Comparison of Measurements of Waves from a Boat with Model Tank Results

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Results are given of wave survey tests run on a 13-ft boat offshore with those obtained from corresponding ¼ and ⅛ scale models in a model tank; the comparison of wave profiles and resistance is very reasonable and encouraging to the Froude hypothesis of model scaling.

Nomenclature

F_r	= Froude number = $V/(gL)^{1/2}$
C_w	= wave resistance coefficient = $R_w/\rho/2\,SV^2$
C_{wT}	= C_w after truncation correction has been applied
V	= speed
L	= length
R_w	= wave resistance
S	= wetted surface
ρ	= fluid density
g	= acceleration of gravity

Introduction

THIS paper reports on recent results comparing wave measurements on a 13-ft full-scale boat, tested off the Webb beach in 1970 and 1972, with model tests on ¼ and ⅛ scale models in the Webb Model Tank in 1974. Wave resistance and wave spectra were derived from wave height data along a longitudinal cut as described in Ref. 1 and compared. Results of a previous attempt at such a comparison, using model tests run in 1970 on a ¼ scale model made from designers' lines, had shown a large difference[2]; for that reason a new ¼ scale model, based on faired lines taken off the actual boat, was constructed and run in the model tank. In addition, it was thought[2] that the finite tank breadth might have been an important factor in causing the aforementioned discrepancy, and for that reason a ⅛ scale model was made and run in the model tank to test that hypothesis. Care was also taken in the 1974 tests to match the speed, displacement, and running trim of the model more exactly to those in the 1972 offshore tests. Comparison of the 1970 offshore and model tests, as reported in Ref. 2, might be called "Phase I" of this effort, and comparison of the 1972 offshore tests with the 1974 model tests "Phase II." It will be seen that Phase II produced as good a comparison as Phase I did a bad one, for reasons to be discussed.

It should be noted that one purpose of the foregoing research, other than the attempted correlation itself, was to get into the business of running tests of this nature offshore, and to discover the special difficulties and problems involved with the eventual goal of running such tests on a full-scale ship.

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The latter has already been attempted by Tanaka[3] with indecisive results due to the presence in the tests of an important ambient sea. Treatment of the ambient sea, in fact, is thought to be the most important single technical problem peculiar to jumping out of the model tank into the sea itself, as anticipated by Snyder[4] who suggested signal averaging of multiple records to treat this effect. The present research employs the latter technique, but the search is continually on for a better one that would not require multiple records to be taken offshore.

Finally, mention should be made of the potential importance of the lateral distance y of the wave cut away from the boat or model in affecting the resulting wave resistance and wave spectrum in the model tank, as discussed by Ward and van Hoofff[5] and by Tsai and Landweber,[6] especially at high Froude numbers. Care was taken to investigate this effect in the present research.

Offshore Tests

Equipment and Technique

The layout of the 133 ft measured course is shown in Fig. 1. The facilities consisted of a tripod measuring station, a 10-ft wave staff and a measured course defined by the tripod, a buoy, and two sets of day markers forming two carefully surveyed ranges on shore. A test van, parked at the end of an existing jetty, contained the necessary instrumentation and recording facilities, and was connected via a waterproof 2-wire conductor to the wave staff. The instrumentation, calibration, and testing technique are described in more detail in Ref. 2. The test craft was timed both ahead and back along the course to determine the current; the latter was incorporated into the analysis of the offshore tests by a "Doppler" correction in the program.

The test craft, shown in Fig. 2, was converted from a "Tech" sailing dinghy for the present purpose. Characteristics are given in Table 1. The conversion included fitting of an outboard motor and a skeg, blocking up the centerboard trunk, providing a lever steering system and 2-person seat amidships, and converting the bow and stern flotation safety tanks to ballast tanks for the purpose of producing the correct displacement and trim underway. The craft was propelled by a long shaft outboard motor to minimize the effect of self-propulsion on the wave system.

