Added Resistance & Drift Force Analysis in Regular and Irregular Waves

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Abstract

The sea wave causes excess resistance which is out of scope of calm water resistance. The total wave force in horizontal plane is divided into "Added Resistance" and "Drift Force".

In this study, based on Gerritsma and Beuckelman[3] hypothesis a computer program has been developed for calculation of added resistance and drift force at various ship speeds and various heading angles in oblique seas. This program calculates wave force both in regular and irregular waves. After validation of the program, effects of different parameters on wave force imposed on vessel have been studied.

Keywords: Wave, Added Resistance, Drift Force, Ship, Strip Theory

1-Introduction and literature Review

The sea wave causes excess resistance, which is out of scope of calm water resistance. Wave force is defined as resistance imposed on ship by ship motions.

The total wave force is divided into two parts:

- added resistance that is the component of wave force in longitudinal direction which causes to reduce ship's speed.
- Drift force that is the component of wave force in transverse direction and causes to drift vessel from its main course. Additionally, the drift force also causes some difficulties to control a vessel in seaway.

Havelock[6] was the first who investigated the problem of added resistance, however his theory based on a first order approximation which is considered to be not accurate in comparison with those based on second order approximation.

Maruos's theory[6] is based on potential flow solution in which velocity potential is divided into three components; incident wave potential, radiated potential and diffracted potential. This theory is valid only for head sea. Boese and Haffman[5] considered the problem of added resistance based on pressure distribution on ship hull. Salvesen[5] used velocity potential to find the added resistance in head and oblique seas. He said that the pitch and heave motions have dominant effects on added resistance. He sustained a good agreement between experiment and theory. Gerritsma and

Beuckelman[7] method is based on radiated energy by ship sideways.

The original theory is for head sea and later on it was developed for oblique seas by Loukakis[5]. Through out publications the Gerritsma & Bueckelman method is known as simple accurate method for all type of ships.

Zeraatgar[3] has used Gerritsma & Beuckelman and Loukakis method and developed it further on. In his work some simplifications are introduced then in comparison with Salvesen method the simplified method has almost the same agreement in comparison with the original one.

In this paper based on Gerritsma & Beuckelman and Loukakis hypothesis a computer program, “Wave Resistance”, has been developed for calculation of added resistance and drift force at various ship speeds and various heading angles in oblique seas. This program calculates added resistance and drift force both for regular and irregular waves. Comparing with exciting results, the results of this computer program are quite satisfactory. “Wave Resistance” program is used to show the effect of parameters such as ship speed, heading angle, significant wave height and wave period.

2-Mathematical Model

According to the Gerritsma & Bueckelman hypothesis, the energy radiated by ship’s motions during a period of encounter is equal to energy lost by ship because of wave force. According to this principle:

$$P_R = (-\vec{R}_R)(-\vec{C} - \vec{U} Cos\beta) \qquad (1)$$

Where:

P_R : Total radiated energy

R_R : Total radiated force

C : Wave speed

U: Ship speed

β : Heading angle

According to Salvesen’s theory pitch and heave motions have dominant effects on wave resistance, it can be written:

$$P_R = P_{35} \qquad (2)$$

P_{35} : Heave- Pitch radiated energy.

For calculation of the radiated energy, two coordinate systems are used, one fixed in space with its origin on calm water surface, the X-axis along the path of the ship and Z- axis normal to the calm water surface and pointing downward. Another system is fixed in the body and moves with the ship with ship forward speed, V. Moving coordinate system is shown in figure (1).

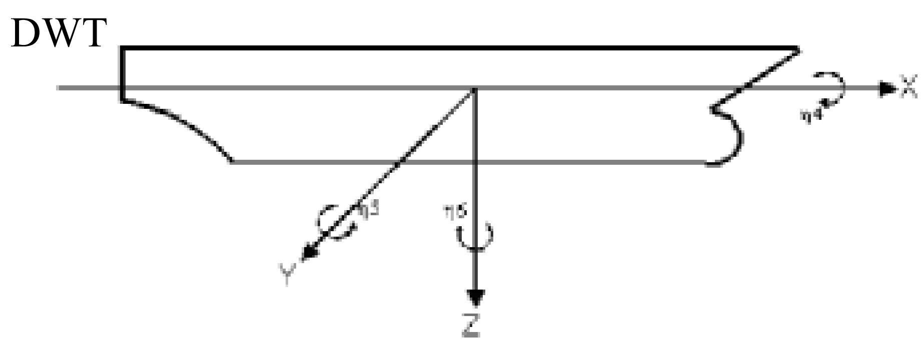


Fig.1-Moving coordinate system

2-1-Heave- Pitch radiated energy

Gerritsma and Beuckelman calculated $\mathbf{P_{35}}$ as follows:

$$P_{35} = \frac{1}{2}\int_0^L b_{35} \, |U_{RZ}^m|^2 \, dx \qquad (3)$$

$$b_{35} = b_{33} - U\frac{da_{33}}{dx} \qquad (4)$$

$$U_{RZ}^m = V_Z^m - U_Z^m \qquad (5)$$

Where:

U_{RZ}^m : Vertical relative velocity.

V_z^m : Average vertical velocity of a point on ship.

