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Operational margin from weather and motion database for heavy transport vessels

by

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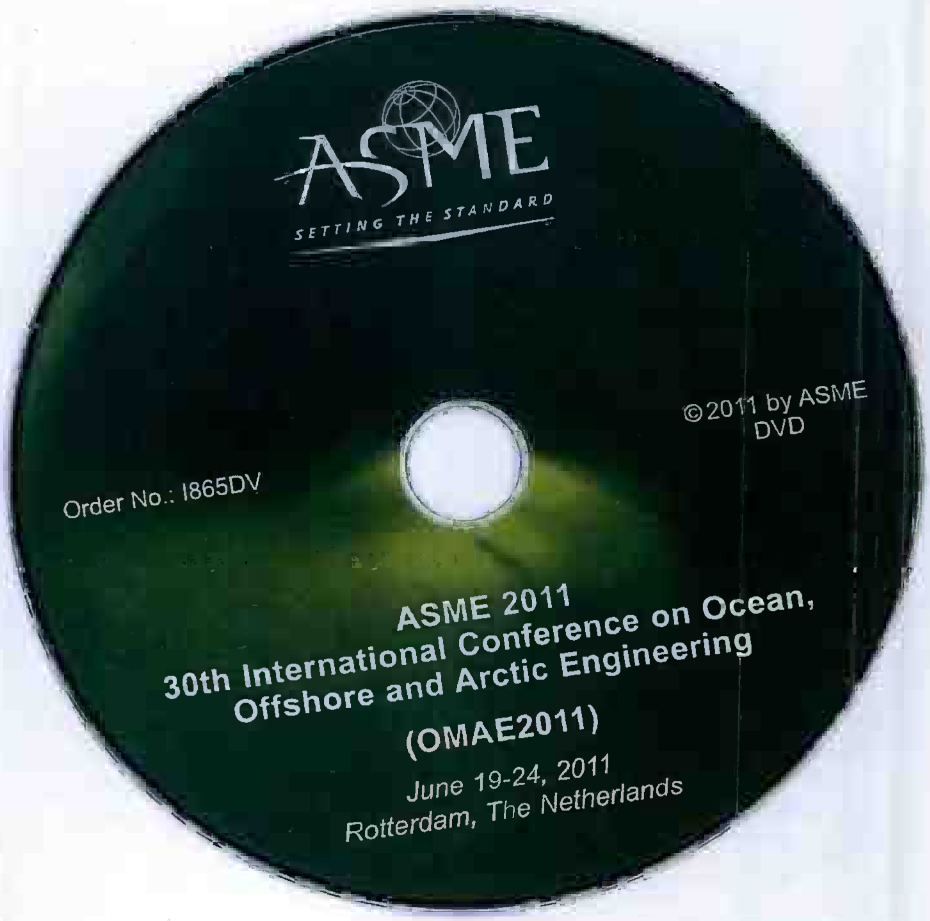
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OPERATIONAL MARGIN FROM WEATHER AND MOTION DATABASE FOR HEAVY TRANSPORT VESSELS

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ABSTRACT

While shipping large and heavy cargo like jack-up rigs or semi-submersibles, the Motion Monitoring and Captain Decision Support system is a valuable tool to ensure a safe and economical voyage. Using the dynamic characteristics of the vessel, in combination with 5-day weather forecasts and design limits like maximum accelerations at the cargo location, roll motion and/or leg bending moments, more and better information is available to the Master to choose safe route, heading and speed. This way the best knowledge of what to expect is contributing to the safety of cargo, vessel and crew.

The Octopus onboard system gathers a large amount of information about ship position, speed, heading, nowcast weather data and corresponding ship motion data. Reference is made to the paper of Peters [2] for background information of the Octopus Motion Monitoring and Decision Support system and an overview of methods used by the motion measurement system. In May 2008 the first Dockwise vessel started to gather weather and ship motion data. It is estimated that each vessel gathers around 50.000 nautical miles of data in a year, which is all collected in a database. The paper presents how this information is used for general research to environmental data, ship motion data and comparison to design values.

Scatter diagrams from nowcast weather data can be produced. After collecting a certain amount of measurements, so called Dockwise scatter diagrams could be used as input for future voyage calculations. With this engineering approach Masters decisions for weather routing and bad weather avoidance is taken into account. This could lead for example to reduced design wave for a passage around the Cape of Good Hope.

