Translations of...

THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Naval Architecture and Marine Engineering

TRANSLATIONS OF TWO JAPANESE PAPERS ON CATAMARANS

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Translated by:

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ORA Project 04886

under contract with:

BUREAU OF SHIPS
DEPARTMENT OF THE NAVY
CONTRACT NO. NOBS 4485
WASHINGTON, D.C.

administered through:

OFFICE OF RESEARCH ADMINISTRATION ANN ARBOR

October 1962

ON THE TWIN-HULL SHIP (NO. 1)

Koichi Yokoo
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Report of Transporation Technical Research Institute of Japan,
Vol. 1, No. 1, 1951

INTRODUCTION

As is well known, the resistance of a ship can be divided into frictional and residual parts. Wave-making resistance, which comprises most of the residual resistance, changes with speed in a complex manner due to the interference effect of ship wave systems, hence the characteristic humps and hollows.

For a twin-hull ship, the change in wave-making resistance becomes even more complex. It is conceivable that the reduction in wave-making resistance, which can be brought about either by a favorable interference effect or by a reduction of beam of a hull[1] by dividing the required displacement into two hulls, could offset the increase in frictional resistance.

There have already been several twin-hull ships built,[2,3] and theoretical studies[4,5] as well as experimental studies[6] have been conducted. But a satisfactory conclusion on wave-making characteristics is lacking.

Currently, at the ship propulsion division of the Transportation Technical Research Institute, Japan, merits of twin-hull ships are under study. One phase of that study, theoretical calculations and experiments, has now been completed and the results are presented herein.

THEORETICAL CALCULATIONS

First, relationships between the length of the ship, distance between two hulls and ship speed were investigated. Using the results, resistances of a single-hull ship and a twin-hull ship, of simple hull form, were compared at the same ship length, draft, and displacement.

a) As a first approximation, wave resistance of a twin-hull ship can be obtained by superimposing velocity potentials[7] or free wave patterns[8,9] obtained for a single ship hull assuming that the boundary conditions are not disturbed by the presence of the other hull.

Nomenclature:

L = length of the ship

$2k$ = centerline distance between the two hulls

$k_o = g/C^2$; g = gravitational constant C = ship speed

F = Froude number $= C/\sqrt{gL} = 1/\sqrt{k_o L}$

R_{2W} = wave resistance of twin-hull ship

R_{OW} = wave resistance of one hull of the twin-hull ship

$2R_W$ = increase in wave resistance of twin hull ship due to the interference effect of the wave systems of the individual hulls

$m(\xi,\eta,\zeta)$ = strength of the source field (flow per unit time) distributed along a suitable surface, S, the hull surface being formed when a uniform flow is superimposed on the singularity distribution.

As defined above and from Fig. 1

$$R_{2W} = 2R_{OW} + 2R_W \qquad (1)$$

where

$$R_{OW} = \frac{k_o^2 \rho}{2\pi} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} (P^2 + Q^2) \sec^3 \theta \, d\theta$$

$$R_W = \frac{k_o^2 \rho}{2\pi} \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \cos (2k_o \; k \sec^2 \theta \sin \theta)(P^2 + Q^2) \sec^3 \theta \, d\theta$$

$$\begin{matrix} P \\ Q \end{matrix} = \iint_S m(\xi,\eta,\zeta) e^{k_o \zeta \sec^2 \theta} \begin{matrix} \cos \\ \sin \end{matrix} \left[k_o \sec^2 \theta \; (\xi \cos \theta - \eta \sin \theta) \right] d\theta$$

If $m(\xi,\eta,\zeta)$ is distributed along the surface ξ-ζ, the above is simplified to

$$R_{2W} = 2R_{OW} + 2R_W \tag{2}$$

where

$$R_{OW} = \frac{k_o^2 \rho}{\pi} \int_0^{\frac{\pi}{2}} (P^2 + Q^2) \sec^3 \theta \, d\theta$$

$$R_W = \frac{k_o^2 \rho}{\pi} \int_0^{\frac{\pi}{2}} \cos (2k_o \; k \sec^2 \theta \sin \theta)(P^2 + Q^2) \sec^3 \theta \, d\theta$$

$$\begin{matrix} P \\ Q \end{matrix} = \int_0^{\infty} d\zeta \int_{-\infty}^{\infty} m(\xi,0,\zeta) e^{k_o \zeta \sec^2 \theta} \begin{matrix} \cos \\ \sin \end{matrix} (k_o \; \xi \sec \theta) d\xi$$

Normally, the integration of the above equations is done graphically using curves of $(P^2 + Q^2)$ and $\cos (2 k_o k \sec^2 \theta \sin \theta)(P^2 + Q^2)$ for particular values of k_o and k.

First, however, certain properties of R_W can be noted. The curve of $(P^2 + Q^2)$ varies with hull form, some general characteristics being shown in Figs. 2 (a), (b), and (c). A hump in curve (a) corresponds to that of $(P^2 + Q^2)$

shown in curve (b), and a hollow, likewise, corresponds to that in curve (c). Since the curve of cos ($k_0 k \sec^2 \theta \sin \theta$) varies as shown in Fig. 2 (d), the negative resistance in R_w corresponds to the shaded areas in the figure. The minimum value of R_w occurs approximately when the maximum amplitude of the ($P^2 + Q^2$) curve for the hollow condition coincides with the first minimum amplitude of the curve of cos ($2k_0 k \sec^2 \theta \sin \theta$). At hump speeds, R_w is always positive. For large values of $2k_0 k$, or for large k or small F (from $k = 1/F^2L$), the so-called rapidly varying zone in the curve of cos ($2k_0 k \sec^2 \theta \sin \theta$) starts from small values of θ, and it can be seen that the interference effects are small. For k = 0 the twin-hull becomes a single hull with a doubled distribution of $m(\xi,\eta,\zeta)$ and the wave resistance increases by a factor of four.

For wave lines of the cosine type, the values of k and k_0 or F, for which the smallest negative resistance exists are:

F	.564	.326	.252	.213
$\frac{2k}{L}$	.274	.284	.252	.261

Hence, the distance between the two hulls is 0.25 to 0.28. The humps and hollows of one hull in twin-hull ships coincide with those of the twin-hull ship itself. In these cases, the hollows correspond to the minimum wave resistance.

From physical point of view, the above result of $2k/L \doteq 0.3$ may be explained as shown in Fig. 3. The cusp of the bow wave of one hull fits the stern of the other hull and the humps and hollows of the twin-hull ship occur as does the transverse wave system of one hull only. The interference effect, therefore, becomes pronounced at these humps and hollows. Thus the theoretical findings are explained.

b) In the above, some general characteristics of resistance of twin-hull ships have been investigated. Next, assuming a simple linear distribution of $m(\xi,\eta,\zeta)$:

$$\begin{aligned} m(\xi,\eta,\zeta) &= m(\xi,0,\zeta) \\ &= 4\,\frac{B}{L}\,\xi = a_1\,\xi \end{aligned} \tag{3a}$$

when

$$-\frac{L}{2} \leq \xi \leq \frac{L}{2}$$

$$\eta = 0$$

$$-T \leq \zeta \leq 0$$

$$m(\xi,\eta,\zeta) = 0 \tag{3b}$$

when

$$-\frac{L}{2} \leq \xi \leq \frac{L}{2}$$

$$\eta \neq 0$$

$$\zeta < -T$$

and integrating as in Eq. (2) for $T/L = t = 0.1$, the result R_W/R_{OW} is as shown in Figs. 4 and 5, plotted against $2k/L$ and k_oF. These exhibit the characteristics described in the previous section.

