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

Technical Report

WAVE-MAKING RESISTANCE INTERFERENCE EFFECTS ON A CATAMARAN MODEL

R. Tasaki
T. Takahei
J. L. Moss

Project Director: R. B. Couch

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

March 1963

CONTENTS

		Page
I.	Introduction	1
II.	Models and Test Procedure	2
III.	Test Results	5
IV.	Conclusions	10
	References	12
	Table I	13
	Figures	14

FIGURES

Figure

1. Pounds residual resistance per ton displacement from Taylor Standard Series.

2. Pounds residual resistance per ton displacement from Taylor Standard Series.

3. Pounds residual resistance per ton displacement from Taylor Standard Series.

4. Lines of single hull.

5. Total model resistance for light displacement condition.

6. Increase in wave-making resistance due to interference. Light displacement condition.

7. R_w/R_{ow} (%) versus Froude number and speed-length ratio for light displacement condition.

8. R_w/R_{ow} (%) plotted against the spacing parameter, k. Light displacement condition.

9. Total model resistance for heavy displacement condition.

10. Increase in wave-making resistance due to interference. Heavy displacement condition.

11. R_w/R_{ow} (%) versus Froude number and speed-length ratio for heavy displacement condition.

12. R_w/R_{ow} (%) plotted against the spacing parameter, k. Heavy displacement.

13. Separation of resistance increase due to interference into two terms. Light displacement condition.

14. Variation with spacing of the two terms of resistance increase due to interference. Light displacement condition.

15. Separation of resistance increase due to interference into two terms. Heavy displacement condition.

16. Variation with spacing of the two terms of resistance increase due to interference. Heavy displacement condition.

I- INTRODUCTION

Reported herein are resistance test results for a catamaran displacement hull the lines of which were conceived employing conventional hull design considerations. The hull was tested at two displacements and various spacings, the data being reduced with emphasis on wave-making resistance interference effects. Aside from the effect of reduction of wave-making resistance introduced by splitting the required displacement into two parts and that of the increased frictional wetted area, the effect on the resistance of the interference between the wave systems created by the two hulls may be considered to be the most important aspect of the resistance of catamarans.

In 1951 K. Yokoo and one of the present authors, R. Tasaki, showed theoretically that there should exist a speed range over which the wave-making resistance of a catamaran, with the proper hull spacing, exhibits a negative interference such that the resistance of the catamaran is less than twice that of one of the hulls.[(1)] In the same report results of tests on non-symmetric hulled catamarans were presented, but negative interference was not found.

Subsequently, in 1953 Yokoo and Tasaki reported results of tests on a symmetric hulled, theoretically derived catamaran and small negative interference was exhibited.[(2)]

Under the Bureau of Ships contract NOBS 4485 The University of Michigan has undertaken to further investigate the interference phenomena. Tasaki has shown that the resistance increase can be divided into two parts. (3) The first part is a positive monotonically decreasing function with respect to the increase of the product of the speed parameter $K_o \left(\frac{1}{2F^2}\right)$ and the spacing parameter k, where k equals the hull centerline separation divided by hull length. Theory showed that for a catamaran with a small distance between the two hulls, the increase in wave-making resistance due to the monotonic term is dominant over the second term, or oscillating function, which oscillates with respect to Froude number but does not change rapidly with changes in hull spacing. It was also shown that the ratio of the resistance increase, due to the interference, to the resistance of each hull is not appreciably affected by changes in draft.

II- MODELS AND TEST PROCEDURE

In order to verify the above theoretical findings and investigate interference effects on a conventional hull form, two identical symmetric eight foot models were built of wood. A light-weight, durable magnesium channel structure was used to accurately space the hulls at k = 0.1, 0.2, 0.3, 0.4 and 0.6. The characteristics of the hulls for both displacements are given in Table I.

The eight foot length was chosen for the following reasons. In order for the results not to be affected by waves reflecting from the tank walls, the model should be approximately one length away from the walls which in the Michigan tank are 21.5 feet apart. For a hull spacing of k = 0.6, and for an eight foot model, the centerline of each hull is about 8.3 feet away from the wall such that the length chosen is about the maximum practical length.

It has been said that the wave-making resistance of a ship is proportional to the square of its beam and that, in the case of catamarans, the reduction of beam of the hulls introduced by splitting the required displacement into two parts can reduce the wave-making resistance to $\frac{1}{2}$ that of the single hulled ship of the same displacement. The effect of the beam on the resistance is actually more complicated than this, however. In order to examine the effect of beam on the wave-making resistance the residual resistance per unit displacement was calculated from the data of the Taylor Standard Series. In the calculation, the length-draft ratio was kept constant for a given prismatic coefficient so that the displacement or displacement-length ratio is proportional to the beam. The residual resistance per unit displacement, R_r/Δ in lbs. / ton was plotted against the beam-draft ratio, B/H for several speed-length ratios. The prismatic coefficient and length-draft ratio are given under the figures. Fig. 1 shows the results for the ratio of the displacement-length ratio to beam-draft ratio of 1.47×10^{-3}. Fig. 2 and Fig. 3 are the results for those of 0.80×10^{-3} and 0.60×10^{-3} respectively.

If the wave-making resistance is proportinal to the square of the beam, the curves in the figures should have an inclination of 45° with the abscissa. The curves show that this is not necessarily the case. It is interesting to note that the resistance per ton increases with the reduction of beam for a full ship form, $\frac{\nabla}{L^3} / \frac{B}{H} = 1.47 \times 10^{-3}$ with $C_p = 0.70$, and for fine ship forms, $\frac{\nabla}{L^3} / \frac{B}{H} = 0.60 \times 10^{-3}$ with $C_p = 0.50 \sim 0.65$ over part of the range calculated. It can be said in general examining the figures, that reduction of the beam reduces the residual resistance the most for $\frac{\nabla}{L^3} / \frac{B}{H} = 0.60 \times 10^{-3}$ with $C_p = 0.60$ at least for the group of the series for which the calculations were performed. Hence, $\frac{\nabla}{L^3} / \frac{B}{H} = 0.60 \times 10^{-3}$ and $C_p = 0.60$ were chosen as the values for the model to be tested.

For the case chosen, the length-draft ratio is 30.4 as shown in Fig. 3c. Therefore, a length-draft ratio of 32 was chosen for the model.

B/H was decided from practical considerations, for example building costs, structural considerations, etc.

In order to examine the effect of the draft on the interference, the model was also tested with 2 inches deeper than designed draft. Finally, the lines of form of a single hull of the model are shown in Fig. 4.

III- TEST RESULTS

The notations used throughout this report are as follows:

- R_{2W} wave-making resistance of the catamaran
- R_{OW} wave-making resistance of each hull of the catamaran, i.e., half the wave-making resistance of the catamaran with infinite hull spacing
- $2R_W$ increase in wave-making resistance due to the interference between the wave systems of both hulls

That is,

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

Model resistance was measured in pounds and speed in feet per second.

Owing to probable discrepancies between theoretically predicted values and experimental results because of the viscous nature of water, it is desirable not to include viscous effects in the presentation of the results. Therefore, where possible, data is expressed as the ratio of the two wave-making resistances, However, the method of wave-making resistance separation does not necessarily preclude all viscous effects. In order to separate the components of resistance, the Hughes' method was utilized but the ATTC friction line was used as a base rather than that of Hughes. In equation form for finite hull spacing

$$C_t = \frac{R_T}{\frac{1}{2}\rho S V^2} = C_{2W} + (1 + k')\ C_f$$

where

$$C_{2w} = \frac{R_{2w}}{\frac{1}{2}\rho S V^2}$$

C_f = 1947 ATTC friction coefficient

k' = form factor

such that the total viscous resistance is

$$(1 + k') \quad C_f$$

For the case of infinite hull spacing

$$2C_{ow} = \frac{2 R_{ow}}{\frac{1}{2}\rho S V^2}$$

may be substituted for C_{2w} in the above equation for C_t.

In order to determine the form factor accurately an extremely large number of data points was taken throughout the low speed range for each displacement. Mean lines through the data conformed to lines yielded by

k' = 0.16 for the light displacement

and k' = 0.30 for the heavy displacement.

Had the basic Hughes friction line been used, slightly higher form factor values would have resulted. The relatively large difference in values of form factor for the two cases may be attributed to the deeply immersed transom stern in the heavy displacement condition. Over the range of Reynolds Numbers tested the resulting viscous resistance coefficient curves separate from the total that resistance above the curves as being wave-making resistance.

For measured values of the ratio of R_w/R_{ow}, the numerator is one half the difference between the total resistance curve for finite spacing and that for infinite spacing, and therefore is assumed to be very nearly all resistance increase due to wave interference between the two hulls. The extent of the viscous effects on the denominator, R_{OW}, is a function of the accuracy of the form factor method employed.

The test results are shown in Figs. 5 through 8 for the light displacement condition and Figs. 9 through 12 for the heavy displacement condition. It should be noted that the model waterline length in the latter condition was slightly greater than in the former. However, the spacing parameter, k, and Froude number were based on a length of 8 ft. for both conditions.

In Figs. 7 and 11 the calculated interference was taken from Ref. 2, or Fig. 10 of Ref. 3. To date, two theoretical calculations of R_w/R_{ow} have been carried out (Figs. 9 and 10 of Ref. 3) and only small differences between the two calculations in any curve of constant hull spacing were shown. It has been theoretically demonstrated that hull proportions do not significantly affect the theoretical curves of R_w/R_{ow}.[3] Therefore, because the hull proportions for the form corresponding to Fig. 10 of Ref. 3 coincided more nearly to those of the catamaran of present interest, it was that theoretical calculation which was chosen for comparison herein.

Light Displacement Condition

Fig. 5 gives the total model resistance, Fig. 6 the wave-making resistance of the catamaran, Fig. 7 the R_W/R_{OW} curves, and Fig. 8 cross-curves of Fig. 7 with each curve being of constant speed.

Fig. 5 shows that through the design speed range only two hull spacings yielded total resistance less than that of twice the single hull. Over the remaining speed range all curves show significantly increased resistance. Figs. 7.c. and 7.d. reflect the results just discussed, but further show that although the magnitude of the negative interference is much less than predicted by theory, the speed at which the negative wave-making interference occurs is accurately predicted. The cross-curve of points at which the wave-making resistance is least, Fig. 8, shows that the optimum spacing is about $k \doteq 0.35$ to 0.40.

