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PREDICTION OF ADDED RESISTANCE OF SHIP DUE TO REGULAR HEAD WAVES

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ABSTRACT

This paper presents the added resistance of a 100m Product Tanker due to waves. It includes the study of influence of ship speed and wavelength to the added resistance. This work was carried out by theoretical calculation and model testing in towing tank. The method proposed by Gerritsma & Beukelmen was used in the theoretical calculation technique. This method required ship motion and hydrodynamic coefficients data as input, which was determined using Strip Theory. The model testing was carried out on a 3.382 m model in the towing tank 120m x 4m x 2.5m at the Universiti Teknologi Malaysia's (UTM) Towing Tank in Skudai, Johore Bahru. Both of the techniques were investigated in three Froude number values, namely 0.21, 0.25 and 0.28. For each Froude number, the study was conducted at wavelength to model length ratio, L_w/L_m between 1.0 and 2.0. The outcomes from both experimental and theoretical calculations were also compared.

Keywords: *Added resistance, strip theory*

1.0 INTRODUCTION

The success of a ship design ultimately depends on its ability to sustain its calm water performance in a seaway. Added resistance in waves is an important part of ship performance due to its economical effect on ship operation. The knowledge of added resistance due to waves and possibility to minimize it by changes in ship particulars and hull form has stirred up the operator's interest in optimizing ships in this respect [1]. Added resistance in waves can be determined from model tests or analytical methods. Model experiments are carried out in regular or irregular head seas, and added resistance is measured as the difference between the time

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average resistance in waves and the calm-water resistance measured at the same speed.

2.0 EXPERIMENTAL STUDY

2.1 Model Testing

The resistance tests in calm water and in regular waves were carried out in the towing tank 120 m x 4 m x 2.5 m of Marine Technology Laboratory UTM. This laboratory is equipped with the hydraulic driven and computer controlled wave generator which is capable to generate regular and irregular waves over a period range of 0.5 to 2.5 secs. The irregular waves characterized by JONSWAP or Pierson-Moskowitz spectrum can be generated up to a significant wave height of 0.44m, while it is also possible to generate irregular wave according to a spectrum of an arbitrary form.

For this experimental study a model of a 100m product tanker with 31.93 scale ratio was used. The main particulars of the ship and model are shown in Table 1.

Table 1: Ship and model particulars

Item	Ship	Model
Length Overall L_{OA}	108.0	3.382
Length Between Perpendicular	100.0	3.132
Breath B	17.50	0.548
Bow Height h_B	14.37	0.450
Depth D	9.25	0.290
Draught Forward T_f	6.65	0.208
Draught Aft T_a	6.65	0.208
Volume Displacement ∇	8695	0.267
VCG or KG	5.00	0.157
LCG aft of FP	49.05	1.536
Rad. of gyration, 25%L, K_{yy}	25	25
Rad. of gyration, 40%B, K_{xx}	40	40
Block Coefficient, C_B	0.747	0.747
Midship Coefficent, C_M	0.952	0.952

2.2 Calm Water Testing

The calm water experiments were carried out for three model speeds which are 1.0925, 1.2745 and 1.4567 m/s. These speeds are equivalent to 12, 14 and 16 knots of ship speed according to the Froude's Law of Similitude.

2.3 Regular Head Waves Testing

For conventional ship forms, a sufficient number of tests should be carried out at each speed to provide adequate data for a range of wavelength from 0.5 L_{bp} to 2.0 L_{bp} [7]. For this experiment, regular head waves were used covering a wave length to ship length ratio from 1.0 to 2.0. The wave height to ship length is varied for different model speed. The testing protocol for this regular head waves experiment stated in Table 2.

The added resistance in regular waves is the difference between the calm water resistance and the resistance in the waves at the same speed. The added resistance obtained from the experiment would be presented in the form of the non-dimensional resistance coefficient σ_{AW} versus non-dimensional frequency of encounter, $\omega_e(L/g)^{1/2}$. The non-dimensional resistance coefficient is expressed as,

$$\sigma_{AW} = \frac{R_{AW}}{\rho g (B^2 / L) \xi^2} \qquad (1)$$

It is seen from the above equation that the assumption about added resistance being proportional to the wave height squared is contained in this non-dimensional ratio.

Table 2: Regular waves details used in resistance tests in waves

V_m (m/s)	F_n	Wave characteristics				
		L_w/L_m	L_w (m)	H_w (m)	T_w (s)	ω rad/s
1.093	0.197	1.00	3.13	0.039	1.416	4.436
1.093	0.197	1.10	3.45	0.043	1.486	4.230
1.093	0.197	1.30	4.07	0.051	1.615	3.891
1.093	0.197	1.40	4.39	0.055	1.676	3.750
1.093	0.197	1.50	4.70	0.059	1.735	3.622
1.093	0.197	1.70	5.32	0.067	1.847	3.402
1.093	0.197	2.00	6.26	0.063	2.003	3.137
1.275	0.230	1.20	3.76	0.038	1.552	4.050
1.275	0.230	1.40	4.39	0.044	1.676	3.750
1.275	0.230	1.60	5.01	0.050	1.792	3.507
1.275	0.230	1.80	5.64	0.056	1.900	3.307
1.275	0.230	2.00	6.26	0.063	2.003	3.137
1.457	0.263	1.00	3.13	0.026	1.416	4.436
1.457	0.263	1.20	3.76	0.031	1.552	4.050
1.457	0.263	1.40	4.39	0.037	1.676	3.750
1.457	0.263	1.50	4.70	0.034	1.735	3.622
1.457	0.263	1.60	5.01	0.042	1.792	3.507
1.457	0.263	1.80	5.64	0.040	1.900	3.307

