EXPERIMENTAL EVALUATION OF THE PARAMETERS FOR THE WEATHER CRITERION

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Abstract

The papers was developed as part of the research "Analisi critica del Criterio di Stabilità Meteorologico e formulazione di proposte di modifica per le grandi navi passeggeri" financed by CETENA SpA in the frame of CETENA Research Plan 2002, with the aim of the possible revision of IMO Weather Criterion for ships having the characteristics of the Large Passengers Ships. Tests on two large model of Passenger Vessel were held in the wind tunnel of the Vienna Model Basin. The aim of the tests were to obtain the experimental results of the wind forces and moment acting on two Ship, built from Fincantieri, at various angle of heel, with beam wind, for comparison with those assumed from the Weather Criterion. Suggestion for a new procedure of the calculation of the Weather Criterion based on wind tunnel model test is given

Nomenclature

SLF is the Stability, Load Lines and Fishing Vessels Sub-committee of MSC
MSC is the IMO Maritime Safety Committee
IMO is the International Maritime Organisation
SOLAS International Convention for Safety of Life at Sea
Re Reynolds number

1. EXPERIMENTAL WIND TUNNEL TESTS

The aim of the tests was to obtain the experimental results of the wind forces and moment acting on two Ships, built from Fincantieri, at various angle of heel, with beam wind, for comparison with those assumed from the Weather Criterion.

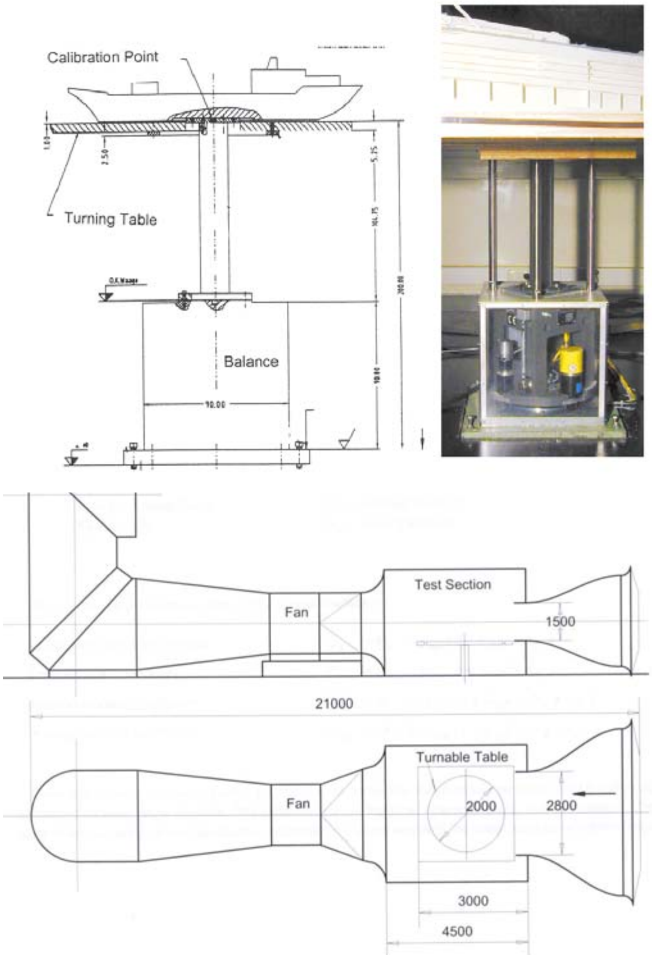

Fig. 1 – 2. The Vienna Model Basin wind tunnel

1.1. Description of the models

The models were built in wood, scale 1/125, having represented the particulars with accuracy. To put the model in the correct heeled floating position, wedges have been applied to the model.