U_z^m: Sectional wave average orbital vertical velocity.

b_{35} : Sectional (two dimensional) damping coefficient of heave-pitch motion

a_{33} : Sectional (two dimensional) added mass coefficient at heave-pitch motion

The mean vertical velocity of water particles in waves U_z^m in each station could be modeled as follows [3]:

$$U_Z^m(x) = \frac{-2a\omega}{B\sin\beta}\left[M_1\cos(kx\cos\beta)\cos\omega_e t + M_1\sin(kx\cos\beta)\sin\omega_e t\right] \qquad (6)$$

$$M_1 = \int_0^T e^{-kz}\sin(ky\sin\beta)dz - \frac{1}{k}\sin\left(\frac{KB}{2}\sin\beta\right) \qquad (7)$$

y>0

where:

a: Wave amplitude
ω : Wave frequency
B: Sectional beam
K : Wave number
ω_e : Wave encounter frequency
T: Sectional draft

The mean vertical velocity of of a ship station V_z^m could be modeled as follows [3]:

$$V_z^m(x) = -\dot{\eta}_3 + x\dot{\eta}_5 - U\eta_5 \qquad (8)$$

where:

η_3 : Heave motion
η_5 : Pitch motion
U : Ship speed

The relation between radiated energy and radiated force is as following:

$$F_R = \frac{k}{\omega_e}P_R \qquad (9)$$

Gerritsma and Beuckelman theory emphasis that wave resistance is equal to radiated force:

$$F_W = F_R = \frac{k}{\omega_e}P_R \qquad (10)$$

where:

F_R : Radiated force
P_R : Radiated energy
F_W : Wave resistance

Added resistance and drift force are horizontal and vertical components of the wave force, respectively. (Fig.2)

$$f_{Add} = F_W\cos(180-\beta) = -F_W\cos\beta \qquad (11)$$

$$f_{Dr} = F_W\sin(180-\beta) = F_W\sin\beta \qquad (12)$$

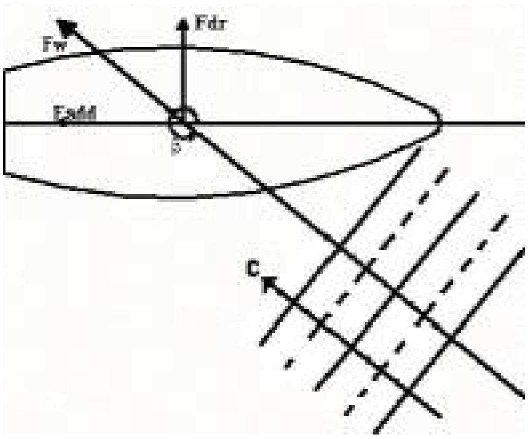


Fig.2-Difinition of added resistance and drift force

3-Computer program and validation

In order to calculate wave force on ship, firstly, the ship motions are to be calculated. In this work the ship motions are calculated by STATEK[9] computer program. Then, based on above mathematical model, a computer program is developed which is called “Wave Resistance”. In this program, at first, the STATEK program is executed then having known the ship motion the added resistance and drift force are calculated both for regular and irregular waves.

3-1-Validation

Calculations have been done for a sample ship called MARINER with main particulars shown in table1.

LOA	171.8 (m)
LBP	161 (m)
Breath	23 (m)
Depth	13.6 (m)
Draught	9 (m)
Speed	7.71 (m/s)
C_B	0.624

Table1-Main particulars of MARINER

The results of the “Wave Resistance”computer program is compared with the results of Salvesen[3] method in Fig 3, Fig 4, Fig 5 and Fig 6.

Fig.3a, 3b, 4a and 4b compares added resistance calculated by Salvesen[3] and “Wave Resistance” computer program for Fr = 0.194 at ship heading of 180^o, 150^o, 120^o and 105^o respectively. For ship heading of 180, 150 and 120 the difference between two methods is quite fair.

For the ship heading of 105 the difference between two methods is more. It is worth to mention that, the error of 2o% for calculated ship motion and model tests is quite satisfactory. Additionally, as one may see from Equation (3) the added resistance is proportional to square of ship motions. Therefore, the difference between present method and Salvesen method for ship heading of 105 degrees is due to the nature of such a method. However, the Salvesen method itself is the result of calculations.

Fig 5a, 5b, 6a and 6b show Drift Force calculated by Salvesen[3] and "Wave Resistance" program for Fr = 0.194 at ship heading of 150, 135, 120 and 150 degrees respectively. Taking into account reliability of a strip theory method[4], the maximum differences between the “Wave Resistance” program and the Salvesen[3] method for all ship headings are within the accepted range.

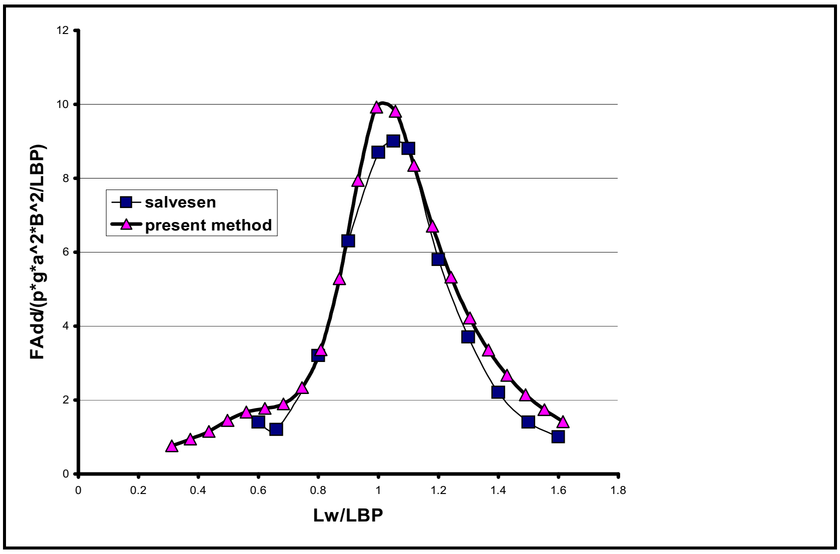


Fig.(3 a): Added Resistance in Regular Wave, calculated by "Wave Resistance" program and Salvesen for Mariner, Fr=0.194180 atμ=180.

