

# On an Advanced Shipboard Information and Decision-making System for Safe and Efficient Passage Planning

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**ABSTRACT:** Shipboard weather information and decision-support systems have been developed to assist the officer on watch by supplying dedicated weather forecasts along a planned route. An added value can be achieved by combining an existing system with functionalities providing information about the ship's performance in a seaway and an optimum routing algorithm. This paper describes functionalities for predicting slamming, green water on deck, synchronous and parametric roll and the implementation in an existing system to support safe and efficient ocean passage planning. A full scale test on board a container ship crossing the North Atlantic Ocean has been carried out in order to gain operational experience for evaluation of the concept. Further testing is required for validation purposes.

## 1 INTRODUCTION

An electronic nautical chart system is suitable as platform to offer sophisticated and user-friendly navigational functionalities with high accuracy rendition of the geographic and environmental information. Data from various sources can be fully integrated and provide the user a total situation awareness. It can be an expert system capable of providing solutions to navigational and safety problems.

Various shipboard information and decision-support systems have been developed to assist the OOW. An example is WeatherView™ (a product of C-Map by Jeppesen) that is providing the mariner with dedicated weather forecast.

This paper proposes and evaluates functionalities suitable for an advanced shipboard information and decision-making system that support safe and efficient passage planning. A test system has been developed on the software platform of Weather View™ and includes implementation of functionalities for prediction of slamming, green water, synchronised and parametric roll. Relevant graphical and numerical outputs are presented.

The system has been tested on board an A.P.Møller-Maersk container ship for evaluation purposes. It is argued that the proposed functionalities are capable to provide valuable information to the OOW in ocean passage planning. Further testing is required

to determine that sufficiently accurate and reliable outputs can be obtained.

## 2 SYSTEM

WeatherView™ is a weather information system that supplies the user with information about the forecasted weather and satisfies the demand for low cost downloads. The system has a route planning functionality where a selected route can be shown on an electronic chart display. This enables information about the weather to be compared for several routes. The most suitable route (regarding the weather) can then be selected and exported to a Word document to be used in documentation for the passage planning. Along the route it is also possible to monitor response calculations for the ship where heave, pitch and roll are calculated. A polar diagram highlights area of danger where synchronous roll has a probability to occur.

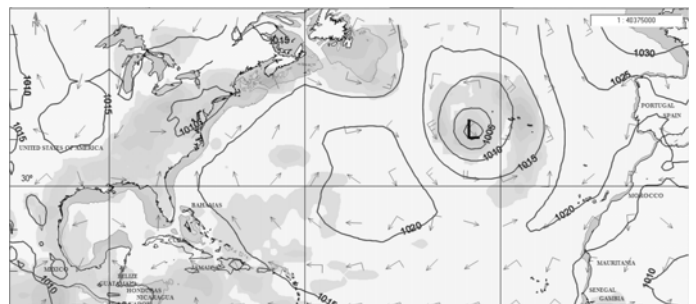


Fig. 1. Screenshot of WeatherView™

The calculations are based on basic ship data and its load condition. The results can give an indication of the ship's performance in a seaway. Tidal information is given for selected ports as well as information of ice concentration. Typhoon warnings and forecasted development of these are also shown on the chart. It is possible to identify various danger areas given by input from the user and these can be displayed on a timeline if chosen.

### 3 ADDED FUNCTIONALITIES

#### 3.1 IMO MSC 707 parameters

A ship sailing under heavy weather conditions may encounter various kinds of dangerous phenomena which may lead to severe roll motions capable of causing damage to cargo, equipment and people on board. The sensitivity of a ship to dangerous phenomena depends on actual stability parameters, hull geometry, size and speed of the ship. This implies that the vulnerability to the dangerous response and its probability of occurrence in a particular sea state may differ for each ship.

The guidance issued by IMO's Maritime Safety Committee [IMO MSC 707, 1995], aims at giving seafarers caution on dangerous phenomena that may be encountered when navigating in following/quartering seas. It provides the basis for a decision on ship handling in order to avoid such dangerous situations as well as advice on safe and unsafe combinations of ship speed and course relative to waves in a simplified form of a polar diagram. Phenomena like synchronous/parametric roll, broaching/surfriding and high wave group encounter are included in the guidance.

