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AN INVESTIGATION OF SHIP PERFORMANCE IN SEAS

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ABSTRACT

Numerical calculations of total added resistance both in regular and irregular long crested waves for Series 60 ships, parent form, have been carried out. The total added resistance in regular waves has been determined by adding separately Maruo's method for ship motion to that of Fujii-Takahashi's method for wave reflection. Computed results have been compared with experimental ones. Average added resistance in a seaway is obtained from the analytically obtained mean response curve for added resistance in regular waves and the ISSC spectrum applying linear superposition technique. In order to determine the performance, two situations have been considered. They are: power increase at constant speed and speed loss at constant power. The performance of series 60 ships, parent form, has then been presented in graphical forms for prediction in a seaway. Effect of ship speed, wave direction and block coefficient on performance has been examined and the percentage added power or speed loss with respect to calm water characteristics at different sea states has been presented.

KEY WORDS: Added resistance, Added power, Ship performance

1. INTRODUCTION

The knowledge of hydrodynamic behavior of a ship is important because the success of a ship design eventually depends on its performance in a seaway. The horsepower of a ship predicted by a tank test is usually the value in a calm sea and a considerable power should be added to this when a ship is steaming in a seaway. The prediction of ship motions, resistance and power in a realistic seaway is such a complex problem that the added power required in a seaway is traditionally accounted for by increasing a certain percentage of its calm water characteristics. While this method has been adequate, it would certainly be advantageous to the designer if he could predict accurately the increase in power of a ship in a seaway. Though the increase of resistance of a ship due to the waves has been recognized for a long time, there are different opinions as to the cause of excess resistance. Presently there is large number of methods available for the calculation of resistance increase in waves. The object of the paper is not to make a comparative study of the different methods for prediction of added resistance rather the object is to investigate the performance of ship in seas due to waves only by applying certain theories and methods without considering the effects of wind and current. In order to do this, numerical calculations of total added resistance both in regular and irregular long crested waves for Series 60 ships, parent form, have been carried out. Of the several alternative approaches, total added resistance in regular waves has been determined by adding separately Maruo's method [1] for resistance increase due to ship motion to that of Fujii-Takahashi's method [2] for wave reflection. A number of researchers have proposed similar methods for predicting total added resistance, reference [8]. Average added resistance in a seaway is obtained from the analytically obtained mean response curve for added resistance in regular waves and the ISSC spectrum applying linear superposition technique. In order to determine the performance, two situations have been considered. They are: power increase at constant speed and speed loss at constant power. The performance of series 60 ships, parent form, has then been presented in graphical forms for prediction in a seaway. Influence of ship speed, wave direction and block coefficient on performance has been examined and the percentage added power or speed loss with respect to calm water characteristics at different sea states has been determined.

2. PREDICTION METHOD

As pointed out earlier, total added resistance in regular waves has been determined by adding separately Maruo's method [1] for resistance increase due to ship motion to that of Fujii-Takahashi's method [2] for wave reflection. In regular waves, the added resistance R_{AW} is computed for different wave-encounter frequencies to obtain an accurate representation of the response amplitude operator for added resistance, 'R_{AW}/ζ_a^2', where ζ_a is the wave amplitude. Average added resistance in irregular long crested waves is then predicted from the mean curve of response amplitude operator for added resistance in regular waves and energy spectrum of the sea recommended by ISSC by following linear superposition technique.

Hosoda [3] pointed out that the contribution of the lateral motions to the added resistance in oblique waves is almost negligible and according to this conclusion, the added resistance in oblique waves is calculated on the basis of prediction for head sea waves, for example, Fujii and Takahashi [2]. It should be noted that the motion responses have been obtained by applying Ordinary Strip Method (OSM).

3. COMPUTATIONS AND COMPARISONS

Numerical calculations have been carried out for three Series 60 ships, parent form, reference [4] in order to predict the added resistance both in regular and irregular waves. The computed results in regular waves are compared with the thrust increase coefficient of experimental results for Series 60 ships. The comparisons have been shown in Figs. 1 to 4. It should be noted that the experimental results of added resistance in oblique waves are very rare. Fortunately extensive model tests of Series 60 forms in oblique long crested waves were conducted in a unique seakeeping facility at MARIN as reported by Vossers et al. in reference [6]. Fourteen models were tested in five different wavelengths and five different oblique directions at 170°, 130°, 90°, 50° and 10°. Four speeds were used in the range of F_n = 0.10 to 0.25. Among other things the extensive measurements made included thrust increase coefficient. The results were presented graphically. Among these, the results of the model with block coefficient C_B = 0.70 and L/H= 17.50 conform to that of the parent form.

