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THRUSTER SESSION

Propulsion and Power Supply Optimization Based on OPTI-DP Case Studies

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Abstract

In order to get the best understanding of the performance of complex DP-systems, a DP-capability calculation tool is developed. In this tool, the detailed hydrodynamic performance of the propulsion units on the one hand and the power-supply aspects on the other hand are analysed at the same moment. Typical thruster-hull interaction losses in the aft-ship with skegs or with legs are calculated with CFD and the 360° unit performance data is used for the DP-capability calculation. The power supply, including the switchboard layout and overload protection are implemented in the calculations as well. Development of the intelligent TAL is based on the 360-performance input, where the method uses an initial guess from a Langrage Multiplier Optimization method to reach the final solution including all forbidden zones and interaction losses. Dedicated tests cases have been used which provided (semi-)analytical solutions. The DP-capability tool has been used to analyse some typical aspects of both shuttle-tanker and wind-turbine-installation vessels (WTIV). For the shuttle-tanker, a comparison of conventional single-screw layout and new twin-screw, fully electric concept has been made. For the WTIV, a comparison has been made between concepts with tunnel-thrusters and combined Retractable-Transversal Thruster units (RTT). Since the combined Retractable-Transversal units will suffer from reduced hydrodynamic performance (expressed in T/P-ratio), the impact of this lower thrust versus the steering flexibility will be reviewed.

Abbreviation / Definition

CFD	Computational Fluid Dynamics
RTT	Retractable-Transverse Thruster
TAL	Thrust Allocation Logic
T/P-ratio	Thrust/Power-ratio (kN/kW)
SLD	Single Line Diagram
WTIV	Wind-turbine installation vessel

Introduction

The process of optimization of any design includes the reduction of engineering margins in the design phase which have been based on previous experience. With increased knowledge and understanding of the occurring phenomena, situations can be revealed where the applied margins are over-specified. On the other hand, it may also provide insights which contribute to the understanding of problematic situations which occurred in operation. In the early design phase, a delicate balance exists between considering all the details that play a part in the overall efficiency of the vessel and not overcomplicating the calculations. For next generation vessels, it is good to get a clear view on the true DP-performance of the vessel. To the opinion of the authors, this starts in the water with the actual performance of the propulsion equipment. The application of CFD-simulations has widened the scope from a single thruster unit (Bulten, 2006) to simulations of tilted-thrusters under a hull-shape (Jurgens, 2008 and Palm, 2010). In the wind-turbine installation business, the impact of the legs of jack-up vessels has received renewed attention. Interaction of these legs and a thruster wake results in a sector of reduced thruster performance. Moreover, the drag of the legs due to current can become a significant contributor of the environmental forces.

In this paper, results from detailed CFD simulations of a jack-up vessel will be presented, with the focus on the effects of the legs. It will be shown that clear performance loss is observed in some of the 360° sectors of an azimuth thruster unit. Similar effects are known to occur due to interaction between thrusters and aft-skegs. The thrust-deductions are transformed into 360° unit performance maps and these are input to the OPTI-DP™ Thrust-Allocation-Logic (TAL).

In order to demonstrate the intelligence of the Thrust-Allocation-Logic, a set of test-cases has been defined. The starting point is a vessel with two main-propulsion azimuth thrusters in the stern and tunnel-thrusters in the bow. In case of a main-thruster failure, the solution for the TAL of the remaining thrusters can be calculated directly. This is the analytical solution of the system, which can be used for comparison with the results from the developed TAL. In the next step, the configuration is changed to simulate an azimuth unit in the bow as well. Even though this will not provide a direct analytical solution of the system, it is still possible to determine the optimal utilization rate with limited effort for comparison purposes.

Once the intelligence of the newly developed TAL has been confirmed, the method can be applied to different vessel types. In this paper, results of case studies will be shown for shuttle-tankers and wind-turbine-installation vessels (WTIV). For the shuttle-tanker case, different propulsion lay-outs will be considered; single and twin-screw main-propulsion complemented with a number of tunnels and retractable thrusters. The power-supply system of the electric driven equipment will be analysed as well. It will be shown that the performance in the critical failure modes can be improved significantly with a proper combination of propulsion units (in the water) and the power-supply/switch-board concepts inside. For the WTIV, the impact of legs and skegs is considered in the optimization studies. The presented case study focusses on the comparison of a Retractable-Transversal Thruster (RTT) with a dedicated Tunnel-thruster configuration. When the RTT-unit is deployed the flexibility of azimuth steering angle can be utilized. Whether this flexibility brings benefits in operation, whilst accepting lower hydrodynamic efficiency, will be reviewed.

Thruster interaction loss determination

Continuous developments on computing power and CFD software have paved the way to widen the scope of thruster CFD simulations. The time required to build a single thruster multiblock mesh in 2006 is by now well exceeding the time required to generate the mesh of a complex hull-geometry with legs and all details including an 8-degree tilted thruster-unit. As a consequence, more research questions can be addressed within commercial acceptable time-scales. The purpose of these activities is to identify the accuracy of the applied engineering margins in the overall DP-capability evaluation.

For the jack-up vessel that is evaluated in this study, CFD simulations have been conducted to determine the thruster interaction losses of a steerable thrust unit. In worst-case scenario, the jet of this thruster is impinging on a partially extended leg, presumably causing severe thrust losses. By simulating this case using CFD, an accurate value for the thruster-hull/leg interaction losses can be obtained. In the Thrust-Allocation-Logic (TAL) of the DP-capability calculation, it can be decided whether the interaction losses are to be avoided with a prescribed forbidden zone when exceeding a certain threshold or that the TAL has to take the reduced unit performance into account.

The CFD simulations of the thruster-leg interaction were conducted in Simcenter Star-CCM+ 15.04.010 where use was made of the three-dimensional, time-dependent Reynolds-Averaged Navier Stokes equations. The RANS equations were supplemented by a Realizable k-ϵ Two-Layer closure model and a Two-Layer All y^+ Wall Treatment. Although an all y^+ wall treatment model is used, it is aimed to have a high y^+ prism layer mesh to reduce the computational cost. This prism layer mesh is inflated from an unstructured, hexahedral, trimmed cell mesh that was created using a part-based meshing approach. Mesh refinements are located at strategic positions and locations of interest, such as around the thruster unit, hull, and wake of the leg trusses. The final mesh (Figure 1) used for the simulations consisted of 16.8M cells. All the simulations are conducted using second order solvers, both spatial and temporal, and a timestep size that corresponds to a two degree propeller rotation per timestep.