Now casted weather data and ship motions data is compared to design values from the cargo securing manual. Statistics like maximum difference, average difference give extensive data and insight in the operational margin of Dockwise transports. The calculation of the operational margin is independent of the standard safety margin valid for each transport.

The conclusion is that the recorded nowcast significant wave height for the analyzed voyages never exceeded 5.0 [m]. With larger design wave heights the minimum operational margin increases to more than 40%, while the lowest operational margin occurs at design wave heights around 4.5 [m]. The database built by gathering all relevant information from the system and from crew observations, increases insight in the operational margins, which contributes to increased knowledge and safety.

INTRODUCTION

With the octopus system installed on 15 HTV's, a lot of valuable data is gathered. In 2½ year over 1.000,000 [nm] voyage data was gathered and post processed. During writing about 530,000 [nm] from 55 transports is investigated for this research, see Annex A. From the data several important insights can be obtained:

- How does nowcast wave height compares to design wave height?
- How do acceleration measurements compare to design accelerations?
- How does predicted response and measured response compare?
- Which environment has been encountered by the vessels?
- How often did the master need to deviate from route to avoid bad weather?
- How close was the maximum encountered condition to the design conditions?

These questions can be answered for all voyages together, for each voyage, for each area as indicated in Annex A and/or for specific voyage legs, like rounding of Cape of Good Hope. Also seasonal variation can be investigated.

By answering these questions more insight is given to the heavy transport engineering and it improves knowledge about operational margins.

Annex B shows an example comparison of nowcast accelerations and measured accelerations. Here, a reasonable match is found, however during other voyages larger differences have been found. It is obvious that crew observations and/or wave radar and/or wave buoy data is desired to identify if weather forecast is accurate. Some weather observations from the vessels crew are available and are used for verifications of single voyages; this is not presented in this paper. Please note that all recorded nowcast data is included in the calculations and the figures.

NOMENCLATURE

CoG	Center of Gravity
CSM	Cargo Securing Manual
DW	Dockwise
GWS	Global Wave Statistics
HTV	Heavy Transport Vessel
MPE	Most probable extreme
RAO	Response Amplitude Operator
SPOS	Ship Performance Optimization System
$x/\ddot{x}$	Motion /acceleration in longitudinal direction
$y/\ddot{y}$	Motion /acceleration in transverse direction
$z/\ddot{z}$	Motion /acceleration in vertical direction
$\ddot{x}_p$	Measured acceleration in single point
$\ddot{x}_{ref}$	Reference point like cargo CoG where the accelerations are transferred to

SYSTEM DESCRIPTION

A description is given about signal processing details of the Octopus system. For more general information regarding the Octopus system reference is made to Adegeest [1] and Peters [2].

Response prediction

The response of the vessel like roll angles, pitch angles and accelerations in the CoG of the cargo are calculated by the Octopus system based on several input sources. Input for the calculation contains the loading condition from the onboard program General Hydrostatics (GHS), the hydrodynamic database with added mass, damping and wave force terms, the weather forecast & nowcast and some project specific data like the position of the CoG of the cargo and radii of gyration.

For each transport a project file is created that contains information about the position of the cargo, the weight and the own radii of gyration. Together with the loading condition data from GHS, Octopus calculates the actual radii of gyration of the system.

For each vessel the hydrodynamic database, as derived with 3-D diffraction method, contains added mass, damping and wave force tables for a range of vessel drafts. The influence of trim is taken into account by deriving the hydrodynamic data for a number of longitudinal segments. By inserting the actual draft and trim the system interpolates and derives a speed dependant RAO for the actual loading condition. The RAO contains also bilge keel damping and stochastic linearization for roll motions.

Weather data

The DW vessels receive weather forecast and nowcast files for SPOS from Meteo Consult two times a day. Nowcast data is the predicted weather at the actual vessels position and moment in time. The GPS position is logged every minute as the vessels speed and heading changes continuously. Due to the moving vessel and a certain grid size as used by SPOS the weather forecast may change quickly. Therefore the weather data, depending on vessels position is logged also every minute. The weather data contains, but is not limited to, significant wave height, wave direction, wave period, swell wave height, swell direction, swell period, wind speed and wind direction.

