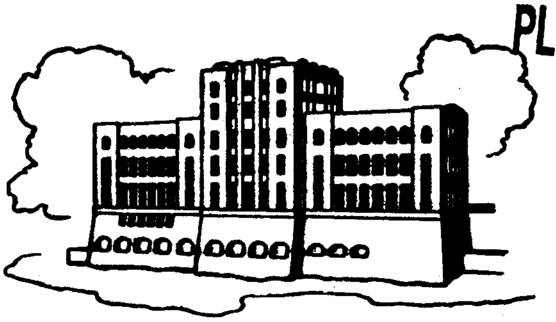
EXPERIMENTAL STUDY OF THE WAVEMAKING OF HORIZONTALLY-ORIENTED VORTICITY IN A WAKE

by

A. Swain and L. Landweber

This research was carried out under the
Naval Ship Systems Command
General Hydromechanics Research Program
Subproject SR 023 01 01, administered by the
Naval Ship Research and Development Center
Contract No. N00014-68-A-0196-0010



IIHR Report No. 153

Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa

January 1974

Approved for public release; distribution unlimited

EXPERIMENTAL STUDY OF THE WAVEMAKING OF HORIZONTALLY-ORIENTED VORTICITY IN A WAKE

by

A. Swain and L. Landweber

This research was carried out under the

Naval Ship Systems Command
General Hydromechanics Research Program
Subproject SR 023 01 01, administered by the
Naval Ship Research and Development Center

Contract No. N00014-68-A-0196-0010

IIHR Report No. 153

Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa

January 1974

SUMMARY

Towing-tank experiments were conducted in order to investigate the wavemaking of horizontally-oriented vorticity in a wake. It was found that the amplitudes of the surface disturbance, measured with three capacitance wires, were about one tenth of those generated by a ship model of the same length and Froude number. Furthermore, the wave resistance was about one percent of that obtained for a Series-60 model of the same wetted-surface area.

ACKNOWLEDGEMENT

This report is based upon research conducted under the General Hydrodynamics Research Program of the Naval Ship Systems Command, technically administered by the Naval Ship Research and Development Center, under Contract No. N00014-68-A-0196-0010. The assistance of Mr. C. E. Tsai in conducting the experiments is gratefully acknowledged.

TABLE OF CONTENTS

LIST OF SYMBOLS

b	Channel width
C_W	Wave-resistance coefficient
F	Froude number = $V/\sqrt{gL_{WL}}$
g	Acceleration of gravity
L_{WL}	Waterline length
R_w	Wave resistance
V	Velocity of model
$V_{t1}V_{t2}V_{t3}$	Readings of the three capacitance wires, in millivolts
x	Longitudinal distance
X_0	Upstream truncation point
X_T	Downstream truncation point
y_1,y_2,y_3	Position of longitudinal cuts from centerline of model
z	Elevation of wave probes with respect to undisturbed free surface, used for calibration
η_{max}, η_{min}	Maximum and minimum wave heights respectively
ρ	Density of fluid
Δt	Preset constant time increment for sampling data

EXPERIMENTAL STUDY ON THE WAVEMAKING OF HORIZONTALLY-ORIENTED VORTICITY IN A WAKE

I. INTRODUCTION

When a body moves in a fluid, vortices are generated in the boundary layer and wake behind the body. Brard [1] has strongly raised the question as to whether vorticity generates waves. Tatinclaux [2], Brard [1] and Beck [3] have given analytical expressions for vorticity-generated waves. Gadd [4] has shown that the wavemaking of a vertical-piercing flat plate is negligible, although ship waves are attenuated by thickening of the wake. In this case the vorticity in the boundary layers and wake did not generate waves. Calisal [5] on the other hand, sucked the boundary layer at the stern of a ship model to control the extent of the wake, and found that the surface-profile wave drag was only slightly affected by large variation in the wake. A possible explanation for this result is that the waves generated by the vorticity compensated approximately for the change in the wavemaking of the hull at the stern. Thus there appears to be contradictory evidence concerning the importance of vorticity-generated waves and their effect on the analysis of longitudinal-cut surface-wave profiles. Thus to supplement Gadd's results, it was decided to investigate whether horizontally-oriented vorticity is a more effective wavemaker. In order to investigate this phenomenon, a toboggan-shaped flat plate was towed horizontally at the water surface and the surface disturbances were measured by means of longitudinal cuts in the manner described by Tsai [6].

