Standardization and the need of new tools for the DP industry

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2 Abstract

Design, planning and optimization of marine operations are today mainly based on experience of project teams but rely also a lot on available engineering tools and numerical models. When station keeping comes into play one of the essential tool is the capability plots. Despite the useful specification made by the International Maritime Contractors Association (IMCA) for DP capability plots, we are still suffering today from a lack of standardization and technical limitations when it comes to assess stationkeeping performances of a ship. For harsh weather environment – and not limited to the North Sea - where equipments are likely to be used close to design limits, approximations and conservative approach widely adopted for running DP capability study can prevent operators from finding suitable vessel and/or window for their operations. In some cases it may simply kill a project in the bud or even worse interrupt the running of an operational program after massive investments.

This paper intends to review those weak points and attempts to propose updated methodologies and additional requirements for the establishment of calculations with the objective of improving the vessel selection process through a sharp and fair comparison of performances. The final goal being to enhance the global operating strategy which includes safety, efficiency and costs of operations.

In addition to this “quasi-static” studies, complex simulators can be used to render the dynamics of the structures. Multi-physics simulators are today available but with some restrictions. Real successful technology DP is today facing important challenges with more and more complex operations in harsh environmental conditions like drilling operations in South Africa or in South America. Moreover the development of DP technology for Arctic operations is also recognized as one of the next challenge. In these cases the standard mathematical models and algorithms are not adapted and will be subject to deep changes. Furthermore additional requirements may raise for marine renewable energy (MRE) installations. In this context many limitations of the standard models and systems can also been reported while the large scale deployment for MREs is an unmatched argument in favour of DP. But when dealing with the safety of professionals the models, the accuracy and the validity of systems and simulators must be questioned and assessed. Finally the paper will focus on the DP system itself and more precisely on the DP Human Man Interface (HMI). The risk of human error has been widely depicted in the literature and HMI is the first contact between the DP system and the DP Operator. Thus this paper will propose some principles for the HMI designs for improving the operators to switch between competitors systems.

3 Introduction

Several different types of considerations are used by engineers and operations personnel when elaborating the overall operating strategy and related sequence of operation -selection of operational means, identification of operating windows and preparation of contingency plans-. Experience and feedback of teams - as operators, engineers, managers, etc. – is crucial but rely also on several engineering tools, data, studies and analyses such as

- Metocean data
- Metocean criteria
- DP capability plots
- Consequence analysis
- Drift-off studies
- Structural analyses
- Sea trials and former tests results
- Simulation studies
- Etc.

Depending on project some more specific studies could also be taken in account like riser analyses, drift off/drive off analysis, motion response study and dynamic study when preparing for instance drilling operations. It is also noteworthy that the obtaining of metocean data is of importance and is often very difficult to determine especially in untapped areas.
4 Capability Plots

The capability plot (CP) is an essential tool for Dynamic Positioning (DP) vessels’ designers and a crucial assistance for operators when preparing operations [1]. The CP lies in the analysis and the prediction of stationkeeping performances of floating platforms. It aims to represent the maximum theoretical abilities of a structure to maintain dynamically its position and heading under certain environmental conditions. Since DP systems are extensively used in all kinds of offshore operations, such a tool for the forecasting of the stationkeeping possibilities is extremely valuable. The CP can therefore be used for the design, the qualification and selection of ships. It permits then the direct comparison of multiple vessels under the same environmental conditions. Certification societies also use this tool for the certification of ships and risk assessments. In conclusion CP is today an essential tool. The validation or the continuation of the operations are often based purely on the capability plots.

4.1 Capability Plots standard

The International Marine Contractors Association (IMCA) has specified the CP in recommendations that ensure the same understanding worldwide [2]. This standardization was originally developed around offshore activity in the North Sea (NS). As underlined before CP studies are required for the delivery of a DP notation from certification societies like Det Norkse Veritas (DNV), Bureau Veritas (BV), American Bureau of shipping (ABS), etc. The requirements from DNV are just subcases and recommendations for the presentation of results [3].

As for the DPS the considered degrees of freedom are surge, sway and yaw. The environment considers wind, current and waves. The considered coordinate system is represented on Figure 1 while \( u \) and \( v \) are respectively related to surge and sway and \( \psi \) is the heading of the vessel. In addition \( \alpha_w \), \( \alpha_c \) and \( \alpha_{waves} \) are the incidence between the bow and the incoming direction of respectively the wind, the current and waves.

![Figure 1. Coordinate system representation.](image)

4.2 Mathematical models

In the document [4] DNV gives a framework for the calculation of the external forces.