Based on the nowcast weather data the vessels response in the CoG of the cargo is calculated. The response for acceleration and roll and pitch angles is given in 3-hour Most Probable Extreme values (MPE).

Measurements

The Octopus system determines the translational and rotational accelerations in the center of gravity of the cargo, using the following equations. Eq .1 defines the translational accelerations in a given location p with respect to a reference location ref. This equation is simplified to Eq. 2

$$\ddot{x}_p = \begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & z_p & -y_p \\ 0 & 1 & 0 & -z_p & 0 & x_p \\ 0 & 0 & 1 & y_p & -x_p & 0 \end{bmatrix} \cdot \begin{bmatrix} \ddot{x}_{ref} \\ \ddot{y}_{ref} \\ \ddot{z}_{ref} \\ \ddot{\varphi} \\ \ddot{\theta} \\ \ddot{\psi} \end{bmatrix} \qquad \text{Eq. 1}$$

$$\ddot{x}_p = T_{ref \to p} \cdot \ddot{x}_{ref} \qquad \text{Eq. 2}$$

As accelerations in three locations are measured, the accelerations in the reference location can be determined by solving Eq. 3. Acceleration in the reference location is defined by Eq. 4.

$$\begin{bmatrix} \ddot{x}_{p1} \\ \ddot{x}_{p2} \\ \ddot{x}_{p3} \end{bmatrix} = \begin{bmatrix} T_{ref \to p1} \\ T_{ref \to p2} \\ T_{ref \to p3} \end{bmatrix} \cdot \ddot{X}_{ref} \quad \text{or} \quad \ddot{X}_{sns} = T_{sns} \cdot \ddot{X}_{ref} \qquad \text{Eq. 3}$$

$$\ddot{X}_{ref} = (T'_{sns} \cdot T_{sns})^{-1} \cdot T'_{sns} \cdot \ddot{X}_{sns} \qquad \text{Eq. 4}$$

The measurements are performed with a rate of 20 [Hz]. From the direct measurements the data is filtered and converted to a MPE value every 15 minute interval for all signals.

Interpolation and Synchronization

Nowcast data, with one minute intervals, and measured data, with fifteen minute intervals, is interpolated and synchronized to one minute intervals in order to allow for numerically comparison between the nowcast data and the measured data.

Figures

All calculations are performed with the interpolated signals at a refresh rate of one minute. For clarity reasons the points in all figures are reduced by plotting 3-hour maximum values.

METHOD

The available data is post processed into a number of parameters and figures in order to compare the nowcast, measured and design values. Below paragraphs describe how different parameters are determined and which output is used for comparison of the data. All calculations are performed for each transport separately and saved in a database. From the database information is extracted for the combination of all transports.

Nowcast compared to Design

The logged GPS position is used to determine which Areas according the GWS are crossed during each transport. The nowcast significant wave height is compared to the design wave height for each area of a voyage; the design wave height is determined for each single transport based on Scatter diagrams, for each Area, season and transit time. Reference is made to Dockwise Guidelines and Criteria [3] for a detailed description on design environmental calculations.

From the nowcast wind and swell waves a total wave height per time step is determined by taking the quadratic sum of both waves. Results of the wave height comparison are shown in Figure 1. The following formula is used to determine the non-dimensional $\delta_{nowcast\_Design}$, which will be used for a comparison to $\delta_{Measured\_Design}$ in Figure 8 and Figure 9.

$$\delta_{Nowcast\_Design} = \frac{nowcast}{Design} \quad \text{Eq. 5}$$

Measured compared to Design acceleration

The measured acceleration is compared to a single design acceleration value, which is determined with Shipmo for each voyage. Reference is made to Dockwise Guidelines and Criteria [4] for a detailed description on ship motion calculations by Shipmo. The measured acceleration is plotted against the design acceleration in Figure 2 and Figure 3. A different way of interpreting the data is by calculating the $\delta_{Measured\_Design}$ according to Eq. 6.

$$\delta_{Measured\_Design} = \frac{Measured}{Design} \quad \text{Eq. 6}$$

The number of occurrences versus the value of this δ gives important information on the actual operational margin during heavy transports. The total number of 3-hour occurrences, as plotted in Figure 4 and Figure 5 is 13470, which is around 1684 sailing days of different Dockwise vessels.

