Calculation of Wind Heeling Arms for Static Stability with CFD Methods

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ABSTRACT

According to IMO, the forces and moments resulting from the action of winds on a vessel can be computed as a function of the projected area of the objects, of its shape coefficients and of other parameters like the velocity of the wind and the density of the air. These data is collected and used to determine the wind heeling curve, that together with the GZ curve has to meet the adequate IMO criteria. Usually wind tunnel tests are used to verify if this type of approach produces reasonable results. In these tests the above water part of the platform is heeled with different angles around a calculated critical azimuth angle. The upper part of the platform is also heeled in the same way as its submerged counterpart. The flow is very complex once the offshore platforms decks are composed by a series of process plant modules and related structures. The submerged hull also results in a complex flow as the platform heels, and the hull acquires different shapes. This paper proposes to run in a commercial CFD package the sequence of positions tested in a wind tunnel for an offshore platform. Both the submerged and emersed parts of the platform are going to be simulated. In this way the numerical results can be verified and a procedure to use the numerical tool can be derived. The main advantage is that even in the early stages of the project, the wind heeling arms can be estimated more accurately.

Keywords: stability, wind loads, heeling lever, computational fluid mechanics

1. INTRODUCTION

The assessment of the stability criteria for semisubmersible platforms is very important because it defines the main dimensions of the unit and also its load carrying capabilities. The main dimensions are governed by the requirement to meet the GZ curve requirements, therefore defining the water plane area, center of gravity height (KG), displaced volume and so on. The hull de

finition is related to the intact stability evaluation. The load carrying capacity is related to the definition of the Maximum Allowable KG, bringing into the picture the damaged and flooded conditions. Besides all the hull shape properties, another important aspect in the definition of the attendance criterion is the heeling moment. The θ_1, or angle of equilibrium under the action of winds. So far the estimates of wind forces and moments have to rely on similar designs or more precisely have to be run in a wind tunnel. The objective of this paper is to verify if the numerical methods based on the Finite Volume methods can predict the wind forced and moments adequately. The verification will be carried out for the P-55 project that is a Floating Production Unit to operate in Campos Basin offshore Brazil.

2. P-55 MAIN DATA

The FPU P-55 is a semi-submersible platform with closed ring pontoon shape, designed to operate in 1795 m water depth.

2.1 Main Characteristics

The main particulars of the SEMI-BR P-55 are shown in Table1.

Table 1. Main Characteristics

Item	Value	Unit
Length (at pontoon level)	94.32	m
Breadth (at pontoon level)	94.32	m
Height to Main Deck	55.50	m
Pontoon height	11.40	m
Column Width x Length	19.80 x 19.80	m
Operational Draft	34.00	m
Operational Displacement	105237	t

3. WIND TUNNEL TESTS

The platform topsides and hull have been tested in the BMT (Johnson (2006)) wind tunnel in order to determine its 6 degree of freedom forces and moments due to wind action. The tests have been carried out with wind incidences varying from 0^o to 350^o, for both parts separately. The critical axis has been determined and the forces and moments were also measured for heel angles around the critical axis

3.1 Above Water Part

This part is composed by all the structures located above the water line. In general the process plant structure is very complex and cannot be fully modelled in the tunnel model. However, the most representative parts are included in the model.

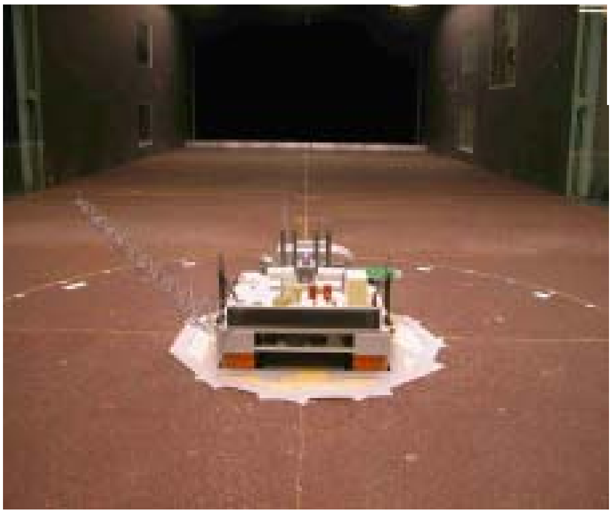

Figure 1 Above water part in the Wind Tunnel

3.2 Under water Part

This includes all the submerged structures considering the operational draft of 34 m. Again one should consider the difference between the tunnel test representation and the actual structure.

