On the uncertainties of the weather routing and support system against dangerous conditions

Teemu Manderbacka, *NAPA*, teemu.manderbacka@napa.fi

ABSTRACT

Better operational efficiency by fuel savings can be achieved by applying voyage optimization. Weather routing can improve the safety of operation. The route selection is dependent on the weather forecast, which contains uncertainty. Response of the ship and vulnerability to dynamic stability failures in certain sea conditions can be very different depending on the loading condition of the ship. The ship loading condition may not be exactly known for some ship types, introducing another source of uncertainty. Besides these, the methods used to assess the vulnerability also have some level of uncertainty. Taking all these factors into account, some level of safety margin should be introduced, which would in some cases narrow down the benefit of the fuel saving. In this paper the sources of uncertainties from the point of voyage optimization and weather routing are discussed.

Keywords: *Voyage Optimization, Operational Safety, Dynamic Stability Failure, Weather Routing, Operational Conditions.*

1. INTRODUCTION

Voyage optimization can provide significant savings in consumed fuel. It can also help to choose safe navigation route to avoid dangerous conditions. The duration of trans-oceanic voyages can be several weeks. Typically, a trans-pacific voyage of a container vessel takes approximately 2 weeks and a trans-Atlantic voyage around 10 days. Uncertainty in the weather forecast increases, the longer in the future it is extended. New updated forecasts will be received during the voyage, still some route selections in the beginning have effect on the later stages of the voyage.

Loading condition of the ship has important contribution to the motion response in waves. In the real operation, there is an uncertainty in the values of initial stability of the ship, namely GM and mass distribution and consequent rotational inertias, which affect the ship responses. Also, the applied methods to calculate the forces and motion response have limited accuracy in all realistic conditions. Total uncertainty of the estimated motions is a result of all these factors: uncertainty in:

- environmental conditions,
- ship mass distribution
- and calculation method.

In some route selections the fuel efficiency and safety might be conflicting. Some of the most fuel-efficient routes may not be the safest, or vice versa, the safest route may not be the most fuel efficient. Captain of the ship would emphasize the safety in route selection, because it is his responsibility. The operating company and the charter would emphasize timely arrival and total fuel oil consumption. Generally, in this order, because the compensation of late arrival generally would result more costly than excessive fuel oil consumption. Both factors are important for economical operations, where their weight depends on the type of transportation.

However, it is possible and essential to fulfill all the requirements, safe, punctual and energy efficient navigation. The question is, how much margin of safety need to be allowed in the planning of the voyage? Some choices in the route selection cannot be easily reverted, or at least not without compromising the planned arrival time or without excessive fuel consumption. As an example, voyages departing from the North Sea area would have alternatives of passing either north of Great Britain or through the English Channel. If the northern route is selected and the weather forecast changes, so that it would no more result as a feasible safe option, then changing the route could lead into arriving later than what was planned. The uncertainty and the related risk in safety and economical risk easily leads into conservative and possibly not the most energy efficient route selections.

Bačkalov et al. (2016) studied the opportunity to improve the safety of navigation by mitigating the risks through operational measures. This paper aims at clarifying the related uncertainties and their sources. In this way paving way to approach on the planning and execution of energy efficient and safe voyages. Identification of uncertainties in the weather routing become essential also if and when the rules will allow navigation for ships that are susceptible to some failure modes but are allowed to operate in limited conditions or under operational guidance (Hashimoto et al. 2017). Huss (2016) point out the possibility to improve the stability by operational measures and possibility to avoid dangerous condition with help of decision support system (DSS), mentioning that even ships vulnerable to stability failures do not need to be less safe when would be operated with more active management, support and care.

2. CHALLENGES IN ROUTE SELECTION

If we optimize the fuel consumption of a sea passage, the optimal route with respect of minimum fuel consumption can be such that the ship would navigate with strong tail winds, but also with following waves, see Figure 1. This kind of conditions, following or stern quartering waves, may result difficult in terms of maneuvering and even stability, by introducing possibility to pure loss of stability, surf riding and broaching or parametric roll resonance.

Figure 1: An example of fuel-efficient route without considering risk of stability failures vs shortest route.