Tests were carried out during two-month periods in the summers of 1970 and 1972. During this period, it was possible to obtain only a limited series of runs comprising from 6-12 useful runs in a series. There are a number of reasons for such a small number of successful test series. Because of the considerable amount of boating activity on Long Island Sound in the summer months, it was planned to test only in the early morning just after sunrise. Furthermore, it was necessary to test at high tide (± ½ hour) and zero current. Since the latter

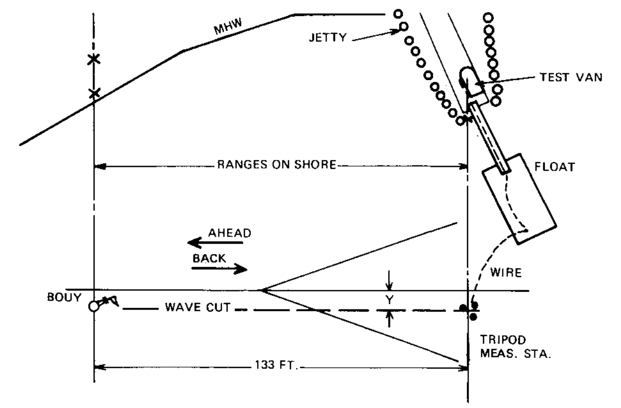

Fig. 1 Measured course off Webb Beach.

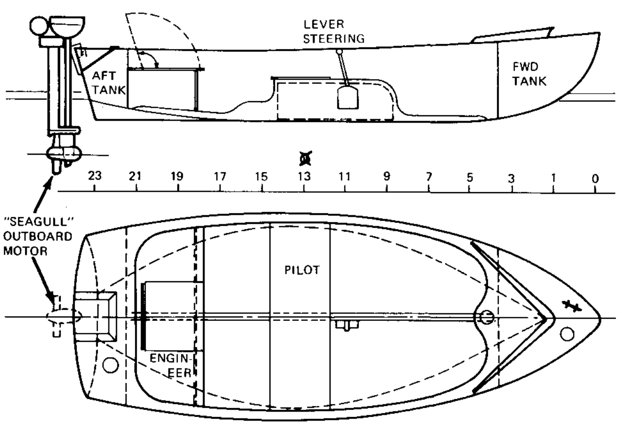

Fig. 2 Test craft.

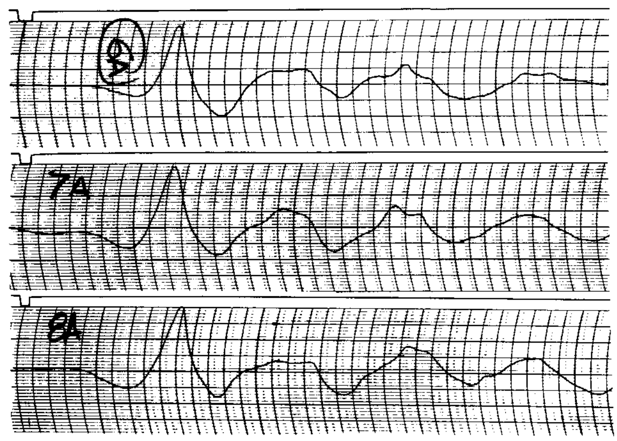

Fig. 3 Offshore records.

Table 1 Model and boat characteristics[a]

Item	mm ¼ Scale model	⅛ Scale model	Boat
LOA	3.125 ft	1.563 ft	12 ft 6 in.
LWL	2.84 ft	1.42 ft	11 ft 4⅜ in.
Beam (max)	1.25 ft	0.625 ft	5 ft 0 in.
Draft (skeg)	...	...	0 ft 8½ in.
Displacement	15.24 lb	1.91 lb	1,000 lb
Wetted surface	2.68 ft^2	...	...
Speed	4.22 fps	2.99 fps	5.0 knots

