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Published in:
Mercator

Publication date:
2012

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Citation (APA):
Andersen, I. M. V. (2012). Wind Forces on Container Ships. *Mercator*, (Marts).

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Wind Forces on Container Ships

- Wind-Tunnel Investigation of Wind Loads on a Post-Panamax Container Ship as a Function of the Container Configuration on Deck

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English summary

An investigation of the wind forces acting on a 9,000+ TEU container ship has been carried out through a series of wind tunnel tests. It was investigated how the wind forces depend on the container configuration on the deck using a 1:450 scale model and a series of appropriate container configurations. The wind tunnel tests were carried out in the naturally existing boundary layer of the wind tunnel. The longitudinal and transverse forces and the yaw moment were measured and the measurements were corrected for the effects of the boundary layer and blockage in the wind tunnel. The results are presented as non-dimensional coefficients. It is concluded, that the measured forces and moment depend on the container configuration on deck, and the results may provide a general idea of how the magnitude of the wind forces is affected by a given container stacking configuration on a similar container ship.

Dansk resumé

En undersøgelse af vindkræfterne på et større containerskib er udført. Undersøgelsen omfatter, hvordan kræfter og momenter afhænger af containernes placering, containerkonfigurationen, på dæk. Vindtunnelforsøg er udført med en model af et større containerskib konstrueret af træ i målestoksforhold 1:450. Forsøgene er foretaget i vindtunnelens naturlige grænselag, der i den forbindelse er opmålt, ligesom der inden forsøgenes start er foretaget en test af koefficienternes afhængighed af Reynoldstallet. Måleapparatet, der er benyttet til at måle kræfter og momenter er en 6-komponent strain gauge, der inden forsøgene er kalibreret. Langsgående kraft og tværkraft samt krængende og girende moment er undersøgt. Resultaterne er præsenteret som dimensionsløse koefficienter. Det viser sig som ventet, at kræfter og det moment, det var muligt at måle, i høj grad afhænger af containerkonfigurationen på dæk, og sammenhængen er søgt beskrevet.

INTRODUCTION

The fuel efficiency and performance of container vessels is of great concern for shipowners due to economic and environmental considerations. Much effort is put into measures that can improve ships' fuel efficiency by even a few per cent.

All ships experience air and wind resistance while under way at sea, and they may experience adverse effects of wind while manoeuvring in harbours and confined waterways. From a fuel-consumption point-of-view the resistance experienced while the ship is under way is of greatest interest.

The wind resistance is proportional to relative wind speed squared, wind direction and the projected windage area of the ship. Unlike most other ship types a container ship has a windage area that varies significantly with the loading condition i.e. the configuration of containers on deck.

Wind tunnel investigations of the container configuration's influence on the wind forces have been carried out for smaller container ships and investigation of concerning more general ship types also exist, although they are of an earlier date (Andersson 1978, Aage 1968, Berlekom 1981, Blendermann 1997). Today, the size of container ships has increased and it is considered relevant to investigate a larger ship. Furthermore, the service speed of container ships has increased in recent years, which results in relative wind directions closer to head wind and higher relative wind speeds giving the wind resistance a larger share of the total resistance.

The aim of the present study is, through a purely experimental approach, to provide directly applicable results for container ship operators.

METHODS

Coordinate system

The coordinate system is a standard Cartesian right handed coordinate system fixed to the ship. It is illustrated in Figure 1 and defined as follows:

- The *x*-axis is positive forward.
- The *y*-axis is positive to starboard.
- The *z*-axis is positive downwards.

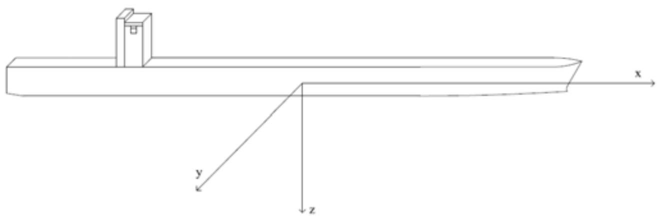

Figure 1 – Definition of coordinate system.