II. EXPERIMENTAL PROCEDURE

Experiments were carried out in the towing tank (300 ft. long, 10 ft. wide and 10 ft. deep) of the Iowa Institute of Hydraulic Research. A "toboggan"-shaped flat plate, 8 ft. long, 2 ft. wide and 0.125 in. thick, was constructed, using aluminum plate, stiffened by steel angles (see figure 1). However, no attention was paid to the smoothness of the surface, because the stronger wake generated by a rough surface was desirable for the present purpose. The plate was attached to the towing-tank carriage, rigidly supported by means of struts in front and by wires at the rear, as shown in figure 2.

Preliminary adjustment of the struts and wires was made and levels at different points on the plate surface were checked until the toboggan touched the water surface horizontally. As initially adjusted, waves were generated throughout the entire length of the plate (see figure 3a). Therefore, successive adjustments, although tedious, were tried until finally no waves were generated from the front and sides of the toboggan. Figure 3b presents such a condition. It is seen that one can hardly see any waves. This is due to the fact that the vorticity-generated waves are too small to notice. The adjustment corresponding to the above situation was considered as the proper experimental condition for data collection.

Three wave gauges were mounted on an aluminum channel perpendicular to the channel wall (see figure 4). The probes were made of single teflon-coated wire with the lower end sealed with silicon rubber. The probes were calibrated statically in still water. Figure 5 shows a static calibration curve for the three gauges. The established relationship between static and dynamic calibrations [6] was used in the computer program to interpret the recorded data. Because the probe response is sensitive to contamination on the surface of the wire, the probes were washed with a brush and initial readings of the three probes recorded before and after a series of runs.

The toboggan was then towed at a constant speed along the length of the channel. The wave profiles were recorded with the Institute's IBM 1800 Computer by sampling simultaneously the three separate outputs of the wave-gauge circuits at a preset constant time increment, Δt, which was so adjusted that the corresponding distance increment was approximately 0.1 foot. The recording of data by the IBM 1800 commences when a light source mounted on the carriage with the toboggan passes a photocell attached to the channel wall. The collected data was then punched on IBM cards. A detailed procedure for data collection can be found elsewhere [6]. Experiments were performed for the Froude numbers $F = 0.280, 0.305, 0.316, 0.350$ and 0.379, and for the three longitudinal-cut positions $y_1 = 2.1$ ft., $y_2 = 3.0$ ft. and $y_3 = 3.6$ ft. from the center of the model.

III. DISCUSSION OF RESULTS

The experimental data obtained from the multiple longitudinal-cut technique for the toboggan were fed into a computer program to plot the longitudinal water-surface profile with distance measured along the direction of motion of the model. The computer plotted the surface profiles for the three longitudinal-cut positions and indicated the maximum and minimum heights of the wave profile for each of the longitudinal-cut positions. Table 1 presents the maximum and minimum wave heights so obtained for Froude numbers 0.280, 0.305, 0.316, 0.350 and 0.379. The suffixes 1, 2 and 3 with η_{max} or η_{min} ("max" corresponds to maximum wave height and "min" corresponds to minimum wave height) represent the wave heights for longitudinal-cut positions y = 2.1, 3.0 and 3.6 ft. respectively.

Following Landweber [7, 8, 9] and Tsai [6], the wave resistance for the toboggan was obtained by the finite-integral method, neglecting near-field effects. A record length of 45 ft. was used, beginning at 10 ft. from the center of the model. Table 1 shows the values of wave resistance for various Froude numbers.