Heavy Displacement Condition

Curves analogous to those plotted for the light displacement condition are also given for the heavy displacement condition. Fig. 9 gives the total model resistance, Fig. 10 the wave-making resistance of the catamaran, Fig. 11 the R_W/R_{OW} curves, and Fig. 12 the cross-curves from Fig. 11.

Similarly Fig. 9 indicates that through the design speed range two hull spacings yielded total resistance less than twice that of the single hull. Once again, the resistance was markedly increased over the rest of the speed range. Fig. 11 shows fairly good speed prediction by the theory for minimum interference although there is a slight phase shift towards higher Froude numbers. As for the light displacement condition the magnitude of the negative interference was far less than that predicted analytically. There was also a phase shift in optimum spacing, and that spacing occurred at about $k = 0.5$ as shown in Fig. 12.

The phase shifts for the heavy displacement condition mentioned above might be partially explained in the following manner. The transom stern did not run clean until a Froude number of approximately 0.45 had been attained so that the large wake existing directly behind the transom and near the surface would have the effect of increasing the wave-making length of the hull somewhat, hence decreasing the hull spacing parameter and Froude number simultaneously. Such an effect would tend to align the phases of the experimantal curves of R_w/R_{ow} with those predicted theoretically.

With regard to the hull spacing of 10 percent of length, for both displacement conditions, observation of the tests indicated severe constriction of the flow between the hulls and radical travelling wave formations such that the large positive interference exhibited in the figures was to be expected.

It has been pointed out previously that the interference wave-making resistance can be subdivided into monotonic and oscillating parts which has been done graphically for the experimental results. Fig. 13 shows the two terms for the various hull spacings for the light displacement condition as derived from Fig. 6. For the heavy displacement condition, Fig. 15 was derived from Fig. 10. Cross-curves of constant Froude number are given in Figs. 14 and 16 for the light and heavy displacement conditions, respectively. The experiments verify the theory insofar that the monotonic term is of highest magnitude for the smallest hull spacings. Figs. 14 and 16 show that for closely spaced hulls the monotonic term changes more rapidly than the oscillating term. It is these facts which yield the optimum hull spacing of about 35 percent of hull length. Direct comparison of the monotonic and oscillating terms of the experimental results with the analytical calculations is made difficult, because of the anomalies owing to viscous properties, unless ratios of these terms are used. Presently the necessary theoretical results are not available.

IV- CONCLUSIONS

From the standpoint of overall ship hull resistance, the major principles may be summarized as follows. Interference between the wave systems of the hulls of a catamaran is only slightly beneficial, and then only over a limited speed range near a Froude number of 0.33 (speed-length ratio of 1.1) and a limited range of hull spacings near 35 percent of ship length. Moreover, detrimental interference exists over the remainder of the speed range and range of spacings. With hull spacings less than 20 percent of length the interference effects on resistance would be very high. Spacings somewhat less than 35% of ship length might compensate increased power requirements by decreased bridge structure. However, by properly designing the hulls the advantage of sharply decreasing wave-making resistance, as the prisimatic coefficient decreases, when the displacement-length ratio is lower than normally used for single-hulled ships can be realized. Because the static transverse stability problem is alleviated by the catamaran hull the breadth-draft ratio can then be determined from the viewpoint of least wave-making resistance.

The program of tests carried out and reported here were limited to one long, slender hull design. It was originally planned to investigate other hull forms and in particular shorter hulls with higher displacement length ratios. Such an extension of this program, it is hoped, will be financed in the future.

REFERENCES

1. Yokoo, K., and Tasaki, R. "On the Twin-Hull Ship: Report No. 1." Report of Transportation Technical Research Institute of Japan, Vol. 1, No. 1, 1951. (Translated by H. C. Kim, Univ. of Mich. Department of Naval Architecture, Oct. 1962.)

2. Yokoo, K., and Tasaki, R. "On the Twin-Hull Ship: Report No. 2." Report of Transportation Technical Research Institute of Japan, Vol. 3, No. 3, 1953. (Translated by H. C. Kim, Univ. of Mich. Department of Naval Architecture, Oct. 1962.)

3. Tasaki, R., "A Note on Wave-Making Resistance of Catamarans", Department of Naval Architecture and Marine Engineering, University of Michigan, October 1962. Bureau of Ships Contract No. NOBS 4485.

TABLE I

CATAMARAN HULL CHARACTERISTICS

(SINGLE HULL)

SPONSOR : Bureau of Ships, Navy Department

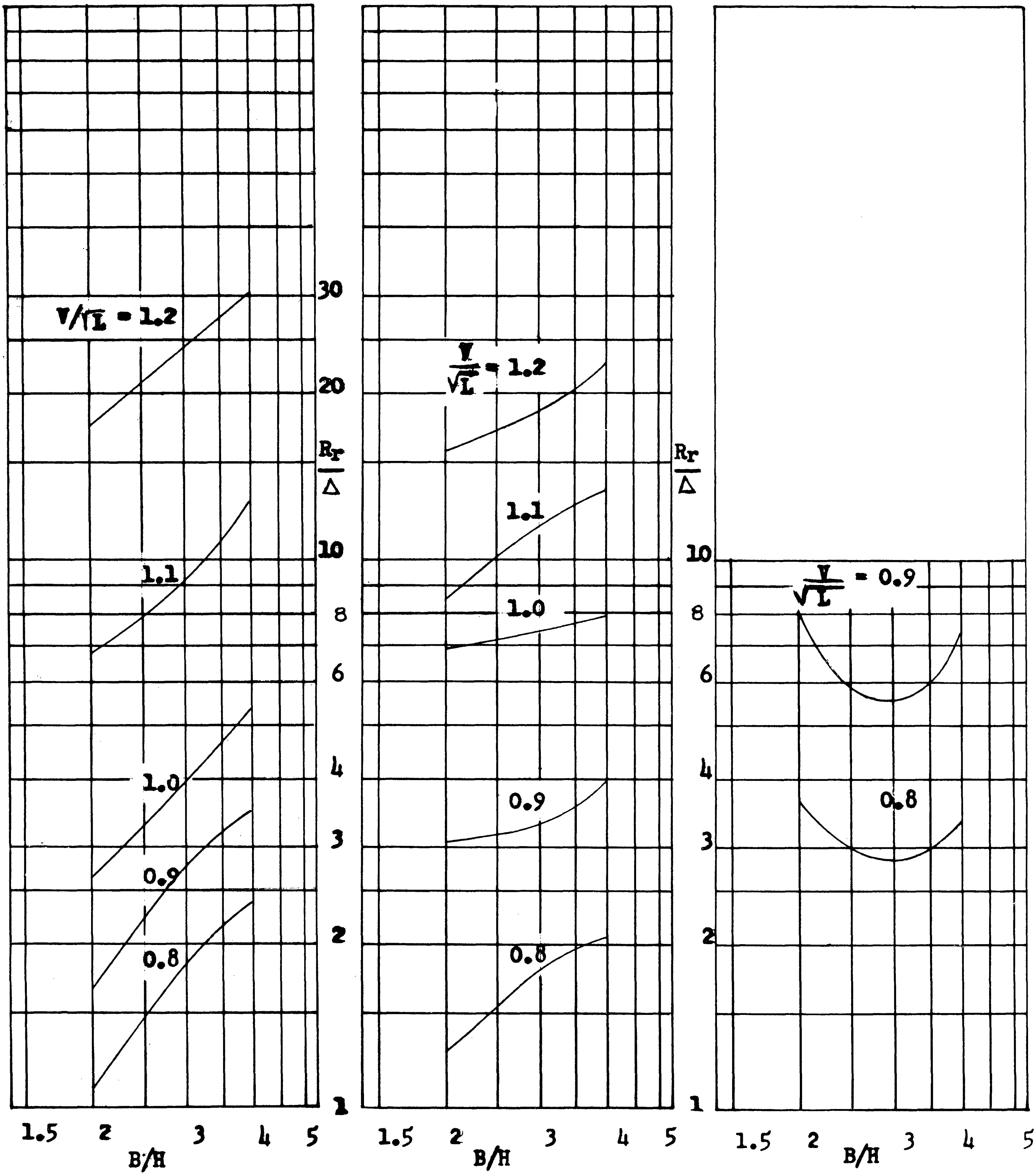
U of M MODEL No. : 960

MODEL MATERIAL : Sugar Pine

	LIGHT DISP.	HEAVY DISP.
LBP	8.000 Ft.	8.000 Ft.
LWL	8.000 Ft.	8.066 Ft.
B_{max} (STA 12)	0.521 Ft.	0.535 Ft.
B	0.500 Ft.	0.519 Ft.
H	0.250 Ft.	0.417 Ft.
∇	0.5085 Cu. Ft.	1.0408 Cu. Ft.
Wetted Surface	5.291 Sq. Ft.	7.850 Sq. Ft.

FORM PARAMETERS :

C_P (LBP)	0.605	0.672
C_B (LBP)	0.488	0.583
C_x (STA 12)	0.806	0.868
LBP/B (STA 12)	15.35	14.95
B/H (STA 12)	2.08	1.28
$\nabla / (LBP)^3$	0.993×10^{-3}	2.033×10^{-3}



