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# Comparative Analysis of the Dynamic Angle of Heel of a Shipe 888 Project Type Defined of the Calculation and Model Tests

W. Mironiuk[1]

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ABSTRACT

Results of initial research on air flow's dynamic impact on a ship model of 888 project type are presented in the elaboration. The research has been executed at a test stand located in the Polish Naval Academy. The ship model of 888 project type has been an object of the tests. Results of executed measurements have been compared with theoretical calculations for an angle of dynamic heel. Input parameters for the tests and calculations have been defined in accordance with recommendations of Polish Register of Shipping (PRS) and IMO (IMO Instruments 1993, 2008, PRS 2007). Determination of a heeling moment by wind operation has been a key issue. The executed research has revealed that the way the criteria of the ship's dynamic stability are defined by PRS and IMO takes a certain safety margin into account.

## 1. Introduction

During operation, a ship is open to dynamic effects resulting from specifics of marine environment. Among these effects, wind dynamic impact together with a wavy motion is especially hazardous for the ship. Therefore, there are applicable criteria, taking the above said situations into consideration, in classification societies' regulations. A way to calculate a heeling moment originated by the wind operation is given in dynamic stability criteria. One may determine an angle of dynamic heel based on a function of this moment and righting levers' curve. But, assumptions and simplifications accepted by the classification societies result in omission of some phenomena and the angle of dynamic heel, determined based on theoretical calculations, differs from the real one (Moreno, Chaos, Aranda, Muñoz, Díaz, Dormido, 2009). Determination of a real value of the dynamic angle of heel is possible by executing model tests performed with geometric and dynamic similarity scale taken into consideration. Results of theoretical calculations and measurements of dynamic angle of heel, executed with a ship model of 888 project type as an example, are given in this elaboration (Lewandowski, 2010). Results of the presented tests allow formulating practical conclusions that may be used by the classification societies, among the others.

## 2. Research facility and object of the test

Tests on the wind dynamic impact on a ship have been executed at a facility located in the Polish Naval Academy (Mironiuk, W. 2006). Main elements of the stand are as the following:

Model basin for surface ships of internal dimensions of LxBxH 3x2x0,5 m,

— Ship model of 888 project type,
— Ship model of 660 project type,
— Computer registering parameters of the ship model position,
— Device generating air flow.

There is a set of fans fixed in a casing making a jet of a changeable section on the basin's shorter side. Dimensions of the jet's outlet are sufficient to let the airflow operate on entire flank of the model, with a suitable reserve. There are 5 big and 5 small fans in the jet's housing – all together, they are capable of generating air flow faster than 5 m/s.

A ship model of 888 project type has been the object of the study. It was made in a scale 1:50 in respect to a real vessel. The scheme of the model is shown in the Figure 2.

[1] Naval Academy, Faculty of Navigation and Naval Weapons; Śmidowicza Street 69, 81-103 Gdynia, Poland; tel.+48 58 6262903,e-mail: w.mironiuk@amw.gdynia.pl, wmiro@o2.pl.

