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Design

DP Design Studies

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ABSTRACT

Kongsberg Simrad works in close cooperation with its clients also in the design phase of a DP (Dynamic Positioning) vessel. This paper presents the typical major elements of a detailed design study for drill ships or semi submersibles:

- DP capability analyses in the frequency domain to assess DP capability in typical operational and failure modes
- Performance simulations to assess station keeping accuracy, DP power usage and to investigate control strategies, DP operations and for moored vessels; mooring systems
- Drift-off and drive-off simulations to investigate the effects of single and double failures causing drift-off and drive-off and to assess typical time-to-limits

INTRODUCTION

Being an important DP vendor on the world market Kongsberg Simrad often works closely with its clients in the design phase of a variety of DP vessels, their applications spanning from e.g. mine hunting to drilling and cable-laying. Kongsberg Simrad offers design studies ranging from DP capability analyses in the frequency domain to six degree-of-freedom simulations in the time domain. Design in this context refers to thruster types, sizes and locations and power generation configuration and capacities in addition to necessary sensor accuracy and required dynamic capabilities of thrusters and power generators.

DP CAPABILITY ANALYSES

DP capability analyses in the frequency domain are generally used to establish the maximum weather conditions in which a DP vessel can maintain its position and heading for a proposed thruster configuration. Additional static forces e.g. a pipe pull can be taken into account. The environmental forces and moments are increased until they are exactly balanced by the maximum available thrust offered by the thruster configuration. Thus, a limiting weather condition is obtained as a combination of a mean wind speed, significant wave height and a sea current speed. . The relationships between the mean wind speed and the significant wave height defined by IMCA (The International Marine Contractors Association), see ***Ref. 1***, and DNV (Det Norske Veritas), see ***Ref. 2***, are built into StatCap, but arbitrary relationships may be defined. Wind, current and waves are normally taken as being coincident in direction. By letting the environmental components rotate in steps around the vessel the results of a DP capability analysis can be presented by means of a limiting mean wind speed for a discrete number of wind angles of attack. The resulting polar plot is often referred to as a DP capability envelope. An example generated by the Kongsberg Simrad computer program StatCap is shown in ***Figure 1***.

The main objectives of frequency domain DP capability analyses are typically to determine DP capability envelopes for a particular thruster configuration or to establish thruster configurations that yields a particular DP capability envelope. This brings about the need for accurate environmental force modelling and thrust allocation. The latter should preferably be identical to that of the DP control system. Force and moment coefficients can be calculated using empirical methods and/or scaling of data from similar vessels. A method for calculation of current loads on ships is given in ***Ref. 3*** and a method for calculation of wind loads on ships in ***Ref. 4***. It is recommended, however, that empirical methods and scaling methods are used only in the early design stages of the project and that more accurate load coefficients are obtained through e.g. wind tunnel tests later on. Not only simulations and studies will benefit from having accurate hydrodynamic input but also the DP control system itself when installed. As an example the wind feed forward function benefits from accurate wind load coefficient input.