#### 3.2 Synchronous and parametric roll

Synchronous rolling resonance conditions occur when the natural roll periods  $T_r$  of the vessel coincides to the encounter period  $T_e$  of the waves, Figure 2, i.e.

$$T_n = 2\pi \sqrt{\frac{Mr_{44}^2 + A_{44}}{\rho g \nabla GM_t}} \sim T_e = \frac{T_0}{1 + \frac{2\pi U \cos \beta}{gT_0}}$$

where  $r_{44}$  is the roll radius of gyration with respect to an axis parallel with the x-axis through the centre of gravity,  $A_{44}$  is the roll added moment and  $GM_t$  is the transverse metacentric height (the parameter which has most influence on the roll period).  $M$  is the mass,  $\rho$  is the density of seawater and  $\nabla$  is the displaced volume of the ship.  $U$  is the ship's speed,  $T_0$  is the wave period and  $\beta$  is the wave heading angle.

Parametric rolling resonance conditions occur when the natural roll periods of the vessel is equal to half of the encounter period of the waves, Figure 2.

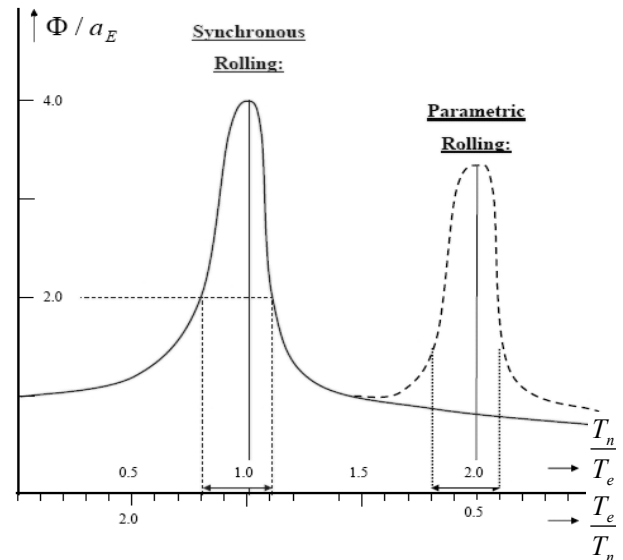


Fig. 2. Ranges of roll resonance

Furthermore, the vessel should be travelling with a small heading angle to the predominant wave direction (head or stern seas), wavelength should be comparable to ship length, wave height should be large and the roll damping characteristics of the vessel should be low (low speed).

#### 3.3 Slamming / green water

Wave impact typically occurs in the bow section of the ship, at flat bottom sections, and at the upper bow flare. For modern containerships slamming may also occur at the stern section due to flat bottom design. The impact loads are highly concentrated in a very short time period and may result in damage of local structure and accentuate structural vibration throughout the hull, also known as whipping. Its severity will depend on ship speed, wave height and wave length as well as the design of the bow sections, wet deck height forward and deadrise. The probability of slamming to occur can be formulated as [Faltinsen, 1990]

$$P(\text{slamming}) = \exp \left[ - \left( \frac{V_{cr}^2}{2\sigma_v^2} + \frac{d^2}{2\sigma_r^2} \right) \right]$$

where  $V_{cr}$  is the threshold velocity,  $\sigma_v^2$  is the variance of the relative velocity,  $d$  is the distance from waterline to the slamming point and  $\sigma_r^2$  is the variance of the relative motion.

The green water problem arises when a ship is sailing in heavy weather conditions and encounters waves exceeding the freeboard level. The deck is then wetted and the term "green water" refers to the shipped water on deck, Figure 3. In most green

water incidents, the shipped water will not have any destabilizing/damaging effect. However, in some cases the amount of shipped water can be so large it causes damage to deck equipment and cargo as it could flood damaged compartments and cause reductions in stability. The probability of green water on deck to occur can be written as [Faltinsen, 1990]

$$P(\text{GreenWater}) = \exp\left[-\frac{d_f^2}{2\sigma_r^2}\right]$$

where  $d_f$  is the freeboard distance and  $\sigma_r^2$  is the variance of the relative motion.



Fig. 3. Green water load on a ship

## 4 MODELLING AND IMPLEMENTATION

### 4.1 Algorithms and data structure

A set of algorithms (appendix) for the MSC 707 parameters have developed for WeatherView™. The algorithms are based on general ship information, the ship's natural roll period and the wave data obtained from the forecast in WeatherView™. The required inputs and details in data flow are described in the Appendix.