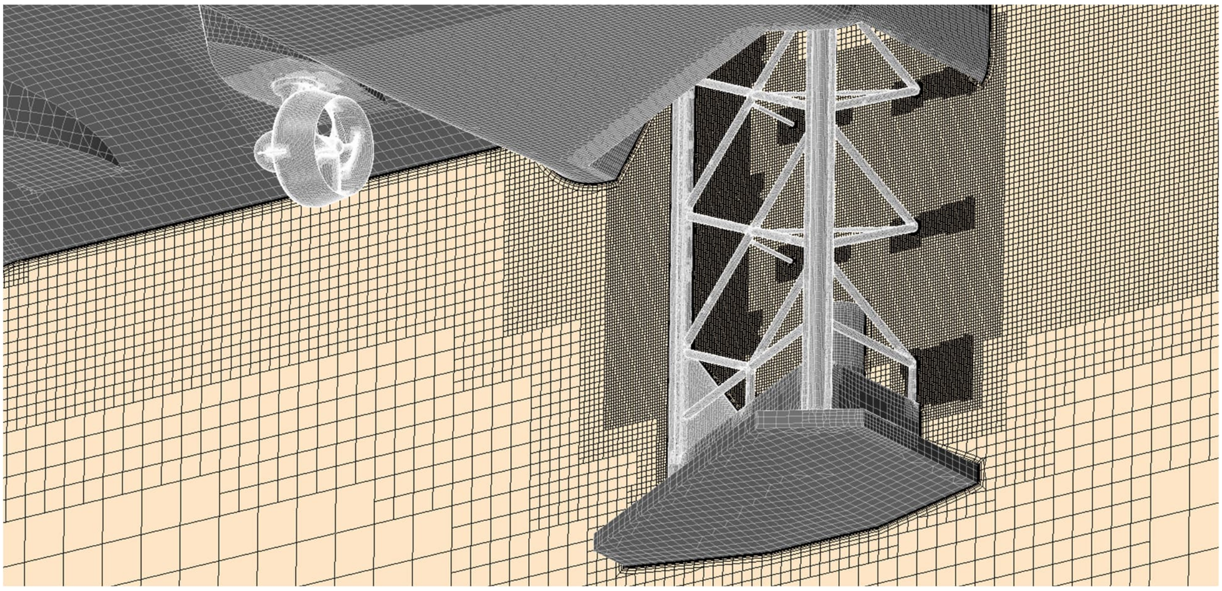


Figure 1: The hexahedral volume mesh used for the thruster-leg interaction simulations.

From the simulations, it was determined that there was indeed a significant interaction between the thruster and hull with the extended leg. The jet not only collides with the hull but is also obstructed by various trusses of the leg, as shown in Figure 2. The total thrust deduction factor for this worst-case scenario was determined to be 58%. In comparison, prior to running the simulations with an extended leg, a simulation was run with a retracted leg where the jet was only impinging on the hull and spud can. The thrust deduction factor for this case was 36%, meaning that a deployed leg results in an additional 22% loss of thrust. In order to ensure that the TAL will not select the azimuth sector with most extreme interaction losses, a forbidden zone can be introduced, so that these steering angles with severe thruster-leg interaction will be avoided.

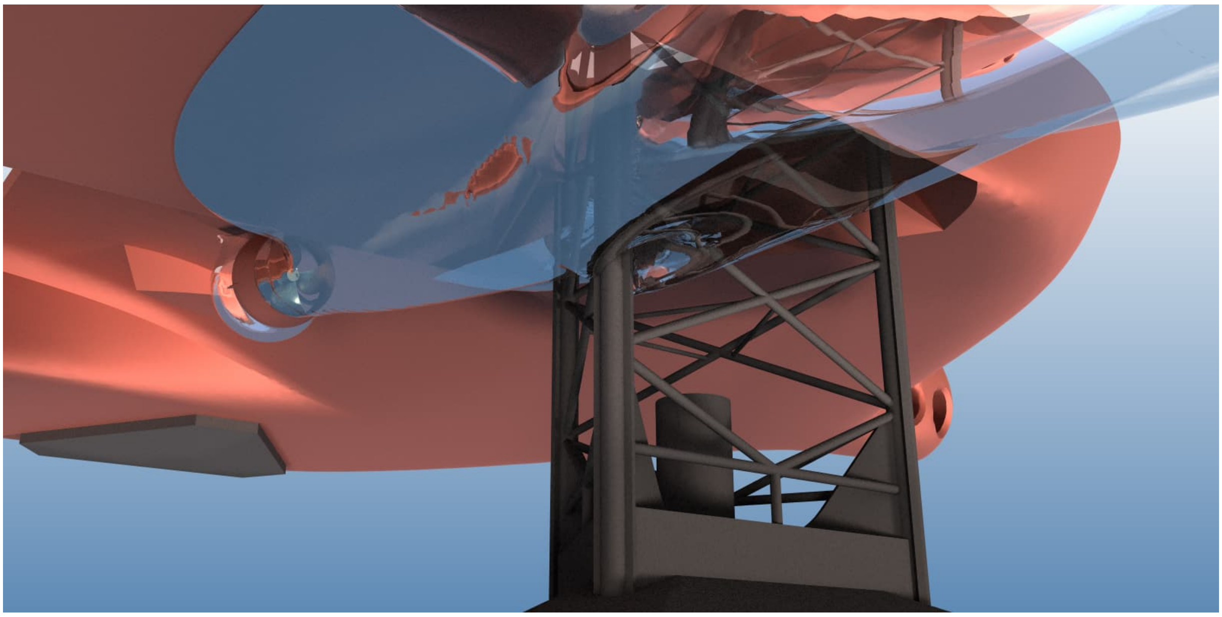


Figure 2: The thrust jet colliding with the hull and partially extended leg.

Although performing these complex simulations has becoming a lot more feasible, they are still rather computationally expensive. In the early design phase, an alternative approach can be used based on thruster-hull interaction values based on experience from similar vessels or computed using the more traditional guidelines provided in (DNV AS, 2021). During the various design-cycles of the complex vessels, the accuracy of the thruster-hull interaction losses for the full 360° can be further improved.

TAL verification

Developing a new Thrust-Allocation-Logic is a rather challenging assignment. The first step of determining the quality of the TAL is a simple evaluation of the forces and moment balance. For the static DP-performance evaluation, the forces and moments from the environment (wind, waves and current) need to be balanced by the propulsion equipment. In general, this means the determination of thruster load and azimuth angle. The second step in the development is the question how intelligent the TAL is.

