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

Final Report

INVESTIGATION OF BULBOUS BOW DESIGN FOR "MARINER" CARGO SHIP

Takao Inui

Project Director: R. B. Couch

ORA Project 05589

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THE UNIVERSITY OF TOKYO
SHIP MODEL BASIN LABORATORY

— First Report —

Preliminary Calculations for the Alternative MARINER (With-Bulb) Design

By

Project Director:
Takao Inui, Prof., Dr. Eng.,
Superintendent, Ship Model
Basin Laboratory, The University
of Tokyo.

University of Michigan,
ORA Project 05589
Maritime Administration
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Section 1 — Primary Object of the Project

The primary object of the present research project is evident in the head paragraph of Mr. Russo's letter dated March 2, 1962, Reference (1), which reads as follows:

— "The Maritime Administration would be interested in exploring the possibility of adopting the "Inui" Bow concept to one of the cargo ships scheduled for construction in the near future in order to evaluate under operating conditions, the advantages claimed for this form."

Later on, the "Mariner" was selected as the original type ship, and the requirement by the Maritime Administration reads in the item (a), Reference (1), like:

— "Modification of ship's lines, to be furnished by the Maritime Administration, to fit an optimum "Inui" Bow while maintaining present ship's characteristics such as: Dimensions, draft, cargo cubic, trim and transverse stability."

Here, the details are not so clear with respect to the allowable limit of modification. If the restriction were too strict, the compromise between theory and practice would sometimes turn out to be most difficult.

Section 2 — Conditions for the "Waveless" State

In all practical applications of the "with-bulb" waveless concept, the way of modification of a given original lines is the key point.

First of all, for the purpose of realizing the "waveless" state as completely as possible, the main hull form must be carefully designed so as to be entirely free from the shoulder wave systems. Experiences in Tokyo University Tank show that this requirement of "no shoulder waves" can be satisfied only by starting with a continuous "source" distribution curve and by applying the stream-line tracing method, as explained in Reference (2), Part 1, Section 2, pp. 289-296.

Next, from ship's operating points of views, the size and the forward projection of the bulb must be limited to as small as possible.

In order to fulfill this second requirement, the waterlines near at the designed draft must be carefully determined so as to have a fairly hollow tendency with a very small angle of entrance. The above requirement can be attained again by selecting an appropriate "source" distribution curve with a very small initial source strength $(m_0) = m(\xi)$ at $\xi = 1$ (F. P.), as shown in Reference (2), Part 2, Section 5, Figs. 27, 28 and 29.

Thirdly and finally, the square moment of the design waterplane area (I_T) must maintain a certain lower limit to meet the transverse stability requirement.

These three requirements are very often conflicting among themselves. For example, under a certain limited value of the maximum beam (B_m), an ample transverse stability or a large (I_T) is always conflicting with a hollow waterline of a small entrance angle and of no parallel part.

Generally speaking, in cases when the original waterline at the designed draft has no parallel part, it is not so difficult to find a suitable "waveless" form under the very severe restriction, i.e. no allowances for any small deviation of B_m, d_m, and C_B.

Actually, on June 13, 1963, when the reporter visited the Maritime Administration, the following nine particulars were suggested to be kept unchanged.

L_{pp} = 528' - 0"

L = 520' - 0" (effective form length)

B_m = 76' - 0"

d_m = 27' - 0" (the designed draft)

Δ = 18,803 LT

C_B = 0.6125

C_P = 0.6246

C_M = 0.9807

KM = 31.09'

However, in case of the Mariner, the designed load waterline has a fairly long parallel part at the station number 8 through 13, corresponding to one quarter of ship's length, as shown in Fig. 2.

Consequently, in the present case, it is indispensable to increase the beam (B_m) to some allowable extent. Otherwise, we should be obliged to sacrifice, more or less, the aforementioned three requirements. This means that we must endure

(a) larger shoulder wave → poor performance

(b) larger size and farmore forward location of the bulb → poor operation, or/and

(c) less (I_T) → poor stability.

Section 3 — Revised Requirement by the Maritime Administration

During the reporter's stay in Ann Arbor, Michigan, in August 1963, the discussions were held by Prof. Couch, Mr. Taylor (MARAD) and Mr. Sarchin (BuShips) with respect to the point mentioned in the preceding section.

Finally it was agreed to carry out some preliminary design calculations so as to find out to what extent the deviation in beam (B_m) would be needed.

Further, it was decided to keep the block coefficient (C_B) throughout these calculations, which means that the draft (d_m) decreases with increasing beam (B_m) under the derived relation ($B_m x d_m$) = $\nabla/(LxC_B)$ = const.

Here it should be noted that, there is another way of modification— a larger beam (B_m) with a finer block coefficient (C_B) and constant draft (d_m).