If the above source distribution is to represent a hull form in the context of the Michell Theory, the hull form appears as

$$\eta = \frac{4B}{L}\left(\frac{L}{8}\right) - \frac{\xi^2}{2}$$

when

$$-\frac{L}{2} \le \xi \le \frac{L}{2} \qquad (4a)$$

$$-T \le \zeta \le 0$$

$$\eta = 0$$

when

$$\xi < \frac{L}{2}, \qquad \frac{L}{2} < \xi, \qquad \zeta < -T \qquad (4b)$$

For $4B/L = a_1 = 0.4$ and 0.8, and $t = 0.1$, the total resistance, obtained by adding the frictional resistance to the calculated wave-making resistance, is shown in Fig. 6. In the figure, R_1 is the total resistance for a single-hull ship ($a_1 = 0.8$) of the same length, displacement, and draft as the twin-hull ship, and R_2 is that of the twin-hull ship ($a_1 = 0.4$).

From the above, it can be seen that for a suitable distance between the two hulls, the total resistance of the twin-hull ship is less than that of the single-hull ship for speeds above 1.0 m/sec ($F = 0.23$). In the calculation, if the exact hull surface condition such as Inui's is applied, R_{2f} and R_{1f} will vary slightly, but it seems possible to have ranges of lower total resistance for a catamaran compared to a single-hull ship for speeds above 1.3 m/sec ($F = 0.30$).

c) Summing up, one can see that the humps and hollows become severe in catamarans, and at relatively high speeds it may be possible to compensate for the increase in frictional resistance if the distance between the two hulls is chosen suitably ($2k/L = 0.25 \sim 0.29$).

Also to be considered are the interference effects of draft, the ability of the flow to pass between the hulls, and the attraction and repulsion between the hulls. These will be left to some future studies.

EXPERIMENTAL RESULTS

Detailed results of experiments currently being conducted will be available in the next report. Partial results of experiments on half-body hulls are given in the following:

a) Model principal dimensions, coefficients and lines are given in Fig. 7. For twin-hull ships, hull forms in Fig. 7 cut into half longitudinally and separated a suitable distance are used.

b) Experimental results are shown in Fig. 9. Frictional resistances were subtracted from the total resistance by Froude's method and residual resistances were obtained as shown in Fig. 10. Trim and heave were also measured, but they have been omitted from the report.

As can be seen from Fig. 9., for increasing values of distances ℓ and ℓ' the resistance curve of ℓ group approaches that of the largest ℓ from the lower side and the resistance curve of ℓ' group approaches from the upper side.

It is noted from Fig. 10 that the minimum resistance occurs for $\ell = 0$. The resistance increases rapidly with increasing values of ℓ, and the residual resistance coefficient for large values of ℓ and ℓ', which may be regarded as twice that of the half-body hull alone, is larger than that for the symmetrical hull by the approximately constant amount, 0.005. This may have resulted from induced resistance of a non-symmetrical hull form or from a change in the wave-making phenomenon. Details of this fact will be studied further both theoretically and experimentally.

For ℓ group, the interference effect is small as expected, but for ℓ' group the interference phenomenon is very pronounced. Although other humps and hollows are present because of nonsymmetry and other factors the general tendency is similar to theoretical expectations.

It is somewhat premature to make conclusions without clearer knowledge about the resistance characteristics of non-symmetrical hull forms, but from this experiment, presently it seems obvious that the use of half-body hull forms of this type for the purpose of reducing the resistance of a twin-hull ship is not advantageous.

CONCLUSIONS

Because of convenience in the schedule, twin-hull ships of half-body hull forms were tested for resistance, and, as described, unexpectedly large resistances were measured. Until the current studies on wave-making characteristics of non-symmetrical hull forms are completed, it is somewhat premature to make conclusions, but this type of hull form does not seem to be advantageous for a twin-hull ship from the resistance point of view.

Experiments on ship forms for which calculations have been made are being planned. The results will be given in the next report together with the results of theoretical studies of non-symmetrical hull forms.

The authors would like to thank Professor Masurao Yamagata, who has given valuable guidance and Assistant Professor Takao Inui, both of Tokyo University, who has given various calculation materials.

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(2) Saller: "Russisches Expussgleitboat," *Werft Reederei Hafen 1940*, Sept., 1 S. 224.
Russian Highspeed Craft
L = 24m, B = 3.76m, T = 1.4m (still water)
The above hull is separated 8m ℄ to ℄. Total beam 11.76m. Passengers 125, Crew 12, 675 HP.
Service speed 60~70 Km/HR
32.4~37.8 KTS.
F: 1.09~1.27
Operates between Kurarteu Sotschi and Suchum (120 Km), Black Sea.

(3) "Tunnel hull boat, Venturi," designed by Garwood, 180' x 40'(57.3m x 12.2m), Prop. 4-1/2', draft at the stem 8', 4 Pancake diesels total 4800 HP.

(4) Havelock, T. H.: "Wave resistance—the mutual action of two bodies," *Proc. Roy. Soc.*, Ser. A, *155* (1936) 460.

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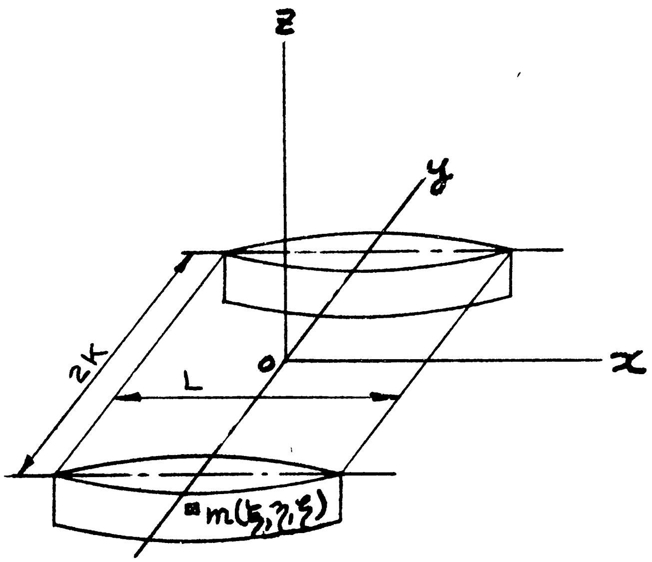


