# A COMPARISON OF DIFFERENT METHODS FOR ADDED RESISTANCE PREDICTION

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## Abstract

Added resistance prediction represents an important challenge for ship-owners due to its economic implications in terms of choice of engines, fuel consumption and route-time evaluation. Design offices should consider seriously this problem already in the early stages of the design.

Usually, the performance evaluation of a ship in a seaway is primary based on the calm water resistance without properly considering the weather conditions prevailing on the operating route. Even if the calm water resistance is used as a first estimation of the power required, an allowance is added to this value of the resistance to consider the effect of the environment. The designers consider this effect on over-powering by application of a standard “sea margin factor”, independently from actual behavior of the designed ship in a seaway. This value of the sea margin is usually stated at the design stage by the ship owner or ship designer (often 15–30% of the ship calm water power), based on tradition or experience of similar ships sailing on the same route.

However, reliable evaluation of added resistance in a confused sea allows to quantifying the real overload on the propeller and the engine power needed to achieve the required service speed. A more accurate value of sea margin can be obtained through towing tank tests or theoretical methods that compute the added resistance in waves on the basis of regression formulas or well consolidated seakeeping theories. An approximate value of wind resistance is effectively determined by means of systematization of numerous model test results published by different researchers. In this respect, to make practical design predictions, several commercial codes are available on the market.

In this paper attention is given to a recent Ro-Ro/pax ship operating in Mediterranean. The most popular prediction methods, both analytical and statistical, have been considered and compared. A critical analysis of the statistical formulation for the wind loads has been carried out and the conclusion is that such regressions should be updated with recent Ro-Ro profiles. As a result, the maximum operating conditions have been obtained for the ship by taking into account both involuntary and voluntary speed reduction that is required by comfort on board. The main characteristics of the examined Ro-Ro/pax ship are given in Table 1.

| Main Characteristic | Value |
|---|---|
| Length Between Perpendiculars | 192.4 m |
| Beam | 26.4 m |
| Depth | 21.5 m |
| Draft | 7.1 m |
| Displacement | 21937 t |
| Design Speed | 31 kn |
| Installed Power | 4×16800 kW |

Table 1: Main characteristics, Ro-Ro/pax Knossos.

## Results

In general, the total resistance of a ship in a seaway is divided into three parts, i.e., the still water resistance, the wind resistance and the added resistance due to waves. The determination of these three components of the resistance is given in more detail in the following paragraphs. Guidelines are given to the designer for computing the ship speed in storm conditions.

### Still Water Resistance

Several methods able to determine the still water resistance of ships have been described in literature. These methods have been based on the results of a large number of model and full-scale experiments which have been developed systematically or statistically into graphs, tables or empirical formulas. In the present analysis the method of Holtrop and Mennen (1982) has been used.

### Wind Resistance

Isherwood (1973) has analysed the results of wind resistance experiments carried out at different laboratories with models covering a wide range of merchant ships. He gives empirical formulas for determining the two horizontal components of wind force and the wind-induced yawing moment on any merchant ship form for a wind from any direction. Unfortunately new ship forms are not included this database, which is now more than 30 years old.

More recent investigations due to Blendermann (1996) have been used for a comparison with previous method. In Figure 1 we show the predicted wind resistance according to both methods and the large difference existing between them. This difference should be accounted for since ships in ballast conditions exhibit a wind resistance which often is a consistent part of the total resistance.

### Wave Added Resistance

The increase of resistance in regular waves is calculated with several methods, including both empirical and analytical predictions. The empirical methods are those of Shifrin (1973), Jinkine and Ferdinande (1974), while the analytical methods considered have been developed by Havelock (1937), Gerritsma and Beukelman (1972), Maruo (1957) and Hosoda (1973). The comparison between all the above methods, which are able to predict the added resistance as a function of regular wave characteristics, are shown in Figure 2 for head sea conditions.

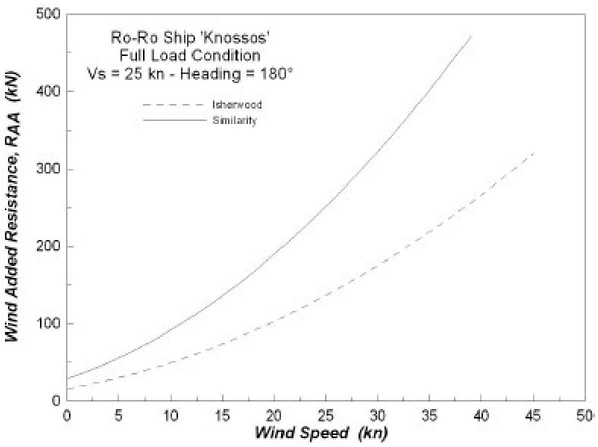


Figure 1: Wind resistance predicted by two different methods.