Actually, this second way of modification is superior to the former if the "best attainable" performance would be pursued, not only from wave-making but also from frictional point of views.

However, the former way of modification was finally adopted in view of the block coefficient being the primary base of resistance comparison.

Concerning the stability requirement another two points were also suggested as follows:

(a) The deviation in beam (B_m) and draft (d_m) must be limited as small as possible just to maintain the stability requirement.

(b) The stability requirement should be examined not only with GM (initial stability), but also with the over-all stability characteristics (the vanishing range, the amount and angle of the maximum righting lever, etc.).

Section 4 — Outline of Calculations

The conditions under which the present calculations were made are as follows:

(a) Displacement:

Δ = 18,803 LT, corresponding to the designed draft ($d_m = 27' - 0''$) of the Mariner "as built."

(b) Principal Dimensions:

$$\left.\begin{array}{lcl} L_{pp} & = & 528' - 6'' \\ C_B & = & 0.6125 \end{array}\right\} \text{ same with the Mariner "as built"}$$

$$\left.\begin{array}{lcl} B_m & = & 76' \text{ (as built), } 78',\ 80' \\ d_m & = & 27' \text{ (as built), } 26.3',\ 25.7' \end{array}\right\} \text{ three models}$$

$$\left(B_m \times d_m = \frac{\nabla}{L \times C_B} = \text{const.}\right)$$

(c) Transverse Stability:

$I_T \geq 1085 \times 10^4$ ft^4 (same with the Mariner) where I_T = Square moment of the designed waterplane area.

By virtue of the approximate relation $KB \propto d_m$, this requirement will roughly maintain the equal value of GM.

(d) Designed Speed:

Design sea speed = 20 knots

Corresponding speed - length ratio = 0.877

(e) Source Distribution:

Fore half-body was derived from the assumed source distribution, like

$$m\,(\xi,\zeta) = a_1\xi \mp a_2\xi^2, \left(\begin{array}{l} -\quad 0 \leq \xi \leq 1 \\ +\ -1 \leq \xi \leq 0 \end{array}\right)$$

T/L = 0.04, where

m = source strength

T = depth of source distribution.

(f) Aft Half-Body:

Aft half-body was roughly approximated to the Mariner "as built," except that the aft shoulder was carefully moderated as best as possible.

Section 5 — Discussions on the Results Obtained

Three alternative main hull models M-1 (B_m = 76'), M-2 (B_m = 78') and M-3 (B_m = 80') were obtained by satisfying the aforementioned stability requirement, etc. The obtained source distributions are shown both in Table 1 and in Fig. 1. The main hull bow wave characteristics such as the elementary wave amplitude function and its effective origin were determined theoretically.

On the other hand, the waterline curves at the designed draft were derived by stream-line tracing method as shown in Fig. 2.

Finally, the optimum bulbs corresponding to these three main hull models were obtained as shown in Table 1 and in Fig. 3.

Referring to these results, it can be safely concluded that Models M-1 (B_m = 76') and M-2 (B_m = 78') have the defects as follows:

(a) The aft-body waterline has a fairly long parallel part, which may cause a noticeable aft-shoulder wave.

(b) The size and forward projection of the bulb is too large to be permissible for operation.

On the contrary, Model M-3 (B_m = 80') looks like favourable in all respects except the fact that its deviation (four feet increment in B_m) is not so small as desired as well as that its beam-draft ratio B_m/d_m (= 3.118) is too large, which may suggest a relatively large wetted-surface area. (This defect is one of the results of constant C_B.)

In conclusion, it seems to be recommendable to select the beam (B_m) within the range B_m = 78' ~ 80'.

With this respect further rough estimation was added by assuming B_m = 79' (Model M-4), which has turned out to be very close to the optimum beam, as shown in Table 1, Figs. 1 and 3.

* * * * *

List of Tables and Figures

References

(1) Vito L. Russo: Correspondence to Inui (March 2, 1962)

(2) T. Inui: Wave-Making Resistance of Ships, TSNAME Vol. 70 (1962)

(3) Vito L. Russo: Design of the Mariner-Type Ship, TSNAME Vol. 61 (1953)

(4) Tsunoda, Kasahara, Takekuma: A High-Speed Cargo Liner Design Based upon the "With-Bulb" Waveless Concept, Presented at the International Seminar on Theoretical Wave Resistance at The University of Michigan, August 1963.