Fig. 1. Coordinate system

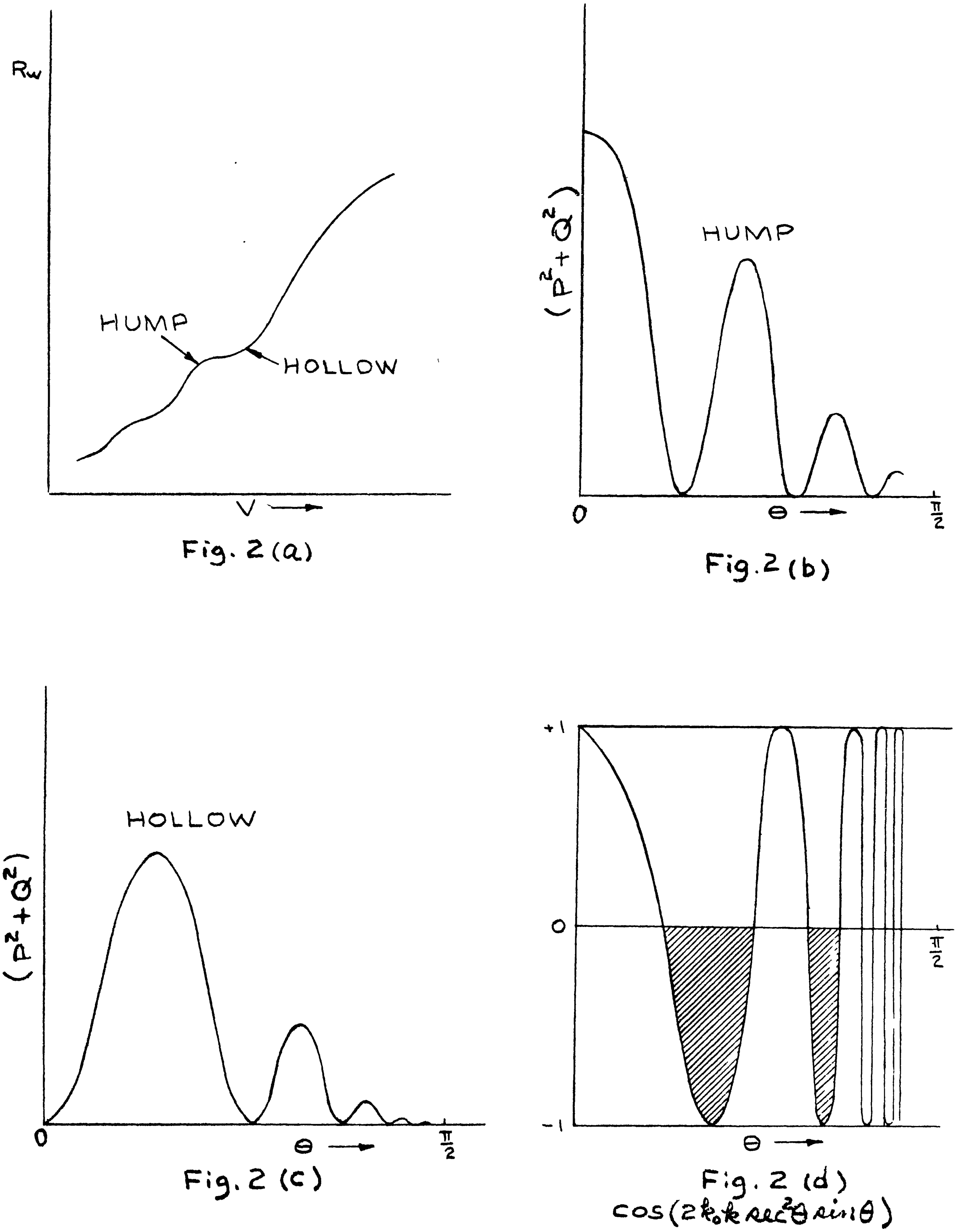


Fig. 2. Components of wave resistance for constants k_o and k.

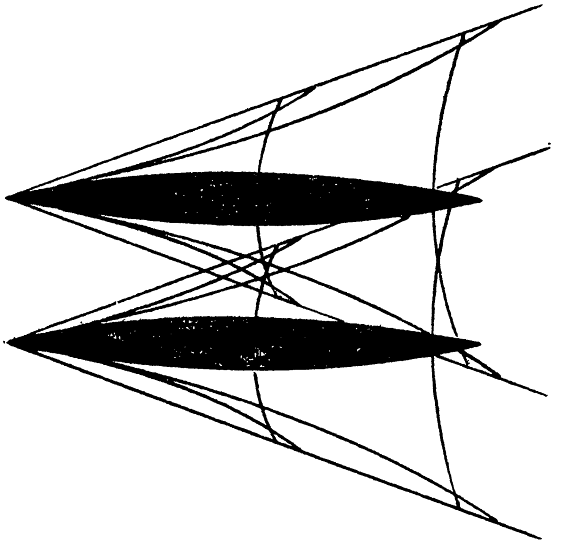


Fig. 3. Bow wave pattern in catamaran.

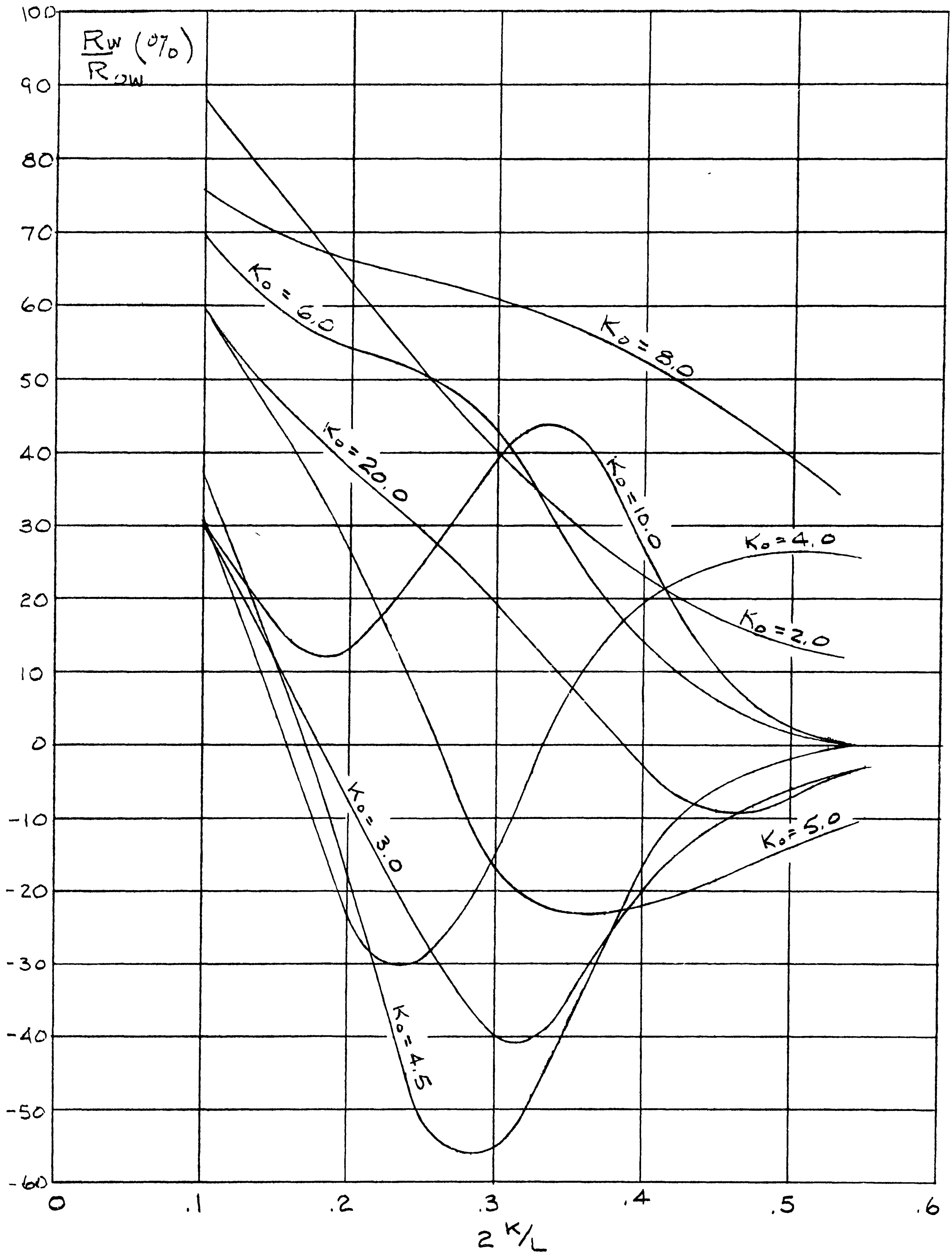


Fig. 4. Interference term plotted against the distance parameter 2k/L.