Figs. 1-4 show the comparison of non-dimensional added resistance with the thrust increase coefficient of experimental results for Series 60 hull, parent form, with block coefficient C_B = 0.70 at four different Froude numbers with each figure representing for individual wave heading. It should be noted that the experimental results of thrust increase coefficient is expressed by $\tau_\zeta = \dfrac{T_\zeta}{\rho g \zeta_a^2 B^2 / L}$ where T_ζ is the thrust increase. It may be noted that Hosoda [3] has given a similar comparison between theoretically obtained resistance increase coefficients with that of experimentally obtained thrust increase coefficients.

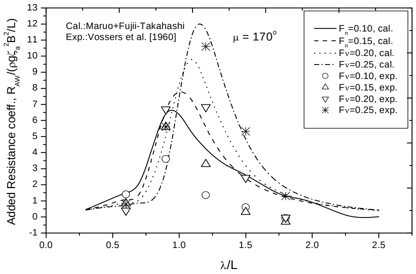

Fig.1: Comparison of added resistance between numerical and experimental results for C_B = 0.70 at a wave heading of 170°

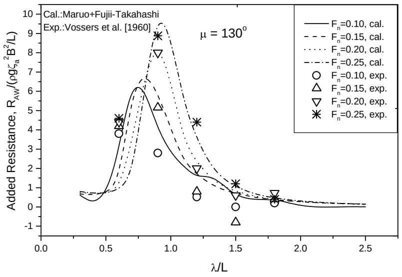

Fig.2: Comparison of added resistance between numerical and experimental results for C_B = 0.70 at a wave heading of 130°

From Figs. 1-4, in head and bow waves, at lower speeds, the agreement is found to be not satisfactory, while relatively better agreement is found at higher speeds. While in beam and following seas, comparatively better agreement is obtained. From the overall comparisons, prediction seems to give better agreement especially in oblique directions. However it may be noted that there are discrepancies between various laboratory measurements and various theories as pointed out by different investigators, for example; reference [7].

It should be noted again that the wavelength to ship length ratios covered in the experimental results range from 0.6 to 1.8 and as such at shorter wavelength ratios below 0.6, it was not possible to show the comparison, which is important especially for fuller ships.

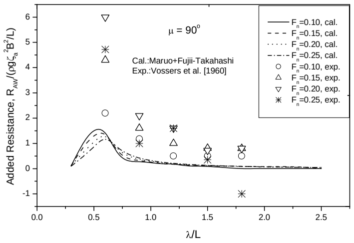

Fig.3: Comparison of added resistance between numerical and experimental results for C_B = 0.70 at a wave heading of 90°

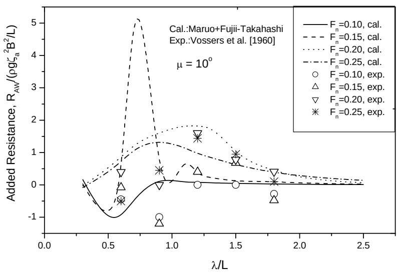

Fig.4: Comparison of added resistance between numerical and experimental results for $C_B = 0.70$ at a wave heading of 10^o

4. PERFORMANCE RESPONSE TO ADDED RESISTANCE

The response of a ship due to added resistance from waves will depend upon engine control system and any intervention by the ship's operator. However two situations have been considered for prediction of performance of the vessels under study; one is the power increase at constant speed and the other is the speed loss at constant power.

4.1 POWER INCREASE AT CONSTANT SPEED

From reference [10], power increase at a given speed when the ship experiences an added resistance can be expressed by

$$\frac{\Delta P}{P_0} = \frac{1+\dfrac{\Delta R}{R_0}}{1+\dfrac{\Delta \eta_0}{(\eta_0)_0}} - 1$$

where ΔP is the increase in power P_0 to maintain speed when the resistance is increased by ΔR. $\Delta \eta_0$ is the change in propeller efficiency η_0 consequent upon the change in propeller loading. Reference [9] provides a diagram of the relationship between $\dfrac{\Delta R}{R_0}$ and $\dfrac{\Delta \eta_0}{\eta_0}$ of series 60 ship propeller. This diagram is reproduced as Figure 12. Whilst it is easily possible to calculate the relationship for a particular propeller and ship, if the data is available, it is considered adequate to estimate appropriate values from figure 12.

