# THE DAVID W. TAYLOR MODEL BASIN

## UNITED STATES NAVY

# A COMPARISON OF RESISTANCE TESTS IN TWO BASINS OF A 13-FOOT MODEL OF A GREAT LAKES FREIGHTER

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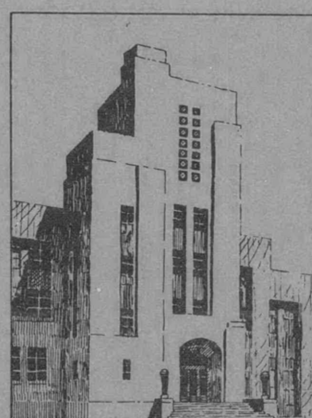

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## ABSTRACT

Comparative resistance tests of a 13-foot model of a Great Lakes freighter made at the University of Michigan Naval Tank and the David Taylor Model Basin show that the effective horsepower predicted from the Taylor Model Basin test is 5 per cent less, at design speed, than that predicted from the Universit of Michigan tests. The effective horsepower predicted from the results of Taylor Model Basin tests of a geometrically-similar 32-foot model is 4 per cent higher, at design speed, than that predicted from the Taylor Model Basin tests of the 13-foot model.

## INTRODUCTION

At the request of the University of Michigan Naval Tank (1)* the Taylor Model Basin made a comparative study of the results of resistance tests of a 13-foot model conducted in two different towing basins. The model, which represented a 630-foot Great Lakes freighter, had first been tested in the University of Michigan Naval Tank for the Pittsburgh Steamship Company. Subsequently, the Taylor Model Basin made resistance tests of a 32-foot model of the same vessel, built from the basic lines used for the 13-foot model. The effective horsepowers predicted from the tests of the 32-foot model (2), validated by a retest (3), were found to be not in agreement

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* Numbers in parentheses indicate references on page 16 of this report.

with those predicted from the tests of the smaller model. Consequently, a test by the Taylor Model Basin of the 13-foot model was considered advisable.

The purpose in testing the 13-foot model at the Taylor Model Basin was to determine whether the discrepancies between the predictions based on results obtained by the two model basins were due to the difference in size of the models or to peculiarities of the two test plants.

To determine which of these two factors was responsible the measured offsets of the 13-foot model are first compared to verify the similarity of the models. The test apparatus and procedures used for testing the 13-foot model at each of the basins are briefly described, and the results of these tests are analyzed. The discrepancies between the results of the Taylor Model Basin tests of the 13- and 32-foot models are discussed, and several theories which would explain discrepancies are offered.

## DESCRIPTION OF MODELS

The 13-foot model, designated Model 250, was constructed by the University of Michigan from the American Shipbuilding Company Plan H-407-35-0-1. This model has a streamlined stern post. The model as tested had a sole piece projecting from the bottom of the sternpost but the rudder was omitted.

The 32-foot model, designated Model 3994, was constructed by the Taylor Model Basin from the same basic plan used for Model 250, except for a contra-stern and contra-rudder which were built in accordance with Goldschmidt Plan 734.

The body plan of TMB Model 3994 and the measured offsets of Michigan Model 250 are compared in Figure 1. The stern arrangements of the two models are shown in Figure 2. As will be noted from the figures there are some differences in the shapes of the two models which might impair their geometrical similarity. An examination of Figure 1 indicates that the 13-foot and 32-foot models may have been constructed from slightly different lines. However, the overall dimensions are very nearly similar.

The texture of the surfaces of the two models which may affect their relative roughnesses is not discernible in the photographs in Figure 2. However, when Model 250 arrived at the Taylor Model Basin it was somewhat scarred from handling during shipment. The model was repaired and a preliminary test was made. The model was then sanded and refinished for the subsequent tests.

## TEST APPARATUS

The test of Model 250 at the University of Michigan was conducted, it is assumed, with their usual towing-test apparatus. Vertical water jets were ejected ahead of the stem of the model to stimulate turbulence.

