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Studies on the Resistance of Catamarans in Restricted Water

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Experiments on the Resistance of a Catamaran in Restricted Water

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Abstract

The question of resistance is a very important one in the case of catamarans. In particular, one is interested in determining the influence of the spacing between the hulls and water depth on the drag. The work reported here includes a series of towing-tank experiments in which these parameters were changed systematically and curves of wave resistance were obtained. It is also shown that inviscid wave-resistance theory can be used to predict with reasonable accuracy the influence of these parameters.

Introduction

Background

In the last two decades, the catamaran has enjoyed a considerable amount of success in terms of both the development effort that has been invested in their improved design and in terms of the number of craft that have been constructed and placed in passenger and cargo service.

The subject of ship resistance is one which has been studied for over a century now. The work of Michell [1] was the first which resulted in a usable formula for the *wave* resistance for a ship travelling at a constant speed in deep water. The assumptions in his theory were that the effects of viscosity and surface tension could be ignored. Additionally, the ship was considered to be *thin*. That is to say, the beam of the hull is small compared to its length or draft.

The wave resistance is defined as the drag associated with generating the wave pattern in the neighborhood of the vessel. In addition to this component of drag, one must add the *viscous* resistance, which can be estimated by one of the flat-plate skin-friction formulas. Additional components of resistance for a marine vessel can be identified and have been the subject of much research. These components of resistance include the contributions resulting from the influence of hull form on the viscous drag, whose effect is commonly quantified by means of the form factor. Finally, one should consider the resistance created by keels and eddy-generating devices such as fins, rudders, and other control surfaces.

Specific research into the components of resistance of twin-hulled craft, including the wave interferences between the two demihulls, has been addressed by Insel and Molland [2]. The question of optimizing the hull forms to minimize the resistance was studied by Hsiung and Xu [3]. Hydrodynamic aspects of catamarans were also addressed by Doctors [4]. These references show that great importance has been attached to developing a greater understanding of the mechanics of catamaran resistance.

Current Work

The work to be described here has its origins in a series of collaborative papers by Doctors, Renilson, Parker, and Hornsby [5], Hornsby, Parker, Doctors, and Renilson [6], and Doctors and Renilson [7]. There, both catamarans and a monohull were tested in a towing tank in water of various depths. Attempts to correlate the experimental results for the resistance with the linearized theory were made. It was found that the theory could be used quite accurately to predict the effects of *changes* in the water depth or the spacing between the demihulls of a catamaran. Of course, many other researchers have studied the question of catamaran resistance. For example, Millward [8] also considered the influence of demihull spacing and water depth using a similar theory.

The intention now is to describe a more detailed series of numerical and experimental investigations on a catamaran model in which the concept of using the simple theory to bridge from one test condition to another is examined in detail. In particular, these conditions include the spacing of the two demihulls, the width of the towing tank (representing the width of the river at prototype scale), the depth of the water, and the possible inclusion of sloping river banks. This paper continues and concludes the research on this topic described by Doctors and Renilson [9].

Analytic Work

Linearized Theory

In the current work, the theory of Michell as extended by Srettensky [10] for an infinitely deep canal and by Lunde [11] for a canal of width H and depth d, has been used. That is, the effects of finite water depth *and* lateral restriction on the width of the waterway are included. The formulation has also been presented elsewhere, for example by Doctors and Renilson [9], and will not be repeated here.

The experimental setup is shown in Figure 1. The hull defined by Wigley [12] was used for the tests. The hull has parabolic sections and waterplanes. The local beam is defined by the formula:

$$\mathcal{B} \;=\; B_1[1-(2x/L)^2][1-(z/T)^2]\,, \qquad (1)$$

where L is the length, B_1 is the demihull beam, and T is the draft. Also, x, y, and z are the longitudinal, transverse, and vertical coordinates, respectively. The centreplanes of the two demihulls are located on $y = \pm s/2$, respectively, where s is the spacing between the centreplanes of the two demihulls.