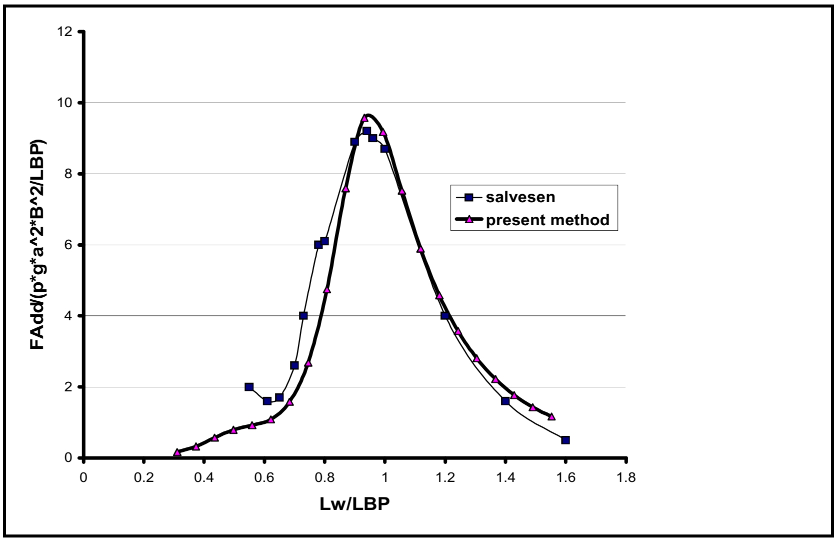


Fig.(3 b): Added Resistance in Regular Wave, calculated by "Wave Resistance" program and Salvesen for Mariner, Fr=0.194180 atμ=150.

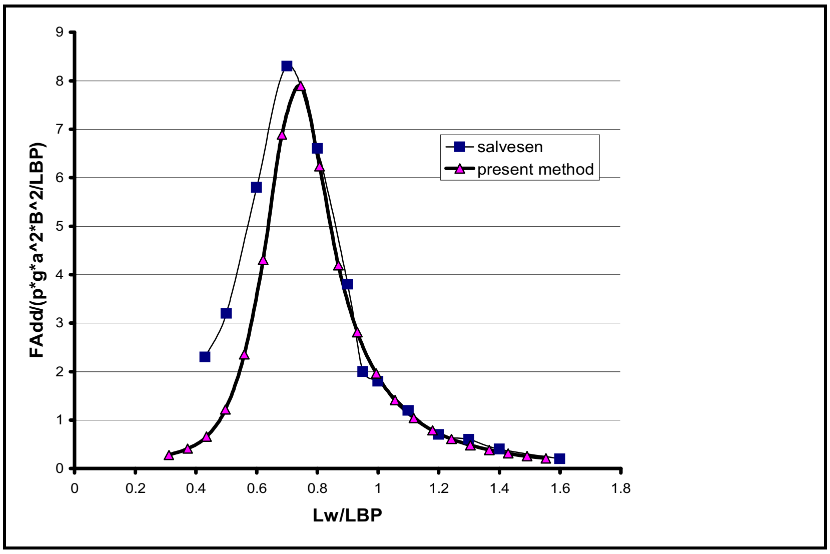


Fig.(4a): Added Resistance in Regular Wave, calculated by "Wave Resistance" program and Salvesen for Mariner, Fr=0.194180 atμ=120.

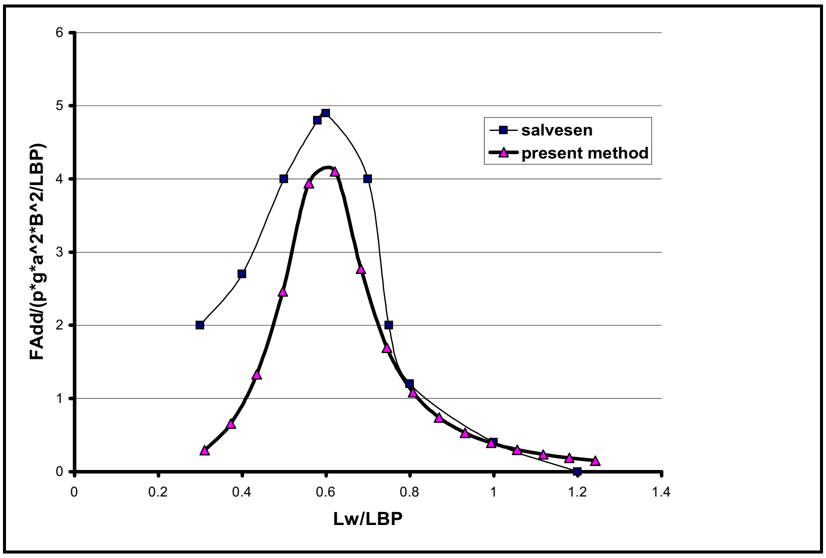


Fig (4b): Added Resistance in Regular Wave, calculated by "Wave Resistance" program and Salvesen for Mariner, Fr=0.194180 at μ=105.