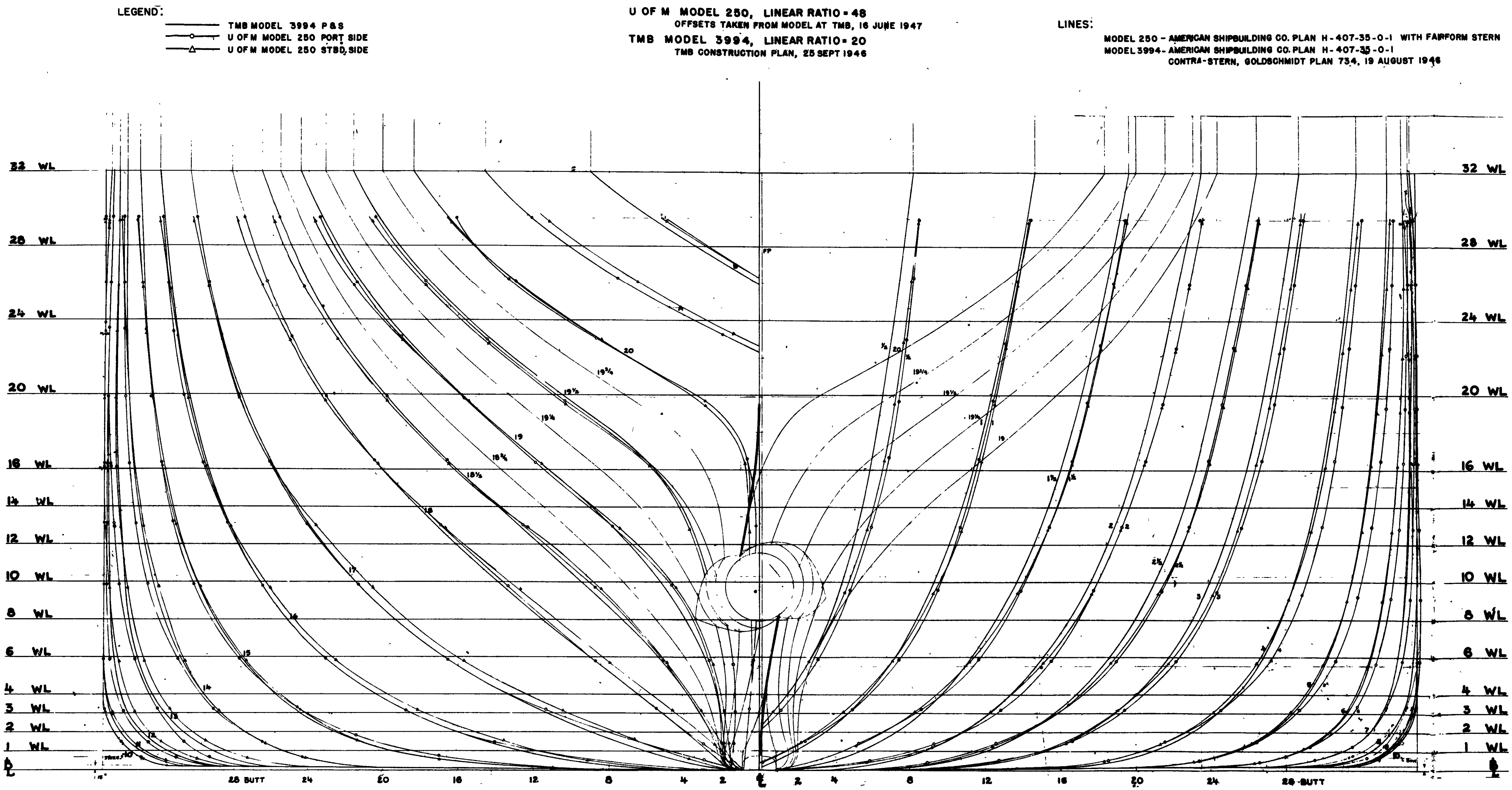


Figure 1 - Comparison of the Body Plan of Model 3994
with the measured offsets of Model 250