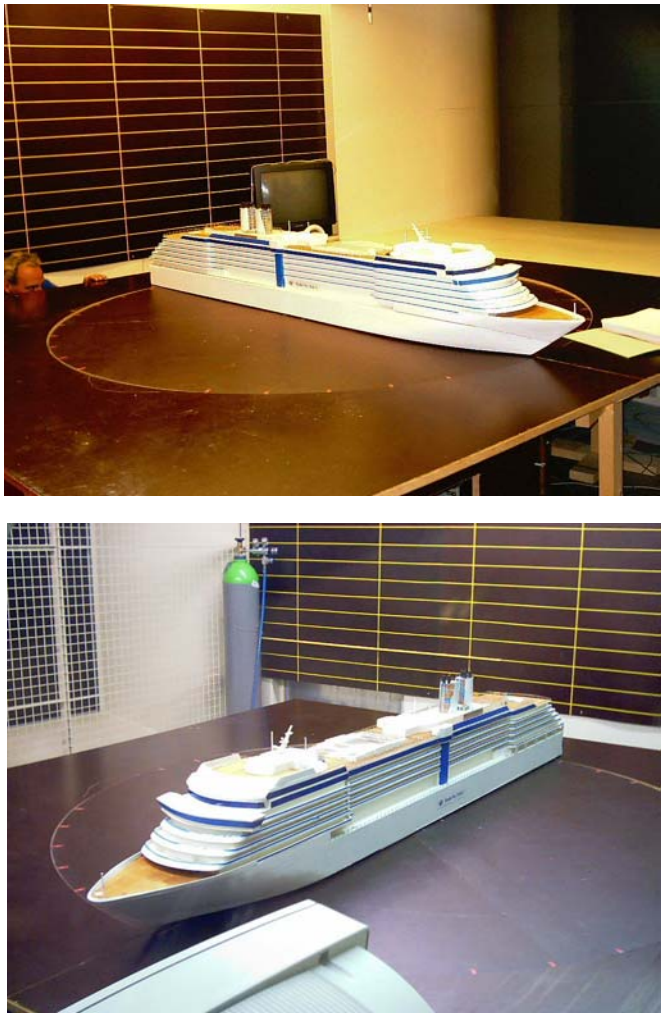

Fig. 3 - 4. Model n. 2036

Fig.5 - 6. Model n. 1852

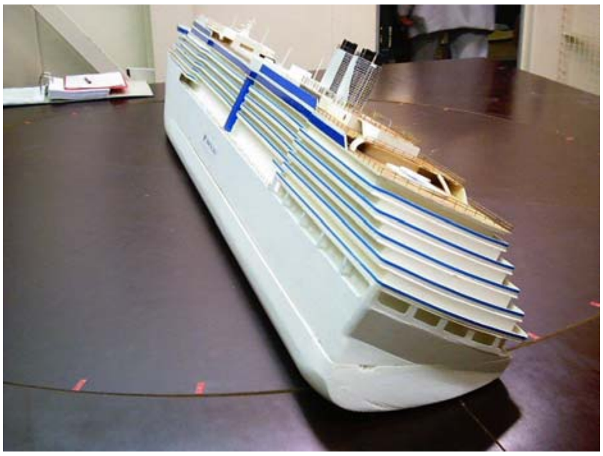

Fig. 8. Model n. 2036 in heeled position

Fig. 7. Wedges applied to the models in order to obtain the correct floating position

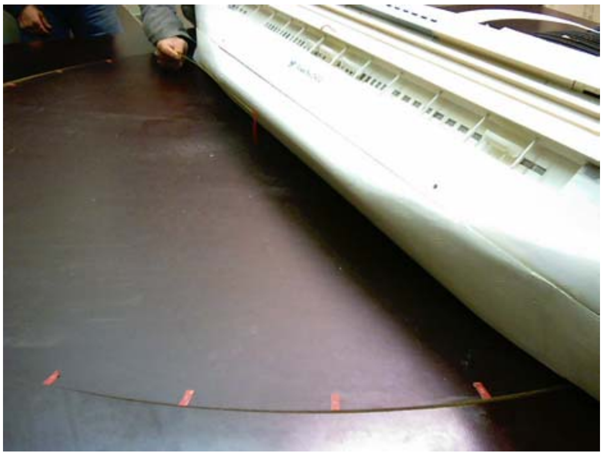

Fig. 9 - 10. Model n. 1852 in heeled position

1.2. Measurements

The measurements have been performed with an undisturbed wind speed of 13 m/s, the Reynolds number (with the reference of the length of the model) is:

$$Re = \frac{v\,l}{\nu} = \frac{13 \cdot 2{,}32}{14{,}607 \cdot 10^{-6}} \cong 2 \cdot 10^{6}$$

if one takes the breadth of the smaller model as references, it is:

$$Re = \frac{v\,l}{\nu} = \frac{13 \cdot 0{,}258}{14{,}607 \cdot 10^{-6}} \cong 2{,}3 \cdot 10^{5}$$

a condition not completely turbulent, but as already found by Blendermann [17], the local phenomenon of separations does not have a big effect on the total force on the model; then it is possible apply the same wind coefficient for the Ship in real scale.

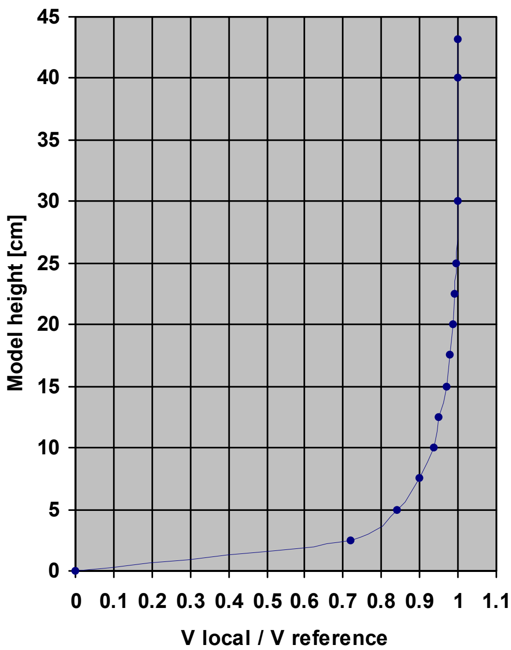

Fig. 11. Wind speed ratio used at the Vienna Model basin

A wind speed variation test on the model n.2036 was conducted to demonstrate the constancy of the wind coefficient.

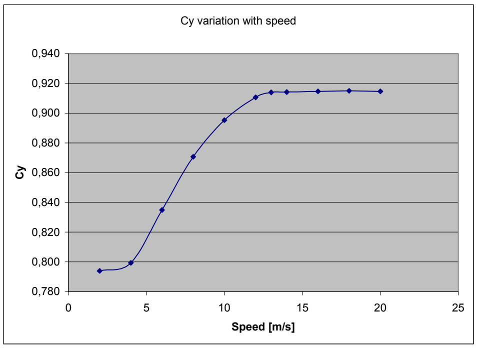

Fig. 12. Wind drag coefficient speed dependency

The wind velocity was chosen in order to satisfy the Newton law (constancy of the wind coefficients with speed) valid for the model and the Ship in real scale being in geometrical similitude. Most of the Ship superstructure are sharp edges giving a defined point of separation; for this reason, although are not satisfying the constancy of the Reynolds number for the model and the Ship (in this case a wind speed for the model of 125 times 26 m/s have to been applied), the constancy of the wind coefficient are considered valid for model and for the Ship in real scale, because possible difference in the flow between the model and the Ship are local point and do not have effect on the global force (total force acting on the Ship). From the figure 12, after abt 12 m/s of wind undisturbed speed, the condition of the constancy of the wind coefficient is reached.

The speed variation test has been performed only for the transversal force as the moment is related to the force. Theoretically the roll moment increase with the square of the speed. The Cy coefficient is the measured component in the transversal direction; the roll moment around the longitudinal axis lying in the waterplane is obtained from the measured moment coefficient; all the forces acting on the model (transversal, lift) have been considered in the measured moment coefficient.

1.3. Wind area

The calculated area values versus the heel are plotted below for the model n. 2036:

The value of the calculated area reaches a maximum at 30 degrees of heeling and then reduces.