4.2.1 Wind forces

The calculation of the wind loads in the CP is based on a classical approach which is widely documented in the literature, e.g. in [5]. Expressed at the centre of gravity of a ship, the equations have the following form:
where:
- \( A_T^w \) is the transverse emerged area
- \( A_L^w \) is the lateral emerged area
- \( \alpha_w \) is the wind incidence as shown in Figure 1
- \( v_w \) is the wind velocity
- \( L \) is the length between perpendiculars
- \( C_w \) are polar coefficients for each motion
- \( \rho_a \) is the density of the air

The values of \( C_w \) coefficients can be obtained by several methods:
- Experiments
- Interpolation and estimations (e.g. Isherwood’s method [6], Blendermann [7], Haddara [8] Fujirawa [9, 10])
- CFD calculations with the recommendations given in [4].

Turk and Prpic-Orsic indicate that Blendermann method is one of the most accurate [11] and can therefore be considered as the reference method today. However the work of Fujiwara must be further investigated. Nevertheless as confirmed in [4] wind tunnel tests and CFD are respectively the first and the second choices for the establishment of the models. The wind profile must also be documented in the report.

### 4.2.2 Current forces

Current forces are also expressed similarly to the wind forces [12] (Rayleigh forms):

\[
F_{\text{current}}/x = \frac{1}{2} \rho_w C_{c/x}(\alpha_c) A_T^c v_c^2 \\
F_{\text{current}}/y = \frac{1}{2} \rho_w C_{c/y}(\alpha_c) A_L^c v_c^2 \\
F_{\text{current}}/\psi = \frac{1}{2} \rho_w C_{c/\psi}(\alpha_c) A_L^c v_c^2 L
\]

(2)

Where:
- \( A_T^c \) is the transverse submerged area
- \( A_L^c \) is the lateral submerged area
- \( \alpha_c \) is the current incidence as shown in Figure 1
- \( v_c \) is the current velocity
- \( L_{pp} \) is the length between perpendiculars
- \( C_c \) are polar coefficients for each motion
- \( \rho_w \) is the density of the water

The current coefficients \( C_c \) can be obtained either from
- Experiments and interpolations/extrapolations
- CFD calculations
- Data base and interpolations/extrapolations
- Linear Strip Theory

To the best of the authors’ knowledge, no interpolation methods, similar to the Isherwood or Blendermann method for wind. Nevertheless OCIMF gives coefficients for very large ships depending on the shape of the bow [13]
The calculations of the coefficients can also be made using the strip theory as presented in [5]. Today CFD are far the best compromise between accuracy and economical solution.

4.2.3 Waves

The potential theory shows that wave's interactions on floating structures deal with first and second order effects [8]. The first order wave forces are described by zero-mean loads oscillating at the wave frequency. The second order wave forces show low frequency loads. In the CP calculations, as outlined in [2], the first order forces and only the high frequency of the second order waves forces will not taken into account because they are not counteracted by the DP system (their dynamics are too high and furthermore, they do not affect the average position of the ship).

Considering Newmann approximation the second order wave loads can be computed from the response amplitude operator (RAO) and a wave spectral representation, e.g. Pierson-Moskovitz [15] or JONSWAP [16]. The model itself is not described herein, but the reader may refer to [5]. The calculation of the RAO can be managed using industrial softwares like WAMIT, Diodore, HydroStar or open-source code Nemoh [17] etc. All of these solutions are based on the potential theory [18].

The reader may also note that the full understanding and the complete representation of wave actions on marine structures are actually still a field of on-going intense research. For example the Newman approximations can indeed become very bad in shallow water [19]. Furthermore even if the standard spectrum is widely recognized as the North Sea, new areas of interest are considered today like near Brazilian coasts, Uruguay, West Africa, South Africa, etc. In these regions the metocean data may be very different from the standard spectrum and this must be taken in account in order to have accurate calculations. The update of current tools is really needed and demanded by the contractors and the offshore industry. Operational windows may indeed be enlarged and more accurately studied considering the real input.
4.2.4 Propulsion forces

Several types of thrusters are used Nowadays ships can be equipped with various types of actuators, such as the tunnel thrusters, azimuth thrusters or propellers with rudders. These propulsion devices are schematically shown in the next figure.
The steady-state force developed by an actuator can be expressed as:

\[ F = k_T n^2 \]  (3)

where \( k_T \) is the thrust coefficient and \( n \) is the revolution velocity of the propeller. The steady consumed power is given by

\[ P = k_n n^3 \]  (4)

Where \( k_n \) is the torque coefficient. The reader may refer to [21] for more details.