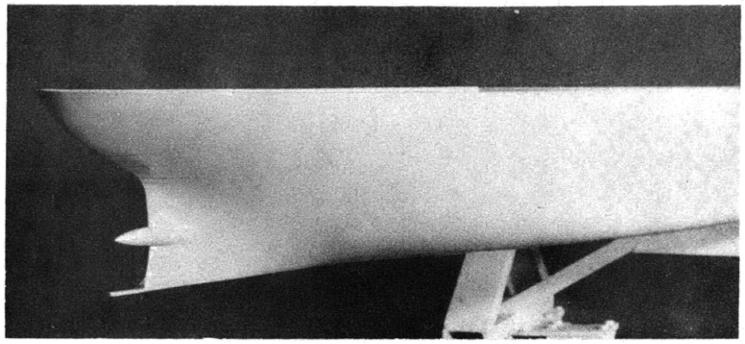

Figure 2a - Stern View of Model 250

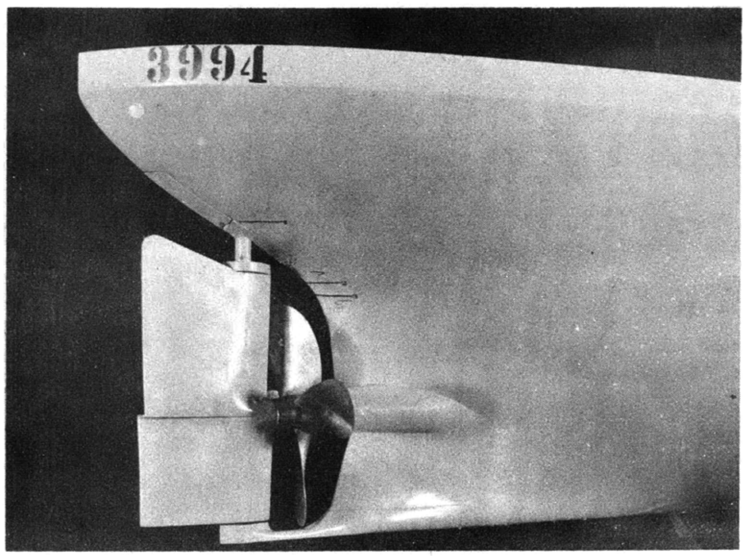


Figure 2b - Stern View of Model 3994
Propeller was unshipped for
Resistance Tests

Figure 2 - Stern Arrangement of Models of a Great Lakes Freighter

The tests of Model 250 at the Taylor Model Basin were first conducted with the towing apparatus normally used for small models. This apparatus consists of a light-duty towing bracket attached to the model at the bow, and a guide rod and fork at the stern. This device was discarded when it was found that, because of the play in the towing bracket, the model was not fully restrained from yawing. The yawing of the model caused considerable variation in the resistance data and the data could not be repeated on check runs. Therefore, for the later test, the model was towed with a 3-foot towline attached to the model at the top of the stem. The model was restrained laterally by two guide rods and forks, one near the bow and the other near the stern. With this arrangement the model could not yaw but was free to trim. The data obtained with this arrangement could be repeated and were therefore satisfactory. To determine whether the flow about the model was adequately turbulent, the tests were conducted both with and without a turbulence-stimulating rod fixed to the towing carriage ahead of the stem of the model. These tests showed no differences in resistance.

The tests of Model 3994 at the Taylor Model Basin were conducted with the usual heavy-duty towing apparatus which consists of a towing bracket at the bow and a counterbalance guide on the stern.

PRESENTATION OF DATA

The test conditions and other dimensions for each of the models are given in terms of their corresponding full-scale values in Table 1.

TABLE 1

Dimensions for Great Lakes Freighters Represented by Models 250 and 3994

| | Vessel Represented by Model 250 | Vessel Represented by Model 3994 |
|---|---|---|
| Waterline length, feet | 632.0 | 632.0 |
| Beam, feet | 70.00 | 70.00 |
| Draft, feet, fresh water | 24.00 | 24.00 |
| Displacement, tons | 25265 | 25383 |
| Trim | Zero | Zero |
| Wetted surface, square feet | 65,710 | 65,790 |

The test data from all the resistance tests, including those tests which were conducted with unsuitable apparatus, are tabulated as resistance in pounds against speed in knots in Appendix 1. These data are provided to permit the reader to make an independent analysis.

The significant tests are compared in Figure 3 as curves of non-dimensional residual-resistance coefficients plotted against speed-length ratio. On this basis, if the curves of residual-resistance coefficients of geometrically similar models coincide, the effective horsepowers calculated from them will be equal. The residual-resistance coefficients in Figure 3 were calculated as follows:

The total-resistance coefficient, which is defined as

$$C_t = \frac{R_t}{\frac{\rho}{2} S V^2}$$

where $C_t$ is the total-resistance coefficient,

$R_t$ is the total resistance,

$\rho$ is the mass density,

S is the wetted surface, and

V is the speed,

is calculated for each of the test spots. The frictional-resistance coefficient is obtained from the Schoenherr formula*

$$\frac{0.242}{\sqrt{C_t}} = \log_{10} R_e - C_t$$

where $C_t$ is the frictional-resistance coefficient,

$R_e$ is the Reynolds number, equal to $\frac{VL}{\nu}$,

V is the speed,

L is the waterline length, and

$\nu$ is the kinematic viscosity.

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* The Schoenherr formula is used for the calculation of frictional resistance both at the University of Michigan and the Taylor Model Basin

