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PERFORMANCE PREDICTION OF A SLENDER HALF-DISPLACEMENT PASSENGER CRAFT FOR INLAND NAVIGATION

Vittorio Bucci
University of Trieste,
Department of Engineering and Architecture,
10 Via A. Valerio, I-34127, Trieste, Italy,
E-mail: vbucci@units.it

Francesco Mauro
University of Trieste,
Department of Engineering and Architecture,
10 Via A. Valerio, I-34127, Trieste, Italy,
E-mail: fmauro@units.it

Alberto Marino'
University of Trieste,
Department of Engineering and Architecture,
10 Via A. Valerio, I-34127, Trieste, Italy,
E-mail: marino@units.it

ABSTRACT

The design of a small passenger craft for Venice is presented. The paper deals with hydrodynamic aspects mainly concerning resistance prediction in shallow water for subcritical, critical and supercritical regimes. Open literature usually provides methods for the subcritical regime only. Here, a procedure for the estimation of added resistance in subcritical, critical and supercritical regimes is presented within the slender body approximation. The developed procedure is suitable to be used in the early design stage to predict a preliminary speed-power curve. A test case based on the designed half-displacement craft is thoroughly exposed.

Keywords: Venice navigation, small craft, shallow water resistance, wave reduction.

1. INTRODUCTION

Venice and its Lagoon are a UNESCO World Heritage Site that encompasses unique and very special places. The city lives in a delicate balance with its sea environment, and at the same time is invaded constantly by many people. In fact, the local population in the historical centre of the city is quite small (~56.000 in 2014 [1]), but the number of tourists is very huge (8÷10 millions per year [2]). The transport of tourists and goods requires a high number of vessels, which must operate safely and in accordance with the respect for the environment. In particular, hullforms and speeds must minimize wave generation in order not to damage the foundations of the buildings overlooking the canals. Moreover, air and noise emissions must be reduced within the limits imposed by the new Directives introduced by both the European Community and various local Authorities.

The present paper deals with the project of a small passenger craft to be used for the public transport between the airport and the centre of the city. The propulsion system of the craft is based on the hybrid-electric concept, which allows to perform a zero emission navigation within the canals of Venice without using the Diesel engine.

New hullforms have been designed in order to limit the main dimensions of the craft compatibly with the restrains of the waterway in Venice and the air draught allowed by the various bridges. Moreover, a particular attention has been devoted to minimize the hull resistance during navigation and consequently the waves generated. The adoption of relatively wide spray-rails has permitted to enlarge the volumes above the waterline, and to accommodate in a comfortable manner both passengers and their luggage.

The estimation of the resistance in infinite depth and calm water has been carried out on the basis of the NPL systematic series for semi-displacement hulls [3]. To predict the variation of the hull resistance due to shallow water, the slender-body theory of Tuck [4] has been adopted.

2. THE SMALL PASSENGER CRAFT

The small passenger craft has been designed on the basis of its specific service profile within a given reference course. In other terms, are well known which scheduled course must be performed and which obstacles will be encountered during navigation. In particular, the vessel will be used for a daily service from the "Marco Polo" Airport to Piazza S. Marco. Along such a reference course (Fig. 1) there are two distinct sections with very different environmental constraints: from the airport to the entrance of the city the course is composed by straight segments in a wide lagoon area, where speed can be relatively high (v_{max} = 20 km/h), while within the historical centre, the course winds through a relatively large, but densely trafficked, canal (Canal Grande), where speed cannot be more than 7 km/h in order to preserve the buildings from damages caused by waves. Besides, in Canal Grande a number of regular stops have to be made to comply with the public transport service.

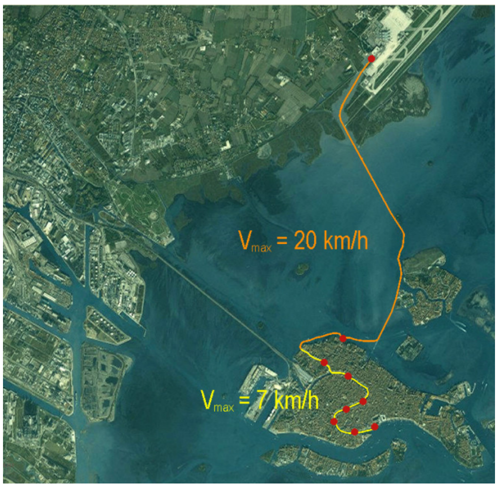

Fig. 1. The reference course

A semi-displacement hull, manufactured in fibreglass and marine plywood, has been adopted (Fig. 2).