Figure 2 Underwater part in the wind tunnel

4. CFD COMPUTATIONS

The numerical computations have been carried out using the software CFX 10 that solves the non-linear Navier-Stokes equations in three dimensions through the use of the socalled Finite Volume element based method. This software enables the user to select between stationary or transient options to solve the flow in the domain of interest. Another important aspect is the inclusion of the turbulence, once the grid size is not enough to solve all scales of this phenomenon. Please refer to the program documentation for more information. (Ansys CFX 10.0 Manuals 2005)

4.1 Parametric Study

The main objective was to verify which parameters of the simulations should be used in order to provide accurate results without having to execute time consuming simulations. The main parameters evaluated during these study, carried out by Menezes, Oliveira & Damian (2005) are:

Far field dimensions

Mesh refinement (global and superficial

Prism elements layer

Y plus

Mesh quality

Near hull refinement

The main conclusion of this study is that steady simulations could be used to represent the global “average” configuration of the flow. As the flow around marine structures is not steady, but varies along the time, this is a simplification introduced to make it feasible in terms of computer time. The figure below shows the force coefficients obtained from the steady simulation:

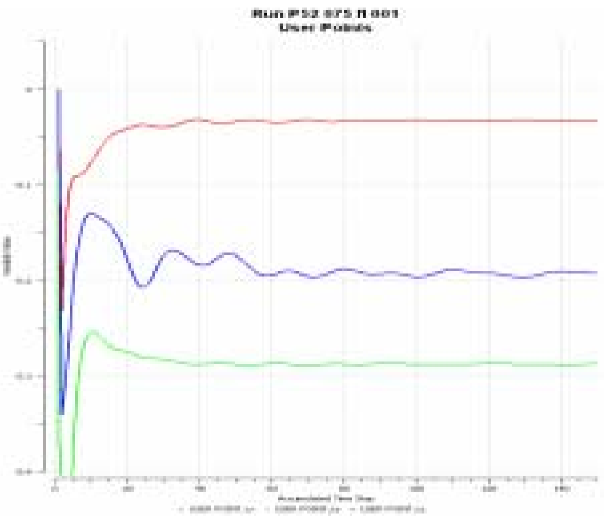

Figure 3 Steady state simulations

The next figure shows the results of the same simulation run for a transient case:

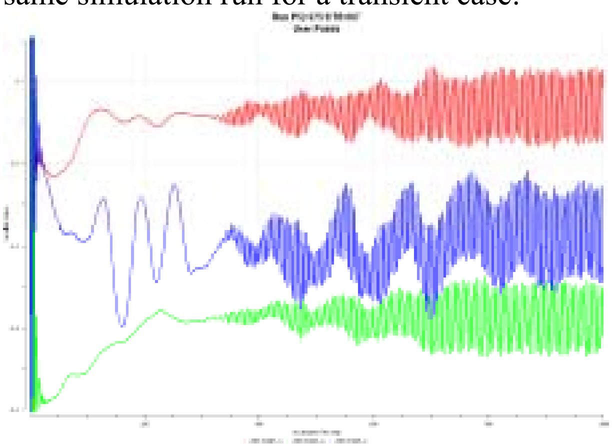

Figure 4 Transient Simulations

One can observe that the average values of the transient case are in the same range in the steady state simulation. As the interest is in the mean value of the force coefficients this approach could be used, enabling the simulations in a reasonable duration.

The rms of the residua, that is a measure of the error, should be below 10^{-5}, but in some cases this is not reached. The convergence difficulties (maximum residuum's), however, are located at the vortex street. These problems are not related to the mesh or boundary conditions, but related to the unsteady characteristics of flows around bluff bodies.