In the wind tunnel two forces and one moment were measured (see Figure 2):

- Longitudinal force, positive in the direction of *x*. Here designated *X*.
- Transverse force, positive in the direction of *y*. Here designated *Y*.
- Moment about *z*-axis (causes the ship to yaw). Positive when ship bow moves to starboard. Here designated *N*.

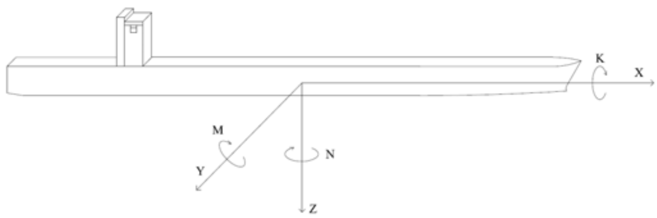

Figure 2 - Definition of forces and moments.

Wind Forces on Ships

The wind forces on a ship generally influence the ship by increasing the resistance while the ship is under way. The longitudinal force generally constitutes the largest part of the total wind induced resistance.

The transverse force causes yaw, drift and deviation from the intended course, which can cause added resistance in two ways. The ship's heading is not aligned with the steered course, which alone gives greater resistance. The drift must be compensated for, which means that the rudder angle must be increased. Increased rudder angle will also cause increased resistance.

Generally, the longitudinal force is of greatest importance for the propulsion resistance. However, there is general agreement that under normal operational circumstances the wave resistance constitutes the largest part of the total resistance (see, for example, Berlekom 1981, Andersson 1978, Aage 1968).

Relative Wind

When the air flows over the ocean surface from any direction a natural boundary layer is formed. This means that the wind velocity at the surface is zero and increases with higher altitude. The local wind field caused by the movement of the ship does not have a boundary layer and is homogenous as illustrated in Figure 3.

Figure 3 - Local wind field caused by ship and the natural velocity profile at sea.

The actual wind field encountered by the part of the ship above the water surface is thus a combination of the wind field with a boundary layer and the homogenous wind field caused by the ship's forward speed. The relative wind direction φ is found by vector addition of the ship's wind field and the relative wind. Here $\varphi = 0°$ is head wind.

Non-dimensional Coefficients

The measured forces and moments are post-processed into non-dimensional coefficients. This is to make the results independent of wind velocity and ship size. The results are normalised using the flow velocity in the middle of the wind tunnel, U, the density of the air, ρ, and the ship's length between the perpendiculars (L_{pp}) in a suitable exponent. The described procedure is practical if different configurations of the same ship are to be compared because they are normalised using the constant length between perpendiculars. If one wishes to compare different container ships, that are not geometrically identical to the tested ship, the results should be normalised using the projected side and front areas instead of ship length. The following non-dimensional coefficients are defined and used in presentation of the results:

$$X' = \frac{X}{½ \cdot \rho \cdot U^2 \cdot L_{pp}^2}$$

$$Y' = \frac{Y}{½ \cdot \rho \cdot U^2 \cdot L_{pp}^2}$$

$$N' = \frac{N}{½ \cdot \rho \cdot U^2 \cdot L_{pp}^3}$$

Earlier Investigations

Earlier investigations (Andersson 1978, Berlekom 1981) involving wind tunnel tests of physical models of container ships conclude that the container configuration influences the wind forces. Uneven bay height increases the wind resistance, and a ship with randomly stacked containers on deck compared with a fully loaded ship experience:

- Significantly higher longitudinal force.
- Smaller transverse force.
- Smaller roll moment.
- Smaller yaw moment.

Additionally, a ship with random configuration on the fore deck (forward of the superstructure) and a full container stacking on the aft deck (aft of the superstructure) has a significantly reduced yaw moment for relative wind directions between 0° and 50°. Furthermore, the following conclusions are drawn:

- Changes in the configuration on the aft deck have little influence on the magnitude of the longitudinal force. Thus there is little difference between the empty ship and a ship, which only carries containers on the aft deck.
- Changes to the configuration on the fore deck are of great importance for the magnitude of the longitudinal force.
- Random container configuration can increase the longitudinal force significantly. Large irregularities such as many empty bays can increase the longitudinal force by 70-100% compared to the fully loaded reference ship for relative wind from ahead.
- Streamlining of the container configuration on the front deck has little influence on the longitudinal force.
- The influence of the configuration on the yaw moment is remarkable. A configuration with containers on the front deck but without containers on the aft deck is disadvantageous (the yaw moment becomes large) for relative wind from ahead. The opposite is the case for relative wind from aft.
- The influence of the side area of the ship on the transverse force and the roll moment is large.