Fig. 2. External view of the designed slender half-displacement passenger craft

The main particulars of the craft are reported in Table 1.

Table 1. Main characteristics

Length overall	L_{OA} =	14,99	m
Waterline length	L_{WL} =	14,90	m
Breadth	B =	3,20	m
Depth	D =	1,56	m
Draught, design	T =	0,80	m
Displacement, lightship	Δ_{LS} =	9,42	t
Displacement, full load	Δ =	12,44	t
Speed, maximum	v_{max} =	30	km/h
Speed, safety	v_s =	7	km/h
Gross tonnage, Italian	GT =	12,96	tsl
Passengers		39	
Crew		1	

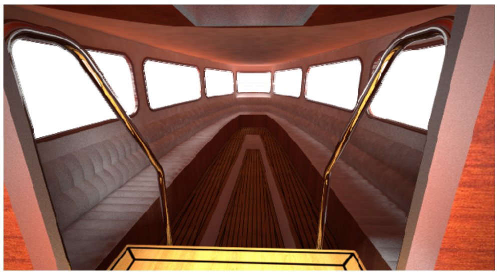

Fig. 3. Forward cabin

Fig. 4. Aft cabin

The vessel subdivision considers three main compartments. The cabins for passengers have been obtained in the forward (25 passengers) and the aftermost (14 passengers) compartments. The central zone is mainly occupied by the wheelhouse, but there is also a small area devoted to standing passengers, and racks for 12 standard items of hand-luggage. Furthermore, 12 standard items of hand-luggage can be put into the aft cabin behind the seatbacks of passengers. Moreover, facilities for 1 passenger with reduced mobility are installed in the aft cabin, just at its entrance. Fig. 3 and 4 show rendered views of the interiors.

Engine room has been arranged beneath the wheelhouse deck, while the battery packs have been placed under the dunnage of the forward cabin. A hybrid-electric propulsion system in series configuration has been adopted. The propeller is driven by an AC electric motor through a reduction gear. The battery packs may be charged by either the Diesel generator on-board or a shore connection installed on the quays.

3. HULL RESISTANCE

The dynamic behaviour of a vessel moving in shallow water varies a lot from the deep water condition. Significant variations can be found not only in the total resistance value, but also in the dynamic trim and sinkage of the vessel as well as in its manoeuvring performances. To complicate the situation even more, under "shallow water" condition several hydrodynamic regimes can be defined resulting from different combinations of vessel speed and water depth. Vessel behaviour and hydrodynamic modelling change between different regimes.

Previous studies were carried out to determine the magnitude of shallow water effects on ships, but especially the most recent ones [8] are focused on displacement ships sailing at relatively low speed. Those studies are mainly oriented to CFD applications for shallow water.

The focus of the present paper is on the evaluation of resistance. A procedure which does not require too many computational efforts to provide a preliminary prediction has been set up. The procedure has been then tested on the designed small passenger craft, which is an example of a rounded bilge half-displacement hull sailing in shallow waters.

The total resistance R_T of vessels sailing in unrestricted waters can be essentially divided into two components (frictional R_F and pressure R_P):

$$R_T = R_F + R_P \quad (1)$$

where R_F is due to the tangential forces acting on the wetted surface, while R_P concerns the normal forces. The most consistent part of R_P is given by the wave-making resistance R_{PW} which in turn can be divided in resistance due to wave propagation R_W and resistance due to wave dissipation R_D (mainly due to breaking waves and sprays). The remaining part of R_P is given by viscous effects R_{PV}, which concern a form effect of the body R_{PFM} (caused by the presence of the boundary layer and, in case, by the flow separation) and an induced component R_{PI} (essentially lift and drag forces). Also the frictional component R_F presents an internal distinction; in fact, it can be divided in the equivalent flat plate component R_{F0} and the form effect component R_{FFM}, due to the three dimensionality of the hull.

Having described all the different components that make up the total resistance (1) of the vessel, it is possible to group them in different ways, discarding the components that are of secondary importance in the contribution to the total resistance. For the purpose of this study, it is of primary importance to analyse separately viscous and wave forces. So that, the total resistance formulation (1) can be changed as follows:

$$R_T = R_V + R_W \quad (2)$$

where R_V is the viscous resistance given by:

$$R_V = R_F + R_{PV} \quad (3)$$

and R_W is the wave resistance not considering the spray and breaking waves effects.

In accordance with the total resistance definition (2), the viscous effects (mainly influenced by the Reynolds number Rn) are separated by the gravitational effects (i.e., waves, which are mainly related to the Froude number Fn of the system). It must be pointed out that such an assumption is a simplification of the problem, because both viscous and wave resistances are mutually influenced by Rn and Fn (the mutual interaction is sometimes included in an additional so-called allowance resistance).