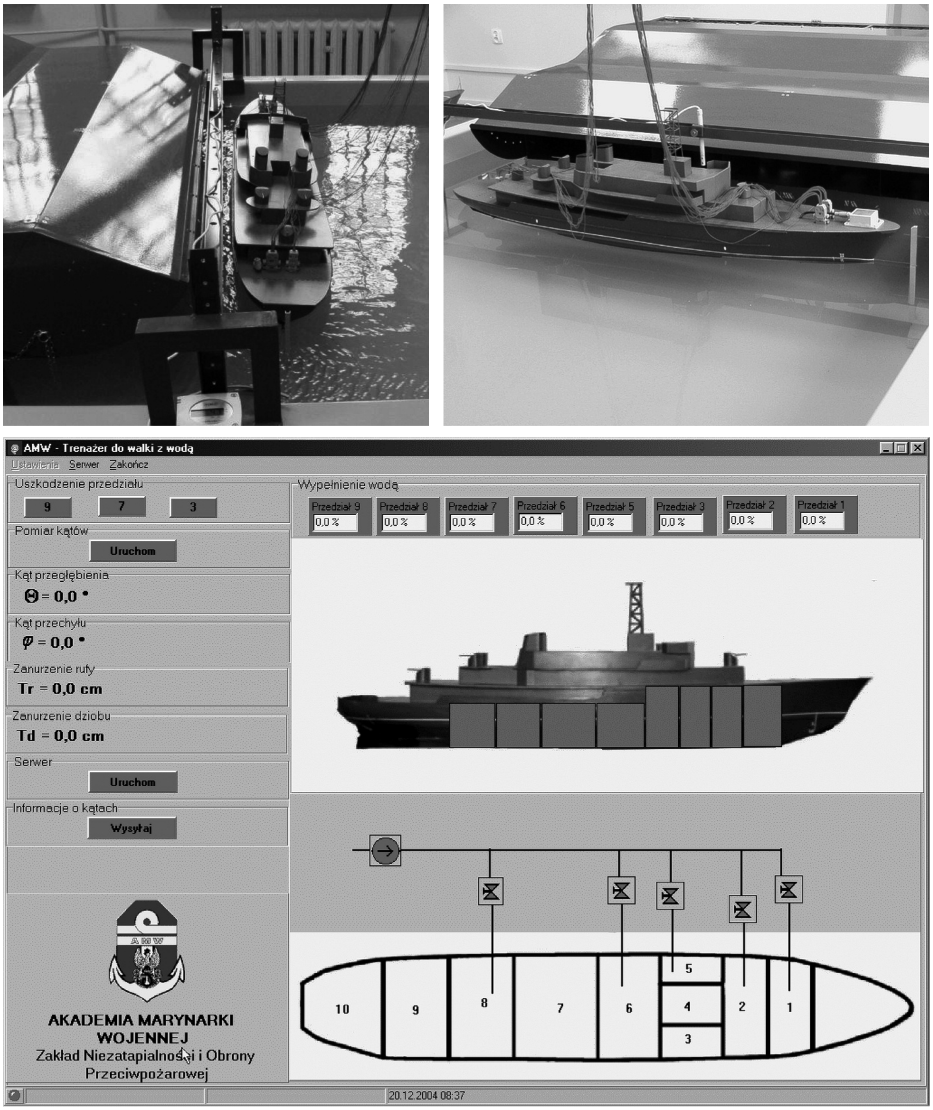



**Fig. 1.** Facility for tests on dynamic impact of wind.

Its basic data have been as the following (Mironiuk, W. 2006):

— Overall length of the model: Lc = 1,444 m;
— Length between perpendiculars: Lpp = 1,284 m;
— Displacement of the model: D = 13,15 kg;
— Average draught of the vessel: T = 0,078 m;
— Depth of the model's centre of gravity: $Z_G$ = 0,096 m.

1, 2 and 3 - Valves for a puncture simulation in the compartments PIII, PV and PVII; 4, 5, 6, 7 and 8 - Valves for flooding the compartment PVI, PIV, PIII, PII and PI; 9,10,11 - Water level indicators in the compartment PVII, PV and PI; 12. Indicator of ship draught; 13. List indicator.

At the level of floatation line, openings – horizontally arranged – are made in the model's stem and stern frame. Rods limiting the ship's drift caused by the air flow operation may be placed in the openings. Such an arrangement results in defining a fixed axis of rotation of the ship model. In fact, position of the ship model's axis of rotation is not permanent because, it depends – among the others – on dynamics of the wind effect. Location of the ship model's axis of rotation is crucial to determine the heeling moment. The IMO's stability code (IMO Instruments, 1993, 2008,) provides with instructions that the heeling moment's lever should be calculated as a distance from a centre of the topside projected area to the centre of the underwater part of the hull's projection on the symmetry plane, or – approximately – to the vessel's half draught depth. In this connection, results of measurements of and calculations for the dynamic angles of heel, executed in compliance with the IMO's recommendations, shall differ.

A sensor of the heeling and trim angles registering the angles with an accuracy of up to 0,01 of degree is installed on the model. Signals from the sensor are transmitted by means of a cable to a computer. Influence of the cables connected to the model has been omitted because of their insignificant weight and section areas.