Method of Applying Correction

Two approaches for correcting the resistance (due to

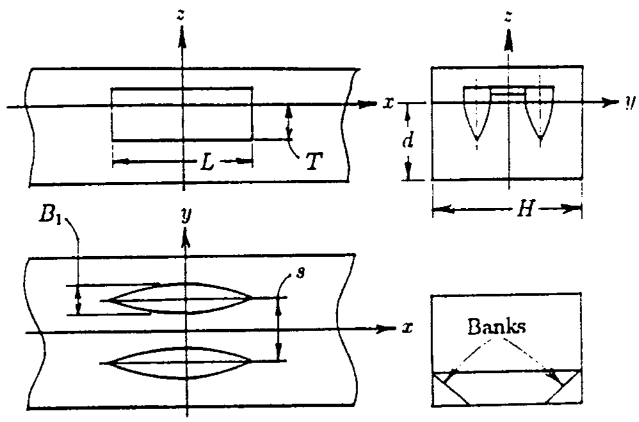

Figure 1: The Wigley Catamaran Model in the Towing Tank

inaccuracies in the theory) for the influence of demihull spacing, waterway width, and water depth were tried. In the first method, the assumption was made that the influence was to alter the *ratio* of the wave resistance. That is:

$$R_W^{\text{Pred.}}(F,s,H,d) = \frac{R_W^{\text{Theory}}(F,s,H,d)}{R_W^{\text{Theory}}(F,s^*,H^*,d^*)} \times \times R_W^{\text{Exp.}}(F,s^*,H^*,d^*) . \quad (2)$$

Here, $R_W^{\text{Pred.}}(F,s,H,d)$ is the improved prediction of the wave resistance for the case of interest, $R_W^{\text{Theory}}(F,s,H,d)$ is the theoretical result for the case of interest, $R_W^{\text{Theory}}(F,s^*,H^*,d^*)$ is the theoretical result for the base case, and $R_W^{\text{Exp.}}(F,s^*,H^*,d^*)$ is the experimental result for the base case. As can be seen in Equation (2), the experiment is done with base values of the demihull spacing s^*, waterway width H^*, and water depth d^*. The prediction for the resistance at different values of the demihull spacing s, waterway width H, and water depth d is computed at the same Froude number F.

The latter is defined in the usual way as

$$F = U/\sqrt{gL} , \quad (3)$$

where g is the acceleration due to gravity and U is the speed of the ship.

In order to be able to effect the prediction using Equation (2), the frictional resistance must first be subtracted. The frictional drag on the model was computed on the basis of the 1957 International Towing Tank Committee (ITTC) formula, described by Lewis [13] (Section 3.5).

In the second approach, the assumption was made that the influence of inaccuracies in the theory was to cause a *shift*, or difference, in the wave resistance. That is:

$$R_W^{\text{Pred.}}(F,s,H,d) = R_W^{\text{Theory}}(F,s,H,d) - - R_W^{\text{Theory}}(F,s^*,H^*,d^*) + R_W^{\text{Exp.}}(F,s^*,H^*,d^*) . \quad (4)$$

It is interesting to note that using typical different formulations for the frictional drag will slightly alter the result given by Equation (2). On the other hand, the result of Equation (4) is *unaffected* by the choice of method for the friction calculation.

Results

Test Cases

The model catamaran was comprised of a pair of Wigley hulls with a length of 1.5 m. The hulls had the standard beam-to-length ratio B/L of 0.1 and the standard draft-to-length ratio T/L of 0.0625. Four different demihull-spacing-to-length ratios s/L, namely 0.2, 0.3, 0.4, and 0.5, were tested.

Two depth-to-length ratios d/L, namely 1 and 0.25, were considered. The towing-tank-width-to-model-length ratio H/L was fixed at 2.333.

For the shallower case of d/L, a series of tests with sloping banks, as indicated in Figure 1, was also conducted. The banks were flat and intersected the towing-tank walls at the undisturbed water surface along their upper edges. At their lower edges, the two banks met the towing-tank bottom along lines which were $H/2$ apart, so that one could argue that the *average* tank-width-to-model-length ratio $\overline{H}/L$ for the experiments with banks was 2.333(1 + 1/2)/2, or 1.75.

The ordinate for all the figures is the wave-resistance coefficient, defined in the usual way, as

$$C_W = R_W/\frac{1}{2}\rho U^2 S , \quad (5)$$

where R_W is the wave resistance, ρ is the water density, and S is the wetted-surface area of both demihulls. The abscissa is the Froude number F.

Test of the Shift Predictive Method

The four parts of Figure 2 each compare the experiments, the theory, and the predictive method, with different demihull spacings, for the case of the greatest depth studied, that is, $d/L = 1$. For the predictive calculations, the base depth d^* and the base tank width H^* for use in Equation (4) were equal to the actual water depth d and the actual tank width H. The base demihull spacing s^* was chosen to be the maximum in the series of tests. For this reason, there is perfect agreement between the predictive method and the experiments in Figure 2(d). Figures 2(a), (b), and (c) show that considerable improvement on the theory is achieved by using the predictive method described here.

