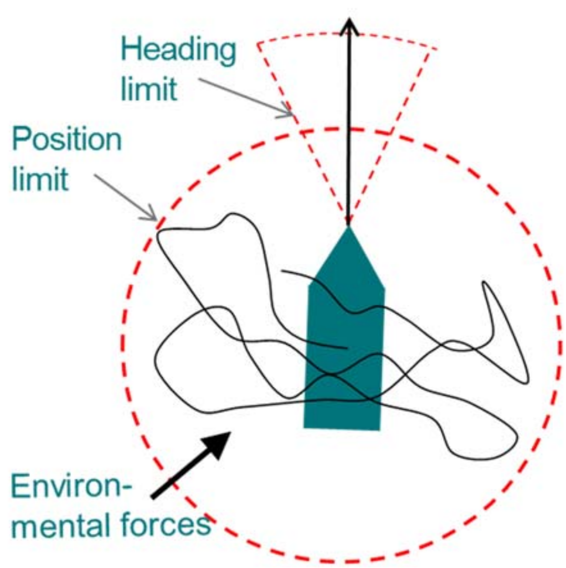

Figure 1: Example of heading and position acceptance limits

Traditional operability studies typically are divided in two separate analyses: A DP Capability study to investigate the station-keeping ability of the vessel in the design environmental conditions, and a sea-keeping analysis to investigate the wave-induced motion of the vessel, typically emplying the motion RAO's (Response Amplitude Operators) of the vessel. The DP Capability study then focuses on the horizontal-plane motion (surge, sway, yaw) and the ability to stay on position, whereas the sea-keeping analysis focuses on the vertical-plane motion (heave, roll, pitch) and the limits this motion imposes on the desired operation. With DynCap, these two analyses may be combined in one, since the full 6DOF motion including wave-induced motion is simulated. The acceptance criteria may e.g. be a combination of station-keeping limits (watch circle) and heave/roll/pitch motion.

Experiences

Running dynamic capability analyses is a complex task with many facets that will affect the end results, and there are significant challenges in setting up, running and understanding the analyses. The following lists some of our key experiences through a number of commercial projects performed in the last years.

Vessel motion can be divided in several components and it is essential to see this in connection with the chosen acceptance criteria. The first-order wave-induced (WF) vessel motion, typically described by motion RAO's[1], are harmonic motions oscillating about the "mean" or low-frequency (LF) vessel motion. The WF motion is normally not possible to counteract by use of thrusters, and is attempted filtered out in the DP system. The LF vessel motion is due to mean and slowly-varying environmental forces, as well as thruster and other external forces, and is the motion the DP system is attempting to control. For higher sea states, the LF motion is typically dominated by the slowly-varying wave drift forces, which can peak at 10 times the magnitude of the mean wave drift force. This will give temporary position and heading excursions of significantly larger magnitude than the WF motion. If the mean environmental load becomes too large, then the vessel will be forced off position permanently. Finally, the vessel may experience temporary excursions due to transients after a failure, before the DP system manages to re-allocate thrust and regain position.

Acceptance criteria must be carefully chosen to reflect the actual operational requirements, and must be seen in connection with the vessel motion components included in the analysis. This is essential to clarify with all stakeholders in the analysis in order to avoid misunderstandings. As an example, if the operation to be conducted is vessel-to-vessel or vessel-to-fixed installation, then the total vessel motion (LF+WF) may be of key interest and the acceptance criteria chosen quite narrow. However, if the sea state becomes too big, the WF motion alone may violate the acceptance criteria such that the seakeeping characteristics and not the DP capability becomes the limiting factor. Another example may be a pipe-lay operation, where the WF motion is not of key interest, but the LF motion including temporary excursions due to slowly-varying wave drift (especially in beam seas), may violate restrictions of the stinger. Similar examples can be drawn out e.g. for drilling operations with limitations in the riser tensioning system or for diving operations with restrictions in the diving bell handling equipment. In the latter example, the temporary excursion after a thruster failure may be a limiting criteria [6]. In a third example, e.g. for standby operation, both WF and slowly-varying position excursions are acceptable, as long as the vessel is not forced off position permanently. In this case, the acceptance criteria can be set wide, and results from the DynCap analysis get closer to the results from a high-quality quasi-static analysis. In this case, DynCap studies can add value by providing statistics on e.g. fuel consumption and thruster usage.

Slowly-varying wave drift forces can in some cases become the dimensioning loads, if temporary position excursions outside the typical watch circle are unacceptable. Drift force transfer functions based on potential theory programs like WAMIT [10] and corresponding time-domain implementation typically yield peak forces with magnitude 10 times larger than the mean (static) wave drift force. For higher sea states with beam or quartering seas, these forces have large energy content, especially for ship-shape

[1] Motion response amplitude per unit wave amplitude. Relationship between wave surface elevation amplitude at a reference location and the vessel motion response amplitude, and the phase lag between the two.

vessels with a long waterline (since drift forces are due to reflections of the waves from the hull). This is important to consider in choice of acceptance criteria and interpretation of the results.

