Numerical and Experimental Study on the Wave Resistance of Fast Displacement Asymmetric Catamarans

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Abstract

The effect of asymmetric demihulls on the wave resistance of displacement-type Catamarans is investigated both numerically and experimentally. It is shown that, depending on the Froude number and separation distance, properly optimized asymmetric demihulls exhibit reduced wave resistance, resulting from the favorable interaction between the wave patterns of the two demihulls.

1. Introduction

High speed twin-hull vessels are widely used as car/passenger ferries and also employed for other applications where a large deck area is required. Their size varies from small planing passenger vessels to large semi-displacement ferries carrying more than 200 cars and 1500 passengers. At the same time, there seems to be a steady local interest for medium-size, moderate speed, displacement type catamarans to serve between the Greek islands. Among the basic requirements for these vessels, one should mention a service speed around 17 to 25 knots, a satisfactory seakeeping behavior in relatively short and steep waves, typical for Greek waters, and last but not least, the simplicity of their design and construction, so that they can be easily built using existing local facilities with comparatively reduced building cost. However, for a displacement type hull of 60 to 80m in length, the comparatively moderate speed of 17-25kn corresponds to rather unfavorable Froude numbers around 0.45, see e.g. Papanikolaou et al. (1997). It is therefore very important to carefully optimize the main dimensions and hullform to keep the wave resistance to a minimum. The demihull separation is very crucial for the interaction of the two wave patterns and at the same time determines the roll resonance frequency and the cross-deck area. For a certain separation distance, the staggered-hull concept can be used to obtain favorable interaction effects, Söding (1997). Another way to obtain similar results could be the consideration of asymmetric demihulls, Bruzzone et al. (1999).

In the following, the effect of asymmetric demihulls on the wave resistance of displacement-type twinwulls will be investigated both numerically and experimentally. It will be shown that with the proper design of the demihulls, depending on the Froude number and separation distance, the wave resistance can be significantly reduced, leading even to negative interaction effects. An analytical-numerical method for the calculation of the wave resistance of twinhull vessels with asymmetric demihulls has been developed and presented earlier by Kaklis et al (1992) and Papanikolaou, Kaklis et al (1996) based on an asymmetric thin ship theory. A series of experiments has been also performed at NTUA, Papanikolaou and Spanos (1999) for the validation of this theory, using a simplified catamaran model with asymmetric demihulls. The experiments were performed at various separation distances and demihull arrangements providing alternative asymmetric configurations. The comparison of the numerical results obtained by the above theory with the experimental measurements are presented, along with a discussion of the effects of asymmetric demihulls on the wave interaction phenomena for displacement-type catamarans.
2. Theoretical Background

An extension of the Michell’s approach has been established by Kaklis et al. (1996), Papanikolaou et al. (1996), Spanos (1995) suitable for the calculation of the wave resistance of twin-hulls with asymmetric demi-hulls. The flow induced by the steady forward motion, at moderate Froude numbers, of a catamaran with thin asymmetric demi-hulls at sufficiently large separation distance, can be modelled, to the leading order of approximation with respect to two small parameters (namely the breadth to length ratio and draft to length ratio), introducing, along with the Kelvin-source distribution, an additional normal Kelvin-dipole distribution, over each demi-hull’s centre plane. The Kelvin-source distribution is explicitly determined from the lengthwise derivatives on both port and starboard sides of the demi-hull surface, while the dipole distribution is proportional to the difference of these derivatives. With the singularity distributions being known, Kochin’s formula is applied, to obtain the wave resistance through a far field relation.

The above approach has been implemented in the computer program TOWRES, developed at the Ship Design Laboratory of NTUA. Triangular patches are used to discretize the wetted surface of each demi-hull and its projection to the centre plane, over which the Kelvin sources and normal dipoles are distributed. Actually, in the absence of port-starboard symmetry, the centre plane is defined through a characteristic lateral plane, which divides the port and starboard part of each demi-hull. The source strengths are calculated analytically on the three corners of each triangular patch, and based on this information a piecewise linear distribution is defined over the patch. Finally the integration of the Kochin function itself is performed applying a standard integration scheme.

Viscous effects are accounted for by using ITTC ‘57 formulation for the calculation of frictional resistance and considering a semi-empirical form factor to estimate the viscous pressure resistance. For the presently studied Wigley hull form, considering its slenderness, a constant form factor equal to 0.10 has been used.

