Ship resistance and powering prediction of a fishing vessel

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Abstract. The ship resistance and powering are the most important hydrodynamics performances. In the case of a fishing vessel, both the design speed and trawling speed conditions must be analysed. The ship resistance and powering prediction at design speed were performed in this paper, on the basis of the Holtrop-Mennen method, by using two specific CAD-CAE platforms: AVEVA MARINE (Initial Design module) and PHP (developed in the Naval Architecture Faculty of “Dunărea de Jos” University of Galati). A comparative analysis of the theoretical prediction of the fishing vessel resistance, at full loading condition, with experimental results obtained at the model resistance tests, was presented and the level of accuracy was evaluated. Significant differences were determined between theoretical and experimental results. Also, the trawling condition was analysed. The trawl resistance was estimated on the basis of the typical empirical relations and the simulation software Trawl Vision Software (TVS), developed by AcruxSoft. A considerable increase of the trawl resistance with the ship speed was observed. The trawling speed was calculated on the basis of the brake power necessary for the design speed condition. Taking into account both the ship resistance and trawl resistance estimation, an increase in the accuracy level of the theoretical methods must be performed. Also, numerical and experimental researches must be developed related to the influence of the typical geometry of the trawl, on the resistance performance.

1. Introduction
Fishing has been one of the main sources of food. There is an increasing need for bigger and more efficient fishing vessels to cope with market requirement. Therefore, the fishing vessels design represents an important subject, both in terms of hydrodynamics performances of the hull forms and fishing equipments.

Based on many years of practical experience, the fishing technology represents an actual research domain. Efficient fishing equipments must be developed to satisfy the higher fishing demand. The main problem of the fishermen has been selecting the typical fishing gear for the vessel, considering the growing range of new and sophisticated equipments.

Trawling is an active fishing method that implies pulling a cone-shaped net into the sea, behind the fishing vessel. This type requires a continuous running of the vessel, until the fish is hauled onto the ship. Depending on the trawl position and fish species, two types of the trawling can be mentioned:

- Bottom trawling, which involves dragging the net directly on the seabed;
- Mid-water (pelagic) trawling, where the net is dragged in the variable column of water.
In both cases, the net mouth is spread by trawl doors. Although the bottom trawling is more common in the fishing industry, it carries a high risk of affecting the seabed habitats.

A relevant concern related to the fishing vessels is the environmental impact of the fishing gear. The new technical solutions for fish detection, bottom scanning or smarter use of equipments take into account the minimization of the environmental negative effects. With the reason to preserve the environment, the mid-water version was selected for this study. A representation of the mid-water trawling configuration and of the constructive elements is shown in figure 1 [1].

Figure 1. Constructive elements of pelagic trawling configuration.

Considering the importance of the ship resistance and powering, both the design speed and trawling speed conditions are analysed. In this paper, a typical fishing vessel operating in the Mediterranean Sea was used and the transverse sections of the body lines plan are presented in figure 2. The main characteristics of the fishing vessel and of the experimental model (scale 1/12) are presented in table 1.

Figure 2. Mediterranean fishing vessel. Transverse sections of the body lines plan.

The hull forms influence the hydrodynamic performances of the ship. The relatively small block coefficient, the bulbous bow, the hard-chine transverse sections and the non-immersed transom stern are essential characteristics of the studied vessel that help reduce the ship resistance.

From the point of view of the initial design stage, distinct theoretical methods can be used to estimate the fishing vessel resistance at design speed. The Holtrop-Mennen method [2] was applied in
this paper, by means of two specific CAD-CAE platforms: AVEVA MARINE (Initial Design module) and PHP (Preliminary Hydrodynamics Performances-developed in the Naval Architecture Faculty of “Dunărea de Jos” University of Galati) [3]. The theoretical results were compared with the experimental model tests results, mentioned in the reference [4]. The full-scale extrapolated results have been obtained on the basis of ITTC-1957 method [5]. Also, the brake power necessary to the design speed condition has been evaluated.