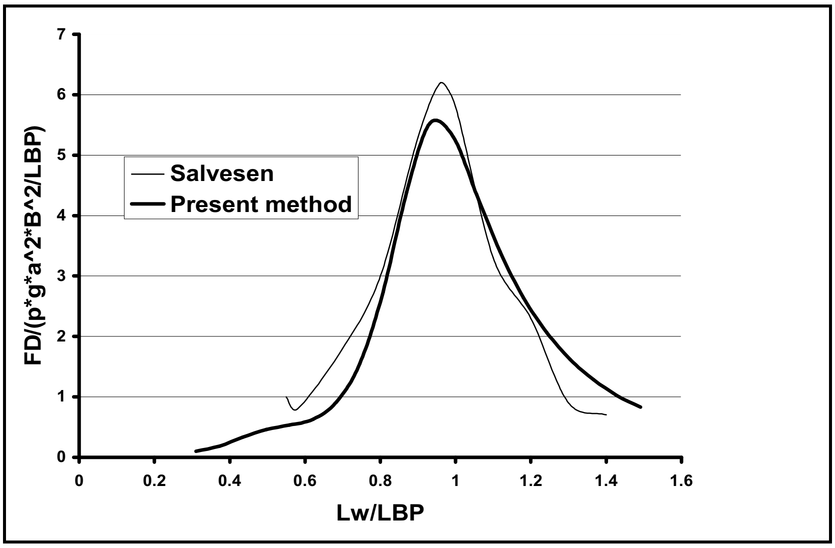


Fig.(5a): Drift Force in Regular Wave calculated by "wave Resistance " program and Salvesen for Mariner, Fr=0.194 atμ=150.

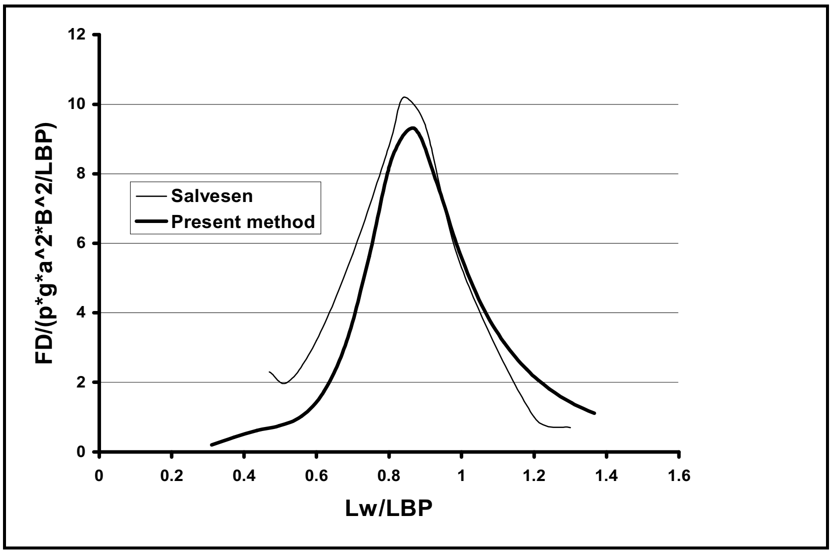


Fig.(5b): Drift Force in Regular Wave calculated by "wave Resistance " program and Salvesen for Mariner, Fr=0.194 atμ=135.

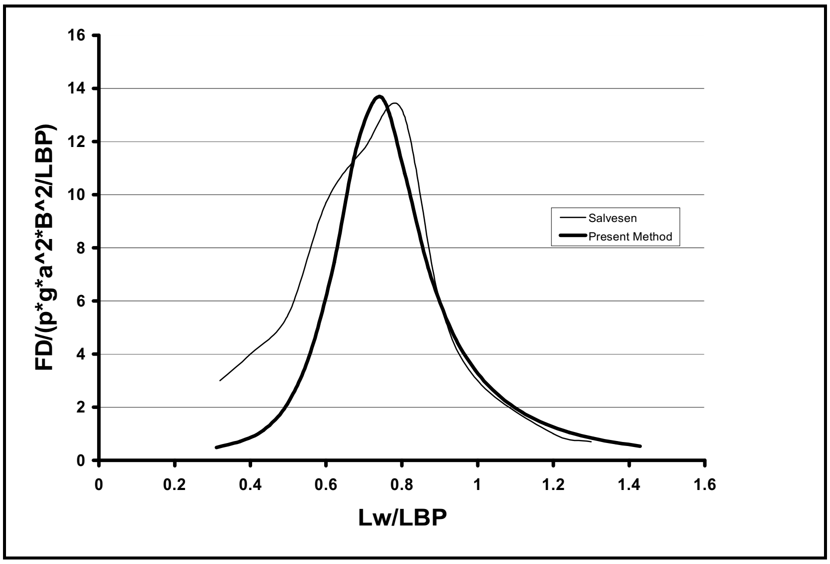


Fig.(6a): Drift Force in Regular Wave calculated by "wave Resistance " program and Salvesen for Mariner, Fr=0.194 at μ=120.