TABLE 1

		As Built	Alternative			
		M-0 (MARINER)	M-1	M-2	M-3	(M-4)
PRINCIPAL DIMENSIONS	L_{pp}	528'6"	528'6"	528'6"	528'6"	528'6"
	L	520'	520'	520'	520'	520'
	B_m	76'	76'	78'	80'	79'
	d_m	27'	27'	26.3'	25.7'	25.95'
	Δ	18,803LT	18,803LT	18,803LT	18,803LT	18,803LT
	C_B	0.6125	0.6125	0.6125	0.6125	0.6125
	B_m/L_{pp}	0.1438	0.1438	0.1475	0.1514	0.1495
	B_m/d_m	2.815	2.815	2.982	3.118	3.045
STABILITY	I_T = Square moment of area of the designed waterplane area about the longitudinal axis					
	I_T(required)	———	$1085\text{x}10^4\text{ft}^4$	$1108\text{x}10^4\text{ft}^4$	$1133\text{x}10^4\text{ft}^4$	$1121\text{x}10^4\text{ft}^4$
	I_T(obtained)	$1085\text{x}10^4\text{ft}^4$	$1085\text{x}10^4\text{ft}^4$	$1112\text{x}10^4\text{ft}^4$	$1137\text{x}10^4\text{ft}^4$	———
MAIN HULL (FORE-BODY)	Assumed source distribution Lengthwise : $m(x)=a_1x-a_2x^2$, Draftwise : Uniform with depth T/L=0.04					
	a_1	———	2.544	3.348	3.744	3.660
	a_2	———	2.044	3.148	3.644	3.560
	$m_0 = m(1)$	———	0.5	0.2	0.1	0.1
BULB CHARACTERISTICS	a = Effective radius of the bulb f = Immersion of the centre of the bulb h = Longitudinal position of the centre of the bulb from F.P. (+) foreward, (-) aftward					
	$100a/L_{pp}$	———	2.6	2.0	1.8	1.8
	$100f/L_{pp}$	———	3.75	3.22	2.82	2.82
	$100h/L_{pp}$	———	2.0	0(F.P.)	-1.0	-1.0
	$100(a+h)/L_{pp}$	———	4.6	2.0	0.8	0.8
	a	———	13.74'	10.57'	9.51'	9.51'
	f	———	19.82'	17.28'	14.90'	14.90'
	h	———	10.57'	0	-5.29'	-5.29'
	(a+h)	———	24.31'	10.57'	4.22'	4.22'

$$\overline{m}(\xi,\zeta) = A_1\xi \mp A_2\xi^2 \quad \begin{pmatrix} 0 \leqq \xi \leqq 1 \\ -1 \leqq \xi \leqq 0 \end{pmatrix}$$

	A_1	A_2	Marks
M-1	2.544	2.044	—·—·—
M-2	3.348	3.148	— — —
M-3	3.744	3.644	———
M-4	3.660	3.560	- - - -