The turbulence is modelled with the Shear Stress Transport option, that is a two-equation turbulence model. It blends the *k-ε* and the *k-ω* models where they work better, being a good choice for drag calculations. For drag calculations, an Y+ value below 1 would be excellent, but expensive for these analysis. Therefore a value of 10 is the target proposed.

The main conclusions of the parametric study are:

The far field distance from the hull is very important;

Surface mesh and prism mesh refinement turns the convergence more difficult in the steady state;

The results of coarse meshes in steady state are sufficient;

The mesh refinement away from the hull (vortex street and far field) is not significant;

The mesh quality impact directly the convergence;

Boundary layer refinement for a Y+ below 1 is not necessary

4.2 Model

The first step is the generation of the platform geometry. This has been done in accordance with the wind tunnel model, i.e., the numerical model tries to be analogous to the tunnel test one.

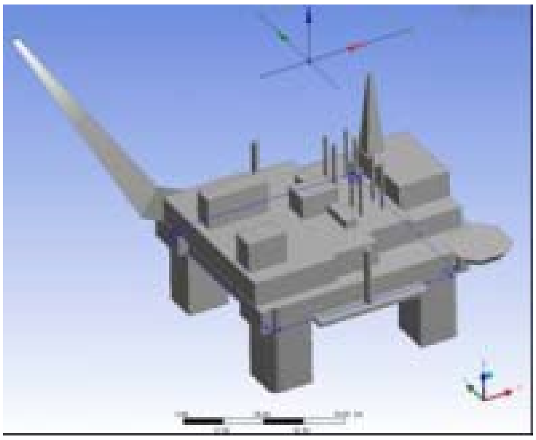

Figure 5 Above water part model

The mesh set-up is a key process in the use of numerical methods to solve the Navier-Stokes equations in complex structures. The first step comprises the definition of the main mesh parameters in order to generate the most adequate mesh. The mesh size is always a balance between the precision and the processing time requirements. The mesh is composed of tetrahedrons, but close to the surfaces with no slip boundaries, some layers of prisms are placed in order to take into account the gradient of velocities. Based on a previous parametric study, the main parameters that should be considered are:

Circular Far Field (Radius = 10L).

Global element size = L

Surface element size = Global/32.

Near hull refinement size = Global/4.

Prism layer: Total height = 5

Based on the parameters defined above and in order to enable one to use the same mesh geometry for the different incidences, a circular disk has come up as the final choice for the drag calculations.

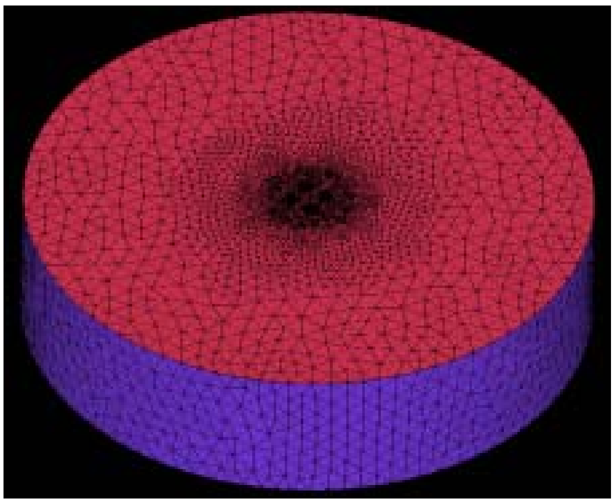

Figure 6 Mesh of the fluid domain

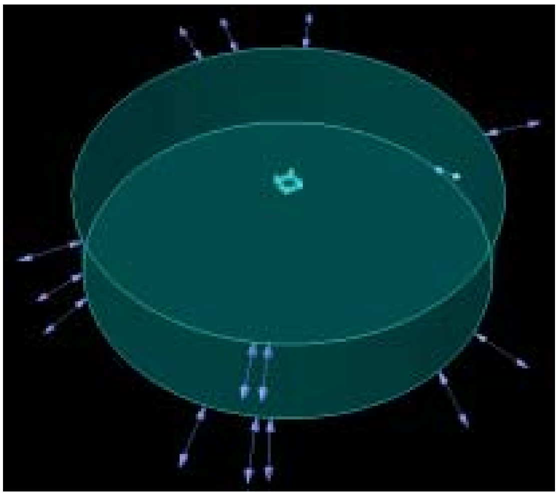

Figure 7 Boundary Conditions

Boundary conditions:

Hull: Wall No Slip.