This model is obviously very simplified. Severe degradations may occur and are related to
- Thruster/Thruster interactions
- Thruster/Hull interaction
- Thruster/Current interaction
- Ventilation
- Cavitation

An illustrative example of thruster/thruster interactions obtained from CFD computations is presented on the next figure.

Thruster/Thrusters interactions are usually avoided by the mean of so-called “forbidden zones”. However these forbidden zones are not the sole solution since tilted thrusters may avoid these effects [23]. Moreover a new real-time algorithm including more detailed modeling of thrusters/thrusters interactions has been proposed recently by Arditi et al. in [24]. It shows enhanced station keeping possibilities compared to the “forbidden zones” approach.
4.3 Resolution

The 3 degrees of freedom (DOF) model expressed at the centre of gravity of a DP vessel can be written in the body frame as [21]:

\[ M \ddot{\mathbf{v}} = F_{\text{coriolis}} + F_{\text{wind}} + F_{\text{current}} + F_{\text{waves}} + F_{\text{prop}} \]  \hspace{1cm} (5)

By definition of the CP, the velocity of the ship is equal to zero. Then the equation becomes:

\[ 0 = F_{\text{wind}} + F_{\text{current}} + F_{\text{waves}} + F_{\text{prop}} \]  \hspace{1cm} (6)

The possibility of holding the position can therefore be expressed as the following problem:

**CP problem:**
- Compute environmental forces
- Feasibility of solving (6) under inequality constraints of power and actuators' limits
- Browse environment parameters

In order to take into account dynamic effects and un-modelled effects - for example as detailed in the thrusters section - margins are applied.

Two types of margins have been reported in the use

- the first is to reduce the maximal thrust available per thruster by a selected ratio (in many times, it was taken to 80% of the maximal thrust) – 15% is then specified by DNV in [3]
- The second solution is to increase the forces vector by a ratio for example about 20%

Increasing the forces vector is not the best solution since it the resulting vector may be unrealistic and is absolutely not in accordance with the objective to understand well the physical process involved.

4.4 Capability plot representation

CP represents the ability to perform stationkeeping depending on the incidence of the external conditions (Figure 1). The line on the CP represents the first unfeasible condition and the results are presented as polar plots.

Figure 5. Example of a wind capability plot, from [1].

An example is shown on the next figure using the software StatCap from Kongsberg.
4.5 Limitations and extensions

The environmental load models, presented in this section, have some limitations. While the wind and the current representations have a relatively wide domain of validity, the wave modelling may be oversimplified. This can lead to inconsistent results, e.g. reaching the limits of the vessel before the prediction.

With these considerations Dynamic Capability plots have been proposed in [25] with the objective to handle dynamic considerations. The same methodology has in parallel been proposed by Kerkeni et al. in [26] in order to extend the capability plots environment to ice covered seas. As underlined in this paper, the ice forces are very complex to handle and simple static considerations for the establishment of capability plots are not very well suited. In addition an identical method has been proposed by Zhou et al. [27] for a moored structure with heading control in ice. The reader may note that a more conventional method for ice capability assessment has been proposed by Su et al. in [28]. The definition of significant ice load is introduced leading to standard classical considerations. The shape of the results are very similar to the ones presented in [26] and [27].

Moreover as recalled in the previous section the IMCA standard of CP was established considering the North Sea (NS) environment. Nowadays NS is not anymore the sole area for running DP operations at sea. Drilling explorations are more and more conducted in unpublished harsh weather environment, sometimes even more complex than NS due for instance to the addition of very strong currents. Developments in other challenging areas are therefore expected for the years ahead and the offshore industry needs to be prepared with adapted standardization for those “new – innovative” DP operation.
4.6 Capability plots standard proposition

The objective of this section is to detail a standard for the capability plots. The results obtained using the proposed assumptions are desired to be very complementary of existing studies. The goal is to propose a real procedure, a framework and a base case. This may further allow the real comparison of ships with the minimum of errors. The comparison of the results of this standard with the studies already existing and offered by different companies will be also very interesting.

4.6.1 Wind forces coefficient calculation

Tunnel tests are of course the best solution for the establishment of the wind coefficients but they are expensive. CFD studies are today the best compromise between scientific accuracy and economy. All assumptions (wind profile, mass, etc.) must be confined in the report – or in annex. After review of the existing techniques only Blendermann method shall be considered. Finally if selected the parameters of this interpolation method must be carefully detailed in the report.

