Optimizing Voyage Plan in way of Persian Gulf and Red Sea Using Meteorology and Oceanography Satellite Data

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ABSTRACT: The weather forecast by satellite data is a good guideline for assessment of voyage planning route in order to have safe and economic voyage for shipping. ISO15016, "Guidelines for the assessment of speed and performance by analysis of speed trial data", has been developed by the working group ISO/TC 8/SC 9/WG 2. This paper presents the effects of wave speed & direction, wind speed and direction, current speed and direction, and depth of water in vessel voyage planning which is based on meteorology and satellite data and computer program based in the ISO/DIS 15016. The interpolation between satellite data, historical chart data and observed data can optimize voyage route and cause reduction in sea passage time and fuel oil consumption. Various analysis methods for resistance increase due to ship motion, wave diffraction, wind, steering, drifting, water temperature, salt content, deviation of displacement, hull and propeller surface roughness and shallow water effects are considered in this paper and could be contained in computer program.

Keywords: ISO; Satellite; Meteorology; Analysis; Program; Resistance

INTRODUCTION

The objective of weather forecast by satellite is to assist the navigators to improve ships voyage planning and optimize fuel consumption. It could simply be said that a computer program enable us to calculate the increase resistences on ship’s hull for navigators. It could be given immediately by selection of route, speed and environmental conditions effect on fuel consumption with interpolation of data. This is the aim to improve the ships performance by means of optimizing the vessel voyage planning and way of proceeding for the voyage.

This system is being utilise in airline industry since early 80’s airplanes have used the system based on a similar idea by knowing the planes performance and fuel consumption in different speeds, weather conditions and jet streams in upper atmosphere and finally, the presumed time of arrival they generate a voyage plan with speed profile for keeping up with the schedule and taking the benefit from known winds and streams.

In view of the above to achieve a logical result it is required to have knowledge of the increase in resistance due to currents, winds, waves, shallow waters and the effect of them on vessel speed and engine power. The structure of this paper is made on the basis of ISO15016, entitled "Guidelines for the assessment of speed and performance by analysis of speed trial data".

All of the symbols are used according to the ISO/DIS 15016 (ISO/TC8, 2000) and ITTC (Performance Committee, 1994) standard symbols.

MATERIALS AND METHODS

2.1. Ship propulsion performance & speed analysis procedure of ISO/DIS 15016

Ship propulsion performance (referred to as the performance) is a measure of the energy consumption at a certain state, i.e. speed, loaded condition, weather condition and other factors.

During the lifetime of a ship the performance decreases e.g. the fuel consumption will increase at a certain state or the speed will decrease at a certain power setting.
This is mainly due to fouling of the hull and propeller. A typical trend of the speed reduction is illustrated in Fig. 1.

Hence, performance evaluation is about comparing the fuel consumption or propeller power at one time to another time, in other word to compare the ship performance at one state with another state (Pedersen, 2009). Since a ship is subjected to external factors such as wind, waves, shallow water, change in sea water temperature, etc. as illustrated in Fig. 2, it is unlikely that the ship would be in the exact same situation more than once. Furthermore these external factors can be difficult to measure accurately and thus the detection of a similar situation is problematic.

The vessel performance efficiency is divided into three steps as follow:- Engine efficiency, which depends on engine type and maintenance - Propeller efficiency, which depends on propeller characteristic and cleanliness - Hull efficiency, which depends on resistance, where resistance, could be increased by some factors such as waves, wind, shallow water, draught and trim, water temperature, density and hull fouling.

2.2 Total Resistance
The total resistance of a ship due to ship's speed through the water, $R_T$, is calculated as equation 1:

$$R_T = \rho D^2 V_x^2 (1-w) m (1-t) \tau$$

(1)

Where:
- $R_T$: total resistance, in N
- $\rho$: mass density in general, in kg/m$^3$
- $D$: propeller diameter, in m
- $V_x$: ship's speed through the water, in m/s
- $(1-w)m$: Wake factor
- $(1-t)$: thrust deduction factor
- $\tau$: Load factor

2.2.1. Wind Resistance
In almost all conditions the ship’s hull and superstructure will result in a resistance component from the relative wind and sometimes the resistance can be negative, in case of strong following wind blowing from behind of vessel.