The definition of the total resistance of the vessel according to equation (2) complies with the general guidelines given by ITTC 78, which is still recommended for the evaluation of ship resistance. Before ITTC 78, the traditional subdivision of the total resistance was as follows:

$$R_T = R_{F_0} + R_R \quad (4)$$

where R_{F0} is the above-mentioned equivalent flat plate resistance and R_R is the so-called residual resistance, which includes both viscous and wave resistance components.

All the described resistance components regard the hydrodynamic hull only. Of course, to complete the evaluation of the total resistance of the entire ship, other components must be taken into account such as, for example, the air drag R_{Air} of the superstructures that is not considered in the present study because of secondary importance.

4. SHALLOW WATER EFFECT

In shallow water, the presence of the sea bottom influences the behaviour of the vessel. The interaction between the hull and the sea bottom gets a significant impact on the total resistance of the vessel. Adopting the subdivision of the resistance components given in (2), it can be stated that the presence of the sea bottom influences both the viscous and the wave part of the resistance. The constriction between the hull bottom and the sea bottom generates an increment in the potential flow velocity (Venturi effect), this will automatically affect the pressure distribution on the hull, and then the behaviour of the boundary layer and the wave pattern of the vessel comes to be modified with respect to unrestricted water. Consequently, both viscous and wave resistance change, depending on the different combinations of ship speed and water depth, affecting also the surface wave pattern generated by the vessel.

4.1 Wave Pattern

In accordance with the theory of Lord Kelvin (1887, 1904) describing the wave system generated by a punctual pressure source moving on the water free surface at constant speed in deep water, a transverse and a divergent wave systems are generated (Fig. 5).

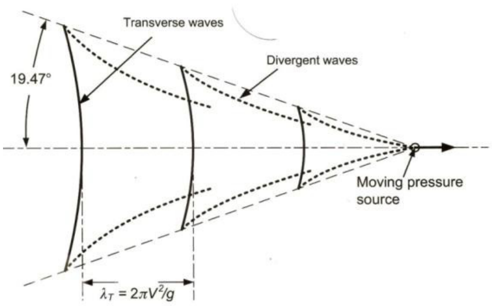

Fig. 5. Kelvin wave systems in deep water

The transverse wave system moves astern the point in the same direction with opposite sign respect to the point velocity, while the divergent system travels aside.

The angle θ between the intersection line of the two systems and the pressure source moving direction has an amplitude of 19.47°.

The transverse wave component has a celerity c, which is equal to the point velocity V but with opposite sign, and according to the dispersion equation it has a length:

$$\lambda = \frac{2\pi c^2}{g} \tag{5}$$

where g is the gravity acceleration.

The divergent wave components are expressed by the following relations:

$$c = V\cos\theta \tag{6a}$$

$$\lambda = \frac{2\pi c^2}{g}\cos^2\theta \tag{6b}$$

In this case the wave system is characterised only by the length and the speed, so it can be described by the linear Fn.

Once the pressure source moves on a surface of water with depth h, the celerity of the wave system can be defined as follows:

$$c = \sqrt{\frac{g\lambda_h}{2\pi}\tanh\frac{2\pi h}{\lambda_h}} \tag{7}$$

where λ_h is the wave length for a specific depth h.

From equation (7) it results that the celerity is a function of the h/λ_h ratio. Decreasing the water depth h, when h/λ_h tend to 0, equation (7) becomes:

$$c = \sqrt{gh} \tag{8}$$

That means celerity is a function only of the water depth, so that waves with different length propagate with the same speed, which assumes a critical value when:

$$V = V_{cr} = \sqrt{gh} \tag{9}$$

It is then convenient to define a Froude number with respect to water depth h in order to analyse the wave patterns in shallow water. The Froude number is defined as follows:

$$Fn_h = \frac{V}{\sqrt{gh}} \tag{10}$$

The hydrodynamic regime in shallow water is strongly influenced by the Fn_h value.

The wave pattern generated by the pressure source goes through a critical transition when Fn_h becomes equal to 1 (Fig. 6). In this case the angle θ of propagation of the waves approaches 90 deg, and then the wave-making effect is concentrated in a single crest that travels in the direction of the source motion. This situation is indicated as *critical* regime.

When Fn_h is lower than 1.0, the wave system consists of both transverse and divergent components. In particular, if Fn_h is less than 0.4, the wave system is comparable with the one in unrestricted waters. With Fn_h ranging from 0.4 to 1.0, the angle θ increases up to the critical condition value.

