T H E U N I V E R S I T Y O F M I C H I G A N

COLLEGE OF ENGINEERING
Department of Naval Architecture and Marine Engineering

Final Report

RESISTANCE AND PROPULSION TESTS ON TWO SERIES 60 MODELS

Finn C. Michelsen
R. B. Couch
Hun Chol Kim

ORA Project 03509

under contract with:

DEPARTMENT OF COMMERCE
MARITIME ADMINISTRATION
CONTRACT NO. MA-2084
WASHINGTON, D.C.

administered through:

OFFICE OF RESEARCH ADMINISTRATION   ANN ARBOR

April 1961

I. INTRODUCTION

This report presents the result of resistance and self-propulsion tests of two Series 60 parent models carried out at the Ship Model Towing Tank of The University of Michigan from March to August, 1960, and November, 1960. The parent models pertaining to these tests are David Taylor Model Basin (DTMB) Series 60 Model Nos. 4210 (0.60 block coefficient) and 4213 (0.75 block coefficient). Corresponding numbers of the Michigan models are Nos. 912 and 913, respectively.

The original DTMB parent models were 20 feet (LBP) long compared to the 14-foot models used at Michigan. DTBM data were to be used as the basis for comparison. Thus the purposes of the tests may be summed up as follows:

1. Development of techniques and instrumentation for propulsion and propeller tests at The University of Michigan Tank.

2. Correlation of data from the Michigan Tank with those of DTMB.

It may be pointed out that self-propulsion tests have not previously been conducted at Michigan.

For these purposes, the U.S. Maritime Administration has sponsored the project under U.S. MARAD Contract No. MA-2084, ORA Project 03509.

II. SUMMARY

Results of the resistance tests are summarized in Figs. 1-4. Those of the open-water and self-propulsion tests follow in Figs. 5-8. Calculation of self-propulsion data are given in Tables 3-6 in the appendix.

The figures are self-explanatory. Methods of data reduction are identical to the standard method used at DTMB. The 1947 ATTC friction formulation is used throughout.

The resistance data agree within 5% of C_r for Model No. 912 (0.60 block) and within 10% for Model No. 913 (0.75 block). Better agreement is achieved with the finer model, but all data show a reasonably good correlation.

Correlation of open-water propeller data show better agreement for UM Prop. No. 2 (used with UM Model No. 913). The first propeller, UM Prop. No. 1, was found to have 6.7% higher pitch than the parent's. This would account for some of the deviation in the test data for Prop. No. 1.

Self-propulsion test data indicate a good agreement in shaft horsepower. The higher pitch of propeller No. 1 accounts for the deviation in rpm in Model 912. Wake frictions and thrust deduction fractions are generally higher than shown by DTMB data.

Wall-effect corrections made in both EHP and SHP tests were based on a tentative, unpublished formula developed in the National Physical Laboratory in England.

For turbulence stimulators, a 0.036-in.-diameter trip wire placed at 5% LBP from the fore perpendicular was used. For Model 913, an additional trip wire placed at the quarter point of the stern was used. This is believed to stabilize the separation point. Although it seems to be effective, in the light of slightly higher C_r values found in Model No. 913 compared to those of DTMB, it will have to be more fully explored.

In summing up, the correlation of data from the Michigan Tank with those of DTMB is believed to be good. The technique of conducting these tests has been worked out, and with a new carriage and more test data better correlation should be obtainable.

III. MODELS, EQUIPMENT, AND TEST PROCEDURES

A. MODELS AND THEIR SELECTION

Model sizes were chosen so that the propeller size would not be less than six inches in diameter to avoid appreciable scale effect and that the model would not be so large that appreciable restricted channel effects were present. Both models were built to a size of 14 feet LBP. The propellers selected were the intermediate sizes of the three tested by DTMB on each of their models, DTMB Prop. No. 3378 and No. 3379 for 0.60 block and 0.75 block models, respectively. The Michigan Prop. No. 1 for 0.60 block model is 6.272 in. in diameter, and Prop. No. 2 for 0.75 block model, 6.969 in. in diamter.

The ship models were constructed of lifts of sugar pine in much the same manner as is done with wood models at DTMB. They were painted with several coats of gray enamel and varnished. The models were fitted with shoepiece and rudder (and a dummy hub for resistance tests) made geometrically similar to the DTMB models. Location of propellers with respect to bossing was controlled by reading the thrust gage within a given range while running—a necessary procedure because the thrust gage is directly connected to the propeller in such a way that the propeller has about 3/8 in. of "play" in a fore and aft direction over the full range of the gage. Rudder angles were zero for all tests. All tests were run at design displacements. Model and propeller data are given in the appendix, Tables 1 and 2.

B. EQUIPMENT

For resistance tests the old spring dynamometer was used to some extent. In most cases, however, and for all self-propulsion tests the towing force was measured with an electronic dynamometer developed at this tank. In addition to being more accurate, the electronic dynamometer indicates force directly in pounds, and makes it possible to obtain several sets of data points during one run in the tank. Self-propulsion data were obtained from simultaneous readings of all instruments, and not from average values.

A brief description of the instrumentation is as follows.

Towing Carriage.—Electric-powered with Ward Leonard control system. 25-hp motor, maximum speed about 7.5 knots. (To be replaced with a new carriage with a maximum speed of about 20 ft/sec and equipped with electronic speed control in 1961.)

Resistance Dynamometer.—The new electronic resistance dynamometer built at The University of Michigan consists of a transducer and displacement indicator connected to an x-y plotter. It was used both for resistance tests and for the propulsion tests. This dynamometer is designed so that any part of total resistance can be counterbalanced by means of weights.

Propulsion Dynamometer.—Standard 1/8-hp Kempf and Remmers J-05 mechanical propulsion dynamometer utilizing a 220-volt d-c drive. The tachometer was altered from the original mechanical to a photoelectric type using a digital counter for revolution display.

Carriage Speed Indicator.—A new rotopulser driven from the motor shaft with an electronic digital display unit was used to indicate carriage speed. With proper settings of constants on the instrument panel, carriage speed may be directly read in ft/sec, mph, knots, etc.

Figure 10 shows the equipment arrangement for self-propulsion tests. The equipment list, corresponding to the numbers indicated on Fig. 10, is as follows:

1. Autograf - Two-axis recorder, Model No. 3, Series 78, F. L. Mosely Co., Pasadena, California.

2. Displacement Indicator - Model 300, Daytronic Corp., Dayton, Ohio.

3. Force Transducer - Model 140-10 (with magnetic shield), Daytronic Corp.

4. R-C Filter - 0-10,000 MFD in steps of 1,000 MFD, 15 max volts.

5. Rheostat Control.

6. Tachometer Head - Model 506 A, Series 003-01393, Hewlett Packard Co.

7. Propeller Dynamometer - Kempf and Remmers J-05.

8. Electronic Counter, Model 523B, Series 675, Hewlett Packard Co.

9. Dynamometer Frequency Counter - 610, Series No. 101, Dynapar Corp., Chicago, Illinois

10. Rotopulser - Dynapar, 1200 pulses per revolution.

Propeller Boat.—For open-water propeller tests, a stainless-steel boat was built. Both dynamometers, Kempf and Remmers J-05 and J-04, fit into this boat.

Open-Water Dynamometer.—Both propellers were first tested with the 1/8-

hp Kempf and Remmers J-05 dynamometer. A new 1-hp Kempf and Remmers J-04 was later used for retests at higher Reynolds numbers and and low values of speed of advance. Propeller dynamometers are shown in Figs. 12 and 13. Installations of dynamometers in the model and propeller boat are shown in Figs. 14 and 15.

C. TEST PROCEDURES

Prior to each self-propulsion test, a D_f correction chart was prepared from the results of previous resistance tests. Resistance increase due to the wall effects was estimated and added to the amount of viscous correction of D_f to bring the model propeller loading equivalent to the ship point of propulsion.

Although the present carriage speed control at the Michigan Tank does not permit an easy preselection of speed and hence an exact amount of D_f, the values of D_f have been matched by duplicating the same spot more than once at a constant carriage speed setting.[1]

As the instrumentation was set up, resistance was directly read in pounds; speed in ft/sec; revolutions in milli-seconds per revolution; and thrust and torque in grams and gram-centimeters, respectively.

Other than these, all the procedures are identical to the method described in W. T. Potter's "A Manual for the Calculation of Propulsion Tests at the DTMB."[2]

Open-water propeller tests were run essentially at constant carriage speed and varying rpm, to cover the required range of propeller speed of advance. With the 1/8-hp propulsion dynamometer, due to the small power, it was not possible to obtain low J-values even at reduced carriage speeds. With the 1-hp motor of the J-04 dynamometer, however, it is possible to obtain a full range of J-values at maximum carriage speed, thus maintaining the highest possible Reynolds number with the present equipment.

Reynolds numbers were in the range of 2.5×10^5 to 3.2×10^5.

---

[1] D_{f_o} values (measured amount of viscous correction to propeller loading) have been matched to D_f values (theoretically exact amount of correction) within about $\pm$ 4% on the average and to a $\pm$ 12% maximum.

[2] DTMB, October, 1954, 2nd ed.

IV. DISCUSSION OF RESULTS

The result of the resistance test of 0.60 block Model No. 912 correlates excellently with DTMB results, but that of the 0.75 block Model No. 913 has slightly more scatter and differs about 10% in C_r, the Michigan data being slightly higher in general. This seems to result from instability of turbulent flows on fuller models, inadequate wall-effect correction, and/or inadequacy of the flat-plate friction extrapolator.

Although a very small difference is involved, Michigan data are a shade lower from speed-length ratio 0.89 to 0.96 for Model 912, and from 0.78 to 0.82 for Model 913. At the high-speed end, Michigan data tend to become appreciably higher. A similar observation is noted for the SHP data at almost the same speeds. It is believed that this condition is partially due to blockage effect correction.

As for the results of the self-propulsion test, SHP and EHP/SHP agree well with DTMB data. For Model 912, rpm is about 3% lower throughout. This is mainly due to the 6.7% higher propeller pitch than that of the DTMB propeller. Thrust deduction in general shows appreciably higher values than those of DTMB contrary to expectations. No explanations of this fact has been attempted at this time. Wake values, however, are as expected in view of the smaller model size.[3]

BLOCKAGE EFFECT

It was estimated that the maximum increase in total resistance due to blockage would be about 2-3% at about 10% above the trial speed for 14-foot models. Previously, in a similar comparative study on a Series 60 model, a 12-1/2-foot model had been tested. This model had a blockage ratio (model cross-sectional area over the tank cross-sectional area) of about 1/2 of 1% and had shown no blockage effect as far as could be determined within the accuracy of measurements. The present models had blockage ratios of 0.74 of 1% for Model 912 and 0.81 of 1% for Model 913 with an estimated effective tank cross-sectional area of 190 square feet. Rather than accept the consequences of having possible laminar flow on propellers of diameters smaller than 6 inches, a 14-foot model size was chosen.