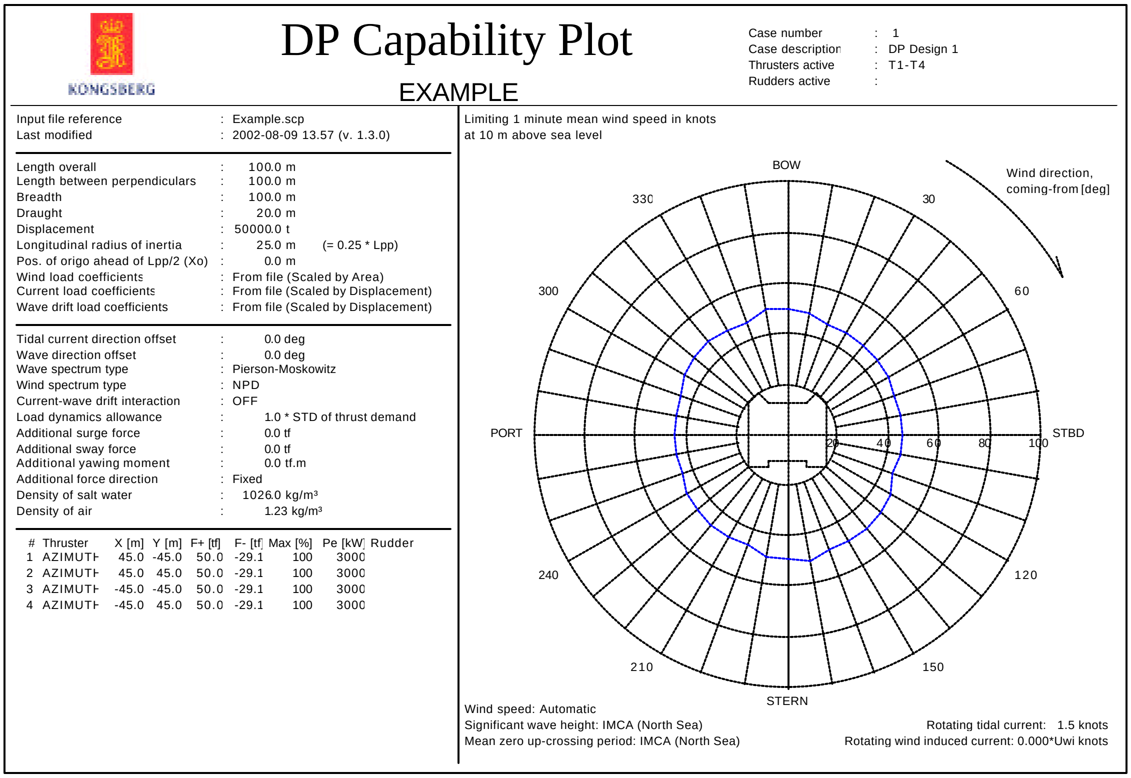


Figure 1 DP capability envelope example. The envelope is calculated using the Kongsberg Simrad computer program StatCap.

A DP vessel needs a certain amount of 'spare' thrust to compensate for the dynamic behaviour of the wind and wave drift loads. The 'spare' thrust can be taken into account as a given percentage of the wind and wave drift loads or it can be calculated from the spectral densities of the wind and wave drift loads and the controller's restoring and damping terms. Thrust losses affect the DP capability envelopes heavily since there may be substantial losses when the thrusters are working in extreme conditions, see ***Ref. 5*** and ***Ref. 6***. Losses due to thruster-thruster interactions can be dealt with by imposing forbidden azimuth zones on azimuth thrusters. Losses due to thruster-hull interactions and transverse and axial current should also be taken into account.

When a limiting wind speed envelope is calculated a simulation case is defined by the following:

- Tidal and wind induced current speed
- Relationship between wind speed and significant wave height and mean zero up-crossing period
- Current and wave direction offset from the wind direction
- Wind and wave spectrum type
- The amount of 'spare' thrust taken into account and the type of model selected for calculation
- Additional static forces and moments taken into account
- Thruster configuration (thruster locations, types and sizes)
- Thrusters and rudders selected for use

When a design sea state is determined by the client DP capability can be presented by means of a thrust utilisation envelope instead of a limiting wind speed envelope. The required thrust to maintain position and heading in the design sea state is calculated and compared to the vessel's maximum available thrust. The ratio between the two is plotted as a function of wind direction, see example in ***Figure 2***. A thrust utilisation less or equal to 100 % means that the vessel is able to hold position and heading in the specified design sea state. If the ratio exceeds 100 % the vessel will experience poor positioning performance or drift off.

When calculating a thrust utilisation envelope the necessary input data is as given above with the exception of the wind speed to wave height relationship which is replaced by the following:

- Wind speed
- Significant wave height
- Mean zero up-crossing period

Frequency domain analysis is a powerful and efficient method for assessing DP capability for a particular vessel design. Thruster configurations and environmental specifications may be easily changed and a DP capability analysis study is often an iterative process where different thruster configurations are investigated. A study typically requires in the order of man-days to complete. The alternative to the frequency domain approach would be to perform time-consuming time domain simulations to establish the limiting environmental conditions.