Model

The model in the present study is of scale 1:450. Only the part of the ship above the waterline is modelled. For practical reasons the model only has one draught which is the design draught of 13 meters. The ship has the following approximate main dimensions:

L_{oa}:	340 m
L_{pp}:	320 m
Beam:	45 m
TEU capacity:	9000+

The maximum length of the model is limited by the width of the wind tunnel. The model must be able to be turned 180° in the wind tunnel, which limits the length of the model to about 75 cm and a decides the model scale of 1:450.

The model is very simple, but the small degree of detail is not considered to impact the result negatively. On the contrary, the effect on the model test results of a high degree of detail would be larger than in full scale, because the relative effect of all small details would be larger in the model tests.

The model has 20 container bays numbered from aft as seen in Figure 4. The model itself is illustrated in Figure 5. The container blocks were cut out in hard foam and fixed to the model with strong double adhesive tape in order to make them replaceable. A container bay has the same height across the width of the ship.

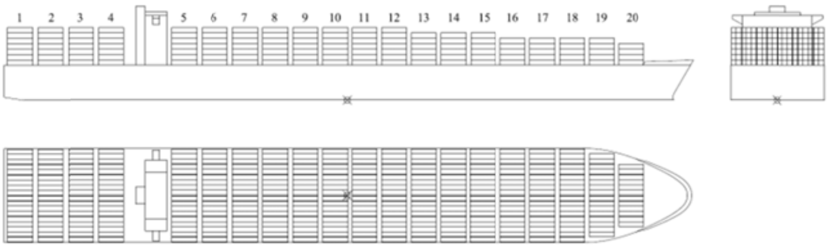

Figure 4 - Ship model with full load reference condition (01-01-02) and numbered bays. 100% of full deck load.

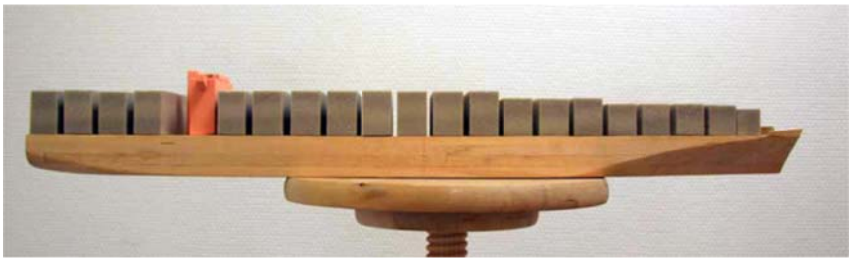

Figure 5 - Wind tunnel model with full deck load.

Wind Tunnel Equipment

The wind tunnel is a closed tunnel with a maximum speed of 80 m/s. The tunnel is used for testing small-scale models of ships and off-shore structures. The model and the strain gauge are mounted through holes in the floor of the wind tunnel. The flow speed in the tunnel is controlled by adjusting the dynamic pressure. The wind tunnel can be seen in Figure 6.

Figure 6 - Wind tunnel at FORCE Technology.

The forces and moments acting on the model were measured with a strain gauge with six degrees of freedom.

Boundary Layer

The previously mentioned combined wind field is difficult to create in any wind tunnel and not possible to create in this particular wind tunnel. Alternatively the aim was, if possible, to do the tests in a velocity profile corresponding to the natural profile over the ocean (blue dots in Figure 7.

The flow velocity profile was measured in two different locations in the wind tunnel in order to locate the most suitable position of the model in the wind tunnel and enable correction for the effect of the boundary layer on the measurements. The measured flow velocities are plotted as a function of the height above the floor of the wind tunnel in Figure 7 together with the desired ocean wind velocity profile scaled to the model scale (blue).