The analysis method of resistance which increases due to winds has been suggested to be used as here below formula.

The wind resistance coefficient is based on data which is derived from model tests in wind tunnel or test result of similar ship.

Resistance increased due to wind deviation is calculated as equation 2 (Taniguchi and Tamura, 1994):

$$R_{AA} = 0.5 \rho_A C_{AA0} K(\psi_{WR}) A_{wv} V_{wv}^2$$

(2)

Where:
- $R_{AA}$: resistance increase due to wind, in N
- $\rho_A$: mass density of air, in m/kg$^3$
- $C_{AA0}$: wind resistance coefficient in head wind, in Rad
- $K(\psi_{WR})$: directional coefficient of wind resistance
- $A_{wv}$: area of maximum transverse section exposed to wind, in m$^2$
- $V_{wv}$: relative wind velocity, in m/s

2.2.2. Waves Resistance
Calculation of resistance increases due to waves being divided into two stages. One is pre-calculation of response function of added resistance in regular waves prior to speed trials. The other is main calculation to be made on board for particular irregular waves during sea passage. When both seas and swell observed, are taken into account, the total resistance increase is given by the sum of resistance increase due to seas and swell calculated independently.

The calculation of resistance increase due to waves is based on Maruo’s formula (Maruo, 1960). In short waves, diffraction of incident waves is observed around the water, $R_T$, is calculated as equation 1:
the bow, and this causes the main resistance in waves.

$$\Delta r = \frac{d^2}{dt^2} \int [\int \int \int \frac{k(m-k \cos \gamma)}{\sqrt{k^2(m^2)}} \cdot \frac{\sin^2(\gamma - \theta) \sin(\theta t)}{g}] \sin \theta t$$

$$n_1 = \frac{k_0}{2} \left( 1 + 2 \tau \pm \sqrt{1 + 4 \tau} \right)$$

$$\Delta r = \frac{1}{2} \rho g \alpha^2 \left[ \int \left( \sin^2(\gamma - \theta) \sin(\theta t) \right) \sin \theta t \right]$$

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Where:
- $$\Delta r$$: response increase due to regular waves
- $$g$$: acceleration due to gravity, in m/s²
- $$k$$: wave number ($= \omega / g$), in 1/m
- $$k_0$$: wave number ($\omega^2 / g$), in 1/m
- $$\tau$$: wave amplitude, in m
- $$\omega$$: circular frequency of encounter, in radians per second;
- $$C(m)$$ is the symmetric Kochin function, in m³/s
- $$S(m)$$ is the asymmetric Kochin function, in m/s
- It is assumed that $$m_3 = m_4$$ for $$\tau > 1/4$$. It can be ignored in case of moderate sea conditions because ship motion appears at rough sea conditions.

As the correction of this effect, Faltinsen’s formula (Faltinsen et al., 1980), Kwon’s formula (Kwon, 1982) and Fujii-Takahashi’s formula (Fujii et al., 1975) are being suggested to be used for the resistance increase due to waves, the Townsin-Kwon’s method (Townsin et al., 1993) is suggested to be used also.

Faltinsen’s Method (Faltinsen et al., 1980):

$$\Delta r = \frac{1}{2} \rho g \alpha^2 \left[ \int \left( \sin^2(\gamma - \theta) - \frac{2mV^2}{g} \cdot \cos(\gamma - \theta) \cdot \cos(\theta t) \right) \sin \theta t \right]$$

$$\Delta r = \frac{1}{2} \rho g \alpha^2 \left[ \int \left( \sin^2(\gamma - \theta) - \frac{2mV^2}{g} \cdot \cos(\gamma - \theta) \cdot \cos(\theta t) \right) \sin \theta t \right]$$