### 4.2 Layout and interfaces

A graphical user interface has been proposed as a “Condition Display” to provide relevant information

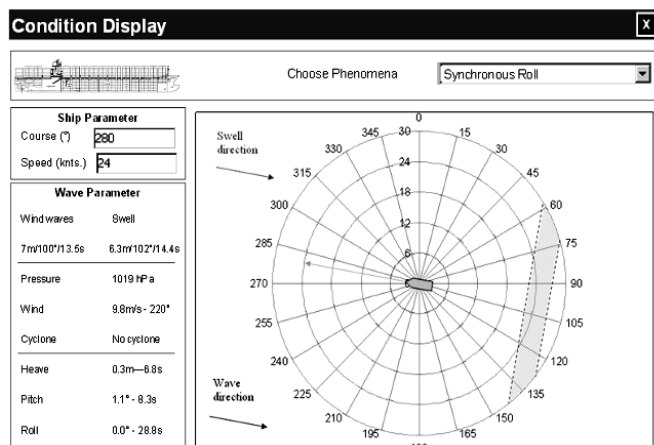


Fig. 4. Condition display

on the ship's response under the predicted environmental conditions, Figure 4. This interface enables the OOW to view the environmental conditions and the ship's predicted response in heave, pitch and roll. The polar diagram utilises a roll down menu to show the selected phenomena (or all) of the user's choice. It also displays the ship's GZ curve to give an indication of whether the natural roll period is higher or lower than the calculated value. Finally, the ship's course and speed will be shown – as default from route calculations or by user's choice. This enables the OOW to watch effects of course and/or speed changes on the polar diagram.

## 5 FULL SCALE TEST

### 5.1 Ship and route

The test was conducted on a container ship m/v *Olga Maersk* (3000 TEU) en route from Felixstowe (UK) to Kingston (Jamaica) in April 2007, Figure 5. The route was chosen on basis of the current weather forecast to follow a rhumb line. Under way, weather routing information and guidance was obtained from the Danish Meteorological Institute (DMI).

### 5.2 Configuration set-up

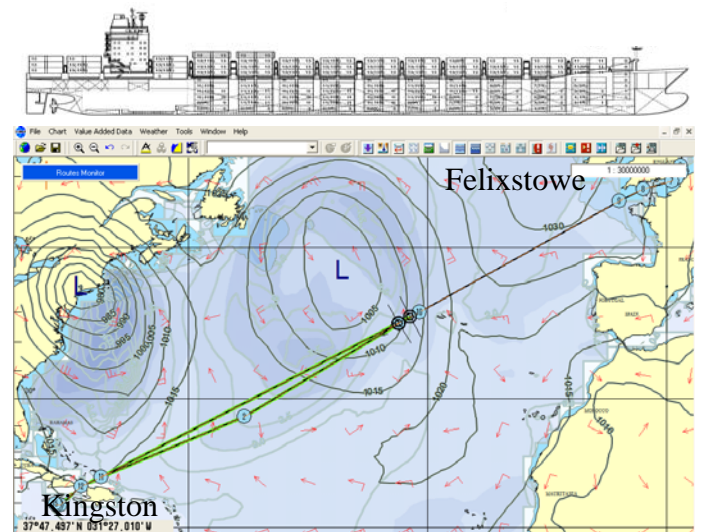


Fig. 5. m/v “Olga Maersk” and route. Screenshot of WeatherView™ on 16. April 2007 at 1205 UTC. The northerly route is the planned route and the southerly is based on advice from weather routing service

A trial version of WeatherView™ was installed on a laptop and weather forecast was downloaded twice a day. The ship's motion was recorded by a Xsens MTi motion sensor [Xsens Motion Technologies, [www.xsens.com](http://www.xsens.com)] that was connected to a laptop and placed at the bow section. The sensor recorded accelerations and rate of turn in  $x$ ,  $y$  and  $z$  directions and provided direct output of roll, pitch and yaw.

The sensor was calibrated when alongside quay in Felixstowe by using the calibration method as advised by Xsens. The sensor was calibrated to follow a coordinate system defined by ship's movements (positive  $x$  direction towards the bow, positive  $y$  direction towards starboard and positive  $z$  direction up).

### 5.3 Recorded data

The following parameters were recorded for analysis:

- Ship motion (roll, pitch, heave acceleration), course, speed and position.
- Engine RPM and kW, torque on propeller shaft.
- Fuel consumption pr. day.
- Environmental information.