Figure 3 shows a similar set of results for the shallower case of $d/L = 0.25$. Once again, it can be observed that there is a considerable advantage in using the predictive method instead of the pure theory, resulting in a much higher accuracy.

The jump in wave resistance, when the depth Froude number, given by

$$F_d = U/\sqrt{gd} , \quad (6)$$

equals unity, is evident. The linear theory predicts a sudden jump in wave resistance given by

$$\Delta R_W = 3W^2/2\rho g H d^2 , \quad (7)$$

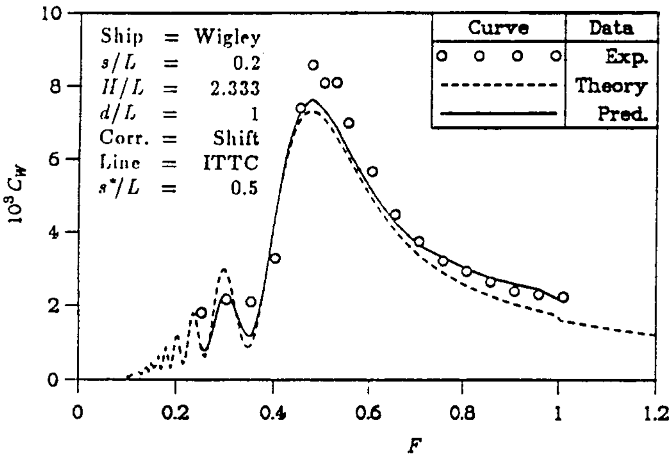

Figure 2: Shift Method at $d/L = 1$ with Walls (a) $s/L = 0.2$

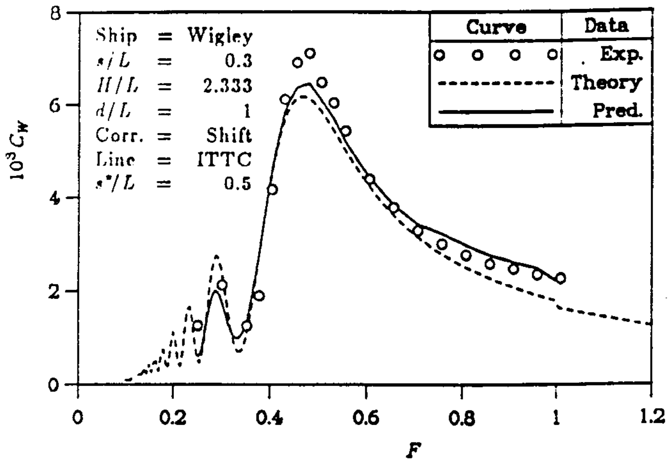

Figure 2: Shift Method at $d/L = 1$ with Walls (b) $s/L = 0.3$

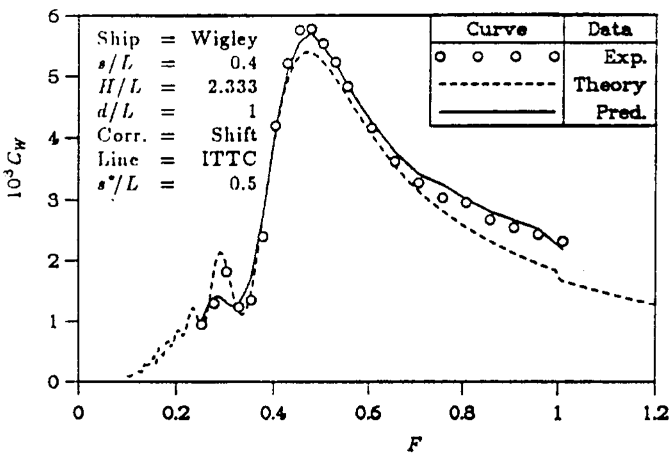

Figure 2: Shift Method at $d/L = 1$ with Walls (c) $s/L = 0.4$

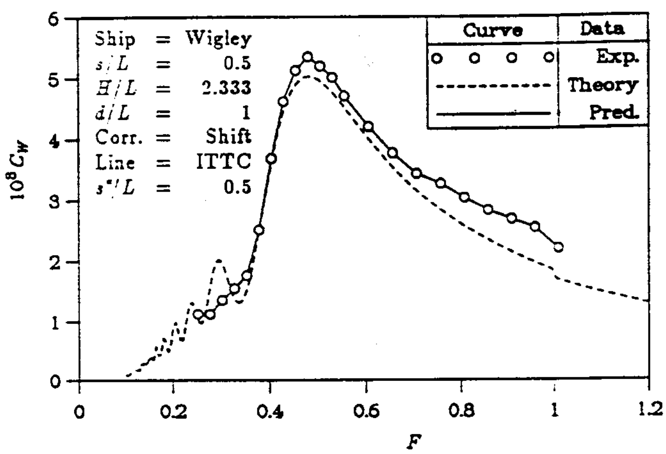

Figure 2: Shift Method at $d/L = 1$ with Walls (d) $s/L = 0.5$

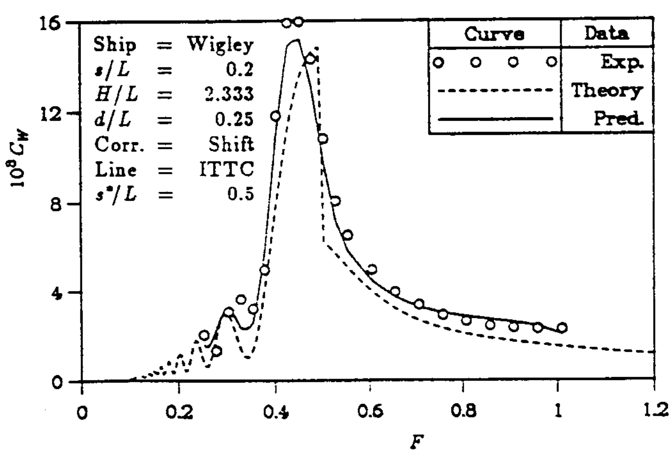

Figure 3: Shift Method at $d/L = 0.25$ with Walls (a) $s/L = 0.2$

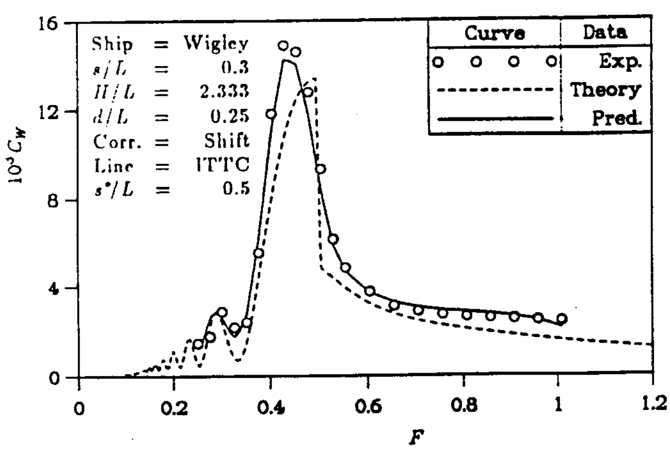

Figure 3: Shift Method at $d/L = 0.25$ with Walls (b) $s/L = 0.3$

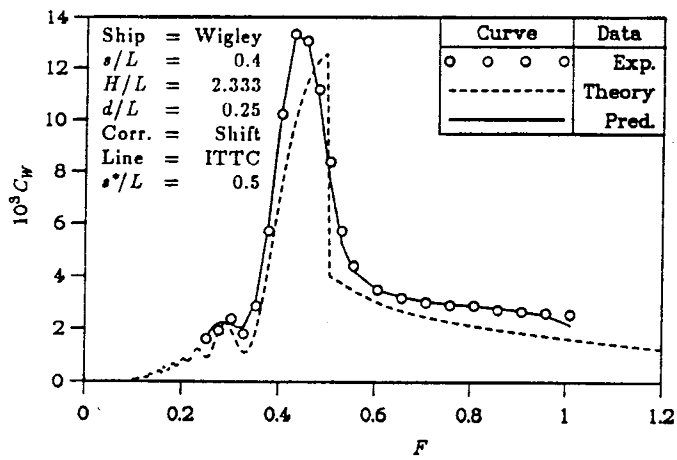

Figure 3: Shift Method at $d/L = 0.25$ with Walls (c) $s/L = 0.4$

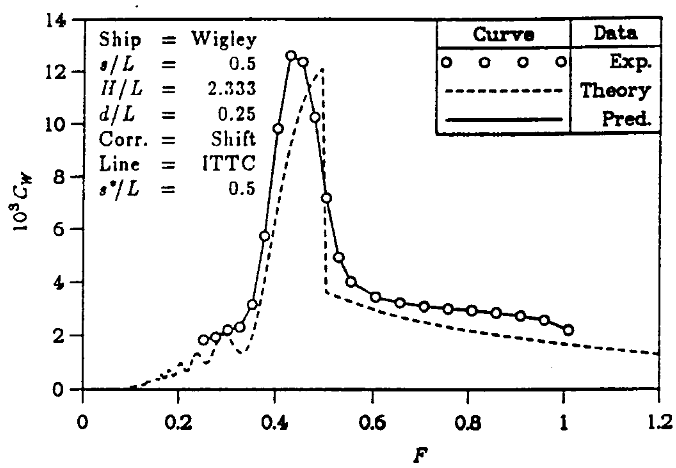

Figure 3: Shift Method at $d/L = 0.25$ with Walls (d) $s/L = 0.5$

where W is the weight of the vessel. It is curious that the magnitude of this jump is independent of the geometry of the vessel.

It is particularly important to emphasize the fact that these somewhat unrealistic sharp jumps are now moderated by the modification to the analysis, producing very realistic predictions at the critical depth Froude number. As already noted in the case of Figure 2(d), the predictive method gives a perfect result in Figure 3(d).

