Modeling Cargo Ship behavior in Extreme Rough Weather Condition

Nitonye Samson and Dick Festus Ibitoru

Abstract— This work is on the study of rough weather on the speed and fuel consumption of the ship. Rough weather increases the resistance of the ship and thus results in speed loss which may be voluntary or involuntary speed loss. This effect results in increased power which will be needed to overcome the resistance and thus increasing the fuel consumption. To attain desired speed in rough weather, the best combination of low resistance and high propulsion efficiency should be attained and the use of weather routing device. Taylor's standard series contours and ATTC-line along some empirical formulas were used to estimate the various components of ship resistance, Effective Power, Brake Power and Mass of fuel consumed. The rough weather was simulated using perturbation wind speeds of 30knots, 40 knots and 47 knots typical values obtainable in Indian Ocean. The behavior of the variation was similar across the four parameters R_T, P_E, P_B, and M_F investigated. However there was always a noticeable shift in the curve in a manner that suggests that the parameters increase with increase in wind speed.

Index Terms— Cargo Vessel, Fuel Consumption, Power, Resistance, Rough weather, Ship, ATTC, ITTC, vessels

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1 INTRODUCTION

A ship differs from any other large engineering structure, in that in addition to all its other functions it must be designed to move efficiently through the water with a minimum external assistance. Naval architects in the marine industry are faced with the problem of providing adequate structure for the support of the ship and its contents, both in calm and rough waters. The task of naval architects is to ensure that, within the limits of other design requirements, the hull form and propulsion arrangement will be the most efficient in the hydrodynamic sense. The ultimate test is that the ship should perform at required speed with the minimum of shaft power, and the problem is to attain the best combination of low resistance and high propulsive efficiency. In general, this can only be attained by a proper matching of hull and propeller [1].

Another factor that influences the hydrodynamic designed of a ship is the need to ensure that not only smooth or good water performance, but also that under average service conditions at sea the ship should not suffer from excessive motions, wetness of decks or lose more speed than necessary in bad weather and also consume more fuel for economics purpose [2].

The assumption that a hull form that is optimum in calm water will also be optimum in rough water is not necessarily valid. Recent research in oceanography on the sea keeping qualities of a ship has it possible to predict the relative performance of designs of varying hull proportions and forms under deferent realistic sea conditions, using both model tests and computing techniques [3].

As in the case of stability, subdivision, and structure criteria are needed in design for determining acceptable levels of powering. In general, the basic contractual obligation laid on the ship builder is that the ship should achieve a certain speed with a specified power and also the specific fuel consumption should be as low as possible, in good weather on trial, and for this reason, smooth-water performance is of great importance. As previously noted, good sea performance, particularly the maintenance of sea speed is often a more important requirement. The effect of sea condition is customarily allowed for, by a provision of a service power margin above the power required in smooth water, an allowance which depends on the type of ship and the average weather on the sea routes on which the ships is designed to operate. The determination of this service allowance depends on the accumulation of sea performance data on similar ships in similar trades [4].

Power criteria in the form of conventional services allowance for both sea conditions and surface deterioration are considered in this work. Another important factor that affects the behavior of a ship is rough weather. A typical rough weather brings about a level of resistance on the propulsion of the ship. The wind speeds associated with deferent rough weather conditions in a typical sea way, are listed in the table below:

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Table: 1: Showing Wind Speeds in a Typical Sea way (Indian Ocean)

System	Pressure Deficient (hpa)	Associated wind speeds in knots
Low pressure area	1	< 17
Depression	1.0 – 3.0	17 – 27
Deep Depression	3.0 – 4.5	28 – 33
Cyclonic storm	4.5 – 8.5	34 – 47
Severe Cyclonic storm	8.5 – 15.5	48 – 63
Very Severe Cyclonic storm	15.5 – 65.6	64 – 119
Super Cyclonic storm	>65.6	>119

Source: www.Google.com

With wind speeds of 17 – 119 knots and above, acting against the propulsion of the ship, there will be an increase in resistance which will also cause a loss in the ship speed. Since there is a speed loss, as a result of increase in resistance, the power will also be increased because a greater power will be required to overcome the increased resistance. As a result of this, the fuel consumption of the ship will also increase.

The data given in the society's sheets and in many published papers are valuable guides in the design of closely similar ships. On the other hand, they refer to a group of completely unrelated forms, and is difficult to determine the trends in resistance value with changes in proportions and coefficients or, what is equally important, the penalties involved in specific changes.

Information of this kind is obtained by running a series of models in which the principal characteristics are changed in a systematic manner. The results of such methodical series can be used to plot design charts which are of inestimable value to the designer.

Such a series may be based upon a single parents form or upon a number of parents related to one another in some graphical or mathematical pattern [5].

Taylor's Standard Series.

A complete investigation of the effects of altering proportions using a single parents form made by Admiral Taylor in the Experimental Model Basin (EMB), Washington, giving rise to the well-Known Taylor's standard Series [6].

The original parent was patterned after the British cruiser Leviathan of 1900, which had a ram bow and twin-screw, cruiser stern. For the series parent, the ram was eliminated, the maximum section was moved to midlength, and a 3 parent bulb was adopted at the bow. The sectional-area curves and body lines for the other models were derived from the parent partly by mathematical means. The models were run at various periods up to 1914, and the first full presentation of results was in the 1933 edition of speed and power of ships. The data appeared as contours of residual resistance per tonne of displacement against prismatic coefficient and displacement-length ratio [7].