4.2 SPEED LOSS AT CONSTANT POWER

Reference [11] gives:

$$\frac{\Delta V}{V_0} = \frac{1}{n+1}\frac{\Delta P}{P_0}$$

or the speed loss fraction at constant power is $(n+1)^{-1}$ times the power increase at constant speed. Here V_0 is the ship speed at calm water and n is the local speed exponent of the resistance curve in the region of interest. In the determination of speed loss at constant power, it is seen that the essential controlling feature is the slope of the power-speed curve in the range of speed of interest. Some typical values for n may be found in reference [9] as follows:

Ship (C_B =0.60)	Fn=0.25	n =2.886
Ship (C_B =0.80)	Fn=0.15	n =2.153

5. RESULTS AND DISCUSSION

In Fig. 5, variation of mean added resistance in irregular waves are shown against wave headings at different significant wave heights for Series 60 ship with C_B=0.70 at F_n=0.20. It is seen that the added resistance increases with increase of significant wave heights at all wave headings. Head sea waves are seen to give maximum added resistance, while from quartering to following seas, it increases again with the increase of significant wave heights. At a wave heading of approximately 60 to 70 degrees, the added resistances are found to be minimum and independent of significant wave height.

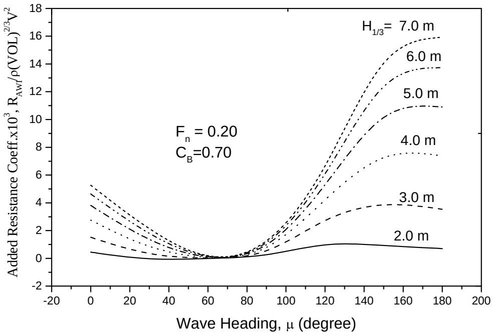

Fig.5.Variation of Added Resistance against wave headings for Series 60 ship with C_B=0.70 and L_{BP}=121.95 m at different significant wave heights

In Figures from 6 to 11, the percentage added resistance with respect to calm water resistance of three Series 60 ships with C_B=0.60, 0.70 and 0.80 have been shown at different Froude numbers. The three block coefficients are chosen so that it represents fine, medium and full ship forms. Fig. 6 and 7 represent the percentage added resistance for C_B=0.60 at F_n= 0.20 and 0.25 respectively. Fig. 8 and 9 represent the same for C_B=0.70 at F_n= 0.20 and 0.25 respectively, while Fig. 10 and 11 are for C_B=0.80 at F_n=0.15 and 0.20 respectively. The Froude numbers are chosen so that it represents the region around service speeds for this type of ships. As can be seen from the figures, the results are presented against non-dimensional sea state defined by $H_{1/3}/L_{BP.}$ The use of non-dimensional sea states for the calculation has the advantage that it ties the importance of sea state to the length of the ship. In this way, a description of the ship’s behavior in all seaways of interest is possible. It may be noted that calm water resistance is calculated from reference [5] for naked hull only. Considering a non-dimensional sea state of 0.025, a Series 60 ship with C_B=0.60 is seen to experience an added resistance of approximately 1 to more than 50% at F_n=0.20 depending upon the wave heading, while at F_n=0.25, the range is from 0 to more than 30%. At the same non-dimensional sea state, a Series 60 ship with C_B=0.70, is seen to experience an added resistance of 1 to more than 40% at Fn=0.20 and from 1 to more than 20% at Fn=0.25. Series 60 ship with C_B=0.80, is seen to experience an added resistance from 0 to approximately 55% at Fn=0.15 and from 0 to 25% at Fn=0.20 at the same non-dimensional sea-state depending upon different wave headings. It may be noted that at lower speeds, the percentage increase of added resistance is more than that at higher speeds. The lower values of percentage increase of added resistance is due the fact that calm water resistance is a function of square of ship speed, whereas the added resistance is not that speed sensitive [8].

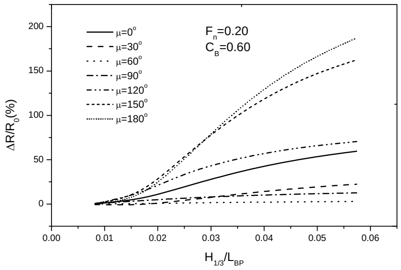

Fig.6. Variation of percentage added resistance for Series 60 ship with C_B=0.60 at F_n=0.20

Figures 13 to 16 have been prepared for ships with block coefficient 0.60 and 0.80, for prediction of power increase at constant speed and speed loss at constant power. The figures therefore represent the performance of fine and full ships in terms of penalties for power or speed. The Froude numbers are chosen so that it represents the service speed for these types of ships.