## 3. Problem of geometric and dynamic similarity scale

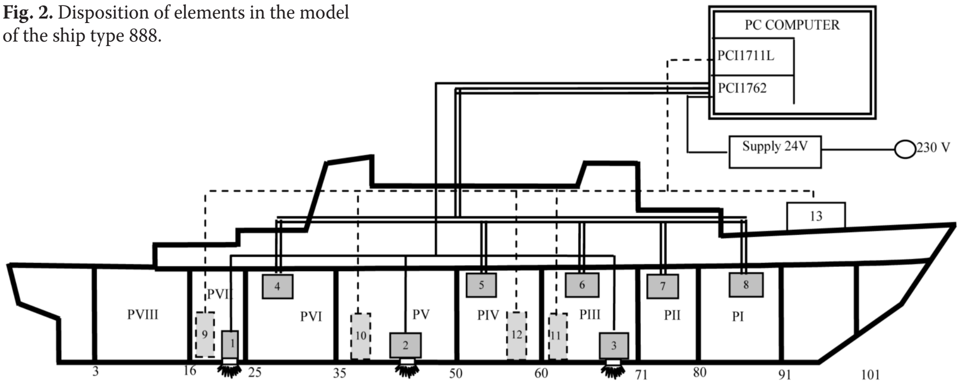
Solving the geometric and dynamic similarity scale problem has consisted in meeting given conditions. The ship model was made in the 1:50 scale - that is why all geometric quantities could have been easily calculated. Values of the righting levers curve of the ship model also have been subject to the geometric similarity principle. The heeling moment should effect in proportion to the vessel's righting levers, i.e. ratio of the ship's righting levers maximum value and value of the wind affected heeling moment's lever should be the same for both the model and the ship, as below:

$$\frac{GZ_{\max o}}{l_{wo}} = \frac{GZ_{\max m}}{l_{wm}} = const \tag{1}$$

where the "o" subscript refers to the vessel, while the „m" subscript refers to the model. Figure 3 makes a graphical mapping of the (1) dependence.

Wind pressure affecting the vessel depends on the wind affected heeling moment. Therefore, the pressure should be defined in compliance with a suitable dynamic scale in

**Fig. 2.** Disposition of elements in the model of the ship type 888.




$$p = \frac{\rho v^2}{2} \tag{2}$$

The pressure value of 756 Pa gives the air speed of 35 m/s – at the density of 1,2 kg/m³. To determine the wind velocity in respect to the pressure, one may also use table values provided in published references (Dudziak, J. 2006). It follows from them that the velocity should be some 29 m/s for squall of 756 Pa pressure.

relation to the model. Value of the pressure having dynamic impact on a real object, i.e. IMO and PRS regulations (IMO Instruments 1993, 2008, PRS 2007). It is 504 Pa for ships of unrestricted operational water areas and wind operating statically. However, a value 1,5 times bigger, i.e. 756 Pa is given for dynamic wind. A given wind velocity corresponds with this pressure value, and the velocity may be determined with many ways. Using dependence on the dynamic pressure is one of them, as the following:

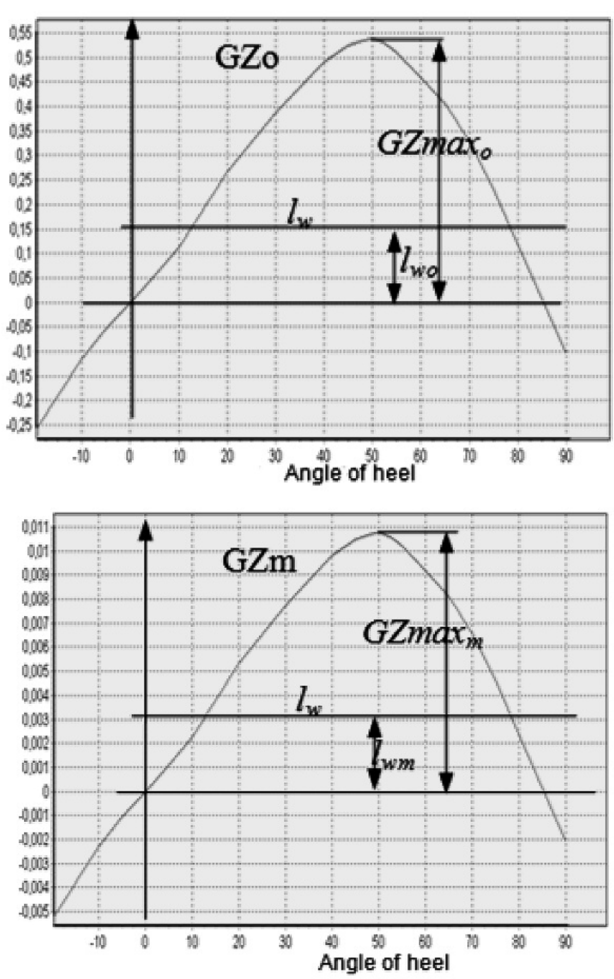



**Fig. 3.** Determination of wind affected heeling moment lever's value for ship model.

The air speed obtained for the ship should be recalculated for a speed for the model. Suitable recalculations may be done with many ways. Using Euler coordinate is one of them (Grobyś 1998), as below:

$$Eu = \frac{p}{\rho v^2} \tag{3}$$

The pressure of 756 Pa and the speed of 32 m/s both defined for the ship gives the wind velocity of 4,52 m/s, i.e. the velocity that should have impact on the model.

In case the following dependence on the wind affected heeling moment is applied (PRS 2008):

$$M_w = 2 \cdot 10^{-5} \cdot F_w \cdot z_w \cdot v_w^2 \cdot \cos^2 \varphi \tag{4}$$

Where:

$F_w$ – topside projected area [m²],

$z_w$ – distance from centre of wind projected area to waterline positioned at height of T/2 above basic plane, at given load condition [m],

$\varphi$ – angle of heel,

$v_w$ – wind velocity at height of wind projected flank's geometric centre, defined with the following formula (PRS 2008),

$$v_w = v_{10}\left(\frac{z_w}{10}\right)[\text{knots}] \tag{5}$$

Where:

$v_{10}$ – wind velocity at height of 10 metres above waterline, $v_{10}$=80 knots is accepted for the ships of unrestricted operational water areas.

The wind velocity is 4,51 m/s for the ship model.

The presented solutions for the problem of dynamic similarity scale follow to similar results of the air flow speed. Therefore, it is probable that the calculations for the wind velocity have been done correctly.

## 4. Execution of the tests

The study's programme has been executed in several stages. Determination of the airflow speed distribution has been one of the first activities at the research stand. Measurements of the airflow speed have been executed in 18 points. Results of the measurements for the speed of the airflow generated only by the big fans are given in Table 1. Average value of the speed of the airflow affecting the model had 4,52 m/s.

**Table 1.** Results of measurements of air flow speed.

| Measurement height | Place of measurement and value of speed [m/s] | | | | | | Average value [m/s] |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | |
| 35,5 cm | 4,57 | 4,68 | 4,69 | 4,16 | 4,10 | 4,53 | 4,46 |
| 18,5 cm | 4,67 | 4,86 | 4,77 | 4,53 | 4,16 | 4,65 | 4,61 |
| 8,5 cm | 4,33 | 4,63 | 4,60 | 4,65 | 4,65 | 4,10 | 4,49 |
| | | | | | | | **4,52** |

Next stage of the research has been to determine the dynamic angle of heel. Tests at the stand have been executed, among the others, for the following values of the angles of heel towards the windward shipboard: 6°, 15°, 18°. Values of these angles result from calculations of weather criteria executed for the ship project of type 888 in accordance with the regulations of IMO and PRS.

The fans have worked with constant velocity during registering the angles of heel what corresponds with constant characteristics of the heeling moment. Results of the measurements of the registered angles of heels are given in Fig. 4.