Observations, table 1 were combined to a set of time-series which were used to validate results from calculations performed in WeatherView™.

### 5.4 Validation

The following data were validated from observations:

- Ship's response in current sea state: Roll and pitch calculations were compared to observations from motion sensor while heave motion was derived from acceleration in  $z$ -direction and compared to calculations in WeatherView™.
- IMO MSC707 parameters were calculated for various observations and compared to those shown in WeatherView™.
- Suggestions for optimized route was compared to the route actually sailed. Comparison parameters were speed and fuel consumption.

## 6 RESULT ANALYSIS

### 6.1 Setup

During the voyage numerous observations were made, example:

Time UTC	Latitude	Longitude	Course	Speed water	Speed ground
1205	38°07'4N	33°01'0W	238°	23.8 knots	23.3 knots
Wind direction	Wind speed	Waves direction	Waves height	Swell direction	Swell height
220°	9.1 m/s	200°	3.0 m	200°	3 m
Engine RPM	Torque	Actual kW	Average kW	Fuel consump.	
95.0	2944x	28.90x	28.51x	5.47 t/h	
	10 <sup>3</sup> kN	10 <sup>3</sup> kW	10 <sup>3</sup> kW	(average)	

The motion sensor was set to record all ship's motion during the voyage. The observed data was used to verify response calculations made in WeatherView™, example Figure 6.

The MSC 707 parameters shown on polar diagrams were manually calculated for each observation and compared to those shown in WeatherView™, example Figures 7 and 8.

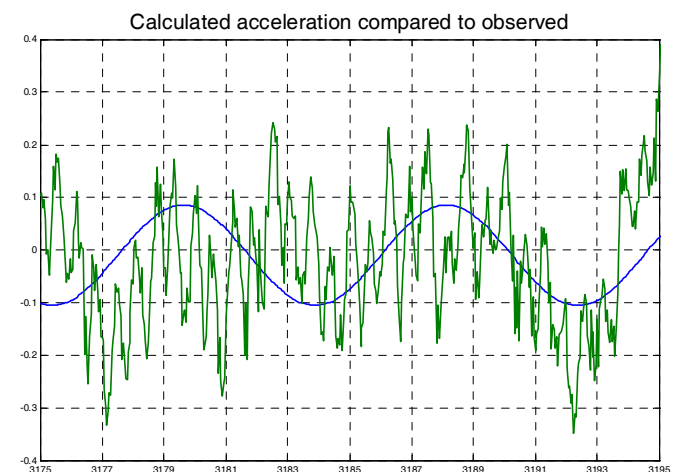
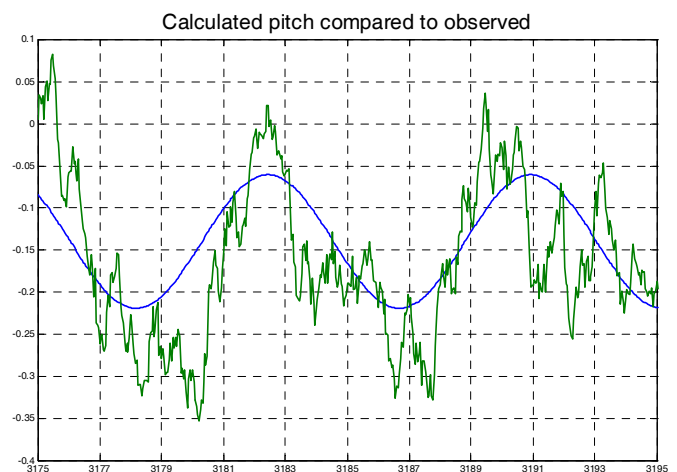
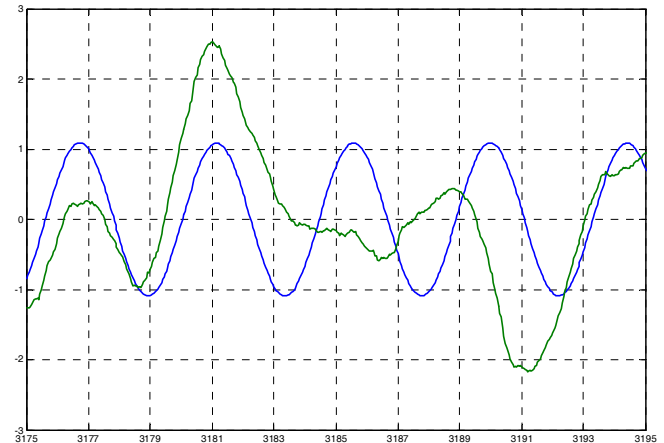