The case of the shallow case with sloping banks is depicted in Figure 4. As the theory used here assumes vertical tank sides, the tank width is taken to be the *average* value, giving $H/L = 1.75$. Again, one can see an excellent improvement using the predictive method. However, the prediction does indicate somewhat low values of the wave resistance at the higher speeds, not apparent in Figure 4; this probably indicates that application of the vertical-wall theory to the case of sloping banks ignores some additional phenomena. Once again, the predictive method gives precise results in Figure 4(d), because the case under consideration is, in fact, the base case.

It should be emphasized in the case of the results plotted in Figure 4, that there are *two* hypotheses under examination. The first is that one can use the theory to bridge from one demihull spacing to another. The second is that the theory, while assuming vertical tank sides, can be used if an average tank width is employed in the formula.

Test of the Ratio Predictive Method

Calculations based on the ratio predictive method are now considered. The method is defined by Equation (2). All the cases shown in the previous Section were recalculated using the ratio method. Most showed almost identical results, except for the following three figures, which indicated less improvement in accuracy.

Thus, the four parts of Figure 5 should be compared with the corresponding four parts of Figure 3. There are now unwanted jumps in the predictions, due to the different starting positions for the jumps in the wave resistance for catamarans with different demihull spacings. Those jumps were not present in the shift method, which is unaffected by this characteristic.

Conclusions

Current Work

The research described here shows that there are very worthwhile gains to be made in the standard wave-resistance theory, by using simple intuitive corrections.

It has also been shown that the shift method is recommended over the ratio method, particularly when considering cases of finite depth, where there are theoretical jumps in the wave-resistance curve. A second reason for opting in favor of the shift method, is that the value of the friction coefficient is not needed at all.

The methods can be used in at least two modes. In the first, they can be used to correct towing-tank data, where one or more values of the demihull spacing, tank width, or tank water depth does not have the desired value. In the second mode, results for other cases for the full-size vessel can be obtained without having to rerun the model tests. In this regard, it should be emphasized that the accuracy is higher for the greater water depths.

Future Work

Future work should be devoted to improving the theory in certain obvious directions. For example, the theory represents the demihulls as simple source distributions. It is clear, however, that when the two demihulls are close to one another, it would be increasingly important to include a transverse dipole distribution on the centreplane of each demihull in order to correctly incorporate the flow curvature effects that the demihulls induce on each other.

From the practical point of view, many high-speed catamarans have transom sterns. The current theory only handles displacement vessels and so it would be very useful to include such forms of vessel.