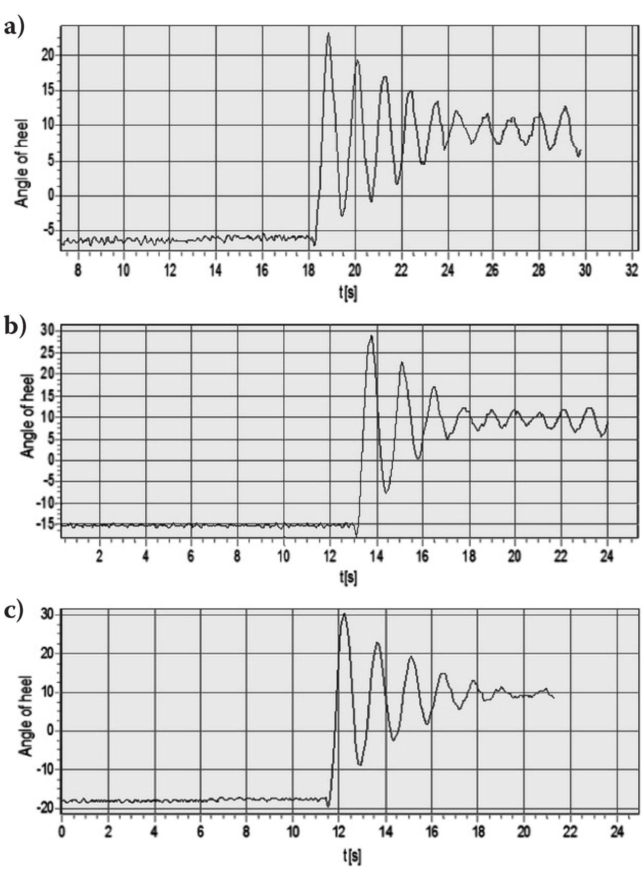



**Fig.4.** Measurements of dynamic angle of heel after deflecting model towards windward shipboard to angle of: a) 6°; b) 15°; c) 18°.

Table 2 contains a listing of the results for the measurements executed at the stand. The biggest values of the dynamic angle of heel have been obtained when the model has been deflected to the angle of 18 degrees towards the windward shipboard.

**Table 2.** Values of dynamic angles of heel.

| No. | 1 | 2 | 3 |
|---|---|---|---|
| Angle of heel towards windward shipboard [deg] | -6 | -15 | -18 |
| Dynamic angle of heel [deg] | 23 | 29 | 31 |

## 5. Theoretical calculations

Calculations for the ship's dynamic angle of heel have been executed for the heeling moment defined in accordance with the IMO and PRS recommendations. Based on them, lever of the dynamically operating heeling moment has been determined assuming that the distance of the topside projected area's centre was measured from the half draught depth. The prospected lever has been calculated with the following dependence (IMO Instruments, 1993, 2008, PRS 2007).

$$l_w = 1{,}5 \frac{q_v F_w Z_v}{1000\, g\, D} [m] \tag{6}$$

where: $q_v$ = 504 Pa – wind pressure;

$F_w$ – topside projected area [m$^2$];

$Z_v$ – measured perpendicularly, distance from centre of topside projected area to centre of underwater part of hull's projection on symmetry plane, or – approximately – to vessel's half draught depth [m];

$D$ – ship's displacement [t];

$g$ – 9,81 m/s$^2$;

and for the data:

$Fw$ = 533 m$^2$;

$Zv$ = 6.46 m;

D =1643.7 t,

to result in obtaining value of the wind affected heeling lever equal 0,162 m.

For this value, the dynamic angles of heel have been read on a graph (Fig. 5) and placed in a Table 3.

**Table 3.** Values of dynamic angles of heel.

| No. | 1 | 2 | 3 |
|---|---|---|---|
| Angle of heel towards windward shipboard [deg] | -6 | -15 | -18 |
| Dynamic angle of heel [deg] | 33 | 40 | 43 |

The results show that the values of the dynamic angles of heel obtained from the calculations are seriously bigger than the values obtained from the measurements. The fact that lever on which force of the wind pressure operates was defined from the ship's half draught depth, instead of from the operative waterline, is one of the reasons. Should one