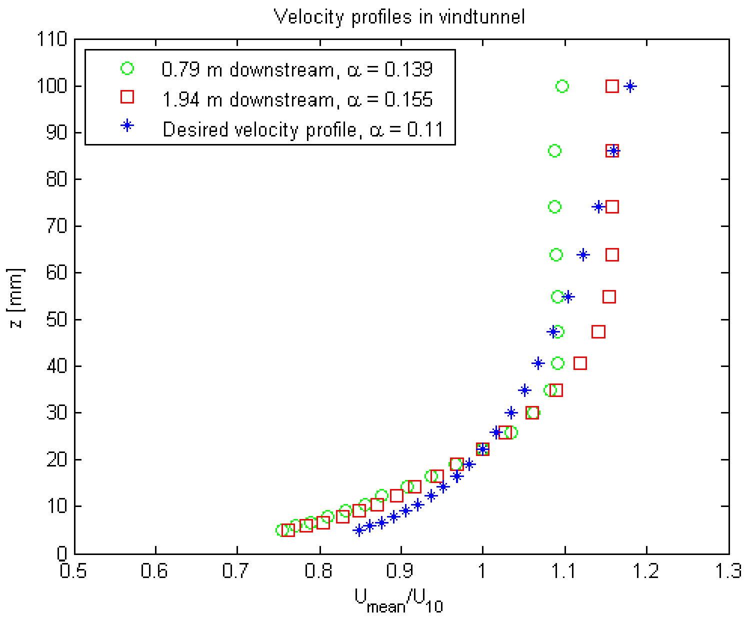

Figure 7 - Hot wire measurements of mean velocity in wind tunnel.

Reynolds number

Prior to the tests it was investigated how the measured coefficients depend on the Reynolds number[1]. The Reynolds number is of great importance for model tests and generally the Reynolds number in model scale should correspond to the full scale Reynolds number. However, the required flow speed is not possible to obtain in this wind tunnel. Nevertheless it is considered possible to conduct model tests even if the Reynolds number is not matched, if the model is sufficiently "sharp-edged" and the flow separation corresponds to full scale. From the tests it was confirmed that the measured coefficients were constant, and thereby independent of the flow velocity, for Reynolds number larger than 1.5×10^6. It was thus decided to carry out the tests at a flow velocity of about 45 m/s, which corresponds to a Reynolds number of about 2.2×10^6.

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[1] The Reynolds number is a dimensionless measure of the ratio of inertial forces to viscous forces for given flow conditions.

Wind Tunnel Test Procedure

The model could be turned 360° in the wind tunnel to expose it to flow from all possible relative wind directions. In practice only 0-180° with intervals of 10° were investigated, since the model was assumed to be symmetric. It was possible to change the container configuration on deck without removing the model from the wind tunnel.

Corrections

The free flow velocity was measured at a position in the middle of the wind tunnel. However, the velocity used for making the measurement results non-dimensional should be the velocity experienced by the model. The model is located within the boundary layer and thus the flow velocity experienced by the model is thus lower than the free flow velocity. The measurements are corrected for the boundary layer effect using the results from Figure 7.

In the wind tunnel the model partly blocked the flow, so a further correction had to be applied. The measurements were corrected for the effect of blockage using a standard procedure for wind tunnel tests. The blockage was max 7.4%.

Container Configurations

Many conditions are considered when loading containers on board a ship:

- Reefer containers must be placed where the power supply for the refrigeration is located. Hazardous goods containers have designated locations.
- Containers are loaded for unloading in the right order at different ports of call.
- Heel, trim and stability are taken into consideration when loading the ship.
- The weight of the individual containers dictates the maximum allowable height of a stack to avoid destructive forces on the containers in a seaway.
- For ships of this size it must be possible to see the sea surface from the bridge 500 m in front of the ship.

Thus, it is far from coincidental how the containers on deck are stacked, but the result may very well look coincidental. Very uneven container configurations are widespread and the influence of container configuration on the wind forces rarely seems to be taken into account.