Summing up the wave and viscous components described above, the total resistance is calculated by a quite fast and stable computer code (approx. 20 sec/speed for 3000 elements per demi-hull at a Pentium III-800 computer), permitting the efficient employment of this resistance prediction scheme within global hull form optimisation procedures.

3. Model Tests

In order to gain some insight in the performance of asymmetric catamaran hullforms and at the same time to obtain necessary experimental data for the validation of the above theoretical approach and the related numerical code, a series of experiments has been set up and performed in the Towing Tank of the Marine Hydrodynamics Laboratory at NTUA, Papanikolaou, Spanos (1999).

A very simple hullform has been selected to start with, having one curved side of Wigley form, while the other side is flat (see Figure 1, FSI and FSO). This form was preferred over other, more shiplike models, because of its slenderness, simplicity and standardized nature, permitting us to herein concentrate on the effects of hull form asymmetry on the wave interaction between the two demi-hulls. The two demi-hulls were constructed from wood and their main dimensions are given in Table 1.

Table 1: Wigley Demihull Main Dimensions

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (L)</td>
<td>3.00 m</td>
</tr>
<tr>
<td>Beam (B)</td>
<td>0.30 m</td>
</tr>
</tbody>
</table>
Draught (T) 0.188 m
Volume (\(V\)) 0.078 m\(^3\)
Wetted Surface (WS) 1.47 m\(^2\)
Hullform Coefficient (\(C_B\)) 0.46
L/B 10
B/T 1.6
\(L/\sqrt{V}\) \(1/3\) 7.02

During the experiments, three separation distances have been tested, ranging from a minimum distance \(S=0.6\) m (\(S/L=0.2\)) to a medium distance \(S=0.9\) m (\(S/L=0.3\)) and a maximum distance \(S=1.2\) m (\(S/L=0.4\)). Initially the two demihulls were arranged so that their flat side was placed inwards. After the completion of the series of experiments, the two demihulls have been reversed so that their flat side was placed outwards and the experiments have been repeated. Although the latter is a rather unusual configuration, it was considered useful to test it, not only to get some more insight on the interaction effects, but also to obtain experimental measurements for the validation of the analytical/numerical method in this so to say extreme situation. The single demihull case was also tested, and its calm water resistance was measured and recorded, along with the transverse force acting on the demihull. From now on, the following abbreviation is introduced: FSI stands for the twin hull configuration with the Flat Side Inwards, while FSO for the configuration having Flat Side Outwards (Figure 1).

![Fig. 1: Alternative twin hull configurations](image)

It should be noted that due to the lack of a demihull’s centre plane in asymmetric forms, the separation distance stands herein for the minimum distance between the two inner sides. For the same separation distance, although the three alternative configurations poses the same maximum overall beam and the same minimum tunnel width, the volume of the vessel is slightly moved inwards for FSI, (resp. outwards for FSO), with respect to SYM.

The model was connected to the dynamometer at a point located amidships and vertically at a height of 450 mm above base line, allowing for various degrees of freedom in the vertical plane: In some test cases, both sinkage and trim were permitted. In other cases, only sinkage was allowed while trim was restrained. In the fixed model case, both sinkage and trim were restrained. The latter case was systematically tested, in order to obtain results directly comparable to the numerical predictions, since the employed analytical-numerical approach does not account for sinkage and trim.

The demihulls were not fitted with any turbulence strip wires, since our intention was not to perform full-scale resistance predictions but to qualitatively study the wave system interaction phenomenon and to obtain experimental measurements for the validation of the theoretical model.

### 4. Discussion of results

In the following the numerical predictions and experimental measurements are presented, compared and discussed.
The effect of restraining sinkage and trim on the calm water resistance is demonstrated in Figure 2, where the experimental measurements for the FSI configuration at the medium separation distance (S/L=0.3) are presented.

The three curves correspond to measurements for the free model (free to heave and pitch), the pitch restrained model (free to heave) and the restrained model (heave and pitch restrained). It can be seen from these results that the restrained model exhibits lower total calm water resistance throughout the considered Froude number range, particularly at Froude numbers greater than 0.35.

Sinkage and trim were measured during the experiments, showing an increase of depth amidships and a gradual trim by stern for increasing speed (Figure 3). Sinkage has a considerable effect on the resistance, at least for Froude number greater than 0.3. Tests with restrained trim show a slight resistance increase, so small that for this vessel with fore and aft symmetry its effect can be considered negligible.
Figure 4 presents experimental measurements for the FSO configuration and for the same separation distance. Again the restrained vessel exhibits lower calm water resistance throughout the considered Froude number range. Sinkage constantly increases resistance, and its effect is particularly significant above Fn=0.35.