Far Field. Opening Prescribed velocity.

Sea Surface: Wall Free Slip.

Above Water Results – Even Keel

The first set of results for the above water part of the platform are the forces and moments coefficients with varying incidences compared with the model test results. Two numerical simulations with different parameters are shown. The first one doesn't include the effect of the atmospheric boundary layer in the incident velocity, whereas the second one includes this effect.

Mesh 1 data:

Total Number of Nodes = 253458

Total Number of Elements = 1036366

Mesh 2 data:

Total Number of Nodes = 413380

Total Number of Elements = 1658833

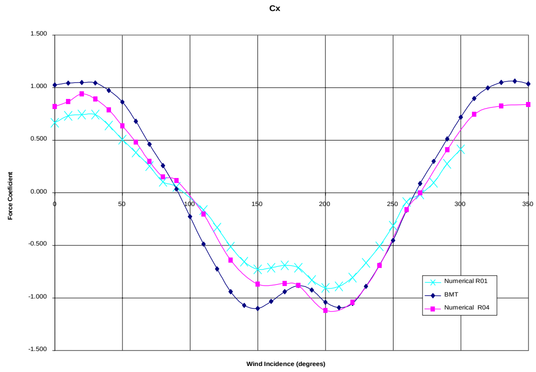

Figure 8 Comparison of AW EK Cx Force Coefficient

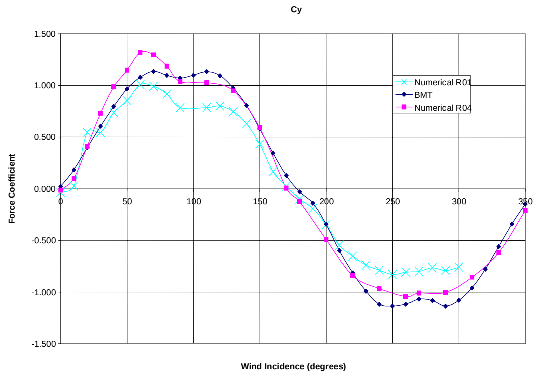

Figure 9 Comparison of AW EK Cy Force Coefficient

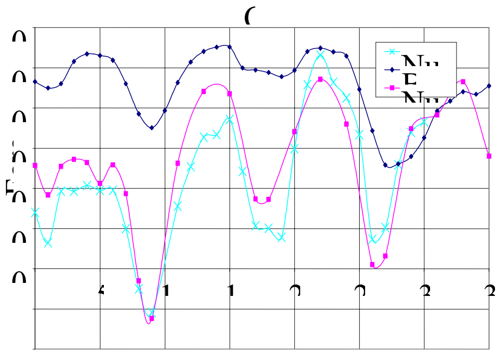

Figure 10 Comparison of AW EK Cz Force Coefficient

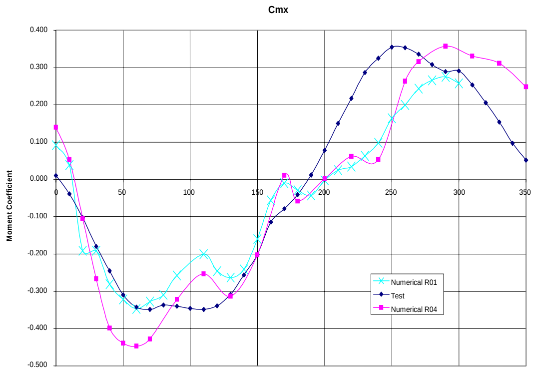

Figure 11 Comparison of AW EK Cmx Moment Coef.