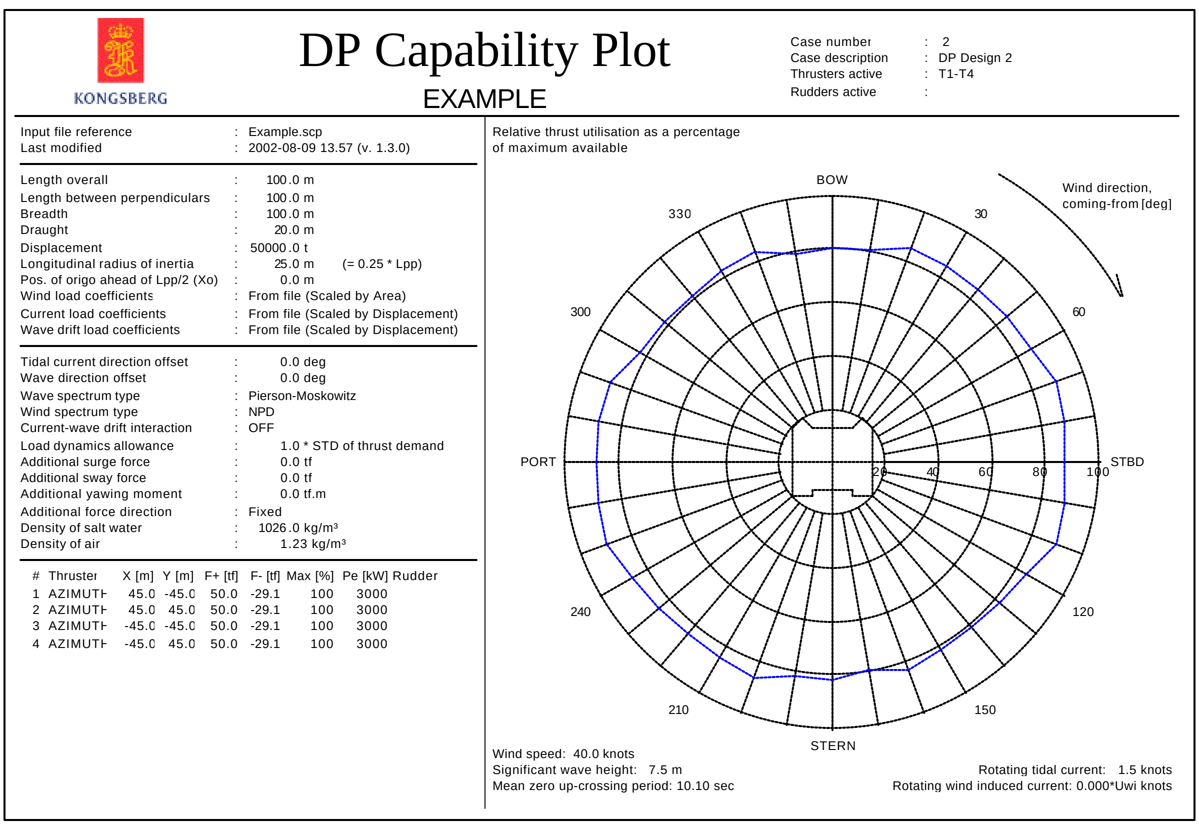


Figure 2 Thrust utilisation envelope example. The envelope is calculated using the Kongsberg Simrad computer program StatCap.

PERFORMANCE SIMULATIONS

Time domain simulations are used to assess station keeping accuracy and power consumption under given environmental and operating conditions. The Kongsberg SDP (the latest product family of Dynamic Positioning and Position Mooring systems from Kongsberg Simrad) systems offer an integrated time domain simulator as a plug-on with the DP control system in the loop. The simulator can therefore be used to investigate the performance of the vessel when it's being controlled by a DP control system. The simulations are conducted on a desktop computer and the system is operated with the SDP user interface controls.

The simulator has realistic sensor signal models and a vessel reference model (simulated vessel), see ***Figure 3*** and ***Figure 4***. It is possible to introduce random noise, coloured noise and recorded noise (position reference systems only) on sensor signals. The dynamic behaviour of wind and waves is modelled along with the dynamics of the thrusters and power generators. Thus the combined wave- and wind-induced low frequency motions (horizontal plane of motions) and wave induced wave frequency motions (six degrees-of-freedom) are obtained from the simulations.

Thruster dynamics (e.g. speed change limitations) may be simulated, along with 'dynamic power' consumption/generation (the additional electrical power used to accelerate the thruster, or generated during deceleration). Power consumption in steady-state operation is calculated using torque curves of open-water diagrams (thrust and torque coefficients as a function of advance ratio), see ***Figure 5***. Thruster-thruster interactions are taken into account by imposing forbidden azimuth zones on the azimuth thrusters. Thruster-hull interactions can be taken into account using thruster efficiency tables. Thrust losses due to increased axial inflow can be dealt with using thrust curves of open-water diagrams see ***Figure 5***. In transverse current the deflection of the propeller race introduces a cross-coupling drag which can be calculated according to a procedure outlined in ***Ref. 5***.