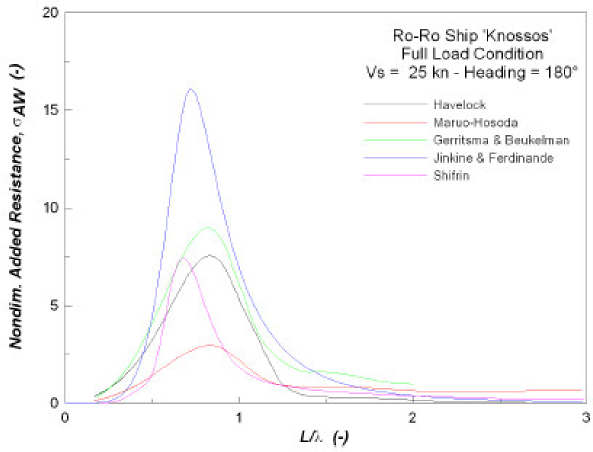


Figure 2: Wave added resistance in regular waves predicted by five different methods.

The calculation in an irregular sea is based on the superposition principle for the components of the wave, motion and resistance spectra as well as on the assumption of linearity for the ship's response. In regular waves the added resistance varies as the square of the wave amplitude. In a wave spectrum the mean added resistance would then be calculated from:

$$\bar{R}_{AW} = 2\int_0^\infty \frac{R_{AW}(\omega_e)}{\zeta_a^2} S_\zeta(\omega_e)\, d\omega_e$$

For the description of the sea surface one ITTC spectra have been used. In Figure 3 we show the wave added resistance predicted for different significant wave height at ship speed of 25 kn.

It results that different design methods used for predicting the wave added resistance give fairly different results. The large difference here obtained amounts to 100% and even more. This fact certainly represents a serious problem for the designer which is certainly unable to select the most appropriate methodology in case of a new Ro-Ro design. Until new experiments will be available in the literature, the support of model tests in seakeeping tank is mandatory to check the validity of the predictions by himself. For the time being, the comments which follow could be used as provisional guidelines. It is generally known (Strom-Tejsen et al., 1973) that the theory of Havelock must be considered as a first order approximation which is not accurate enough for engineering applications. Moreover, it was found that Maruo and Hosoda's theory gives accurate results only for cruiser-stern ships without large bulbous bows and that is not applicable to other hull forms. The method of Gerritsna and Beukelman apparently provides a prediction technique equally accurate for all ship forms, but this approach does not correctly predict added resistance for cruiser-stern ships with low block coefficients.

**Total Resistance**

The total resistance for the significant wave height interval corresponding to Sea State 5 has been computed by means of the above theories. In Figure 4 we show the results obtained for different ship speeds by using the combined methodology of Holtrop and Mennen (1982) for still water resistance, Blendermann (1996) for wind resistance, Gerritsma and Beukelman (1972) for wave added resistance. It results that for the examined Ro-Ro/pax Knossos, the major contribution to the total resistance can be related to the ship resistance in still water. For this type of ship, the contribution due to rough weather amounts only to approximately 10% of the total, including both wind and wave added resistance. It has to be noted that in Mediterranean area probability of exceedance of SS5 is approximately 5% on annual basis.

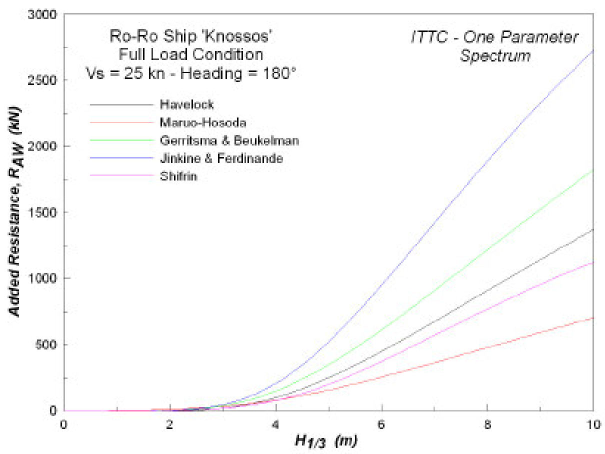


Figure 3: Wave added resistance in irregular sea predicted by five different methods.