a. $C_p = 0.50$

$\frac{\nabla H}{L^3 B} = 1.47 \times 10^{-3}$

L/H = 17.7

b. $C_p = 0.60$

$\frac{\nabla H}{L^3 B} = 1.47 \times 10^{-3}$

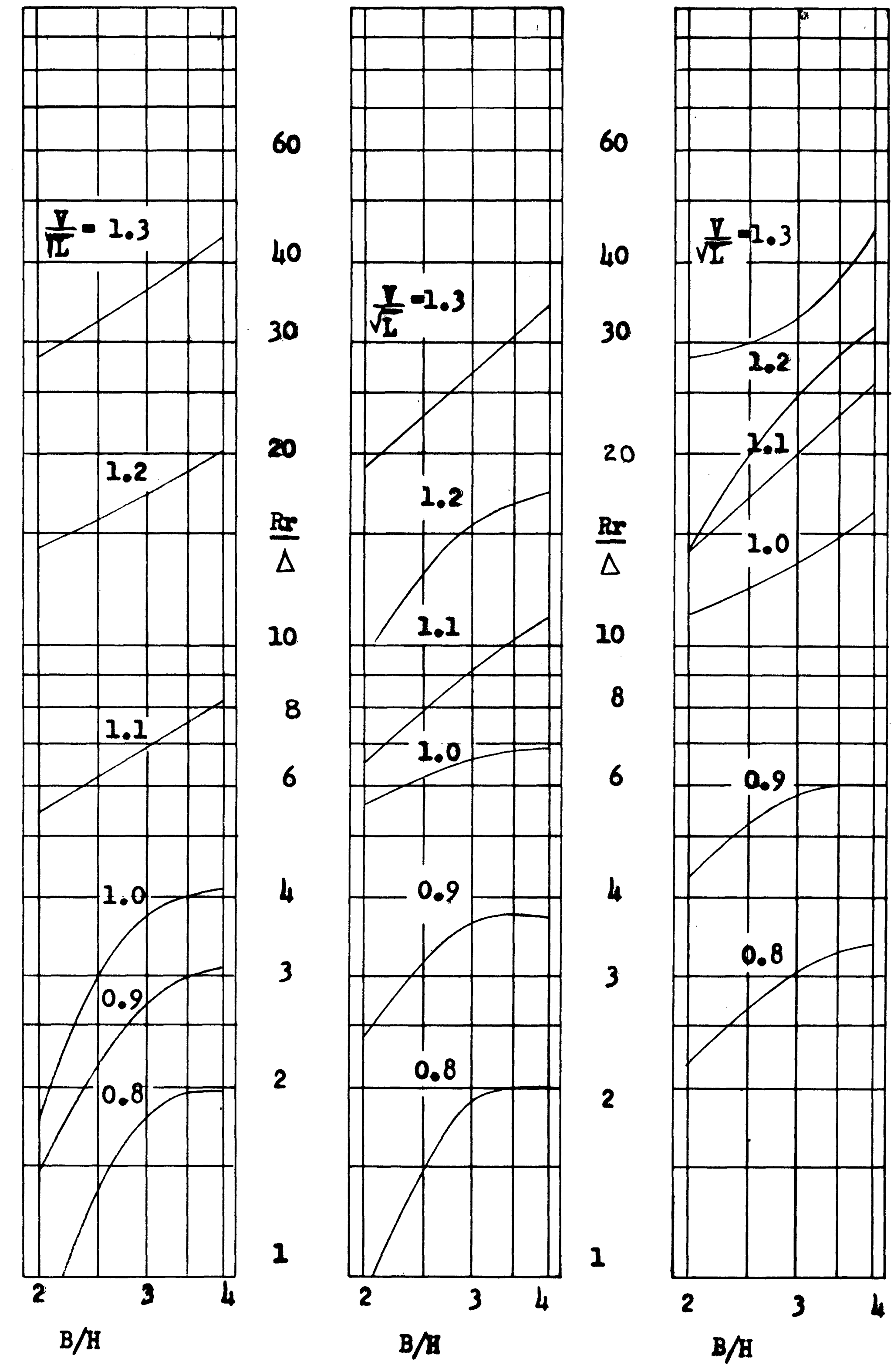
L/H = 19.4

c. $C_p = 0.70$

$\frac{\nabla H}{L^3 B} = 1.47 \times 10^{-3}$

L/H = 21.0

Fig. I. Pounds residual resistance per ton displacement from Taylor Standard Series.



a. Cp = 0.50

$\frac{\nabla H}{L^3 B} = 0.80 \times 10^{-3}$

L/H = 24.1

b. Cp = 0.60

$\frac{\nabla H}{L^3 B} = 0.80 \times 10^{-3}$

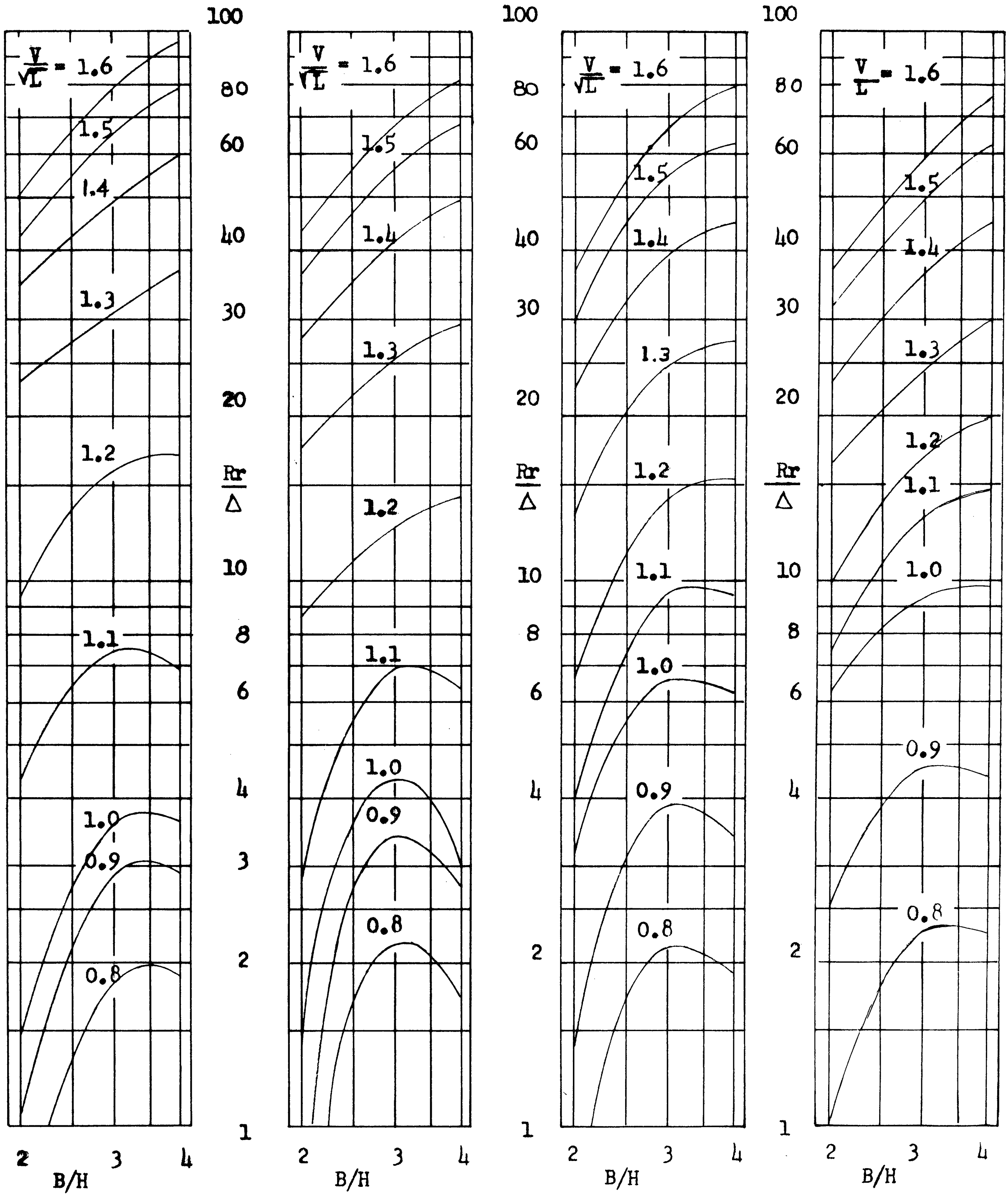
L/H = 26.4

c. Cp = 0.70

$\frac{\nabla H}{L^3 B} = 0.80 \times 10^{-3}$

L/H = 28.5

Fig. 2. Pounds residual resistance per ton displacement from Taylor's Standard Series.



a. Cp = 0.50

$\frac{\nabla H}{L^3 B} = 0.60 \times 10^{-3}$

L/H = 29.7

b. Cp = 0.55

$\frac{\nabla H}{L^3 B} = 0.60 \times 10^{-3}$

L/H = 29.1

c. Cp = 0.60

$\frac{\nabla H}{L^3 B} = 0.60 \times 10^{-3}$

L/H = 30.4

d. Cp = 0.65

$\frac{\nabla H}{L^3 B}$ = 0.60x1

L/H = 31.6

Fig. 3. Pounds residual resistance per ton displacement from Taylor Standard Series.

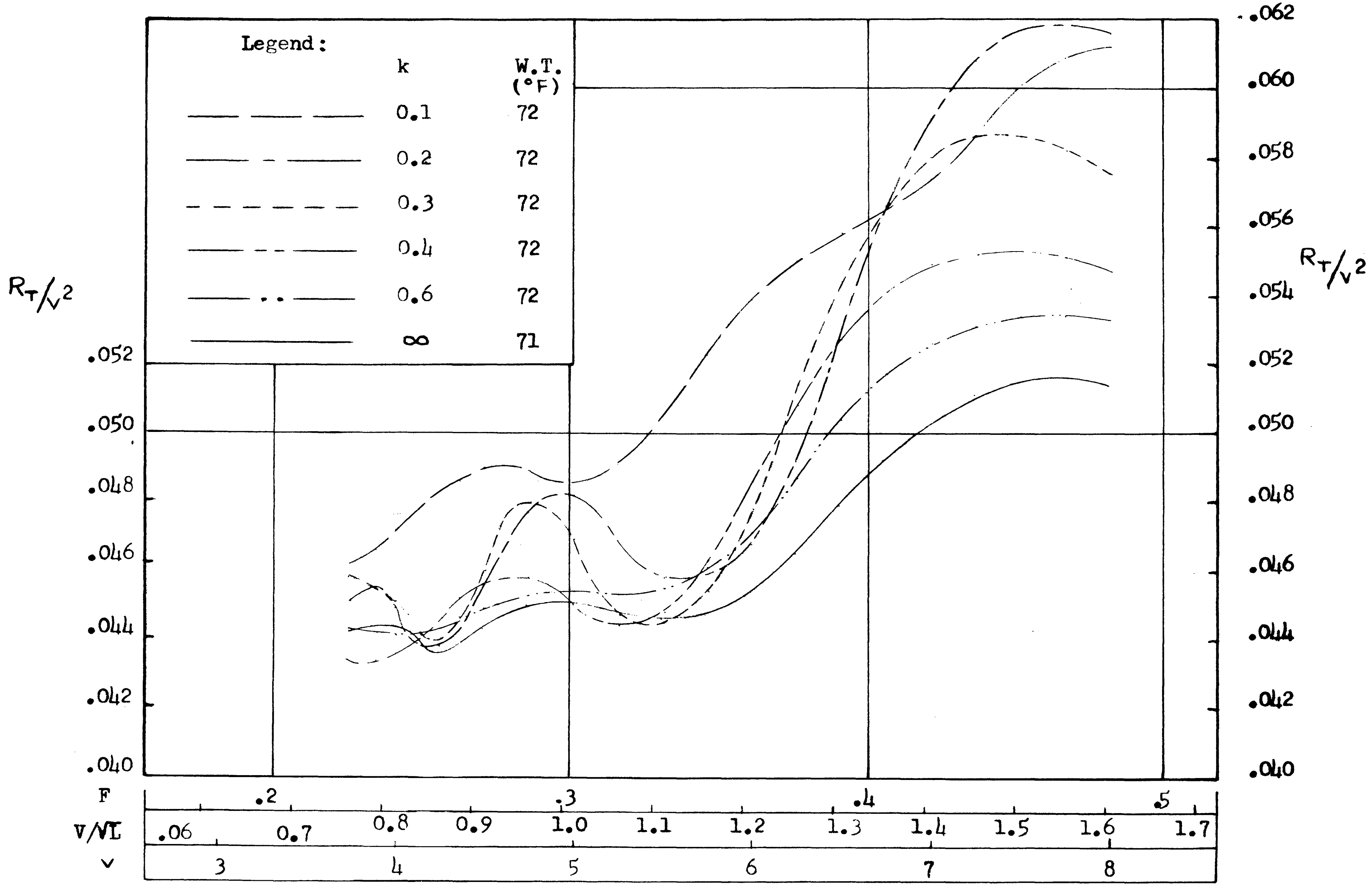


Fig. 5. Total model resistance for light displacement condition.