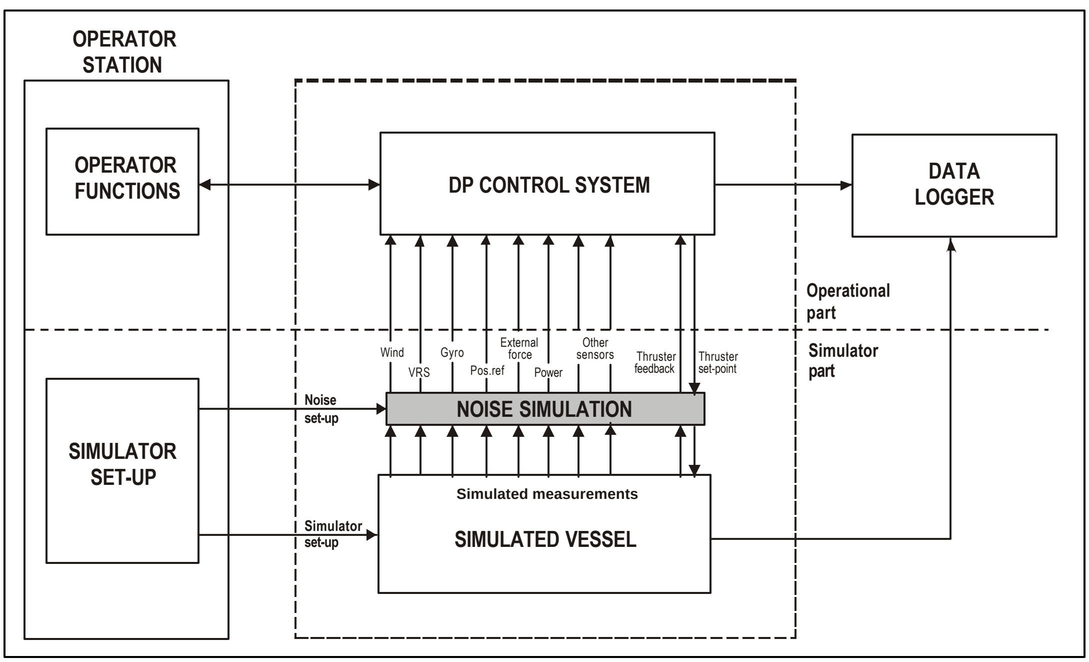


Figure 3 Building blocks in the SDP integrated time domain simulator.