A number of empirical and theoretical studies have been made in regard to blockage effect. Some of these are mostly concerned with either extremely shallow draft or high speed. Corrections applied to Model 912 and Model 913

---

[3]Van Lammerren, Troost, and Koening, Resistance, Propulsion and Steering of Ships, Technical Publishing Company, Holland, 1948, p. 150.

by such methods would be nil. After consideration an estimate was finally based on the semi-empirical formula developed at the National Physical Laboratory in England.[4] The formula is as follows:

$$\text{Resistance increased in } \% = n_T \frac{100\nabla}{A^{3/2}}$$

A = Cross-sectional area of the tank in sq ft.

∇ = Volume of the model in cubic feet.

n_T = Logarithmic index of the change in total resistance with respect to speed.

In the absence of a better estimate, this formula has been used throughout the present analysis. It is planned, however, to study blockage effects in the Michigan tank.

The University of Michigan Ship Model Towing Tank has approximately a 22-foot width and 10-foot depth, but the section is semi-circular at the bottom. At about 140 feet down the length of the tank, there is a false bottom about 7 feet below the water level. It covers only about 4/5 of the 22-foot width. Figure 11 is a sketch of the tank. The cross-sectional area, therefore, can be taken as anywhere from 160 to about 210 square feet. At present, 190 square feet has been used as an estimate.

The effect of the false bottom is unknown and will indeed be difficult to ascertain. The best solution will be to have it removed.

The total resistance increase based on the given equation is shown in percent of total resistance in Fig. 9. This correction has been applied in both the resistance and self-propulsion test analysis.

TURBULENCE STIMULATOR

Based on the experience obtained from the 12-1/2-foot model tested, a trip wire stimulator was used exclusively. For the 12-1/2-foot model, both studs and trip wires were tried, and the trip wire was found to be the most satisfactory. The trip wire stimulator was of 0.036-in.-diameter copper wire placed at 5% LBP from the FP secured to the model by 0.036-in.-diameter bent nails about 1-1/2 in. apart.

Model 913 was initially run with a trip wire stimulator on the bow (as was done with Model 912), and then with an additional trip wire placed at the quarter point of the stern. This was based on the belief that the separation

[4] From the confidential correspondence between Dr. Hughes and Professor Couch.

point of the boundary layer will be stabilized due to the second stimulator. The test seems to confirm this, although the problem will have to be more fully explored. The drag of an additional stimulator in the stern seemed to be negligible.

Water spray was used on the return after high-speed runs. This possibly helps turbulence stimulation, but the major purpose is to clam down waves generated in the tank, and the practice was followed only when needed.

A high-speed practice run at the beginning of a sequence of tests is always made to insure that the water in the basin is moderately stirred. When this precaution is not followed, it has been noticed that the first couple of runs invariably produce lower resistance data.

FRICTION EXTRAPOLATORS

Throughout the test, the 1947 ATTC friction extrapolator was used exclusively. It was found from the 12-1/2-foot-model tests that the 1947 ATTC friction extrapolator resulted in closer agreement between Michigan and DTMB data than could be obtained by using the 1957 ITTC friction extrapolator.

ACKNOWLEDGMENT

The authors are grateful to the members of The University of Michigan staff who participated in the conduct of the test program. In particular, the cooperation of Mr. Albert F. Harloff is greately appreciated.

APPENDIX

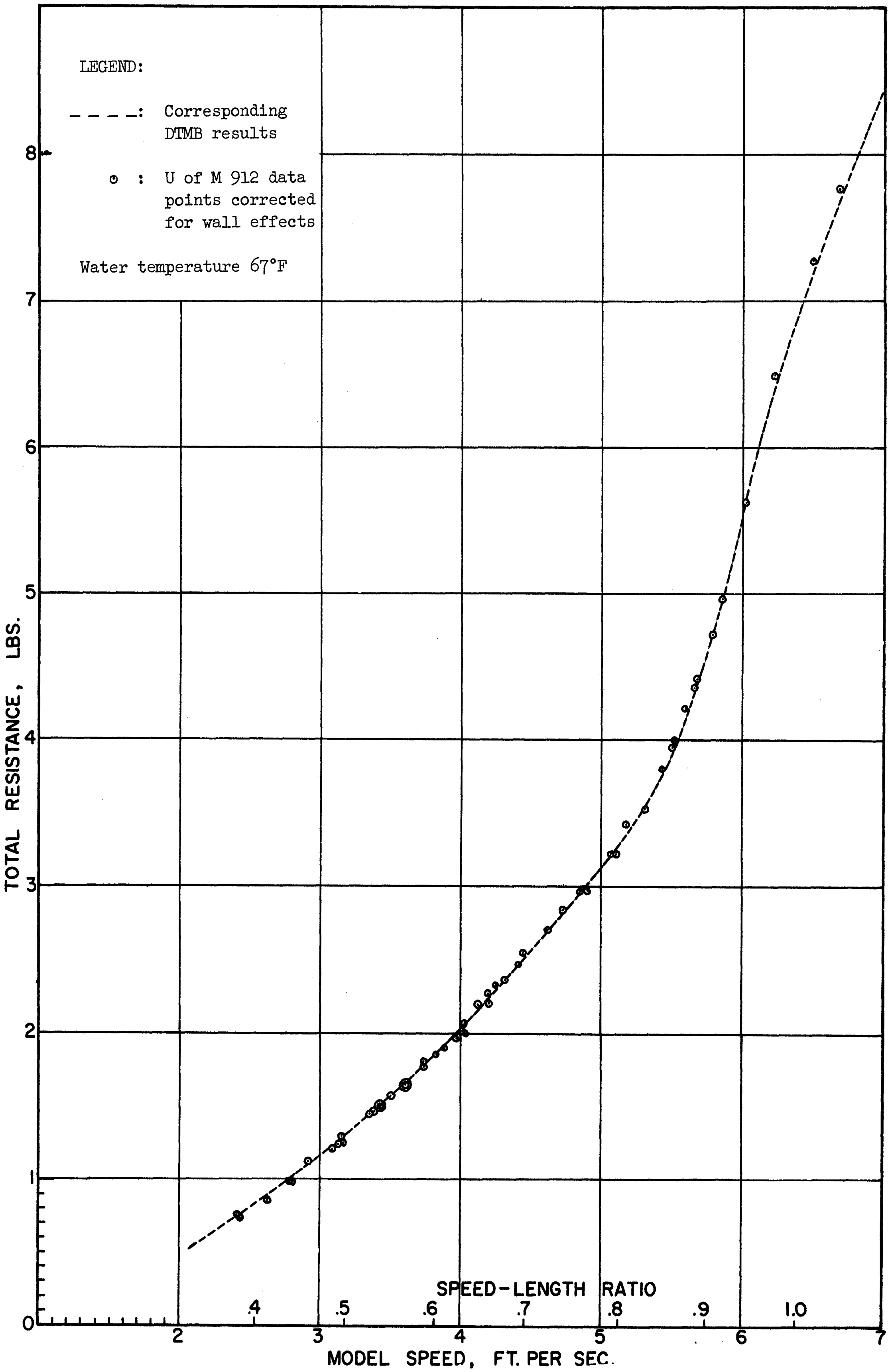

Fig. 1. Total resistance vs. model speed, series 60, .60 block, U of M 912 14-ft model, DTMB 4210 20-ft model with rudder.

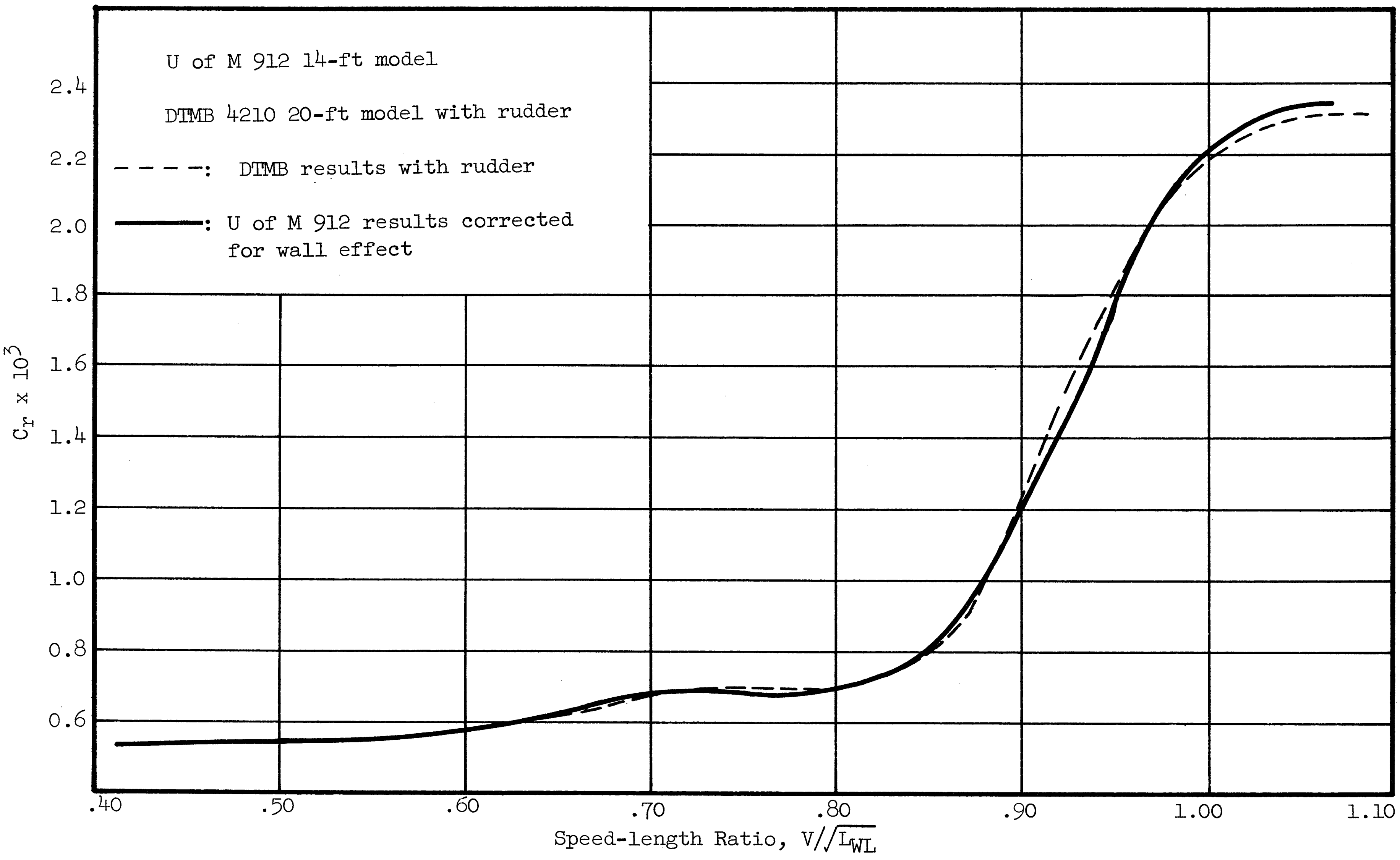

Fig. 2. C_r vs. speed-length ratio, series 60, .60 block.