Consequently, such a hydrodynamic regime is called *subcritical*.

Furtherly increasing the Fn_h value above 1.0, the angle θ decreases again, but in this case the wave system is composed only by the diverging components, in fact the transverse waves disappear. This is typical of the so-called *supercritical* regime.

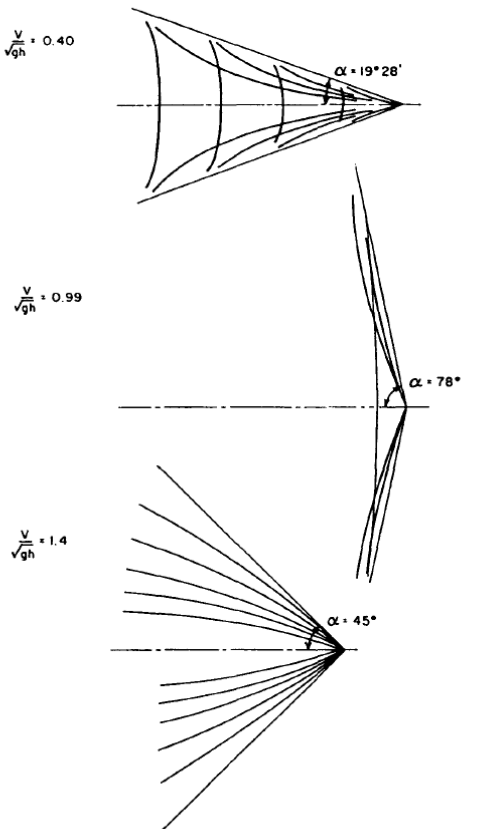

Fig. 6. Wave patterns in shallow water

All the theories valid for the single point source have been generalised for a vessel [6]. The same considerations about the different hydrodynamic regimes above mentioned remain. However, it should be noted that for vessels the critical condition can be reached for Fn_h numbers lower than 1.0. According to past studies [9], it is reasonable to state that critical values may occur at Fn_h between 0.88 and 0.96, depending on the fullness of the vessel.

4.2 Squat Effect

A direct effect of the changes in the wave pattern is the behaviour of the vessel in the vertical plane.

As already mentioned, sailing in shallow water the vessel experiences a pressure drop due to the speed variations along the hull. The pressure drop leads to a change in the dynamic trim and sinkage of the vessel.

This particular effect is called *squat* and produces an increase of the ship sinkage and a change of the dynamic trim (mostly by the stern).

The study of the squat effect is important because when a vessel is traveling without sufficient clearance between hull bottom and seabed, the additional trim and sinkage can cause possible groundings.

The squat is mainly conditioned by the following factors:

- Water depth
- Ship speed
- Ship fullness

Different studies have been carried out in the past to determine the maximum squat of a vessel [9], giving simple formulations as a function of the above-mentioned governing parameters.

5. SLENDER BODY ASSUMPTION

As previously mentioned, the present study is oriented towards developing a procedure valid for slender vessels, so that the theory developed by Mitchell [11] can be used as starting point. The problem is to solve the Laplace equation:

$$\phi_{xx} + \phi_{yy} + \phi_{zz} = 0 \quad (11)$$

in the range $-h < z < 0$ with the following boundary conditions:

$$\phi_z = 0 \quad \text{on } z = -h \quad (12a)$$

$$k_0\phi_z + \phi_{xx} = 0 \quad \text{on } z = 0 \quad (12b)$$

$$\phi_y = \pm V Y_x(x, z) \quad \text{on } y = 0 \quad (12c)$$

which represent the bottom, the Kelvin free surface and the linearized hull boundary conditions, respectively. The vessel is supposed to be laterally symmetric (y-wise) with offsets $y = \pm Y(x,z)$, and $k_0 = g/V^2$.

As already demonstrated [4,5], equation (11) subjected to constraint (12c) yields to an inhomogeneous ordinary differential equation for the potential Φ which needs a double Fourier transform to be solved and an inverse Fourier transform to find the final solution for the potential.

Of particular interest is the solution for the free surface elevation $z = Z(x,y)$ where, in accordance with the boundary conditions, $Z(x,y) = -(V/g)\Phi_x(x,y,0)$.