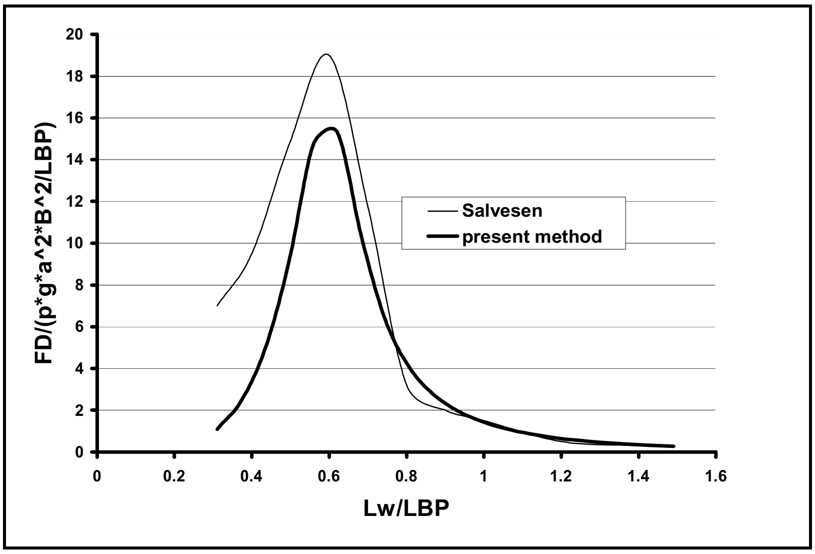


Fig.(6b): Drift Force in Regular Wave calculated by "wave Resistance " program and Salvesen for Mariner, Fr=0.194 atμ=105.

4-Effects of different parameters on added resistance and drift force by spectral analysis

The irregular wave can be presented by different sea spectra. The ITTC two-parameter spectrum defined by following formulae is appropriate for a sea wave in open sea at fully-developed conditions.

$$S(\omega_e) = \frac{A}{\omega_e{}^5} \exp\left(\frac{-B}{\omega_e{}^4}\right) \qquad (13)$$

$$A = 173\frac{H_{1/3}{}^2}{\overline{T}^4}\ (14), B = \frac{691}{\overline{T}^4} \qquad (15)$$

According to principle of linear superposition the mean value of added resistance in irregular wave, presented by sea spectrum, can be written:

$$\overline{F}_{Add} = 2\int_0^\infty \frac{F_{Add}(\omega_e)}{a^2} S(\omega_e) d\omega_e \qquad (16)$$

$$\overline{F}_{Dr} = 2\int_0^\infty \frac{F_{Dr}(\omega_e)}{a^2} S(\omega_e) d\omega_e \qquad (17)$$

Where:

$\overline{F}_{Add}$: mean added resistance spectra

$\overline{F}_{Dr}$: mean drift force spectra

$\frac{F_{Add}(\omega_e)}{a^2}$: added resistance Amplitude Operator

$\frac{F_{Dr}(\omega_e)}{a^2}$: Drift force Amplitude Operator

4-1-Effect of heading angle

Fig 7 and Fig 8 show effect of different heading angle upon added resistance and Fig 9 and Fig 10 show effect of the different heading angle on drift force.

If one compares Fig 7 with Fig 8, it appears that changing ship heading from 120 degrees to 150 degrees the added resistance rapidly increases. The effect of ship heading on drift force shows that changing ship heading from 120 degrees to 150 degrees, the drift force rapidly decreases.

4-2-Effect of ship speed

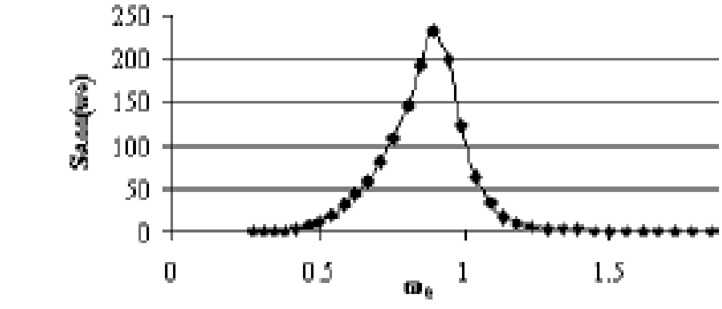
Fig 11 and Fig 12 show effect of different ship speed upon added resistance and Fig 13 and Fig 14 show effect of the different ship speed on drift force.

These Figures show that by increasing of the ship speed, added resistance and drift force increase.

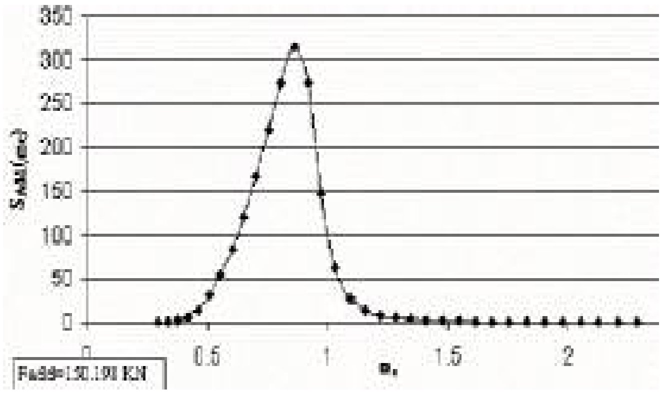
4-3-Effects of spectrum parameters

4-3-1-Effect of significant wave hight

Fig 15 and Fig 16 show effect of different $H_{1/3}$ upon added resistance and Fig 17 and Fig 18 show effect of the different $H_{1/3}$ on drift force. These figures show that by increasing of the $H_{1/3}$, added resistance and drift force increase. The order of increase of added resistance is proportion to square of $H_{1/3}$.