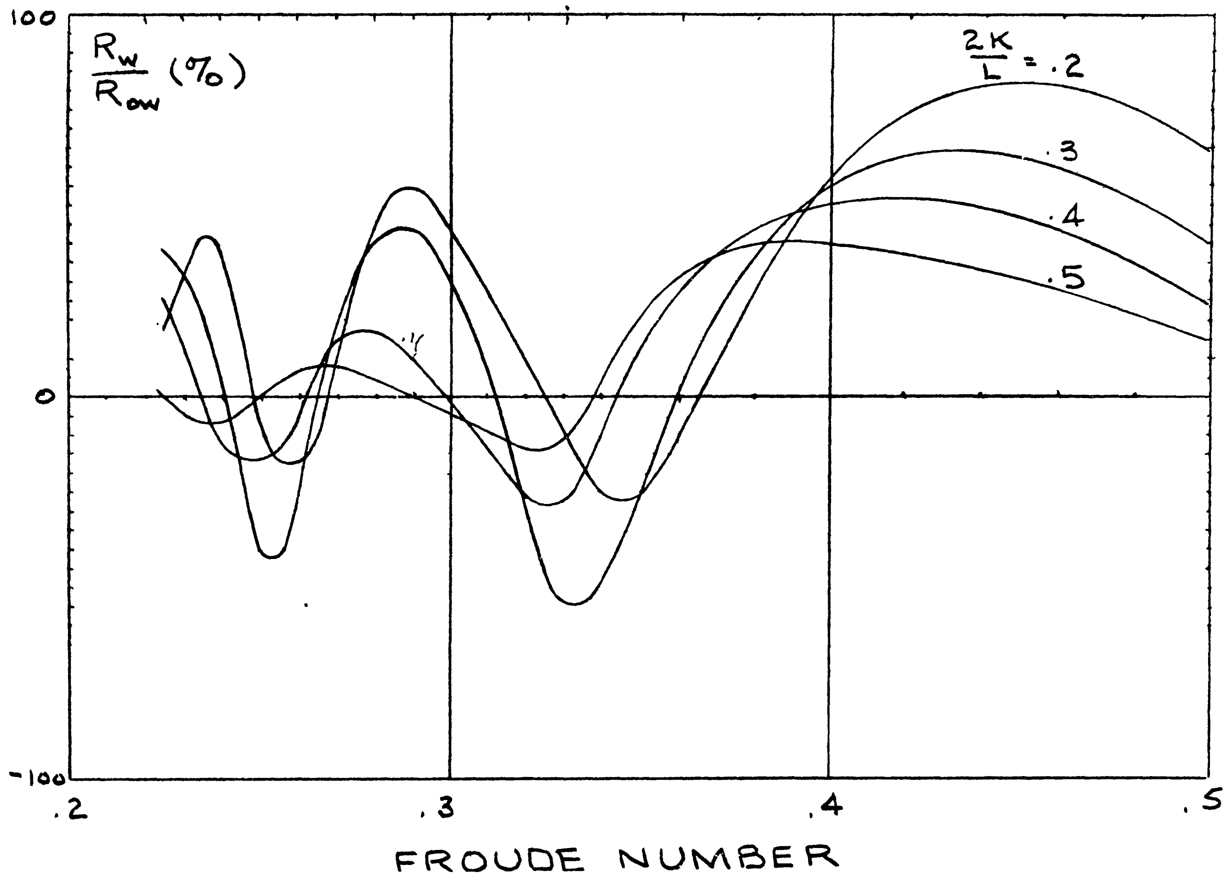


Fig. 5. Interference term plotted against the Froude number.

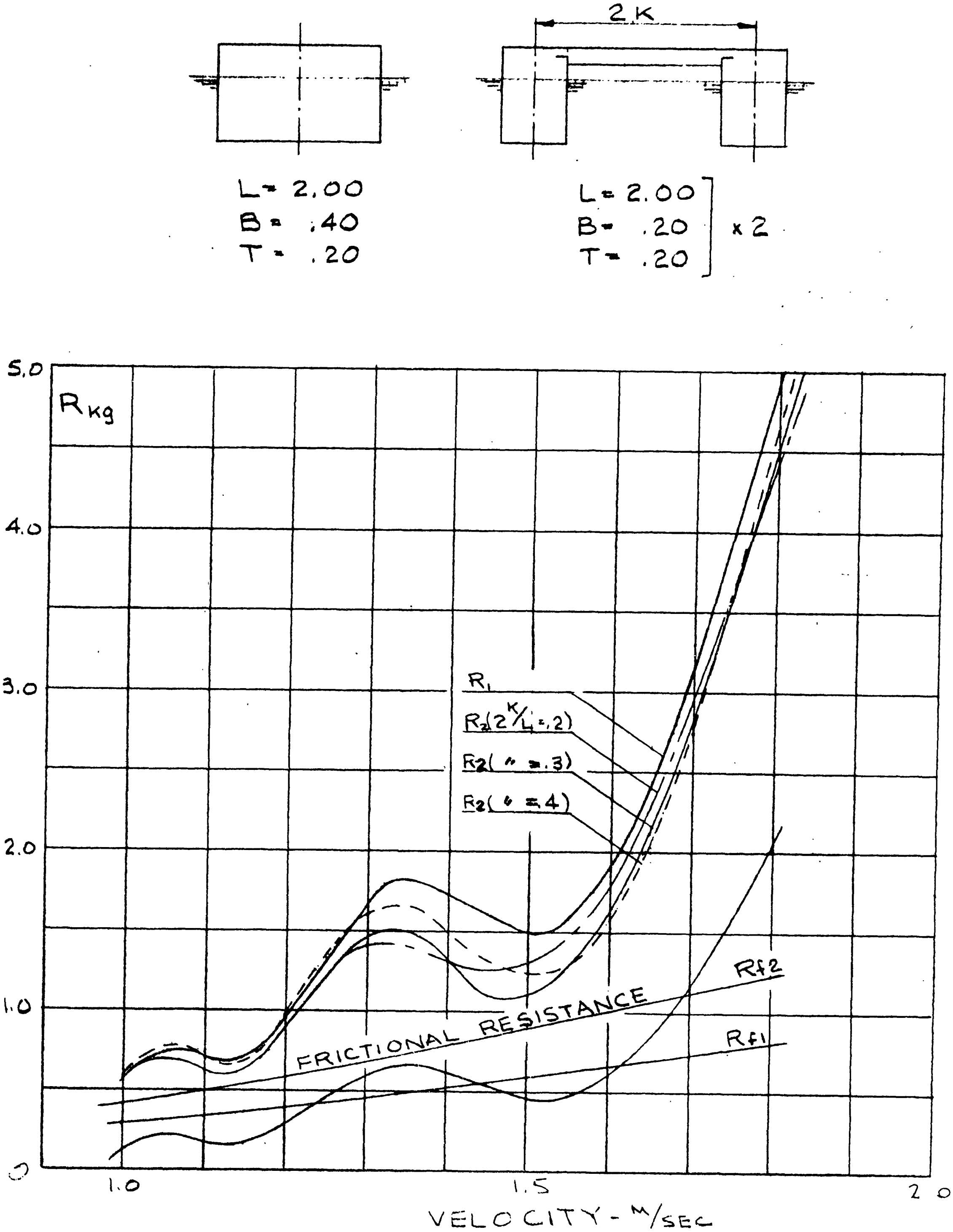


Fig. 6. Total resistance.