Applying at first the double Fourier transform:

$$\bar{Z}(\lambda,\mu) = -\frac{i\,\lambda/\pi^2}{k_0 k \sinh kh - \lambda^2 \cosh kh} \iint Y_x(\xi,\zeta) e^{-i\lambda\xi} \cosh k(\zeta + h)\, d\xi d\zeta \quad (13)$$

Then applying the inverse Fourier transform, making the following polar conversions $\lambda = k\cos\theta$ and $\mu = k\sin\theta$, the solution can be found as a function of the wave-number k:

$$Z(x,y) = 2\Re \int_0^{\frac{\pi}{2}} d\theta \int_0^{\infty} dk\, k e^{ikx\cos\theta} \cos(ky\sin\theta)\, \bar{Z} \quad (14)$$

which satisfies the boundary conditions (12) for:

$$k = k_0 \sec^2\theta \tanh kh \quad (15)$$

As the solution of (14) needs a lot of computational effort, alternatively the free surface elevation can be found in the far-field approximation. This approximation consists in using the particular feature that the free surface waves at $x=+\infty$ can be obtained from the residue at the integration pole. It means that by changing the integration path going under the pole, the new k-integral will tend to 0 as x goes to $+\infty$ instead of $-\infty$. It can be demonstrated that the difference between the two integrals is equal to $-2\pi i$ times the residue at the considered pole. This difference is the desired *far-field wave pattern*.

Thus, for $x\to\infty$ results $Z\to Z^F$, where:

$$Z^F(x,y) = \Re \int_{-\pi/2}^{\pi/2} A(\theta) e^{-ik(x\cos\theta + y\sin\theta)} d\theta \quad (16)$$

$A(\theta)$ is the Kochin function that can be obtained from the Michell formulation [11], and can be expressed as a function of the hull slope $Y_x(x,y)$ in the following way:

$$A(\theta) = \frac{2}{\pi}\sec\theta \frac{k}{1 - k_0 h \sec^2\theta\, \mathrm{sech}^2\, kh} \iint Y_x(x,z) \frac{\cosh k(z+h)}{\cosh kh} e^{ikx\cos\theta} dx dz \quad (17)$$

Expression (17) can be integrated by parts in order to obtain the result:

$$A(\theta) = -\frac{2i}{\pi} \frac{k^2}{1 - k_0 h \sec^2\theta\, \mathrm{sech}^2\, kh} \left[\iint Y(x,z) \frac{\cosh k(z+h)}{\cosh kh} e^{ikx\cos\theta} dx dz - \frac{1}{ik\cos\theta} e^{ikx_s\cos\theta} \int Y(x_s,z) \frac{\cosh k(z+h)}{\cosh kh} dz \right] \quad (18)$$

where $x = x_S$ at the stern (it means that when no transom is present the second part in the square brackets disappears).

The Kochin function expressed in (18) is valid for all the hydrodynamic regimes in shallow water described in the previous section. In fact, for the *subcritical* regime when $k_0 h > 1$, the function is valid for all the θ integration domain. In the *supercritical* regime, where $k_0 h < 1$, the Kochin function is identically equal to 0 for $|\theta| < \theta_0$, being $\cos\theta_0 = k_0 h$. From this formulation the result for infinite depth can be obtained with $k \to k_0 \sec^2 \theta$.

Once the Kochin function is evaluated, it is also possible to determine the wave resistance R_W of the vessel according to the following formulation given by Tuck [4]:

$$R_W = \frac{\pi}{2}\rho V^2 \int_{-\pi/2}^{\pi/2} |A(\theta)|^2 \cos^3\theta \, \mathrm{d}\theta \tag{18}$$

In this way, adopting the slender-body approximation, it is possible to calculate the wave resistance of the vessel when the basic geometry of the vessel is known.

Several studies by Tuck show that such an approach reproduces quite well the wave pattern of slender vessels in shallow water as well as in unrestricted water.

The theory can also be extended to other kinds of restricted water like channels. The slender-body theory can also be used to describe the behaviour of the ship in the vertical plane, and then the estimation of the squat effects in terms of dynamic trim and sinkage can be carried out. In fact, by means of this theory the actions in terms of force and moment acting in the vertical plane of the vessel can be evaluated, and thereafter dynamic trim and sinkage can be derived. The vertical actions on the hull are different when the critical or supercritical regime is investigated. For the subcritical range the following formulations can be found:

$$F_Z = \frac{\rho V^2}{2\pi h\sqrt{1 - {Fn_h}^2}} \iint \mathrm{d}x\mathrm{d}\xi Y_x(x,z) A_\xi \ln|x-\xi| \tag{19}$$

$$M_Y = -\frac{\rho V^2}{2\pi h\sqrt{1 - {Fn_h}^2}} \iint \mathrm{d}x\mathrm{d}\xi x Y_x(x,z) A_\xi \ln|x-\xi| \tag{20}$$

where $A(x)$ is the sectional area curve of the vessel.