Speed Loss in Service

The speed of a ship is depended on the total towing resistance of the ship and effective power which is the power necessary to overcome the resistance. Power requirement and the rate of revolution depend on the ship's hull form and the propeller design. The hull efficiency is the ratio of effective power which is proportional to the work done in moving a ship at a speed (V) against resistance (R_T) to the trust power (P_T) which is proportional to the work by the propeller in delivering a thrust (T) at a speed of advance (V_A) [8].

Types of Speed Losses

There are two forms of speed losses of a losses ship as a result of extreme rough weather:

(1) Voluntary speed loss.
(2) Involuntary speed loss.

Voluntary speed reduction (loss) due to extreme rough weather condition.

In cause of sailing a ships, if its encounter an extreme rough weather condition, the captain of the ship can decide to reduce the speed in order to ease severe motions. The most important phenomena for this decision are the probability of the occurrence also the severity of the following:-

Slamming

Slamming is a phenomenon associated with extreme ship motion in waves. At certain ship speed in rough sea, the forefoot of the ship emerges from the water as a result of large pitch and heave motion and it violently impacts the water surface as it re-enters. The ships fore bottom thereby sustains heavy impulsive pressure from the water and this impulsive force produces a shudder throughout the hull.

The probability of slamming occurrence is the joint probability that the bow emerges and that the relative velocity exceeds a certain magnitude at the instance of re-entry [9].

Accelerations

Too high accelerations can also be a reason to reduce the speed of a ship. The magnitude of acceleration is strongly dependent on the length of the ship [10].

Propeller Racing

The immersion of the propeller results in a fluctuating torque and thrust of the propeller. Although the rpm governors greatly reduce the possible damage to the propelling machinery due to racing, large torque and thrust fluctuations are observed in waves, even at constant rpm. Aertssen analyzed a lot of full scale trails for propeller racing. [11]

Involuntary Speed Loss Due To Extreme Rough Weather Condition

When a ship encounters rough weather, the resistance, increases, thereby reducing the speed of the ship. The phenomena for this increase in resistance, includes the following:-

Vertical Ship Motions

The relative motion of a ship with respect to the water surface causes an added resistance. In 1970, Boese published a theory to calculate the added resistance from the water pressure on the hull, cause by the relative motions in regular waves. In 1972, Gerritsma and Beukelman published another theory based on the relation between the radiated energy of the damping waves and the added resistance. A close agreement is shown between theory and experiments in head to beam regular waves.

Steering

In a seaway, wind and waves will disturb the ship's heading. To maintain a heading at a beam wind, rudder angles are necessary to counteract the wind moment at any instance.

For instance a beam wind with strength of 9 on the beau fort scale can cause rudder angles 150 or more. This results in an increase in a ship's resistance.

In waves, the ship will sail with yaw motions cause by sea and the correcting pilot. These yaw motions cause centrifugal forces, of which the component in the longitudinal direction means an increase in resistance [12].

Fouling

Rough weather in connection with an inappropriate distribution of the cargo, can be a reason for buckled bottom plates. The hull has being fouled and will no longer have a technical smooth surface, which means that the frictional resistance will be greater. The total resistance caused by fouling, may increase by 25 – 50 percent throughout the life time of a ship.

In principle, the increased resistance caused by rough weather could be related to the following:-

Gale

Storms

Wind and current

Heavy waves

Cyclones

Hurricanes, etc. [13].

Challenging Wind and Waves – Their Impact on Fuel Consumption

Wind and waves effect fuel consumption through added resistance and because of reduced propulsive efficiency [14].

If the propulsion system has a considerable power margin it is possible to maintain constant speed. The additional fuel consumption is determined by the increase in resistance and the decreasing propulsive efficiency at increase propeller rpm or pitch.

In case the propulsive system is already running at the maximum continues engine rating, the speed drops until the increasing thrust balances the total resistance. The additional fuel consumption is then given by the increase in trip duration, in which the decreasing propulsive efficiency plays a role.

In practice, constant power is typical for ships with controllable pitch propeller or diesel – electric propulsion systems. Due to the fact that diesel engine behaves to some extent as "constant torque" devices, directly driven, fixed – pitch propeller systems are generally not capable of maintaining full power in the overload situation that occurs if the ship is slowed down by an additional resistance. Since no additional torque can be delivered, the rpm reduces until equilibrium in torque is obtained. The reduction in rpm and power increases the involuntary speed loss. In this case, the fuel consumption is determined by the trip duration and absorbed power.

In many instances and in particular if the weather forecast is very bad, the captain will be reluctant to accept the inevitable risk associated with sailing in bad weather. In this case he will take proactive measures by deviating from the shortest route. This will increase the sailing time and consequently the total fuel consumption over the route.

Both reactive and proactive measures lead to additional miles that together with the loss time, will often motivate efforts to recover the delays. But through these efforts, fuel is wasted by saving at uneconomically high speed levels [14].

Magnitude of increase in fuel consumption.

The impact of weather on shipping economics shows itself in the trip's duration and by increased fuel consumption. Results of scenario simulations for relative-fast ships on fixed routes, concentrating on the involuntary speed loss, suggest that the mean added resistance from wind and waves is somewhere around 5-10% of total resistance. Wind usually contributes around a third of this increase.

Added Resistance in Waves.