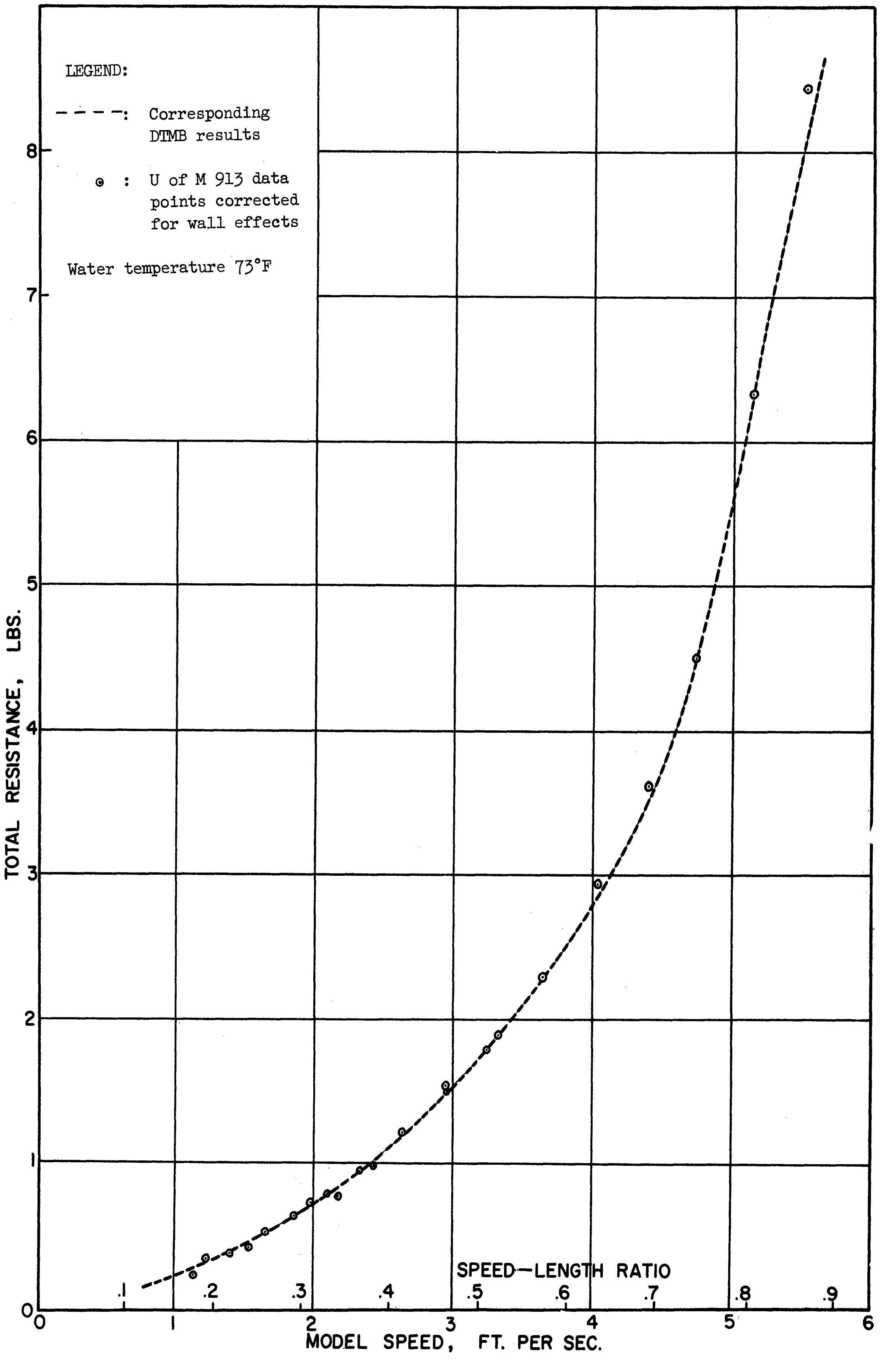

Fig. 3. Total resistance vs. model speed, series 60, .75 block, U of M 913 14-ft model, DTMB 4213 20-ft model with rudder.

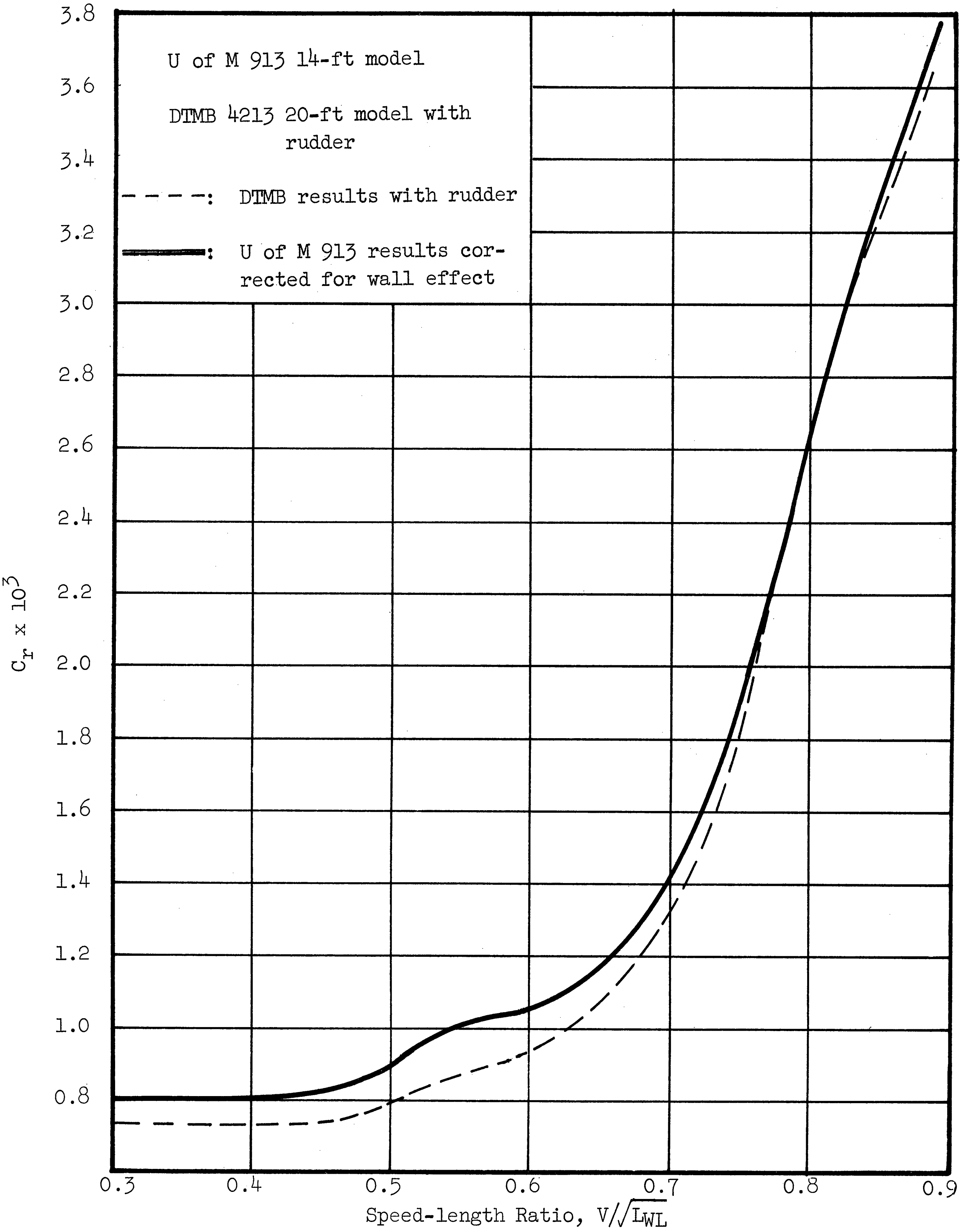

Fig. 4. C_r vs. speed-length ratio, series 60, .75 block.