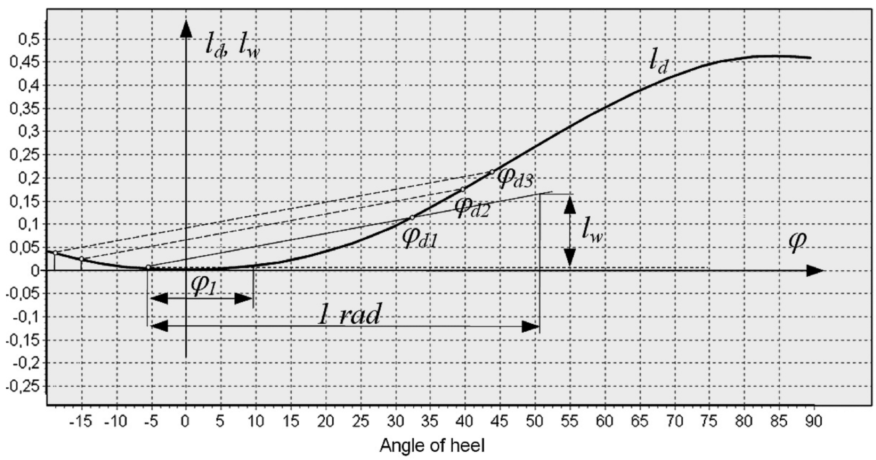



**Fig.5.** Determination of dynamic angles of heel for ship of 888 project type – for Zv=6.46 m.

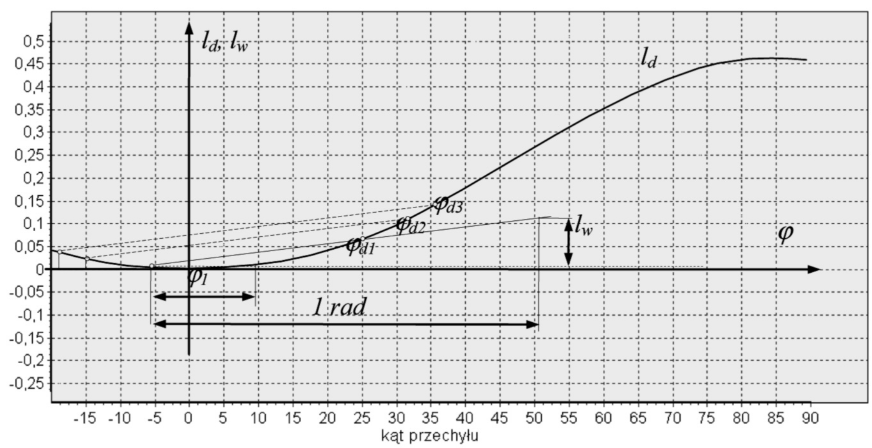



**Fig.6**. Determination of dynamic angles of heel for ship of 888 project type – for Zv=4.49 m.

take this note into consideration, the wind affected dynamic lever $l_w$ shall equal 0.111 m. A next graph, given on Figure 6, allowing defining the dynamic angles of heel, has been executed for this case. Obtained values of the angles are presented in a Table 4. Moreover, a line with values of the dynamic stability angles measured at the stand has been added - to enable to compare the results.

**Table 4.** Values of dynamic angles of heel.

| No. | 1 | 2 | 3 |
|---|---|---|---|
| Angle of heel towards windward shipboard [deg] | -6 | -15 | -18 |
| Dynamic angle of heel determined for $Zv$=4.49 m [deg] | 25 | 32 | 36 |
| Dynamic angle of heel measured at stand [deg] | 23 | 29 | 31 |

This time, the results of the dynamic angle of heel calculations and measurements are very similar. Differences are from 10 to 16%. It is possible to obtain more similar results after damping of movement and size of the wind exposed area's projection, which changes during the heel, are taken into account.

## 6. Summary

The executed initial research on the dynamic influence of the wind affected heeling moment shows high convergence of the theoretical calculations with the measured values. The obtained results prove that the way the wind affected heeling lever is determined has significant impact on the values of the dynamic angles of heel. The ship model has had the fixed axis of rotation, positioned in not waving water plane. Therefore, it has not been possible to compare the measurements results with the results of calculations for the dynamic angle of heel accurately, if determined based on the heeling moment imposed by IMO. Further research on the described issue shall allow executing more accurate analysis.

## 7. References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