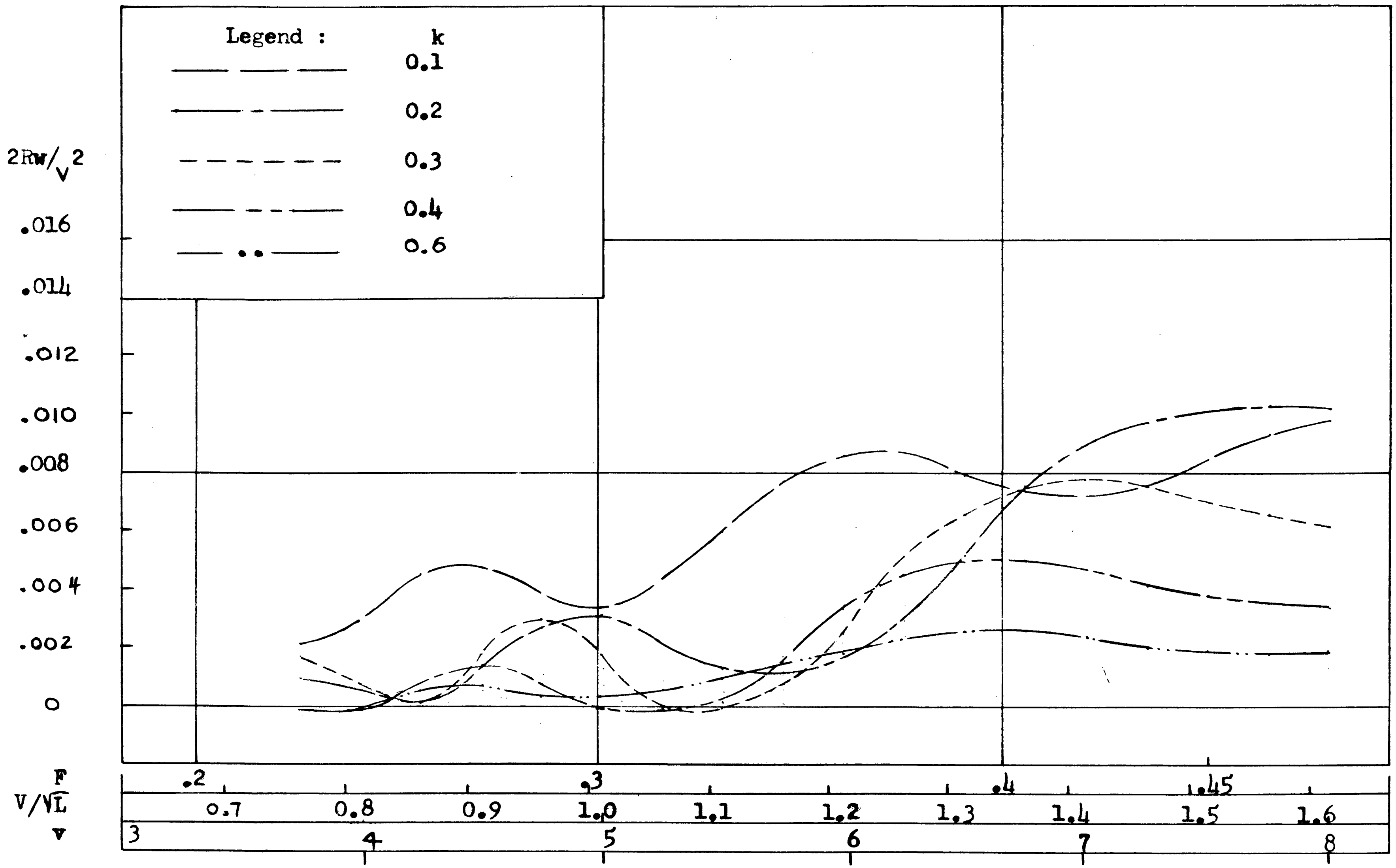


Fig. 6. Increase in wave-making resistance due to interference. Light displacement condition.

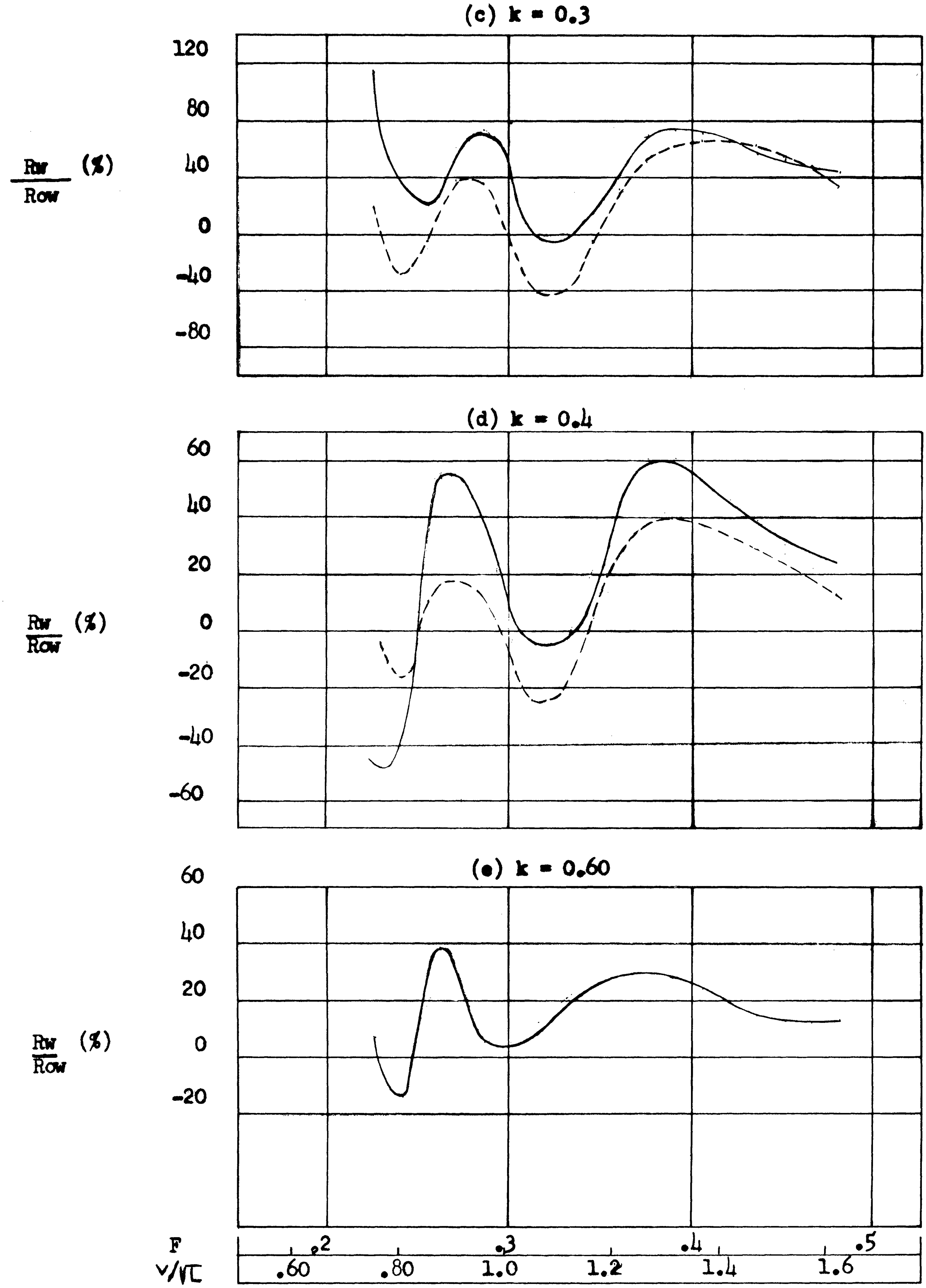


Fig. 7. Rw/Row (%) versus Froude number and speed-length ratio for light displacement condition