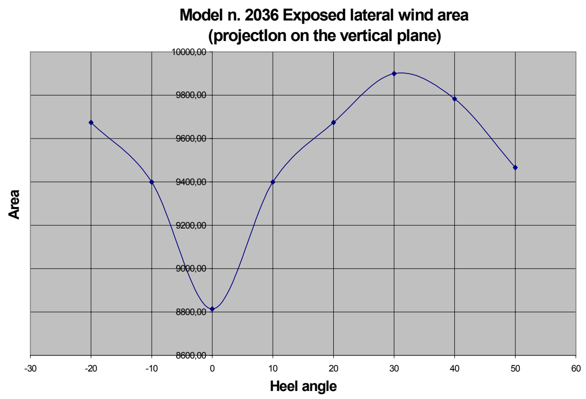

Fig.13.Model n. 2036 Exposed lateral wind area (projection on the vertical plane) at the various angles of heeling

1.4. Forces, moments, centres of pressures coordinates related to the respective geometrical centre.

Here following (fig. 14) are presented the trend of wind coefficients related to undisturbed wind speed of 13 m/s and of the medium speed of 12,168 m/s resulted from the wind speed distribution up to 54 m (in the real scale) compared with the IMO suggestion.

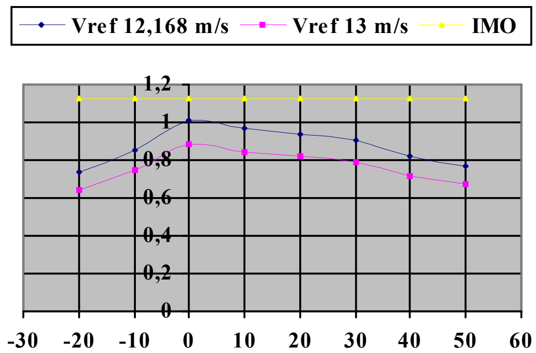

Fig. 14. Wind drag coefficient for the model 1852 compared with IMO wind drag coefficient (the comparison has to be made with the coefficient related to 12.168 m/s)

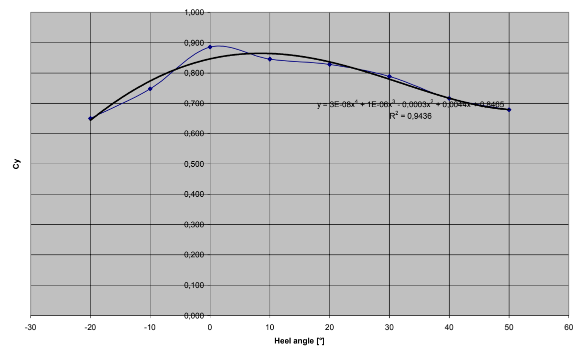

Fig. 15. Wind drag coefficients for the model n.1852

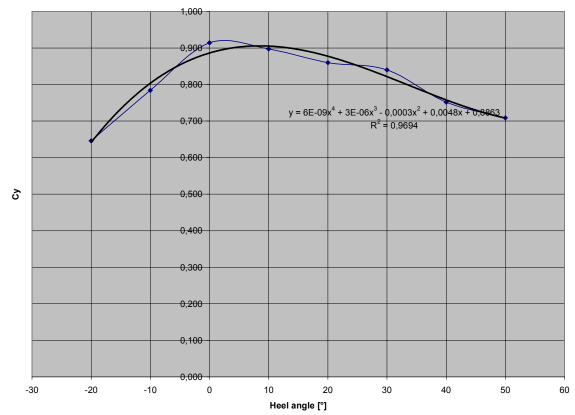

Fig 16. Wind drag coefficients for the model n.2036

The wind speed of 12.168 m/s is the medium of the wind local speed up to 43.2 cm (the height of the model). This was made to compare the wind coefficient with the wind coefficient assumed from IMO (1.13), that considers a constant distribution of speed with the height for the purpose of the calculation but correcting the resulting moment taking in to account the real position of the centre of pressure in respect to the geometrical centre of the area exposed to the wind (this correction is 1.08 as appears from the IMO document STAB XX/4). The constant wind speed associated with the IMO Weather Criterion is abt 26 m/s; the gust wind speed is 1.5 times greater.