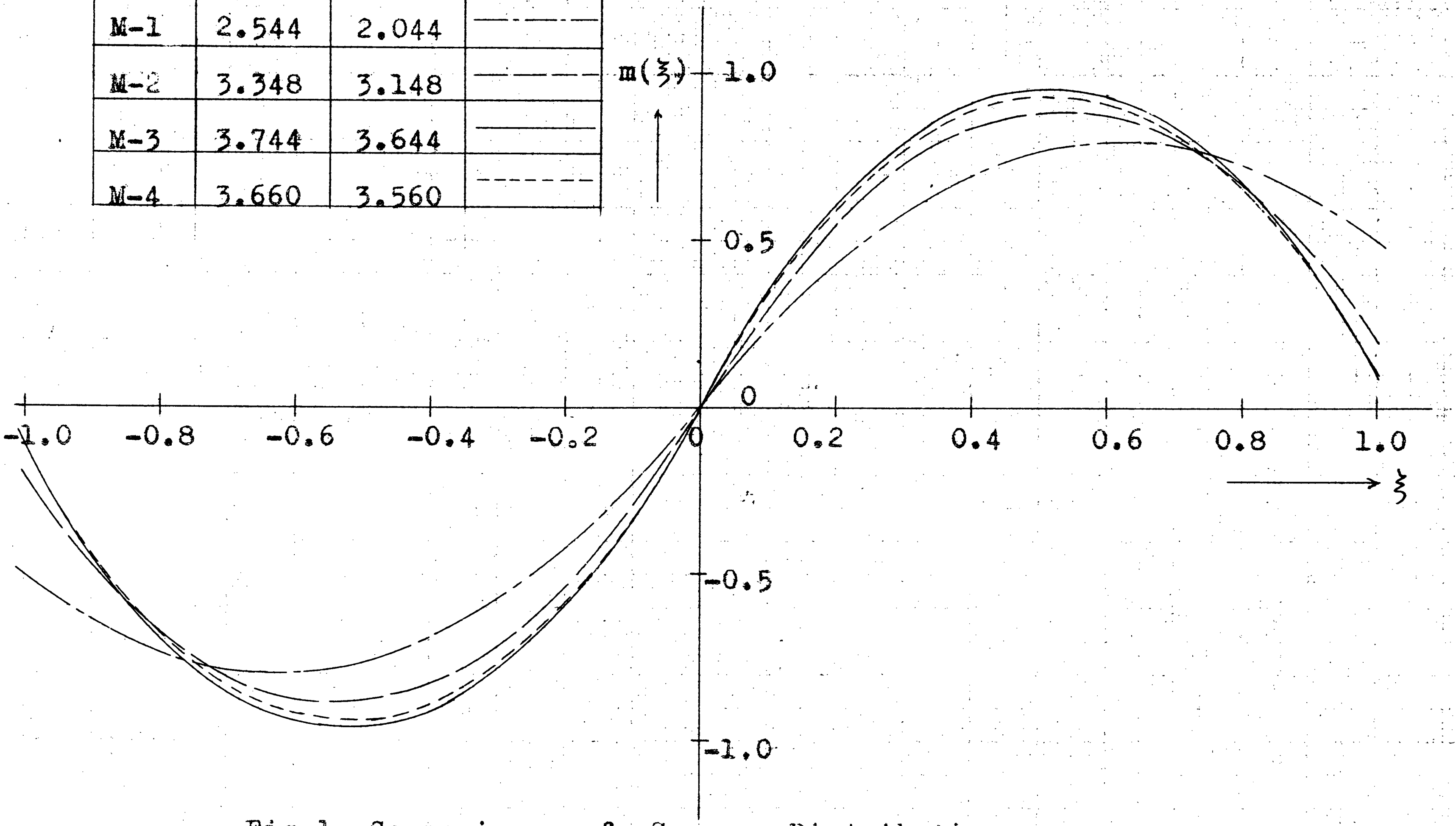

Fig.1 Comparison of Source Distributions

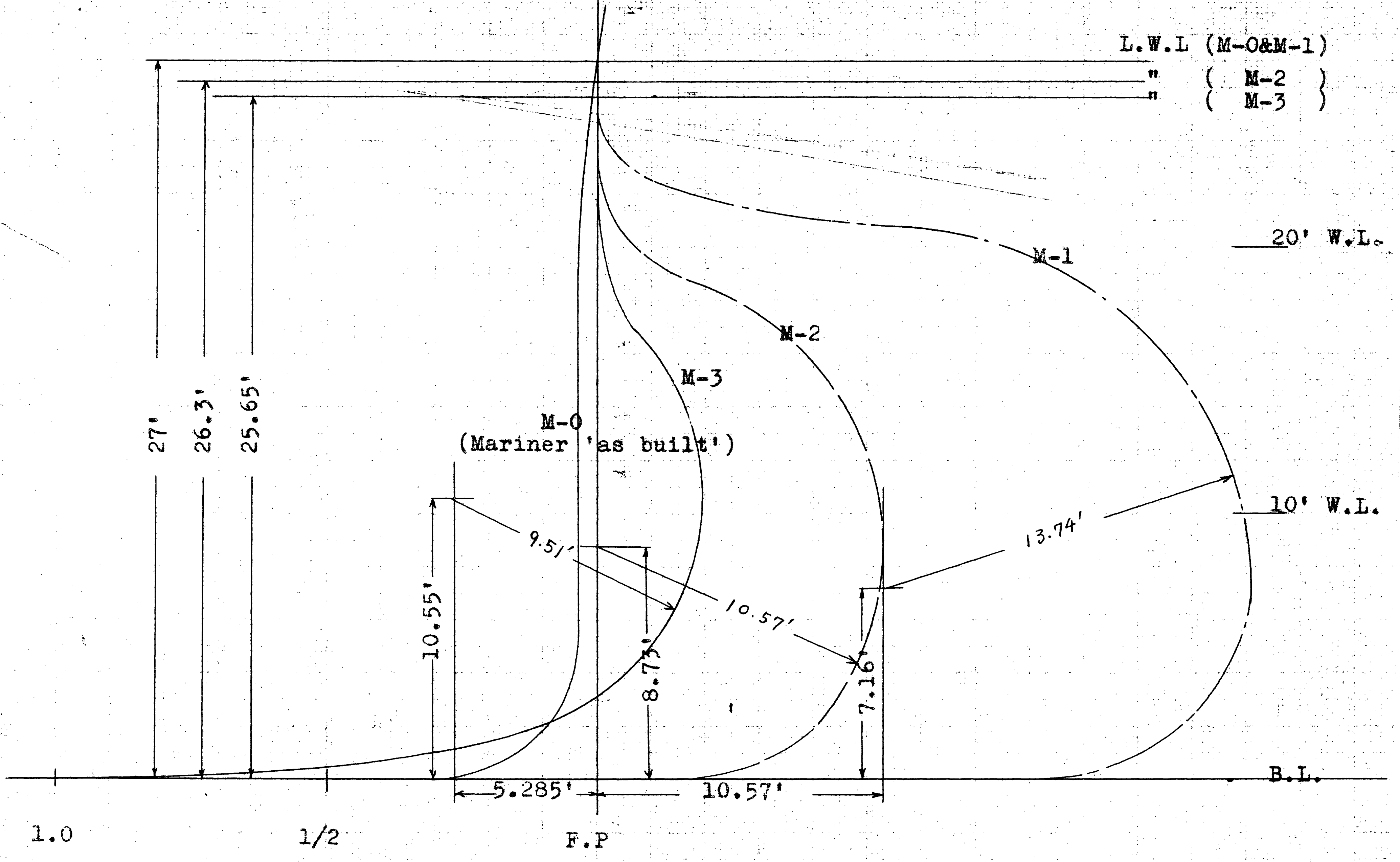

Fig.3 Profiles of Bulbs

FURTHER PRELIMINARY CALCULATIONS FOR THE ALTERNATIVE MARINER (WITH-BULB) DESIGN

THE UNIVERSITY OF TOKYO
SHIP MODEL BASIN LABORATORY

— Second Report —

Further Preliminary Calculations for the Alternative MARINER (With-Bulb) Design

By

Project Director :
Takao Inui, Prof., Dr. Eng.,
Superintendent, Ship Model
Basin Laboratory, The University
of Tokyo.

University of Michigan,
ORA Project 05589,
Maritime Administration
Contract MA-2564,
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Change No.1.

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Introduction

During the last three months (January through March 1964) the research works at the University of Tokyo Experimental Tank on the present project (University of Michigan ORA Project 05589, Maritime Administration Contract MA-2564, Task Order 111, Change No.1) have been carried out in two phases in parallel ; like

(a) Further preliminary calculations for the alternative Mariner (with-bulb) design, and

(b) Tank experiments on a 2.5 meter model of Mariner "as built".

In accordance with these two different subjects, two separate reports, the Second Report and the Third Report, have recently been prepared. This Second Report is devoted for the subject (a), while the Third Report, which will be sent early in April, treats the subject (b).

Section 1 —— Principal Particulars and Lines of Design M-4

Through the correspondences by Reference (5) and Reference (6), an approval was given by MARAD to proceed with the work using Design M-4 in January 1964.

The principal particulars and the hull coefficients of Design M-4 are listed in Table 1. Fig. 1 shows the body-plans, while Fig. 2 shows the sectional area curves as well as the designed load waterlines, both in comparison with the Mariner "as built" (M-0).