Normally the ship loses speed when there is insufficient power to maintain the speed. A resistance increase of 5-10% means a speed loss of approximately 2-5%. At constant power, the increase in fuel consumption is directly related to the extra travelling time; therefore this increase is also in the region of 2-5%.

2 MATERIALS AND METHODS

Ship Resistance Analysis

A Simple Ship Resistance analysis can be carried out, using data derived from ship model testing.

Table 2: Principal Ship Data for a Cargo vessel.

Ship Length (m)	L	158.50
Molded breadth (m)	B	23.16
Model ship correlation coefficient	C_A	0.0004
Block Coefficient	C_B	0.612
Molded Draft	D	8.23
Wetted Surface area (m)2	S	2006.8
Density of sea water	ϱ_{sw}	1025
Sea water kinematic viscosity	μ	5.0 x 10-7
Propulsive efficiency	η_P	0.70
Brake efficiency	η_B	0.45

Given that the total resistance (R_{TC}) for calm sea:

$$R_{TC} = R_F + R_R + R_{Air} + R_{APP} \qquad (1)$$

Assuming that Appendage resistance represents 3% of ($R_F + R_R$).

For ship speed V = 16 knots

The frictional resistance is given by:

$$R_f = (R_f + C_A) \text{ x } ½ \text{ x } \varrho_{sw} \text{ x S x } V^2 \qquad (2)$$

C_f is obtain from the ATTC-line via Reynolds number

$$\text{Reynolds number Re} = \frac{VL}{\mu} \qquad (3)$$

Thus:

$$\text{Re} = \frac{(16 \; x \; 0.5144) \; x \; 158.50}{5.0 \; x \; 10^{-7}}$$

$$= 2.6 \text{ x} 10^9$$

$$= 3.0 \text{ x} 10^9$$

C_f from the ATTC –Line at Re =3.0 x 10^9

= 1.342 x 10^{-3}

R_F, = [(1.342 x 10^{-3}) + (0.4 x10-3)] x 0.5 x 1025 x 2006.8 x (16x0.5144)^2

= 121,363.5N

= 121.36KN

Displacement – length Ratio

$$= \frac{\nabla}{L^3}, \; But \; \nabla = ?$$

$$\nabla = C_B \text{ x L x B x D} \qquad (4)$$

= 0.612 x 1588.50x23.16x8.25 = 18,534M^3

$$\frac{18534}{(158.50)^2} = 4.7 \; x \; 10^{-3} \; \underset{\sim}{} 5.0 \text{ x } 10^{-3}$$

The residuary resistance (R_R) is given by

$$R_R = C_R \text{ x } ½ \text{x } \varrho_{sw} \text{ x s x } V^2 \qquad (5)$$

But Froude's number is given by

$$F_n = \frac{v}{\sqrt{9 \; x \; L}} \qquad (6)$$

$$= \frac{(16 \; x \; 0.5144)}{\sqrt{9.81 \, (158.50)}}$$

$$= 0.21$$

Using the F_n and $\frac{\nabla}{L^3}$, C_R can be obtained from Taylor's standard series Contours.

. . C_R = 0.95 x 10^{-3}

From equation 5,

R_R = 0.95 x 10^{-3} x 0.5 x 1025 x 2006.8 x (16 x 0.5144)^2

= 66185.59 N = 66.19 KN

Appendage Resistance, R_{app} is given by

$$R_{app} = \frac{3}{100} \text{ x } (66.19 + 121.36) = 5.63KN$$

Air resistance is given by

$$R_{Air} = C_{Air} \; x \; \frac{1}{2} \; x \; \rho_{Air} \; x \; A_T \; x \; V^2 \qquad (7)$$

$$. \quad = 1.28 \text{ x } \frac{1}{2} \; x \; \rho \; A_T \; x \; (V^2)$$

$$= 1.28 \; x \frac{1}{2} \; x \, 1.23 \; x \; \frac{1}{2} \; B^2 \; x \, V^2$$

= 0.783 x 0.5 x B^2 x V^2

R_{Air} can be obtained using Equation 7

R_{Air} = 0.783 x 0.5 x (23.16) x (16 x 0.5144)^2 x (16 x 0.5144)^2

= 14,224.95N = 14.23KN.

Total Resistance for Calm sea at V = 16 knots, from equation 1

= 121.36 + 66.19 + 5.63 + 14.23 = 207.41KN

Effective Power

$$P_{EC} = R_{TC} \text{ x V} \qquad (8)$$

= 207.41 x (16 x 0.5144) = 1707KW

Brake Power Output (P_{SC}) for Calm Sea at 16knots

$$\eta_P = \frac{P_E}{P_B}$$

$$P_B = \frac{P_E}{\eta_P} \qquad (9)$$

Where η_P = propulsive efficiency = 0.70

$$P_{BC} = \frac{P_{EC}}{\eta_P}$$

$$= \frac{1707}{0.70}$$

$$= 2438.6Kw$$

The mass of the fuel consumed M_F

$$(M_r) = \frac{\eta_{BC}}{\eta_B \ x \ LC_V} \qquad (10)$$

Where η_B = brake thermal efficiency = 0.45 = 45%

LCV = Lower Calorific Value of Diesel = 42,000

$$\cdot M_F = \frac{2438.6}{0.45 \ X \ 42,000}$$

$= 0.129$kg/sec

For speed 2 V = 18knots

Reynold's number (R_e) from equation 3

$$= \frac{(18 \ x \ 0.5144) \ x \ (158.50)}{5.0 \ x \ 10^{-3}}$$

$$= 2.9 \ x \ 10^9$$

$\simeq 3.0 \ x \ 10^9$

C_f from the ATTC – line at $R_e = 3.0 \ x \ 10^9$

$= 1.342 \ x \ 10^9$

From equation 2,

$$R_f = \left[\left(1.342 \ x \ 10^{-3}\right) + \left(0.4 \ x \ 10^{-3}\right)\right] \ x \ 0.5 \ x \ 1025 \ x \ 2006.8 \ x \ (18 \ x \ 0.5144)^2$$