[a] Quantities not listed are to scale.

occurs twice a day and advances by an hour every day, there is only one set of two consecutive test days possible every 12 days, or 5 such occurrences or 10 days available in the 2-month period. But even this presupposes no early morning wind nor old sea left over from wind on the previous day. Moreover, many of the runs in a given day had to be thrown out for not hitting the course or speed exactly or due to an obvious swell from a commercial ship. Although 12 runs were possible over the period of negligible current, in 1970, around half the runs were thrown out on the average. One of the important factors in decreasing the number of lost runs was crew training, and by 1972 considerable reduction in lost runs had been accomplished.

Results

Typical records of wave elevation are shown in Fig. 3—it can be seen that these are contaminated by an ambient sea of about the same average height. These records are averaged to produce a "clean" signal; for this purpose, a minimum of 6 records seems to be necessary. A "clean" signal is shown in Fig. 4. A typical "clean" spectrum is shown in Fig. 5. The 1972 set, in which two groups of 12-13 were available, were used to investigate the convergence of the signal averaging technique. Figure 6 shows values of the wave resistance coefficient C_{wT} resulting from averaging different groups taken on August 18, 1972 to illustrate convergence. Results of the offshore tests in each group are shown in Table 2.

Model Tests

The model tests primarily used in this report were run in February 1974 on ¼ and ⅛ scale models of the actual craft, as discussed previously. The tests were run in the Webb Model Tank which is 10 ft wide and 5 ft deep. The model characteristics are given in Table 1 and the lines are shown in Fig. 7. Total resistance tests were run on both models, mainly to establish compensating trim moments to match running trim to that of the self-propelled craft. Wave survey tests were then run. Use of the actual model lines apparently produced a marked improvement over the previous 1970 results, almost a factor of 2:1. Values of C_w and C_{wT} are given in Table 3.

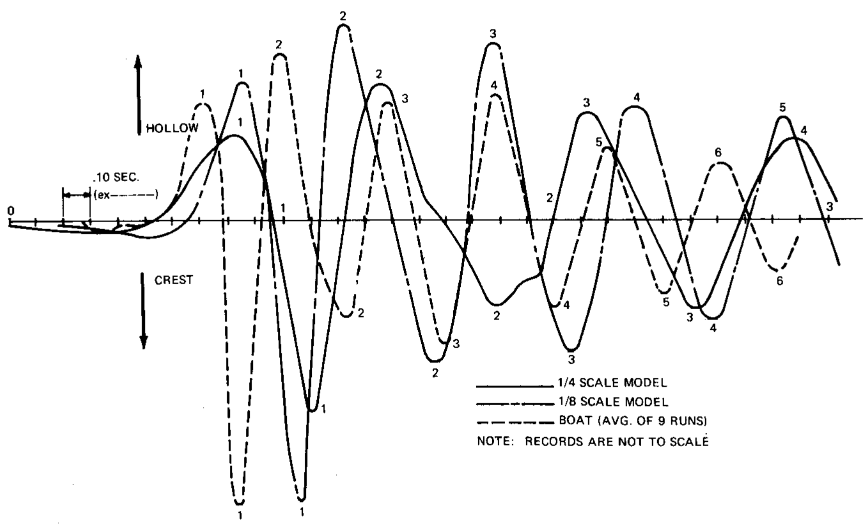

Fig. 4 Comparison of wave records.

Some minor variations in speed, trim, and displacement were made in the ¼ scale tests as well as in lateral position y. The latter was set at the same scaled value, for both models, as that obtained in the offshore tests. It can be seen that the model tests are consistent between the two scale models under similar conditions; here one should look at the values of C_{wT} after truncation. It can be seen also that the ⅛ scale model addition due to truncation is much less than that of the ¼ scale model (and this can be seen in Table 2 to be true for the offshore boat). This is entirely consistent with the idea that the tank "channels" the wave system, thus reinforcing the centerline system, for the wider model in the tank. The total energy, however, seems to not be affected by this process—an encouraging result for persons who carry out such tests in narrow tanks. One should be cautious, however, in drawing broad conclusions from such limited tests as others[5,6] have shown important y effects.