To overcome the possibility of the route optimization algorithm to suggest a fuel-efficient but potentially dangerous route we can introduce limits to the allowed conditions. Most simple way is by limiting the allowed predicted wave height on the planned route. Which is an approach, that many of the operators choose in practice for the sake of simplicity. However, some of the stability failure modes, are not only dependent on the wave height, but the period and encounter angle, together with ship speed play an important role (Hashimoto et al 2017). For this reason, it would be possible to safely navigate at certain speed and heading in conditions that would result dangerous at different heading and speed for the same ship. Thus, by introducing the limits of heading and speed in certain wave height and period conditions to avoid stability failures taking into account the ship properties, we could in theory find the optimal route without compromising safety (Kobayashi et al., 2015).

The challenge is in defining what is an acceptable and reasonable margin of safety. The margin of safety should allow room for all the uncertainties; in the

- weather forecast,
- ship loading condition
- and calculation methods.

The naval architecture hydrodynamics and stability research has concentrated on improving the calculation methods and thus reducing the uncertainties originated from assessment of motion responses in waves. However, in real operation, the ship mass distribution is not exactly known. Depending on the ship type, even the initial stability, metacentric height GM, can vary significantly. Container ships can have very different GM values at same draft and similar number of containers, depending on their mass distribution. In theory the masses of containers loaded on board the ship should be well known, but in practice the weights vary from the announced ones, in this way causing uncertainty in the actual load case of the ship.

In ship design, and regulatory approval as well as in the regulation development the environmental conditions that the ship is required to withstand without compromising its safety are well defined. The designer can assess the ship's vulnerability to dynamic stability failure by applying Second Generation Intact Stability Criteria, SGISC (Umeda and Francescutto, 2016) regulation to ensure the compliance of the ship to the rules. However, the methods used to check compliance at levels 1 and 2 are simplified and the ship not passing the first level L1 SGIS criteria should pass the second level L2 and if failing to pass the second level then Direct Stability Assessment (DSA) methods (Shigunov 2016, 2017) should be applied. The first level is intended to be the most conservative one. DSA methods are still under development, and many of the weather routing methods take the approach to constrain the allowable weather conditions. Whereas Yoon et al. (2018) are considering also the potential risks of dangerous motions in the selected route.

3. UNCERTAINTIES

Weather forecast

The weather routing services rely on the prediction of weather conditions, namely wave, wind and ocean current predictions. Currents consists of larger, prevailing ocean current systems with smaller variations, and tidal currents, which are well predicted and more important at the coastal areas. The effect of currents is relatively more important to the fuel consumption and efficient navigation of slower ships, nonetheless they do not generally pose any significant safety issue to a normally functioning ship.

The wave conditions, combination of wave height, period and encounter angle can result dangerous to the stability of the ship. Wind gusts may compound the situation, however generally the wind alone is not a stability risk. Wave conditions are dependent on the wind, however the wave propagation is well predicted since it takes time to transfer energy from the wind to ocean waves. Prediction of wind often bears larger uncertainty.

All the main international wave forecast providers have similar accuracy, as seen in yearly study by Bidlot (2017), who compare hundreds of globally positioned wave buoy measurement during the year 2016 with the forecasted wave conditions. Comparison on the forecasts at the location of wave buoys show how much in average the forecasts deviate from the measured real conditions. Globally, prediction of significant wave height Root Mean Square Error RMSE ranges from around 0.3 meters (nowcast) to around 0.6 to 0.8 meters for forecasts to five days ahead (Figure 2). Wave peak period RMSE does not seem to be so much affected by the extent of the forecast, the RMSE for wave peak period ranges from around 1.8 seconds to around 2.4 seconds for most of the weather providers. The wind speed forecast RMSE starts at around 0.9 to 1.5 m/s at 0 days ahead nowcast and increases nearly threefold to five days forecast having RMSE around 3.0 m/s to 3.4 m/s.