In order to compare the results obtained for the toboggan, a Series-60, 10-foot model of the parent form of 0.60-block coefficient was chosen [5]. Table 2 gives some characteristics of this model.

Table 2. Characteristics of Series-60 Model

Length between perpendiculars, ft.	10.00
Waterline length, ft.	10.17
Block coefficient	0.60
Displacement, pounds	273.30
Wetted surface area, sq. ft.	17.64

The comparison between the results for the toboggan and this Series-60 model is given in Table 3.

Table 1. Values of Wave Amplitude and Wave Resistance for the Toboggan

Length of model = 8 ft; breadth = 2 ft; position of longitudinal cuts from the center of model: $y_1 = 2.1$ ft; $y_2 = 3.0$ ft; $y_3 = 3.6$ ft.

Suffix indicates the wave height at the corresponding position of longitudinal cut.

Run No.	Velocity ft/sec	Froude No.	$(\eta_{max})_1$ ft	$(\eta_{min})_1$ ft	$(\eta_{max})_2$ ft	$(\eta_{min})_2$ ft	$(\eta_{max})_3$ ft	$(\eta_{min})_3$ ft	Wave Resistance Coefficient $C_W x 10^6$
1	4.504	0.280	0.00362	-.00557	0.00529	-.00354	0.00565	-.00710	1.01
2	4.899	0.305	0.00570	-.00581	0.00366	-.00502	0.00659	-.00515	1.24
3	5.069	0.316	0.00462	-.00761	0.00568	-.00672	0.00602	-.00604	0.93
4	5.612	0.350	0.00351	-.00696	0.00549	-.00495	0.00504	-.00613	0.74
5	6.074	0.379	0.00425	-.00614	0.00793	-.00439	0.00678	-.00533	0.74

$$C_W = \frac{R_W}{\frac{1}{2}\rho V^2 L_{WL}^2}$$

Table 3. Comparison between Results for Toboggan and Series-60, 0.60-Block Model

Item	Froude Number	$(\eta_{max})_{max}$ inch	$(\eta_{min})_{min}$ inch	Wave-resistance coefficient $C_W x10^{-5}$
Toboggan	0.280	0.068	-0.085	0.101
	0.305	0.077	-0.070	0.124
	0.316	0.072	-0.091	0.093
10-ft Model	0.277	0.997	-0.683	79.9
	0.305	1.045	-0.694	85.9
	0.319	1.022	-0.663	86.8

One sees from Table 3 that the absolute values of the maximum and minimum wave heights for the Series-60 model are about 10 times larger than the corresponding values for the toboggan.

Figure 6 presents a typical longitudinal-cut surface profile for the toboggan at a Froude number of 0.305 and longitudinal-cut position at 3 ft. from the tank centerline. It is seen that, in the initial part, there is an insignificant variation of wave profile for a record length of about 12 ft. This is due to the fact that the waves from the wake have not yet reached the probe, unlike those of a ship model generating bow waves. This is indicated in figure 6 where the position at which the waves generated at the stern intersect the probe is shown. This verifies that the recorded waves were generated within the wake.

A typical longitudinal-cut surface profile for a Series-60 10-ft. model, at identical experimental conditions as the toboggan, is shown in figure 7. Comparison of figures 6 and 7 reveals that the mean wave length between the peaks is much higher for the 10-ft. model than for the toboggan. Furthermore, for the toboggan, the maximum amplitudes were 0.0043 ft. at a trough and 0.0032 ft. at a crest for the wave profile shown. For the 10-ft. model, however, a value of 0.058 ft. at a trough and 0.087 ft. at a crest were obtained. As is seen from the nature of the profiles in figures 6 and 7, the principal waves generated by the toboggan wake are of much smaller wave length than those of the Series-60 ship model, and a fine structure of higher harmonics is superimposed on them. Thus the two wave patterns are essentially uncorrelated. Hence, in considering the waves generated by the vorticity in the wake of a ship model, it appears reasonable to estimate the wave resistance of these waves separately from the wave resistance of the ship model. Since the wave amplitude of the former was found to be about 10 percent of the latter, this indicates that the wake would contribute only about one percent of the total wave resistance.