3.0 THEORETICAL APPROXIMATION

There are several theoretical methods to obtain added resistance of ship in waves. However, based on the study done by Aribas [2] and Strom-Tejsen *et. al* [3] the

Gerritsma and Beukelmen method has been used to predict the added resistance in waves in this study. This method requires information about the ship hull i.e. the sectional offsets or sectional geometric coefficients as an input.

Hydrodynamic characteristics such as added mass and damping coefficients are also required for the stations that define the ship hull. Calculations are performed for a range of regular waves and the hydrodynamic coefficients must be provided for each wave frequency, and also the heave and pitch motion value. In this work, strip theory was used to determine these inputs.

4.0 RESULTS AND DISCUSSION

4.1 Influence of Speed and Wave Length on Added Resistance

Figures 1 and 2 show the plot of experimental and theoretical non-dimensional added resistance against wave length to model length ratio at three different Froude numbers respectively. Figure 1 shows that the added resistance increases with model speed. The peak value occurred at the ratio wave length to model length of 1.5 to 1.6. Results by theoretical calculation demonstrated that added resistance decreases when model speed is increased before peak value region. But, the added resistance increases at and after the peak value region with increasing model speed. These maximum added resistances occur at wave length to model length ratio around 1.4 to 1.6.

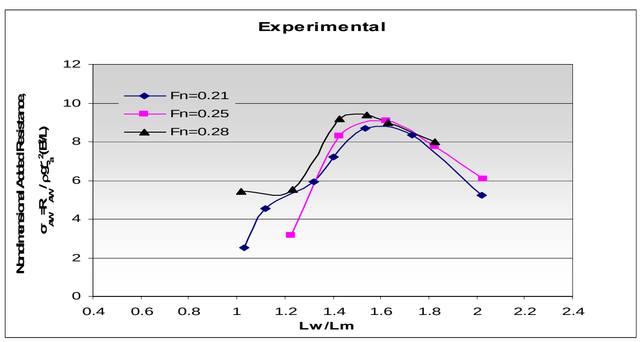

Figure 1: Experimental non-dimensional added resistance

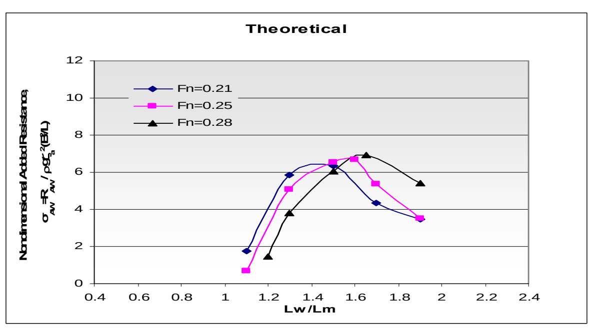

Figure 2: Theoretical non-dimensional added resistance

4.2 Comparison of Experimental and Theoretical Added Resistance Results

Figures 3, 4 and 5 illustrate non dimensional added resistance versus wave length to model length ratio, L_w/L_m at Froude numbers 0.21, 0.25 and 0.28, respectively. The peak value of both experimental and theoretical results for F_n=0.21 occurred at approximately 1.5 of L_w/L_m. Meanwhile, the maximum value was observed at 1.6 of L_w/L_m for F_n=0.25. However, in F_n=0.28, the maximum value of experimental data and theoretical data occurred at different L_w/L_m. The peak value of experimental data seems to have occurred at 1.5 of L_w/L_m while the theoretical data was at 1.6.

Generally, the added resistance values obtained in experimental testing were seems higher than the theoretical calculation. However, the differences of value at lower L_w/L_m (high frequencies) were smaller than at higher L_w/L_m. It was supported by the theory that at high frequencies, the diffraction effect constitute the major portion of the added resistance and the Gerritsma and Beukelman's method have included this effects [6]. Thus, it may conveniently be concluded that at lower L_w/L_m the theoretical was to be in closer agreement with the experimental data. Nevertheless, at F_n=0.28, the added resistance of experimental data demonstrated unexpected value at 1.0 of L_w/L_m. This probably due to an experimental error involved during data measurement.