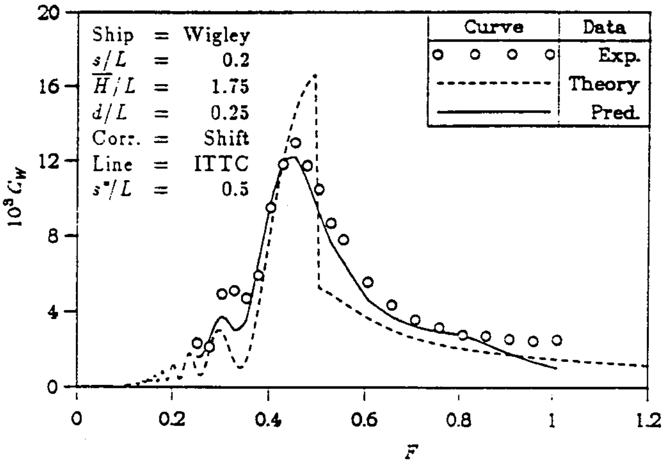

Figure 4: Shift Method at $d/L = 0.25$ with Banks (a) $s/L = 0.2$

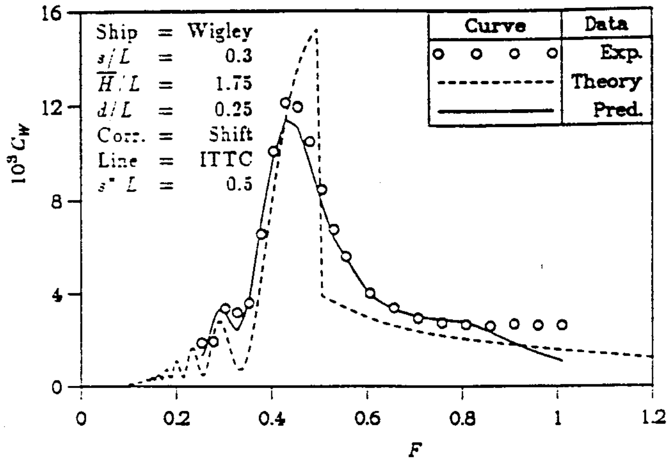

Figure 4: Shift Method at $d/L = 0.25$ with Banks (b) $s/L = 0.3$

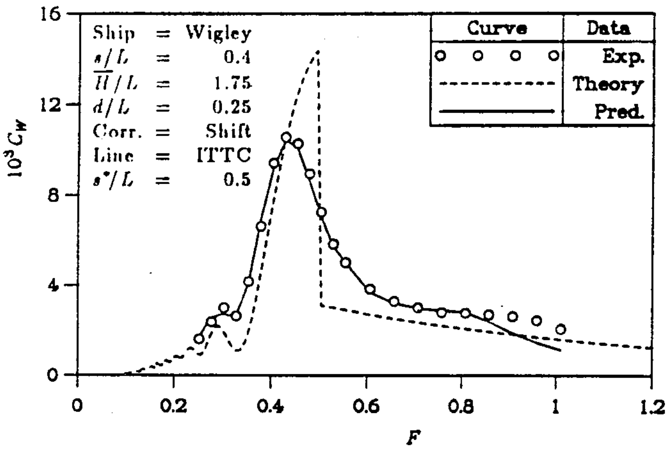

Figure 4: Shift Method at $d/L = 0.25$ with Banks (c) $s/L = 0.4$

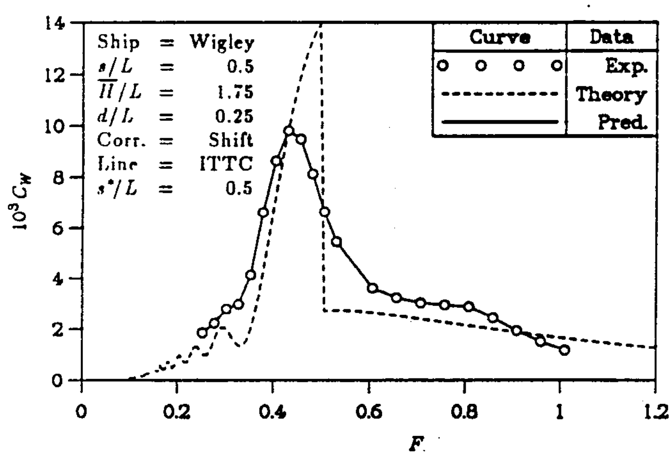

Figure 4: Shift Method at $d/L = 0.25$ with Banks (d) $s/L = 0.5$

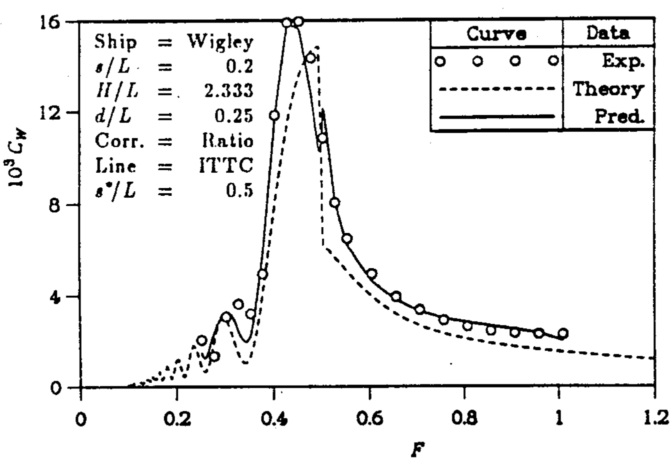