IV. CONCLUSIONS

1. Horizontally-oriented vorticity in a wake of a horizontal flat plate generates waves of amplitudes less than one-tenth of those of a ship form of the same length and wetted-surface area at the same Froude number.
2. The longitudinal-cut wave resistance due to the vorticity in a wake is about one percent of that of the associated ship model. This indicates that horizontally-oriented vorticity is a poor wave maker.

Figure 1, View of Toboggan

REFERENCES

1. R. Brard, "Viscosity, Wake and Ship Waves", *Journal of Ship Research*, Vol. 14, No. 4, December 1970.

2. J.C. Tatinclaux, "Effect of a Rotational Wake on the Wavemaking Resistance of an Ogive", *Journal of Ship Research*, Vol. 14, No. 2, June 1970.

3. R.F. Beck, "The Wave Resistance of a Thin Ship with a Rotational Wake", *Journal of Ship Research*, Vol. 15, No. 3, September 1971.

4. G.E. Gadd, "A Brief Note on Boundary Layer Effects on Ship Waves", N.P.L. Ship Division T.M. 23, April 1963.

5. S. Çalisal, "Effect of Wake on Wave Resistance", University of California, Berkeley, College of Engineering, Report No. 133, August 1971.

6. Chii-ell Tsai, "Study of Total, Viscous and Wave Resistance of a Family of Series-60 Models; Further Development of a Procedure for Determination of Wave Resistance from Longitudinal-Cut, Surface Profile Measurements", Ph. D. thesis, The University of Iowa, December 1972.

7. L. Landweber and K.T.S. Tzou, "Study of Eggers' Method for the Determination of Wavemaking Resistance", *Journal of Ship Research*, Vol. 12, No. 3, September 1968.

8. D.D. Moran and L. Landweber, "A Longitudinal-Cut Method for Determining Wavemaking Resistance", *Journal of Ship Research*, Vol. 16, No. 1, March 1972.

9. L. Landweber, "An Evaluation of the Method of Direct Determination of Wavemaking Resistance from Surface Profile Measurements", Proceedings of the International Seminar on Theoretical Wave Resistance, University of Michigan, Ann Arbor, Michigan, August 1963.