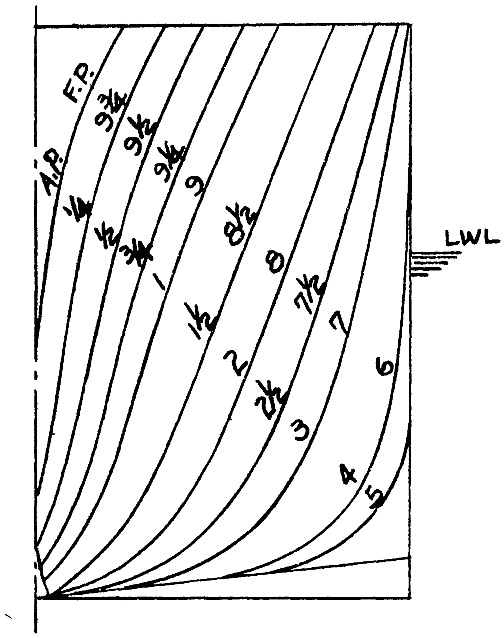


Fig. 7. Model principal dimensions and lines.

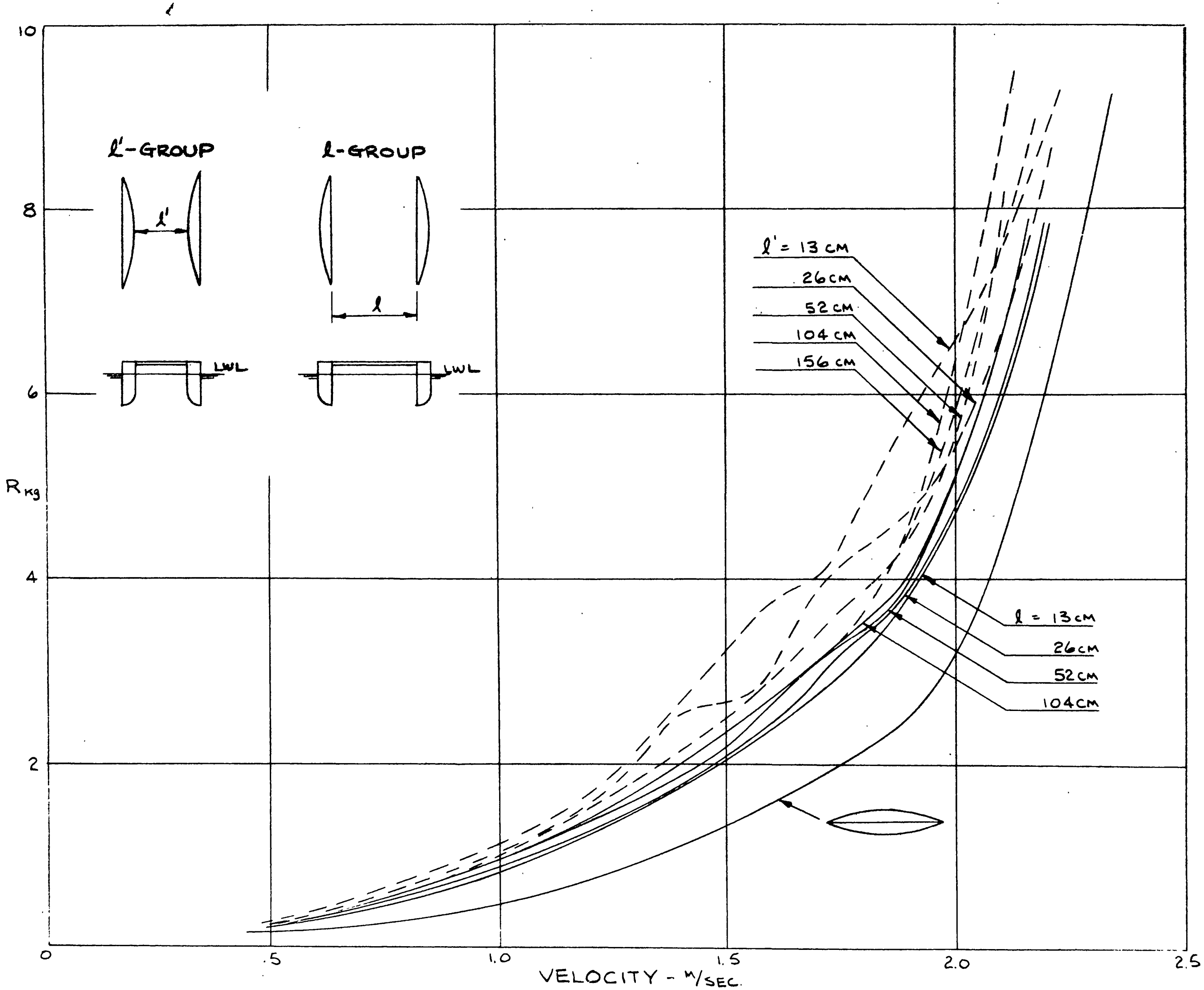
$L = 3.00$ m $\Delta = 0.2093$ m^3

$B = 0.520$ $\delta = 0.545$

$T = 0.240$ $\rho = 0.601$

$\beta = 0.907$

(Symmetrical fore and aft)



Figs. 8-9. Total resistance curves ℓ and ℓ' group.