Instead, for the supercritical regime, the expressions became:

$$F_Z = \frac{\rho V^2}{2h\sqrt{{Fn_h}^2 - 1}} \int \mathrm{d}x A_x Y(x,z) \tag{21}$$

$$M_Y = -\frac{\rho V^2}{2h\sqrt{{Fn_h}^2 - 1}} \int \mathrm{d}x A_x x Y(x,z) \tag{22}$$

These equations are not easy to solve and several authors (Vermeer, Millward) gave some empirical solutions starting from Tuck's general formulation .

6. ADDED RESISTANCE

The prediction of the total resistance of a vessel in shallow water has been treated by several authors and various methods to estimate the added resistance due to the presence of the seabed have been proposed.

The scope of the present study is to develop a procedure able to evaluate the added resistance in shallow water covering all the three possible hydrodynamic regimes described in the previous sections. The aim is also to make the procedure suitable to derive the added shallow water resistance from the unrestricted water resistance prediction coming from statistical methods, systematic series or model tests.

For this reason, the definition of the resistance made in section 3 is very important to ensure consistency between the prediction for infinite depth and the new one in shallow water. The resistance definition described in (2) has been selected to implement the proposed procedure, considering the effects of shallow water both on viscous resistance R_V and on wave resistance R_W, separately.

6.1 Wave Resistance

The proposed procedure, oriented to slender vessels, evaluates the effect of shallow water on R_W adopting the slender-body approximation described before.

As above exposed, the slender-body approximation is a simplification of the real problem, and in order to tackle the shallow water condition it is necessary to adopt the further approximation concerning the far-field wave pattern description. However, it was already shown that the slender-body assumption is in good agreement with the description of the wave generation phenomena both in infinite and finite water depth.

In our opinion the slender vessel approach here described is able to predict with sufficient accuracy the differences between the wave pattern in infinite depth and the wave pattern in shallow water, and so the varations of the wave resistance R_W.

However, when it is not possible to evaluate with sufficient accuracy the wave resistance of a vessel in infinite depth and whether the vessel is particularly slender, R_W can be also directly determined. Hereafter, the procedure is described assuming that the R_W value in unrestricted water is known with sufficient accuracy.

To determine the final amount of the wave resistance when the vessel is traveling in shallow water with depth h, two calculations are necessary. The first calculation evaluates the wave resistance in infinite depth according to the slender-body assumption through a selected speed range, while the second calculation is executed at the actual water depth h at the same speed range.

At this point it is possible to determine the non-dimensional increase / decrease of wave resistance in shallow water as follows:

$$\Delta R_W = 1 - \frac{{R_{W_h}}^*}{{R_W}^*} \tag{23}$$

where R_{Wh}^* and R_W^* are the wave resistance in shallow water and in infinite depth, respectively, computed by equation (18) according to the slender-body assumption.

Now it is possible to evaluate the wave resistance in shallow water as follows:

$$R_{W_h} = R_W \, \Delta R_W \tag{24}$$

where R_W is the wave resistance in infinite depth from statistical methods or model tests.

6.2 Viscous Resistance

Shallow water affects also the viscous resistance R_V of the vessel. Changes in the pressure distribution along the hull and a different grow of the boundary layer generate an increase of the viscous forces acting on the hull. For this purpose the studies of Millward have been used to determine the increase of viscous effects due to shallow water. Previous study [8] shows that Millward results are in agreement with CFD computations that use double body theory once the considered water depth-draft ratio h/T is not below 0.8-1.0. The following formula is then used for the viscous resistance:

$$R_{V_h} = R_V \left(0.644 + \left(\frac{T}{h}\right)^{1.72}\right) \tag{25}$$

where T is the draft of the vessel and R_V is the viscous resistance evaluated for infinite water depth.

Once wave resistance and viscous resistance in shallow water have been evaluated, the two components can be summed according to equation (2) to find the total resistance R_T at the given speed V.

7. TEST CASE

The above-mentioned procedure has been tested considering the designed half-displacement craft presented in the second section. The designed hull is representative of a typical round-bilge half-displacement vessel and is within the geometric parameter limitations of the NPL series [3]. For this reason, the NPL systematic series has been selected to evaluate the total resistance of the vessel in infinite depth.

The results of the proposed prediction method for shallow water are here presented for three different water depths: 5.0, 3.0 and 2.0 m.

According to the procedure, a first calculation with the slender-body approximation has been executed at infinite depth, so a total of four different conditions have been tested by the slender-body theory.