———— test results

- - - - - calculated results

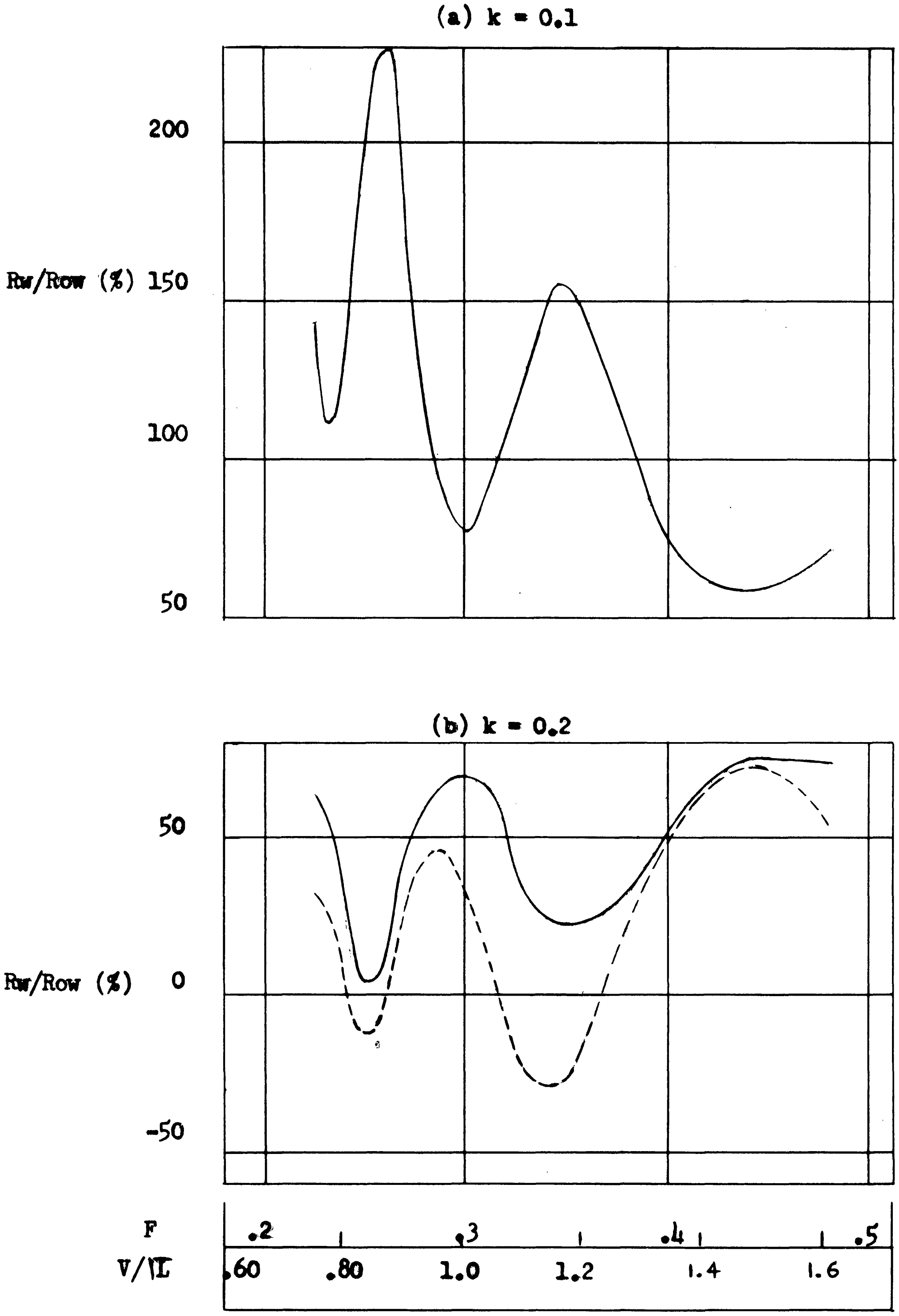


Fig. 7. (Concluded). Rw/Row (%) versus Froude number and speed-length ratio for light displacement condition.

——— test results
- - - - calculated results

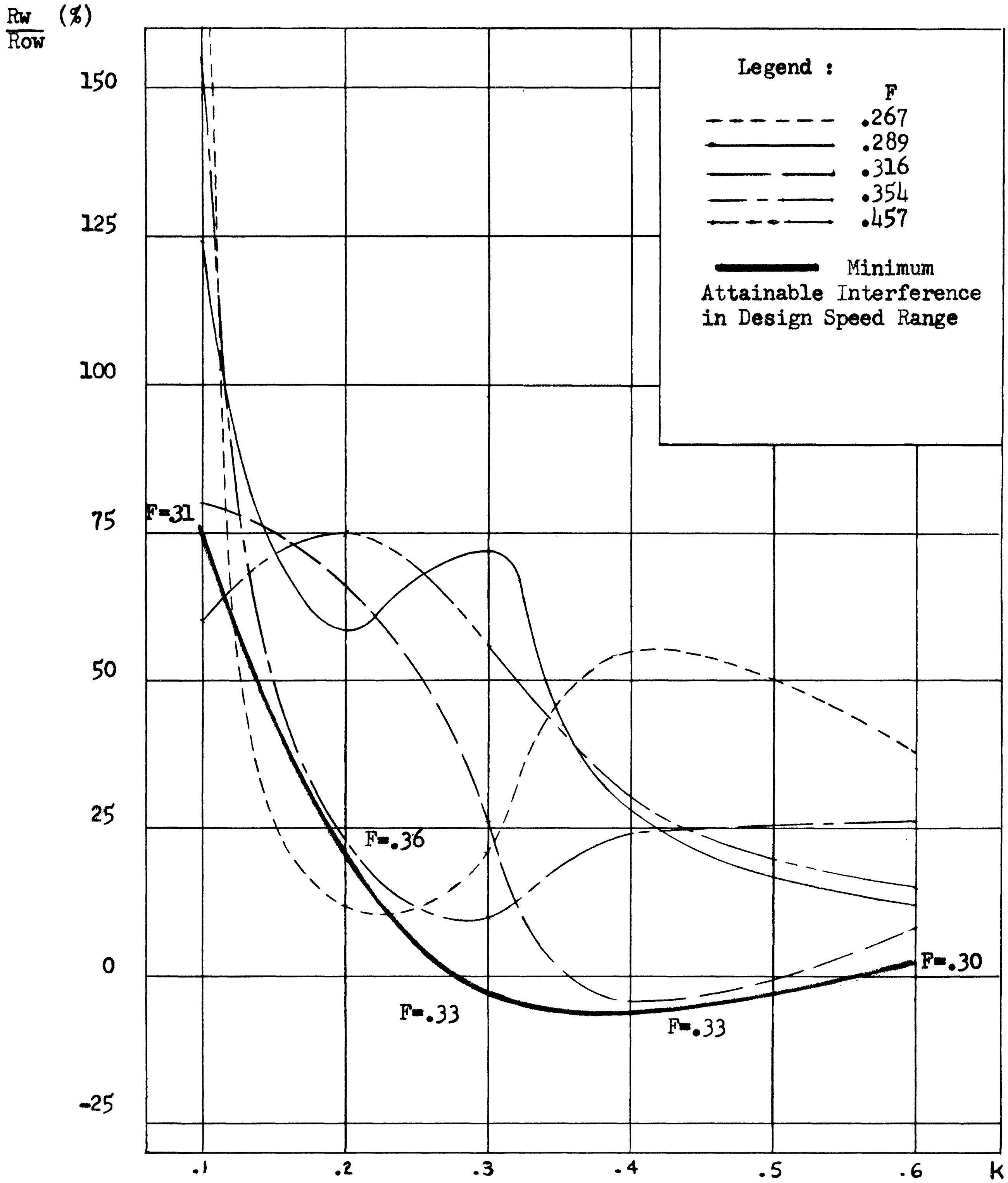


Fig. 8. Rw/Row (%) plotted against the spacing parameter, k. Light displacement condition .

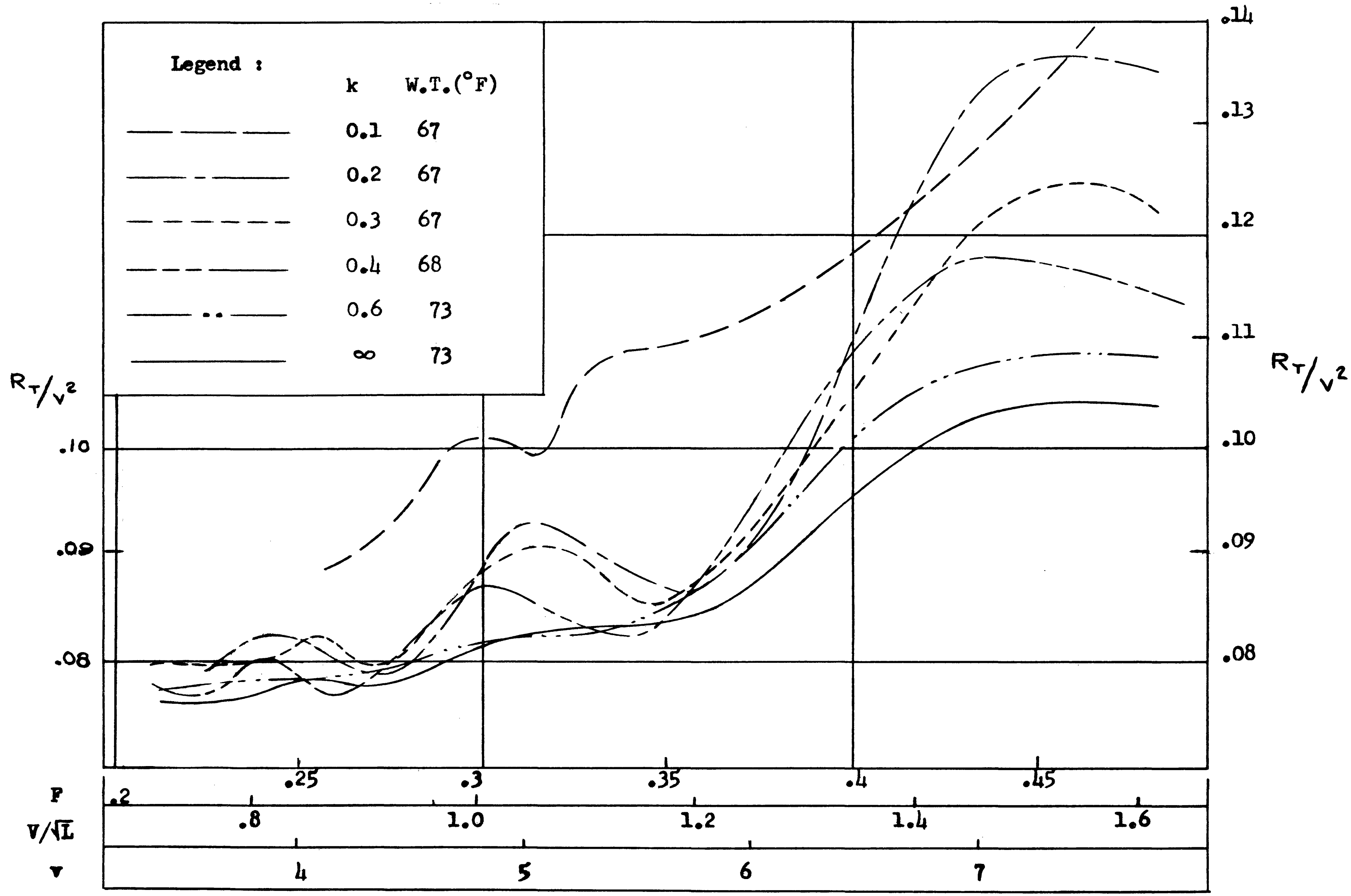


Fig. 9. Total model resistance for heavy displacement condition.