As shown in Fig. 2, a fairly large modification was made with the fore-body sectional area curve. The reason for this rather large modification was explained in Reference (5), Section 2 (Conditions for the "Waveless" State). On the contrary, with the aft-body the sectional area curves are practically same. The aft-shoulder of the designed load waterline of M-0 is slightly moderated alone.

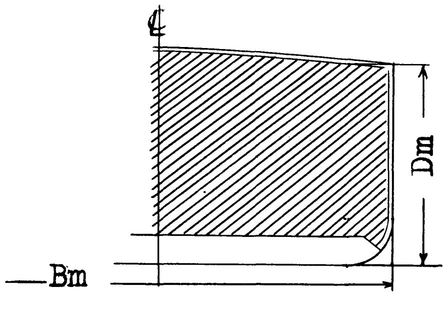
Thus it would be safely predicted that the wave-making characteristics of the aft-body of Design M-4 is practically same with that of the Marine "as built" M-0. This means that, with Design M-4, a fairly remarkable aft-shoulder wave may probably be observed.

With this respect, a modified design M-5 is also shown in Figs. 1 and 2. Concerning the details of Modified Design M-5, discussions will be given later in Sections 4 and 5.

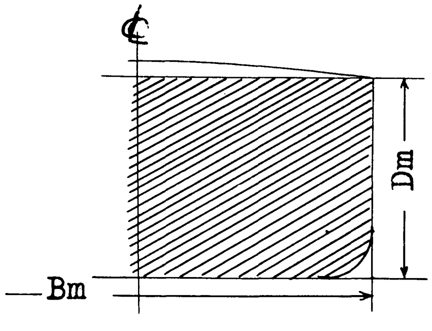
Section 2 — Capacity Calculation on Design M-4

The calculations have been made to confirm to what extent Design M-4 actually fullfil the two important design requirements : (a) the cargo cubic (capacity calculation), and (b) the transverse stability (stability calculation).

In these calculations, however, the principal concerns are put not on finding the absolutely exact figures, but on obtaining the relative values or on the comparison between the two Design M-4 and M-0. For example, as for the cargo cubic, not the detailed ordinary cubic calculation was made, but the simpler way of calculation was adopted. As an approximation, the sectional areas of the "moulded depth form" of the two ships were calculated as shown in Table 2 and Fig. 3. To simplify the calculation, the camber of the deck as well as the side sparring were neglected with the mentioned "moulded depth form" as shown in the following sketches.