Fig. 6. Comparison of response

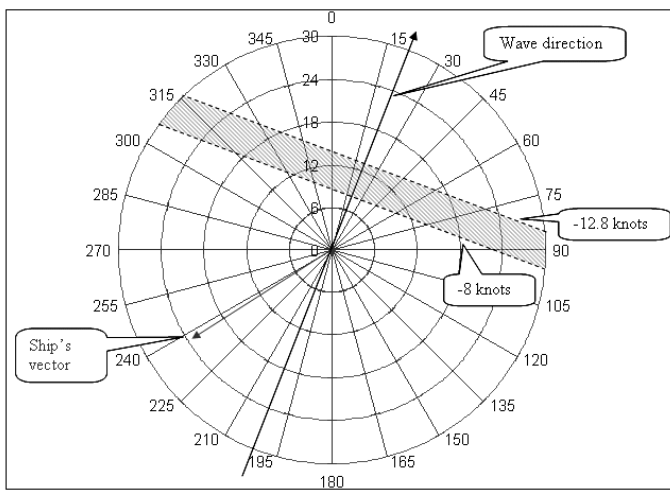


Fig. 7. Calculated synchronous roll zone on polar diagram

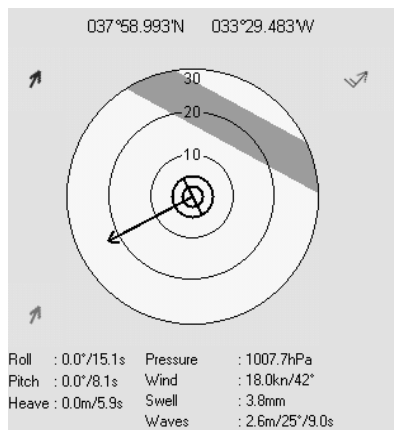


Fig. 8. Polar diagram from WeatherView™

## 6.2 Results of analysis

The results of the analysis shows

- Agreement of observed and calculated response.
- Some errors in polar diagrams shown in WeatherView™. Errors occurred at random and included roll zones and environmental data.

Due to nature of environmental conditions the test results are not sufficient to give a full validation of the system and further testing regarding sensitivity and program structure is considered necessary.

## 7 CONCLUSIONS

Functionalities for prediction of slamming, green water, synchronised and parametric roll have been proposed for an advanced shipboard information and decision-making system to support safe and efficient ocean passage planning. A test system with proposed functionalities has been developed on the software platform of WeatherView™. Relevant graphical and numerical outputs are presented.

The system has been tested on board an A.P. Møller-Maersk container ship for evaluation purposes. It is argued that the proposed functionalities are capable to provide valuable information to the OOW in ocean passage planning. Results from the sea trial indicates further testing and development of the system is required to determine that sufficiently accurate and reliable outputs can be obtained.

## ACKNOWLEDGEMENTS

The authors are grateful to Jeppesen Marine (a Boeing company) for assistance in implementing the proposed added functionalities in a test version of WeatherView™. A.P.Møller-Maersk is appreciated for offering full scale-test to take place on board m/v “Olga Maersk”.

## REFERENCES

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## APPENDIX

The slamming and green water predictions are based on calculated using simple closed form functions [J.J.Jensen et al.,2003].

The wave spectra used is a generalized JONSWAP spectrum formulated by the wave frequency  $\omega$ , the significant wave height  $H_{1/3}$ , the mean wave period  $T_S$  and the peak enhancement factor  $\gamma$ .

Algorithms and data structure for the MSC 707 parameters is shown in Figure 9 Synchronous Roll, 10 Broaching / Surfriding, 11 Parametric roll and 12 High Wave Group Encounter .