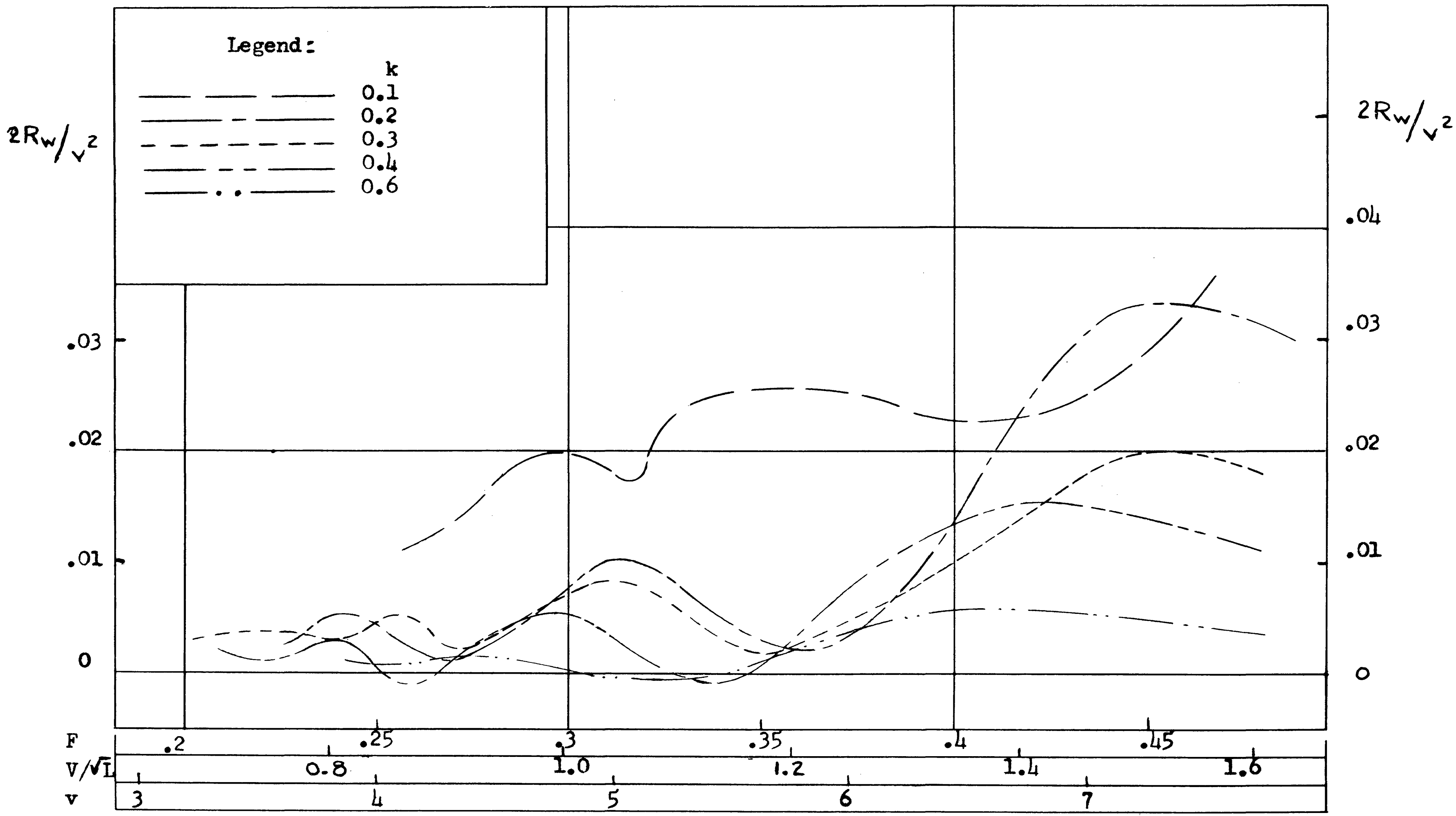


Fig. 10. Increase in wave-making resistance due to interference. Heavy displacement condition.

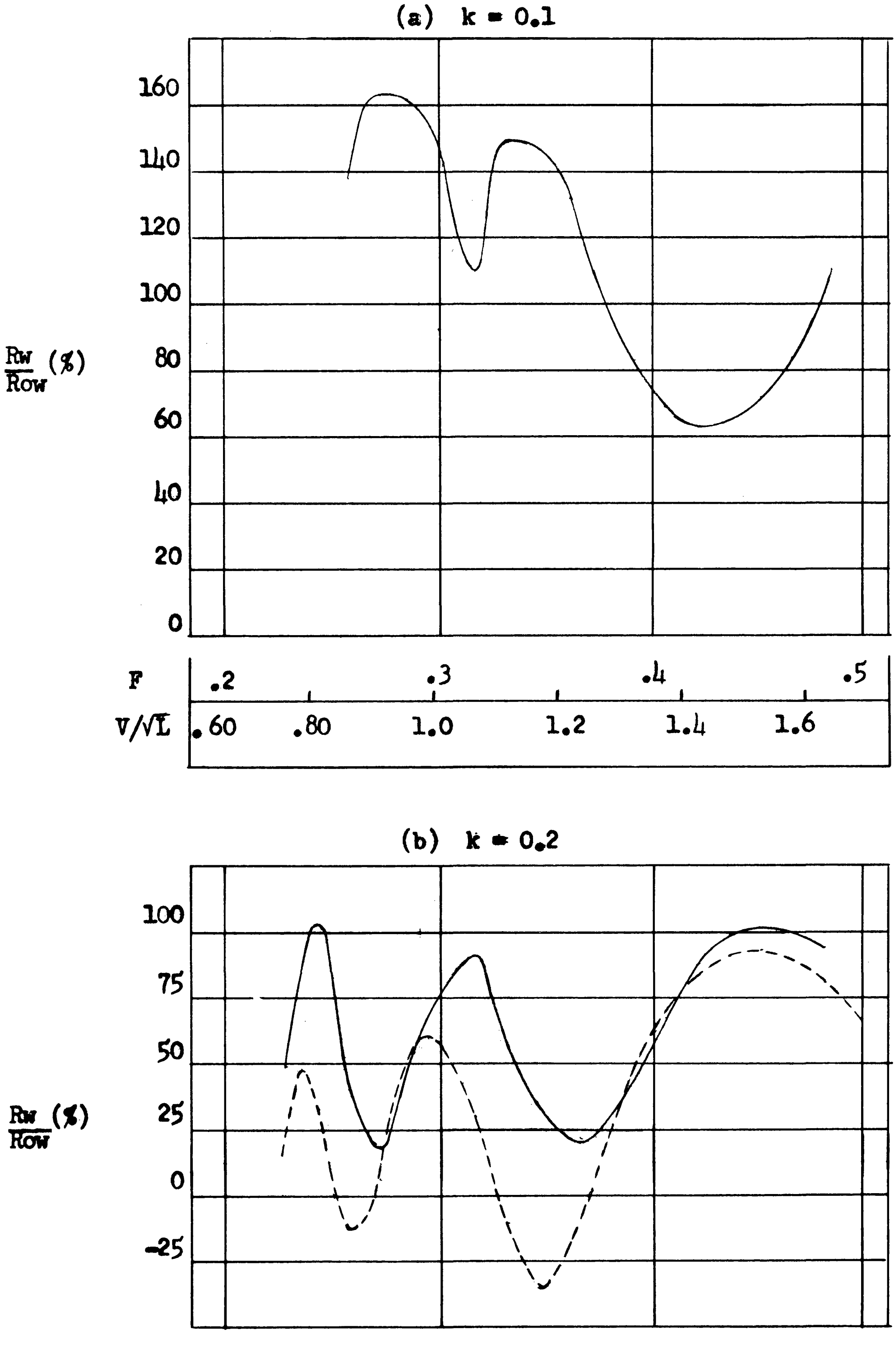


Fig.11. Rw/Row (%) versus Froude number and speed - length ratio for heavy displacement condition.

———— test results

- - - - calculated results

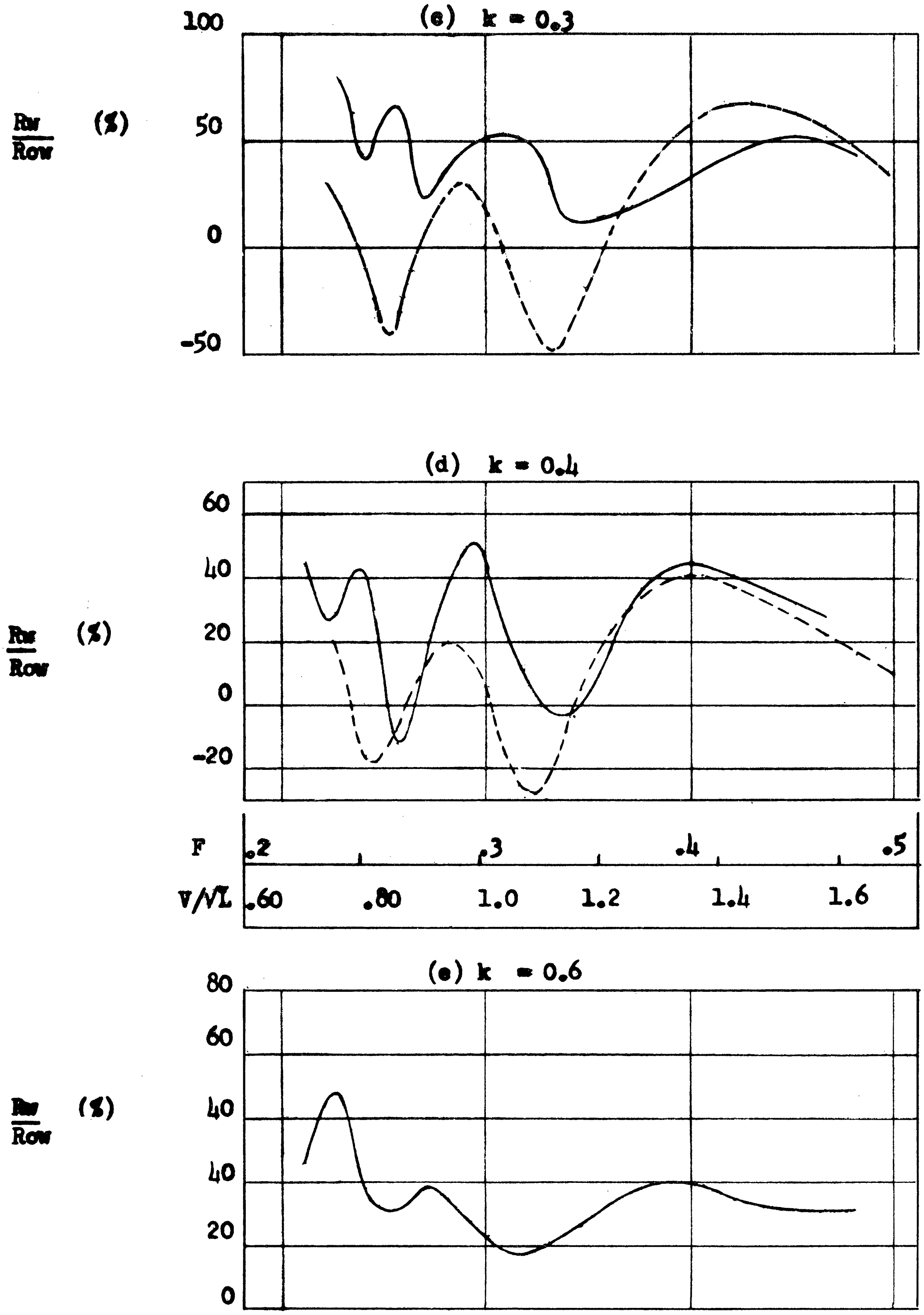


Fig. 11. (Concluded). Rw/Row (%) versus Froude number and speed-length ratio for heavy displacement condition.