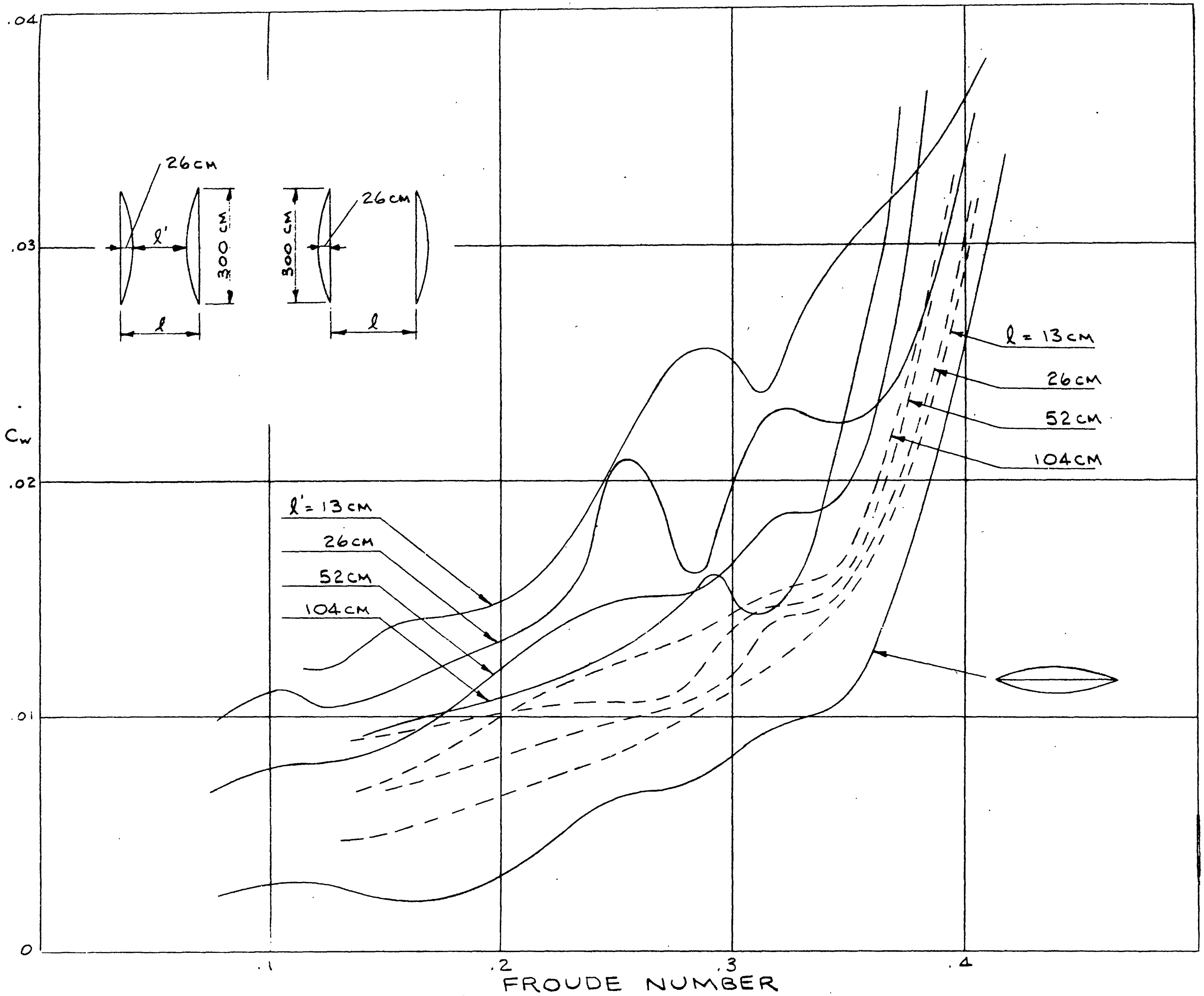


Fig. 10. Curves of residual resistance coefficients.

AU

ON THE TWIN-HULL SHIP (NO. 2)

Koichi Yokoo
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Report of Transporation Technical Research Institute of Japan,
Vol. 3, No. 3, 1953

INTRODUCTION

Theoretical calculations as well as experimental results on non-symmetrical hull forms of twin-hull ships have already been described in Report No. 1. The theoretically expected advantage of twin-hull ships was not exhibited in that experiment, and for all speed ranges, resistance increased. In order to show this increase theoretically, it is necessary to study non-symmetrical hull forms in more detail. But, conducting experiments with symmetrical hull forms will not only give a check on theoretical predictions, but also it will provide valuable data on hull forms of twin-hull ships. In this report, experimental results on twin-hull ships with symmetrical hull forms and the related calculations are presented.

THEORETICAL CALCULATIONS

In the first report calculations were carried out for $T/L = 1/10$, but in this report $T/L = 1/20$ has been added in order to show the draft effects. These are shown in Figs. 1 and 2.

If the source distribution is to represent a hull form according to the Michell theory, it must be as given in Figs. 2 and 3. For the frictional resistance calculation, the Prandtl - Schlichting formula

$$C_f = \frac{0.455}{(\log_{10} R)^{2.58}} ; \qquad R = \frac{VL}{\nu} ; \qquad 23°C$$

has been used. R_W/R_{OW} corresponding to Fig. 5 of Report No. 1 is shown in Fig. 3.

EXPERIMENTAL RESULTS

To check with theoretical calculations on hull forms with port and starboard symmetry, Professor Inui's theoretical hull form was used for this experiment. The results correspond to $T/L = 1/20$ in previous calculations.

Principal dimensions and lines drawing of the model are shown in Fig. 4. Since the theoretical hull form is used, the beam of a conventional ship is actually less than twice the beam of one hull of the twin-hull ship. Draft is slightly deeper, but displacement is approximately twice.

Experiments were conducted for $2k/L$, the ratio of distance between two hulls to the length, equal to 0.2, 0.3, 0.4, 0.5 and ∞, and for one-hull ship. For $2k/L = \infty$, twice the resistance of one hull of the twin-hull ship was used. Since models were small, a trip wire of 0.9 mm diameter was used at station 9-1/2. Result is shown in Figs. 5 to 9.

Resistance and resistance coefficient are shown in Figs. 5-8, and in Fig. 9 are shown resistance increase, R_{2W}, which are obtained by subtracting the resistance value for $2k/L = \infty$ from those for various $2k/L$.

DISCUSSION ON RESULTS

The following may be said from the result of the experiments on symmetrical hull forms. Since wave-making resistance of the conventional hull showed a lower value than calculated, the expected amount of reduction was not obtained. The resistance of twin-hull ship with $2k/L$ larger than 0.3 at the hollow speed $F \doteq 0.3$ becomes almost equal to or less than that of the conventional hull form. But the speed range in this case was found to be limited.

For both R_{OW} and $2R_W$ the theory predicts the occurrence of the humps and hollows at a somewhat slower speed, and the magnitude of the humps and hollows is predicted to be somewhat greater than that exhibited by the experimental results. Resistance increase R_W due to the mutual interference did not become negative except in the case of $2k/L = 0.4$. This shows that it cannot be expected to reduce the resistance by interference. Therefore, reduction in resistance of a twin-hull ship must be accomplished by the effect of the reduction in beam. Also, noted was the fact that humps due to the interference were greater than calculated. The minimum wave resistance increase due to the interference $2R_W$ for $2k/L = 0.3$ occurred at speed corresponding to the hollow for one hull only as has been predicted in Report No. 1.

The tendency of total resistance curves agrees relatively well with calculated ones if the interference term is subtracted . This proves that the theoretical calculation is confirmed by the experiment and that the mutual interference can be calculated by the approximate method explained in the previous report.

For values of $2k/L$, damping of wave systems may exist. In general, at $2k/L = 0.4$, the best agreement was observed.

CONCLUSION

Detailed study on unsymmetrical hull form is lacking, and therefore it is not possible to explain the causes of the poor result obtained for the non-symmetrical twin-hull ship. But based on the experimental results in Report No. 1, it is hard to recognize the advantage of twin hull forms in the normal speed range, F = 0.15-0.5. For symmetrical hull forms, the conventional hull form used had twice the sink source strength and hence the beam was slightly less than twice the beam of one hull of the twin-hull ship. It is conceivable that the resistance of the conventional hull would increase beyond the values found in this experiment if the draft and the displacement were kept equal. Then, it may be possible to find further advantages of twin-hull ships, but in any case it is expected that the useful speed range would be limited.

ACKNOWLEDGMENT

Mr. James L. Moss has been most helpful in preparing the translation. The translator expresses his sincere thanks.