= 153,600.67N

= 153.6KN

From equation 6 Froude's number is:

$$F_n = \frac{V}{\sqrt{g \ x \ L}}$$

$$= \frac{(18 \ x \ 0.5144)}{\sqrt{9.81 \ x \ 158.50}}$$

$$= \frac{9.259}{39.43}$$

$$= \underline{0.23}$$

Using F_n and $\frac{\nabla}{L^3}$, C_R can be obtained using the Taylor's standard's series contours

$C_R = 1.2 \ x \ 10^{-3}$

From Equation 5

$\therefore R_R = 1.2 \ x \ 10^{-3} \ x \ 0.5 \ x \ 1025 \ x \ 2006.8 \ x \ (18 \ x \ 0.5144)^2$

= 105,809.88 KN = 105.8KN

Appendage Resistance

$$R_{app} = \frac{3}{100} \ x \ (153.6 + 105.8)$$

$$= 7.82KN$$

From Equation 7

$R_{Air} = 0.783 \ x \ 0.5 \ x \ (23.16)^2 \ x \ (18 \ x \ 0.5144)^2$

= 18003N = 18KN

Total resistance for calm sea at V = 18knots from equation 1,

$R_{TC} = 153.6 + 105.8 + 7.82 + 18 = 285.22$KN

Effective Power, from equation 8

$P_{EC} = 285.22 \ x \ (18 \ x \ 0.5144) = 2640.9$KW

Brake power output, from equation 9

$$P_{BC} = \frac{3515.57}{0.45 \ x \ 42000}$$

$$= 0.186kg/\sec$$

<u>For V = 20 knots</u>

Reynold's Number from equation 3

$$R_e = \frac{(20 \ x \ 0.5144) \ x \ 158.50}{5.0 \ x \ 10^{-7}}$$

$$= 3.4 \ x \ 10^9$$

$\simeq 3.0 \ x \ 10^9$

C_f from the ATTC – line at $R_e = 3.0 \ x \ 10^9$

$C_f = 1.342 \ x \ 10^{-3}$

From equation 2

$$R_f = \left[\left(1.342 \ x \ 10^{-3}\right) + \left(0.4 \ x \ 10^{-3}\right)\right] x \ 0.5 \ x \ 1025 \ x \ 2006.8 \ x \ (20 \ x \ 0.5144)^2$$

= 189630.53N = 189.6KN

From equation 6,

$$F_n = \frac{V}{\sqrt{g \ x \ L}}$$

$$= \frac{20 \ x \ 0.5144}{\sqrt{9.81 \ x \ 158.50}}$$

$$= \frac{10.288}{39.432}$$

$$= 0.26$$

Using F_n and $\frac{\nabla}{L^3}$, C_R can be obtained from the Taylor's Standard Series contours

$\therefore C_R = 1.7 \ x \ 10^{-3}$

From equation 5,

$R_R = (1.7 \times 10^{-3}) \times 0.5 \times 1025 \times 2006.8 \times (20 \times 0.5144)^2$

$= 185058.39KW$

Appendage Resistance, R_{app} is given by

$$R_{app} = \frac{3}{100} x \left(189.6 \ x \ 185\right)$$
$$= 11.24KN$$

From equation 7

$R_{Air} = 0.783 \times 0.5 \times (23.16)^2 \times (20 \times 0.5144)^2$

$= 22{,}226.49kN = 22KN$

Total Resistance for Calm sea at V = 20knots from equation 1

$R_{TC} = 189.6 + 185 + 11.24 + 22 = 407.84KN$

From equation 8

$P_{EC} = 407.84 \times (20 \times 0.5144) = 4195.86$ KW

From equation 9,

$$P_{BC} = \frac{4195.86}{0.70}$$

From equation 10 Mass of fuel consumed

$$M_f = \frac{5994}{0.45 \ x \ 42000}$$
.
$$= 0.317kg/\sec$$

For V = 22knots

Reynold's Number from equation 3

$$R_e = \frac{\left(22 \ x \ 0.514\right) x158.50}{5.0 \ x \ 10^{-7}}$$
$$= 3.6 \ x \ 10^9$$
$$\simeq 4.0 \times 10^9$$

C_f from the ATTC- Line at Reynold's Number 4.0×10^2

$C_f = 1.299 \times 10^9$

From equation 2

$$R_f = \left[\left(1.299 \ x \ 10^{-3}\right) + \left(0.4 \ x \ 10^{-3}\right)\right] x \ 0.5 \ x \ 1025 \ x \ 2006.8 \ x \left(22 \ x \ 0.5144\right)^2$$
$$= 223{,}789N = 223.79KN$$