Sea state discretization is important to consider in order to achieve a realistic representation of the sea state, which again is important for the wave induced forces – both wave-frequency and slowly-varying. A typical recommendation would be a minimum of 100 harmonic components with phase, frequency and direction for each component chosen randomly within the frequency and directional spectrum, while still preserving the shape and energy of the spectrum [15].

Vessel model fidelity must be sufficient to replicate the main characteristics of the real vessel and equipment, depending on the application. If the vessel model is too inaccurate, no high-quality analysis method will give satisfactory results. For a rough comparison or benchmarking study of different designs, lower model fidelity may be adequate, wheras for operability studies of a specific design, model fidelity must be high. The sensitivity to modeling inaccuracies was further investigated in [5] and [9].

DP tuning including observer and thrust allocation will affect the DynCap results significantly. A well tuned DP would be better at keeping the vessel within the acceptance criteria, and hence yield better capability results. Comparisons showing the consequence of different DP tuning has been presented in [5] and [6]. The key aspect to consider here is that the DP tuning should be comparable to that of the real vessel – in other words, the model DP system in the analysis should replicate the real DP system in the same way as the vessel model in the analysis should replicate the real vessel.

Search algorithms to find the limiting operating condition are key to optimizing simulation run time. Although computing power appears abundant these days, a significant effort is needed to obtain e.g. a complete wind envelope, where a number of time series with different wind speeds must be run to find the limiting wind speed for each angle in the envelope. Thrust or power envelopes require less run-time, since the environmental condition is predefined and no such search is necessary.

Obtaining statistically significant results requires that the analyses are run for a sufficiently long time. This is especially important for projects where the extreme results are of key interest. A commonly used time span is to simulate 3 hours for a given environmental condition [12].

The SimVal project

Marine Cybernetics is participating in the research project “Sea Trials and Model Tests for Validation of Shiphandling Simulation Models” or “SimVal” [12], which aims to improve present validation methodology for ship-handling simulation models. The SimVal project is run by MARINTEK in cooperation with a range of international partners including research institutes, universities and ship owners, and sponsored by the Research Council of Norway. The results presented in this paper have been obtained from sea trials with the Island Offshore platform supply vessel “MV Island Condor”.

MV Island Condor is a DP2 PSV with UT 776 CD design, length 97m, width 20m, and diesel electric main propulsion, see [14]. It is equipped with two CPP Azipulls rated 2200 kW for main propulsion, two CPP bow tunnel thrusters rated 883 kW and a retractable bow azimuth rated 883 kW.

Sea trials with Island Condor were conducted on the journey between the yard at Brevik and Stavanger in the period between 13th and 17th of November 2014. The trials included step responses, maneuvering and station-keeping. Onboard measurements were taken by MARINTEK. The equipment for station-keeping measurements consists of GNSS for measurement of position and velocity; gyrocompass for heading;

vertical reference system for heave, roll and pitch; and wind sensors for wind speed and direction. Power generation/consumption, DP thruster command and feedback were taken from DP logger. Current speed and direction were estimated by the crew based on DP current and visual observation, while a wave bouy close to the vessel was used for sea state estimation.

Figure 2: MV Island Condor[14] and thruster layout

Validation approach and uncertainties

For validation of the DynCap concept using full-scale measurements, the CyberSea® Vessel Simulator was configured for the Island Condor. The configuration is based on commonly available documentation of the vessel and equipment, specifically the following were employed:

- General Arrangement drawing for wind and current areas and thruster locations
- 3D body hull form and loading conditions (draught, trim, metacentric height, etc.) for input to WAMIT to calculate motion RAOs and wave drift coefficients
- Wind and current coefficient curves from database
- Single line diagrams for the power generation and distribution system
- Specifications of thrusters and rudders

The DP system was configured for the vessel and tuned based on conventional rules-of-thumb to match that of a well-tuned actual DP. Further model tuning was done by adjusting the damping in heave, roll and pitch to improve model matching.

The DynCap simulations were then run for the same cases as the full-scale trials, i.e. replicating the environmental conditions and vessel setup from the trials. The following trials and simulations were conducted:

- Step response using various thrusters
- Station-keeping at different headings with respect to the weather

In the results there are several sources of uncertainties. Firstly, there are uncertainties in the estimation of the actual environmental conditions during the full-scale trials and the measurements obtained during the trials. Secondly, there are uncertainties in the DynCap vessel and equipment models. Thirdly, there will be discrepancies between the DP system and the DP system model, encompassing DP controller, observer and thrust allocation including tuning. Fourthly, when comparing time series of a stochastic phenomenon like vessel motion in irregular waves, there will be variations in both standard deviations and maxima depending on the time window used for comparison. Ideally, referring back to the discussion above on statistically significant results, both full-scale trials and simulations should have been conducted for at least 3 hours for every comparison case. This was not practically possible, and the comparison has to be performed for shorter time windows instead. All of the above means that a perfect match between the full-scale trials and the simulations cannot be expected. However, a reasonable match and the correct trends should be achieved.