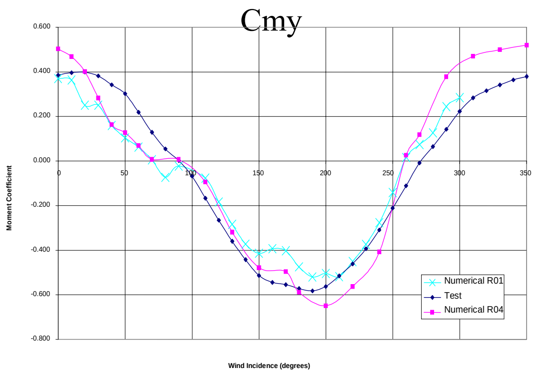

Figure 12 Comparison of AW EK Cmy Moment Coef.

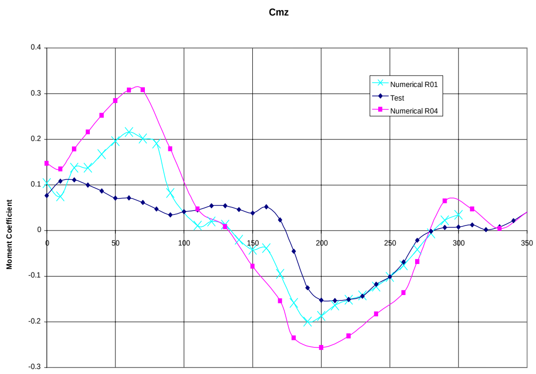

Figure 13 Comparison of AW EK Cmz Moment Coef.

4.3 Above Water Results – Inclined Platform

The above water inclined platform results refer to the heeled platform around the critical axis, defined from the even keel analysis. The wind direction at which the highest wind overturning moments will be encountered, determined on the basis of a test of each draft applicable, is the critical direction. The critical axis is perpendicular to that incidence.

Figure 14 Tunnel Test – Heeled Platform 15 degrees

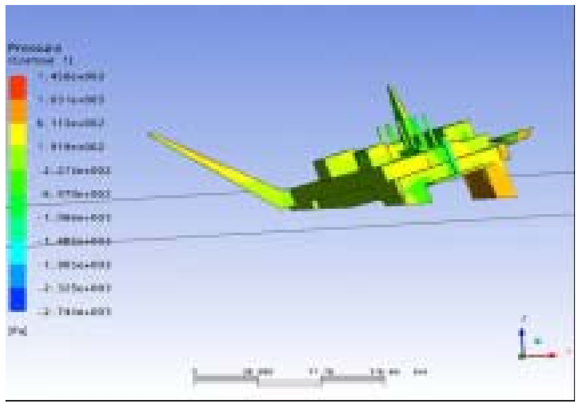

Figure 15 Geometry of the Heeled Platform around the Critical Axis – Pressure Field – 15 degrees

Figure 16 and Figure 17 show the comparison of the force coefficient for the heeled platform:

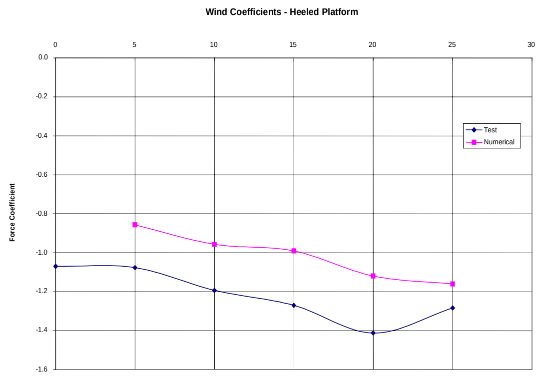

Figure 16 Comparison of AW INC Cx Force Coef.