Figures from 7 to 12 present a set of representative wave patterns in order to show how the calculation method is able to capture the different regimes that the vessel could encounter during navigation.

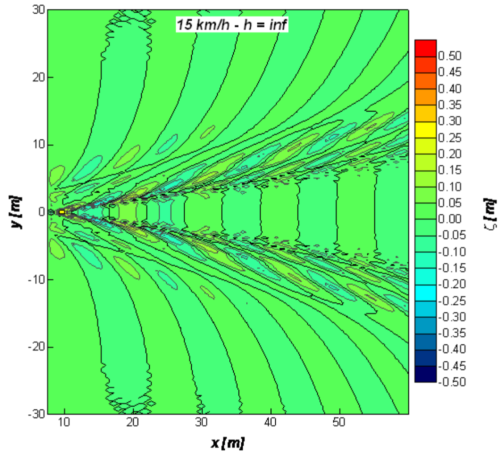

Fig. 7. Far-field pattern V=15 km/h, h=∞

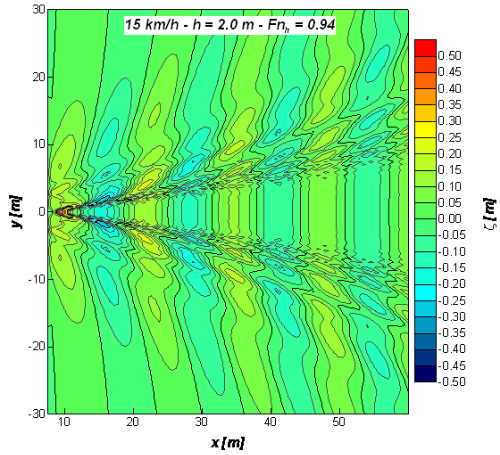

Fig. 8. Far-field pattern V=15 km/h, h=2m

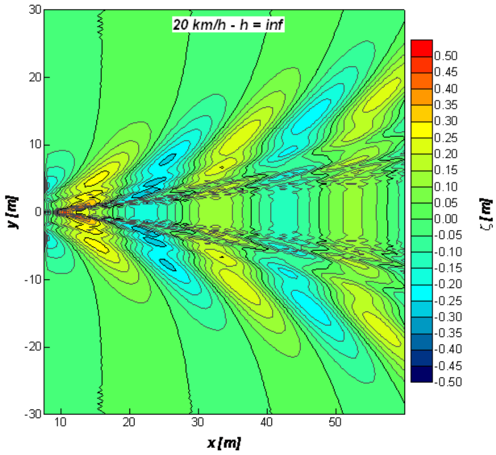

Fig. 9. Far-field pattern V=20 km/h, h=∞

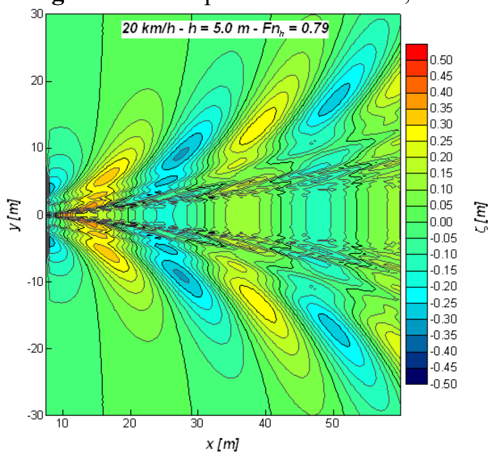

Fig. 10. Far-field pattern V=20 km/h, h=5m

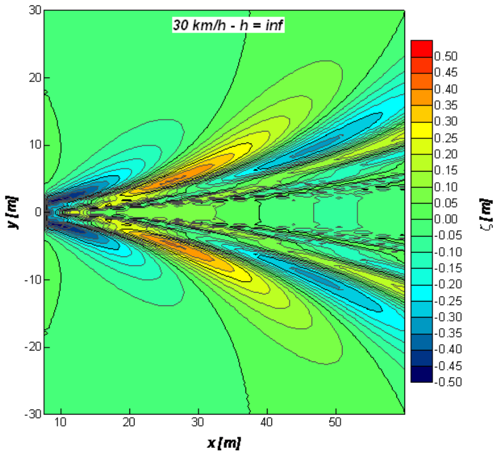

Fig. 11. Far-field pattern V=30 km/h, h=∞

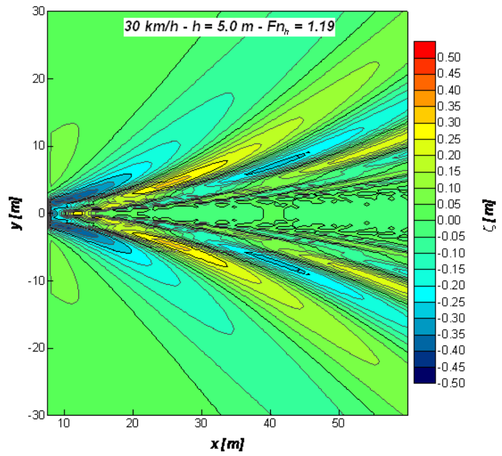

Fig. 12. Far-field pattern *V*=30 km/h, *h*=5m

It can be seen in the comparison with the corresponding infinite depth condition that the shallow water wave patterns show all the peculiarities described in the previous sections for the subcritical, critical and supercritical regimes.

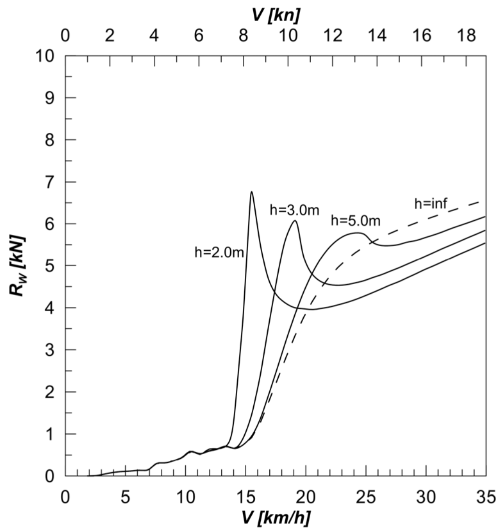

Fig. 13. Wave resistance in shallow waters according to the slender-body theory

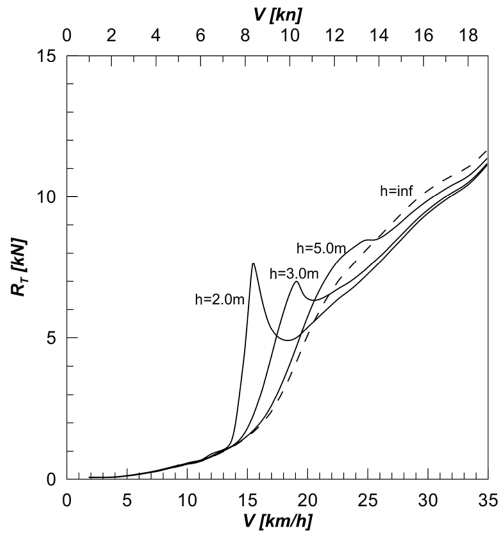

Fig. 14. Total resistance in shallow waters according to the proposed procedure

Once the far-field wave elevation pattern is found, the wave resistance of the vessel can also be evaluated according to the presented theory. In Figure 13 it can be seen that all the shallow water curves present a maximum in correspondence with the critical speed for relevant depth. After the maximum, when the supercritical condition occurs, the resistance drop is due to the absence of the transverse wave components. With the wave resistance evaluated according to the slender-body theory, it is possible to determine the resistance increase / decrease in shallow water. Then, applying the correction on viscous resistance, it is possible to predict the new total resistance curves (Fig. 14).