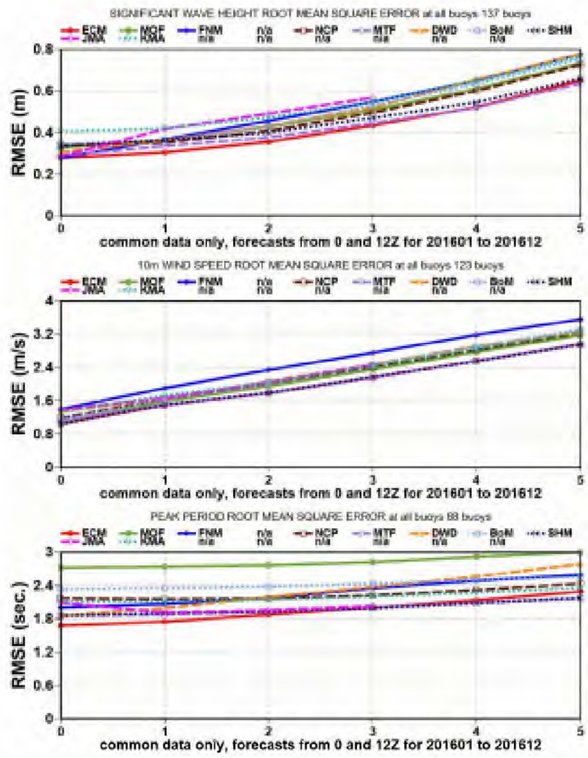

Figure 2: Root Mean Square Errors of forecasted Significant wave height (upper), Wind speed (middle), and Wave peak period (lower), figure adopted from Bidlot (2017).

Ship loading condition

The container vessel can have large variations in initial stability. In general, a container vessel has larger GM at smaller drafts. The GM can be very high for a container vessel in ballast condition in some cases. However, even at the same draft the initial stability can vary significantly. As an example of GM variation for a container vessel of ~5000TEU of capacity and length of nearly 300 m is presented in Figure 3. All recorded loading conditions are shown in non-dimensional format.

Motion response calculation methods

For the voyage or route optimization or weather routing purposes the calculation methods need to be efficient. Several scenarios of route and speed combinations with respect to the predicted weather need to be studied to find the fuel efficient, optimal route, which is safe to navigate. Wind resistance calculation is generally straight forward, basing on predefined wind force and moment coefficients for the ship in question or as general coefficient for different ship types. Thus, the wind effect calculation does not require huge computational effort. Of course, the wind effect can also be calculated in a very detailed manner applying CFD calculations (Luquet et al. 2017) e.g. for all different load cases, however more simple approaches provide reasonably good results for wind effect.

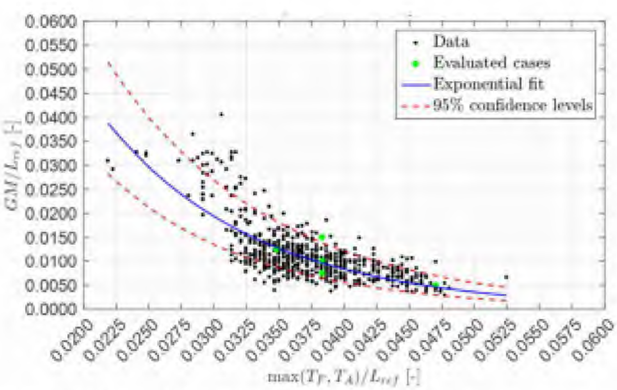

Figure 3: Recorded container vessel load cases.

The wave added resistance in turn is more complicated to estimate. Significant amount of research effort has been addressed to develop methods to estimate the wave added resistance, the state-of-the art methods still give relatively different results in some wave conditions according to the benchmark study performed within the EU funded SHOPERA (2016) project. The route optimizing algorithms generally use precalculated results for the wave added resistance. Sophisticated methods can be applied to pre-calculate added resistance, which can be tabulated and parametrized for fast availability for the optimization. The uncertainties related to the factors affecting on the consumption do not directly affect the uncertainty in safety, however the suggested candidate routes are dependent on the models that calculate the consumption.

Similarly, to the added resistance in waves, ship motion response calculation is challenging and bear uncertainty in the results. The assessment of vulnerability to stability failures is also dependent on the uncertainties in the modelling, like the in case of calculated surf riding probability shown to be dependent on the accuracy of calm water resistance and wave induced surge force modelling (Umeda et al. 2015). Calculation methods can vary in their level of accuracy, however generally it is preferred to use robust and efficient calculation methods, such as presented by Kalske and Manderbacka (2017), to avoid unnecessary long computational times and to have better coverage valid conditions of calculation.