——— test results

– – – – – calculated results

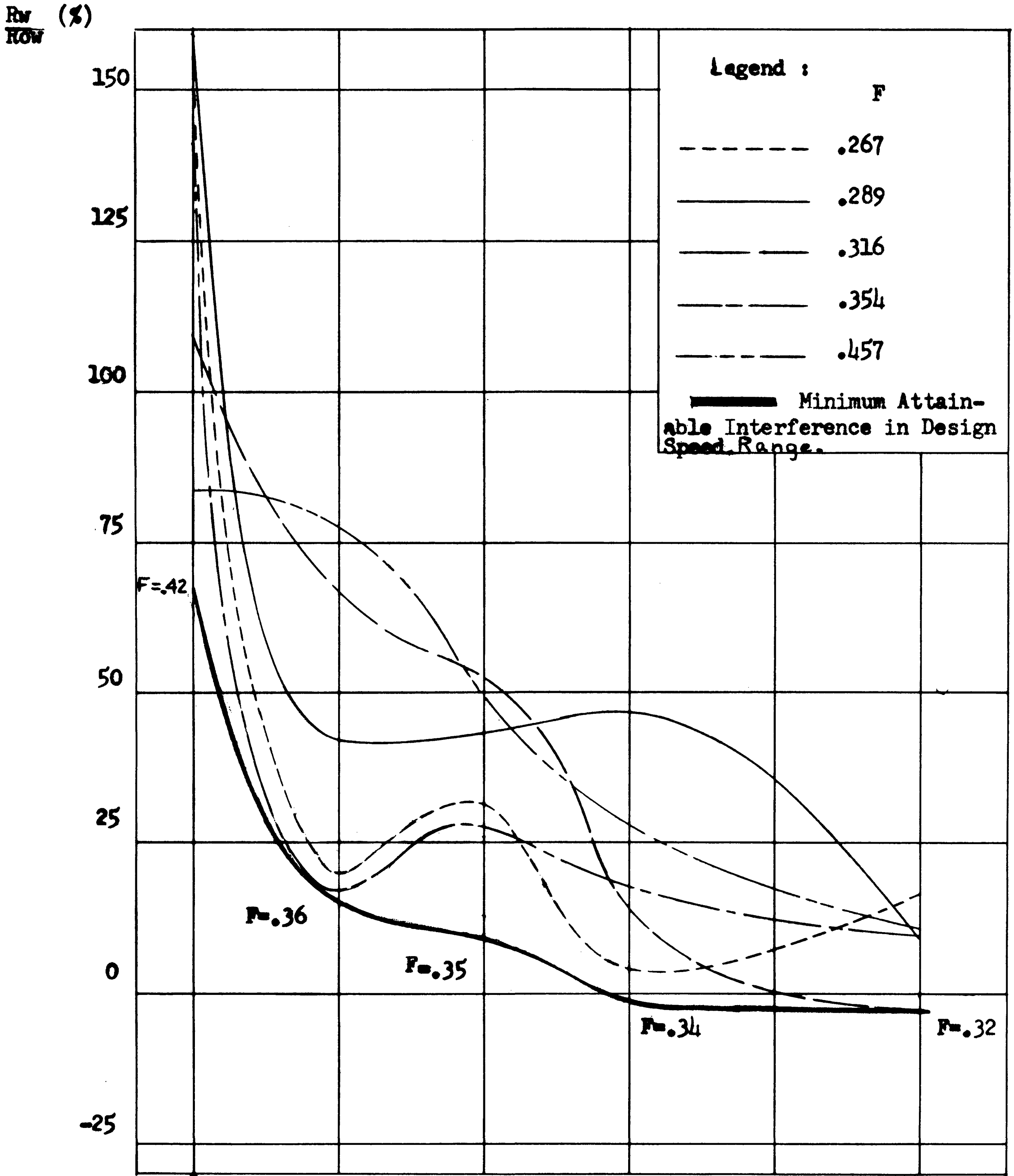


Fig. 12. Rw/Row (%) plotted against the spacing parameter, k. Heavy displacement.

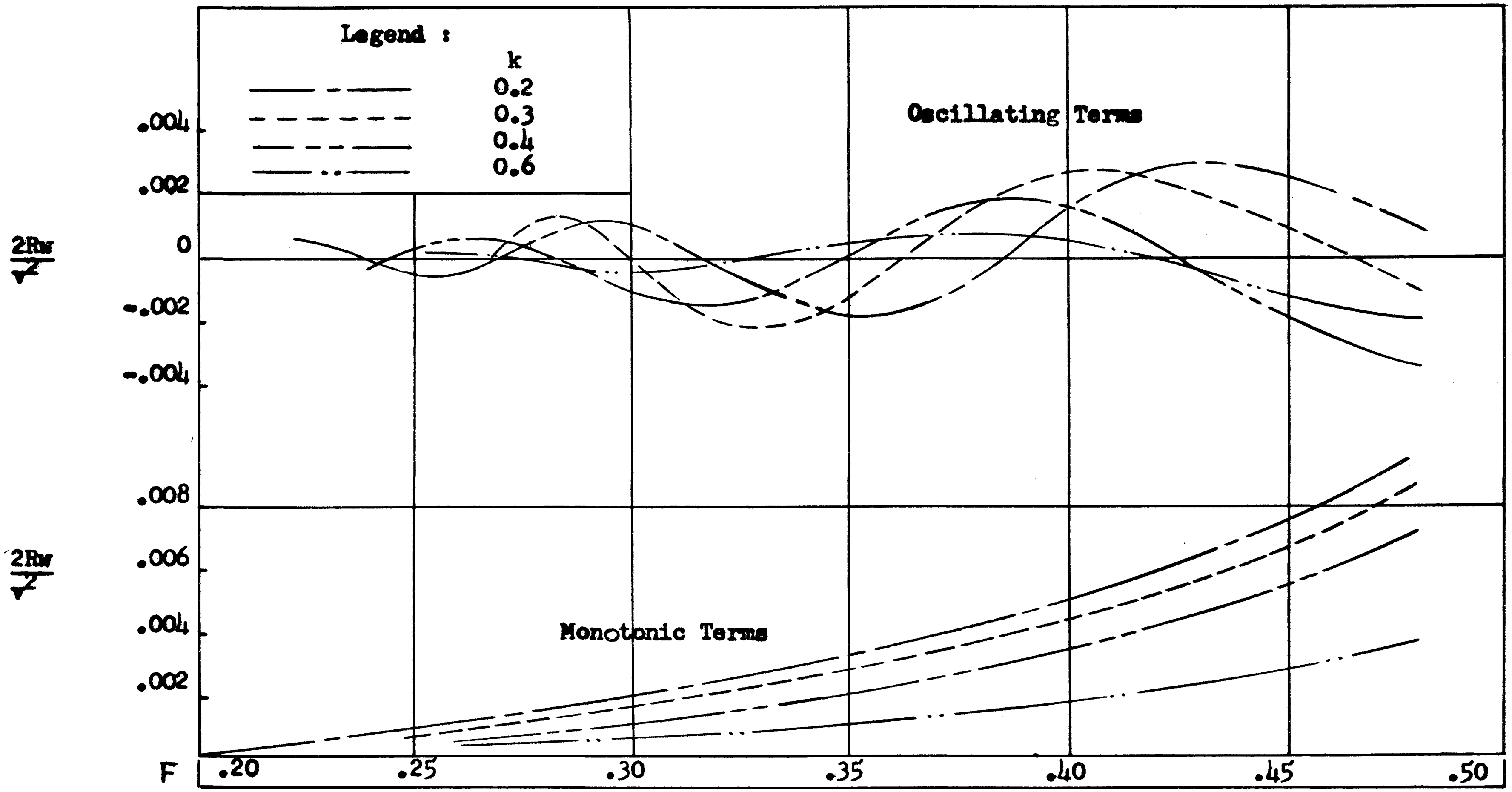


Fig. 13. Separation of resistance increase due to interference into two terms. Light displacement condition.