The environmental models are a principal source of uncertainty, both because of the uncertain full-scale estimates and the uncertainties in the chosen model parametrization. The wind measurements are believed to be quite accurate, and relatively consistent over the course of the trials. The current estimates were unfortunately not taken by a buoy, but instead estimated by the crew based on DP current and observations. This is in best case inaccurate, but will just have to count as an uncertainty – for the validation simulations we have chosen to fix the current speed and direction for all cases. The sea state was estimated by a wave buoy, giving reasonably good estimates of significant wave height Hs and the frequency spectrum. The directional spectrum (spreading) was not possible to retrieve. The sea state has been modeled by a JONSWAP frequency spectrum with peakedness factor 3.3, a cosine squared directional spectrum with spreading factor 2 [12], and 100 harmonic components.

Validation results

In the results presented in the paper, the wind speed and wave height values are not disclosed. This to avoid providing insight and information on the vessel performance to other vessel owners and equipment manufacturers. Wind speeds and significant wave heights are labeled with WS and Hs respectively. The suffix number added to the lables is given for the relative comparison between the values. A larger number is associated to a larger value, i.e. WS2 is largen than WS1.

Table 1 shows a summary of the vessel steady-state responses to steps in the thruster commands. The wave buoy was not active during these experiments, hence we do not have explicit information on the sea state and current speed. From the logs heave, roll and pitch were not significant; therefore it can be assumed that waves were small in the experiments. Wind speed from the DP logger was quite stationary.

In general, the simulated responses match the full-scale experiments quite well. It should be noted that these simulations were carried out without waves, wind and current. This could explain the slight difference between simulations and experiments.

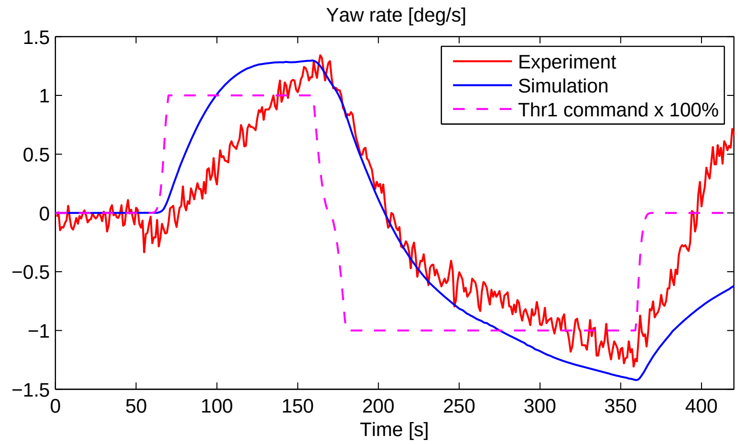

Figure 3: Yaw rate response for Thr1 first at 100% step and then at -100% step.

Error! Reference source not found. shows an example of the step response in yaw for the case with Thruster 1 first stepped from 0 to 100% and then to -100%. The simulation and experiments follow each other quite closely, with the simulated response somewhat quicker than the experiements. This is probably caused by rate limits in the step commands for the real thruster that have not been included in the model.

Table 1: Comparison of step responses between experiment and simulation.

Test Description	**Response**	**Experiment**	**Simulation**	**Thr max power [kW]**		
				Thr #	**Experiment**	**Simulation**
Thr1 at 100%	Max yaw rate [deg/s]	1.42	1.42	Thr 1	855	883
Thr1 and Thr2 at 100%		1.81	1.86	Thr 1 Thr 2	875 854	883 883
Thr3 at 100%		1.27	1.54	Thr 3	876	883
Thr1, Thr2 and Thr3 at 100%		2.2	2.36	Thr 1 Thr 2 Thr 3	850 835 877	883 883 883
Thr1 - Thr5 enabled. Sway test with DP joystick	Max sway [m/s]	1.49	1.40	Thr 1 Thr 2 Thr 3 Thr 4 Thr 5	805 800 845 2130 1910	883 883 883 2160 1900
Thr4 and Thr5 full astern	Max/min surge [m/s]	-5.2	-5.18	Thr 4 Thr 5	2065 2027	2199 2199
Thr4 and Thr5 full ahead		6.57	6.58	Thr 4 Thr 5	2174 2154	2199 2199

Table 2 shows the estimated environmental conditions for the full-scale trials, where each test is denoted as a "case" in the following. Wind, waves and current were quite stationary during the trials. All directions are given relative the bow as shown in Figure 4. Note that the different cases were obtained by changing the vessels heading setpoint. All cases have logs of 15-20 minutes. In terms of seakeeping statistics, this is a quite short duration, which means that both standard deviations and maxima may deviate significantly from the "stationary" values that could have been obtained over e.g. a 3-hour period. For comparison purposes it has been chosen to use also simulation duration of 20 minutes.