Nowcast compared to measured acceleration

For validation purposes regarding the contribution of the Octopus system to safety of the vessel, crew and cargo, it is important to compare the nowcast signals to the measured signals. Ultimately these values should be equal, but due to uncertainty in the weather forecast (wave height and period) or small variation loading condition, differences are found.

For this comparison the non-dimensional $\delta_{nowcast\_Measured}$ is used as given by Eq. 7. This formula delivers values between plus and minus one. For example, if the value is 0.5 then nowcast was larger than Measured and the difference was 50% of the design value.

$$\delta_{Nowcast\_Measured} = \frac{nowcast - Measured}{Design} \quad \text{Eq. 7}$$

For x and y acceleration $\delta_{nowcast\_Measured}$ is plot against measurements in Figure 6 and Figure 7. From this plot conclusion are drawn for small and large measured accelerations.

Figure 8 and Figure 9 show a different way of comparing nowcast and Measured signals. Both the nowcast and Measured signals are made non-dimensional with the design value. If points are located on the red line the nowcast is equal to the Measured.

RESULTS

Nowcast compared to Design wave height

Figure 1 clearly shows that the design wave height was never exceeded according to the recorded nowcast wave height from SPOS. Looking to the maximum recorded nowcast significant wave height of 5.0 [m] our masters have been able to avoid larger forecasted waves. This is an interesting conclusion because it shows that our masters avoid regions where the forecast wave height is larger than 4.5-5.0 [m]. This graph validates the DW/Anglo Eastern policy about avoiding heavy weather for HTV's. In addition there is a time factor which avoids vessels ending up in excessive waves, in the order of 9 to 10 [m], which typically need some time to build up and hence are predictable in advance. Please note that the actual wave height could have been larger when the forecast underestimated the weather.

Figure 1 also clearly shows that with increasing design wave height the operational margin increases. While the lowest operational margin occurs at 4.5 [m] significant design wave height, the $\delta_{nowcast\_Design}$ for higher design sea states reduces to values smaller than 60%. This trend is traced back to the fact that master's decisions about routing and bad weather avoidance increase the operational margin at larger design waves. Generally speaking it is shown that design waves larger than 5.0 [m] are never encountered for the analyzed voyages in this database.

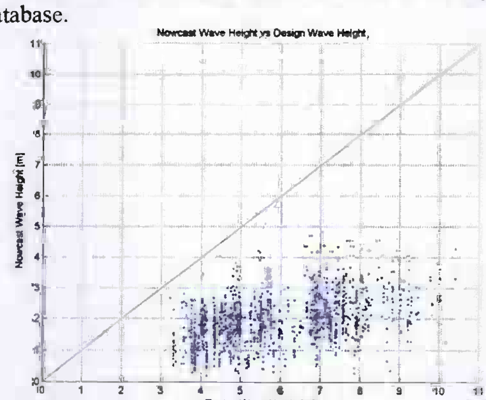


Figure 1: nowcast significant wave height vs. Design wave height per Area according to GWS

Measured compared to Design acceleration

In order to exclude the uncertainty of weather data and the conversion from weather data to motion data, the focus is transferred to ship motion data itself. Figure 2 and Figure 3 are produced to focus on measured X and Y accelerations in the cargo CoG compared to design accelerations. These figures show that the operational margin increases with increasing design acceleration. This conclusion confirms the conclusion from the nowcast wave data.

Another interesting conclusion is that the operational margin for x acceleration is smaller than the operational margin for y acceleration. This conclusion confirms that during heavy weather the master turns his vessel into bow waves. The determination of the design pitch motion and y acceleration could also influence this conclusion, because of usage of the strip theory with limited accuracy for longitudinal motions i.e. surge and pitch.

At the same time it is good to know that x acceleration are generally much smaller than y accelerations. Design accelerations are used to determine seafastening forces between vessel and cargo. As x accelerations are generally small and cribbing friction is significant, the seafastening force is often replaced by a minimum of 5% of the cargo weight, which increases the operational margin. This additional safety margin is not displayed in these graphs because measured and design accelerations are compared directly and thus show the operational margin.