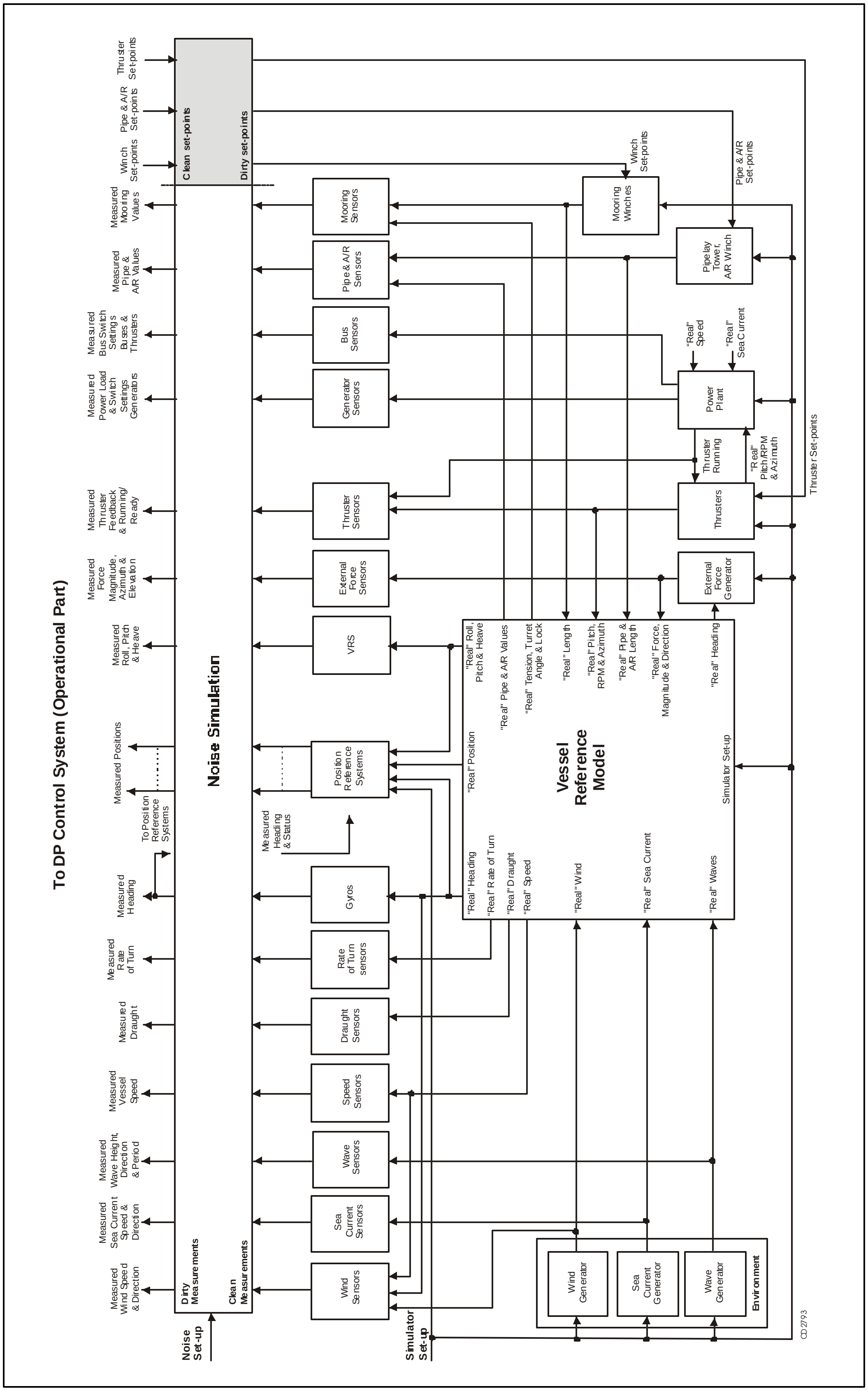


Figure 4 Detailed logical model of the SDP integrated time domain simulator.

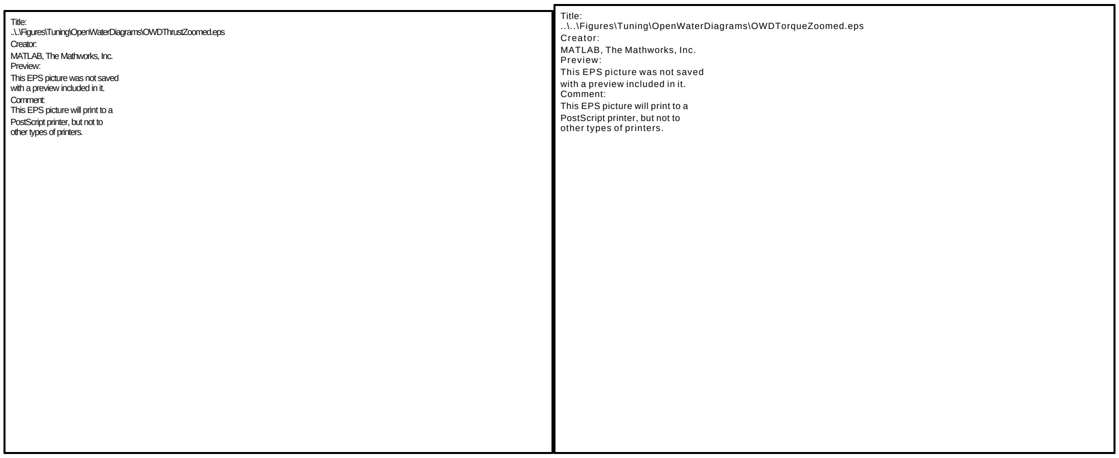


Figure 5 Open water diagrams for RPM controllable thruster (example).

Time domain simulations are very useful for e.g. tailoring new control and thrust allocation strategies and comparing different control strategies and thruster and power configurations. The effects of using different position reference systems, and degraded sensors (increased noise) may also be easily investigated. Time domain simulations require a more extensive data set for configuration, compared to frequency domain DP capability analyses. As for frequency domain DP capability analyses the reliability of the simulation results are closely related to the accuracy of the input data. And as there are important physical effects that may not be accurately modelled, such as thruster ventilation and out-of-water effects, one should exercise caution when interpreting the results. Additional forces and moments can be taken into account, e.g. forces from a mooring system.

A performance simulation case is defined by the following:

- Initial vessel position and heading
- Wind speed and direction
- Significant wave height, mean zero up-crossing period and wave direction
- Current speed and direction
- Wind and wave spectrum type
- Additional forces and moments taken into account (for moored systems this will include definition of the mooring system)
- Thruster configuration (thruster locations, types and sizes)
- Sensor noise
- DP control system set-up
- Thrusters and rudders selected for use
- Simulation duration in time

The results of time domain simulations are presented by means of time series and statistical quantities of selected signals, see ***Figure 6***, ***Figure 7*** and ***Figure 8***. Normally, performance simulations are performed for 3.5 to 4 hours whereof the last three-hour-record is subjected to statistical analysis. Excel or MATLAB is used for post-processing to obtain statistics or to produce graphs.