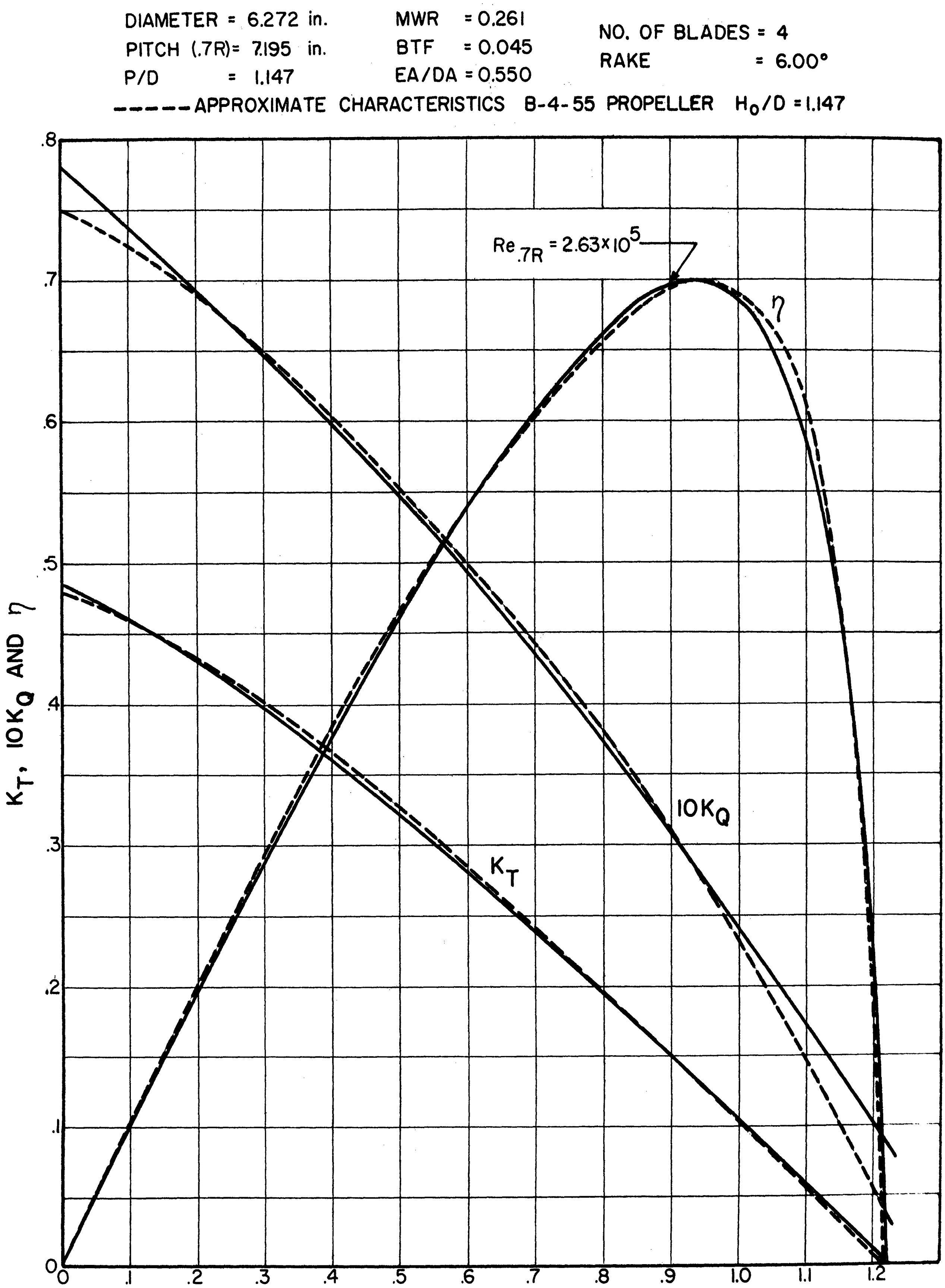

Fig. 5. Propeller open-water test result, U of M prop. No. 1.

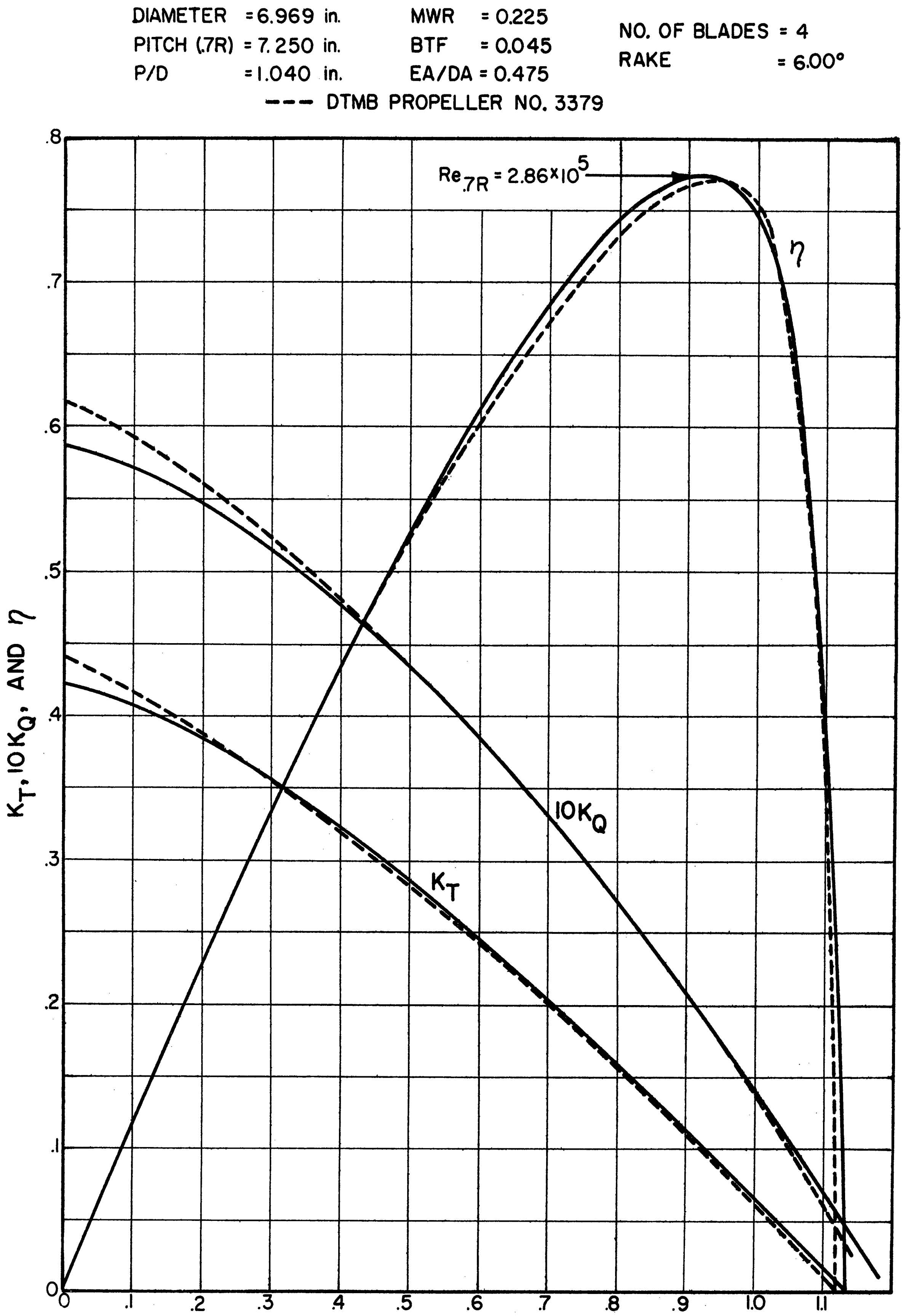

Fig. 6. Propeller open-water test result, U of M prop. No. 2.

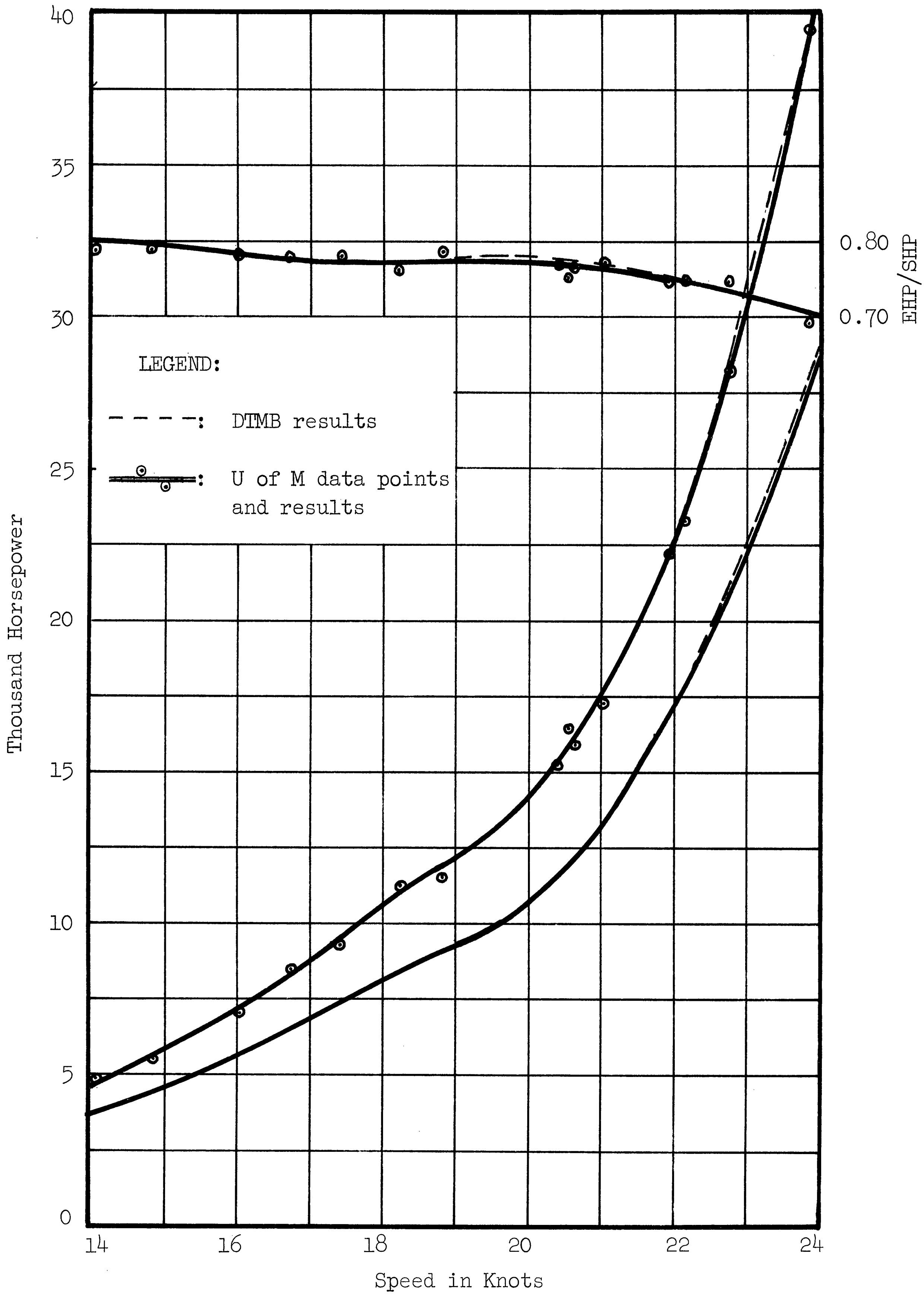

Fig. 7-A. Self-propulsion test results for 600-ft ship. 0.60 block model 912, prop. No. 1 (parent DTMB model 4210, prop. DTMB 3378).