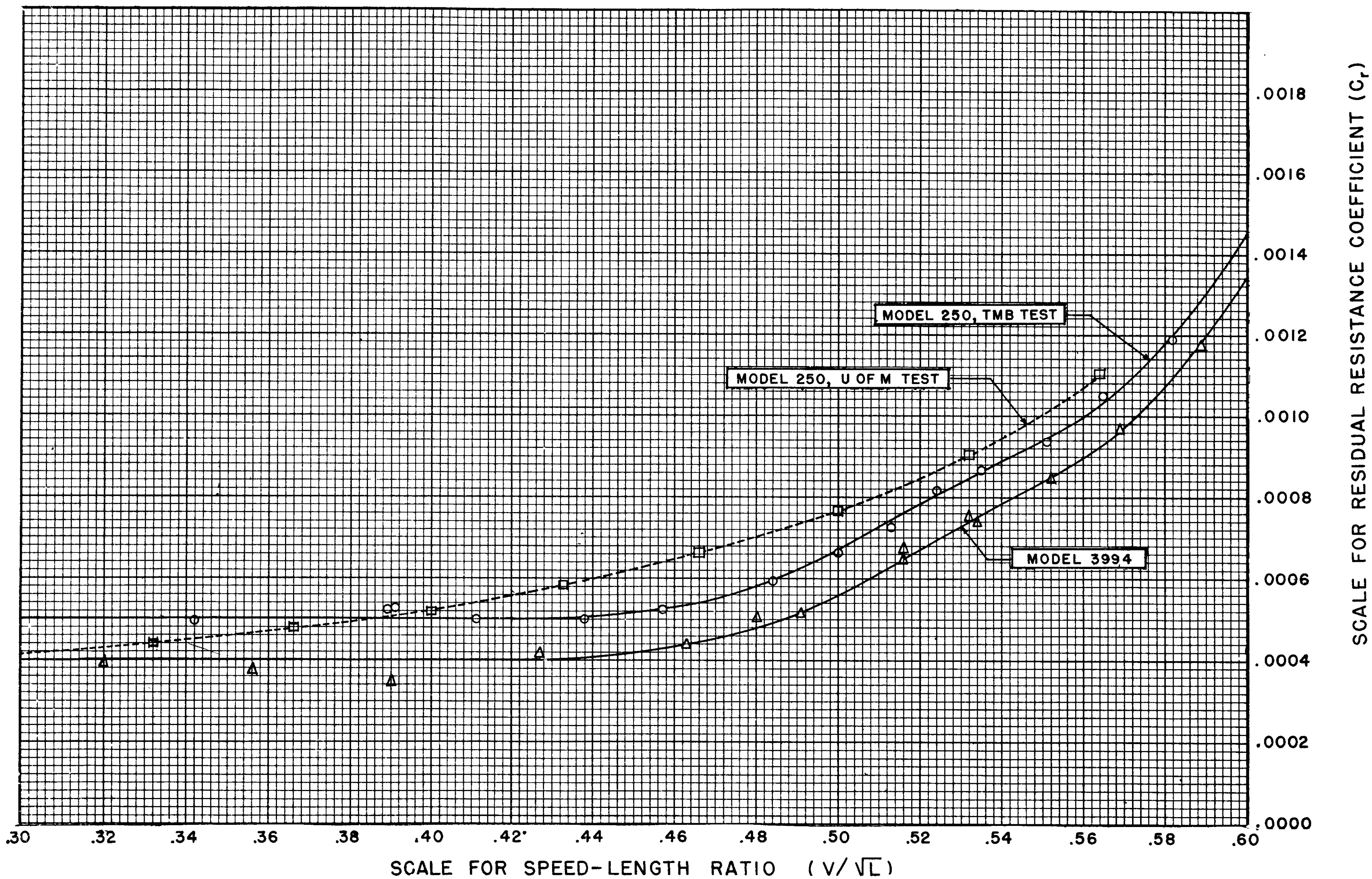


Figure 3 - Residual Resistance Coefficients for a Great Lakes Freighter Represented by Models 250 and 3994 Plotted Against Speed Length Ratio

The frictional-resistance coefficient is subtracted from the total-resistance coefficient to obtain the residual-resistance coefficient, or

$$C_t - C_f = C_r*$$

where $C_r$ is the residual-resistance coefficient.

Photographs showing the wave profiles of Model 250 and Model 3994 are given in Figures 4 and 5.

DISCUSSION OF RESULTS

A comparison of the residual-resistance coefficients obtained from the University of Michigan and the Taylor Model Basin tests of the 13-foot model, Figure 3, show that the latter tests produced somewhat lower coefficients. Since the test techniques employed at the two basins are not the same, it is conceivable that part of the difference in coefficients may be attributed to the difference in test methods and to the difference in basin sizes. Such variations in the results of tests of the same model in different basins are, unfortunately, not unusual. However, the fact that the model was refinished prior to the final tests at the Taylor Model Basin and therefore may have had less frictional resistance is also a factor which could affect the comparison.

The residual-resistance coefficients obtained from tests on the 32-foot model at the Taylor Model Basin are also

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* Since the residual resistance coefficient is by definition the difference between the total-resistance coefficient and the frictional-resistance coefficient calculated from the Schoenherr formula, apparent differences in $C_r$ are not necessarily due to actual differences in residual resistance but may be due to variations in frictional resistance.