![Diagram of Calculation of Wind coefficients](image)

Figure 7. Methodology of calculation of wind coefficients

4.6.2 Current forces

Similarly, model tests and towing tests are the most accurate method for the identification of the current coefficients. Moreover these tests may be coupled with maneuvering or propulsion tests and will be very welcome for the tuning of the DP system. If not available CFD studies are again the best solution. Database may be used rather than strip theory which appears to be oversimplified. However this must be deeply detailed – description and pictures of the hull of the base vessel, description of the calculation method for this base vessel, description of scaling method –. Simplified strip theory shall not be use since today a lot of better tools are available. The capability plots have a too great importance for being calculated with oversimplified data.
4.6.3 Waves forces

The same procedure is again recommended for the waves forces and again an exhaustive description is expected. The base case will consider North Sea spectrum. However as stated in part 4.5 it is more than important to update existing tools and to be able to consider different environments.
4.6.4 Forbidden zones

The forbidden zones are very important and must be considered. Depending on the distance between of azimuth propellers the next table is proposed. For titled propellers, this may not be considered.

<table>
<thead>
<tr>
<th>Distance Between Thrusters</th>
<th>&lt;5m</th>
<th>10m</th>
<th>&gt;30m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of forbidden zone</td>
<td>+/-30°</td>
<td>+/-10°</td>
<td>0°</td>
</tr>
</tbody>
</table>

Table 1 - Size of forbidden zones depending on the propeller distance

The azimuth thruster shall not point to another azimuth thruster with the calculated margin. A schematic example is provided on the next figure.

![Diagram of forbidden zones](image)

4.6.5 Thruster efficiency

The consideration of current velocity is a significant point. The next proposition for the efficiency of the thrusters is made.
The total force of the propeller is reduced by 15% in 2.5kt of current. The lack of specific consideration for dynamic effects in conventional DP capability analysis can also compromise safety of DP operation when operation are planned to be conducted in critical environment. Following DNV proposition the use of a secure margin of 15% of the total thrust per thruster is proposed.

4.6.6 Procedure

Finally the procedure is given in the next figure.
Figure 12 – Procedure for the calculation of standard capability plots

Note: the CP tool shall be able to consider other environment than the North Sea.
5 Reference simulator

Simulators are developed by numerous companies (Kongsberg, Transas, VSTEP, SMSC, etc.) with a lot of different objectives:
- Design of offshore operations
- Risk assessment
- Scientific research
- Training of crew
- Etc.

A reference simulator – licensed or grant free – shall be specified or provided to the ship industry and DP designers in order to test and validate DP systems. This is already the case for the track control systems but not for Dynamic Positioning purposes. The norm IEC 62065 [29] is indeed detailing a model which is shown on the next figure.

![Figure 13 - Model block diagram of the model proposed in [29]](image)

The Marine Systems Simulator (MSS) developed by Fossen and is team is obviously a good candidate. This open-source code developed in Matlab benefits from efforts of the NTNU since 1991. Collaborative works and open-source projects are solutions more and more explored. For example the project NEMOH lead by the LHEEA (laboratory of hydrodynamics of the Ecole Centrale Nantes) has been released open source and is a code dedicated to the calculation of the first order waves loads on offshore structures and the second order is currently implemented [30]. Such an approach for delivering a state of the art simulator to the offshore industry could be more than valuable. It could be for example used to assess DP systems.
6 Standardization of GUI of DP systems

6.1 Introduction

DP operations may involve several ships, threatening environments and complex situations. Well trained and experienced operators are reported as vital. Furthermore human errors are often depicted as the first source of incident. The number of operators are constantly growing and with an important ratio of unexperienced staff – about 2/3 have less than 2 years of experience in 2013 [31]. This is obviously a good signal for the DP industry since it shows the success of this technology. However it leads to question about homogenize and standardize the systems in order to allow the operators to focus more on the operation rather than on the vendor system. The major interface between the operator and the DPS is the Graphical User Interface (GUI) of the Human Man Interface (HMI) and this will be the only focus in this paper. Further work about the complete system shall be lead.

6.2 GUI review

Many vendors share themselves the DP market. The next figures aim to show how big the differences between the systems of the vendors are. This is only a small selection of DP competitors.