Fig(7): **Added Resistance Spectrum**
H1/3=6(m), Tbar=10(s)
Fr=0.194, β=120deg.



Fig(8):Added Resistance Spectrum
H1/3=6(m), Tbar=10s, Fr=0.194, β=150deg.

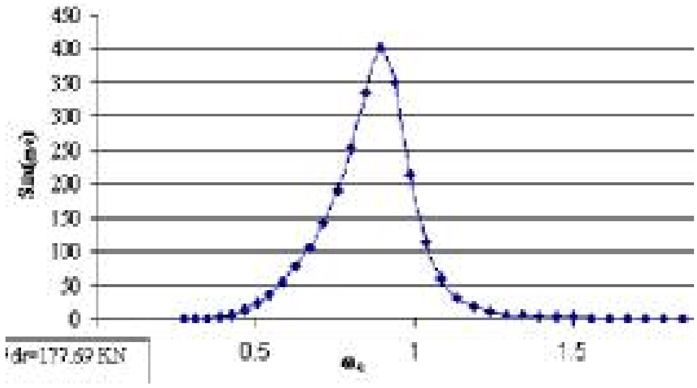


Fig.(9): **Drift Force Spectrum**
H1/3=6(m), Tbar=10(s)
Fr=0.194, β=120deg.

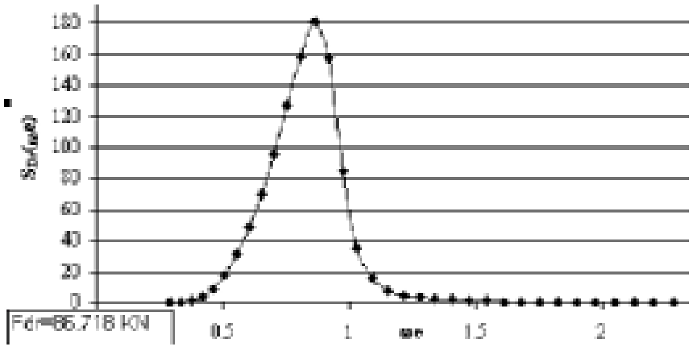


Fig.(10): **Drift Force Spectrum**
H1/3=6(m), Tbar=10(s)
Fr=0.194, β=150deg.

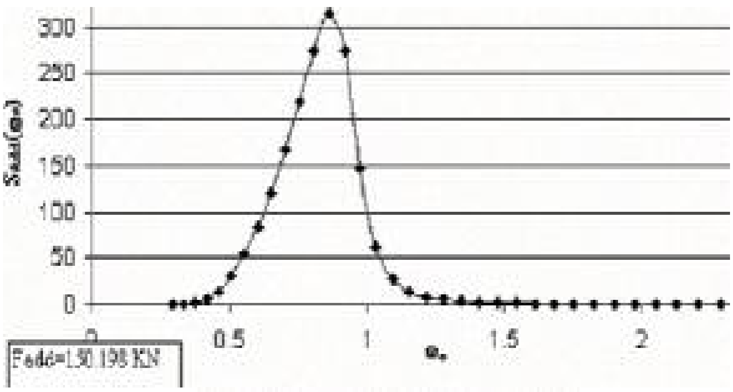


Fig.(11): **Added Resistance Spectrum**
H1/3=6(m), Tbar=10(s)
Fr=0.194, β=150deg.

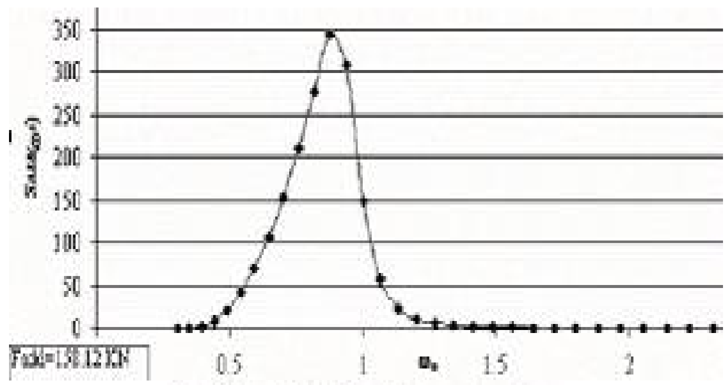


Fig.(12): **Added Resistance Spectrum**
H1/3=6(m), Tbar=10(s)
Fr=0.2516, β=150deg.