Some of the tested configurations are briefly described in the following. For reason of space constraints, only a few of the tested configurations are described in this article. In total, 31 different configurations were tested.

<u>Streamlined</u>
The effect of streamlining the container configurations was investigated to see whether there is a difference between streamlining the configuration fore and aft of the bridge or both.

<u>Random stacking</u>
Most container configurations are more or less random. Obviously there are different degrees of "randomness" or "unevenness" in container configurations and some has been exemplified in the selected configurations. The degree of unevenness is considered to depend on the difference between the highest and lowest container stacks.

RESULTS

The measured forces were made non-dimensional using the measured dynamic pressure for each test run. Thereafter the coefficients were corrected for boundary layer and blockage as previously described. The coefficients were plotted as a function of the relative wind direction, φ.

Uncertainties and Irregularities

Several uncertainties are associated with the results, particularly with transferring the results to full scale. The most important probably being the effect of the velocity profile in the wind tunnel not corresponding to a natural, full scale velocity profile which fully represents the real boundary layer combined by the natural wind boundary layer and the constant velocity profile from the ship's forward speed.

Scaling inaccuracies may also influence the results. Most details are omitted on the model which means that the coefficients are likely to be on the small side.

Results

The results are presented in the following. Of greatest interest for container ships with forward speed is the behaviour of the forces for relative wind directions between 0-50° (head winds). The fully loaded condition is used as the reference condition (see Figure 4).

Streamlined configurations

The smallest longitudinal force was found for the configuration streamlined both fore and aft (Figure 9) as seen in Figure 11. Compared to the fully loaded configuration the reduction in longitudinal force was significant, and for a relative wind direction of 50° the difference was 43%. The difference was almost as large for the configuration that was streamlined aft only (Figure 8).

For the yaw moment there was a distinct difference. The configuration streamlined on the fore deck (Figure 10) had a clearly smaller yaw moment than the other configurations for head winds, and the configuration streamlined aft had the largest yaw moment for head winds.

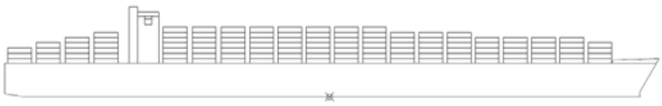

Figure 8 - Configuration 01-04-01 streamlined aft. 91.9% of full deck stacking.

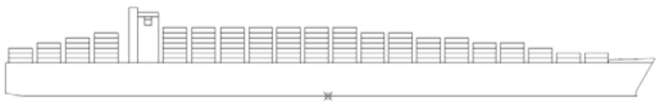

Figure 9 - Configuration 01-04-02 streamlined fore and aft. 83.1% of full deck stacking.

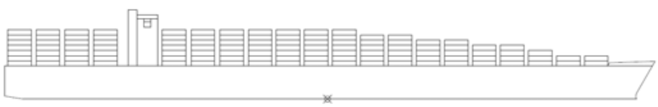

Figure 10 - Configuration 01-04-03 streamlined fore. 91.1% of full deck stacking.

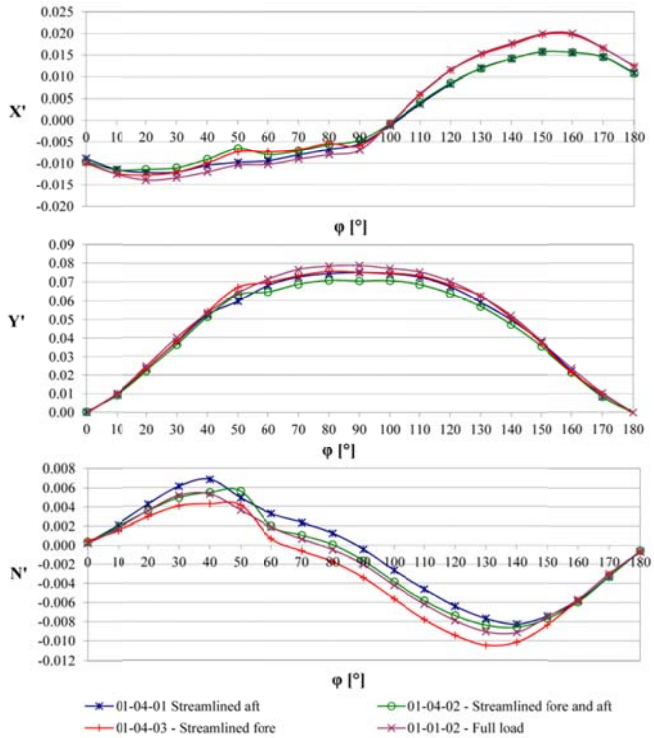

Figure 11 - Streamlined configurations compared to the fully stacked condition.