(a) Ordinary Cubit Form



(b) "Moulded Depth Form"

The total cubic of the mentioned "Moulded Depth Form" of Design M-0 is 1,192,000 cubic feet, while that of Design M-4 is 1,230,000.

Therefore, if it is allowed to maintain just the equal figure for this "Moulded Depth Form", about one foot reduction with the moulded depth M-4 (presently D_m = 44'-6") is considerable.

This is the first reason for our proposal of Modified Design M-5.

Section 3 — Stability Calculation on Design M-4

The exact calculation of the square moment of the designed water-plane area about the longitudinal axis (I_T) of Design M-4 was carried out. The final figure is 1128×10^4 ft^4, which fullfils the required value 1121×10^4 ft^4, Reference (5), Table 1.

Thus the initial transverse stability requirement (GM) is safely confirmed. However, the overall stability characteristics are sometimes more important than the initial stability, as stated in Reference (5), Section 3, Item (b).

In this consideration, stability calculations were carried out for two loading conditions :

(a) Full loaded condition :

Displacement : Δ = 21,093 Tons

Assumed vertical position of C.G. :

KG = 26.8 ft.

(b) All consumed condition :

Displacement : Δ = 17,000 Tons

Assumed vertical position of C.G. :

KG = 30.5 ft.

The righting levers (GZ) versus heeling angles are shown in Table 3 as well as in Fig. 4. In Fig. 4 the dynamical stability curves are also shown. It should be noted herein that in these calculations the super-structure was excluded with both designs M-0 and M-4.

From these table and figure it can be safely concluded that Design M-4 has an overall stability characteristics a little superior to Design M-0.

This is the second reason why we are presently proposing Modified Design M-5 instead of Design M-4.

Section 4 — Discussions on the Results Obtained

From the numerical results presented in the preceeding two sections, it can be briefly summarized that Design M-4 meets both of the two important design requirements : (a) cargo cubic, and (b) transverse stability. Moreover, it has been clarified that Design M-4 has a fairly large extra cargo cubic when the original depth moulded (D_m = 44'-6") is fixed. In addition to this, with respect to the overall transverse stability Design M-4 is superior (eventhough the difference is not so large) to Design M-0.

Now, at this stage of the discussions, it must be remembered that Design M-4 has some defects in the aft-body form from wave resistance's point of view, as stated in Section 1. The designed load waterline curve of M-4, Fig. 2, shows that a fairly hard aft-shoulder still remains. The cause for this undesirable tendency of the aft-body form can principally be attributed to the stability requirement. However, the stability requirement is not always independent with the cargo cubic requirement. In the present case of Design M-4, the cargo cubic has some, say about 3.2 per cent, extra margin.

We can make use of this fact as stated in the following section (Section 5).

Section 5 — Proposal of Modified Design M-5

The procedures of the further modifications herein adopted with Design M-4 are given below.

(1) Slight Reduction of Depth Moulded :

A small modification of the depth moulded (D_m) by maintaining the cargo cubic of the Mariner "as built" (Design M-0) unchanged. Let us denote the corresponding reduction in D_m by ΔD_m, which will be given easily as follows.

The extra margin in cargo cubic with Design M-4 is given as (Table 2),

$$\frac{1{,}230{,}000\ ft^3 - 1{,}192{,}000\ ft^3}{1{,}192{,}000\ ft^3} = \frac{38{,}000\ ft^3}{1{,}192{,}000\ ft^3} = 3.2\ \%$$

As shown in Table 2, this extra margin comes not from the underwater portion, but from the abovewater space exclusively. The per cent extra margin of this abovewater capacity is given as

$$\frac{576{,}000\ ft^3 - 538{,}000\ ft^3}{538{,}000\ ft^3} \quad \frac{38{,}000\ ft^3}{538{,}000\ ft^3} \quad 7.1\ \%$$

Thus the corresponding reduction in D_m is found as

$$D_m = \frac{38{,}000\ ft^3}{\overline{A}_D\,(ft^2)}$$

where $\overline{A}_D$ = Mean deck-plane area at the depth

$$D'_m = D_m - \frac{1}{2}\Delta D_m$$

As shown below, ΔD_m is of the order of one foot, not so large. Then $\overline{A}_D$ can be replaced by A_D, the deck-plane area exactly at the depth moulded D_m = 44'-6", where

$$A_D = L \times B \times C_D$$

L = 520'

B = 79'

C_D = Deck-plane area coefficient at the depth

D_m = 44'-6" = 0.81 (found by an exact calculation)

Therefore we have

$$A_D = 520 \times 79 \times 0.81 = 4108 \times 0.81 = 3{,}327 \text{ ft}^2$$

and
$$\Delta D_m = \frac{38{,}000}{A_D} = \frac{38{,}000}{3{,}327} = 1.14 \text{ ft} .$$

This mean that from cargo cubic standpoint alone, we may reduce the depth moulded by ΔD_m = 1.14 ft.