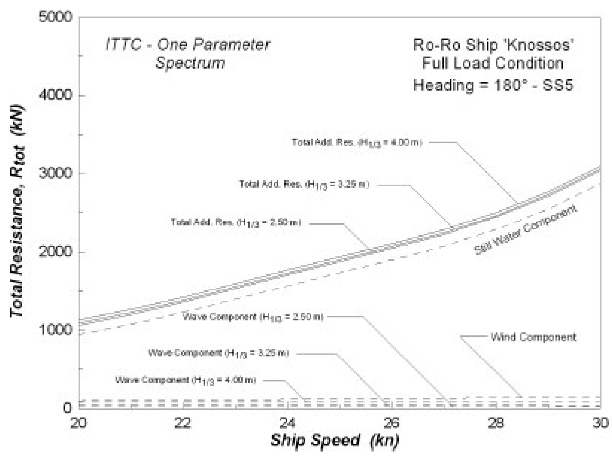


Figure 4: Total resistance predicted in Sea State 5.

**Ship Speed in Seaway**

The attainable ship speed in storm conditions is due to involuntary and voluntary speed reduction. The results of the analysis are shown in Figure 5, where both reductions are given as a function of significant wave height.

The voluntary speed reduction has been predicted by introducing different seakeeping criteria for evaluating the ship motion response to the storm. The design criteria of slamming, propeller emergence and vertical accelerations at wheelhouse have been separately considered and the corresponding maximum attainable speed has been predicted.

The involuntary seed reduction has been computed according to the computation procedure suggested by Journée (1976). According to this approach, for a number of ship speeds, the relation between the torque needed by propeller and rpm are calculated from the torque characteristics of the propeller and an adapted wake fraction. The relation between the torque delivered by the engine to the propeller and rpm is known from engine characteristics and shaft loses. These relations give the condition of equilibrium for speed and rpm, which together with the thrust characteristics of the propeller and the thrust deduction fraction results in a resistance. This resistance can be achieved by propeller and engine as a function of ship's speed. The actual speed of the ship can be found if the total resistance of the ship for a number of speeds is known.

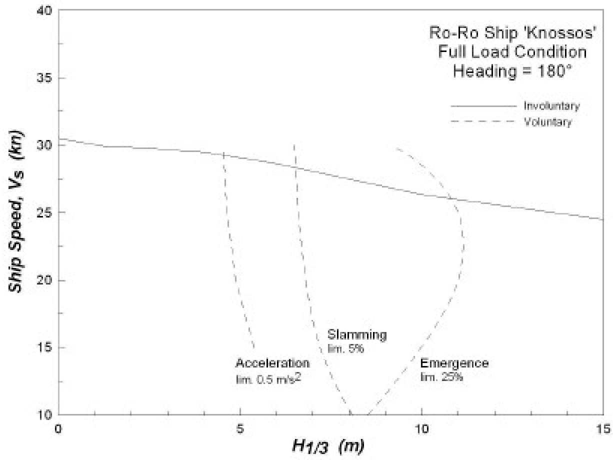


Figure 5: Involuntary and voluntary speed reduction in different sea states.

A further analysis of Figure 5 shows that the maximum attainable speed in severe storm conditions cannot be related to involuntary speed loss due to adverse wind and wave conditions but to the voluntary speed reduction imposed by the master. The most stringent criterion is established by the request of lowering vertical accelerations on board for maintaining an adequate comfort level between the passengers and the personnel.

## References

Blendermann, W., 1996: Wind loading on ships-collected data from wind tunnel tests in uniform wind, Institut für Schiffbau der Universität Hamburg, Report 574.

Gerritsma, J., Beukelman, W., 1972: Analysis of the resistance increase in waves of a fast cargo ship, International Shipbuilding Progress, Vol. 19, pp. 285-293.

Havelock, T.H., 1937: The resistance of a ship among waves, Proceedings of the Royal Society, Report A-161.

Holtrop, J., Mennen, G.G.J., 1982: An approximate power prediction method, International Shipbuilding Progress, Vol. 29, pp. 166-170.

Hosoda, R., 1973: The added resistance of ships in regular oblique waves, Japanese Society of Naval Architects , Vol. 133, pp. 1-20.

Isherwood, R.M., 1973: Wind resistance of merchant ships, Transactions of Royal Institution of Naval Architects, Vol. 115, pp. 327-338.

Jinkine, V., Ferdinande, V., 1974: A method for predicting the added resistance of fast cargo ships in head waves, International Shipbuilding Progress, Vol. 21, pp. 149-167.

Journée, J.M.J., 1976: Prediction of speed and behavior of a ship in a seaway, International Shipbuilding Progress, Vol. 23, pp. 1-24.

Maruo, H., 1957: The excess resistance of a ship in rough sea, International Shipbuilding Progress, Vol. 4, pp. 337-345.

Shifrin, L.S., 1973: Priblizennyj rascet dopolnitel'nogo soprotivlenija sudna na regularnom volnenii, Sudostroenie, Vol. 12, pp. 5-7.

Strom-Tejsen, J., Yeh, H.Y.H., Moran, D.D., 1973: Added resistance in waves, Transactions of the Society of Naval Architects and Marine Engineers, Vol. 81, pp. 109-143.