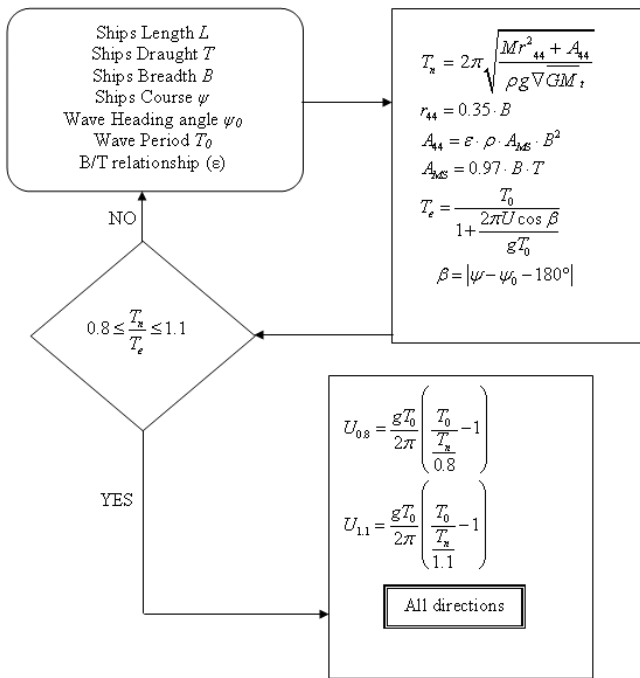


Fig. 9. Synchronous roll

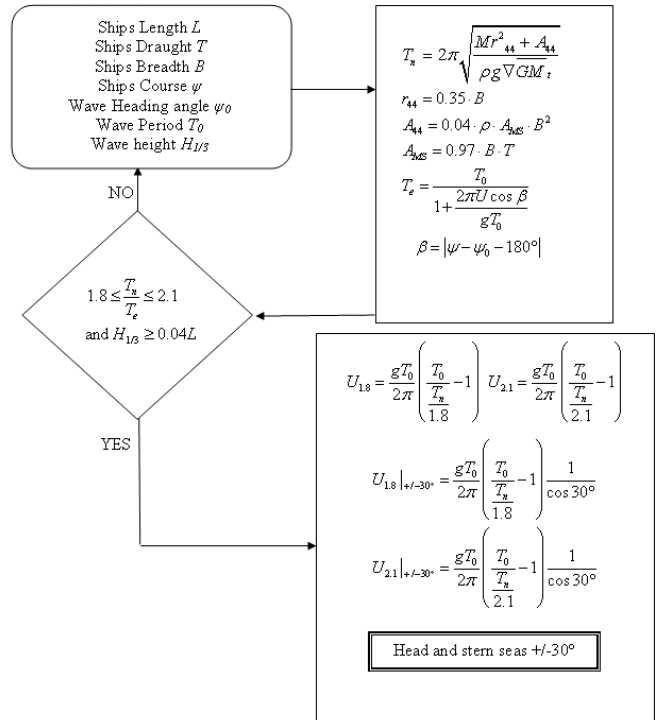


Fig. 11. Parametric roll

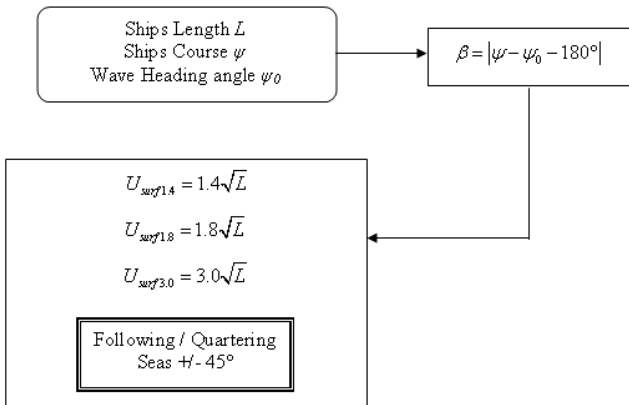


Fig. 10. Broaching / Surfriding

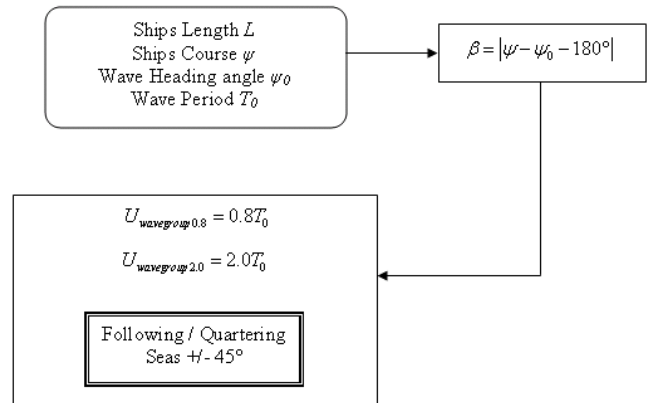


Fig. 12. High Wave Group Encounter