From equation 6 Froudes' number is:

$$.F_n = \frac{V}{\sqrt{g \ x \ L}}$$

$$F_n = \frac{\left(22 \ x \ 0.5144\right)}{\sqrt{9.81 \ x \ 158.50}}$$

$$F = \frac{11{,}3158}{39.432}$$
$$= 0.28$$

Using F_n and $\frac{\nabla}{L^3}$, C_R can be obtained from the Taylor's Standard Series contours

$\therefore C_R = 3.0 \times 10^{-3}$

From equation 5

$.R_R = (3.0 \times 10^{-3}) \times 0.5 \times 1025 \times 2006.8 \times (22 \times 0.5144)^2$

$= 395154N = 395KN$

Appendage Resistance, R_{app} is given by

$$R_{app} = \frac{3}{100} \ x \ \left(223.79 \ x \ 395\right)$$
$$= 18.56KN$$

From equation 7 Air Resistance is:

$R_{Air} = 0.783 \times 0.5 \times (23.16)2 \times (22 \times 0.5144)2$

$= 26894N = 26.89kN$

Total Resistance for Calm sea at V = 22knots from equation 1

$R_{TC} = 223 .79 + 395 + 18.56 + 26.89 = 664.24KN$

From equation 8, Effective power

$P_{EC} = 664.24 \times (22 \times 0.5144) = 7517KW$

From equation 9 Break power

$$P_{BC} = \frac{7517}{0.70} = 10738.67KW$$

From equation 10 Mass of fuel consumed

$$M_{FC} = \frac{10738.67}{0.45 \ x \ 42000}$$
$$= 0.568kg/\sec$$

For V = 24knots

From equation 3 Reynold's Number

$$R_e = \frac{\left(24 \ x \ 0.5144\right) \ x \ 158.50}{5.0 \ x \ 10^{-7}}$$
$$= 3.9 \ x \ 10^9$$
$$\simeq 4.0 \times 10^9$$

C_f from the ATTC- Line at Reynold's Number 4.0×10^9

$C_f = 1.299 \times 109$

From equation 2,

$$R_f = \left[\left(1.299 \ x \ 10^{-3}\right) + \left(0.4 \ x \ 10^{-3}\right)\right] x \ 0.5 \ x \ 1025 \ x \ 2006.8 \ x \left(24 \ x \ 0.5144\right)^2$$
$$= 266327.34N = 266.33KN$$

From equation 6, Froude's number is:

$$F_n = \frac{(24\,x\,0.5144)}{\sqrt{9.81\,x\,158.50}}$$

$$= \frac{12.3456}{39.432}$$

$$= 0.3$$

Using F_n and $\frac{\nabla}{L^3}$, C_R can be obtained from the Taylor's Standard Series contours at the nearest Froude number on the Froude's chart which is 0.28

∴ $C_R = 3.0 \text{ x } 10^{-3}$
From equation 5

$$R_R = \left(3.0\ x\ 10^{-3}\right)\ x\ 0.5\ x\ 1025\ x\ 2006.8\ x\ \left(24\ x\ 0.5144\right)^2$$

= 470266N = 470.27KN
Appendage Resistance, R_{app} is given by

$$R = \frac{3}{100}\ x\ \left(266.33\ x\ 470.27\right) = 22.098\text{N}$$

From equation 7, Air Resistance is:
R_{Air} = 0.783 x 0.5 x (23.16)2 x (24 x 0.5144)2
= 32,006N = 32KN

Total Resistance for Calm sea at V = 24knots from equation 1
R_{TC} = 266.33 + 470.27 + 22.098 + 32 = 790.698KN

From equation 8, Effective power

P_{EC} = 790.698 x (24 x 0.5144) = 9761.6KW

From equation 9, break power

$$P_{BC} = \frac{9761.6}{0.70} = 13945\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FC} = \frac{13945}{0.45\ x\ 42000}$$

$$= 0.738 kg / \sec$$

Perturbing the system by the introduction of a wind resistance, for rough weather

Given (3) wind conditions
W_1 = 30knots
W_2 = 40knots
W_3 = 47knots

The wind resistance can be calculated thus:
R_{wind} = 0.738 x 0.5 x B^2 x V^2 (11)
For the 1st wind condition, (W_1 = 30knots)
.R_{wind} = 0.783 x 0.5 x $(23.16)^2$ x $(30 \text{ x } 0.5144)^2$
= 50, 009N = 50KN
For Ship Speed = 16Knots
Total Resistance of rough weather
R_{TR} = R_{TC} + R_{wind}
(12)
= 207.41 + 50 = 257.41KN

From equation 8,
P_{ER} = 257.41 x (16 x 0.5144) = 2118.59KW
From equation 9, Break power

$$PBC = \frac{2118.59}{0.70} = 3026.56\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{3026.56}{0.45\ x\ 42000} = 0.16 \text{ kg/sec}$$

For Ship Speed = 18Knots

Total Resistance of rough sea at 18knots from equation 12
R_{TR} = 285.22 + 50 = 335.22KN

From equation 8
P_{ER} = 257.41 x (18 x 0.5144) = 3103.87KW
From equation 9, Break power .

$$P_{BC} = \frac{3103.87}{0.70} = 4434\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{4434}{0.45\ x\ 42000} = 0.235 \text{ kg/sec.}$$