![Screenshot of the GUI of Sirehna DP from [32]](image.png)

Figure 14 – Screenshot of the GUI of Sirehna DP from [32]
Figure 15 – Screenshot of the GUI of L3 DP from [33]

Figure 16 – Screenshot of the GUI of L3 DP from [34]
Figure 17 – Screenshot of the GUI of GE DP from [35]

Figure 18 – Screenshot of the GUI of K-Pos DP from [36]
6.3 GUI review and proposition of standardization

The absence of standard is obvious. Many differences may be raised. Consequently it will be difficult for the operators to switch easily from one system to another one.

6.3.1 Naming of functions

It is first important to have the same names at least for the elementary modes of DP systems namely. For example the next study reports

<table>
<thead>
<tr>
<th>Mode</th>
<th>Purpose</th>
<th>Vendors name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joystick</td>
<td>Control of the ship with the joystick</td>
<td>&quot;Joystick Manual&quot;, &quot;Joy&quot;, &quot;Auto Joy&quot; etc.</td>
</tr>
<tr>
<td>Station Keeping</td>
<td>Automatic control of the heading and the position for holding the position and heading</td>
<td>&quot;Station Keeping&quot;, &quot;Auto Pos&quot;, &quot;Hovering&quot;, etc.</td>
</tr>
<tr>
<td>Track keeping</td>
<td>Automatic control of the heading and the position for following a track</td>
<td>&quot;Auto Track&quot;, &quot;Track Keeping&quot;, etc.</td>
</tr>
</tbody>
</table>

Table 2 – Naming of different modes in the different DP systems

The first step is to normalize the names. The convention of K-Pos of Kongsberg Maritime may be used since they are well implanted in the market since many years and they are recognized as the major actor in the domain.

6.3.2 Normalization of colors

A very notable element is the differences of colors between the DPS competitors. Even if the colors of Warning (Orange) and Alarms (Red) are standardized the wind, current, thrusters orders and feedbacks aren’t. This must be homogenized. The following convention is proposed

<table>
<thead>
<tr>
<th>Data</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind</td>
<td>Purple</td>
</tr>
<tr>
<td>Current</td>
<td>Blue</td>
</tr>
<tr>
<td>Thrusters Orders</td>
<td>Black or Grey</td>
</tr>
<tr>
<td>Thrusters Feedback</td>
<td>Blue</td>
</tr>
</tbody>
</table>

Table 3 – Proposition of colors for important DP signals

Red, orange and green colors must be avoided because they are referring to the status of a state.

6.3.3 Convention of Wind and Current

The marine standard must be respected
- Wind is coming FROM (origin of the direction of the wind)
- Current is going TO (direction where is going the current)

Furthermore it is important to recall that the current displayed on the DPS is not the real current but the equivalent current calculated by the DPS using the mathematical model. The DP current includes therefore model errors, unmeasured loads, waves, etc. [37].

6.3.4 Display of information

The arrangement and the design of the Graphical User Interface is primordial. When designing the GUI it is important to note that humans have a limited field of view. We are not see all the data on the entire screen at one time, we have to focus on several zones. Furthermore Humans seems also a privileged zone located slightly above the centre of the screen as shown on the next figure
However a lot of parameters enters in line. It depends on the size on the screen, the distance, etc. For simplification we will define the central zone as a zone with
- width equal to 2/3 of the width of the screen
- height equal to 2/3 of the height of the screen
- centered in the middle of the screen
This zone is represented on the above figure. Therefore the most important information must be located in this area. The following signals may be considered
- Position of the vessel
- Heading of the vessel
- Velocity over ground
- Current velocity and direction
- Wind velocity and direction
- Position deviation
- Heading deviation

Additionally we have in general more ease to look in the horizontal plane rather than in the vertical plane. This is of course true for people with mother tongue written horizontally. However it is representing the major part of the people in the world. Therefore when designing a GUI DP vendors must absolutely consider the arrangement of information in order to have a smooth passage. For example the position deviation preferably located close to the vessel position and preferably in the side etc.

6.4 Warning and alarms sound signals

As required by certification societies warning and alarms must raise sound signals. However the sounds are the same on numerous systems. More and more signals are emitted which is correlated by the greater and greater complexity of the systems. Therefore the sounds of warning and alarms shall be different.
7 Conclusion

This paper deals with several points about the design of DP systems and operations. The Capability plots – a crucial engineering tool for the design of vessels and marine operations – has been reviewed and an enhanced procedure for its establishment has been proposed. Also the paper spotlights on the need to improve the current CP tools for the future operations. The need of a standardized simulator has also been raised. Finally the paper underlines the needs of homogenization of DP systems HMI and some propositions have been formulated. This standardization appears to be vital for many actors and user of the DP technology and must be further investigated.

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9 References