Table 2: Environmental conditions from full-scale trials

Case	1	2	3	4	5
Description	Head wind	Bow quartering wind	Beam wind	Stern quartering wind	Following wind
Wave Hs (m)	Hs1	Hs1	Hs1	Hs1	Hs2
Wave direction (deg) relative to vessel heading	5	333	306	250	197
Mean wind speed (m/s)	WS5	WS3	WS2	WS4	WS1
Wind direction (deg) relative to vessel heading	355	306	273	199	177
Mean current speed (m/s)	0.9	0.9	0.9	0.9	0.9
Current direction (deg) relative to vessel heading	310	265	226	175	130

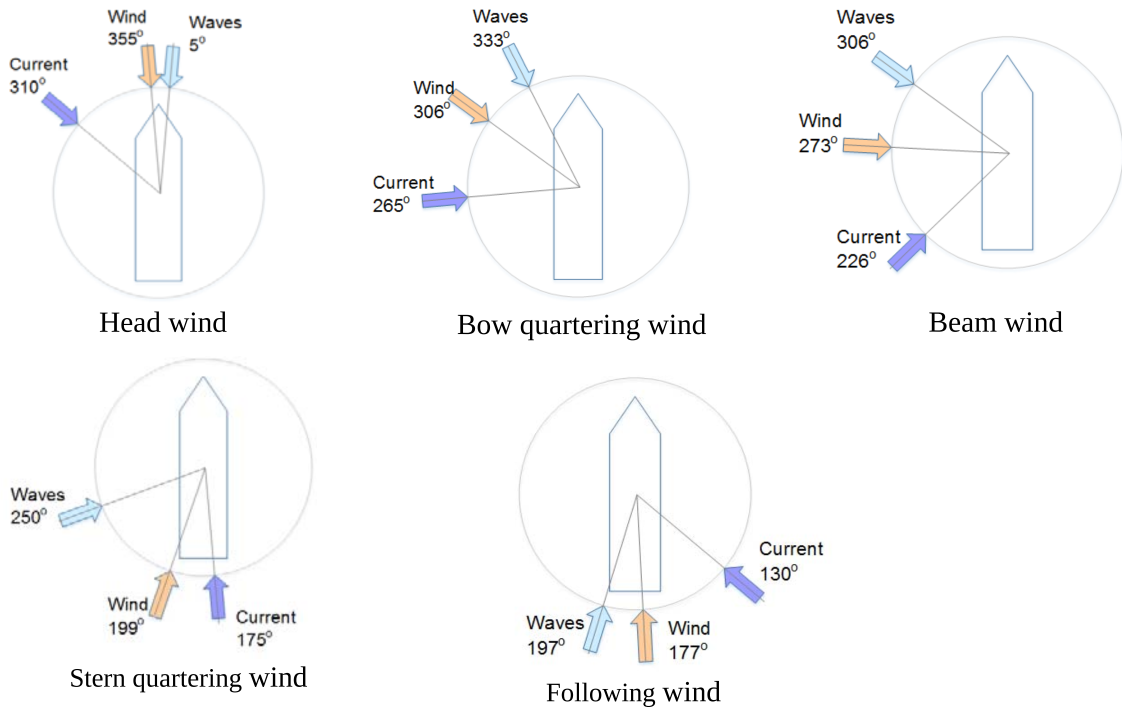

Figure 4: Environmental directions from full-scaled trials

Table 3 shows a comparison of standard deviations and max values in heave, roll and pitch between experiments and simulations. The deviations vary between the degrees of freedom and the different cases. For this study, the vertical degrees of freedom have not been a key priority, and it can be seen that especially the max values in places deviate significantly between experiments and simulations. There may be a number of reasons for this. Most noteably, as discussed above, both the experimental time series and the simulations are quite short, and will therefore not give fully representable statistics. Another factor that will influence these results significantly is the uncertainty in the sea state estimation with corresponding model parametrization, especially the sea state discretization including frequency and directional spectrum. Figure 5 shows example time series from experiments and simulations of heave, roll and pitch for stern quartering wind.

Table 3: Comparison of heave, roll and pitch: standard deviation and max values.

Case number	1		2		3		4		5	
Description	**Head wind**		**Bow quartering wind**		**Beam wind**		**Stern quartering wind**		**Following wind**	
	Experi -ment	Simula -tion	Experi -ment	Simula -tion	Experi -ment	Simula -tion	Experi- ment	Simula -tion	Experi -ment	Simula -tion
Max heave (m)	1.80	1.05	1.89	1.33	2.13	1.77	1.47	1.81	1.54	0.94
Std heave (m)	0.60	0.31	0.53	0.36	0.59	0.54	0.46	0.57	0.49	0.28
Max roll (deg)	1.47	0.94	1.48	1.64	1.72	2.45	2.44	2.51	2.02	1.14
Std roll (deg)	0.39	0.25	0.37	0.34	0.44	0.50	0.70	0.60	0.64	0.39
Max pitch (deg)	2.32	3.14	2.61	2.99	2.66	2.61	1.78	2.50	2.85	2.73
Std pitch (deg)	0.71	0.91	0.73	0.90	0.72	0.83	0.53	0.76	0.88	0.92