For Ship Speed = 20Knots

Total Resistance of rough sea at 20knots from equation 12
R_{TR} = 407.84 + 50 = 457.84KN
From equation 8,
P_{ER} = 457.84 x (20 x 0.5144) = 4710 KW
From equation 9, break power

$$P_{BC} = \frac{4710}{0.70} = 6728.9\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{6728.9}{0.45\ x\ 42000} = 0.356 \text{ kg/sec}$$

For Ship Speed = 22Knots
Total Resistance of rough sea at 22knots from equation 12
R_{TR} = 664.24 + 50 = 714.24KN
From equation 8,
P_{ER} = 714.24 x (22 x 0.5144) = 8082.9 KW
From equation 9, Break power

$$P_{BC} = \frac{8082.9}{0.70} = 11547\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{11547}{0.45\ x\ 42000} = 0.611\text{kg/sec}$$

For Ship Speed = 24 Knots

Total Resistance of rough sea at 24knots from equation 12

R_{TR} = 790.698 + 50 = 840.698KN

From equation 8

P_{ER} = 840.698 x (24 x 0.5144) = 10,378.9 KW

From equation 9, Break power .

$$P_{BC} = \frac{10,378.9}{0.70} = 14827\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{14827}{0.45\ x\ 42000} = 0.785\text{kg/sec.}$$

For the 2nd wind condition, (W_2 = 40knots)

From equation 11,

R_{wind}. = 0.783 x 0.5 x (23.10)2 x (40 x 0.5144)2
= 88905.9N = 88.9KN

For Ship Speed = 16Knots

Total Resistance of rough weather at 16knots from equation 12

R_{TR} = 207.41 + 88.9
= 296.31KN

From equation 8, Effective power

P_{ER} = 296.31 x (16 x 0.5144)
= 2438.8 KW

Brake power

$$P_{BC} = \frac{2438.8}{0.70} = 3483.9\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{3483.9}{0.45\ x\ 42000} = 0.184\text{kg/sec}$$

Ship Speed For = 18Knots

Total Resistance of rough weather at 18knots from equation 12

R_{TR} = 285.22 + 88.9 = 374KN

From equation 8, Effective power

P_{ER} = 374 x (18 x 0.5144) = 3462.9 KW

From equation 9, Break power

$$P_{BR} = \frac{3462.9}{0.70} = 4947\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{4749}{0.45\ x\ 42000} = 0.262\text{kg/sec}$$

Ship Speed For = 20 Knots

Total Resistance of rough weather at 20knots from equation 12

R_{TR} = 407.84 + 88.9 = 496.74KN

From equation 8, Effective power

P_{ER} = 296.31 x (20 x 0.5144) = 5110.46KW

From equation 9, Break power

$$P_{BR} = \frac{5110.46}{0.70} = 7800.66\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{7800.66}{0.45\ x\ 42000} = 0.386\text{kg/sec}$$

Ship Speed For = 22Knots

Total Resistance of rough weather at 22knots from equation 12

R_{TR} = 664.24 + 88.9 = 753.14KN

From equation 8, Effective power

P_{ER} = 753.66.14 x (22 x 0.5144) = 8523 KW

From equation 9, break power .

$$P_{BR} = \frac{8523}{0.70} = 12175.7\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{12175.7}{0.45\ x\ 42000} = 0.644\text{kg/sec}$$

Ship Speed For = 24Knots

Total Resistance of rough weather at 24knots from equation 12

R_{TR} = 790.698 + 88.9 = 879.60KN

From equation 8, Effective power

P_{ER} = 879.60 x (24 x 0.5144) = 10859.19KW

From equation 9, Break power

$$P_{BR} = \frac{10859.19}{0.70} = 15513\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{15513}{0.45\ x\ 42000} = 0.821\text{kg/sec.}$$

For the 3rd Wind Condition (W_3 = 47knots)

From equation 11

R_{wind} = 0.783 x 0.5 x $(23.16)^2$ x $(47 \times 0.5144)^2$

= 122745.76N = 122.75KN

For Ship Speed = 16 knots
Total Resistance of rough weather at 24knots from equation 12
R_{TR} = 207.41 + 122.75 = 330.16KN

From equation 8, Effective power

P_{ER} = 330.16 x (16 x 0.5144) = 2717.4KW

From equation 9, Break power

$$P_{BR} = \frac{2717.4}{0.70} = 3881.9\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{3881.9}{0.45\ x\ 42000} = 0.205\text{kg/sec.}$$

For V = 18 Knots

Total Resistance of rough weather at 18knots from equation 12

R_{TR} = 285.22 + 122.75 = 407.97KN
From equation 8, Effective power
P_{ER} = 407.97 x (18 x 0.5144) = 3777.48KW

From Equation 9, Break power

$$P_{BR} = \frac{3777.48}{0.70} = 5396.4\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{5396.4}{0.45\ x\ 42000} = 0.286\text{kg/sec}$$

For V = 20 Knots
Total Resistance of rough weather at 20knots from equation 12

R_{TR} = 407.84 + 122.75 = 530.59KN

From equation 8, Effective power
P_{ER} = 530.59 x (20 x 0.5144) = 5458.7KW

From equation 9, Break power

$$P_{BR} = \frac{5458.7}{0.70} = 7798\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{BR} = \frac{7798}{0.45\ x\ 42000} = 0.413\text{kg/sec}$$