Figure 3 shows an example of a 360°-varying thruster unit performance, with a zone of increased thrust-deduction as a result of interaction with the aft-skeg. The unit performance can be implemented either on this full 360° data set, or the operational sector can be limited to exclude the sector with largest thrust-deduction and thus lowest thruster performance. With the implementation of 360°-circumferential thruster performance data and unlimited number of forbidden zones, it is not straightforward to prove whether the TAL can find the optimum solution. Note that it is acknowledged that the optimum solution is actually a single mathematical point, and therefore we relax the requirement of the TAL to provide good solutions. In real DP-operation, the focus should be on robust and safe operations, not on the last digits in optimization schemes.

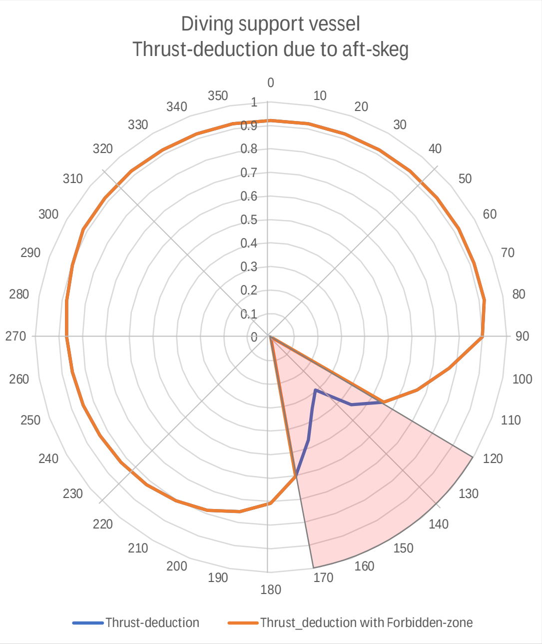


Figure 3: Example of actual thrust-deduction for 360deg circumference.

During the TAL development, a simple test case has been used of a vessel with two main azimuth thrusters in the stern and three tunnel-thrusters in the bow (see Figure 4). In case the failure of one of the stern azimuth units is considered, it turns out that the solution of the DP-equations can be calculated in a simple spreadsheet. In cases of severe thruster-hull interaction losses it will not be possible to achieve full 360° DP capability. In order to achieve this full 360° DP performance, including the significant skeg-thruster losses, one of the bow units has been upgraded to a retractable azimuth unit. Even though this configuration has not a simple analytical solution, it is possible to determine a proper valid solution with limited effort. This is the second test case, which will be discussed in more detail.

Test case 1: TAL analytical solution with Tunnel-thruster in bow

The first test case is based on a diving support vessel with two main thrusters and three tunnel thrusters as shown in Figure 4. Since there are only tunnel-thrusters in the bow, all environmental forces in forward x-direction need to be compensated by the steerable thrusters. Depending on the vessel yaw-moment, the forces in y-direction need to be provided either by the forward tunnel-thrusters or the aft steerable units. The steerable thrusters will experience significant thrust-deduction losses when the wake of the thruster is directed towards the skeg of the vessel. These interaction losses are a typical example of the 360° circumferential performance variation which are taken into account in all calculations.

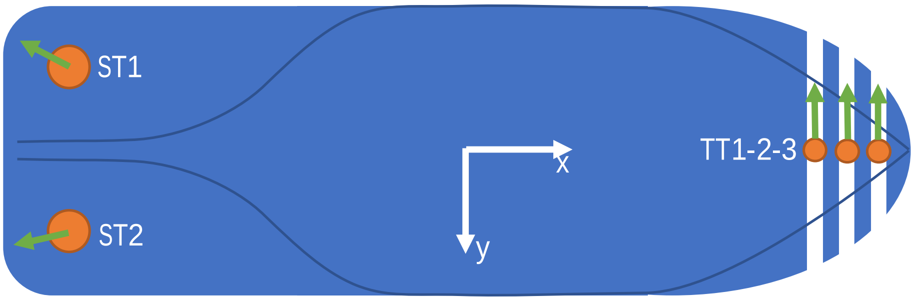


Figure 4: Sketch of propulsion layout (all intact).

The critical operating condition occurs when one of the aft thrusters fails, which leaves a single steerable thruster. For simplicity, the performance of the three bow units can be grouped into a single unit, as indicated in Figure 5. The mathematical problem of the Thrust-Allocation has now been reduced to a simple set of equations, since there is only a single contribution of F_x from the aft steerable unit and there are two F_y contributions from the stern unit and the combined forward units. Once these three variables are solved for forces and moment equilibrium, the actual steering angle and thrust-force can be calculated from F_x-aft and F_y -aft. For each thruster steering angle, the corresponding thrust-deduction factor can be found and this can be translated into the required nett thruster performance level, as shown in Figure 6. In all cases where the nominal thrust of the steerable unit is sufficient to provide the required thrust, the DP-capability is achieved. However, when the required nominal thrust exceeds the available thrust, either due to the environmental loads or the significant thrust-deduction levels, the static DP-performance is not sufficient.

Figure 6 gives a clear example of the impact of the significant thrust-deduction losses due to the interaction with the aft-skeg with a reduction of nominal thrust down to 30%. The sector where the ST2-performance is not capable of delivering the required force, and where no static DP-solution is found, is the sector 120° - 155°. The DP-thrust utilization plot on the right gives therefore no solution in that sector.
The results as shown in Figure 6 also indicate that a full 360° DP-capability would be achieved as long as the thrust-deduction could be kept below 0.47 (giving minimum thruster performance of 1 - 0.47 = 53%). This shows that the DP-capability is sensitive to the thruster hull interaction. Using this knowledge, solutions to improve performance can be found by reducing thruster-hull interaction losses or changing the thruster configuration.

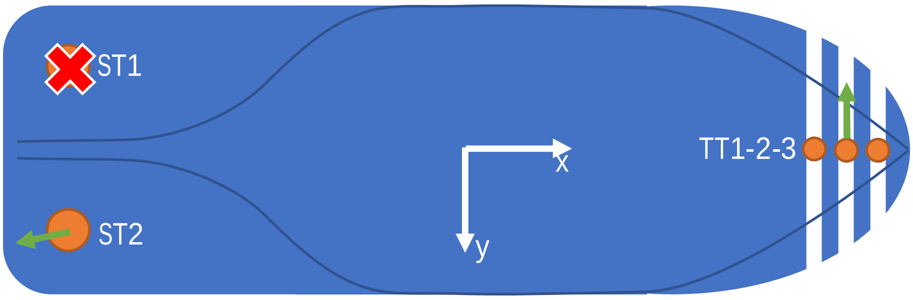


Figure 5: Sketch of simplified propulsion layout for ST1 failure mode.