The figure 12, 13 and 16 are related to the model n.2036 (panamax ship), the figures 14 and 15 are related to the model n. 1852 (overpanamax ship). The figure 13 is the diagram of the lateral exposed wind area projected on the vertical plane (m^2) in function of the heel. The wind coefficient is constant with speed. In the figures 15 and 16 the wind coefficient is related to the speed of 13 m/s as in figures 12. In figures 12 the wind coefficient is measured at zero heel angle and has the same values of the coefficient of figure 16 (abt 0.915). The wind coefficient of figure 15 has the same value of the coefficient of figures 14 (related to the wind speed of 13 m/s).

Being C_M and C_N the wind moment coefficient of the model and of the Ship measured in respect to the longitudinal axis lying in the waterplane

$$C_M = \frac{M_M}{\frac{1}{2} * \rho * A_M * (V_M)^2 * H_M}$$

$$C_N = \frac{M_N}{\frac{1}{2} * \rho * A_N * (V_N)^2 * H_N}$$

The moment on the Ship in respect to the longitudinal axis lying in the waterplane is:

$$M_N = M_M * \lambda^3 * \left(\frac{V_N}{V_M}\right)^2$$

where V_N are the wind speed for the Ship and V_M the wind speed used for the test, λ is the scale of the model.

The total moment (respect to the centre of the lateral immersed area) is calculated accordingly to the formula (see fig. 18):

$$M_{TOT} = \left[\frac{\left(Z_{WL} + \frac{B}{2} * \operatorname{sen}\theta\right)}{2}\right] * F_N + M_N$$

The total moment is calculated in respect to the half draught according to the IMO method; the only improvement respect to the IMO standard calculation is to substitute the IMO moment with the experimental measured moment respecting the hypothesis that the undisturbed wind speed is 26 m/s.

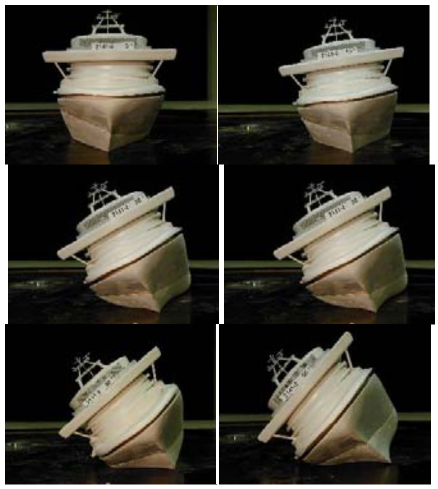

Fig. 17. The model n.1852 in the heeled floating positions from 0 to 50 degrees

To obtain the wind moment acting on the Ship, the moment to the centre of the lateral immersed area has been recalculated:

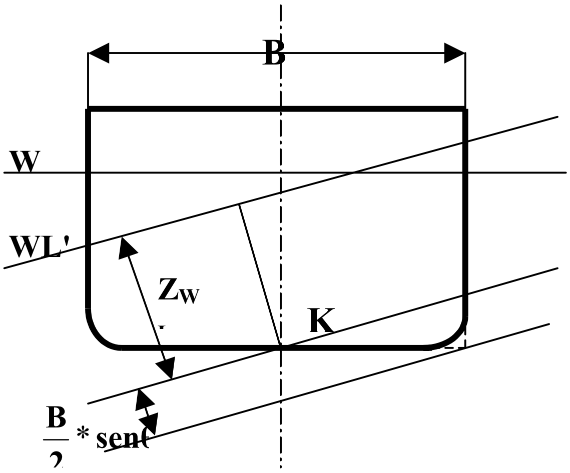

Fig. 18. Reference system used to recalculate the moment to the centre of the lateral immersed area

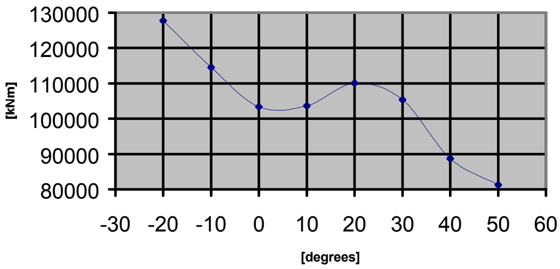

Fig. 19. Wind moment acting on the ship; the moment is calculated respect to the half draught.