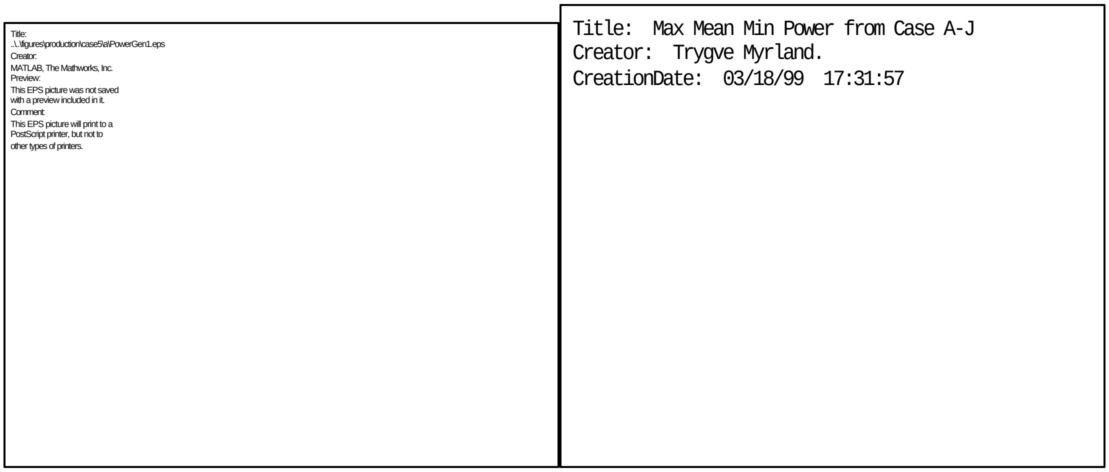


Figure 6 Example of power consumption simulations in the time domain, presented as a function of time and by statistical properties (maximum, minimum, average) as function of sea state (wave height).

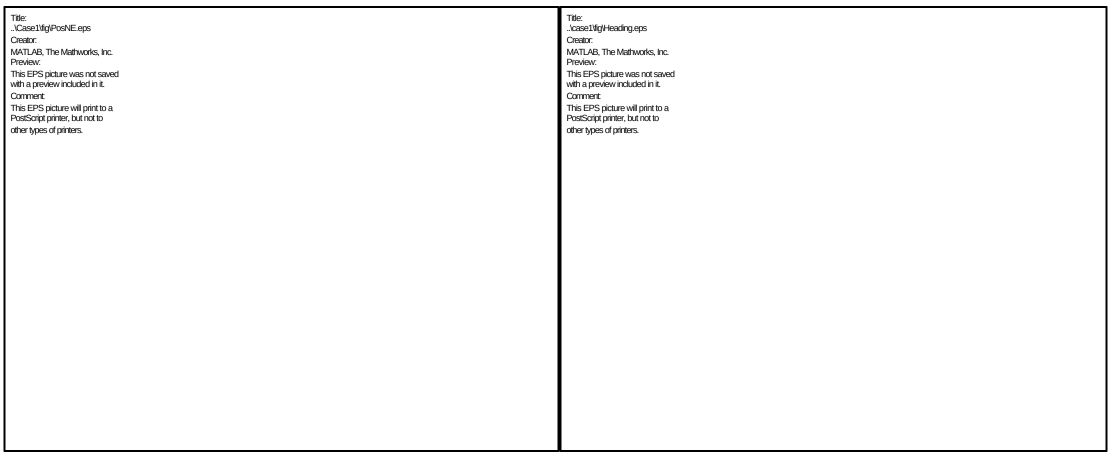
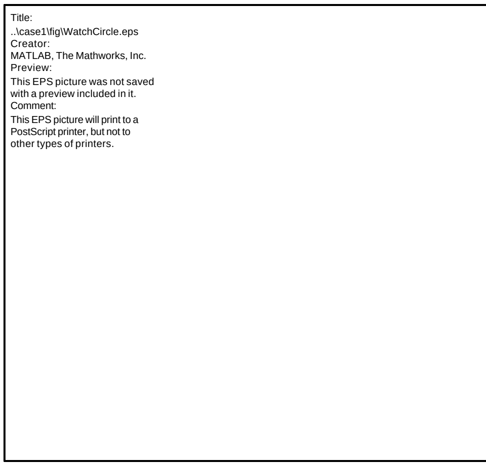


Figure 7 Example of positioning accuracy simulations in the time domain, position and heading deviations as a function of time.



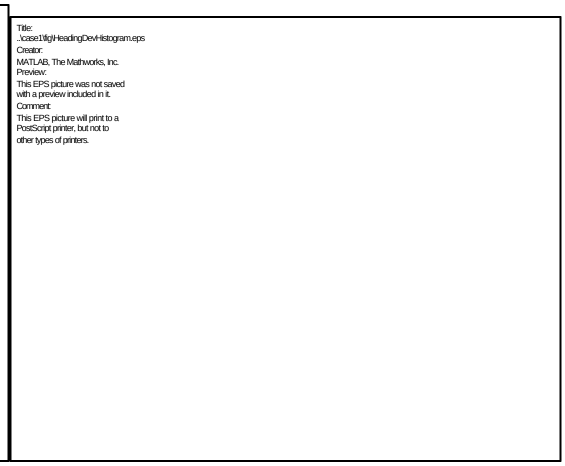


Figure 8 Example of positioning accuracy simulations in the time domain, position and heading deviations by statistical properties.
Left: The Watch circles (also referred to as footprint) show maximum position deviation from setpoint for given fractions of time. (Level=0.680 means that the vessel position deviation lies within the blue curve 68.0% of the total time.) Range of plot is 15 m.
Right: Heading deviation histogram showing number of samples with given deviation from setpoint.