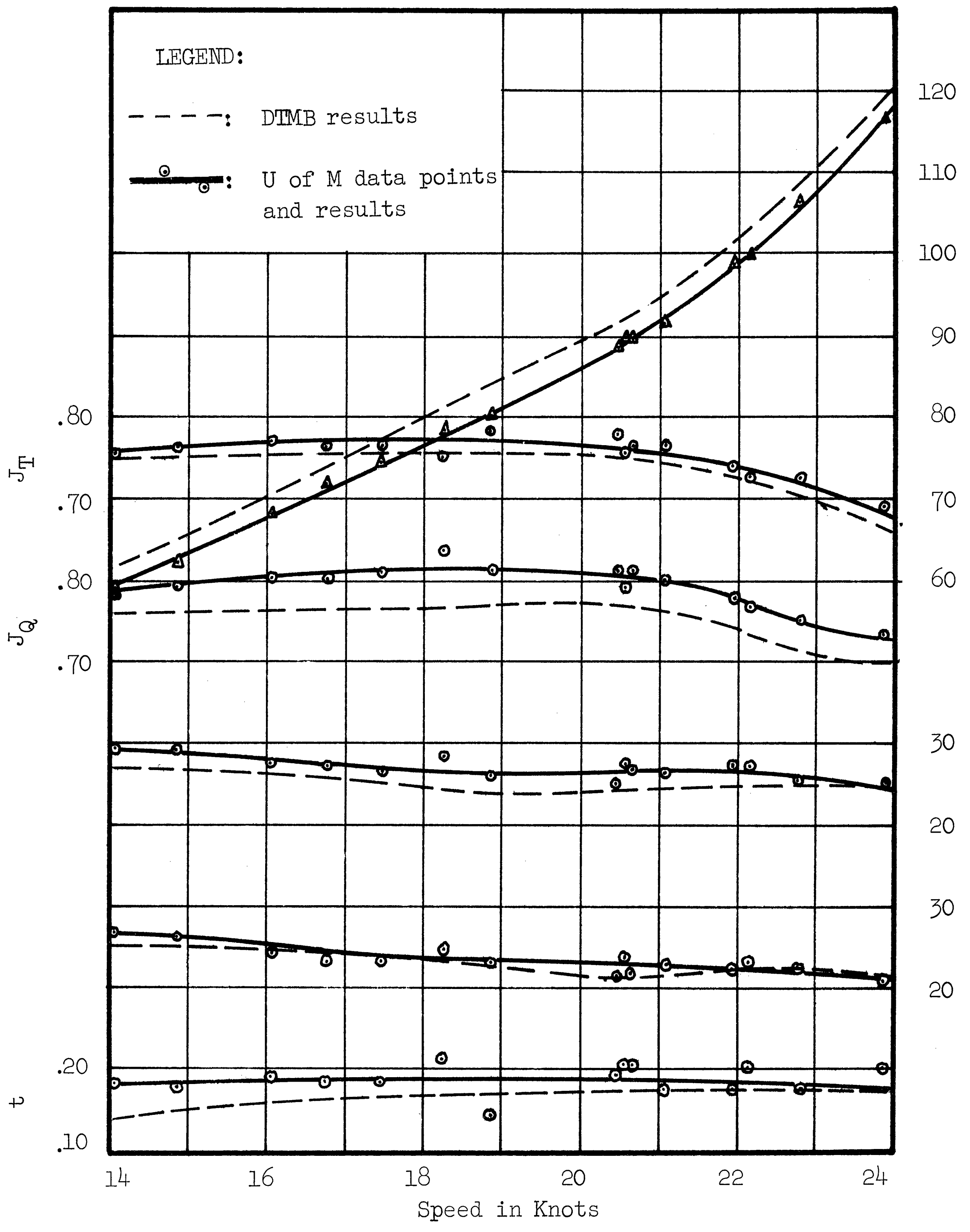

Fig. 7-B. Self-propulsion test results for 600-ft ship. 0.60 block model 912, prop. No. 1 (parent DTMB model 4210, prop. DTMB 3378).

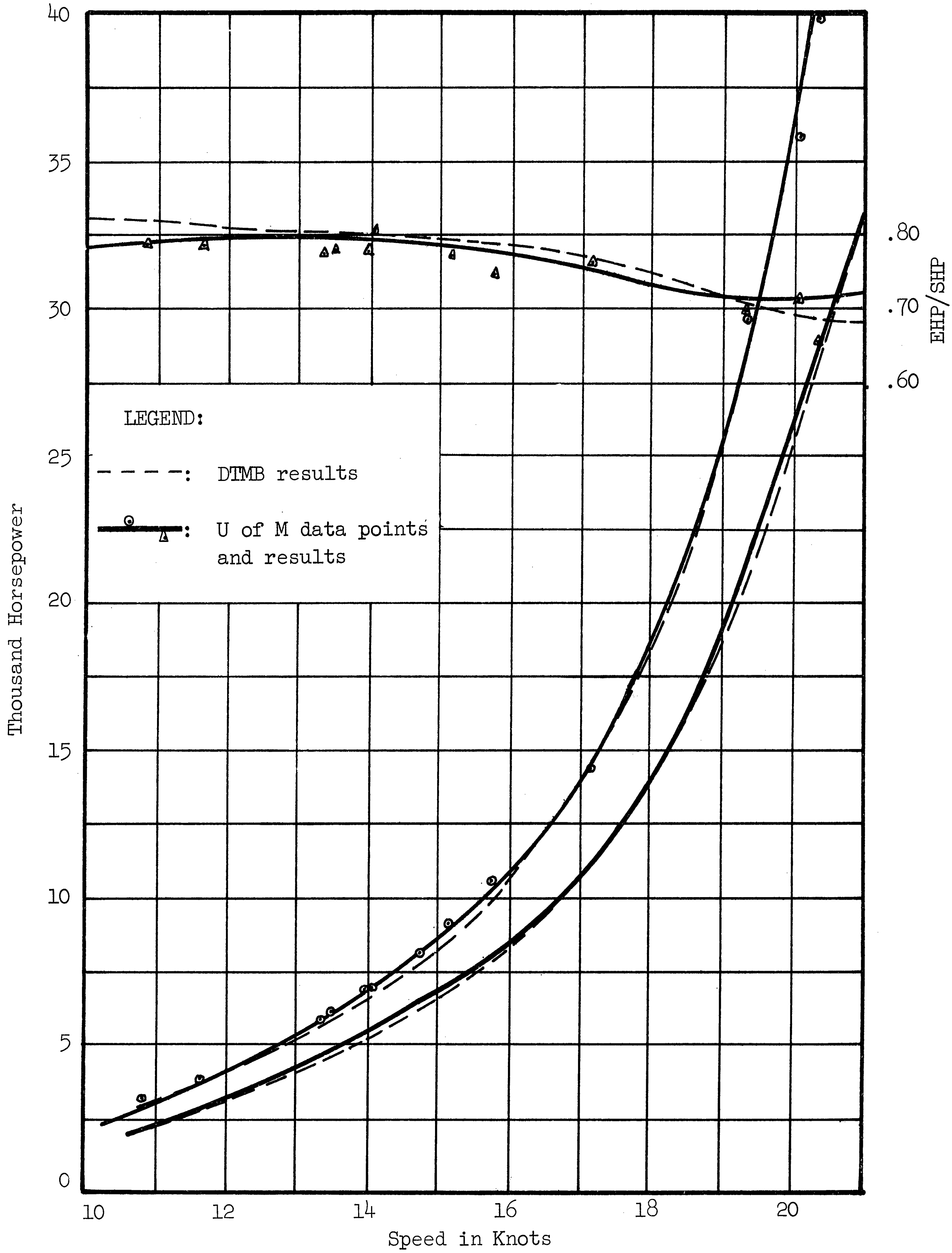

Fig. 8-A. Self-propulsion test results for 600-ft ship. 0.75 block model 913, prop. No. 2 (parent DTMB model 4213, prop. DTMB 3379).