Figure 3 shows also that two measured acceleration points for y acceleration were almost 100% of the design. Please note that for that particular voyage wave height relaxation was used in order to keep the acceleration within limits for cargo strength. The seafastening forces were calculated with non reduced wave heights in order to maintain equal safety standards for all transports. The conclusion is that this practice reduces the operational margin as shown in this figure.

Several conclusions are drawn from Figure 4 and Figure 5, which display for x and y acceleration the $\delta_{Measured\_Design}$ number of 3-hour occurrences. For x and y acceleration respectively the average $\delta_{Measured\_Design}$ is around 0.11 and 0.075. Next to this it can be seen that only a small number of occurrences is larger than 50% of the design value. For x and y direction respectively the probability of 3-hour occurrences is larger than 50% is 2.1% and 2.8%.

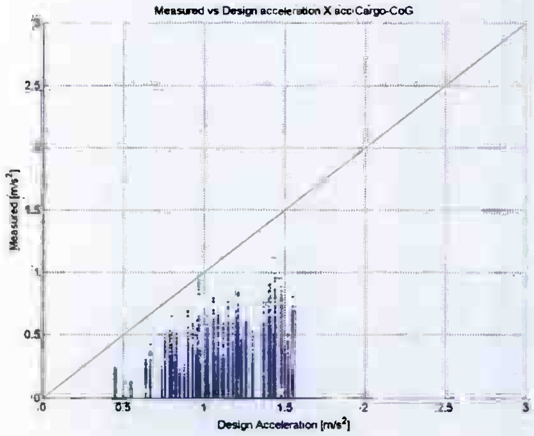


Figure 2: X acceleration Measured vs. Design

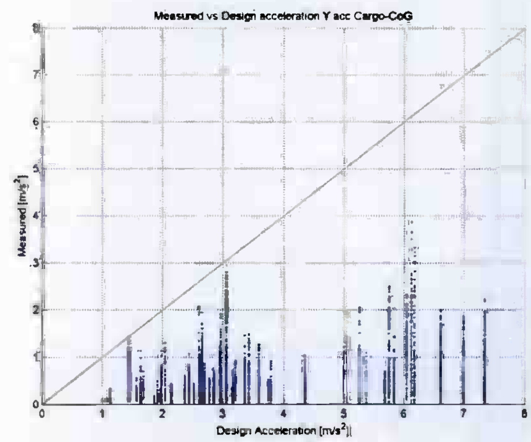


Figure 3: Y acceleration Measured vs. Design

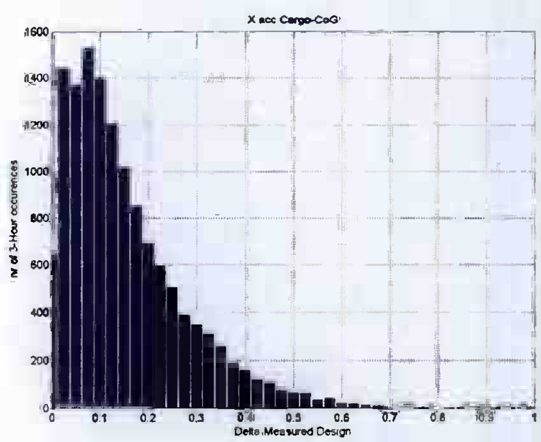


Figure 4: X acceleration in Cargo CoG occurrences vs. $\delta_{Measured\_Design}$

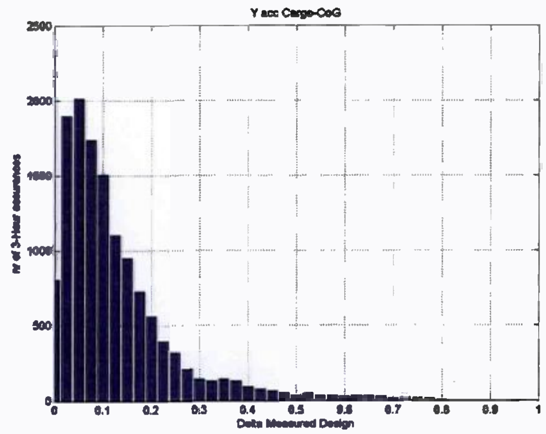


Figure 5: Y acceleration in Cargo CoG occurrences vs. $\delta_{Measured\_Design}$

Nowcast compared to measured acceleration

For x and y acceleration $\delta_{nowcast\_Measured}$ is plotted against measurements in Figure 6 and Figure 7. Two conclusions are drawn from these graphs. The first one is that with small measured accelerations the nowcast is mostly larger than measured. This means that Octopus calculated a larger response than the actual measured value, which is conservative and contributes to the safety of crew, vessel and cargo.