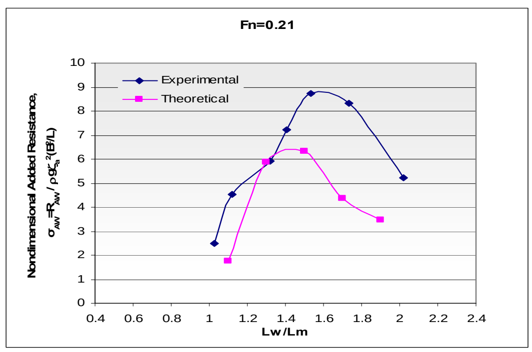

Figure 3: Experimental and theoretical added resistance at Fn=0.21

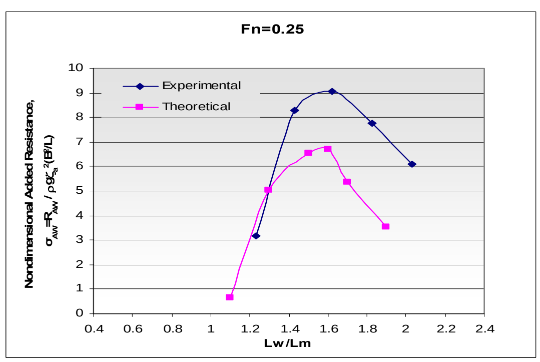

Figure 4: Experimental and theoretical added resistance at Fn=0.25

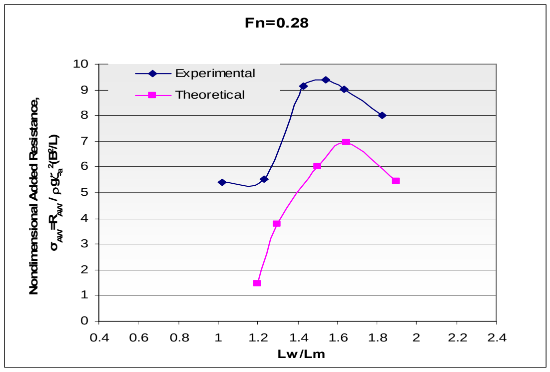

Figure 5: Experimental and theoretical added resistance at Fn=0.28

It was seen that, in the region of the peak added resistances, the experimental result was approximately 34 % higher than the theoretical result for F_n=0.21, 34 % for F_n=0.25 and 33 % for F_n=0.28. It can be concluded that, at the region of maximum added resistance, the experimental result is approximately 33 % higher than theoretical calculation.

In theoretical calculation, strip theory is a method to determine the ship motion and damping coefficient. The discrepancy between the calculated and measured values may be attributed to these three shortcomings of the strip theory [4].

First, the three-dimensional flow, especially at both ends of the ship, is neglected. The three-dimensional effect on the total damping force, which may not be considered to be large, may cause some discrepancy.

Second, only wave effects have been considered in the calculation of the damping coefficient; damping due to viscosity is neglected in the calculations by the strip theory. Damping due to viscosity in the heaving motion is insignificant only at zero speed.

Third, three-dimensional effects for the calculation of added mass and added mass moment of inertia may also contribute to some extent to the discrepancy between the calculated and measured results.

Another factor that influences the discrepancy between the calculated and measured results is the calculation of the relative motion has a strong effect on the Gerritsma and Beukelman's method. In practice, the presence of hull causes a considerable distortion on the waves close the ship and the equation of effective wave amplitude proposed by Gerritsma and Beukelman is only an approximation likely to be reliable at the forward part of the ship. Further aft, the equation may underestimate the relative motion [5].

Data in Table 4 summarizes the published data on the region of maximum added resistance. Meanwhile, Table 4 summarizes the differences between experimental and theoretical calculation using Gerritsma and Beukelman's method at the peak value region. The result of this study differs with the other reported study probably because it was conducted under different conditions.

Table 3: Peak value region of added resistance

Researcher	Model	Peak value	F_n
Blok, J.J., (1993) [3]	Tanker	1.0 L_w/L_m	0.20
Journee, J.M.J., [6]	Cargo	1.0 L_w/L_m	0.20
MARIN [8]	Tanker	1.2 L_w/L_m	0.20
UTM, (2007)[5]	Tanker	1.5 L_w/L_m	0.21

Table 4: Difference between experimental and theoretical (Gerritsma and Beukelman's method)

Researcher	Model	% Difference
Journee, J.M (1976) [6]	Cargo Ship	22 %
Strom-Tejsen (1973) [2]	Series 60 C_B=0.7	25 %
Arribas, F.P., (2006) [1]	Ferry	33 %
UTM, (2007)[5]	Tanker	34 %

5.0 CONCLUSION

The added resistance due to waves increased when the ship speed increased. At a certain ship speed, it was increasing due to the increment of wave length. However, after a peak value, the added resistance would decrease. The peak value occurred approximately at 1.5 of wave length to ship length ratio. This is well agreed with the results from the towing tank model testing and theoretical calculation using Gerritsma and Beukelman's method. The result from experimental has shown to be higher than the theoretical calculation. At the peak value region, the differences between experimental and theoretical were approximately 34 %.

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