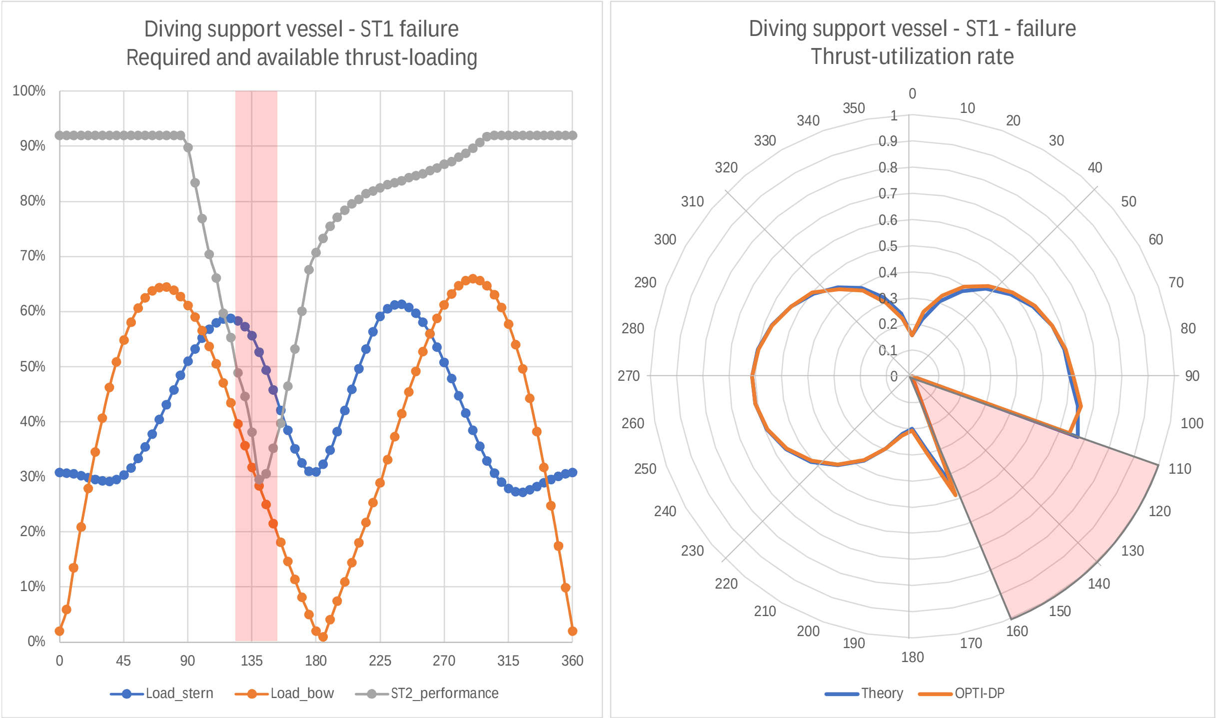


Figure 6: Analytical solution for DP performance evaluation with thrust-deduction due to skeg (ST1 failure mode). Required and available steerable thruster performance (left) and thrust-utilization plot.

Test case 2: TAL theoretical solution with Azimuth thruster in the bow

The underlying logic why the 360° DP-capability is not achieved for the initial tests case as described in the previous subsection is clear. Due to the single source of F_x-force, it is not possible to get the required equilibrium of F_x and F_y forces and M_z-yaw-moment at the same time. In case the layout would be modified to have a retractable azimuth thruster in the bow, then a second source of F_x-thrust is introduced, which will solve the problem (see Figure 7). Even though there is no unique analytical solution with this modification of the initial thruster layout, it is still possible to obtain a theoretical solution for the DP-capability. This solution will include the typical thrust-deduction curve as shown in Figure 3 for the stern steerable thruster. The challenge is to find DP-solutions, which give the lowest utilization rate, which in general means that the worst performing part of the thrust deduction will be avoided.

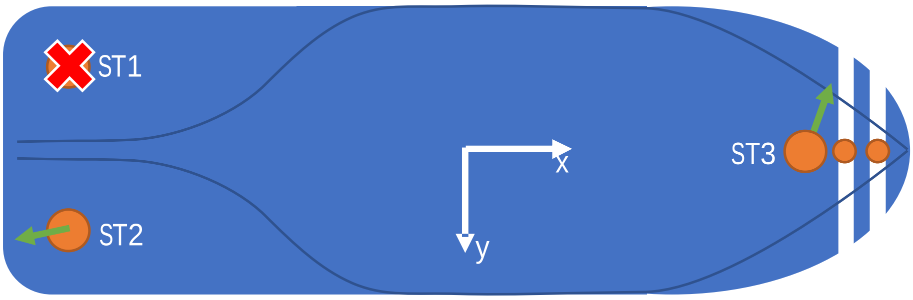


Figure 7: Sketch of the modified propulsion layout with steerable thruster in the bow and ST1 failure mode.

The comparison of the theoretical solution with the results from OPTI-DP are shown in Figure 8, where the thrust-utilization rate and the thruster steering angles of units ST2 and ST3 are shown. It can be seen that the thrust utilization rate agrees well with the theoretical solution. Also, the thruster steering angles of both active steerable thrusters (ST2 and ST3) agree well for both methods. This shows that the TAL can cope correctly with sectors of significant thrust deduction losses. The stern azimuth thruster remains over a large sector of wind-directions around the 90° azimuth angle, before steering to the 180° azimuth angle. The complete red sector as shown in Figure 3 is avoided in the operation.