Time domain simulations generally require a considerable work effort since there are often a number of environmental and operating conditions to be investigated. Nevertheless, time domain simulations are much cheaper than model tests (not to mention full-scale tests) and offer a unique possibility for investigating DP performance and DP operations efficiently in a controllable environment with the DP control system in the loop. A typical time domain simulation study requires man-weeks to complete though the necessary effort varies heavily with the complexity of the study.

Since the time domain simulator is an integrated part of the SDP system it also offers a unique possibility of a realistic operator's training environment with instructor. The instructor can operate the simulator on a separate Instructor Station allowing him or her to modify the environmental conditions, introduce sensor failure(s), take thrusters and generators in and out of service and more as the training session go along. The system is in use in Kongsberg Simrad Advanced Trainers in number of training centres.

DRIFT-OFF AND DRIVE-OFF SIMULATIONS

Drift-off and drive-off simulations in the time domain are used to assess the time available (often referred to as 'time-to-go') before any critical excursion limits are exceeded after a failure. Critical failures, e.g. power system or thruster failures, are introduced and the vessel's offset from the desired position and/or heading measured as a function of time. An example of a blackout simulation is shown in ***Figure 9***. Typical situations that are subject for investigations are thruster setpoint or feedback failures (sudden drop to 0% or increase to 100% or freeze on the present level), thruster(s) or generator(s) stopping, or position reference system failures (freeze, drift, or sudden jump). The failures may be single or multiple failures. In principle, there is no difference between the drift-off and the drive-off simulations, they are only distinguished by the failure causing the incident: Drift-off could be caused by a thruster stopping whereas drive-off may be caused by the same thruster going uncontrolled to 100 %.

Due to the dynamic behaviour of the wind and waves the vessel will experience continuous movement around the desired position and heading. It's therefore likely that a drift- or drive-off simulation give different results for two separate tests under identical environmental and failure conditions. To deal with this problem, Monte Carlo simulations may be performed. This approach would, however; require a large number of simulations with corresponding post-processing. Thus, a long processing time would be expected even if both simulations and post-processing were automated. To avoid having to perform a large number of simulations the following approach can be followed:

1. Perform a performance type simulation in the desired weather condition.
2. Do a statistical analysis on position and heading keeping and on the environmental loads acting upon the vessel, generating average and standard deviation of the environmental loads, and watch circle plot, see ***Figure 8***.
3. Start a new simulation with the vessel subjected to static environmental loads.
4. With the vessel stable at the wanted position and heading introduce the failure.

The static environmental loads applied are the means of the loads from the performance simulation. Additional simulations are performed with mean loads plus two standard deviations and mean loads minus two standard deviations applied. To obtain results for worst-case situations, the vessel can initially be put in the most unfavourable position and/or heading found from the performance simulation, see ***Table 1*** and ***Figure 8***, and repeating steps 3 and 4 in the procedure above. In this manner we perform a limited number of simulations for each case and can in a qualitative manner calculate variations in the results.

Normally, the longest, the average and the shortest time-to-go are determined.

		Start position, see ***Figure 8***		
		Watch circle 0.950 up weather	Average	Watch circle 0.950 down weather
Environmental forces	Average – two standard deviations	Longest		
	Average		Average	
	Average + two standard deviations			Shortest

Table 1 Time-to-go test matrix.

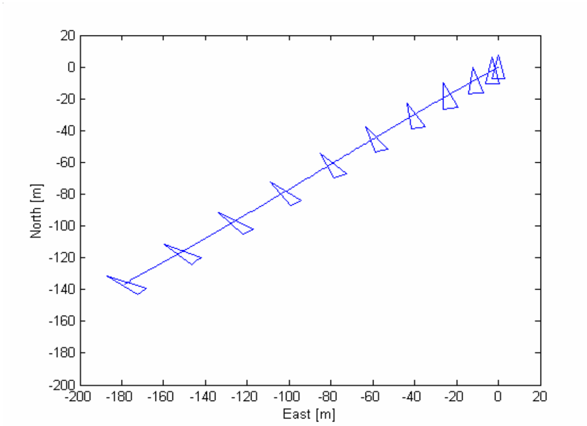


Figure 9 Example of drift-off simulation after blackout. Starting point is in (0, 0). The vessel symbol is plotted every 30 seconds.