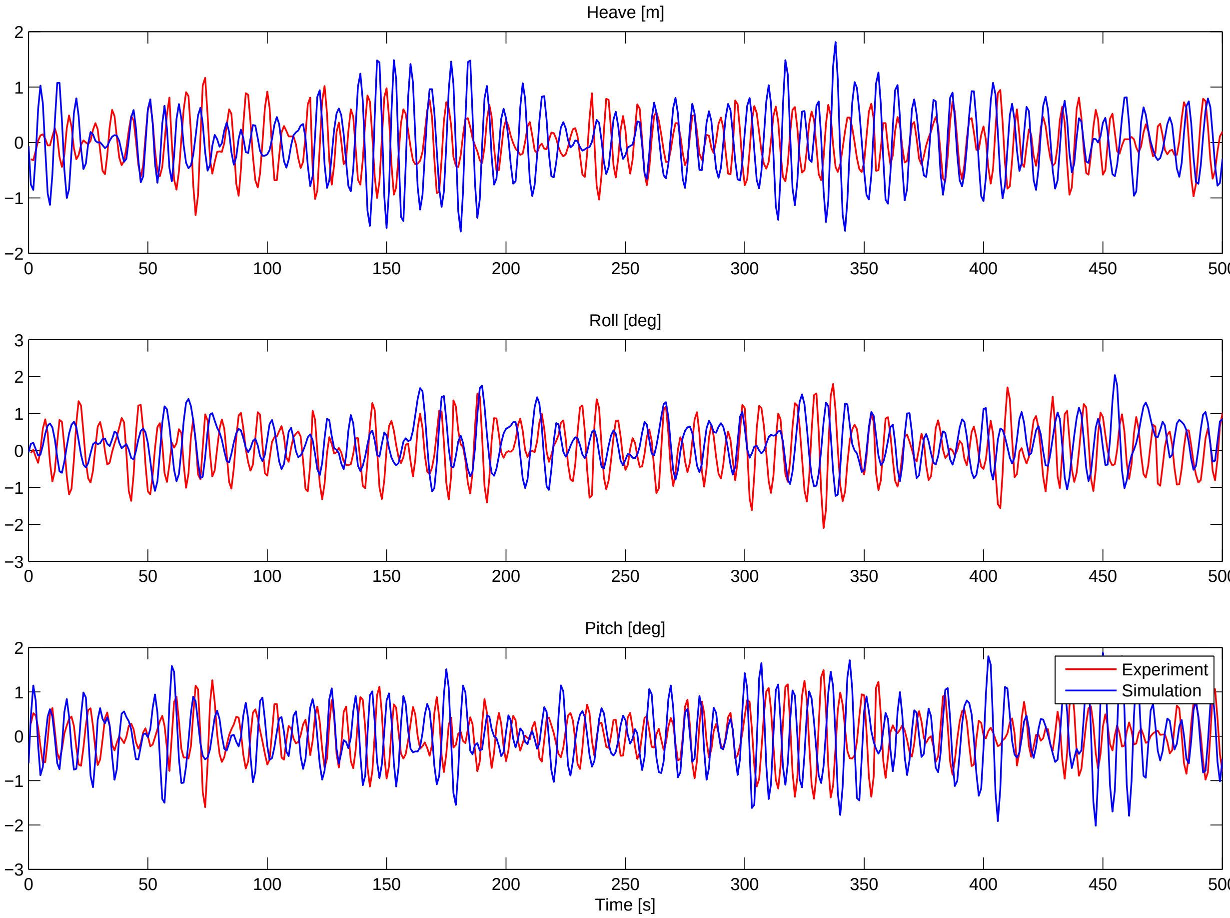

Figure 5: Example of time series of heave, roll and pitch for stern quartering wind test.

Table 4 shows a comparison of stationkeeping performance in terms of standard deviation and max deviation from the setpoint, as well as average power utilization. In general, both the max position and heading deviations and the standard deviations in the simulations are somewhat smaller than or similar to the experiments, with a few exceptions. The differences indicate that the DP tuning in the simulations may be on the aggressive side, but there are also other sources of uncertainties like the short time durations and the environmental conditions as discussed above for roll, pitch and yaw results. Figure 6 shows an example time series of position and heading for head wind, comparing experimental and simulated results. Due to the stochastic nature of the vessel motion (the wave elevation in the simulations and experiments are not synchronized), the time series cannot be directly compared; instead, statistical values like max values and standard deviations must be compared.

The average power of all thrusters are in the same range between the experiments and simulations, and within approximately 10% except for stern quartering wind where the difference is larger. Discrepancies here may originate from the same uncertainties as above, as well as differences in implementation of thrust allocation. This is a good result assuring that fuel consumption and emission estimation will be quite accurate.

For case 2 with bow quartering wind, the vessel was pushed to its limits in terms of stationkeeping capability. Reports from the trials were that the vessel just managed to hold postion and heading, with some temporary excursions. Note that for this case the current is attacking directly at the beam, such that this case is where the vessel has the highest environmental loads.

Table 4: Comparison of stationkeeping performance: standard deviation and max excursion from the setpoint.

Case	1		2		3		4		5	
Description	Head wind		Bow quartering wind		Beam wind		Stern quartering wind		Following wind	
	Experi-ment	Simula-tion	Experi-ment	Simula-tion	Experi-ment	Simula-tion	Experi-ment	Simula-tion	Experi-ment	Simula-tion
Max position deviation (m)	2.48	1.78	4.28	3.77	3.07	2.52	2.94	3.09	3.97	1.80
Std position deviation (m)	0.44	0.31	1.03	0.59	0.58	0.45	0.49	0.55	0.53	0.31
Max heading devation (deg)	2.92	1.66	2.36	4.84	2.49	3.32	2.22	1.61	2.21	1.41
Std heading devation (deg)	0.85	0.43	0.83	0.95	0.73	0.74	0.78	0.64	0.59	0.59
Average power all thrusters (kW)	2124	1902	2857	3058	2515	2238	899	1167	1320	1226