8. CONCLUSIONS

In this paper the design of a new small passenger craft has been presented, highlighting the innovative design of hull form and the internal layout. Thereafter, a new procedure for the estimation of shallow water effect on vessel resistance has been presented, and at the same time an overview of the theory behind the implemented procedure has been exposed. The procedure was then tested on the designed vessel in order to predict the resistance variations due to shallow water.

The new procedure allows to evaluate without too much computational efforts the shallow water resistance of a slender vessel, giving the opportunity to find the final resistance value in different hydrodynamic regimes: subcritical, critical and supercritical. The resistance curves found with the developed procedure are in agreement with the physical phenomenon of the problem, reproducing the effect of shallow water for all the different regimes.

However, further work has to be done in order to improve the accuracy of the prediction, for instance by considering the effect of dynamic trim and sinkage in the evaluation of the shallow water wave resistance, and comparing the results obtained to those drawn from existing procedures such as Schlichting method or Karpov diagrams (even though they are valid only in subcritical conditions). Another approach could be the adoption of a fully viscous CFD analysis. However such an analysis is more time consuming than the presented procedure, but it can provide more detailed information both on the resistance of the vessel and on the modification of the wakefield in shallow water. The latter could be of utmost interest when an accurate prediction of the propulsive performances of the vessel is requested.

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