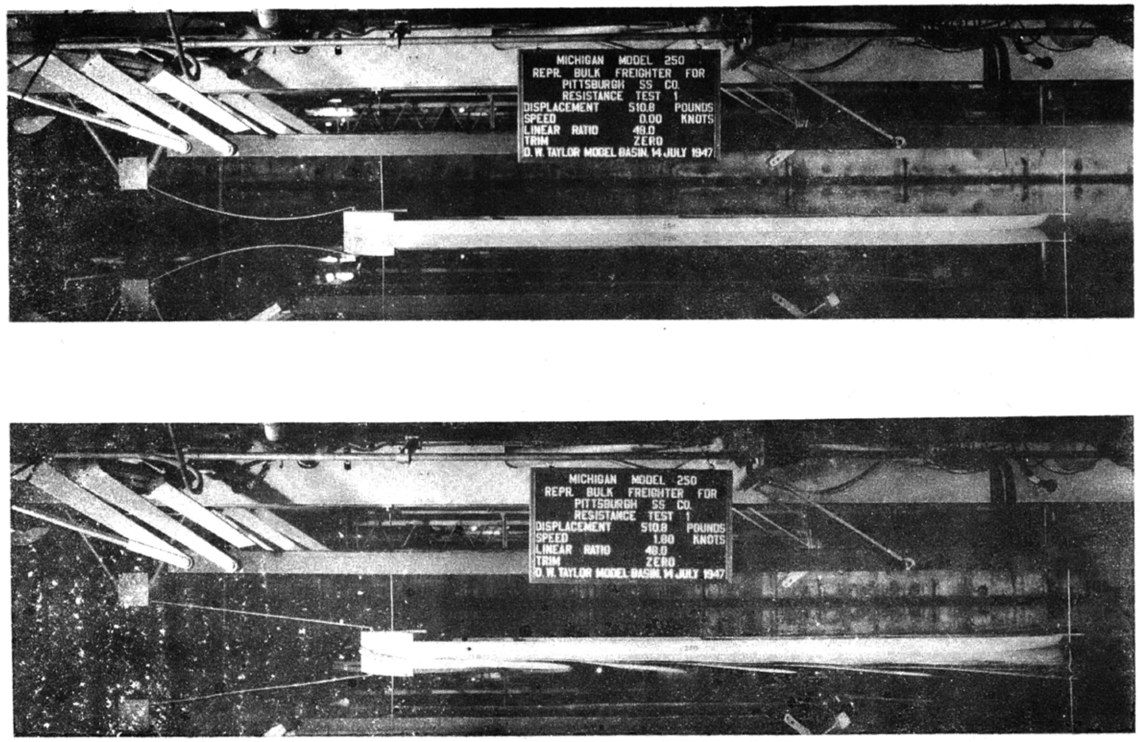


Figure 4 - Wave Profile of Model 250

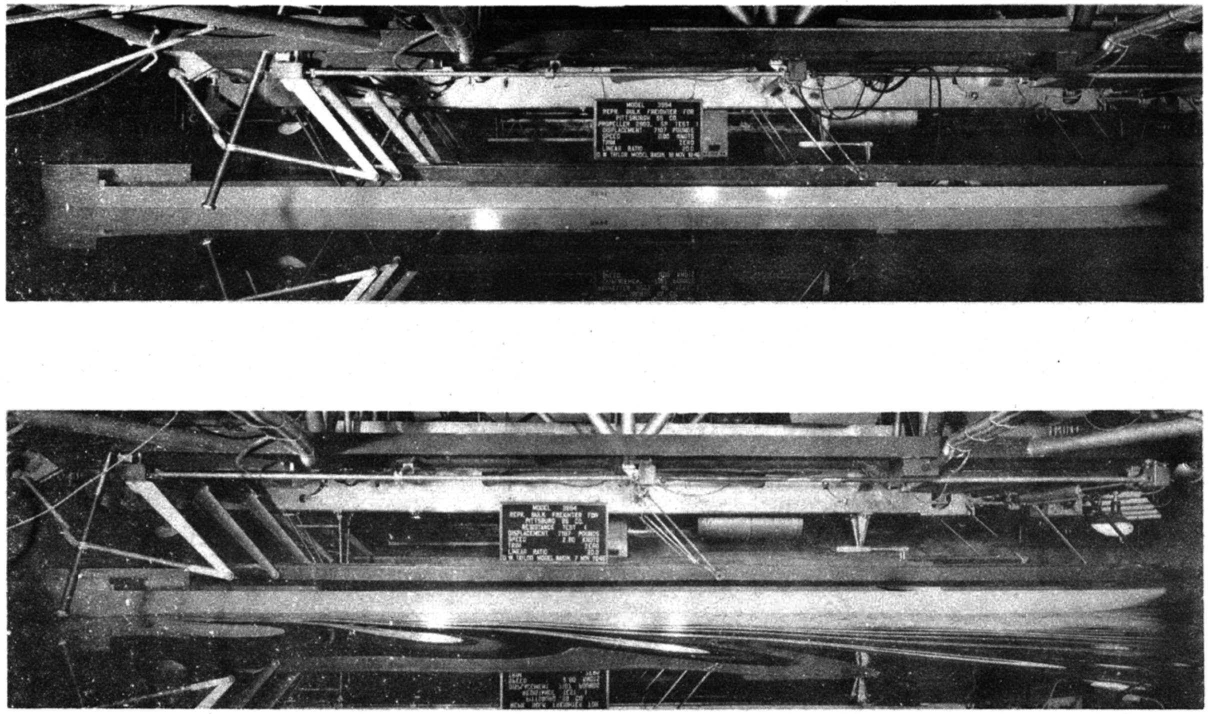


Figure 5 - Wave Profile of Model 3994

shown on Figure 3. It will be noted that these coefficients are lower than those obtained from either test of the 13-foot model.

The residual-resistance coefficients of Figure 3 are of the order of one third of the total-resistance coefficients for the full-scale vessel. The effective horsepowers derived by the use of the coefficients from tests of the 13-foot model are shown in Table 2 as ratios of the effective horsepowers derived from the tests of Model 3994.

TABLE 2

**Ratios of EHP Derived from Tests of Michigan Model 250 to the EHP Derived from Tests of TMB Model 3994.**

| | Ratios | | |
|---|---|---|---|
| | Michigan Model 250 | | TMB Model 3994 |
| Speed, Knots | U. of M. Test | TMB Test | TMB Test |
| 8 | 1.01 | 1.04 | 1.00 |
| 10 | 1.05 | 1.04 | 1.00 |
| 12 | 1.10 | 1.04 | 1.00 |
| 12.5 | 1.09 | 1.04 | 1.00 |
| 14 | 1.06 | 1.03 | 1.00 |

An inspection of the table shows that the Taylor Model Basin tests of the 13-foot University of Michigan model and 32-foot Taylor Model Basin model are consistent in that the ratios of effective horsepowers are about 1.04 for all speeds. This is also shown by a comparison of the shapes of the residual-resistance curves for these tests, Figure 3. On the basis of the experience of the Taylor Model Basin the difference of 4 per cent in effective horsepower as derived from tests of the two geometrically similar models is not considered unusual.

Several theories have been advanced as possible explanations for the effect of the size of the model on the predicted EHP. Although these theories are not within the scope of this report, they can be summed up as follows:

The Froude basic assumption considers that the actual frictional resistance of a given hull form is adequately represented by the frictional resistance of a flat plate of equal wetted surface towed parallel to the stream. This assumption is not strictly valid when geometrically similar models of different sizes are used since the slope of the frictional-resistance coefficient