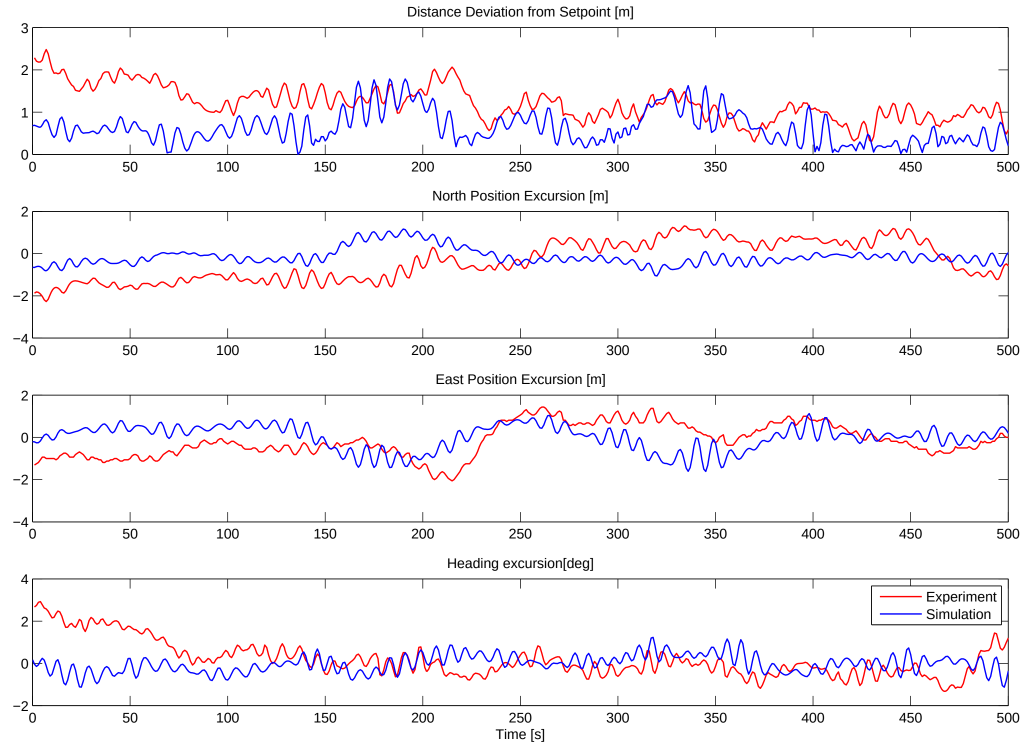

Figure 6: Example of time series of position and heading for head wind test

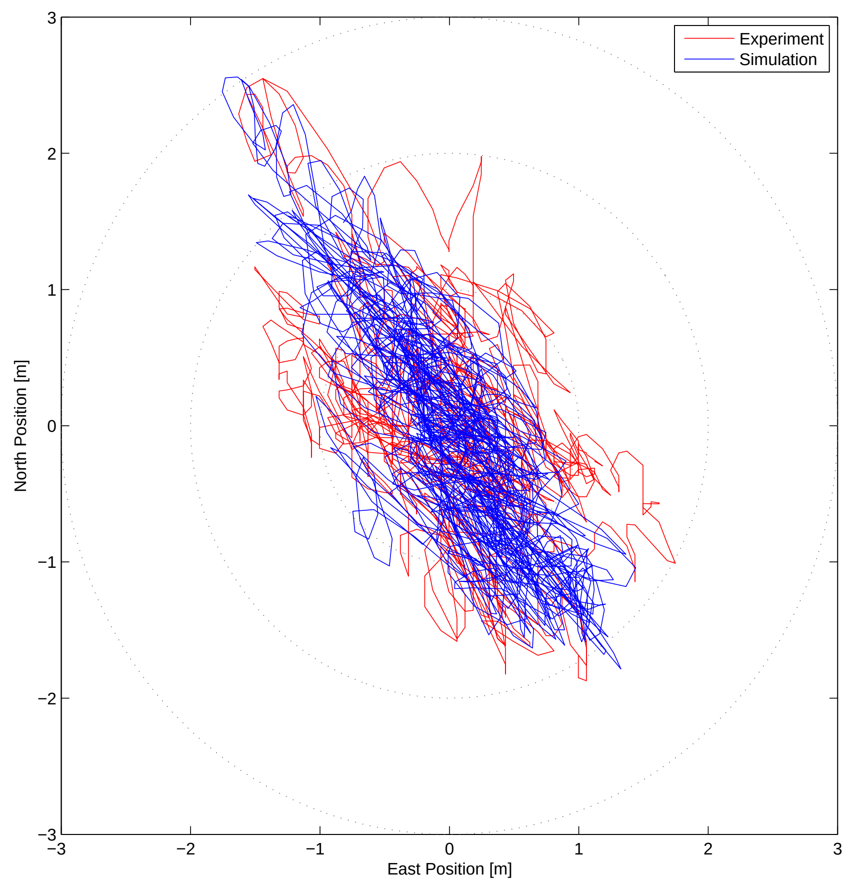

Figure 7: Example of footprint trajectory for stern quartering wind test

DynCap results

To expand on the validation results and provide additional insights into the vessels station-keeping performance, a complete wind envelope and a power envelope was generated. Both curves have been based on the environmental conditions during the full-scale trials, with values as shown in Table 5 and in the following denoted as the design condition. For both studies the wave and current directions are fixed relative to the wind direction, hence rotating together with the wind.