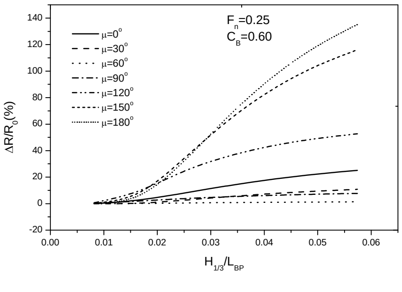

Fig.7. Variation of percentage added resistance for Series 60 ship with C_B=0.60 at F_n=0.25

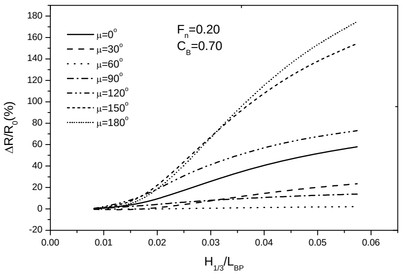

Fig. 8. Variation of percentage added resistance for Series 60 ship with C_B=0.70 at F_n=0.20

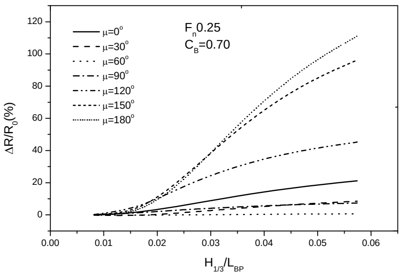

Fig.9. Variation of percentage added resistance for Series 60 ship with C_B=0.70 at F_n=0.25

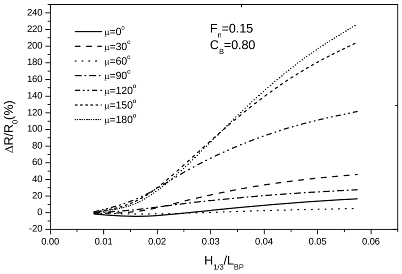

Fig.10. Variation of percentage added resistance for Series 60 ship with C_B=0.80 at F_n=0.15

Fig. 13 represents the percentage increase in power due to waves for the ship with C_B=0.60 at Fn=0.25 while Fig.14 represents percentage speed loss for the same ship. Fig. 15 & 16 repeat Fig. 13 & 14 for ship with C_B=0.80 at Fn=0.15. As can be seen from the figures, the results are presented against non-dimensional sea state defined by $H_{1/3}/L_{BP}$ for different headings.

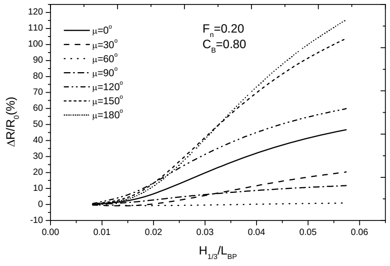

Fig.11. Variation percentage added resistance for Series 60 ship with C_B=0.80 at F_n=0.20

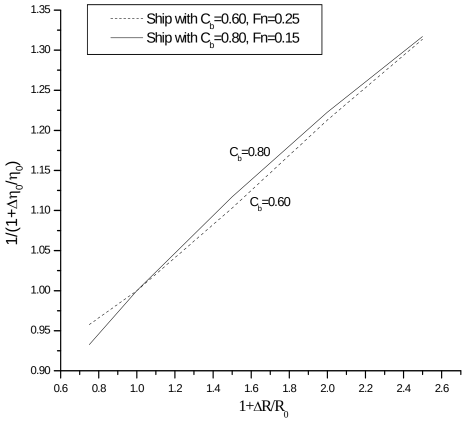

Fig.12. Change in open water efficiency due to increase in resistance of Ships with block coefficient 0.60 and 0.80

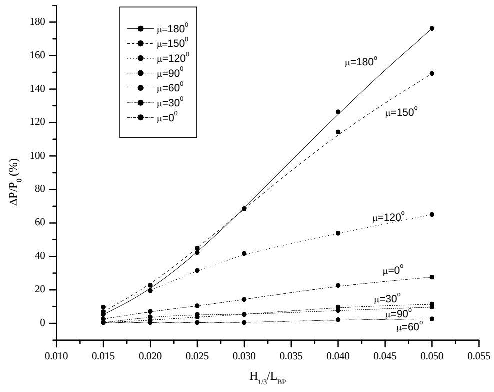

Fig.13. Percentage Increase in Power for Series 60 ship with C_B=0.60 at F_n=0.25