The second conclusion is that with increasing measured accelerations nowcast gets closer to measurements, and nowcast intends to under predict the accelerations. By having a closer look to the under predicting points by comparing nowcast weather data to weather observations data it is found that the heavy weather was not forecasted properly; in fact the waves where significant larger than expected. Unfortunately in this case the forecasted response from the Octopus system could have contributed to a wrong advice to the master. On the other hand the experience and knowledge of the master's is present to determine if the weather forecast is close enough to the actual observations during a specific voyage leg. During this onboard weather verification the Octopus system can be used to calculate the response forecast based on the actual weather observations. Generally it is concluded that inaccuracies between nowcast and measured accelerations are delivered by inaccurate weather forecast for a large part.

Figure 8 and Figure 9 show a different way of comparing nowcast and Measured signals. Both the nowcast and Measured signals are made non-dimensional with the design value. If points are located on the red line the nowcast is equal to the Measured. In these graphs 3 regions can be identified by table and the green and red lines in the figures:

Region	$\delta_{nowcast\_Design}$	$\delta_{Measured\_Design}$
1	-	<0.25, (green line)
2	> red line	> 0.25, (green line)
3	< red line	> 0.25, (green line)

Table 1: indicated regions in Figures 8 and 9

Points located in region one are not worth discussing because the measured accelerations were smaller than 25% of the design value. The points in region two indicate that the response based on nowcast data delivered larger response than measured. This could have been a warning to the master and thus contributed to the safety of crew, vessel and cargo.

The number of points in region three, where measurements are larger than 25% of the design value and larger than the nowcast value, the Octopus system, based on nowcast weather data, underestimated the response of the vessel. As discussed also for Figure 6 and Figure 7 this could have lead to an unsafe situation because of the Octopus system could have given a wrong signal to the master. But as happens sometimes the bad weather was unexpected, and thus the Octopus system was not able to give a warning to the master. Please note that almost all measurement remained below the design values and that only a very small number of points was larger than 75% of the design value.