<u>Random stacking of containers</u>

A configuration with random stacking on the entire deck (Figure 12) was compared with a configuration with random stacking on the front deck and full container stacking of the aft deck (Figure 13) and the fully loaded reference condition in Figure 4. The comparison is illustrated in Figure 14. The longitudinal force turns out to be significantly larger for the two conditions for relative head winds. The difference for relative wind from 30° is 54%. The tendency for following winds is the same though less pronounced. The configuration with random stacking on the fore deck and full stacking on the aft deck experienced a reduced yaw moment compared to the completely random configuration for head winds.

Figure 12 - Configuration 01-05-01. Random stacking over all. Highest stacking height seven containers. 68.9% of full deck stacking.

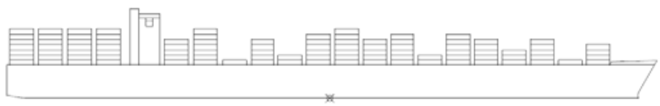

Figure 13 - Configuration 01-05-02. Random stacking fore, full stacking aft. Highest stacking height seven containers. 77.8% of full deck stacking.

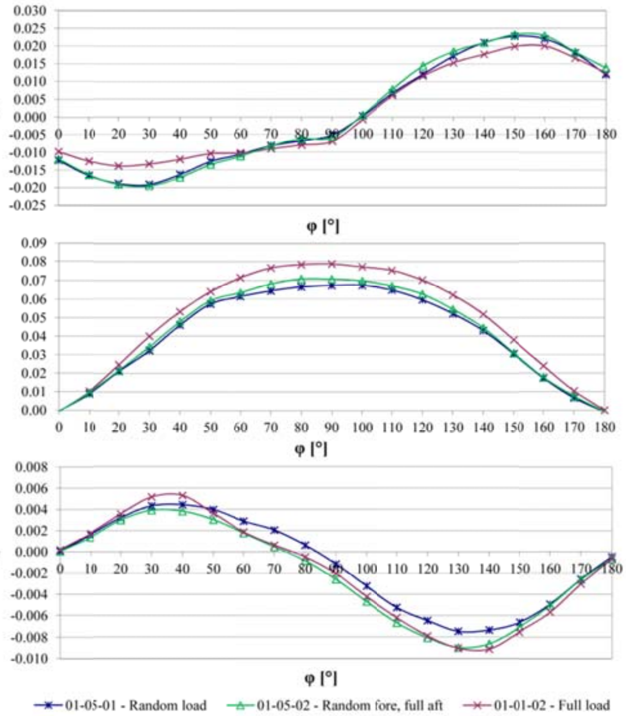

Figure 14 - One configuration with random stacking overall and one with random stacking on fore deck and full container stacking aft compared to the fully loaded condition.

Other stacking combinations have also been investigated, but are omitted here due to space constraints. The results from the complete series of tests can be found in Andersen (2012a, 2012b). However, in the following, the conclusions are drawn based on all tests.

DISCUSSION AND CONCLUSION

The wind forces acting on a large container ship as a function of the container configuration were investigated in wind tunnel tests of a simplified 1:450 model of a container ship in the wind tunnel's naturally occurring boundary layer. The measurements were corrected for the effect of the boundary layer and blockage in the wind tunnel.

The measurements carried out here serve the purpose of indicating the influence, trends and tendencies of different stacking configurations used in practice on board container ships rather than for the purpose of assessing the full scale wind resistance of a given container ship. The small degree of detail and the boundary layer in the wind tunnel probably means that caution must be exercised when scaling up to full size forces.