Where:
- $$\Delta r$$ is the resistance increase due to diffraction in regular waves, in N
- $$d$$: draught of ship, in m
- $$I_r$$: modified Bessel functions
- $$l$$: coordinate along waterline, in m
- $$\alpha$$: draught influence factor
- $$\theta$$: angle between water-line tangent and body axis, in rad
- $$\rho$$: density of water, in kg/m³
- $$g$$: acceleration due to gravity, in m/s²
- $$V$$: ship's speed, in m/s
- $$\zeta$$: wave amplitude, in m
- $$f$$: frequency of the elementary incident wave, in 1/s
- $$G$$: direction distribution of incidence waves; in Rad
- $$S(f)$$: frequency distribution of incident waves, in m²/s
- $$\alpha$$: direction of the elementary incident wave, in radians
- $$\Delta r$$: response function of resistance increase in regular waves, in N/m²
- $$\delta$$: horizontal shift of incident wave, in m
- $$\lambda$$: wavelength of incident wave, in m
- $$\phi$$: incident angle, in rad

Another method which could be used for calculation of wave resistances and given good result once waves are in short period is mentioned below and same one has been used in our program:

Total energy of the wave per area unit (Chegeni, 1998):

$$E = \rho g H L / 8$$

Whereas:
- $$L$$: length of the wave in m
- $$H$$: Total wave height in m
- $$T$$: Mean wave period in s

2.3. Shallow Water

For speed loss due to shallow water, the Lackenby’s formula (Lackenby, 1963) could also be used.

Resistance increase due to shallow water is calculated as equation 4:

$$\frac{\Delta V}{V_s} = 0.1242 \left( \frac{A_{sw}}{h_s} - 0.05 \right) + 1 - \left( \tanh \frac{gh_s}{V_s} \right)^2$$ for $$\frac{A_{sw}}{h_s} \geq 0.05$$.
Whereas:

\( A_m \): midship section area under water, in \( \text{m}^2 \)

\( G \): acceleration due to gravity, in \( \text{m/s}^2 \)

\( h \): water depth, in m

\( VS \): ship’s speed, in \( \text{m/s} \)

\( \Delta V_s \): speed loss due to shallow water, in \( \text{m/s} \)

Increasing resistance due to wind and reduction of speed due to shallow water effect are considered. The program calculate added resistance in both regular seas and swell separately as per mean wave period, significant wave height and incident angle of wave.

With considering ship motions, total wave height and subsequently resistance increase due to waves will be determined.

Finally having total resistance from the ship motions and resistance increase due to waves makes the program enable to calculate total resistance increase.

The resistance increases due to steering which is required for course keeping during the voyage, however due to the vessel not having any noticeable changes in displacement, trim, sea water temperature resistance values, therefore we consider them as negligible increase of resistance in mentioned state.

2.4. Computer Program of Speed Analysis

In ISO/DIS 15016 the analysis procedure is divided into six steps. This analysis procedure is based on Taniguchi-Tamura’s Method (Taniguchi, 1966). In this guideline, it has been described that the methods presented in the annexes are the latest ones available today other scientifically-based methods including model tests may be adopted as agreed between shipyard and ship owner (ISO/TC8, 2000).

The flowchart of analysis program is shown in Fig. 4. All of the suggested methods from ISO/DIS15016 are contained in this program.

There are three kind of data which this program uses them to calculate resistances.

Ship particulars, ship speed and wind specification.

RESULTS AND DISCUSSION

Table 1 shows the voyage speed analysis result for a 318K VLCC (318000 DWT Very Large Crude Oil Carrier) which uses very similar ship and same trial data with the example results of ISO/DIS 15016. These data are taken for one voyage from Khark Island in Iran to Ainsukhna in Egypt, and all records are available.

The structure of the computer program for voyage speeds analysis is presented. It is made according to the ISO/DIS 15016 entitled "Guidelines for the assessment of speed and performance by analysis of speed trial data". In this computer program, various analysis methods for resistance increase due to ship motion, wave diffraction, wind and shallow water effects are contained. The calculation of the mentioned components shows that generally, the total resistance of a ship in a seaway is divided into three essential elements, the shallow-
water resistance, the wind resistance and the added resistance due to waves. Other factors such as a resistance increase due to steering, drift, temperature, salt content and resistance increase due to displacement are negligible.

Analyzing the Table 1 values indicates that added resistance due to waves can be a considerable part of the total resistance.

Engine thrust and torque vary with the wave’s amplitude. By increasing of ship speed, added resistance and drift force increases too.