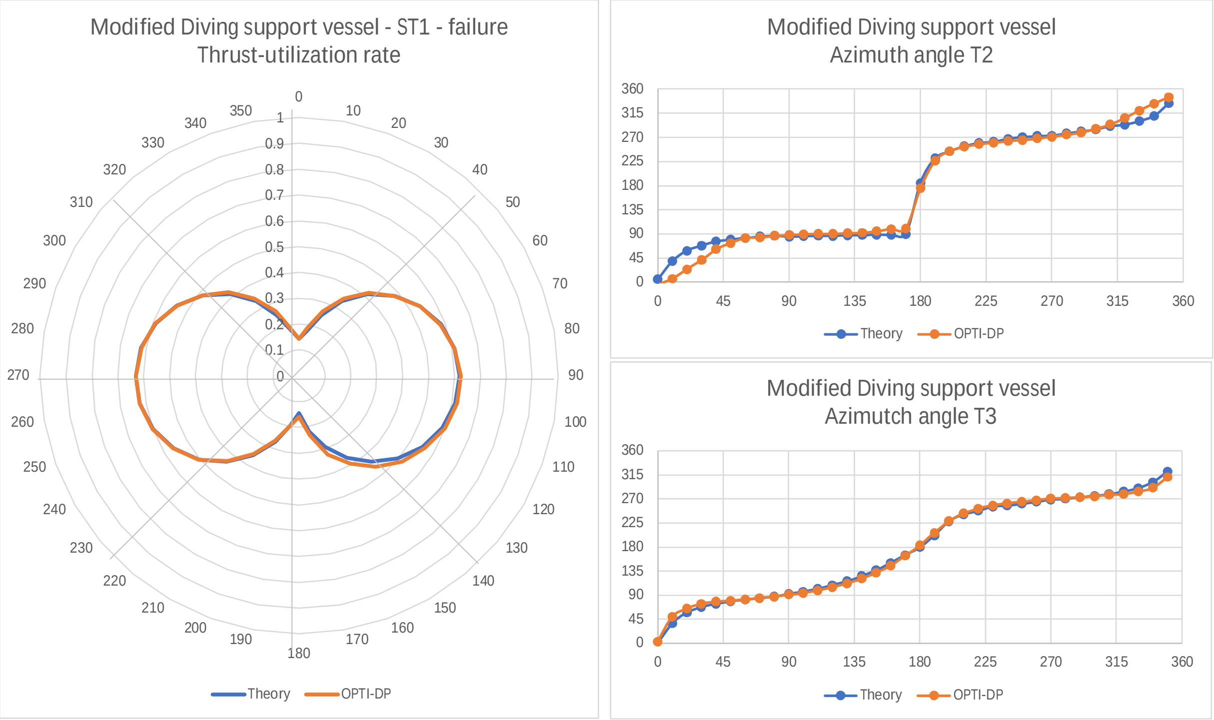


Figure 8: Semi-analytical results of modified vessel with steerable unit in bow. Comparison of thrust-utilization plot (left) and thruster steering angles.

Shuttle-tanker case study

Shuttle-tankers are ideal candidates for the DP-capability analysis, since the vessels need both to reach a proper transit speed and to have a good station-keeping capability for safe loading of the cargo off-shore. Thruster-hull interaction effects of the retractable-azimuth thrusters will be dependent on several aspects. Most important is the angle of applied tilt to the propeller shaft-line. In case sufficient tilt-angle is used, the hull-interaction losses will be limited to a few percent in all azimuth directions. However, when a

conventional thruster unit without tilt is applied, the position at the vessel and the applied steering angle will determine the actual thruster-hull interaction losses, which can go up to 20 percent.
The main propulsion system architecture can be based on a single screw controllable pitch propeller driven by a 2-stroke engine or by a twin-screw layout, where E-motors can drive two fixed-pitch propellers. Both examples are shown in the sketches of Figure 9.

DP-capability Propulsion configurations

The lay-out of the thruster units for DP-operation is based on specifications from Petrobras, where 3 units in the bow, with each 3.1 MW and 2 units aft with each 2.2 MW are required. These 5 units are split into 2 tunnel-thrusters and 3 retractable-azimuth thrusters (as shown in Table 1). Note that the maximum main-propulsion power is given in the table for the propellers. In DP-mode the required level of main-propulsion power will be well below 50%.
In order to ensure safe operation during loading, several failure modes are to be evaluated, related to single failures of switchboards and thrusters units but also double failures of thrusters or switchboards and additional individual thrusters.
In most cases the safe operational sector of the shuttle-tanker is limited to maximum ±35° around the bow. Shuttle-tankers use weathervaning, where the heading angle of the vessel is directed towards the direction where the environmental forces come from. Full 360° DP-capability is thus not the design target for these vessels.
Various concepts have been studied and three cases will be presented in this paper. The first case is the so-called underpowered bow-unit case, where there is only 2.2 MW on each unit in the bow. The second case is representing the requirements as described above. Both cases 1 and 2 are based on a single-screw main-propulsion lay-out with 2-stroke Diesel-engine. The third concept is based on twin-screw main-propulsion and electric motors. Figure 9 shows the single-screw and twin-screw concepts.

Thruster	Type	Single-screw Concept 1	Single-screw Concept 2	Twin-screw Concept
1	TT	2.2 MW	3.1 MW	3.1 MW
2	ST	2.2 MW	3.1 MW	3.1 MW
3	ST	2.2 MW	3.1 MW	3.1 MW
4	ST	2.2 MW	2.2 MW	2.2 MW
5	TT	2.2MW	2.2MW	-
6	CP/FP	14.3MW*	16.3MW*	7.4MW*
7	FP			7.4MW*

Table 1: thruster power levels for different Shuttle-tanker concepts (=max propulsion power)*

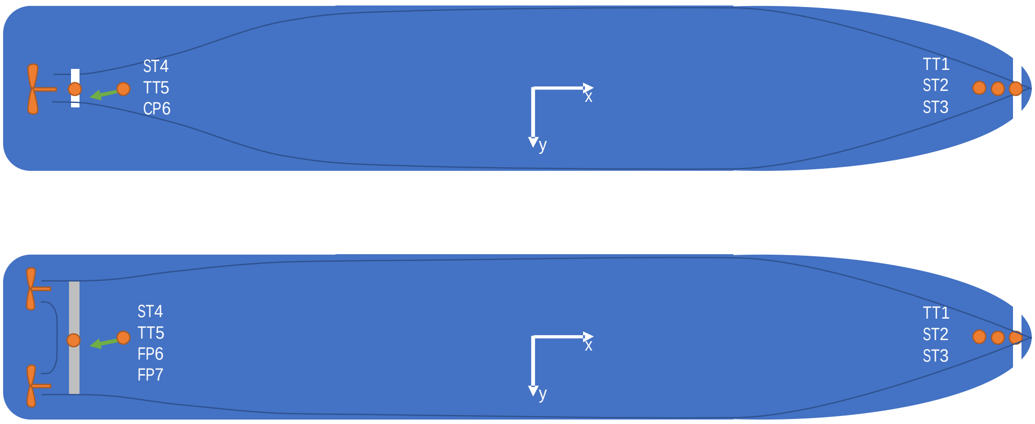


Figure 9: The two shuttle-tanker propulsion configurations, single screw (top) and twin-screw (bottom).

Power-supply configurations

The single-screw variants are based on a straightforward 4-split Single-Line-Diagram (SLD). In these vessels, the main propulsion is directly coupled to the 2-stroke engine and the 5 thruster units are split over the four groups. The vessel with twin-screw propulsion is based on Diesel-electric propulsion with E-motors driving both the thrusters and the main-propellers. Moreover, the Wärtsilä Low-Loss Concept (LLC) is applied in the SLD, as shown in Figure 10. More details of the LLC can be found in the paper of Cheater, Lammers and Van Keep (2010).