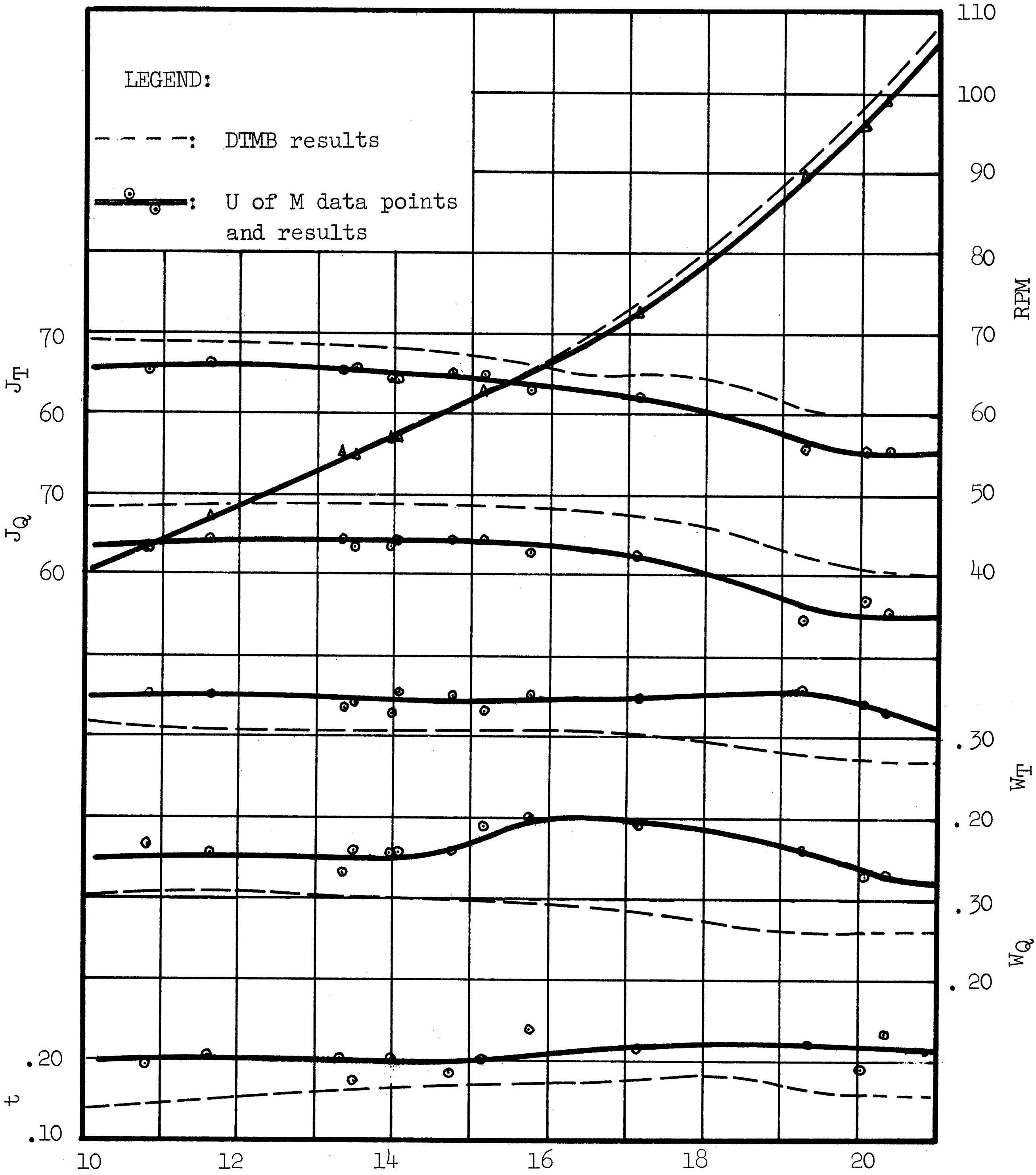

Fig. 8-B. Self-propulsion test results for 600-ft ship. 0.75 block model 913, prop. No. 2 (parent DTMB model 4213, prop. DTMB 3379).

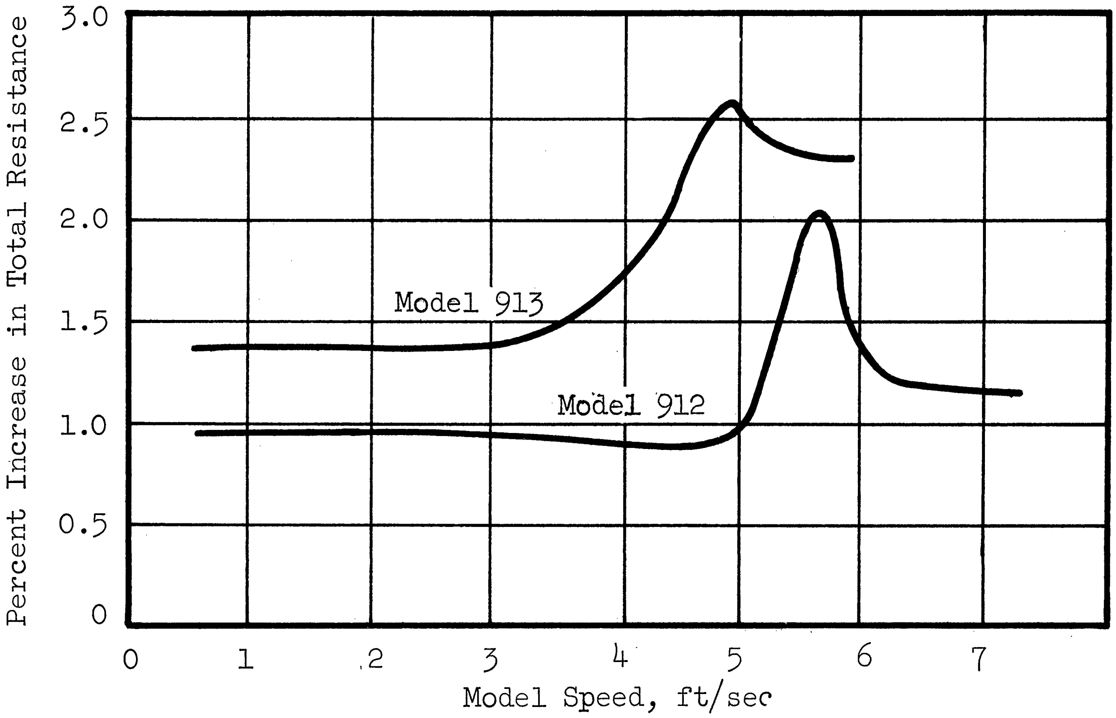

Fig. 9. Estimated blockage effects.

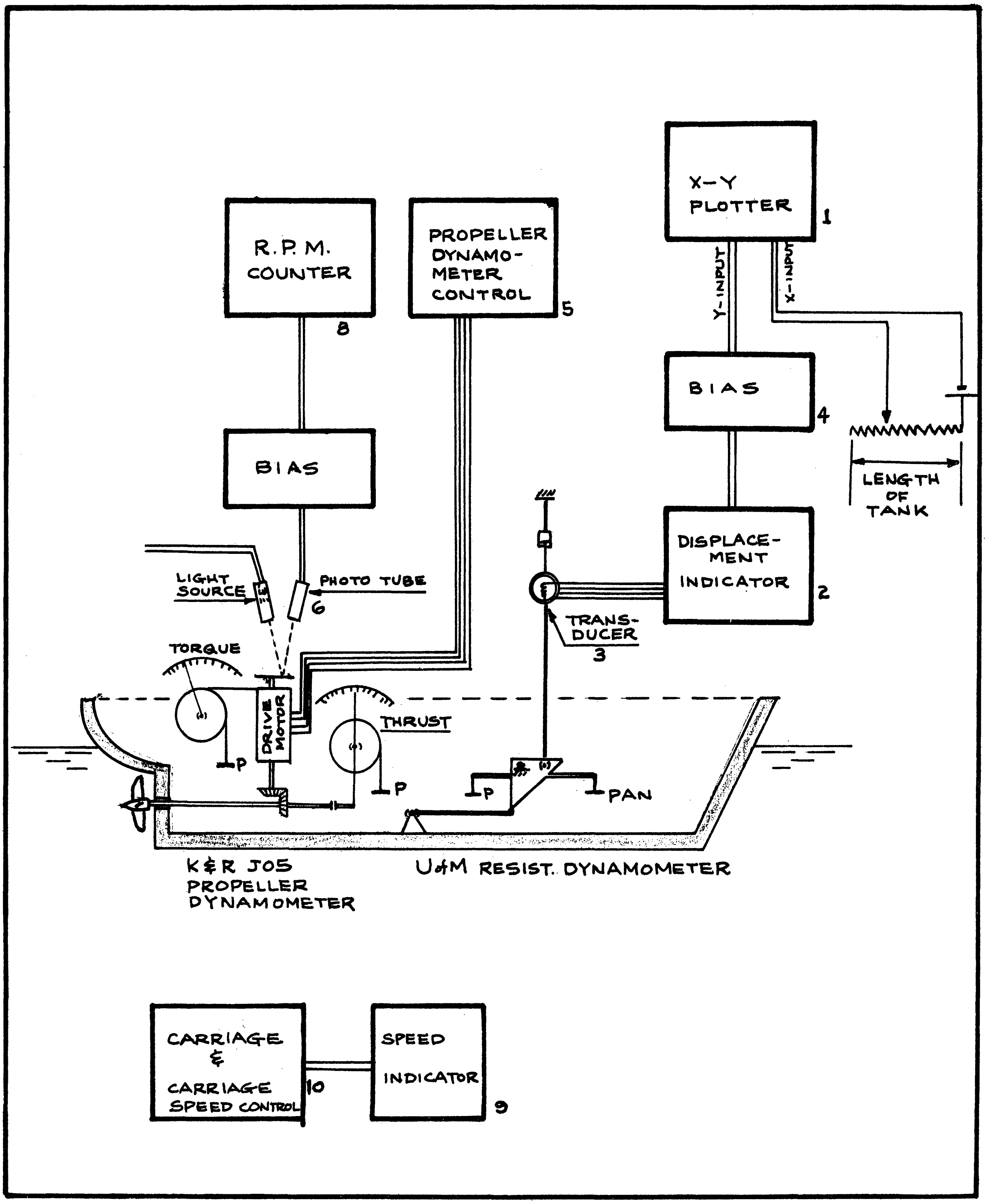

Fig. 10. Equipment arrangement for self-propulsion test.
Numbers refer to the Equipment List.