### Table 1. Main characteristics of the fishing vessel.

| Name                          | Full scale | Model scale (1/12) |
|-------------------------------|------------|--------------------|
| Length overall, $L_{OA}$      | 32.7 m     | 2.725 m            |
| Length between perpendiculars, $L_{BP}$ | 25.0 m     | 2.083 m            |
| Length of waterline, $L_{WL}$ | 25.0 m     | 2.083 m            |
| Moulded breadth, $B$          | 8.0 m      | 0.667 m            |
| $L_{WL}/B$                    | 3.125      | 3.125              |
| Depth, $D$                    | 6.8 m      | 0.567 m            |
| Medium draught, $T_M$         | 2.58 m     | 0.215 m            |
| $B/T_M$                       | 3.1        | 3.1                |
| Longitudinal centre of buoyancy, $LCB$ | 11.32 m     | 0.943 m            |
| Volumetric displacement, $\nabla$ | 296.0 t    | 171.0 kg           |
| Block coefficient, $C_B$      | 0.574      | 0.574              |
| Waterline coefficient, $C_W$  | 0.819      | 0.819              |
| Prismatic coefficient, $C_P$  | 0.675      | 0.675              |
| Ship speed, $v$               | 12.0 Kn    | 1.8 m/s            |
| Froude number, $Fn$           | 0.4        | 0.4                |

Related to the trawling speed condition, the estimation of the trawl resistance constitutes a very complex problem, due to the flexibility of the net and the moving elements. Consequently, the theoretical analysis is based on simplifying assumptions of the real process. Also, the experimental methods cannot take into account all the real factors influencing the fishing operations.

Empirical relations and the simulation software Trawl Vision Software (TVS) developed by AcruxSoft [6] have been used in this paper, in order to estimate the trawl resistance. The maximum trawling speed was calculated on the basis of the brake power necessary in the design speed condition.

### 2. Ship resistance and powering

The assumption of the minimum ship resistance for the design speed condition leads to minimal ship power and reduced fuel consumption. As a consequence, the ship resistance and propulsion estimation represent important hydrodynamics problems, starting with the initial design stage. In this case, theoretical methods can be used in order to estimate the ship resistance and powering performances. The theoretical results must be validated with the experimental model results, in the basic design stage.

One of the most common theoretical methods introduced by Holtrop and Mennen [2] was applied in this paper in order to estimate the fishing vessel resistance. This method is based on the regression analysis of a large number of model tests and trial data, which ensure the estimation accuracy.
The following restrictions are generally imposed for the trawlers: $F_n \leq 0.38; 0.55 \leq C_p \leq 0.65; 3.9 \leq L_{mg}/B \leq 6.3; 2.1 \leq B/L_{W} \leq 3.0$. In the case of the studied fishing vessel, according to the main characteristics presented in table 1, these restrictions are not fulfilled.

According to Holtrop and Mennen [2], the total ship resistance $R_T$ is the sum of the following components

$$R_T = R_F (1 + k_1) + R_{APP} + R_{w} + R_B + R_{TR} + R_A$$

(1)

where, $R_F$ is the frictional resistance of the bare hull, $(1+k_1)$ is the form factor of the bare hull, $R_{APP}$ is the appendages resistance, $R_w$ is the own wave resistance, $R_B$ is the additional pressure resistance of the bulbous bow, $R_{TR}$ is the additional pressure resistance of the immersed transom stern and $R_A$ is the ship-model correlation resistance.