With the LLC-concept, each thruster is fed from two different gen-sets. In case of a single gen-set failure, still 50% of the maximum power can be supplied to the connected thrusters. In conventional switchboard layouts, often the power supply drops to 0% for several thrusters, which can have a larger impact on the overall DP-capability in case of failures. A comparison of the power-supply for a conventional system (single screw with 2-stroke) and with LLC and E-motor-driven twin-screw main propulsion is shown in Table 2.

The SLD of the all-electric layout also shows that both the main propellers and the thrusters are connected to the same gen-sets, which means that these units are utilized in much better way, compared to the combination of 2-stroke main propulsion engine and additional gen-sets for the thrusters.

Thruster	Type	GenSetA	GenSetB	GenSetC	GetSetD	2-stroke
1	TT		100%			
2	ST	100%				
3	ST				100%	
4	ST			100%		
5	TT			100%		
6	CP					100%

Thruster	Type	GenSetA	GenSetB	GenSetC	GenSetD
1	TT			50%	50%
2	ST	50%	50%		
3	ST	50%	50%		
4	ST			50%	50%
5	TT			50%	50%
6	FP	50%	50%		
7	FP			50%	50%

Table 2: Power-supply comparison of conventional single-screw system (left) and LLC-Electric twin-screw system.

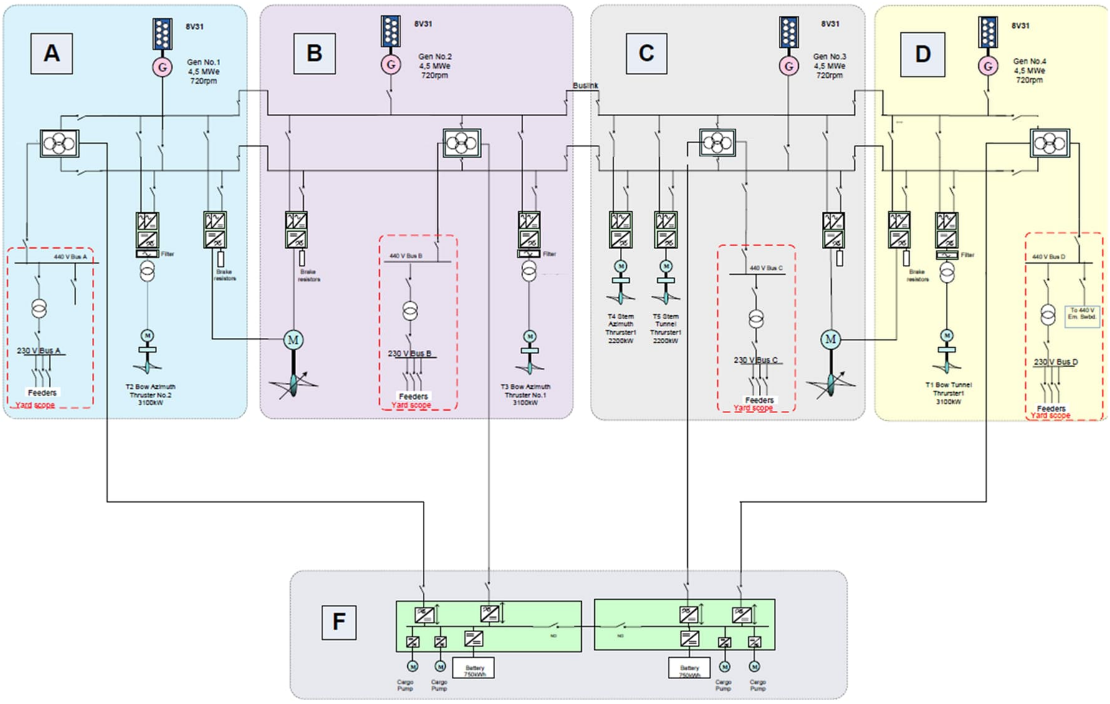


Figure 10: Single-line diagram for Low-Loss Concept.

Shuttle-tanker DP-capability evaluation

The results of the DP-capability evaluation are presented in Figure 11, where the angular sectors are shown for the different concepts and failure modes. The impact of the power increase of the bow-units from 2.2MW to 3.1MW clearly improves the DP-capability. Most critical cases occur when 2 units in the bow fail, which occurs both in the double-bow failure mode and in case of switchboard failure + 1 additional thruster.

The twin-screw concept without aft tunnel-thruster and LLC-switchboard exceeds even the DP-performance of the Single-screw variant with 3.1MW in the bow for most failure modes. Only the single-stern failure gives a slightly lower DP-sector (±70° compared to ±80°), though both are well above the critical limit.

It is remarkable that even without the aft tunnel-thruster the contributions of the two main propellers can exceed the performance of the current reference configuration.

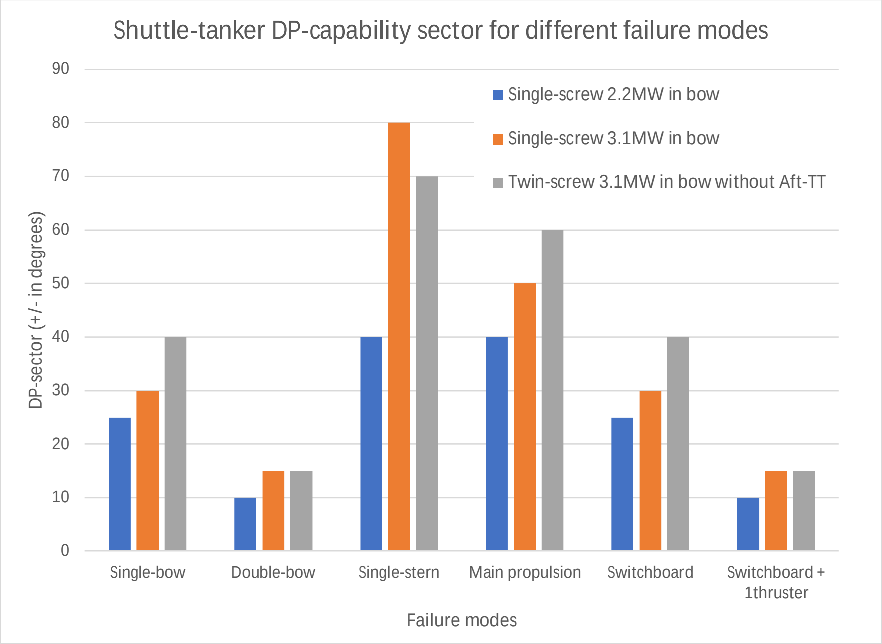


Figure 11: Shuttle-tanker DP-capability evaluation for different propulsion and switchboard configurations.