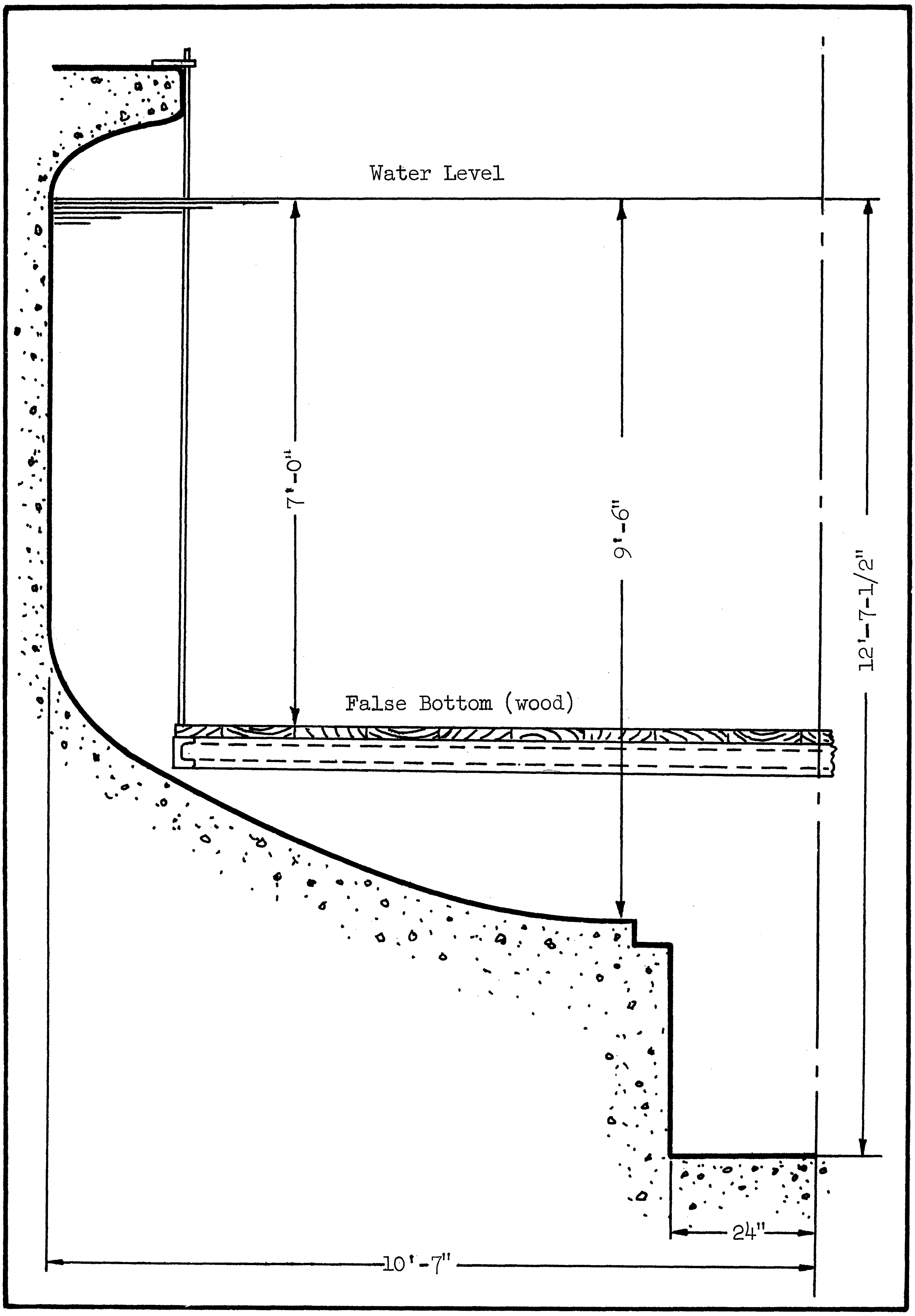

Fig. 11. Cross section of U of M tank.

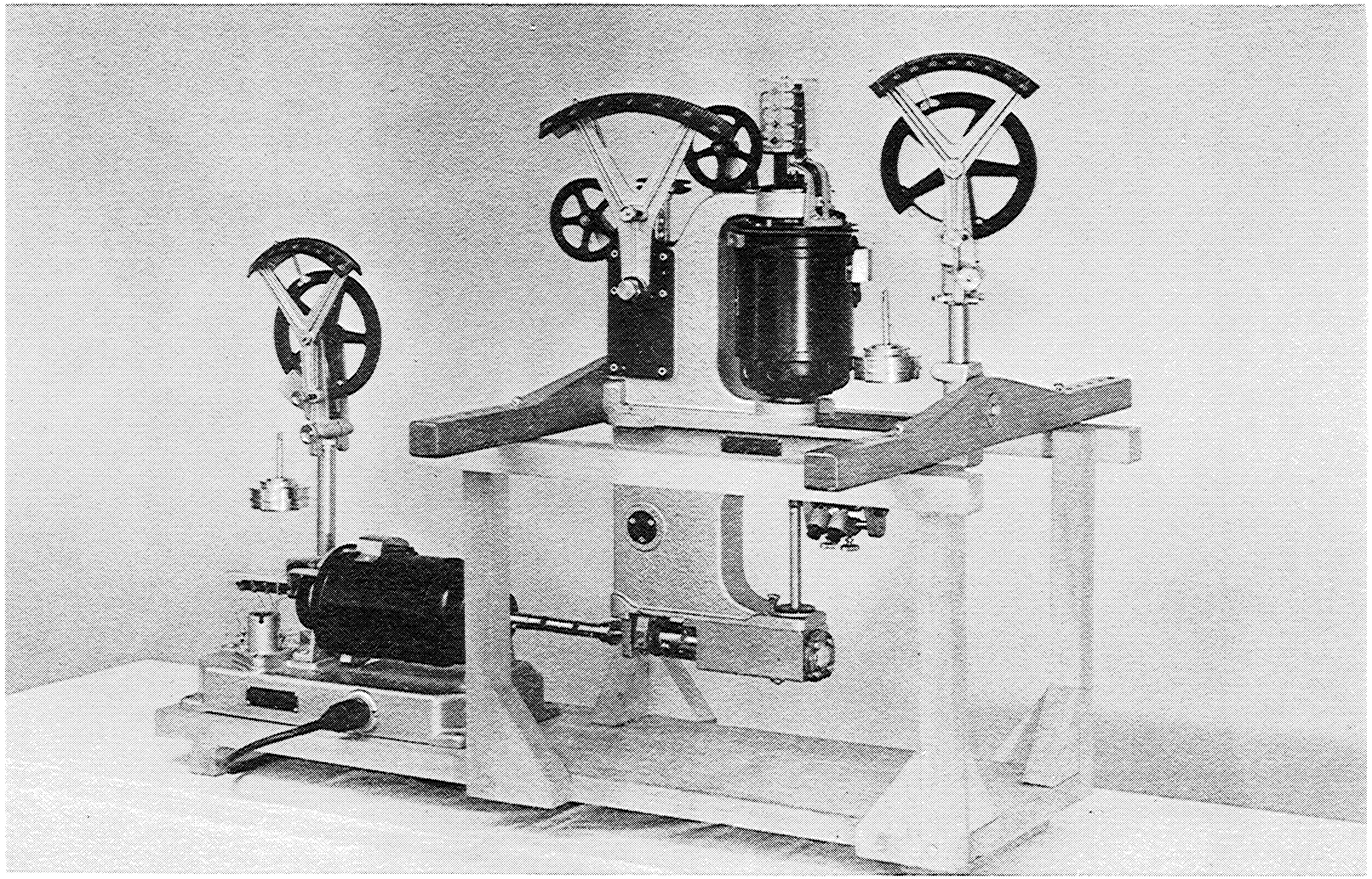

Fig. 12. Kempf and Remmers propeller dynamometer J-05.

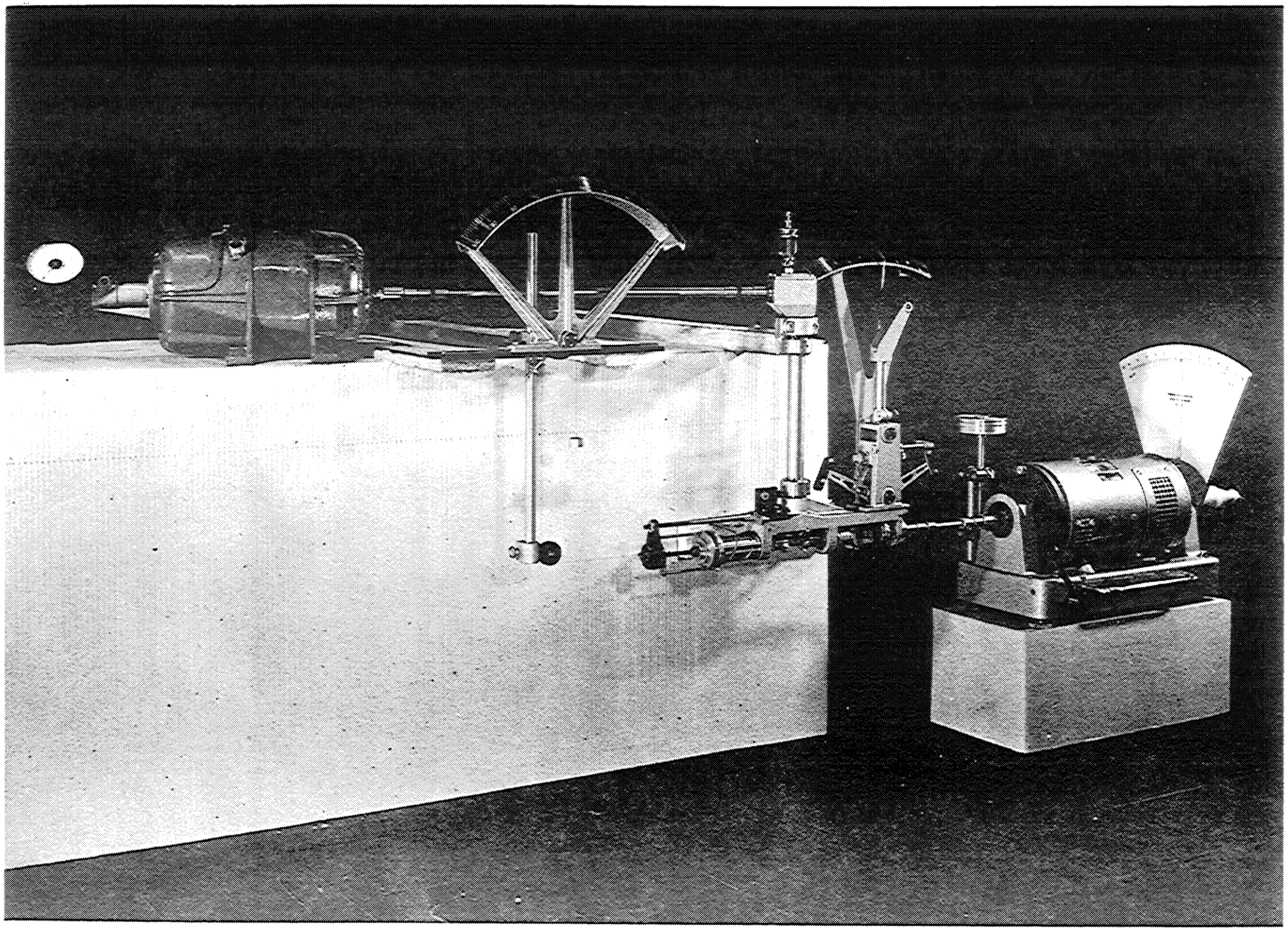

Fig. 13. Kempf and Remmers propeller dynamometer J-04.