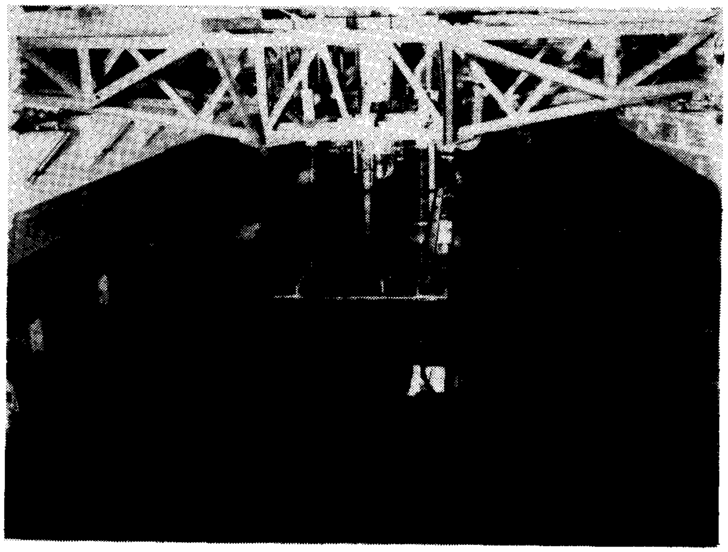
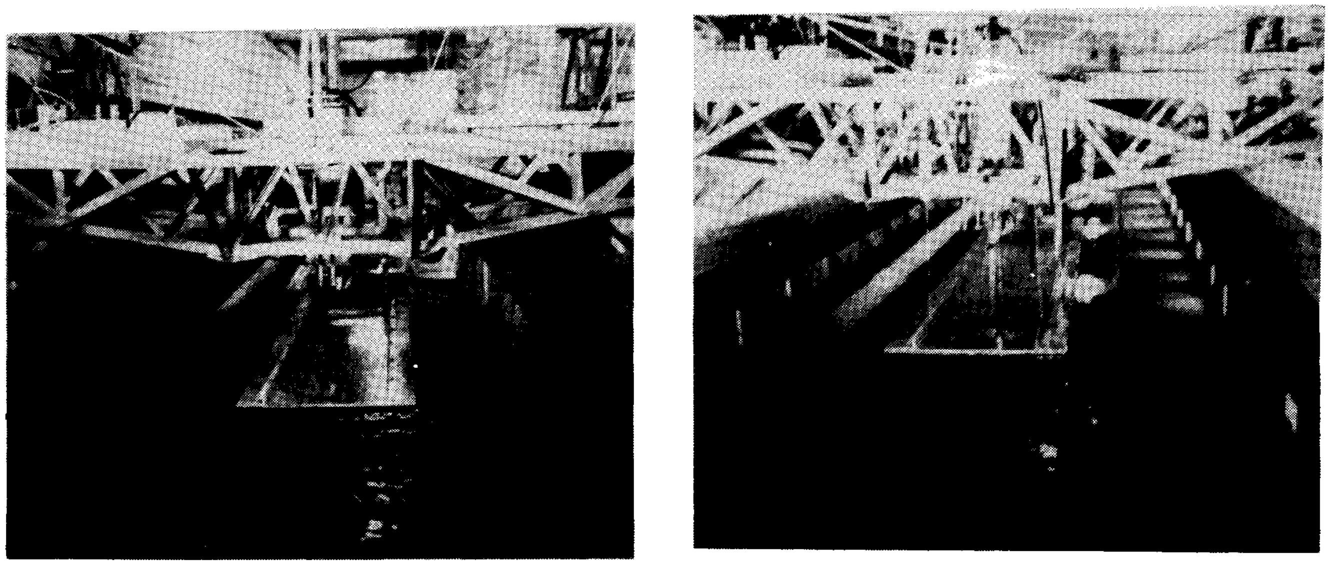