![Figure 4: Experimental measurements for restrained-unrestrained vessel, FSO](image)

In Figure 5 numerical results are compared against experimental measurements for the minimum separation distance (S/L=0.2). The vessel is restrained in heave and pitch. Results for both FSI and FSO configurations are presented.

![Figure 5: Numerical results vs experimental measurements for the small separation distance](image)

The full symbols correspond to the FSI case while open symbols correspond to FSO. The dashed line marked with asterisks equals twice the experimentally measured calm water resistance of the single hull. As can be seen from this plot, the numerical results correlate quite well with the experimental ones, at least qualitatively. However, a resistance underprediction is observed in the range 0.3<Fn<0.38. For the FSI configuration, numerical results slightly overpredict the experimental measurements for Fn above 0.4 but the agreement is fairly acceptable. In the FSO case, there is a very close agreement for Froude number between 0.38
and 0.45, but above that range, numerical results overpredict resistance by about 10-15%.

Another interesting issue in Figure 5 is the comparison between the two alternative configurations (namely FSI vs. FSO). FSI exhibits lower resistance both in the small and the high Froude number range. In particular, for Fn above 0.42, FSO resistance is about 15% higher. There is however a range between Fn=0.33 and Fn=0.39, where both experimental measurements and numerical calculations show that this tendency is reversed and FSO configuration resistance is considerably smaller (up to 15%) from FSI. It should be noted than within this Froude number range, both twin hull configurations exhibit lower resistance than twice the single demihull resistance, which means that for the specific demihulls separation there is a negative interaction effect. This favorable interaction can be attributed to the effect of the bow-generated waves, traveling along the opposite stern. For the specific combination of vessel’s length, forward speed range and separation distance, these wave trains result in an increase of wave deviation and hydrodynamic pressure in the stern region. Furthermore, it can be seen that according to the experimental results, the FSI configuration shows a very smooth resistance curve, very close to the double of the single demihull resistance, which indicates that the interaction effects are particularly weak when the flat side is placed inwards. On the other hand, the FSO configuration resistance curves, both numerical and experimental, possess more pronounced humps and troughs, for Fn=0.31 and 0.35 respectively, indicating stronger interaction effects, as expected.

Analogous results are presented in Figure 6 and 7 for the other two separation distances (S/L=0.3 and 0.4 respectively). Here again, the model is restrained in the vertical plane, while results for both FSI and FSO configurations are presented. As can be seen from these plots also, the numerical and experimental results are again fairly well correlated. For the FSI configuration, numerical results are in very close agreement with the experimental measurements for Fn above 0.4. For the FSO configuration, there is still an overprediction in the numerical results above Fn=0.42, but the agreement is improved with increasing separation distance (less than 8% difference between the numerical and experimental results for S/L=0.3 and less than 5% for S/L=0.4).

![Graph](image)

Fig. 6: Numerical results vs experimental measurements for the medium separation distance

Regarding the performance of the two alternative configurations (FSI vs. FSO), Figure 6 and 7 lead to the same observations as with Figure 5. FSI exhibits lower resistance both in the small and the high Froude number range, but the difference between the two configurations decreases with increasing separation distance, as the interaction effects are getting weakened. There is again a medium speed range, where both experimental measurements and numerical calculations
clearly indicate that this tendency is reversed, but this range gets smaller with increasing S/L ratio and almost vanishes for S/L=0.4. Furthermore, it can be seen from Figures 6 and 7 that according to the experimental results, the FSI configuration shows a very smooth resistance curve, without any clear hump or trough. This result agrees with the observations during the tank tests, that there were practically no waves developed between the two demihulls for the FSI configuration.

As a matter of fact, Figure 7 shows that the calm water resistance of the FSI configuration for the maximum separation (S/L=0.4) is practically equal to the double of the demihull resistance, indicating that for this separation distance, the interaction effect has already vanished. On the other hand, for the FSO configuration, the experimental resistance curve for S/L=0.3 still shows signs of a hump and trough, for Fn=0.31 and 0.33, although very weak. For this configuration during the tank tests, development of strong waves between the two demihulls was observed, while outboards and along the model length the waves were very weak. The same hump and trough behavior—somehow stronger—appears in the numerical results for S/L=0.3. For S/L=0.4, both numerical and experimental results for the FSO configuration are quite flat, indicating that the interaction effects have progressively died-out.