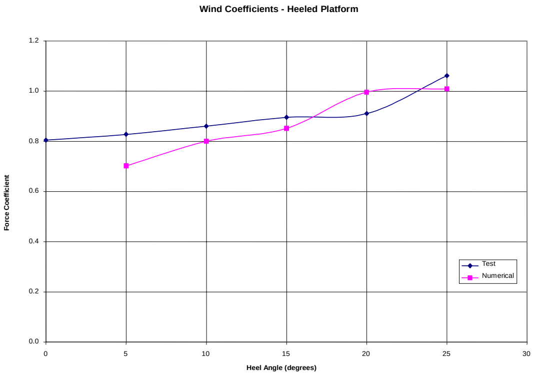

Figure 17 Comparison of AW INC Cy Force Coef.

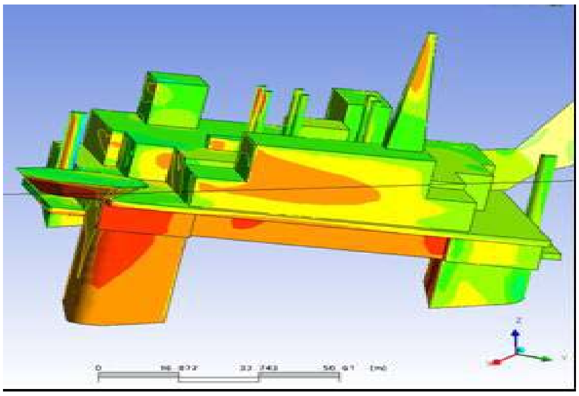

Figure 18 Pressure Field - Heeled Platform 20 degrees around Critical Axis

4.4 Underwater Results – Even Keel

The same set of results will be presented for the underwater part of the platform. Namely the forces and moments coefficients in function of the wind incidence.

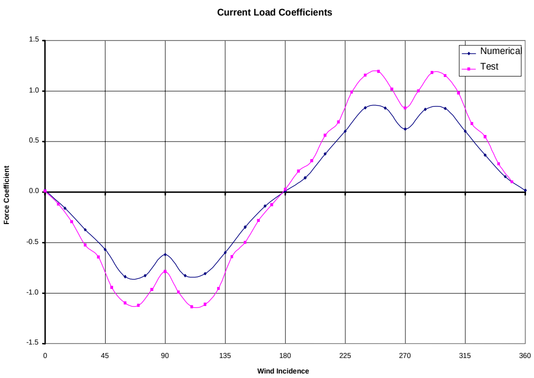

Figure 19 Comparison of UW EK Cx Force Coef.

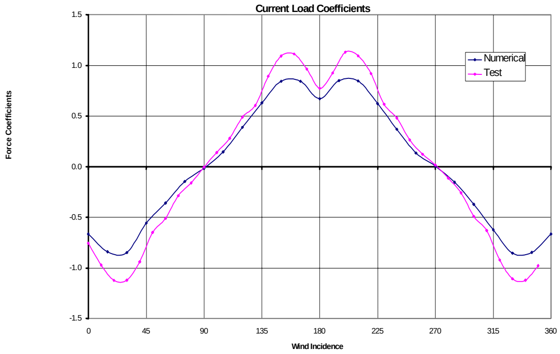

Figure 20 Comparison of UW EK Cy Coef.

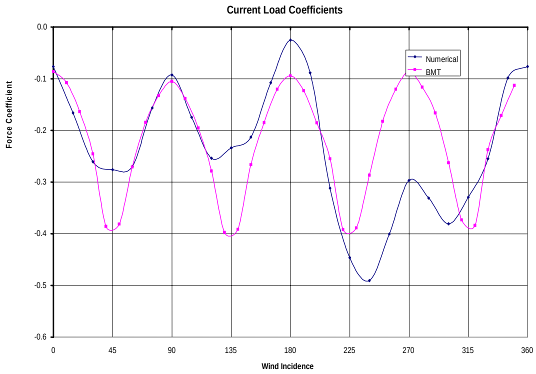

Figure 21 Comparison of UW EK Cz Force Coef.