Table 5: Design condition definition (average from full-scale trials)

	Magnitude	Direction relative to wind
Wind	WS3	-
Wave	Hs1	28 deg
Current	0.9 m/s	-40 deg

The power envelope is shown in Figure 8, where the angle in the envelope is the wind direction relative to the vessel heading. The wind rotates 360 degrees and current and waves follow with the relative angles shown in Table 5. The total power consumption from the experimental results is shown in red dots, while the simulated power consumption is shown by the blue line. Essentially, this is a visualization of the experimental results in Table 4 combined with more DynCap simulations. As discussed above, the match between experiments and simulations is satisfactory.

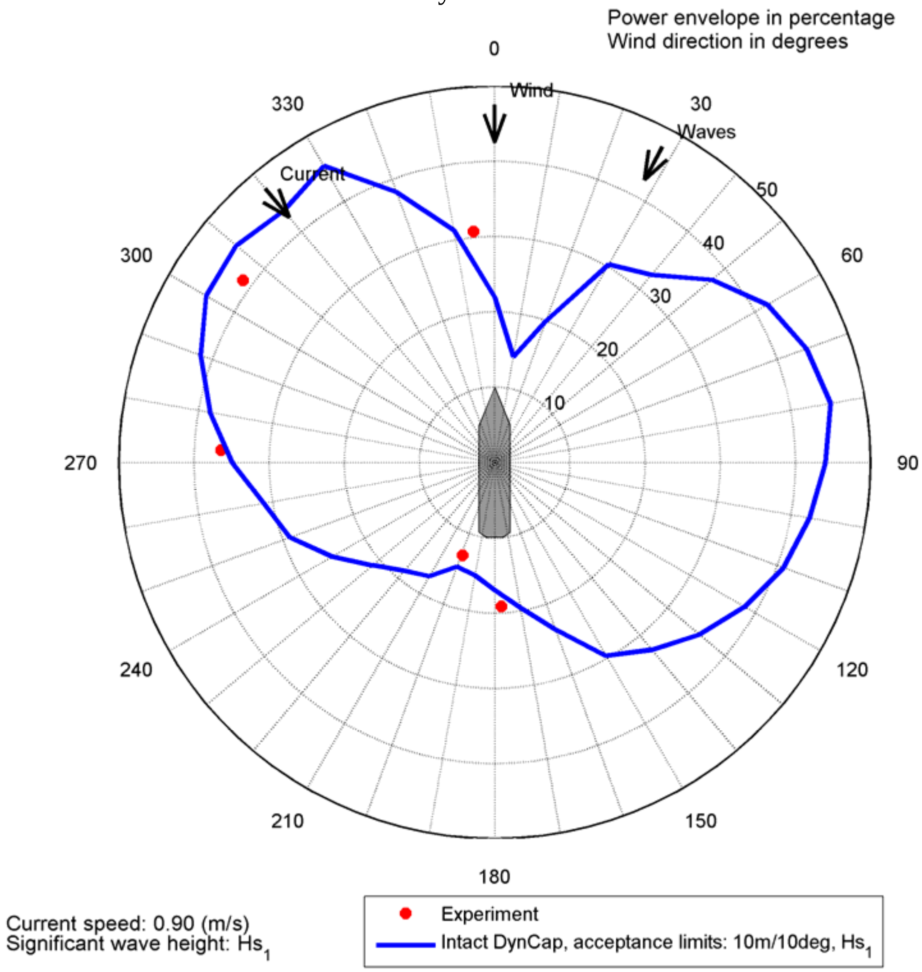

Figure 8: DynCap power envelope for the design condition, comparison between experiments and simulations

For the DynCap wind envelope, the LF motion acceptance criteria was set to 10 meters and 10 degrees from the corresponding setpoints. For this study, in order to match the design condition, the sea state was fixed according to the trial measurement and not varying with the wind (as is usual for wind envelopes). As for the power envelope, the angle shown in the plot is the wind direction, with the wave and current direction following with the relative angles as specified in Table 5. For each angle, the wind was then varied to find the limiting condition for which the vessel was able to stay within the acceptance criteria. The resulting wind envelope is shown in Figure 9, including the DynCap simulations in blue and the full-scala data points as red dots. As seen in the figure, all full-scale trials except one is well within the estimated capability limits. The full-scale trial with bow quartering wind (wind attacking at approximately 310 degrees relative to the bow) can be seen to lie just below the estimated capability limit. This is consistent with reports from the trials, where it was said that the vessel was just on the verge of its capability. Note also that the current here is attacking directly at the beam, such that this case is the one with the largest total environmental loads from the full-scale trials. Note also the asymmetric shape of the wind envelope – this is due to the non-collinear environmental forces.