Typical model wave patterns are shown in Fig. 4 as well as a "cleaned-up" offshore wave pattern. One can see a definite resemblence, although no attempt has been made to convert the records in Fig. 4 to a common scale. The latter has been done and the corresponding wave heights (i.e., crest to hollow distances) are shown in Table 4. It can be seen that there is agreement within ±10% in between the two models and between the models and the boat results offshore. This is in basic agreement with the C_{wT}'s being within ±20% as the latter are derived from the wave profiles using a quadratic type of calculation. A look at Tables 2 and 3 shows the latter to be the case, especially when remembering that there were displacement and trim variations in the offshore tests.

Finally, typical wave spectra $A(\nu)$ are shown in Fig. 5 for the 1974 model tests and for the 1972 offshore tests, corresponding to the wave records in Fig. 4. The scales are arbitrary but peak values are indicated. One can see some resemblance between these curves. One should look at the curves mainly to the left of $\nu = 10$, due to the presence of a strong weighting function in the integration to derive values of C_w and C_{wT}.[5] The ⅛ scale model result is noticeably lower in the low-frequency region showing less tank wall "channeling" effect compared to the ¼ scale model. However, one wonders why this would not be true of the offshore records as well. Comparison of spectra in more detail would seem to be a subject for future investigation. At any rate, the integrated effects C_{wT} seem to agree quite well, as mentioned previously.

Table 2 Results of offshore tests (averaged runs)

Date	Explanation	V_{knots}	$10^3 C_w$	$10^3 C_{wT}$
8/4/72	All 12 records	5.01	4.39	4.57[a]
8/4/72	Best 9 records	5.02	4.51	4.72[a]
8/18/72	All 13 records	5.04	5.81	6.21
8/18/72	Best 10 records	5.04	5.72	6.27
8/13/70	All 6 records	4.92	3.51	3.75[a]
8/26/70	All 7 records	4.98	5.57	5.84

[a] Trimmed aft.

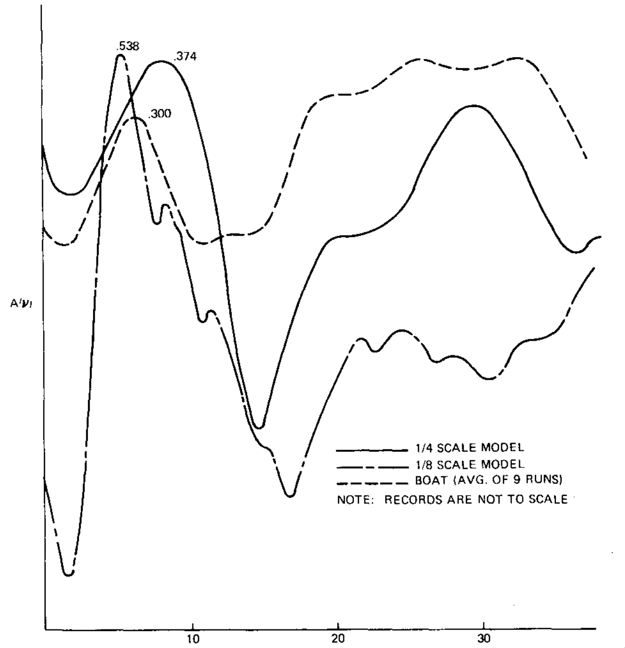

Fig. 5 Wave spectra.