For V = 22 Knots
Total Resistance of rough weather at 22knots from 12

R_{TR} = 664.24 + 122.75 = 786.99KN

From equation 8, Effective power

P_{ER} = 786.99 x (22 x 0.5144) = 8906KW

From equation 9, Break power

$$P_{BR} = \frac{8906}{0.70} = 12723\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{12723}{0.45\ x\ 42000} = 0.673\ \text{kg/sec}$$

For V = 24 Knots
Total Resistance of rough weather at 24knots from equation 12
R_{TR} = 790.698 + 122.75 = 913.45KN

From equation 8, Effective power
P_{ER} = 913.45 x (24 x 0.5144) = 11277KW
From Equation 9, Break power

$$P_{BR} = \frac{11277}{0.70} = 16110\text{KW}$$

From equation 10, Mass of fuel consumed

$$M_{FR} = \frac{16110}{0.45\ x\ 42000} = 0.852\text{kg/sec.}$$

3 RESULTS AND DISCUSSION

Result Analysis
The Result obtained from the estimation of ship resistance (RT), effective power (PE), Brake power (PB) and mass of fuel consume (MF) for rough weather at various wind and conditions are tabulated below:

Table 3: Showing rough weather data for W1 = 30 knots

V(knots)	RTR(KN)	PER (KW)	PBR (KW)	MFR (Kg/sec)
16	257.41	2118.59	3026.56	0.16
18	335.22	3103.87	4436	0.235
20	457.84	4710	6728	0.356
22	714.24	8082	11547	0.611
24	840.698	10378.9	14827	0.785

Table 4: Showing rough weather data for W1 = 40 knots

V(knots)	RTR(KN)	PER (KW)	PBR (KW)	MFR (Kg/sec)
16	296.31	2438.8	3483.9	0.184
18	374	3462.9	4947	0.262
20	496.74	5110.46	7300.66	0.386
22	753.14	8523	12175.7	0.644
24	879.60	10859.19	15513	0.821

Table 5 Showing rough weather data for W1 = 47 knots

V(knots)	RTR(KN)	PER (KW)	PBR (KW)	MFR (Kg/sec)

16	330.16	2717.4	3881.9	0.205
18	407.97	3777.48	5396.4	0.286
20	530.59	5458.7	7798	0.413
22	786.99	8906	12723	0.673
24	913.45	11277	16110	0.852

RESISTANCE

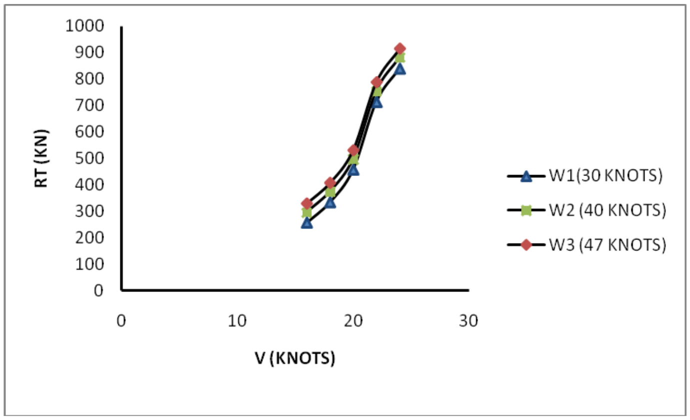

Figure 1: Graph of resistance (RTR) vs ship speed (V)

From figure 1, it is observed that at any ship speed (V), the resistance of the ship (RTR) varies with the wind speeds. When the wind speed increased, it is observed that the ship resistance also increased.

Effective Power

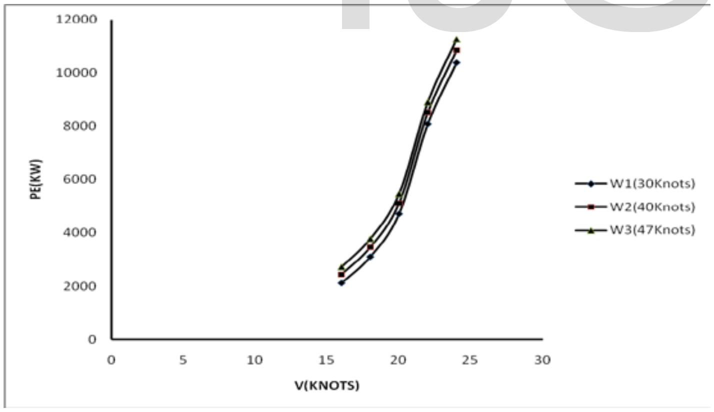

Figure 2 Graph of Effective Power (PER) vs. ship speed (V)

From figure 2, it is observed also that the effective power (PE) increases as the wind speeds increases. Since the effective power is the power required to overcome the resistance, therefore, as the resistance increases with an increase in the wind speed, the effective power also increases with increasing wind speed (W1 –W2 – W3).

BRAKE POWER

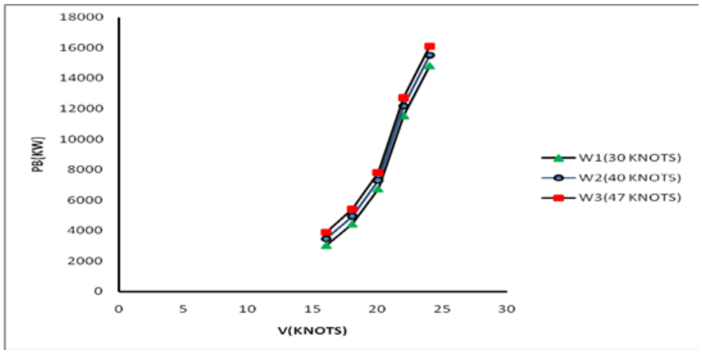

Figure 3 Graph of Brake Power (PBR) vs. ship speed (V)

From figure 3, it is observed that the brake power (PB) at any given speed increases with an increase in wind speeds. Since Brake Power is a power at the output side of the engine, in other to maintain the speed in the presence of increasing resistance, the Brake Power also increases as a wind speed increases.