Figure 5: Ratio Method at $d/L = 0.25$ with Walls (a) $s/L = 0.2$

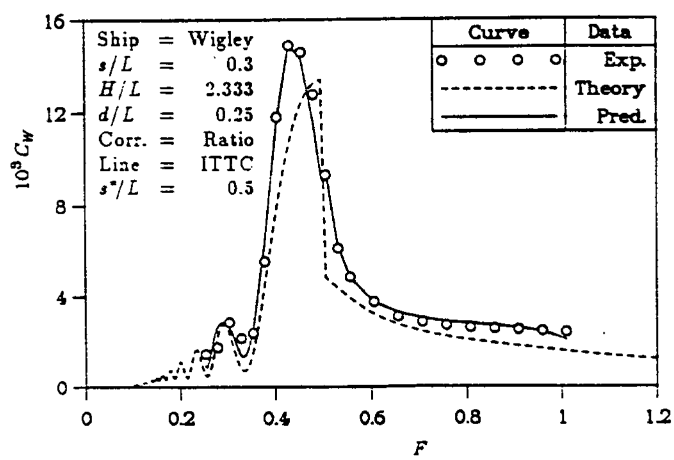

Figure 5: Ratio Method at $d/L = 0.25$ with Walls (b) $s/L = 0.3$

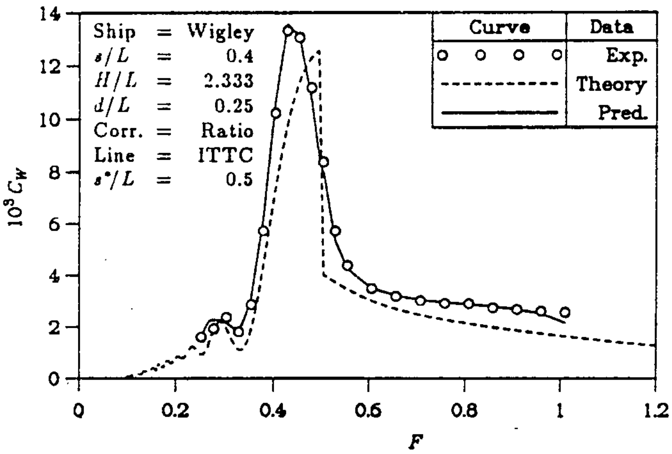

Figure 5: Ratio Method at $d/L = 0.25$ with Walls (c) $s/L = 0.4$

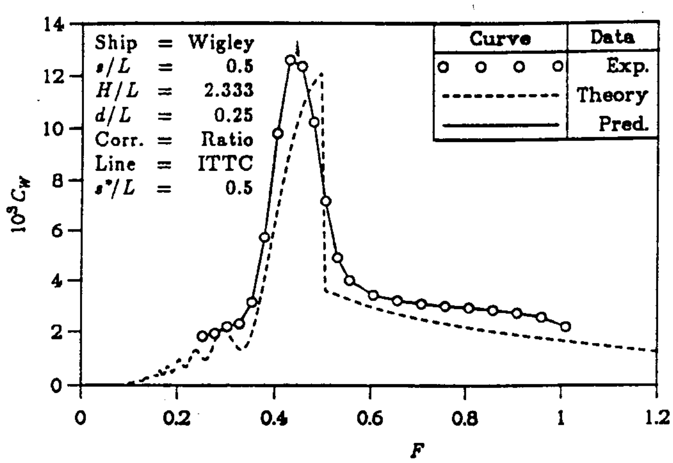

Figure 5: Ratio Method at $d/L = 0.25$ with Walls (d) $s/L = 0.5$

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