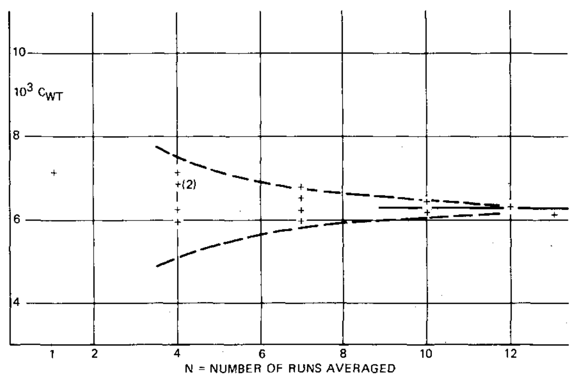

Fig. 6 Convergence of offshore records (Aug. 18, 1972).

Table 3 1974 Model test results (averages of 2-4 runs)

Scale	y ft[a]	V_{knots}[a]	Δlb[a]	$10^3 C_w$	$10^3 C_{wT}$
¼	7.0	5.00	1000	4.82	6.11
¼	7.0	5.00	1032	4.78	5.89
¼	7.0	5.00	1000[b]	4.49	5.58
¼	7.0	5.06	1000	5.04	6.58
¼	6.0	5.00	1000	5.29	6.44
¼	5.0	4.99	1000	5.57	6.43
⅛	7.0	4.95	1000	4.91	5.30
⅛	7.0	5.01	1000	6.09	6.25

[a] Full scale. [b] Trimmed aft 1.5 in.

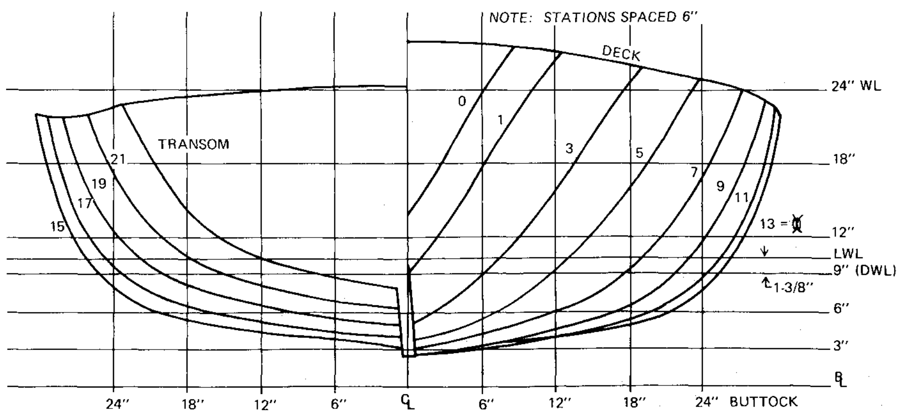

Fig. 7 Body plan (boat and models).

Table 4 Comparison of wave heights converted to inches full scale

Feature[a]	Boat	¼ Scale	⅛ Scale
C_1H_1	5.60	4.43	4.69
C_2H_2	3.68	4.00	3.79
C_3H_3	3.39	3.64	3.46
C_4H_4	2.98	2.61	2.38
C_5H_5	2.03	2.16	2.11
C_6H_6	1.51		1.82

[a] See Fig. 4.

Conclusions and Recommendations

The following conclusions are drawn and recommendations made on the basis of the results of this investigation. 1) Froude model scaling with respect to wave effects seems to be verified within ±10% for the wave records and ±20% for the resulting wave resistance. 2) Notwithstanding the previous conclusion, there are some interesting differences between the models, and between the models and the full-scale boat, considering wave effects which could be investigated further; this is especially true of the spectra involved. 3) Offshore wave survey tests, in conjunction with signal averaging, are seen to be a practical means of assessing wave resistance characteristics of a boat, albeit time-consuming and requiring multiple runs. The search for a data reduction technique requiring fewer runs should be continued. 4) This type of investigation should now be carried out for a full-scale ship, using wave bouys, etc., and a corresponding model in a model tank. Such an investigation, properly carried out, should go a long way towards establishing the validity of Froude scaling over a much larger scale ratio than was possible in the present research.

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