MASS OF FUEL CONSUME

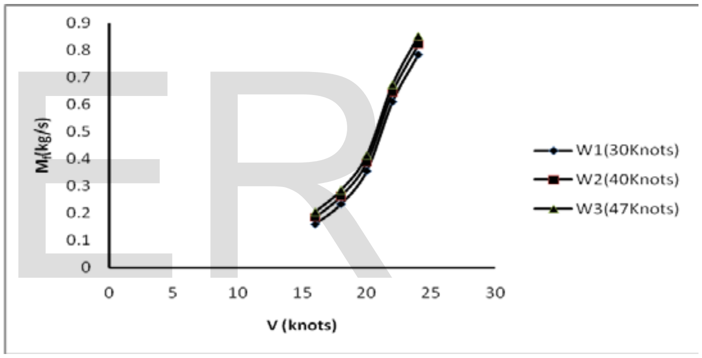

Figure 4 Graph of Mass of fuel consume (MFR) Vs ship speed (V)

From figure 4, it is observed that the Mass of fuel consumed (MF) increases also as the wind speed increases. The increase in the mass of fuel consume, can be attributed to two factors:

(i) Increase in brake power: - since the brake power increases, therefore more fuel will be required to sustain the increase in brake power at any given speed.

(ii) Increase in voyage time:- if the power is not increase to maintain the require speed, there will be speed loss which will in turn increase the voyage time, and therefore fuel consumption will also increase as a result of the extra voyage time.

4 CONCLUSION

The environment where the ship operates influences the performance of the ship. In a typical rough weather, it causes increase in the resistance to the ship's forward motion, which results to loss in speed at sea.

Taylor's standard series contours and ATTC – line along some empirical formulas were used to estimate the various components of ship resistance (i.e. frictional resistance, residuary resistance, air resistance and wind resistance). The ship resistance calculation was first done on a calm weather situation. The results obtained were further perturbed by the introduction of a wind resistance (head wind). The rough weather condition was obtained by the summation of the calm weather resistance and the wind resistance.

The relationship between the resistance and the ship speed, effective power and the ship speed, brake power and the ship speed and mass of fuel consumed and the ship speed at the various wind conditions were established the plotting of their graphs using Excel.

A linear graph was obtained from the four graphs plotted which means that the ship resistance, effective power, brake power increases at any given speed, with increase in the wind speed.

In view of the observations in the preceding chapters, the following recommendations are made.
An optimum hull form which involves the proportions and shape of the ship should be obtained to minimize the resistance during design and construction of the ship.
Ships should be equipped with weather routing programmes.

There should be a proper hull and propeller matching.

There should be a proper propeller and engine matching.

A service power margin above the power required in calm water should be provided. It should be dependent on the type of ship and the average weather on the sea routes on which the ship is designed to operate or the accumulation of performance data on similar ships in similar trades.

5 REFERENCE

[1] SNAME (1976) "*Tables Of Coefficients for ATTC Model Ship Correlation and of Kinematic Viscosity and Density of Fresh an Salt Water*" SNAME Bulletin.

[2] Lewis, E V (1988) " *Principle of Naval Architecture*" vol. 1 and 2 , SNAME

[3] Wilson, C J and Roddy, R F (1970) "*Estimating The Wind Resistance of Cargo Ship and Tankers*" NSRDC report 3355

[4] Todd, F H (1951) "*The Fundamentals of Ship Model Testing*" SNAME transactions.

[5] Peck, R W (1976) "*The Determination of Appendage Resistance of Surface Ships*" AEW Technical Memorandum 76020.

[6] Savitsky, D (1964) "*Hydrodynamics Design of Planning Hulls*" Marine technology, vol.1

[7] ITTC (2005) – Recommended procedures & Guideline, "*Full Scale Measurements, Speeds and Power Trails, Analysis of Speed power Trail Data*" page 2 – 8.

[8] Journee, J M J (2001) "*Prediction of Speed and Behavior of Ship in Seaway*". Pages 1 – 9

[9] Butler, E A (1985) "*The Surface Effect Ship*" Naval Engineers journal, vol.97

[10] Sabit, A S (1976) "*The SSPA Cargo Liner Series Regression Analysis of the Resistance ond Propulsion Coefficient*s" ISP vol.23.

[11] Aertssen, G (1979) "*Method of Ship Resistance predictions*" Institute of Naval Architects of Marine Engineers, Joint Meeting in London, United Nation, Paper No. 5.

[12] Weighardt, K. (1976) "*Remarks to The Viscous Ship Resistance" International Seminar on Ship Technology, Hydrodynamics Session, Seoul*

[13] Patel, M H (1989) "*Dynamics offshore structures*" pages 1 – 15

[14] Dallinga, R, flikkema, M and Grin, R (2008) "*Challenging Wind and Waves*" Marine Journal.