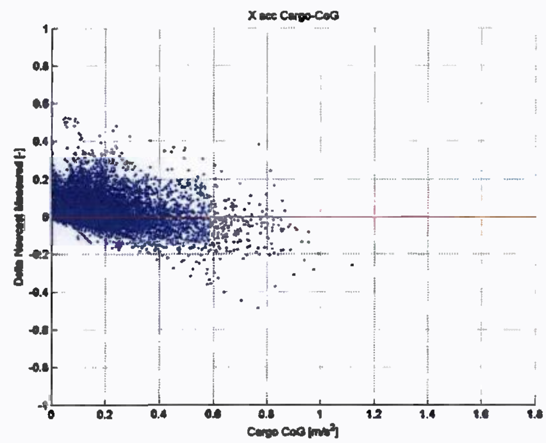


Figure 6: $\delta_{nowcast\_Measured}$ vs. Measured x acceleration in Cargo CoG

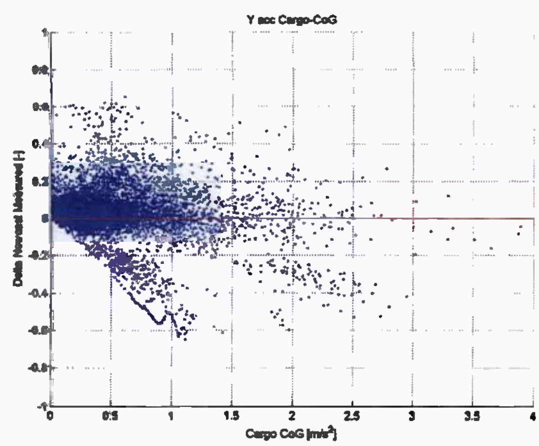


Figure 7: $\delta_{nowcast\_Measured}$ vs. measured y acceleration in Cargo Cog

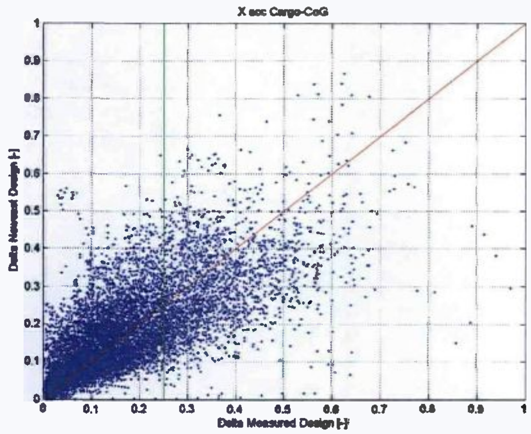


Figure 8: $\delta_{nowcast\_Design}$ vs. $\delta_{Measured\_Design}$ x acceleration in Cargo CoG

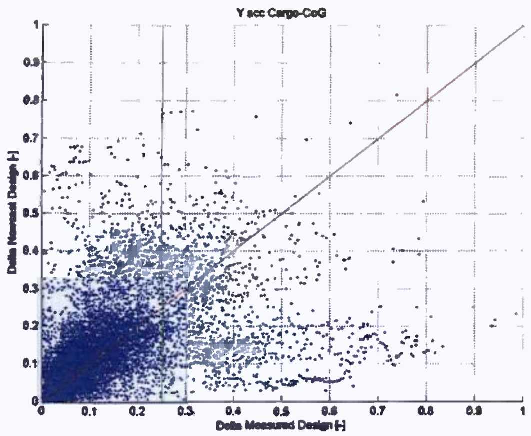


Figure 9: $\delta_{nowcast\_Design}$ vs. $\delta_{Measured\_Design}$ y acceleration in Cargo CoG

CONCLUSION

The maximum recorded nowcast significant wave height, for the analyzed transports is 5.0 [m]. It is shown that the operational margin increases with increasing design wave; for high design sea-states the margin is more than 40%.

The lowest operational margin occurred at design waves smaller or equal to 4.5 [m].

X acceleration is found to be closer to design value than y acceleration. This indicates that the vessel is turned into bow waves in case of heavy weather. The determination of the design pitch motion and y acceleration could also influence this conclusion, because of usage of the strip theory with limited accuracy for longitudinal accelerations.

Response from nowcast data sometimes underestimates the motions at larger $\delta_{Measured\_design}$, which indicates that heavy weather was not predicted properly by the weather forecast. In case it was predicted the master could have acted accordingly, which was not performed in some situations. Generally it is concluded that inaccuracies between nowcast and measured accelerations are delivered by less accurate weather forecast.

With the Motion Monitoring and Decision Support system the Master and officers have a power full tool to plan and execute the transport of heavy cargo. This system, together with integrating it in the engineering process, contributes to increased safety. However, the decision making is most sensitive to the accuracy of the weather forecast.

The database built by gathering all relevant information from the system and from crew observations, increases insight in the operational margins, which contributes to increased knowledge and safety.

RECOMMENDATIONS

It is recommended to include more transports in the database in order to increase the significance of the research.

Determine more statistical values to be able to determine an average operability with a certain standard deviation.

Extract Area specific information from the database in order to derive nowcast scatter diagrams, which could be used for alternative design criteria if the master's decisions are taken into account. The outcome could be compared to results of the program Safetrans, which includes master's decisions in Monte Carlo simulations for a transport. Reference is made to Aalbers et al [5].

Include more use of hind cast weather data from SPOS (Meteo Consult) and other weather providers for validating critical events identified after review of the measured data.

Although it is generally concluded that inaccuracies between nowcast and measured accelerations are delivered by inaccurate weather forecast, still more research is required in order to search for other smaller contributions in inaccuracies. For example what is the influence of non-linearity in ship motions and wind contribution to ship motions?

REFERENCES

[1] L.J.M. Adegeest, "Response based Weather-Routing and Operation Planning of Heavy Transport Vessels", *RINA Marine Heavy Transport & Lift II, London, UK*, p123-131, 2008.

[2] O.A.J. Peters, "Motion monitoring and decision support during heavy transport", *OMAE 2010, China*, 2010.