While Figures 5 to 7 are useful for the comparison of the performance of the two alternative configurations, the next two Figures indicate the effect of increasing demihulls separation for each configuration separately. In Figure 8 the results for the FSI configuration for the three S/L ratios are presented. It can be seen from these curves that for a twin hull vessel with flat inner sides the interaction effects are very small and the calm water resistance is practically independent from their separation distance. The same conclusion is derived both from the experimental and the numerical results.

On the other hand, Figure 9 shows that the interaction effects are quite stronger and more complicated in the FSO case. The spread between the curves for increasing S/L ratio is now considerable. More than that, the effect of increasing S/L ratio depends on the actual value of the Froude number. As a matter of fact, considering the experimental measurements, the following observations can be made: The vessel with the largest S/L ratio exhibits smaller calm water resistance than the other two vessels for Fn above 0.4 and bellow 0.31. On the other hand, for 0.33<Fn<0.37 this vessel has larger resistance than the other two. The vessel with the minimum separation distance (S/L=0.2) has the worst performance among the three for Fn>0.41 and Fn<0.33, while this tendency is reversed in the range 0.35<Fn<0.4, where it shows clearly
better performance than the other two vessels with larger S/L ratio. Finally, the performance of the vessel with S/L=0.3 generally lies between the other two, except that there are two Froude number ranges, one between 0.31 and 0.34, and another between 0.37 and 0.41, where it has the minimum and maximum resistance respectively among the three vessels.

It is very interesting to note that, apart from some small differences in the limits of the various Froude number ranges, the above observations are in all cases verified from the numerical results also.

Let $I_E$ be a coefficient describing the magnitude of the interaction effect, defined as $I_E = R_T / R_{T=\infty}$ where $R_T$ and $R_{T=\infty}$ are the total calm water resistance of the twin hull, for the actual and for infinite separation distance respectively. In Figures 10 and 11 numerical and experimental results are presented for the interaction coefficient as a function of the non-dimensional separation distance, for three different speeds of advance corresponding to $Fn=0.313$, $Fn=0.369$ and $Fn=0.452$. 
In Figure 10, corresponding to the FSI configuration, the interaction coefficient is close to 1 indicating weak interactions, while the curves are very smooth. The magnitude of the interaction effect varies slowly with the separation distance, in accordance with the findings from Figure 8. Negative interaction occurs at Fn=0.313. The magnitude of the interaction slowly decreases with increasing separation, with an exception for S/L<0.18, where for Fn=0.313 and Fn=0.369 this tendency is reversed. The larger differences between the numerical and experimental results are found for Fn=0.369, where the numerical results predict a positive interaction (I_E ≈ 1.1), while the experiments show a negative interaction (I_E = 0.98).

![Fig. 10: Interaction coefficient vs. separation distance, FSI configuration](image)

For the FSO configuration, stronger interactions are observed (Figure 11). The dependence of I_E on S/L is more complicated and clearly not monotonic. A fairly good qualitative agreement between the numerical and the experimental results is obtained in all cases. Interaction effects between the two demihulls are in most cases positive, leading to increased total resistance. However, favourable combinations of the vessel’s length, speed of advance and separation distance have been identified, where negative interaction occurs, resulting in considerable resistance decrease.

![Fig. 11: Interaction coefficient vs. separation distance, FSO configuration](image)
Introduction of the asymmetric demihulls concept has a minor effect on the sign of the interaction, but it clearly affects its magnitude. Increased inner side curvature amplifies the wave interaction between the demihulls. In reverse, a flatter inner side weakens the wave interaction. For most vessels, operating in Fn ranges where interaction is positive, the configuration with a thinner inner demihull is preferable, in order to decrease the interaction magnitude. For relatively slower vessels, operating in Fn ranges below 0.4 where negative interactions often occur, increasing the inner demihull’s curvature and volume increases the interaction magnitude, leading to decreased total resistance.

In the following, an example of the application of the asymmetric demihulls concept for the hydrodynamic optimization of an existing catamaran vessel is presented. The vessel is a moderate speed, displacement-type catamaran, currently employed as a passenger ferry in the North Aegean. The vessel’s main dimensions are presented in Table 2.