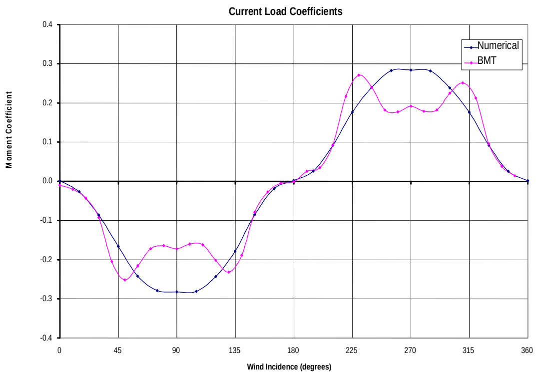

Figure 22 Comparison of UW EK Cmx Moment Coef

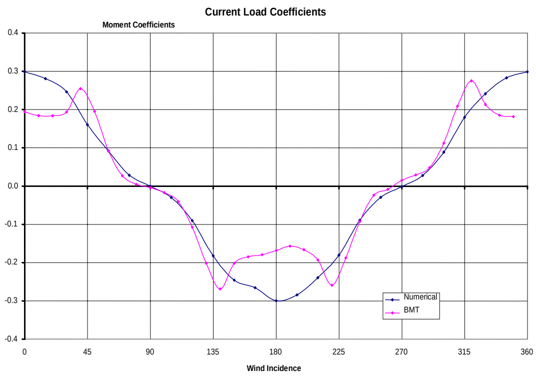

Figure 23 Comparison of UW EK Cmy Coef

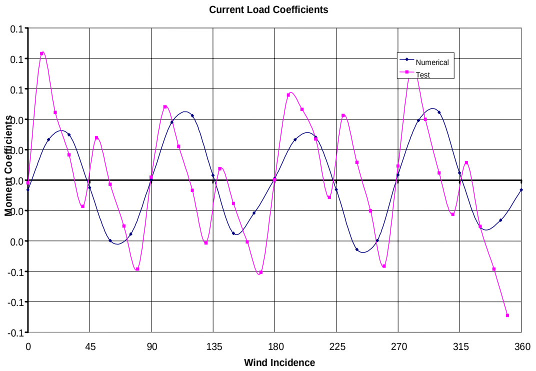

Figure 24 Comparison of UW EK Cmz Coef

4.5 Under Water results – Inclined Platform

The underwater part of the hull should also be heeled and the flow solved in order to compute the force and moments. These results will be later used to calculate the heeling lever.