From these experiments, results that, for this type of ship, the wind drag coefficients considered from IMO are overestimated and also the ratio between the effective centre of pressure and the geometrical centre as is shown in the following graphs:

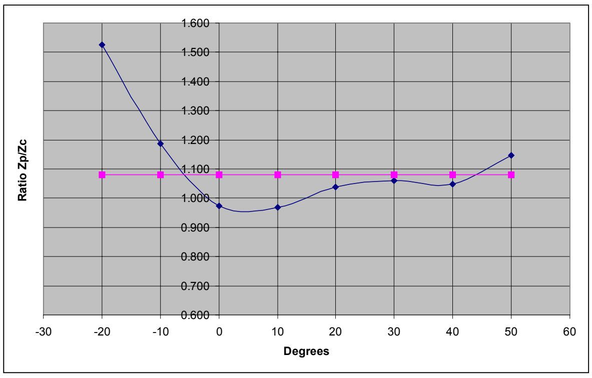

Fig. 20. Comparison between the IMO suggested ratio between the effective centre of pressure and the geometrical centre of the lateral projected area and the experimental results

Comparing the results of the values of KG that verifies the criteria for the model n.1852, it appears that substituting the value of the moment of IMO with the moment coming from the experimental results, the maximum KG could be increased of abt. 25 cm (Fig. 21).

The increasing in maximum KG could reach 40 cm if we consider the new proposed wave steepness at SLF 45.

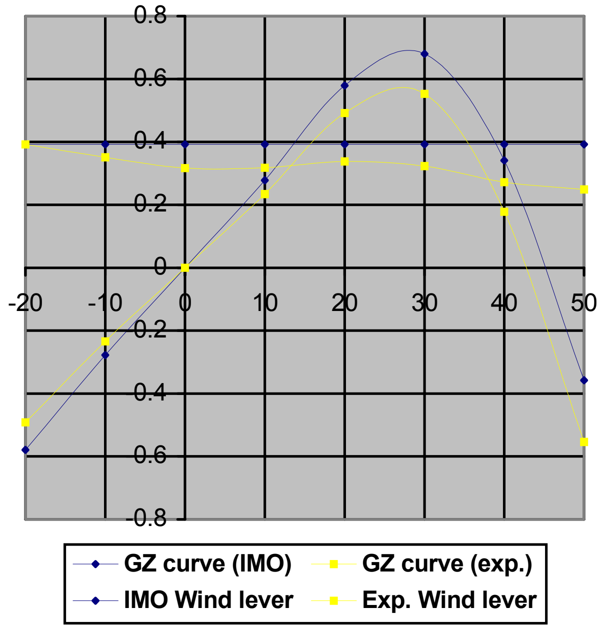

Fig. 21

The effect of experimental wind moment was taken totally in to account; but adopting the method of the weather criterion the absolute value of the backroll angle (θ_1 + θ_0) is abt 5 degrees; where θ_1 (angle of roll to windward due to wave action) is abt 14 degrees and θ_0 (angle of heel under action of steady wind) is abt 9 degrees. For this reason the wind moment is considered only, for this Ship type at 8 m draught even keel, starting from abt -5 degrees, because under the IMO Weather Criterion hypothesis the ship does not reach angles greater than 5 degrees windward.
This allows a release of the height of centre of gravity, which could allow one of the following improvements in the design:

- addition of a light material deck on top;
- removal of the need to use expensive light alloys for the upper deck (part or all).
- Both have a very positive impact on the cost of the construction or on his profitability, while preserving the level of safety of previous design.