Table 2: Vessel’s Main Dimensions

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length Over All (L_{OA})</td>
<td>45.00 m</td>
</tr>
<tr>
<td>Length B.P. (L_{BP})</td>
<td>37.93 m</td>
</tr>
<tr>
<td>Breadth max (B)</td>
<td>15.00 m</td>
</tr>
<tr>
<td>Beam at WL (demihull)</td>
<td>3.44 m</td>
</tr>
<tr>
<td>Draught (T)</td>
<td>3.30 m</td>
</tr>
<tr>
<td>Volume (V)</td>
<td>405 m^3</td>
</tr>
<tr>
<td>Speed max/service</td>
<td>19.8/18.2kn</td>
</tr>
<tr>
<td>Installed Horsepower (BHP)</td>
<td>2x2280PS</td>
</tr>
</tbody>
</table>

The objective was to consider herein the asymmetric demihull concept, not for reducing the calm water resistance, but to improve the vessel’s seakeeping behavior and in particular to reduce the roll resonance frequency, without impairing the vessel’s powering performance. A wooden model (scale 1:20) of the original vessel has been constructed, and experiments have been performed in the Towing Tank of the Marine Hydrodynamics Laboratory at NTUA for various demihulls separations. For a Froude number around 0.5, decreasing the separation results in a significant increase of resistance due to the wave interaction amplification. Similar trends have been identified by the numerical calculations. Introduction of the asymmetric demihull concept, reducing the inner-side curvature, cancels the interaction effect increase, as shown by the numerical calculations.
Experimental and numerical results for the total (model scale) resistance for three different configurations are presented in Figure 12. Both numerical and experimental resistance predictions are presented for the original configuration. The distance between centerplanes for the original configuration is equal to 11.0m. The corresponding minimum tunnel width between the two demihulls is equal to $S_1 = 7.56$ m. Bringing the two demihulls closer by 2.0m (minimum tunnel width reduced to $S_2 = 5.56$ m), results in a resistance increase of about 6%, for a Froude number around 0.5. Numerical results for this configuration are also plotted in Figure 12. Then, keeping the minimum tunnel width constant ($S_2 = 5.56$ m), we apply the asymmetric demihulls concept, reducing the inner side curvature (i.e. bringing each demihull’s ‘centerplane’ further in). Reducing the distance between the two ‘centerplanes’ from 9.0m to 6.421m, we derive the third configuration, for which results are also plotted in Figure 12. To this end, we employ an affine transformation on the inner- and outer-side of each demihull, reducing the volume of the inner-side by 75%, while increasing the outer-side volume by the same amount. According to the numerical prediction, the introduction of the asymmetric demihulls results in the elimination of the interaction effect amplification (less than 0.2% difference in calm water resistance between the original and the asymmetric configuration). At the same time, GM value has been reduced from 11.00m to 5.65m, leading to a drastically improved roll response, especially in short crested beam waves, encountered very often at the specific sea route. The hull shape of the initial and the modified vessel are presented in Figure 13 and 14 respectively.

5. Conclusions

Results of a numerical and experimental investigation on the effect of asymmetric demihulls and increasing separation distance on the resistance of twinhull vessels have been presented. A simple hullform has been used, consisting of two demihulls, having one side flat and one curved side of Wigley form. Comparison of numerical calculations with experimental results has shown fairly good agreement throughout the considered Froude number range. It has been ascertained
that the numerical results are predicting correctly the resistance trends with respect to separation distance variations, as well as the effect of asymmetric demihulls, even when they fail to predict exactly the actual values. It is therefore considered that the present analytic/numerical method can be a useful tool, capable for being integrated in optimization procedures to help the designer in the preliminary design stage, where alternative concepts have to be evaluated and main dimensions must be selected in a rational way.

For the asymmetric twinhull configuration having the curved side placed inwards, systematic tests and numerical calculations revealed the complex nature of the interaction phenomena, usually resulting in an increase of the total resistance when compared to the total resistance of a twinhull with symmetric demihulls. However, a range of Froude numbers have been identified, where favourable interaction phenomena result in a significant resistance decrease, even bellow the sum of the resistance of the two demihulls. On the other hand, for the alternative configuration with the flat side placed inwards, it has been seen that the interaction effects are rather weak and the separation distance between the demihulls does not significantly affect the total resistance. In the considered Froude number range, sinkage effect has been shown to significantly increase the calm water resistance, while the trim effect was not significant, possibly due to the fore and aft symmetry, possessed by the model.

Twinhulls with properly optimised asymmetric demihulls are found to exhibit improved hydrodynamic characteristics with respect to the total resistance, depending on the Froude number range and demihulls separation. It is therefore the opinion of the authors that they should be seriously considered by the designers as possible alternatives for displacement type catamaran designs.

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References