A drift- and drive-off simulation is defined by the same set of data as a performance simulation. Additional data is required, however:

Type of failure(s) to introduce

Drift- and drive-off simulations are often performed as a part of an extensive time domain simulation study. For every failure to investigate (i.e. each case) you perform at least 4 simulations runs. This makes drift-off and drive-off simulations time-consuming and they typically require in the order of man-weeks to complete.

RELATIONSHIP BETWEEN THE SIMULATION TYPES

In a full-blown design study the different simulation types will interconnect. The natural starting point of a study will be to perform DP capability analyses in the frequency domain which outputs limiting environmental conditions and/or thrust utilisation in design sea states. A DP capability analysis can therefore give valuable input regarding the case definitions for time domain performance simulations. Performance simulations can in turn provide a basis for adjusting the amount of ‘spare’ thrust taken into account in the DP capability analysis, see ***Figure 10***.

Performance simulations can also influence the case definitions for the drift-off and drive-off simulations and provide statistical input for these. The results of the drift-off and drive-off simulations may subsequently cause revisions for the performance simulation cases.

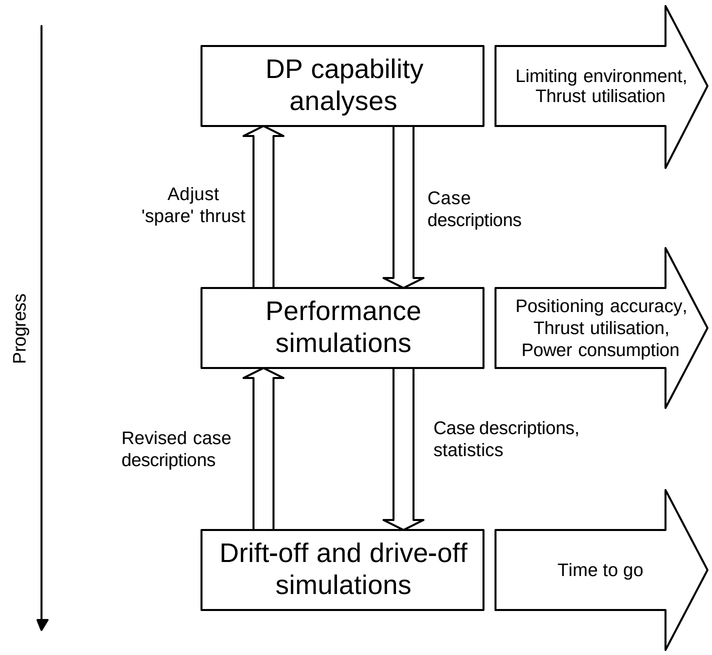


Figure 10 Typical major elements of detailed design studies.

	DP capability analyses	Performance and drift- and drive-off simulations
Main particulars	X	X
Added mass properties and longitudinal radius of gyration	X	X
Wind load coefficients as a function of wind angle of attack	X	X
Current load coefficients as a function of current angle of attack	X	X
Wave drift load coefficients as a function of frequency and wave angle of attack	X	X
Thruster configuration (locations, sizes and types)	X	X
Thruster limitations due to thruster losses	X	X
Rudder sizes and types	X	X
Rudder lift and drag coefficients as a function of rudder angle	X	X
Location of centre of gravity		X
Location of position reference systems and sensors		X
Thruster and rudder dynamic characteristics		X
Open-water diagrams and thruster hull interaction tables		X
Power system configuration (switchboard layout, generator sizes and dynamic characteristics)		X
Resistance coefficient for yawing motions		X
RAOs for wave frequency motions as a function of frequency and wave angle of attack		X
Mooring system data if relevant		X

Table 2 Required vessel input data for performing a detailed design study.

CONCLUDING REMARKS

Simulations are valuable for investigating and comparing different designs. This type of investigation and verification is generally cost- and time-efficient compared to model tests and full-scale tests. However, performing a simulation, regardless of whether it's in the frequency domain or the time domain, is a theoretical exercise and its results should be used with care. The value and reliability of the results of this exercise is a function of the adequacy of the mathematical models and the vessel specific input data on which the simulation is based. Therefore, simulations do generally not replace model tests or full-scale tests, but should be used as a complement to such.

It should be stressed that having relevant and accurate hydrodynamic input data, see ***Table 2***, is of vital importance for simulation studies. A thorough hydrodynamic analysis of a specific vessel design will be money well spent. This is true not only for improving the reliability of simulation results but also for the benefit of the entire project. Having accurate hydrodynamic vessel data is beneficial for the DP control system to be installed onboard the vessel and also contributes to a better test environment for the development of this system. Accurate input data may also reduce time spent for sea trials.

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