The methodology used could be applied, in order to have a modelling of the phenomenon closer to the reality of the possible problems encounter at sea.

2. FURTHER CONSIDERATION

In order to have a more sophisticated model the following considerations have to be made and considered if they could alter the calculations results:

- Real centre of underwater forces

The vertical centre of the underwater forces was assumed at half draught; this seems to be a safe assumption, but further test could be made in order to verify this assumption.

- Effect of drift

The effect of drift of the Ship under the action of the wind forces was neglected; this in fact reduces the heeling moment.
An evaluation could be made adopting a software application tuned on the model test that could represent the combined effect of the sea and wind (dynamic of the Ship in 6 degree of freedom).

- Relation between ship length and heeling moment variance

Up to now, in the framework of a revision of the weather criterion, some efforts have been addressed to the evaluation of new, more physically correct values for wave effective slope coefficient “r” and damping coefficients “X_1” and “X_2” [15][16]. This research work has been concentrated on the “roll side” of the Res. IMO A562. Regarding the analysis on the “wind side”, the majority of works concern about the drag coefficient “C_y”, the heeling moment lever and the dependence of the heeling moment on the heeling angle [15][17][18]. Much less effort has been devoted to the problem of the modelling of the time and spatial correlation of the wind speed field. The ratio between the turbulence scale [19] and the characteristic dimension of the object subjected to the wind load is a parameter that has a very large influence on the coefficient of variation (that is the ratio of standard deviation to the mean value) of the force and of the heeling moment acting on the ship [20]. The larger this ratio, the more the ship can be considered as a “point like structure”, and the larger is the coefficient of variation of moment and force. This is due to the high correlation between wind pressure loads on the different points of the windward (and leeward) side. The smaller this ratio, the larger the ship characteristic dimension when compared with the characteristic dimension of gusts, and thus the less the correlation between loads. In the limit case of an infinitely horizontally long structure, the variance of load and moments would be zero. This effect is well known in the field of civil engineering [21][22][23][24][25] and is already taken into account in the present rules by means of useful diagrams where the relation between building's main dimension and wind field spatial characteristics is reported. The "aerodynamic admittance" function [26] is used together with spectral techniques when the wind spectrum is taken into account for predicting the spectrum of the structure response.

Coming back to Naval Architecture, the probability of exceedence of the moment associated to the gust level prescribed by the present weather criterion is very different when, for example, a 25m long ship is compared with a ship 250m long. The probability of exceedence of the given gust level (1.5 times the mean value of the moment) is higher for the small ship, and lower for the large ship. This is because of the fact that, for a given wind state (modelled as a gaussian stationary, ergodic, homogeneous process), the resulting approximate gaussian probability density function of the force (and moment) is much more narrow for the larger ship (because of the smaller coefficient of variation of the loads). This effect should be taken into account in a future revision of the weather criterion, in order to try to assure the same level of safety against capsize for different ship types, regarding, at least, the "wind side" of the criterion. Today's situation is such that, for different reasons (tuning between real sea spectra and typical roll periods of different ships, lacking of usage of a physically sound modelling of the wind process,...), large ships are associated to a much lower probability of capsizing when compared with small ships [27]. This could be supposed acceptable or not, and could be considered desirable or not, but is a matter of fact and we should be aware of this phenomenon.

3. FUTURE DEVELOPMENTS

An extensive European research project, SAFENVSHIP, has been started on this subject. It will include further studies on the subject, including tests on different shapes of superstructures; at tower configuration, at full beam, overpanamax in order to compare the total heeling moment for the different solutions.

4. CONCLUSIONS

The main aim of the paper is to evidence the opportunity to consider direct calculation coming from the experimental results, preserving the method of the criterion, but, substituting the quantity for which is possible a direct calculation, resulting in much more reliability.

The choice of realistic environmental conditions is very important for the safety and the cost effectiveness of the design. The correct choice is on the other hand a long process that preserves and updates the decisions of the past, based on new experimental proof and observations. The levels of safety are to be kept constant.

5. REFERENCES

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