The frictional resistance of the bare hull $R_F$ can be determined using the following relation

$$R_F = C_F \cdot \frac{1}{2} \cdot \rho \cdot v^2 \cdot S$$

(2)

where $\rho$ is the water density, $v$ is the ship speed and $S$ is the wetted surface of the bare hull. The frictional resistance coefficient $C_F$ is calculated on the basis of the Reynolds number $Re$, using the ITTC-1957 relation

$$C_F = \frac{0.075}{(\log Re)^2}$$

(3)

The appendages resistance $R_{APP}$ is calculated on the basis of the wetted surface of appendages $S_{APP}$ and of the equivalent form factor of appendages $(1+k_2)_{eq}$ using the following expression

$$R_{APP} = C_F \cdot \frac{\rho^2}{2} \cdot S_{APP} (1 + k_2)_{eq}$$

(4)

The own wave resistance $R_w$ is determined with the regression formula

$$R_w = c_1 \cdot c_2 \cdot c_5 \cdot \rho \cdot g \cdot \sqrt{v} \cdot e^{[m_1 F n + m_4 \cdot \cos(\lambda \cdot F n^{-2})]}$$

(5)

where $g$ is the gravity acceleration and the coefficients $c_1, c_2, c_5, m_1, m_4, d, \lambda$ are presented in the reference [2].

The additional pressure resistance of the bulbous bow $R_B$ and of the immersed transom stern $R_{TR}$ can be estimated on the basis of the following relations

$$R_B = 0.11 \cdot e^{(-3.3 \cdot \sqrt{v})} \cdot F n^{0.5} \cdot A_{BT}^{1.5} \cdot \rho \cdot g / (1 + F n^{2})$$

(6)

$$R_{TR} = c_6 \cdot \frac{\rho \cdot v^2}{2} \cdot A_F$$

(7)

where $A_{BT}$ is the transverse surface of the bulbous bow, $A_F$ is the wetted surface of the transom and the coefficients $c_6, \rho_B, F n$, are presented in the reference [2].

The ship-model correlation resistance $R_A$ is determined using the following relation
\[ R_s = C_s \cdot \frac{D^2 \cdot v^2}{2} (S + S_{\text{AP}}) \]  

where \( C_s \) is the ship-model correlation coefficient.

In order to estimate the total fishing vessel resistance based on the Holtrop-Mennen method, two specific CAD-CAE software platforms were used: AVEVA MARINE (Initial Design module) and PHP (developed in Java language, in the Naval Architecture Faculty of “Dunărea de Jos” University of Galati).

Also, experimental model tests [4] were performed in order to measure the model resistance and to obtain the full-scale extrapolated results, by using the ITTC-1957 procedure [5]. The theoretical and experimental results were compared in the figure 3.

The theoretical results calculated on the basis of AVEVA MARINE and PHP software platforms are relatively close, for the chosen speed range. Instead, significant differences were obtained between the theoretical and experimental results (decreasing from 32% at 6 knots to 25% at design speed).

The theoretical prediction based on the Holtrop-Mennen method underestimates the experimental results. The cause could be linked to the non-fulfilling of the typical trawler restrictions, imposed by the Holtrop-Mennen method.

\[ \text{Figure 3. Comparative diagrams of the total fishing vessel resistance.} \]

On the basis of the fishing vessel resistance, the powering performance must be calculated. The B-Wageningen stock propeller was considered, having four blades and the diameter of 1.8 m (closed to 0.7 from the medium draught).

The open water propeller characteristics were obtained by means of the AVEVA MARINE and PHP software platforms and are presented in the table 2.

In order to calculate the powering performance of the ship, the algorithm proposed by Parsons [7] can be applied.

- The effective power \( P_e \) can be determined on the basis of the following relation

\[ P_e = R_T \cdot v \cdot (1 + M_D) \]
where, \( v \) is the ship speed and \( M_D \) is the design margin.
- The delivered power \( P_D \) is calculated using the following expression

\[
P_D = \frac{P_e}{\eta_D \cdot n_p}
\]

where, \( \eta_D \) is the quasipropulsive coefficient and \( n_p \) is the number of the propellers.
- The brake power \( P_B \) is determined on the basis of the following formula

\[
P_B = \frac{P_D}{\eta_s \cdot \eta_g \cdot (1 - M_S)}
\]

where, \( M_S \) is the service margin, \( \eta_s \) is the shaft efficiency and \( \eta_g \) is the reduction gear efficiency.