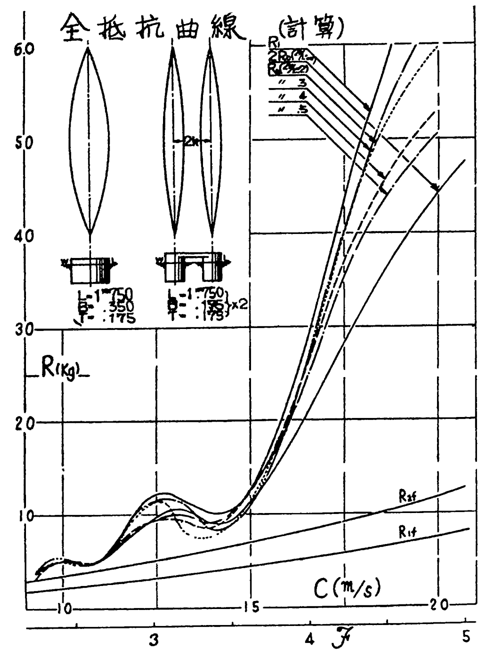

Fig. 1. Total resistance (calculated). F, Froude number; C, speed in m/sec; R, resistance in kg.

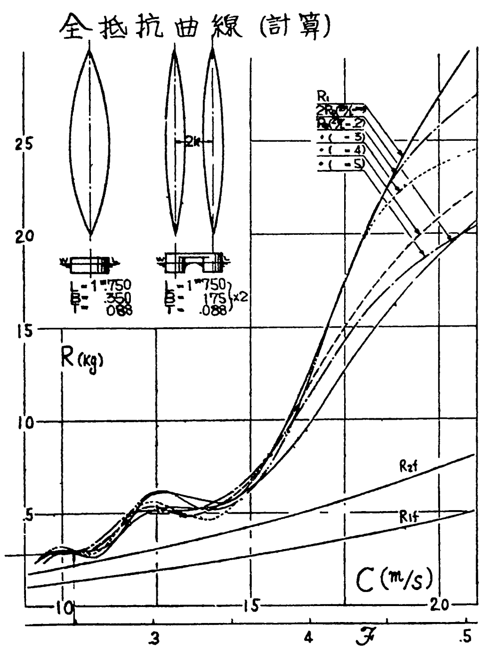

Fig. 2. Total resistance (calculated)

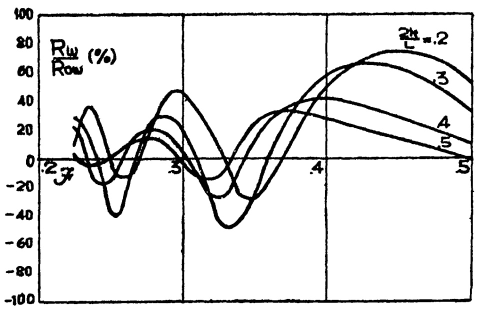

Fig. 3. Interference term for various 2k/L plotted against Froude number.

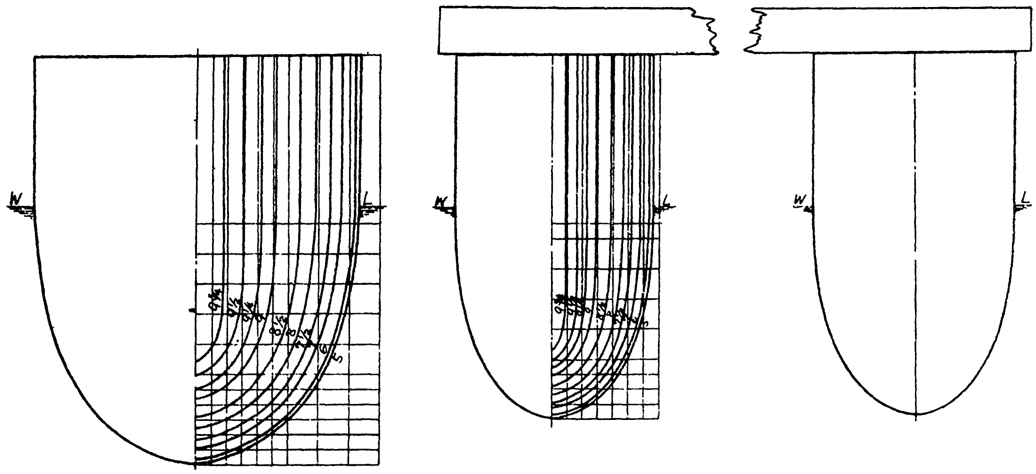

Fig. 4

Conventional Hull

L = 1.750 m
B = 0.215
T = 0.088 AP & FP
0.171 ⊗
∇ = 0.03412 m^3
W.S. = 0.6414 m^2
C_B = 0.529
a_1 = 0.8
t = 2T/L = 0.1
Trip wire:
0.9 mm dia x 25.5 cm
at 9-1/2 station

Catamaran
(Dimensions for one hull only)

L = 1.750 m
B = 0.130
T = 0.087 AP & FP
0.141 ⊗
∇ = 0.01729 m^3
W.S. = 0.5052 m^2
C_B = 0.540
a_1 = 0.4
t = 2T/L = 0.1
Trip wire:
0.9 mm dia x 22.0 cm
at 9-1/2 station

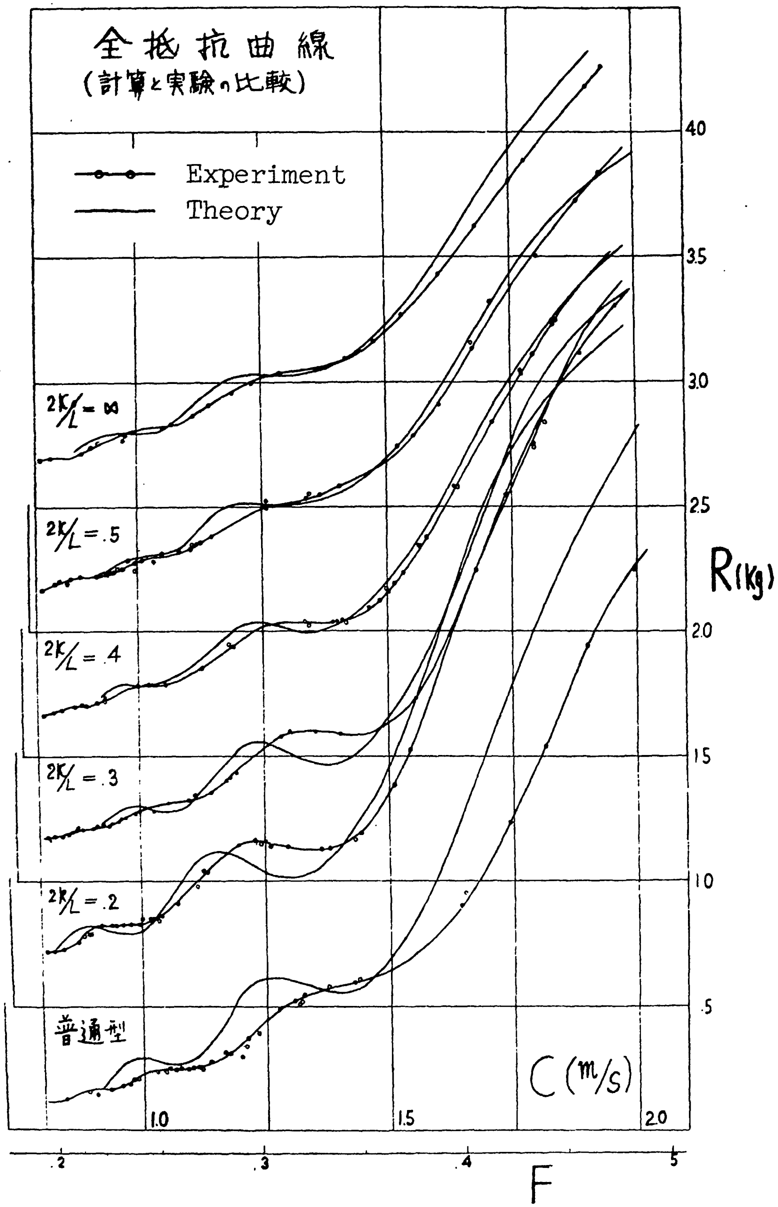

Fig. 5. Total resistance curves (comparison between theory and experiments). Lower most curves are for conventional hull.