Figure 2. View of Toboggan Attached to Carriage



a) before adjustment

b) after adjustment

Figure 3. Waves Generated by Toboggan

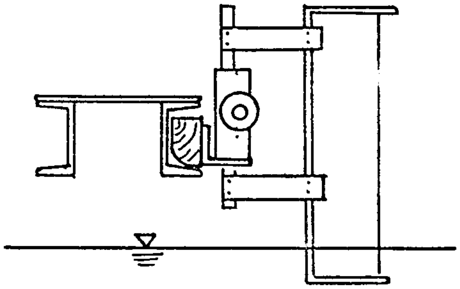


Figure 4. Wave Gauge Mounting

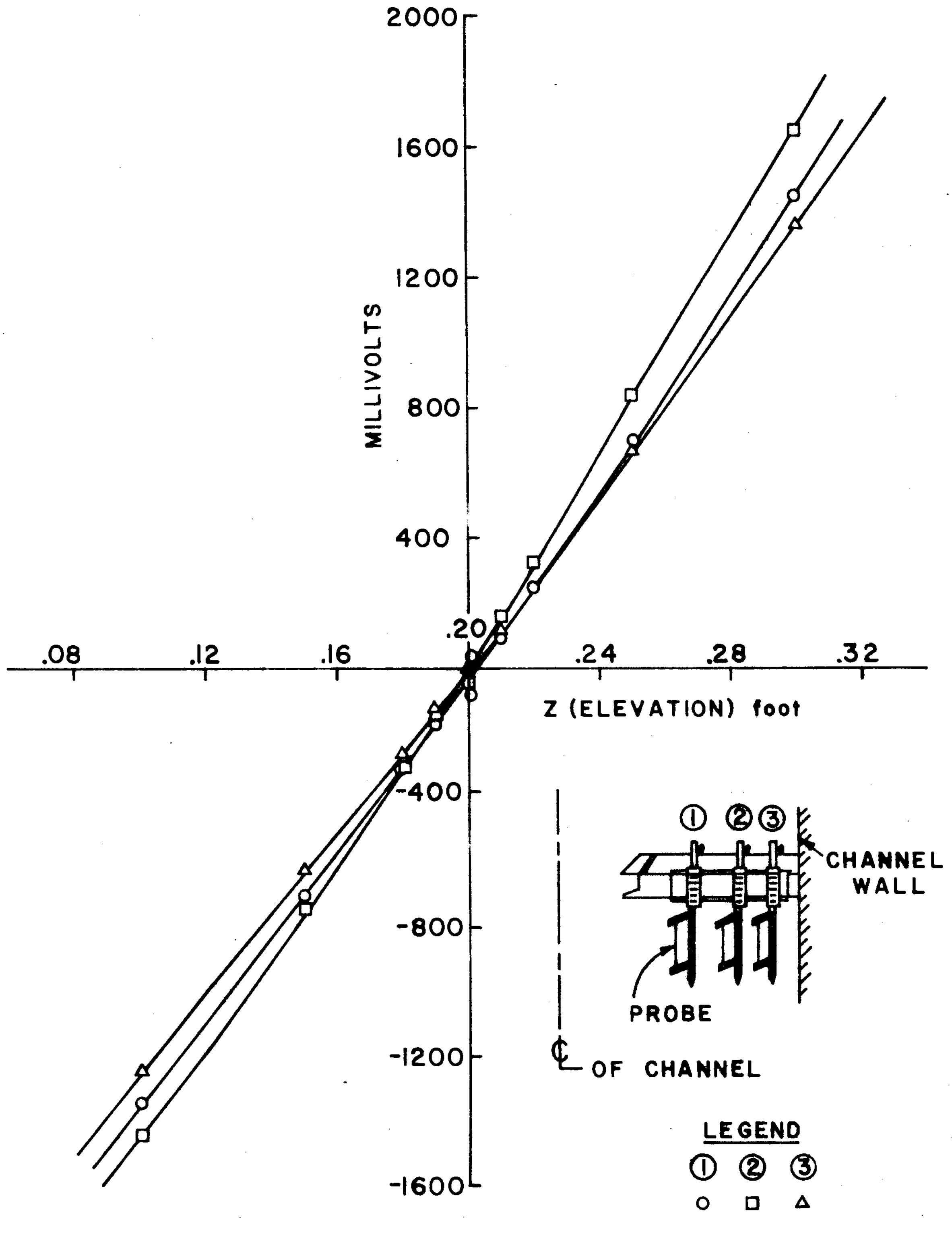


Fig. 5—TYPICAL STATIC-CALIBRATION CURVES FOR THREE STRAIGHT TEFLON-WIRE PROBES

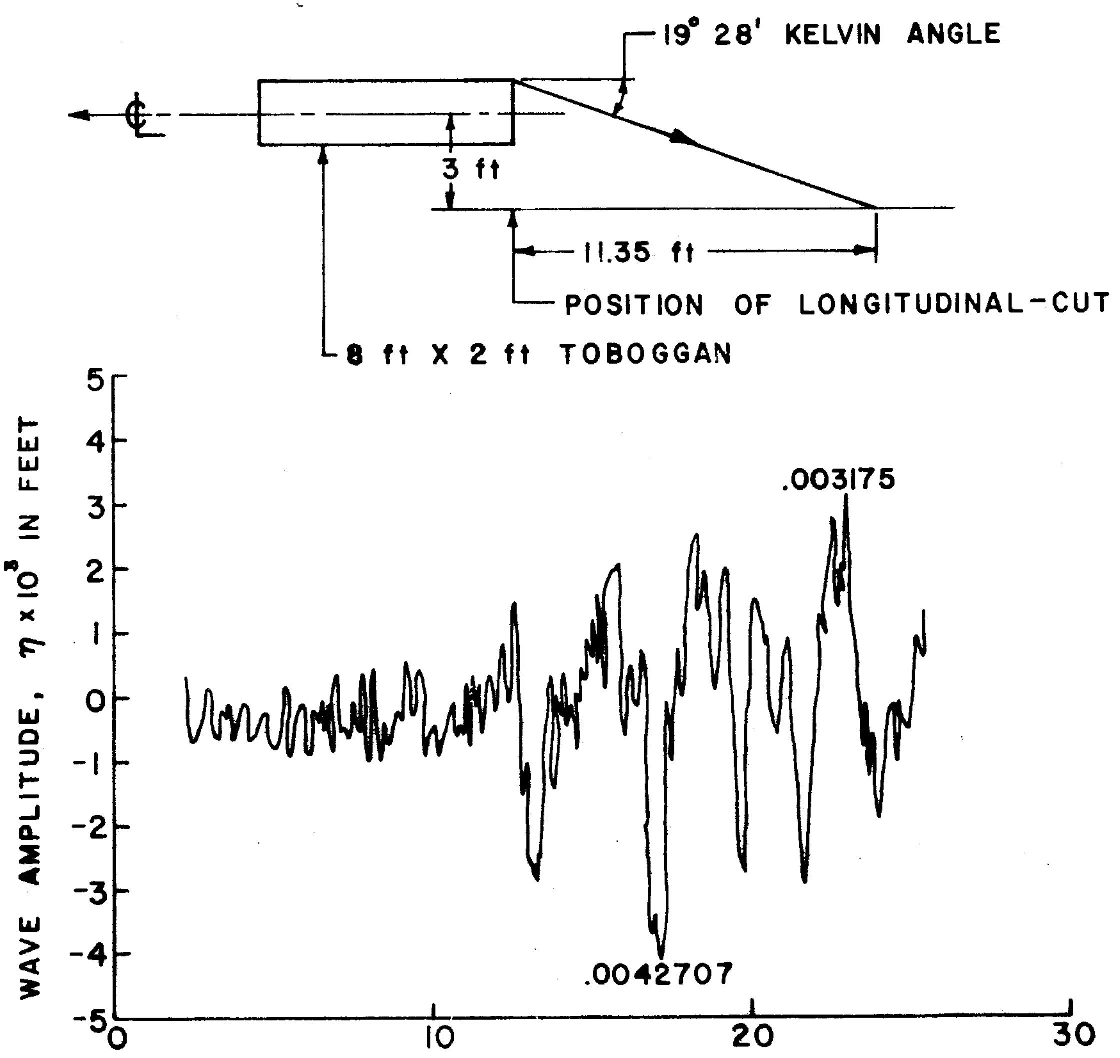


Fig. 6—TYPICAL LONGITUDINAL-CUT SURFACE PROFILE FOR THE TOBOGGAN, FROUDE NUMBER = 0.305

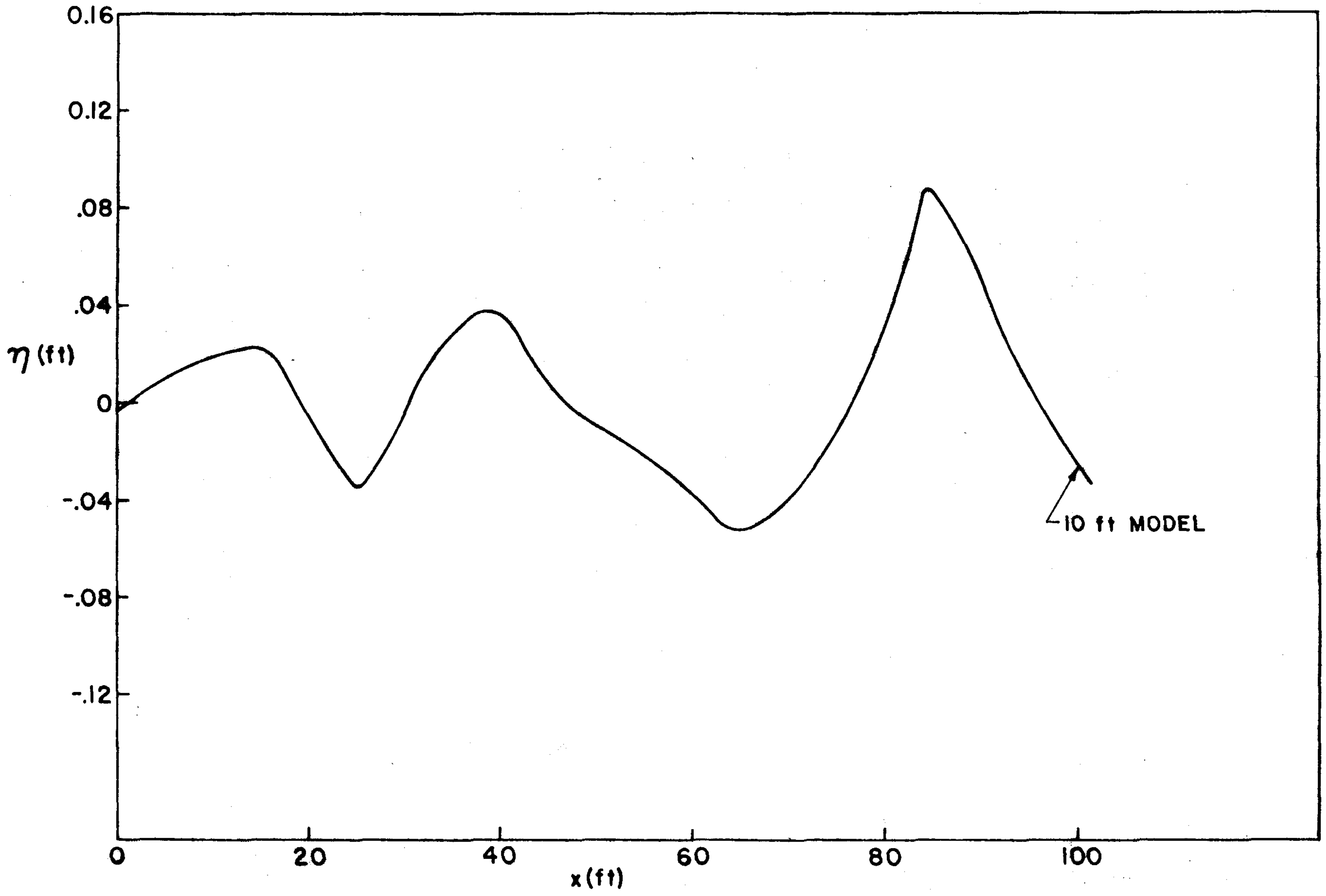


Fig. 7—TYPICAL LONGITUDINAL-CUT SURFACE PROFILE
FOR THE SERIES-60, 10 ft MODEL
FROUDE NUMBER = 0.305, LONGITUDINAL CUT POSITION = 3 ft

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER IIHR Report No. 153	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Experimental Study of the Wavemaking of Horizontally-Oriented Vorticity in a Wake		5. TYPE OF REPORT & PERIOD COVERED Interim
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) A. Swain and L. Landweber		8. CONTRACT OR GRANT NUMBER(s) N00014-68-A-0196-0010
9. PERFORMING ORGANIZATION NAME AND ADDRESS Institute of Hydraulic Research The University of Iowa		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS SR 023 01 01
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ship resistance
Wave making
Ship wakes

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Towing-tank experiments were conducted in order to investigate the wavemaking of horizontally-oriented vorticity in a wake, It was found that the amplitudes of the surface disturbance, measured with three capacitance wires, were about one tenth of those generated by a ship model of the same length and Froude number. Furthermore, the wave resistance was about one percent of that obtained for a Series-60 model of the same wetted-surface area.