If the mentioned characteristics have the following values: \( M_D = 0.07 \), \( M_S = 0.165 \), \( \eta_D = 0.541 \), \( n_p = 1 \), \( \eta_s = 0.97 \) and \( \eta_g = 0.97 \), then the diagrams of the brake power obtained by using the theoretical and experimental ship resistance results are presented in the figure 4.

Based on the brake power value, the main engine selection can be performed.

### Table 2. Open water propeller characteristics.

| Name                      | Full scale |
|---------------------------|------------|
| Propeller diameter, \( D_p \) | 1.8 m      |
| Blades number of the propeller, \( Z \) | 4          |
| Propeller revolution, \( N_p \) | 328.9 rpm |
| Pitch ratio, \( P/D_p \)   | 0.898      |
| Blade area ratio, \( A_e/A_0 \) | 0.685     |
| Advance coefficient, \( J \) | 0.506      |
| Thrust coefficient, \( K_T \) | 0.216      |
| Torque coefficient, \( K_Q \) | 0.0328     |
| Open water propeller efficiency, \( \eta_0 \) | 0.531      |

### 3. Trawling speed condition

The typical fishing gear must be selected in the initial ship design stage. The problem of the fishing gear resistance must be approached to optimize the fuel consumption of the fishing vessel.

All the components of the trawling gear (net, doors, weights and floats, rope lines, warps) contribute to the total trawl resistance and must be determined separately.

Empirical relations [8-12] as well as specific simulation software [5] can be used to estimate the trawl resistance in the initial ship design stage. Depending on the fish species, a trawling speed between 2-5 knots can be adopted.

The total trawl resistance \( R_{TT} \) represents the sum of the following main components

\[
R_{TT} = R_N + R_D + R_O + R_L + R_{WA}
\]

where \( R_N \) is the net resistance, \( R_D \) is the trawl doors resistance, \( R_O \) is the weights and floats resistance, \( R_L \) is the resistance of the ropes and lines (perpendicular to the advance direction) and \( R_{WA} \) is the warps resistance.

The net resistance \( R_O \) can be estimated on the basis of the Reid [13] formula
\[ R_{N-Recid} = \frac{v^2 \cdot A}{54.72 \cdot v + 115.2} \]  \hspace{1cm} (13)

or Mac Lennan [14] relation

\[ R_{N-Lennan} = \frac{A}{9807} \left( \frac{46.6 \cdot v^2 + 61.2}{0.0641 \cdot v + 1} \right) \]  \hspace{1cm} (14)

where \( A \) is the total twine surface and \( v \) is the trawling speed.

The trawl doors resistance \( R_D \) is determined with Fridman [9] relation

\[ R_D = \frac{1}{2} \cdot \rho \cdot v^2 \cdot C_{x1} \cdot A_1 \]  \hspace{1cm} (15)

where \( C_{x1} \) is the specific drag coefficient and \( A_1 \) is the trawl door surface.

The resistance of the weights and floats (with spherical forms) \( R_O \) can be estimated by using the drag coefficient of the spherical forms \( C_{x2} \), dependent on the following relation introduced by Fridman [9]

\[ R_O = \frac{1}{2} \cdot \rho \cdot v^2 \cdot C_{x2} \cdot A_s \cdot n_{wf} \]  \hspace{1cm} (16)

where \( A_s \) is the medium surface of the sphere and \( n_{wf} \) is the number of the weights and floats.

Also, according to Fridman [9], the resistance of the ropes and lines \( R_L \) can be approximated on the basis of the specific drag coefficient \( C_{x3} \) by using the relation

\[ R_L = \frac{1}{2} \cdot \rho \cdot v^2 \cdot C_{x3} \cdot D_r \cdot L_r \]  \hspace{1cm} (17)
where $D_r$ is the rope diameter and $L_r$ is the length of the rope.