However from an overall design point of view, this amount of depth reduction will be too large to be actually adopted. Therefore, we assume here that the maximum practicable depth reduction will be given as

$$\Delta D_m = 0.5 \text{ ft.} = 0'\text{-}6"$$

(2) <u>Change of KG</u> :

The abovementioned modification in the depth moulded ($D_m \rightarrow D_m' = D_m - \Delta D_m$) naturally causes a slight reduction in KG (KG → KG').

By assuming the simple relation

$$KG \propto D_m$$

The new value KG' will be given by

$$KG' = \frac{D_m'}{D_m} \times KG = \frac{D_m - \Delta D_m}{D_m} \times KG .$$

Referring to the well-known relation

$$GM = KM - KG = KB + BM - KG$$

and by assuming that KB remains unchanged, the requirement for constant GM will be written as

$$BM' - KG' = BM - KG ,$$

Where $BM = \frac{I_T}{\nabla}$

$BM' = \frac{I_T'}{\nabla}$

with I_T' = Square moment of the designed waterplane area about the longitudinal axis, corresponding to Modified Design M-5, where the aft-body form will be slightly improved from Design M-4 by moderating the aft-shoulder.

Then we have

$$I_T' = I_T - KG \times \nabla \times \frac{\Delta D_m}{D_m}$$

where $I_T = 1,121 \times 10^4 \ ft^4$

$KG = 26.8$ ft (approximated with allowances)

$Dm = 44'\text{-}6''$

$\Delta Dm = 0'\text{-}6''$

$= 653,000 \ ft^3$

or $I_T' = 1,100 \times 10^4 \ ft^4$

(3) Modified Design M-5 :

Taking these results (1) and (2) into account, the Modified Design M-5 has been finally obtained. The principal particulars, which are entirely same with Design M-4, as well as I_T', approximate cubic, and the hull coefficients (Cw alone being changed) of this Modified Design M-5 are given in Table 1.

The body-plan and the sectional area curve together with the designed load waterline curve are shown in Figs. land 2, respectively, both in comparison with Design M-0 and Design M-4.

This newly obtained Modified Design M-5 looks like most preferrable due to the following several reasons :

(1) Probably near best wave-making characteristics under the given design condition, esp. with the restriction of constant C_B (= 0.6125)

(2) Sufficient cargo cubic.

(3) Sufficient transverse stability.

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References

(1) Vito L. Russo : Correspondence to Inui (March 2, 1962).

(2) T. Inui : Wave-Making Resistance of Ships, TSNAME Vol.70 (1962)

(3) Vito L. Russo : Design of the Mariner-Type Ship, TSNAME Vol.61 (1953).

(4) Tsunoda, Kasahara and Takekuma : A High-Speed Cargo Liner Design Based upon the "With-Bulb" Waveless Concept, presented at the International Seminar on Theoretical Wave Resistance at the University of Michiga, August 1963.

(5) T.Inui : First Report, UM/ORA Projict 05589 - MARAD Contract MA-2564, Task Order III, Change No.1 (December 1963).

(6) R.J. Taylor : Correspondence to Inui (Jan. 3, 1964).

Table 1 — Principal Particulars and Hull Coefficients for Designs M-0, M-4 and M-5.

	M-0 (as built)	M-4 (alternative)	M-5 (modified)
Lpp (ft)	520.0	520.0	520.0
Bm (ft)	76.0	79.0	79.0
Dm (ft)	44.5	44.5	44.0
dm (ft)	27.0	25.95	25.95
C_B	0.6125	0.6125 (0.5955)*	0.6125
C_P	0.6246	0.6246 (0.6071)*	0.6246
C_M	0.9807	0.9807 (0.9807)*	0.9807
C_W	0.7236	0.6999	0.6962
L.C.B. (%)	1.47% aft	1.025% aft (2.206% aft)*	0.67% aft

(*) Parenthesis denotes the main-hull alone (without bulb).

Table 2 — Approximated Cargo Cubic of "Moulded Depth Form" for Designs M-0, M-4 and M-5.

Design	(1) Underwater Cubic	(2) Abovewater Cubic	(3)=(1)+(2) Tatal Cubic
M-0 (as built)	654,000 ft^3	538,000 ft^3	1,192,000 ft^3
M-4 (alternative)	654,000	576,000	1,230,000
M-5 (modified)	654,000	559,000	1,213,000

Table 3 — Transverse Righting Lever (GZ)
versus Heel Sngle (θ)

Loarding Condition	Full Loaded		All Consumed	
Assumed KG	KG = 26.8'		KG = 30.5'	
Heel Angle ( )	M-0	M-4	M-0	M-4
0°	ΘZ = 0^{ft}	GZ = 0^{ft}	GZ = 0^{ft}	GZ = 0^{ft}
7.5°	0.57	0.60	-0.12	0.17
15°	1.82	1.46	0.42	0.47
30°	3.02	3.14	1.80	1.89
45°	3.35	3.63	1.75	2.13
60°	2.45	2.52	0.57	0.66
75°	0.71	0.38	-1.83	- 2.01
90°	- 4.53	- 4.56	-4.43	- 4.59

Note — The super-structures are excluded in stability calculations.