curve for such model hulls may be different from that of the equivalent flat plates. In other words, the results of tests of geometrically similar models of different sizes cannot always be correlated by using a flat-plate frictional-resistance formula. Some of the factors which might affect the slope of frictional-resistance coefficient curve are the effects of transverse and longitudinal curvature upon the thickness and velocity distributions of the boundary layer.

The theories tend to indicate that the results of tests of models of different sizes cannot always be correlated even when strict geometrical similarity exists. However, it must be pointed out that the differences in hull shapes and appendage arrangements between the 13-foot and 32-foot models, mentioned under "Description of Models," would undoubtedly affect the comparison. The effect of these differences cannot be appraised without additional tests of other models.

## CONCLUSIONS

The effective horsepower predicted from the Taylor Model Basin test of a 13-foot model of a Great Lakes freighter is approximately 5 per cent less, at design speed, than that predicted from the University of Michigan test, but is 4 per cent higher than the effective horsepower predicted from the Taylor Model Basin test of a 32-foot model of the same design.

It is considered that the Taylor Model Basin tests of the two models produced results which were consistent and that although the results were not in agreement, the difference was not unreasonably large.

## RECOMMENDATIONS

In view of the fact that the surface finish of Model 250 was changed at the Taylor Model Basin in conjunction with a change in towing gear, it is recommended that the University of Michigan retest the model to more accurately determine the effect of surface finish on its resistance.

REFERENCES

(1) Pittsburgh Steamship Company letter of 26 February 1947 enclosing letter of Professor Baier of the University of Michigan of 26 February 1947 to TMB.

(2) TMB letter QM/Pittsburgh Steamship Co. of 13 Dec 46 to Pittsburgh Steamship Company.

(3) TMB letter QM/Pittsburgh Steamship Co. of 31 Jan 47 to Pittsburgh Steamship Company.