The warps resistance $R_{WA}$ depends on the angle of the straight warp to the flow [9] and can be estimated by using the following expression

$$ R_{WA} = \frac{1}{2} \rho \cdot v^2 \cdot C_{x4} \cdot D_w \cdot L_w $$

(18)

where $C_{x4}$ is the specific drag coefficient, $D_w$ is the warps diameter and $L_w$ is the warps length.

Also, the simulation software Trawl Vision Software (TVS) developed by AcruxSoft [6, 15] has been used in this paper, in order to estimate the trawl resistance.

The diagrams of the trawl resistance and of the fishing vessel resistance are presented in figure 5, in the speed domain between 2-5 knots. The net resistance is the most important component of the trawl resistance and was calculated with Reid formula ($R_{N-Reid}$) and Mac Lennan relation ($R_{N-Lennan}$). As a consequence, both curves of the total trawl resistance ($R_{TT-Reid}$ and $R_{TT-Lennan}$) are presented in the figure 5. Also, the curve obtained on the basis of the simulation software Trawl Vision Software (TVS) is represented ($R_{TT-TVS}$).

Large trawl resistance values were estimated with TVS, compared to the empirical relations results. The $R_{TT-TVS}$ and $R_{TT-Lennan}$ differences are extended between 24.6% - 48.9% for the chosen speed domain. Also, important differences between $R_{TT-Lennan}$ and $R_{TT-Reid}$ were determined (18.4% -27.6%). Small values of the fishing vessel resistance ($R_{F-PHP}$) were estimated by means of PHP software platform, in the same speed domain.

In order to compute the trawling speed, the brake power was calculated in the domain speed between 2-5 knots, using equations (9), (10) and (11), where, in this case, $R_T$ is the total resistance obtained by summing the fishing vessel resistance and the total trawl resistance. The brake power corresponding to the design speed of 12 knots ($P_B=918.476$ kW) was used in order to determine the trawling speed.

The results are presented in figure 6. The brake power determined on the basis of the trawl resistance estimated with Reid formula was noted with $P_B-Reid$. Similarly, $P_B-Lennan$ and $P_B-TVS$ represent the notations of the brake power calculated with trawl resistance obtained using the Mac Lennan
relation and TVS simulation software, respectively. Also, with $P_{B\text{-main engine}}$ was noted the brake power of the fishing vessel corresponding to the design speed of 12 knots.

Based on figure 6, the trawling speed was estimated at the intersection between the curve $P_{B\text{-main engine}}$ and the three curves of the brake power required in the trawling condition: about 3.65 knots in the case of the TVS simulation software, about 4.5 knots with Mac Lennan relation and about 5 knots on Reid formula.

![Figure 6. Diagrams of the brake power (trawling speed condition).](image)

4. Conclusions
The theoretical and experimental analysis of the ship resistance and powering performances on a Mediterranean fishing vessel was performed in this paper, both in the design speed and trawling conditions.

The Holtrop-Mennen method and model experimental tests were used in order to calculate and validate the fishing vessel resistance at design speed condition. Maximum differences of about 32% were obtained between the theoretical and experimental results, in the considered speed domain. Also, the brake power was estimated.

Empirical relations and simulation software were used in order to estimate the trawl resistance. Large differences between the theoretical estimations were observed. Thus, in the considered speed domain, the difference generated by the Lennan and Reid relations on the total trawl resistance is situated between 18.4% - 27.6%. Also, considerable differences between 24.6% - 48.9% were determined in the comparison case of the TVS simulation software results with the trawl resistance estimated by using the Lennan model.

The brake power on the trawling condition was determined and the trawling speed was evaluated in this paper on the basis of the same brake power of the main engine, required on the design speed, a procedure that represents a distinct element related to the classical method based on the towing force estimation.

Taking into account the ship resistance and trawl resistance calculations, an increase in the accuracy level of the theoretical methods must be performed. Also, numerical and experimental researches must be developed related to the influence of the typical geometry of the trawl, on the resistance performance.
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