Figure 25 Tunnel Test Model Under Water part – Heeled 15 degrees

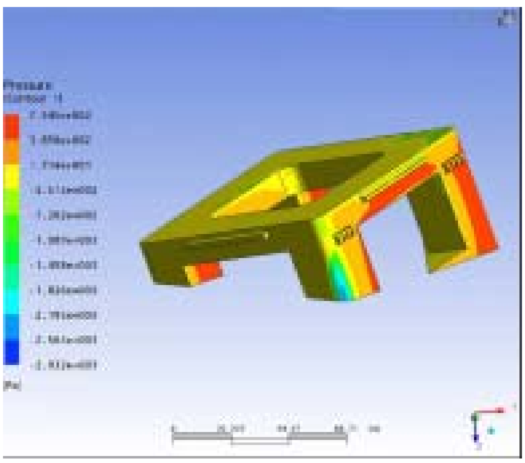

Figure 26 Numerical Model Underwater part Heeled 15 degrees

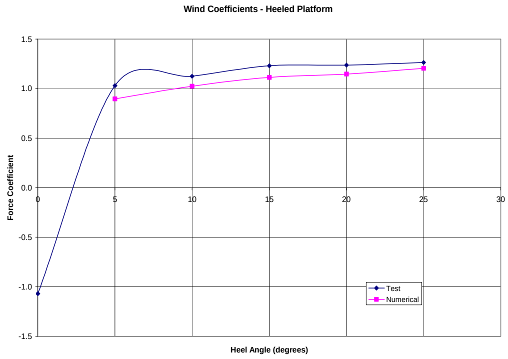

Figure 27 Comparison UW INC Cx Force Coef

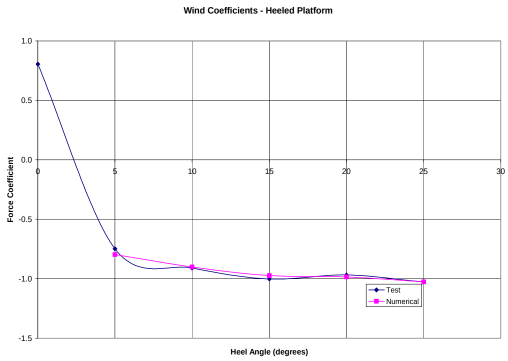

Figure 28 Comparison of UW INC Cy Coef

4.6 Heeling Lever Calculation

After the validation of results with the even keel situation and the evaluation of the coefficients for the heeled platform it is possible to calculate the heeling levers and to compare the results with the experimental data.

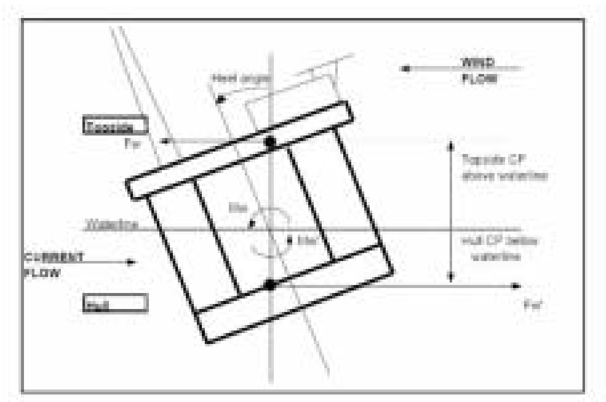

Figure 29 Heeling lever definitions

Fw = resultant drag force on the topside

Mw = resultant overturning moment about the waterline on the topside

Fw’ = resultant drag force on the hull

Mw’ = resultant overturning moment about the waterline on the hull

$$CPtopside = Mw/Fw \quad (1)$$

$$CPhull = Mw'/Fw' \quad (2)$$

$$HL = Fw(CPtopside + CPhull)/Displ. \quad (3)$$

Following expressions (1), (2) and (3), and applying the wind velocities of 51.4, 37 and 25.7 m/s to the coefficients calculated before, the Heeling Lever (HL) can be estimated and compared with the experimental results.

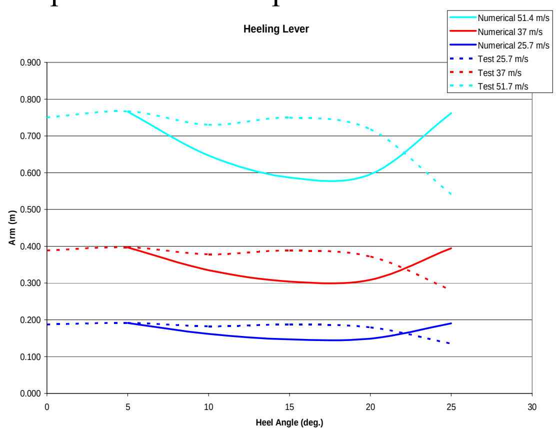

Figure 30 Comparison of Heeling Lever Results

5. CONCLUSIONS

The following conclusions have been drawn from this study:

Considering the level of detail between the physical model and the numerical model the even keel results are reasonably in accordance, i.e., the results from the numerical model could be used for design purposes;

The heeling lever calculations showed a better agreement for the lower wind velocities. Considering that the coefficients of force and moments were calculated for the same velocity, this fact would not be expected;

The numerical analysis has been run in the full scale and in model scale without relevant differences;

The convergence of the numerical results to the prescribed target of 10^{-5} hasn’t compromised the results, once some cases converged and others not, but the force/moment coefficients weren’t influenced by this;

6. ACKNOWLEDGEMENTS

The authors acknowledge the assistance of Ricardo Damian (ESSS) in the parametric study, set up and running of CFX.

7. REFERENCES

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