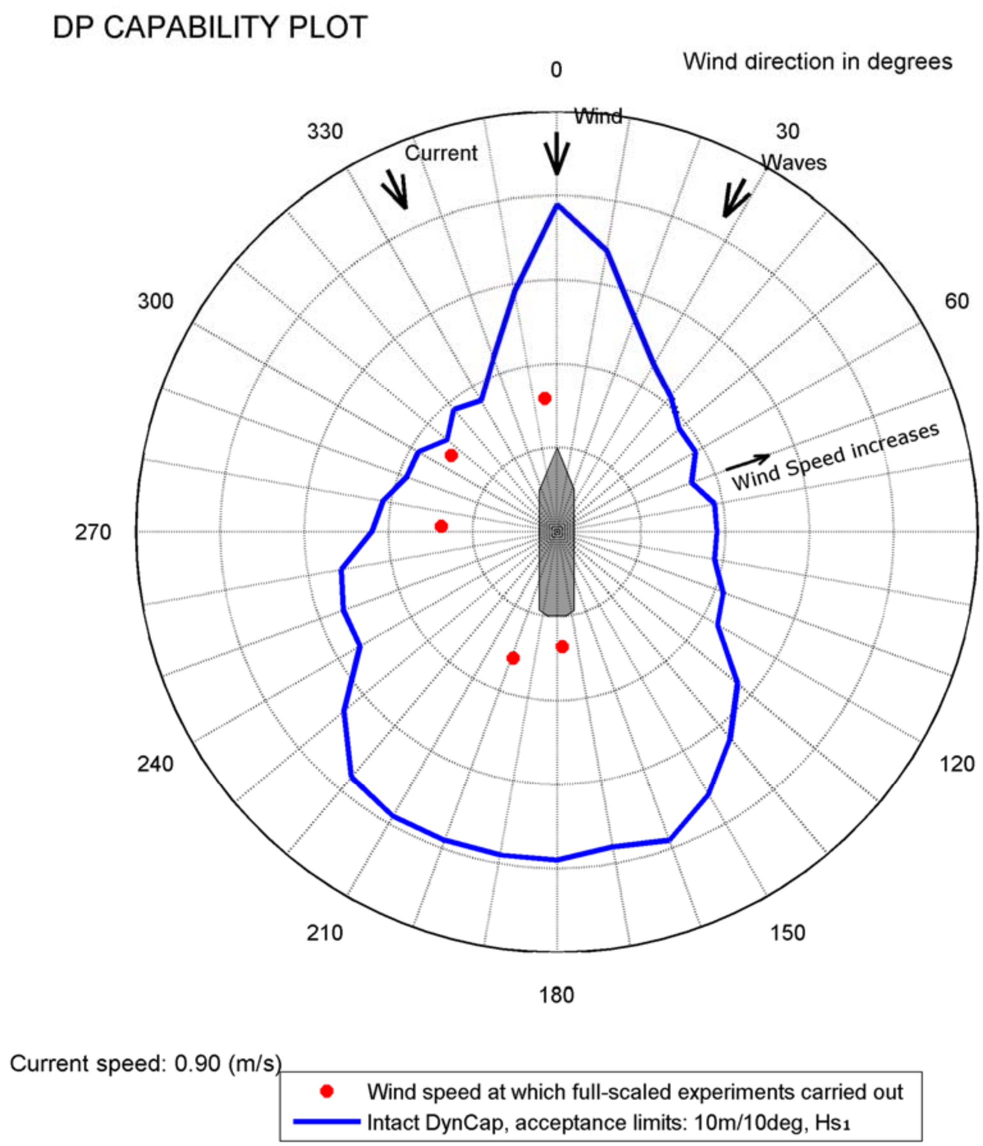

Figure 9: DynCap wind envelope for the design condition, comparison between experiments and simulations

Conclusion

This paper has presented a brief history of and motivation for the DynCap concept, which has matured through papers and commercial projects over the last years. Further, some of the experiences from running DynCap analyses have been shared; specifically some of the critical choices and areas that deserve special attention when setting up, running and analysing the results have been discussed. The experience shows that – while providing unique insights – care must be taken due to the high fidelity models, the number of interdependent choices that must be taken, and the sheer complexity of DP operations.

The key contribution of this work has been a full-scale validation of the DynCap concept, comparing measurements from sea trials with the platform supply vessel "Island Condor" with corresponding simulations using the DynCap methodology. The step response comparison showed that the model response was close to that of the real vessel. Further, the comparison of standard deviation and max values of roll, pitch and yaw showed that the model performance was acceptably comparable to the real vessel. The comparisons of DP footprint including standard deviations and max excursions for different vessel headings showed that the DynCap analysis was in line the full-scale measurements, and within what could be expected with uncertainties in sea state measurements and the limited duration of the full-scale time series.

Finally, a full DynCap wind envelope and power envelope for Island Condor was presented, including the relevant full-scale data points. This illustrates the value of using simulation tools for obtaining a wide set of capability results, and if possible benchmarking some data points with full-scale measurements to increase confidence further.

In conclusion, we have demonstrated that DynCap is an important addition to other available tools, which gives unique insight into the details of a vessels station-keeping performance. We also believe the results have shown that DynCap simulations are comparable to full-scale measurements when the vessel model is sufficiently accurately modelled, and that the simulations thereby provide trustworthy results.

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