4. CONCLUSIONS

Using weather routing and voyage optimization can help to reduce fuel oil consumption and improve operational efficiency. The safety of navigation can also be improved by better preparedness to avoiding dangerous conditions. Attention should be paid to the uncertainties in the planning of voyages through a safety margin. The uncertainties can be divided into three different categories. Arising from the uncertainty in the weather forecast, uncertainty in the actual loading condition affecting the initial stability and rotational inertias of the ship, and from the uncertainties in the methods assessing the responses of the ship in the seaway. The latter is paid a lot of attention by the naval architects and the researchers in the field of ship hydrodynamics. Weather forecasts are also improving, and a significant amount of research is carried by the meteorological institutes, also providing comparisons of the realized forecasts. With this, a need can be identified to further combine the meteorological information with the operational information into the assessment of responses and dangerous conditions. Such research is welcome addition and could be expected to help in practice the uptake of the voyage optimization, by clarifying the required range of the safety margin and to reduce the possible hesitation of the captains to approve the of voyage and route optimization suggestions.

REFERENCES

Bačkalov, I., Bulian G., Rosén, A., Shigunov, V., Themelis, N., 2016, "Improvement of ship stability and safety in intact condition through operational measures: challenges and opportunities", Ocean Engineering, 120, pp.353-361.

BIDLOT J.-R. (2017), Intercomparison of operational wave forecasting systems against buoys: data from ECMWF, MetOffice, FNMOC, MSC, NCEP, MeteoFrance, DWD, BoM, SHOM, JMA, KMA, Puerto del Estado, DMI, CNR-AM, METNO, SHN-SM January 2016 to December 2016, European Centre for Medium-range Weather Forecasts (ECMWF), https://www.jcomm.info/index.php?option=com_oe&task=viewDocumentRecord&docID=18333

Hashimoto, H., Taniguchi, Y. and Fujii, M., 2017, "A case study on operational limitations by means of navigation simulation", Proceedings of ISSW 2017, pp. 41-48.

Huss, M., 2016, "Operational stability beyond rule compliance", Proceedings of ISSW 2016, pp. 193-200.

Kalske, S., Manderbacka, T. 2017. Development of a new practical ship motion calculation method with forward speed. Proceedings of the International Ocean and Polar Engineering Conference (ISOPE 2017). San Francisco, CA, USA.

Kobayashi, H., Hashimoto, H., Taniguchi, Y., Yoneda, S., 2015, "Advanced Optimized Weather Routing for an OceanGoing Vessel", Proceedings of the 2015 International Association of Institutes of Navigation World Congress

Liwång, H., Rosén, A., 2018, "A framework for investigating the potential for operational measures in relation to intact stability", Proceedings of the 13th International Conference on the Stability of Ships and Ocean Vehicles, 16-21 September 2018, Kobe, Japan.

Luquet R., Vonier P., Prior A., Leguen J. F., 2015, "Aerodynamics Loads on a Heeled Ship", Proceedings of STAB 2015, pp. 735-744.

Papatzanakis, G., Papanikolaou, A., Liu, S., Optimization of Routing Considering Uncertainties, Journal of Marine Science and Application, March 2012, 11: 10-17, DOI: 10.1007/s11804-012-1100-y

Shigunov, V., 2016, "Probabilistic direct stability assessment", Proceedings of ISSW 2016, pp. 17-26.

Shigunov, V., 2017, "Possible simplifications of direct stability assessment", Proceedings of ISSW 2017, pp. 27-38

SHOPERA. 2016. SHOPERA Energy Efficient Safe Ship Operation EU FP-7 Project.

Umeda, N., Ihara, T., Usada, S., 2015, "An Investigation into the Factors Affecting Probabilistic Criterion for Surf-Riding", Proceedings of STAB 2015, pp. 319-329

Umeda, N., Francescutto, A., 2016, "Current state of the second generation intact stability criteria - achievements and remaining issues", Proceedings of ISSW 2016, pp. 3-9.

Yoon, H.K., Nguyen, V.M., Nguyen, T.T. 2018, "Development of Solution for Safe Ship Considering Seakeeping Performance", TransNav Vol 12, no 3, 2018, DOI: 10.12716/1001.12.03.10 http://www.transnav.eu/Article_Development_of_Solution_for_Safe_Yoon,47,835.html