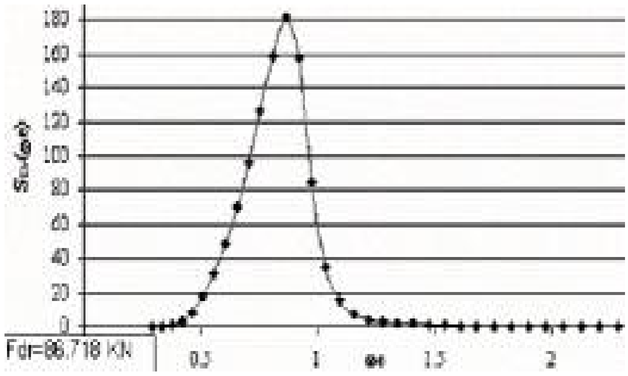


Fig.(13): **Drift Force Spectrum**
H1/3=6(m), Tbar=10(s)
Fr=0.194, β=150deg.

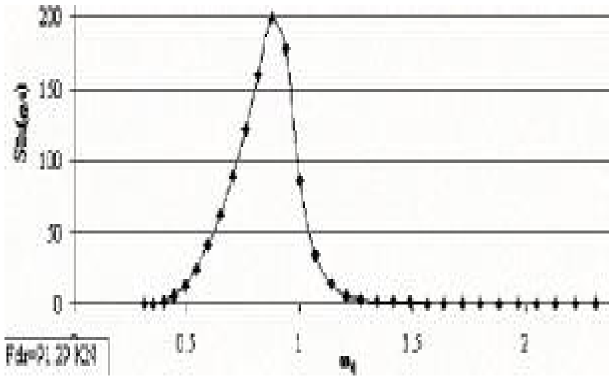


Fig.(14): **Drift Force Spectrum**
H1/3=6(m), Tbar=10(s)
Fr=0.2516, β=150deg.

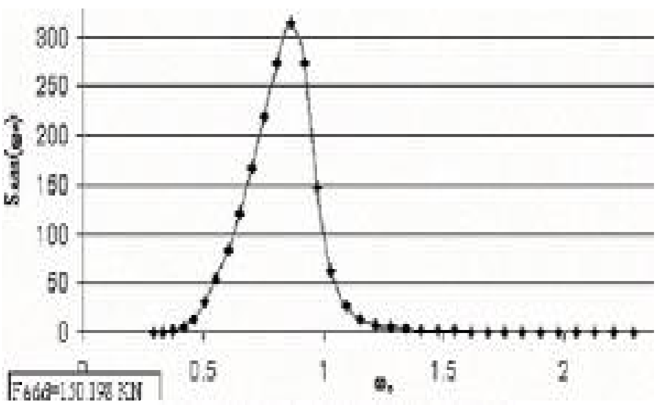


Fig.(15): **Added Resistance Spectrum**
H1/3=6(m), Tbar=10(s)
Fr=0.194, β=150deg.

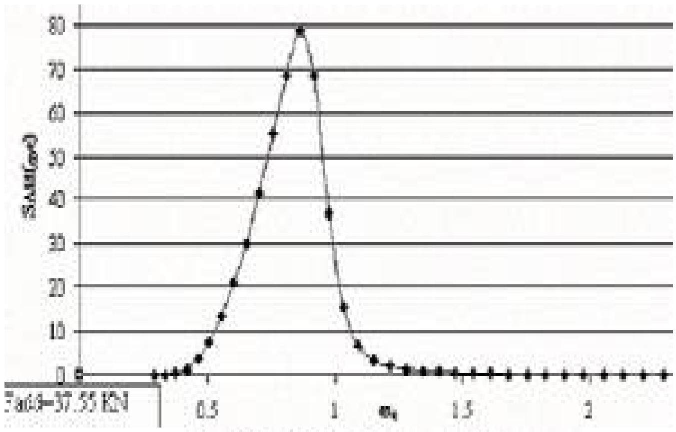


Fig.(16): **Added Resistance Spectrum**
H1/3=3(m), Thar=10(s)
Fr=0.194, β=150deg.

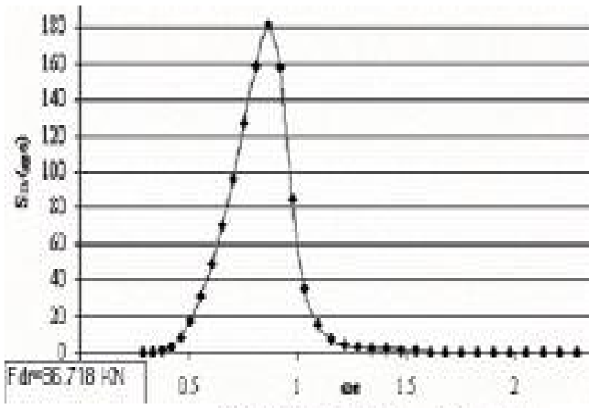


Fig.(17): **Drift Force Spectrum**
H1/3=6(m), Thar=10(s)
Fr=0.194, β=150deg.

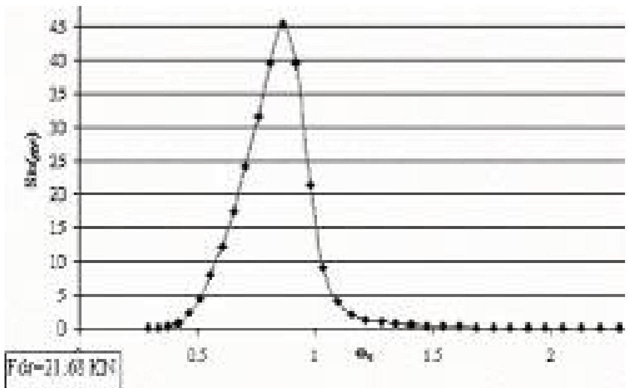


Fig.(18): **Drift Force Spectrum**
H1/3=3(m), Thar=10(s)
Fr=0.194, β=150deg.