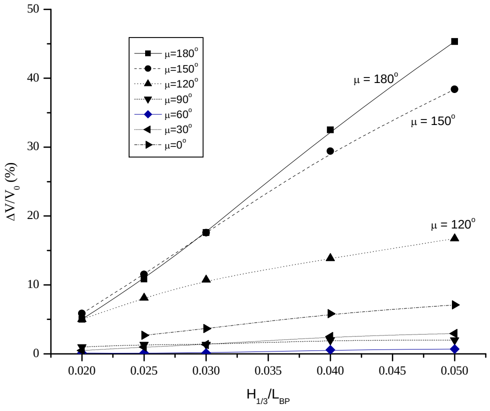

Fig.14. Performance of Speed for Series 60 ship with C_B=0.60 at F_n=0.25

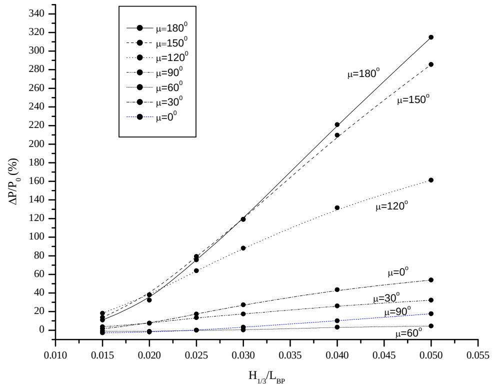

Fig.15. Percentage Increase in Power for Series 60 ship with C_B=0.80 at F_n=0.15

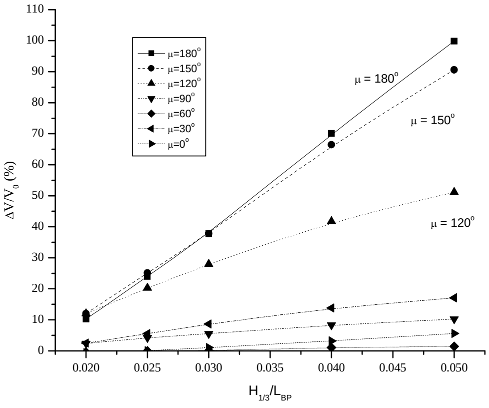

Fig.16. Performance of Speed for Series 60 ship with C_B=0.80 at F_n=0.15

The nature of the curves of Fig.13 to 16, for obvious reason, is similar to those of Fig. 6 to 11. As expected, it is seen that the percentage increase in power increases with increase of non-dimensional significant wave heights at almost all wave headings. Head and bow seas are seen to give maximum added power as usual, while quartering and following seas are seen to give minimum added power. At a wave heading of 60 degree, the added power is found to be minimum and almost independent of non-dimensional significant wave heights, the reason for which is evident from Fig.5.

Now assuming the ships are encountering a non-dimensional significant wave of 0.025 on their route, the penalties in power and that of speed of the ships appear as follows:

At head and bow seas for the ship with C_B=0.8, added power requirement is approximately 60~80%, at beam seas approximately 14%, while in quartering and following seas approximately 0~18% at a constant speed represented by Fn=0.15. On the other hand, at the same wave strength, the same ship at constant power is expected to experience a speed loss of approximately 20~25% at head and bow seas, 4% at beam seas and 0~5% at quartering and following seas.

In a similar situation, for the ship with C_B=0.6, added power requirement is approximately 30~45% at head and bow seas, approximately 5% at beam seas, while in quartering and following seas approximately 0~10% at a constant speed represented by Fn=0.25. On the other hand, at the same wave strength, the same ship at constant power is expected to experience a speed loss of 8~11% at head and bow seas, 1.5% at beam seas and 0~3% at quartering and following seas.

6. CONCLUSIONS

From the computational results and analysis for Series 60 ships, parent form, it may be concluded that for this type of ships, the sea has significant effect on the performance at all speed range. However the effect is more dominant at lower speeds than that at higher ones. Head and bow seas have more dominant effect on performance than other headings. Moreover fuller ships are expected to experience less penalties for power or speed than finer ships. .For a moderate sea represented by non-dimensional significant wave height of 0.025, the finer ships are expected to experience a power increase of 1~45% and a speed loss of 0~11%, while the fuller ships are expected to experience a power increase of 0~80% and a speed loss of 0~25% at their service speeds depending upon different wave headings with the minimum penalty being at a wave heading of 60 to 70 degrees.

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