Wind-turbine installation vessel (WTIV) case study

Wind-turbine installation vessels are versatile vessels which need to install the wind-turbine equipment at sea. In order to execute this task, the vessel needs to collect the cargo in the harbor, sail to the wind-park location and stay in position, either to lower the legs in case of jack-up vessel or during the installation in case of a floating vessel. The typical thruster-hull interaction losses as discussed before play an important role in the DP-capability evaluation of these kind of vessels. A typical layout of a jack-up vessel with 4 legs and with 4 stern main-thrusters and a combination of retractable and tunnel thrusters in the bow is shown in Figure 12.

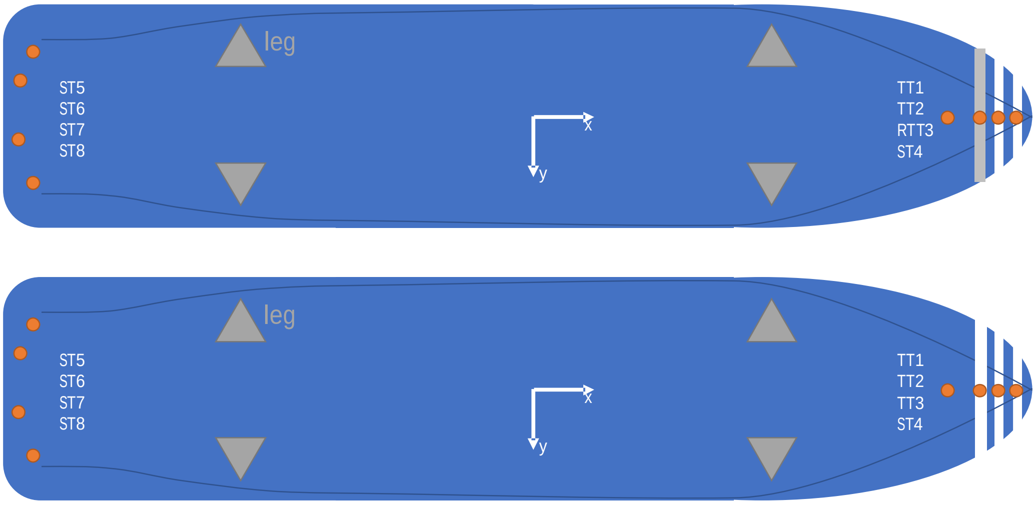
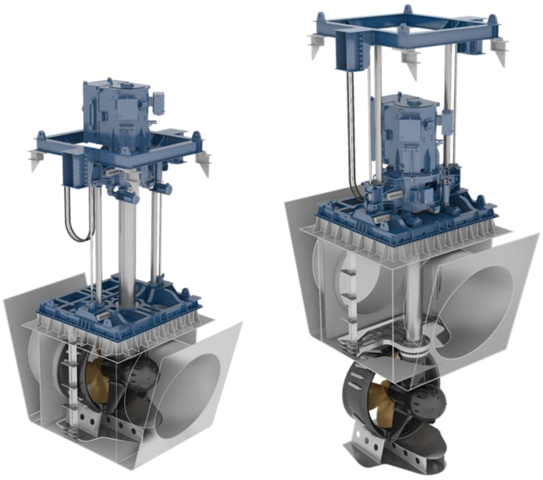


Figure 12: WTIV with combined Tunnel-Retractable unit (top) and dedicated Tunnel-thruster units.

In order to secure sufficient DP-capability in the bow, retractable units seem a good solution. However, when entering the harbor, shallow water operation is to be expected, which limits the use of retractable units. To have a large degree of flexibility, the concept of combined Retractable - Transverse Thrusters (RTT) has been developed (see Figure 13).



(a) (b)

Figure 13: An example of a retractable transverse thruster (WST-32RT), a) in retracted position, b) in deployed condition.

This seems at first glance a decent solution for both DP-operation at sea and maneuvering in shallow waters. The benefit of increased flexibility does not come for free, since the combined concept of Retractable and Tunnel-thruster has a lower hydrodynamic efficiency compared to the dedicated tunnel and retractable tilted-units. A retractable thruster is designed to run in one direction, so that the design of the nozzle and the propeller are optimized for optimal performance for that direction. A tunnel thruster needs to be able to run in both directions; this limits the possibilities in the propeller design as well as the allowed power levels on the thruster gearbox.

In the overall evaluation of the concepts, it could even be favorable for DP-operation to select three tunnel-thrusters and one retractable tilted-thruster. In case the dominant force direction of the units in the bow-section is in the transversal direction, the units will be steered close to the 90° or 270° direction. In such situation, the three tunnel thrusters can work in their optimal way, and the small forward thrust-component can be provided by the tilted-retractable thruster. When sailing in the harbor, the three tunnel-thrusters can be used for maneuvering. The sketches of Figure 12 show the two concepts with either the combined Retractable-Transverse Thruster unit (RTT3) or with the Tunnel-Thruster (TT3).

The SLD layout of the power supply is shown in Table 3, where a conventional set-up of 4-split is used with two units on each switchboard.

Thruster	Type	GenSetA	GenSetB	GenSetC	GenSetD
1	TT			100%	
2	TT		100%		
3	RTT/TT	100%			
4	ST				100%
5	ST				100%
6	ST			100%	
7	ST		100%		
8	ST	100%			

Table 3: Switchboard layout for WTIV.

Actual dominant environmental force direction

The environmental force has been determined for a typical WTIV based on wind, waves and current loads. In Figure 14, the curve of the dominant resultant force direction goes towards the 90° (beam) direction for increasing wind directions. When the wind direction has passed the 90°-direction, the environmental force remains longer aligned with the beam-direction. Once the wind direction has passed 180°, the same phenomenon is repeated around 270°. This is a clear indication that the tunnel thrusters can contribute to DP operation, since the 90° and 270° wind directions are known as most critical.