Container ships in operation will most frequently encounter relative winds in the range of 0-50° which makes this interval the most relevant to concentrate on. From a global resistance point-of-view it is of greatest interest to reduce the longitudinal force and the yaw moment.

The measurements showed clear relationships between the container configuration and the wind forces acting on the ship model.

In general, the longitudinal force increased with increasing unevenness of the container configuration. The degree of unevenness is hard to define, but it appears that the difference in height between the individual bays plays the major role for the force. If the difference in height between individual bays was pronounced and if there were high bays exceeding the height of the other bays on the deck, it increased the longitudinal force. The longitudinal force for head winds did not seem to depend on the projected front area of the model, but more on the container configuration along the full length of the model.

The transverse force appeared to be the easiest to predict being more or less directly proportional to the projected side area of the ship. This was the case for all investigated configurations except three pyramid shaped configurations. However, the degree of extent to which the configurations approximated to a pyramid did not seem to influence the transverse force much. Thus, the transverse force, of concern in beam winds, depends largely on the side area of the ship, and for a fully loaded ship it can be reduced by reducing the stacking height in the outermost stacks.

The factor primarily influencing the yaw moment was the side area of the model and, more importantly, how the area was distributed over the ship's length. For configurations with relatively more containers on the aft deck a clear reduction in the yaw moment was observed for relative head winds. Thus, the yaw moment seemed to depend on the size and centre of gravity of the side area of the ship. The more aft the centre of gravity was located, the smaller was the yaw moment for relative head winds. The yaw moment in relative winds from fore can be reduced by aiming at stacking as many containers as possible on the aft of the ship and thereby make it possible to reduce the resistance induced from drift and increased rudder angle.

For reducing the longitudinal force in relative winds from fore it is advantageously to make the container configuration as smooth as possible, and streamlining can reduce the longitudinal force for head winds further. However, streamlining of the configuration on the aft deck is a trade-off as it increases the yaw moment compared to full stacking on the aft deck. High container stacks (i.e. a bay protruding up over the remaining bays) in the configuration appear to increase the longitudinal force more than a corresponding "hole" (i.e. low or empty container bays) in the configuration.

A general recommendation would be to make the configuration as smooth as possible and furthermore to ensure that the centre of gravity of the side area is as far aft as possible.

ACKNOWLEDGEMENT

The author wishes to sincerely thank Jimmie Stig Beckerlee from FORCE Technology for invaluable help and expertise regarding the use of the wind tunnel, strain gauge and computational equipment. Also thanks to supervisor Poul Andersen, DTU Mechanical Engineering and Co-supervisor Kjeld Roar Jensen from FORCE Technology.

Financial support for constructing the model of the container ship from the Danish Maritime Fund through the Danish Center of Maritime Technology (DCMT) is very much appreciated.

Lastly thanks to Mikkel Nyerup Andersen, Maersk Line for useful information about container stacking practices on board the largest container ships in the Maersk Line fleet.

REFERENCES

Aage, C. (1968). "*Vindkræfter på Skibe*." Institut for Skibs- og Havteknik, Danmarks Tekniske Højskole.

Andersen, I. M. V. (2012a). "*Wind-Tunnel Investigation of Wind Loads on a Post-Panamax Container Ship as a Function of the Container Configuration on Deck*". Conference paper for presentation at the International Marine Design Conference 2012, Glasgow.

Andersen, I. M. V. (2012b) "*Wind Loads on Post-Panamax Container Ship*". Currently being reviewed for publishing in the Journal of Ocean Engineering.

Andersson, G.O. (1978). *"Untersuchung der Fahrtverluste durch Wind und Seegang bei einem schnellen Einschrauben-Containerschiff."* Bundesministerium für Forschung und Technologie, Meerestechnik.

Berlekom, W. B. van. (1981). "*Wind Forces on Modern Ship Forms - Effects on Performance.*" Swedish Maritime Research Centre.

Blendermann, W. (1997). "*Messung der Windlast an zwei Containerschiffen in realem Ladezustand im Windkanal.*" Institut für Schiffbau der Universität Hamburg.

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