# APPENDIX 1

## DATA FROM RESISTANCE TESTS OF

## MICHIGAN MODEL 250 and TMB MODEL 3994

TABLE 3

Data Recorded and Observed on Resistance Tests of Michigan Model 250 at the University of Michigan Naval Tank

Model Number ---------250
Date of Test ---------2 October 1946
Auxiliary Dynamometer Spring -------
Finish of Model Surface -----U of M
Linear Ratio ---------48

Test Number ----------
Displacement ---510.8 pounds
Trim -----------zero
Wetted Surface Area --28.52 square feet
Temperature of Water --72.0 deg. F.

| Speed of Model, knots | Total Resistance of Model, pounds |
|---|---|
| 0.845 | 0.244 |
| 0.965 | 0.314 |
| 1.086 | 0.390 |
| 1.207 | 0.474 |
| 1.327 | 0.569 |
| 1.448 | 0.676 |
| 1.569 | 0.795 |
| 1.689 | 0.931 |
| 1.811 | 1.086 |
| 1.930 | 1.266 |
| 2.052 | 1.480 |

Note: Water jets used to stimulate turbulence.

TABLE 4

Date Recorded and Observed on Resistance Tests of Michigan Model 250 at the Taylor Model Basin

Model Number - - - - - - - - - - 250

Date of Test - - - - - - - - - - 2 June 1947

Auxiliary Dynamometer Spring - Two 2-pound springs

Finish of Model Surface - - - U of M

Linear Ratio - - - - - - - - - -48

Test Number - - - - -1

Displacement - - - - 510.8 pounds

Trim - - - - - - - - - zero

Wetted Surface Area - 28.52 square feet

Temperature of Water -65.5 deg F.

| Speed of Model, knots | Total Resistance of Model, pounds | Speed of Model, knots | Total Resistance of Model, pounds |
|---|---|---|---|
| 0.50 | 0.08 | 1.90 | 1.22 |
| 1.00 | 0.35 | 2.29 | 2.20 |
| 1.40 | 0.65 | 2.50 | 3.05 |
| 1.80 | 1.11 | 0.40 | 0.07 |
| 2.195 | 1.93 | 0.705 | 0.19 |
| 0.805 | 0.22 | 1.095 | 0.41 |
| 1.195 | 0.49 | 1.50 | 0.72 |
| 2.00 | 1.45 | 1.705 | 0.93 |
| 0.59 | 0.13 | 1.85 | 1.18 |
| 1.40 | 0.67 | 2.10 | 1.62 |
| 0.90 | 0.26 | 2.40 | 2.50 |
| 1.30 | 0.56 | 1.80 | 1.07 |
| 1.60 | 0.85 | | |

Note: Light-duty towing bracket at the bow and guide rod and fork at the stern used to tow the model.

TABLE 5

Data Recorded and Observed on Resistance Tests of Michigan Model 250 at the Taylor Model Basin

Model Number - - - - - - - - - - 250

Date of Test - - - - - - - - - - 25 June 1947

Auxiliary Dynamometer Spring - Two-2 pound springs

Finish of Model Surface - - - -TMB

Linear Ratio - - - - - - - - - - 48

Test Number - - - - - 1A

Displacement - - - - -510.8 pounds

Trim - - - - - - - - - -Zero

Wetted Surface Area - 28.52 square feet

Temperature of Water - 65.5 deg. F.

| Speed of Model, knots | Total Resistance of Model, pounds | Speed of Model, knots | Total Resistance of Model pounds |
|---|---|---|---|
| 1.99 | 1.40 | 1.75 | 1.00 |
| 2.50 | 2.93 | 1.75 | 1.01 |
| 0.50 | 0.08 | 1.85 | 1.15 |
| 1.00 | 0.32 | 1.94 | 1.36 |
| 1.49 | 0.71 | 2.15 | 1.74 |
| 0.40 | 0.07 | 1.95 | 1.37 |
| 0.64 | 0.15 | 2.00 | 1.405 |
| 0.85 | 0.26 | 2.35 | 2.37 |
| 1.19 | 0.50 | *0.50 | 0.13 |
| 1.35 | 0.59 | *1.00 | 0.32 |
| 1.65 | 0.95 | *1.49 | 0.71 |
| 1.75 | 1.08 | *0.50 | 0.13 |
| 1.35 | 0.60 | *0.99 | 0.32 |
| 1.65 | 0.87 | *1.49 | 0.72 |

Note: Light-duty towing bracket at the bow and guide rod and fork at the stern used to tow the model.

* 1/16-inch diameter turbulence stimulating rod was towed 8 inches ahead of the model.