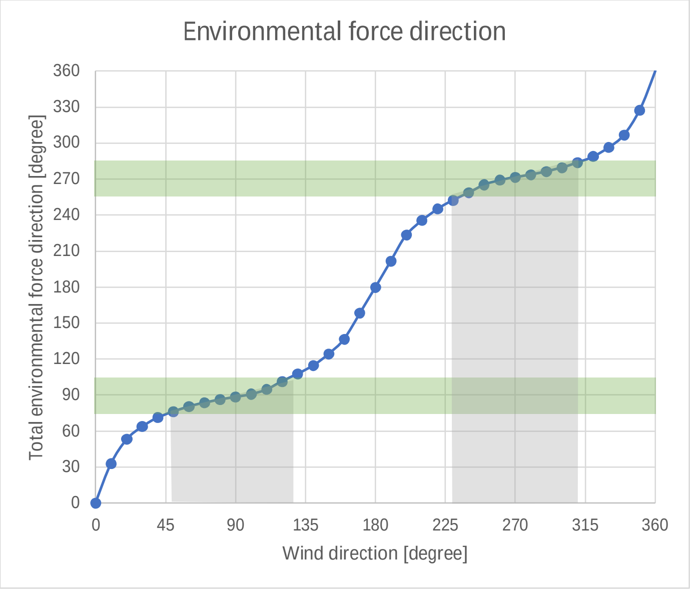


Figure 14: The overall environmental force direction.

Dedicated Tunnel units or combined Retractable-Transverse units

The impact of the performance of either a set of dedicated units (tunnels and retractable) or of a combined Retractable-Transverse Thruster is analysed for the WTIV with Switchboard D failure. In this failure mode, the retractable azimuth unit in the bow and one main thruster aft will be inactive, according Table 3.

Results of the thrust-utilization and the actual thruster steering angles are shown in Figure 15. The thrust-utilization plot shows a comparable performance for the two units. In the most critical beam-wind sectors, the azimuth angle of the Retractable-Tunnel Thruster is aligned with the conventional tunnel-thruster. As a consequence, the additional benefits from azimuth flexibility are not as large as someone might have expected. However, when taking the findings from Figure 14 into account, the results as shown below are understandable and logic.

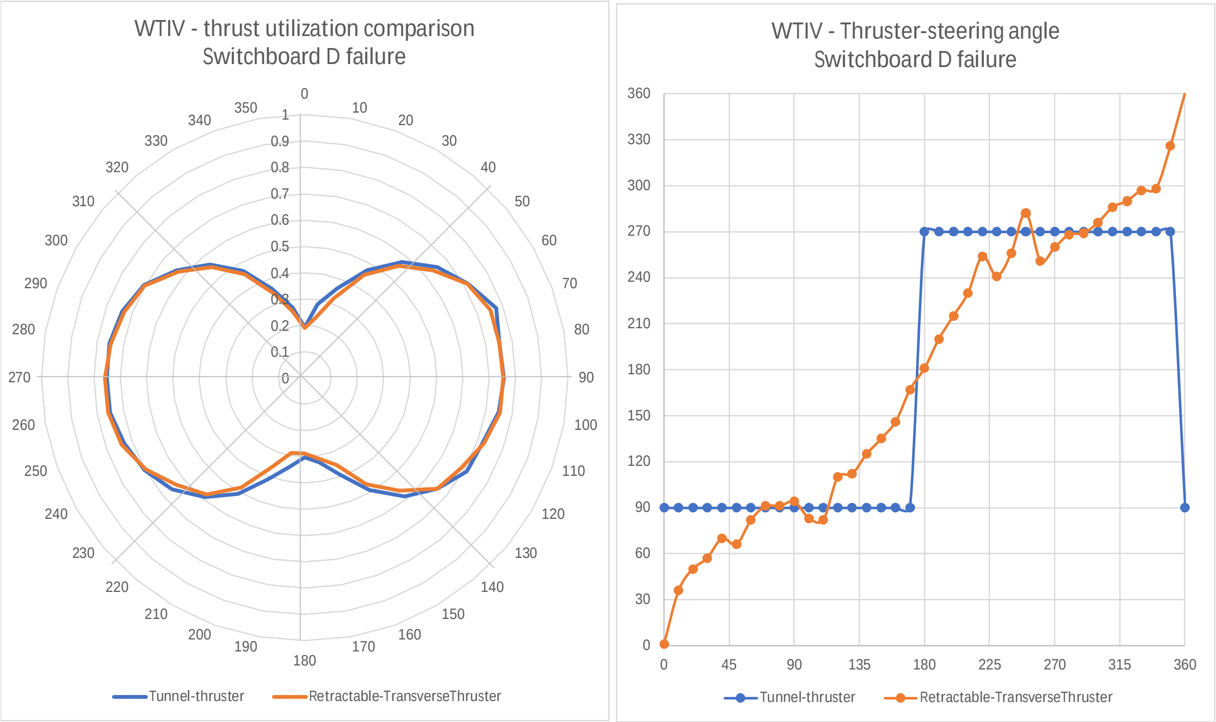


Figure 15: Comparison of thrust-utilization and steering angles for Tunnel-thruster and Combined Retractable-Transverse Thruster.

Conclusion

The propulsion and power-supply configurations for DP-operation of various vessels has been analysed. These analyses have been based on CFD simulations to determine thruster-interaction effects with the hull and/or legs. Knowledge from the detailed CFD simulations provide insight in the occurring thruster-interaction losses, which can become significant. Therefore, the assumption that a constant performance number for an azimuth unit can be used should be reconsidered nowadays.

In order to avoid the unexpected drop in performance in real operation of the DP-vessels, and thus increasing the operations risks considerably, a new DP-capability method has been developed, which takes the actual 360° unit performance into account in the Thrust-Allocation-Logic. With this approach the actual limits in operation can be found more accurately, which should lower the risks in the early design phase of the vessel.

Next to the 360° performance capability, also the aspects of power-supply have been implemented in the tool. This ensures that the required power for each unit will be available from the gen-sets. This may look rather straight forward for the all-intact case, though it can become rather complex in case of failure-mode analyses.

When applying the method to shuttle-tankers, it has been found that the current requirements from Petrobras work well for single-screw vessels. The power-levels of the units in the bow and the stern are balanced, resulting in proper operational envelopes in case of all defined failure cases. In case of twin-screw vessels with Low-Loss-Concept it is found that the aft tunnel-thrust unit is actually obsolete. The two main propellers together with the aft retractable unit can produce sufficient thrust in the desired direction to keep the vessel in position.

The OPTI-DP method has also been used for the performance evaluation of a WTIV, where the concept of the combined Retractable-Transverse Thruster unit is evaluated. This versatile concept may look appealing for operation both in deep water in DP and manoeuvring in shallow water in the harbour, though it actually has rather moderate performance since it will always be a compromise of two concepts. A propulsion configuration with dedicated tunnel-thrusters and a retractable unit can provide the required level of thrust in the right direction. The additional benefits of azimuth flexibility of a Retractable-Transverse Thruster could be of interest for a certain vessel, though it requires a dedicated DP-capability analysis to make the right decision about the final thruster configuration.

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