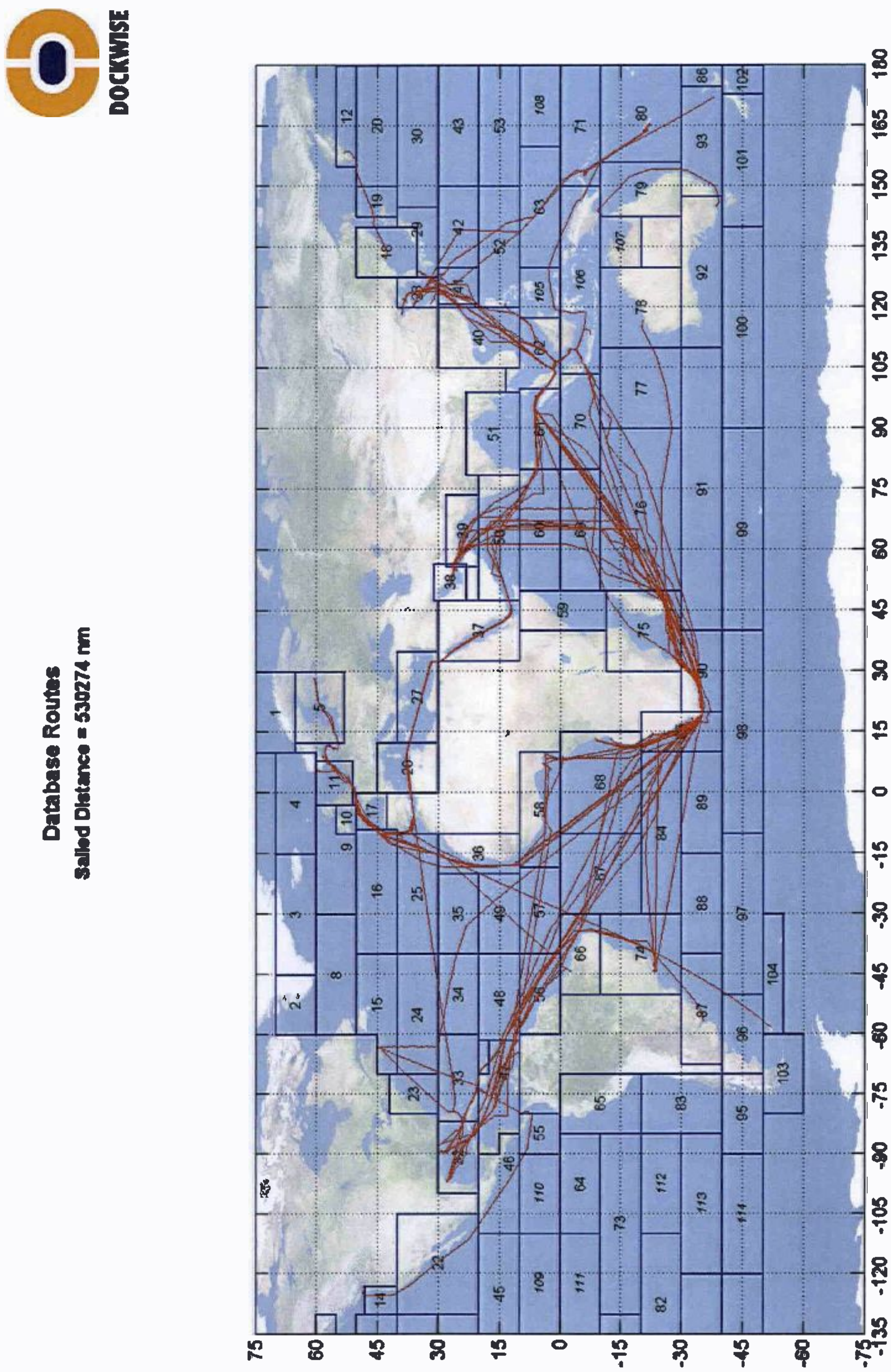
[3] DOCKWISE GC.ENG101 "Routing and Design Environmental Conditions", *Guidelines and Criteria*, November 2008

[4] DOCKWISE GC.ENG.302 "Motion Response Analysis", *Guidelines and Criteria*, November 2008

[5] A.B. Aalbers, "A new software system for safer rig moves", Marin, Safetrans technical notes.

ANNEX A

ROUTE DATABASE



ANNEX B

COMPARISON NOWCAST AND MEASURED ACCELERATION