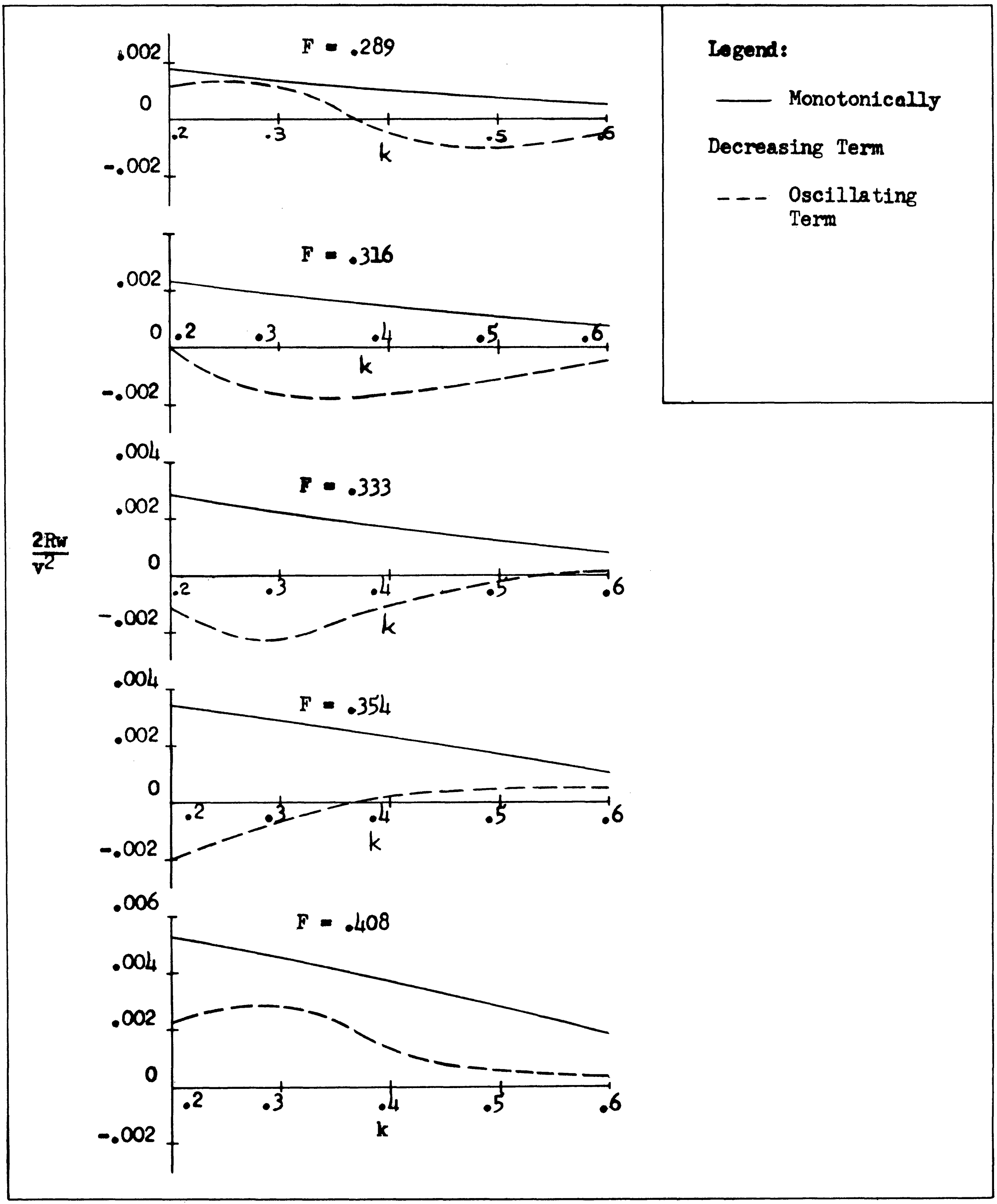


Fig. 14. Variation with spacing of the two terms of resistance increase due to interference. Light displacement condition.

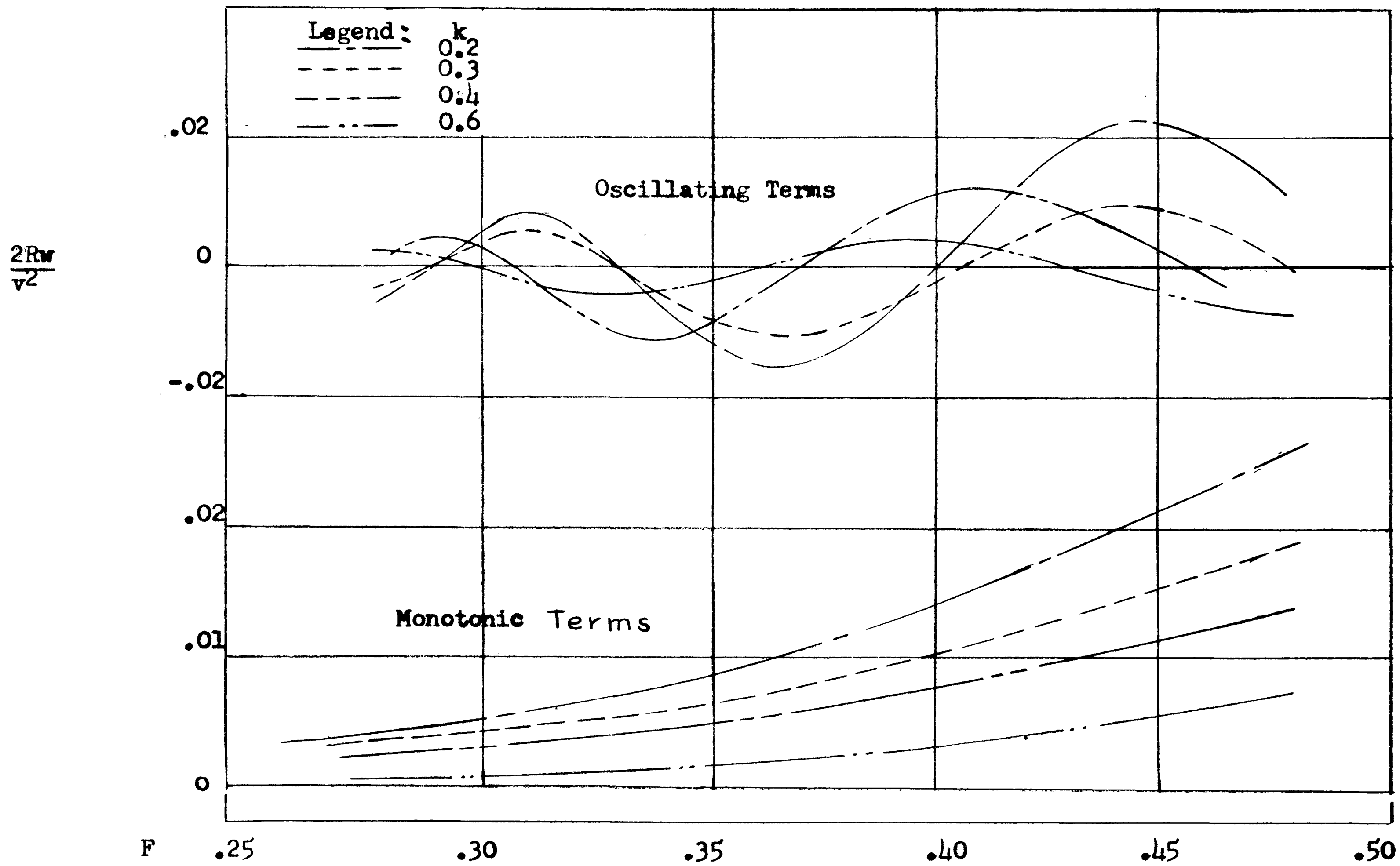


Fig. 15. Separation of resistance increase due to interference into two terms.
Heavy displacement condition.

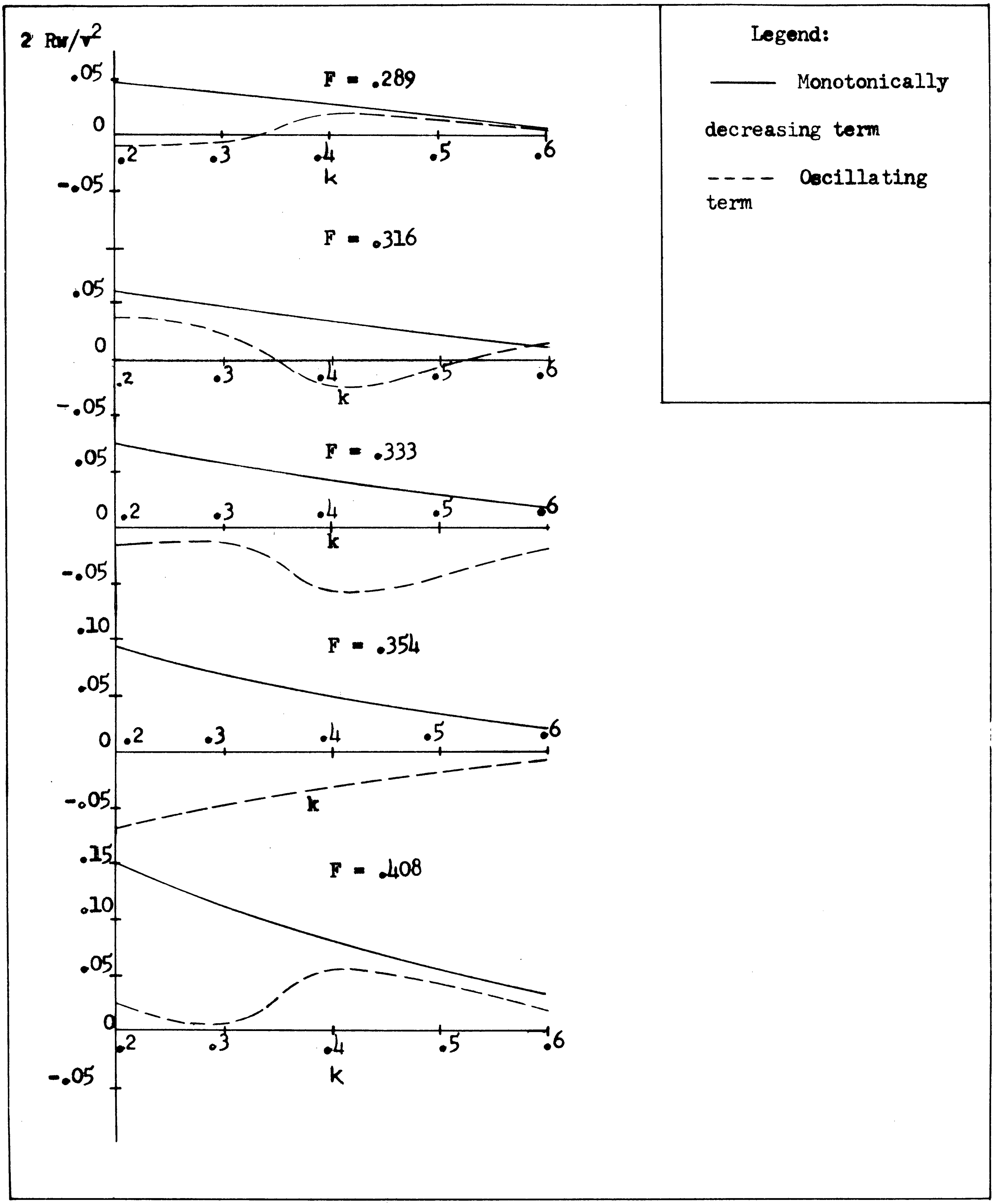


Fig. 16. Variation with spacing of the two terms of resistance increase due to interference. Heavy displacement condition.