4-3-2-Effect of $\overline{T}$

Fig 19 and Fig 20 show effect of different $\overline{T}$ upon added resistance and Fig 21 and Fig 22 show effect of the different $\overline{T}$ on drift force.

Wave period, $\overline{T}$, has a dominant effect on distribution of the spectral energy and does not affect the energy of irregular waves. Therefore, variations of the $\overline{T}$ does not have clear effect on amount of added resistance and drift force. It may cause more added resistance for smaller significant wave heights or vise versa.

5-Conclusions and Final Remarks

In this study a simplification introduced to added resistance and drift force strip theory based mathematical model. This new model has been used for a computer program called “Wave Resistance”. This computer program has been validated by comparison with published results. Finally, the effect of several parameters upon added resistance and drift force have been studied. The conclusion is:

-The maximum Added Resistance happens in 180^0 heading angle where Drift Force is almost zero.

- The maximum Drift Force happens in 90^0 heading angle where Added Resistance is almost zero.

- By increasing of ship speed, added resistance and drift force increase.

- By increasing of the $H_{1/3}$, added resistance and drift force increase. This increase is almost proportional to square of $H_{1/3}$.

- Variations of the $\overline{T}$ do not have clear effect on mean value of added resistance and drift force.

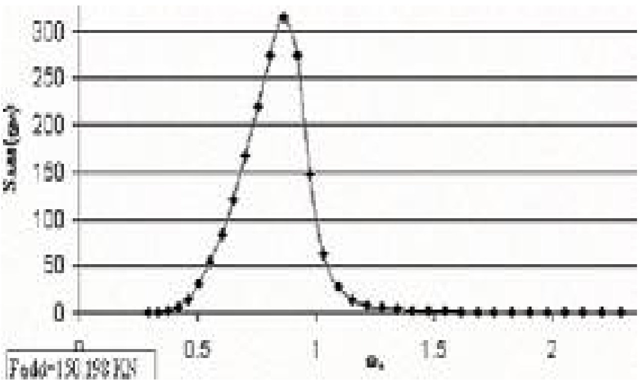


Fig.(19): Added Resistance Spectrum
H1/3=6(m), Tbar=10(s)
Fr=0.194, β=150deg.

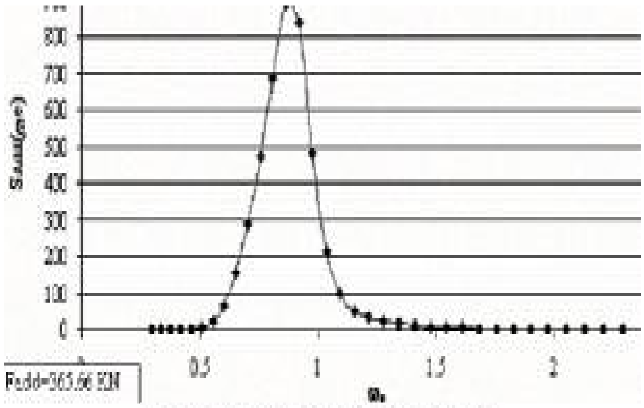


Fig.(20): **Added Resistance Spectrum**
H1/3=6(m), Thar=7(s)
Fr=0.194, β=150deg.

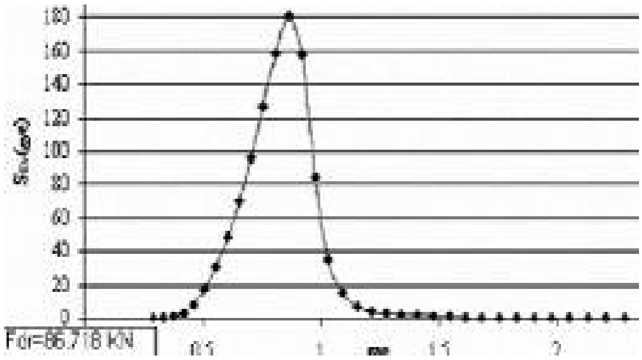


Fig.(21): **Drift Force Spectrum**
H1/3=6(m), Thar=10(s)
Fr=0.194, β=180deg.

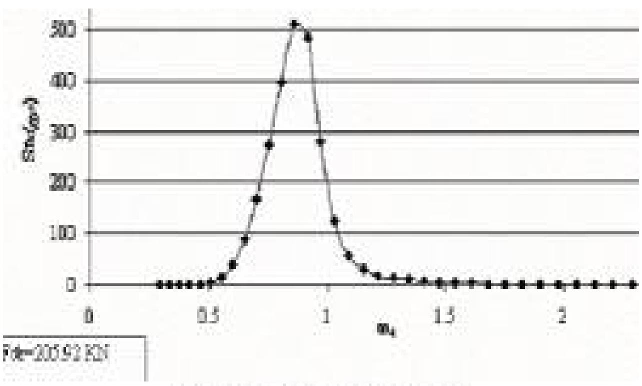


Fig.(22): **Drift Force Spectrum**
H1/3=6(m), Thar=7(s)
Fr=0.194, β=150deg.

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