TABLE 6

Data Recorded and Observed on Resistance Tests of Michigan Model 250 at the Taylor Model Basin

Model Number - - - - - - - - - 250

Date of Test - - - - - - - - - 14 July 1947

Auxiliary Dynamometer Spring -None

Finish of Model Surface - - -TMB

Linear Ratio - - - - - - - - - 48

Test Number - - - - - 1B

Displacement - - - - -518.8 pounds

Trim - - - - - - - - - - Zero

Wetted Surface Area - 28.52 square fee

Temperature of Water - 68.0 deg. F

| Speed of Model, knots | Total Resistance of Model, pounds |
|---|---|
| 1.00 | 0.34 |
| 1.59 | 0.81 |
| 2.00 | 1.37 |
| 0.50 | 0.12 |
| 0.757 | 0.22 |
| 2.50 | 3.07 |
| 1.40 | 0.65 |
| 1.42 | 0.65 |
| 1.85 | 1.14 |
| 2.24 | 2.025 |
| 1.24 | 0.50 |
| 1.49 | 0.71 |
| 1.815 | 1.07 |
| 1.66 | 0.88 |
| 1.755 | 0.99 |
| 1.95 | 1.29 |
| 2.11 | 1.57 |
| 1.90 | 1.21 |
| 2.06 | 1.47 |

Note: Model was towed by a string attached to the bow and guided by two guide rods and forks, one at the bow and the other at the stern.

TABLE 7

**Data Recorded and Observed on Resistance Test of TMB Model 3994 at the Taylor Model Basin**

**Model Number** - - - - - - - - - 3994

**Date of Test** - - - - - - - - - - 7 November 1947

**Auxiliary Dynamometer Spring**-Two 20-pound springs

**Finish of Model Surface** - - -TMB

**Linear Ratio** - - - - - - - - - - 20

Test Number - - - - - - 1

Displacement - - - - -7107 pounds

Trim - - - - - - - - - - -Zero

Wetted Surface Area - 164.48 square feet

Temperature of Water -66 deg. F

| Speed of Model, knots | Total Resistance of Model, pounds |
|---|---|
| 0.70 | 0.89 |
| 1.00 | 1.70 |
| 1.40 | 3.20 |
| 1.80 | 5.00 |
| 2.19 | 7.10 |
| 2.60 | 10.10 |
| 2.80 | 11.80 |
| 2.99 | 14.30 |
| 3.49 | 23.80 |
| 1.20 | 2.38 |
| 1.60 | 4.00 |
| 2.00 | 6.05 |
| 2.40 | 8.60 |
| 2.70 | 11.00 |
| 2.90 | 13.10 |
| 3.20 | 17.25 |
| 2.40 | 8.60 |
| 3.30 | 19.30 |
| 2.90 | 13.20 |
| 3.00 | 14.10 |
| 3.10 | 15.70 |

**Note:** Model was towed by a heavy-duty towing bracket at the bow and a counterbalance guide on the stern.

TABLE 8

Data Recorded and Observed on Resistance Tests of TMB Model 3994 at the Taylor Model Basin

Model Number - - - - - - - - - 3994

Date of Test - - - - - - - - - 24 January 1947

Auxiliary Dynamometer Spring-Two-20-pound springs

Finish of Model Surface - - -TMB

Linear Ratio - - - - - - - - - 20

Test Number - - - - -4

Displacement - - - - 7107 pounds

Trim - - - - - - - - - Zero

Wetted Surface Area- 164.48 square feet

Temperature of Water-61.5 deg. F

| Speed of Model, knots | Total Resistance of Model, pounds | Speed of Model, knots | Total Resistance of Model, pounds |
|---|---|---|---|
| 0.70 | 0.87 | 2.91 | 13.30 |
| 1.00 | 1.68 | 3.19 | 17.25 |
| 1.40 | 3.06 | 3.30 | 19.15 |
| 1.80 | 5.00 | 2.60 | 10.20 |
| 2.19 | 7.10 | 2.79 | 12.10 |
| 2.58 | 9.95 | *0.70 | 0.88 |
| 2.79 | 12.10 | *1.00 | 1.70 |
| 2.99 | 14.30 | *1.40 | 3.10 |
| 3.50 | 24.30 | *1.80 | 5.10 |
| 1.19 | 2.30 | *2.19 | 7.30 |
| 1.60 | 4.00 | *2.60 | 10.30 |
| 2.00 | 6.05 | *2.78 | 12.00 |
| 2.41 | 8.60 | *2.99 | 14.10 |
| 2.70 | 11.25 | *3.49 | 24.60 |

Note: Model was towed by a heavy-duty towing bracket at the bow and a counterbalance guide on the stern.

* 1/8-inch diameter turbulence stimulating rod was towed 9 inches ahead of the model.