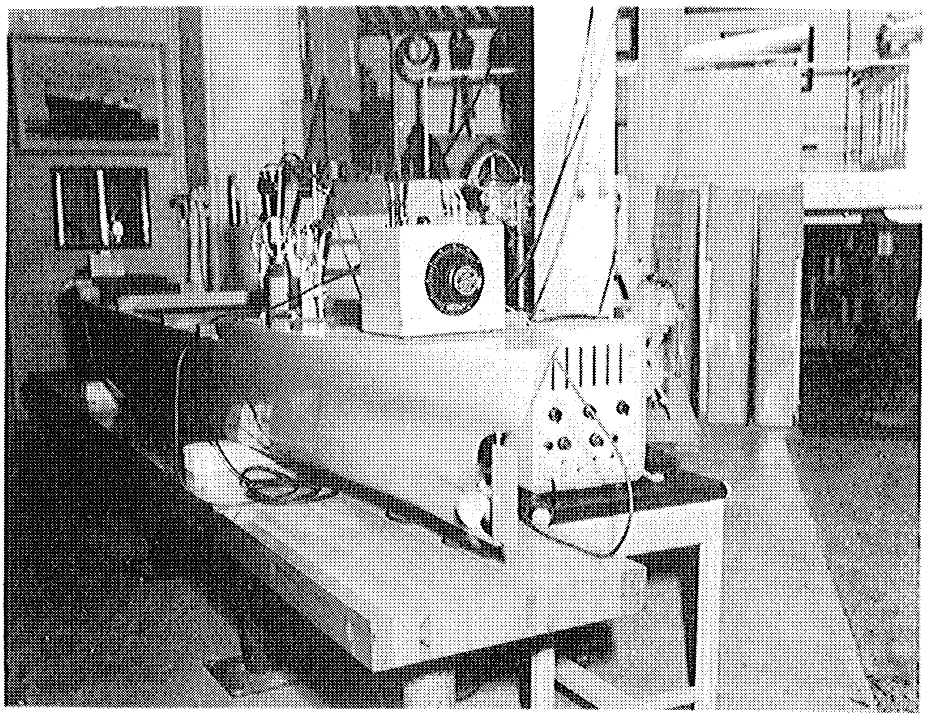

Fig. 14. J-05 dynamometer installed in model 912.

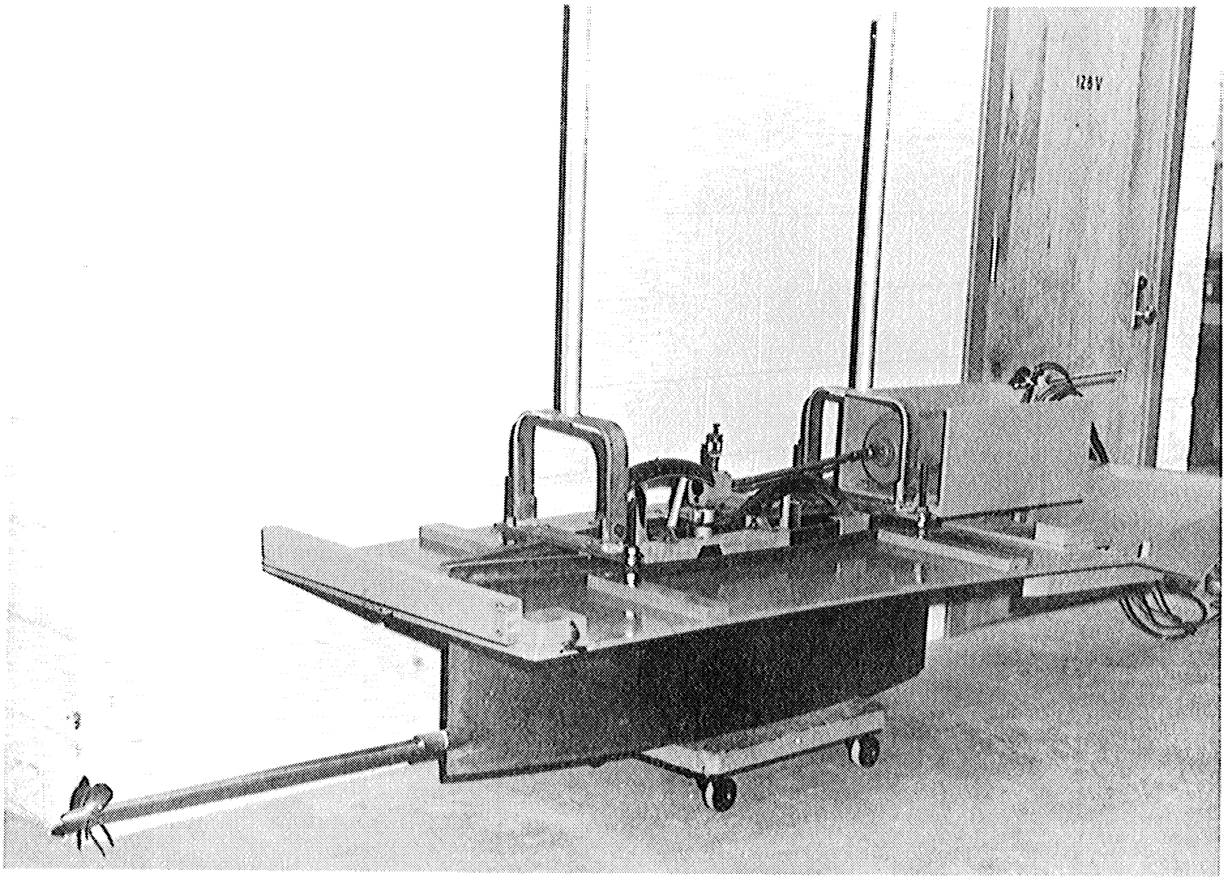

Fig. 15. J-04 dynamometer installed in propeller boat.

TABLE 1

MODEL DATA

Model No. 912 (Parent DTMB Model No. 4210)
Ship Series 60 0.60 Block
Ship Owner MARAD ORA No. 03509 Material: Wood

	Model: λ = 42.8571 (600 ft)	Ship (600 ft)
LOA		
LWL	14.2345 ft; 170.814 in.	610.050 ft
LBP	14.0000 ft; 168.000 in.	600.000 ft
B	1.8666 ft; 22.3986 in.	80.000 ft
H mean	0.7466 ft; 8.9586 in.	32.000 ft
fwd	0.7466 ft; 8.9586 in.	32.000 ft
aft	0.7466 ft; 8.9586 in.	32.000 ft

Δ = 728.8 lb at LWL Draft, 73°F 26,349 tons, STD S.W.

	Model	Ship
W.S. bare	33.4181 sq ft	61,380 sq ft
rudder	0.3136 sq ft	
appendage		
Total	33.7316 sq ft	61,956 sq ft

A_x, LWL	1.362 sq ft	Friction Basis: 1947 ATTC
A_x, LWL	18.449 sq ft	ΔC_f ... 0.0004
A_x, Tank Area	0.74%*	
Designed Speed	5.70 ft/sec	$V/\sqrt{L}$ = .894; 22.08 KTS
Trial Speed	6.06 ft/sec	$V/\sqrt{L}$ = .952; 23.51 KTS

MODEL TEST CONDITIONS: EHP & SHP TESTS

Draft: Mean: LWL Aft: Fwd:
Turbulence Bow Trip Wire Temp: 67 ~ 75°F

MODEL CHARACTERISTICS

LBP/LWL		C_{PA}	.648	B/H	2.5	LCB, %LBP	1.5A of ⊗
L_E/LBP	0.5	C_{PV}	.850			LCF, %LBP	
L_X/LBP	0	C_{PVF}	.910			$L/\nabla^{1/3}$	6.165
L_R/LBP	0.5	C_{PVA}	.802			$S/\nabla^{2/3}$	6.481
C_B	.60	C_W	.706			$K_R = R/\sqrt{BH}$	0.229
C_X	.977	C_{WF}	.624	C_{1T}	.543		
C_P	.614	C_{WA}	.788				
C_{PF}	.581	L/B	7.5	1/2 α_E	7.0		

*Tank cross-sectional area = 190 sq ft.

Model No. 913 (Parent DTMB Model No. 4213)
Ship Series 60 0.75 Block
Ship Owner MARAD ORA No. 03509 Material: Wood

	Model: λ = 42.8571 (600 ft)	Ship (600 ft)
LOA		
LWL	14.2345 ft; 170.814 in.	610.050 ft
LBP	14.0000 ft; 168.000 in.	600.000 ft
B	2.074 ft; 24.888 in.	88.886 ft
H mean	0.8295 ft; 9.954 in.	35.55 ft
fwd	0.8295 ft; 9.954 in.	35.55 ft
aft	0.8295 ft; 9.954 in.	35.55 ft

Δ = 1124.9 lb at LWL Draft, 73°F 40,644 tons, STD S.W.

	Model	Ship
W.S. bare	41.934 sq ft	77,022 sq ft
rudder	9.346 sq ft	635 sq ft
appendage		
Total	42.280 sq ft	77,657 sq ft

A_x, LWL	1.703 sq ft	Friction Basis: 1947 ATTC
A_x, LWL	24.013 sq ft	ΔC_f ... 0.0004
A_x, Tank Area	0.81%	
Designed Speed	3.76 ft/sec	$V/\sqrt{L}$ = .595; 14.70 KTS
Trial Speed	4.16 ft/sec	$V/\sqrt{L}$ = .655; 16.18 KTS

MODEL TEST CONDITIONS: EHP & SHP TESTS

Draft: Mean: LWL Aft: Fwd:
Turbulence Bow and Stern Trip Wire Temp: 67 ~ 75°F

MODEL CHARACTERISTICS

LBP/LWL		C_{PA}	.724	B/H	2.5	LCB, %LBP	1.5F of ⊗
L_E/LBP	.350	C_{PV}	.907			LCF, %LBP	
L_X/LBP	.210	C_{PVF}	.961			$L/\nabla^{1/3}$	5.335
L_R/LBP	.440	C_{PVA}	.856			$S/\nabla^{2/3}$	6.090
C_B	.75	C_W	.827			$K_R = R/\sqrt{BH}$	
C_X	.990	C_{WF}	.817	C_{1T}			
C_P	.758	C_{WA}	.838				
C_{PF}	.792	L/B	6.75	1/2 α_E	22.5		

TABLE 2

PROPELLER DATA

PROP.	UM No. 1	UM No. 2
PARENT	DTMB No. 3378	DTMB No. 3379
DIAMETER (d), inches	6.272	6.969
PITCH (p), inches	7.195 (6.742)*	7.250 (7.143)*
<u>CHARACTERISTICS</u>		
PITCH-DIAMETER RATIO, P/D	1.147 (1.075)*	1.040 (1.025)*
MEAN-WIDTH RATIO, MWR	0.261	0.225
EFFECTIVE AREA-DISC AREA RATIO, EA/DA	0.550	0.470
BLADE THICKNESS FRACTION, BTF	0.045	0.045
RAKE, DEGREES ARC	6.00	6.00
NO. OF BLADES	4	4

*Indicates equivalent values of parent propellers.