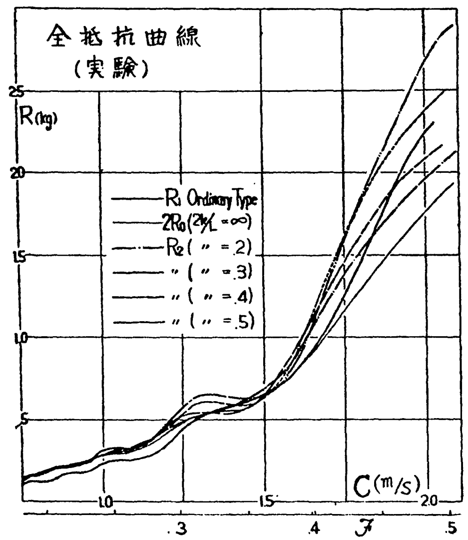

Fig. 6. Total resistance curves (experiment).

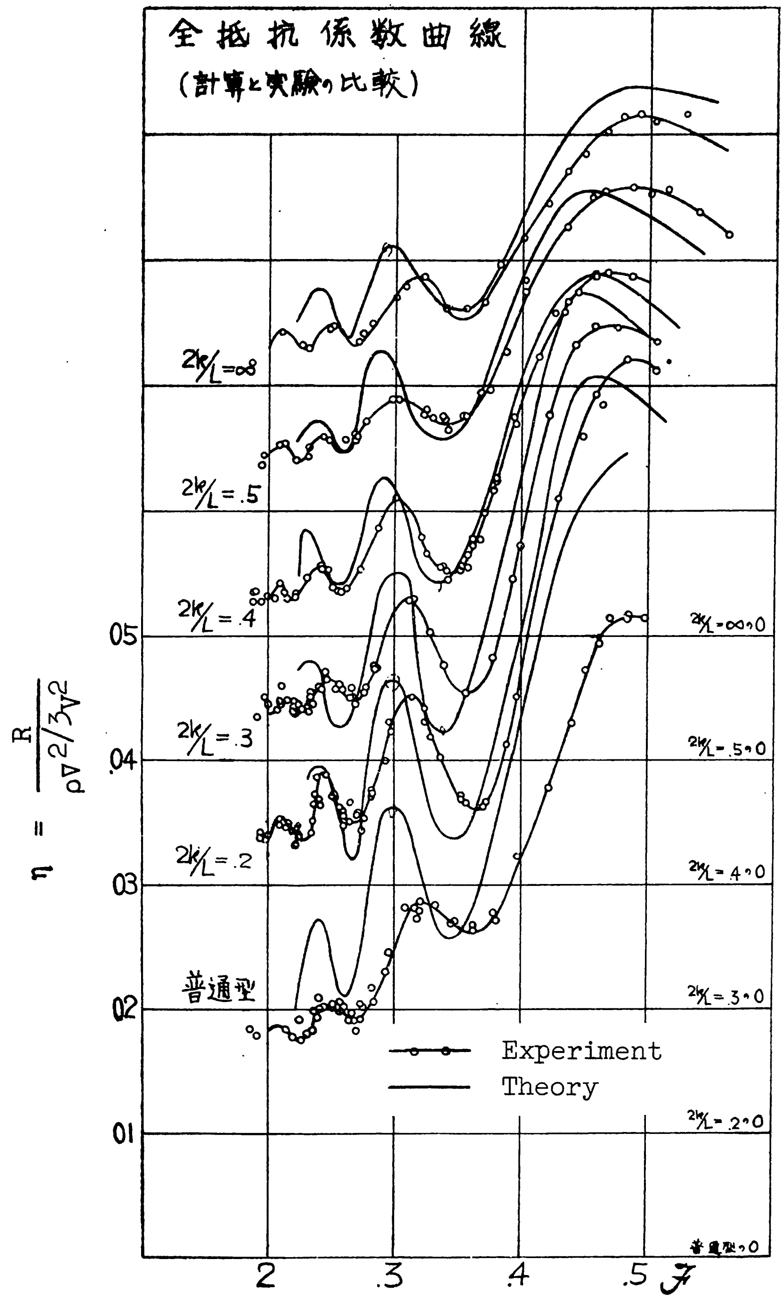

Fig. 7. Total resistance coefficients curves (comparison between theory and experiments). Lower most curves are for conventional hull.

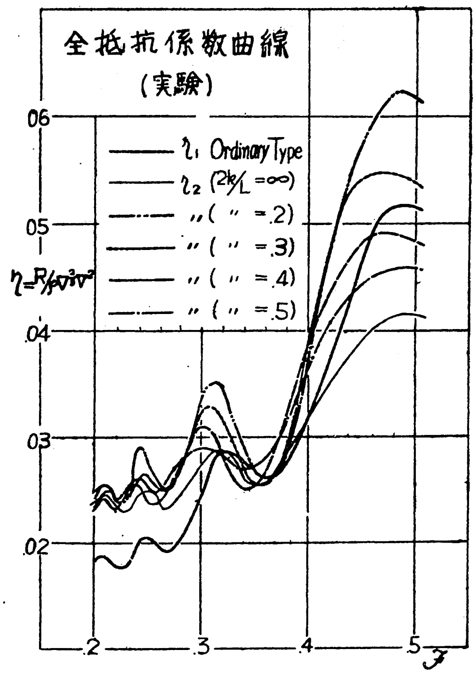

Fig. 8. Total resistance coefficients curves (experiment).

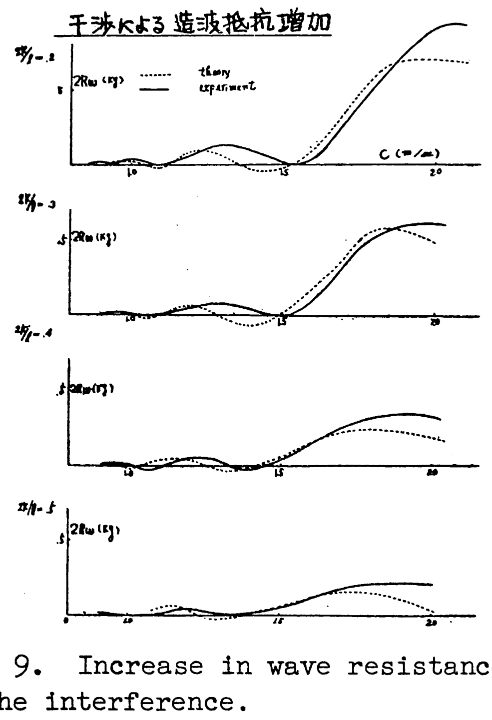

Fig. 9. Increase in wave resistance due to the interference.