All of these calculations are results of resistance

### Table 1: Speed Analysis Result

<table>
<thead>
<tr>
<th>Hull</th>
<th>Rudders</th>
<th>Propeller</th>
<th>Efficiency, etc</th>
<th>Depth</th>
<th>Capacity</th>
<th>Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>m</td>
<td>°C</td>
</tr>
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<td>343000</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1860</td>
<td>19.26</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Date &amp; Time</th>
<th>Date &amp; Time</th>
<th>Date &amp; Time</th>
<th>Date &amp; Time</th>
</tr>
</thead>
<tbody>
<tr>
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<td>09:51 +04:00</td>
<td>11:51 +04:00</td>
<td>17:51 +04:00</td>
</tr>
<tr>
<td>23° 41.3'$N'</td>
<td>22° 32.7'$N'</td>
<td>21° 02.9'$N'</td>
<td>19° 40.5'$N'</td>
</tr>
<tr>
<td>05° 44.8'E</td>
<td>05° 54.3'E</td>
<td>05° 27.7'E</td>
<td>05° 41.7'E</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Course Direction</th>
<th>ψ₀ (°)</th>
<th>ψ₀ (°)</th>
<th>ψ₀ (°)</th>
<th>ψ₀ (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>125</td>
<td>146</td>
<td>206</td>
<td>206</td>
<td>208</td>
</tr>
</tbody>
</table>

| Engine thrust and torque vary with the wave’s amplitude. By increasing of ship speed, added resistance and drift force increases too. |  |  |  |  |  |
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increased due to the disturbances, and the deviations gives good agreement with the calculation results taken from the example of ISO/DIS 15016. The resistance increase due to ship motion is calculated using the Eq. 1, resistance increased due to wind deviation is calculated using the Eq. 2, and the resistance increase due to wave diffraction is calculated using the Eq. 3.

Making clear comparison between two results is impossible because the hull form offsets are not mentioned and the components of the resistance increase due to waves are not available in the example and also the ships will never be in the exact same situation more than once.

Result of comparing satellite data with historical and daily measuring data are illustrated in Figs. 5, 6, 7, 8 and 9.

The wind speed 17.44 m/s given resistance 377 kN which is more than 20% of total resistance.

Right planned ship speed will avoid unnecessary load changes on Main Engine and thus will reduce considerable fuel oil consumption.

Due to security reasons vessel diverted from planed course, therefore planed depths have difference with actual ones.
Ship actual current speed measured by reduction of ship speed through water and ship speed over ground, therefore external forces such as wind could affect the measured value which may show higher.

CONCLUSION
Following points are concluded from this research:

a. The effect of wake factor on total resistance i.e.; with higher ship’s speed through water but with less wake factor amount total resistance less than ship with higher speed through water.

b. The winds/ currents effects on ship’s resistance depend on speed and direction of winds/ currents which sometimes could be negative resistance if winds/ currents is from behind of the ship. Therefore, the mariners will plan their voyage to avoid steaming against ocean winds/ currents whenever possible, and to steam with winds/ currents wherever possible.

c. The mean waves period and incident angle of wave effects on ship’s resistance increases due to waves which could be negative resistance if wave incident angle is from behind of the ship.

d. The ship speed reduction due to effect of shallow water. Shallow water will adversely affect the ship’s resistance, sailing in a narrow waterway such as a canal can produce the same effect. Hence, when sailing in a canal, the ship’s resistance will increase due to the proximity of the banks and the decrease in pressure along the ships body pulls the ship towards the wall of the canal. The mariners are advised to maneuver at moderate speeds when sailing in shallow and/or narrow waters.

Following objectives have been tried to be achieved by the presentation of this paper:

a. Improving the ships performance by means of optimizing the vessel voyage planning and way of proceeding for the voyage.

b. By knowing the ship’s performance and consumption with different speeds,weather conditions and current in sea and finally the needed time of arrival, we can generate a voyage plan with speed profile for keeping up with the schedule of charterer and taking the benefit from known winds and currents directions in various seas. In view of all above; with accessibility to satellite data and comparing with historical and daily measuring data we could analysis and compare result of data in order to avoid facing with strong winds and high waves and also have safe and correct voyage plan including weather routing, speed and route optimizing, real-time monitoring of passage and engine safe modes working.

REFERENCES

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