Volume

(From Base Line to Depth moulded line)

Ship	Total	From B.L to L.W.L.	From LWL to Dmline	Marks
M-0	1192000 ft^3	654000 ft^3	538000 ft^3	– – –
M-4	1230000	654000	576000	——

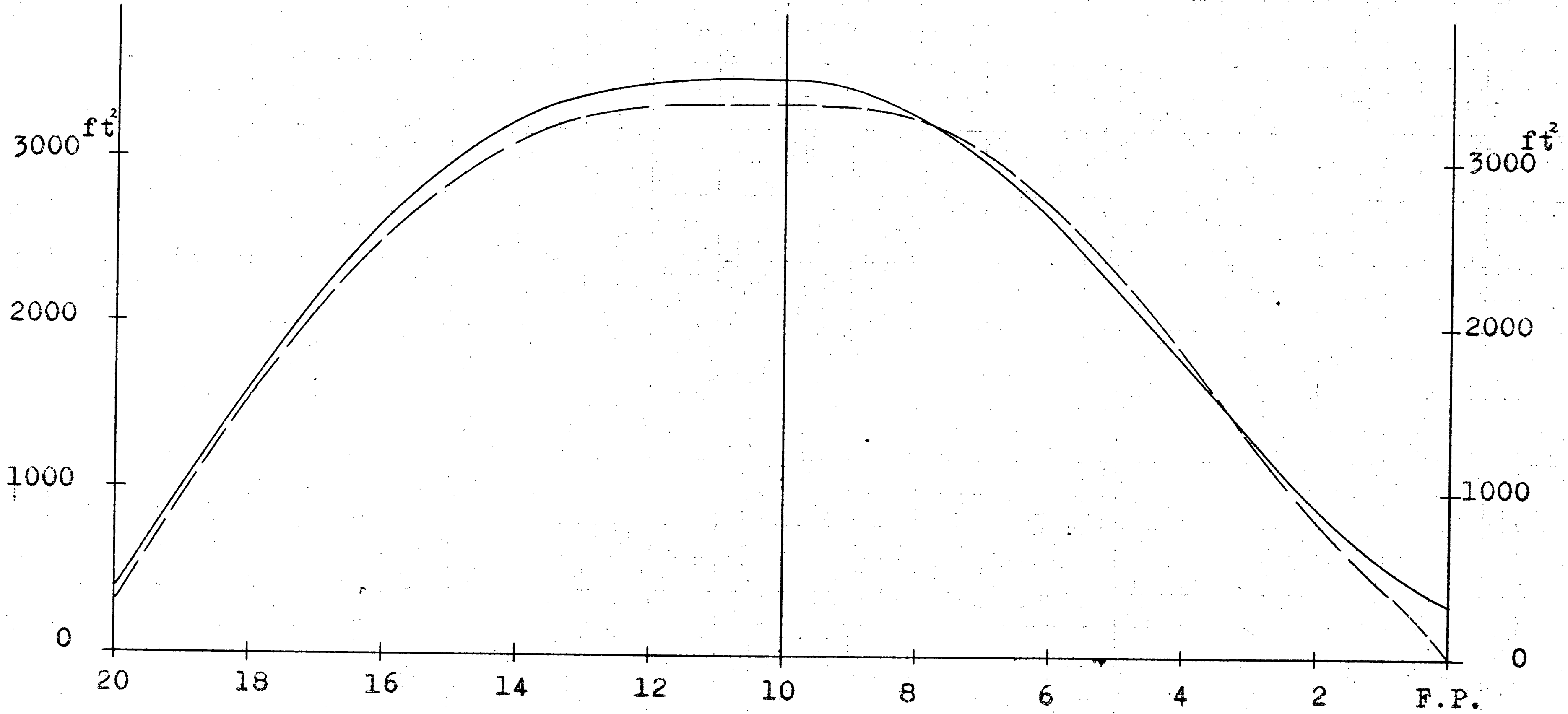

Fig.3 Sectional Area Curves

Ship	Full Loaded			All Consumed			Marks
	Δ	dm	assumed KG	Δ	dm	assumed KG	
M-0	21093^T	$29'10\frac{1}{16}''$	26.8'	17000^T	24.85'	30.5'	— —
M-4	"	28.6'	"	"	23.8'	"	——

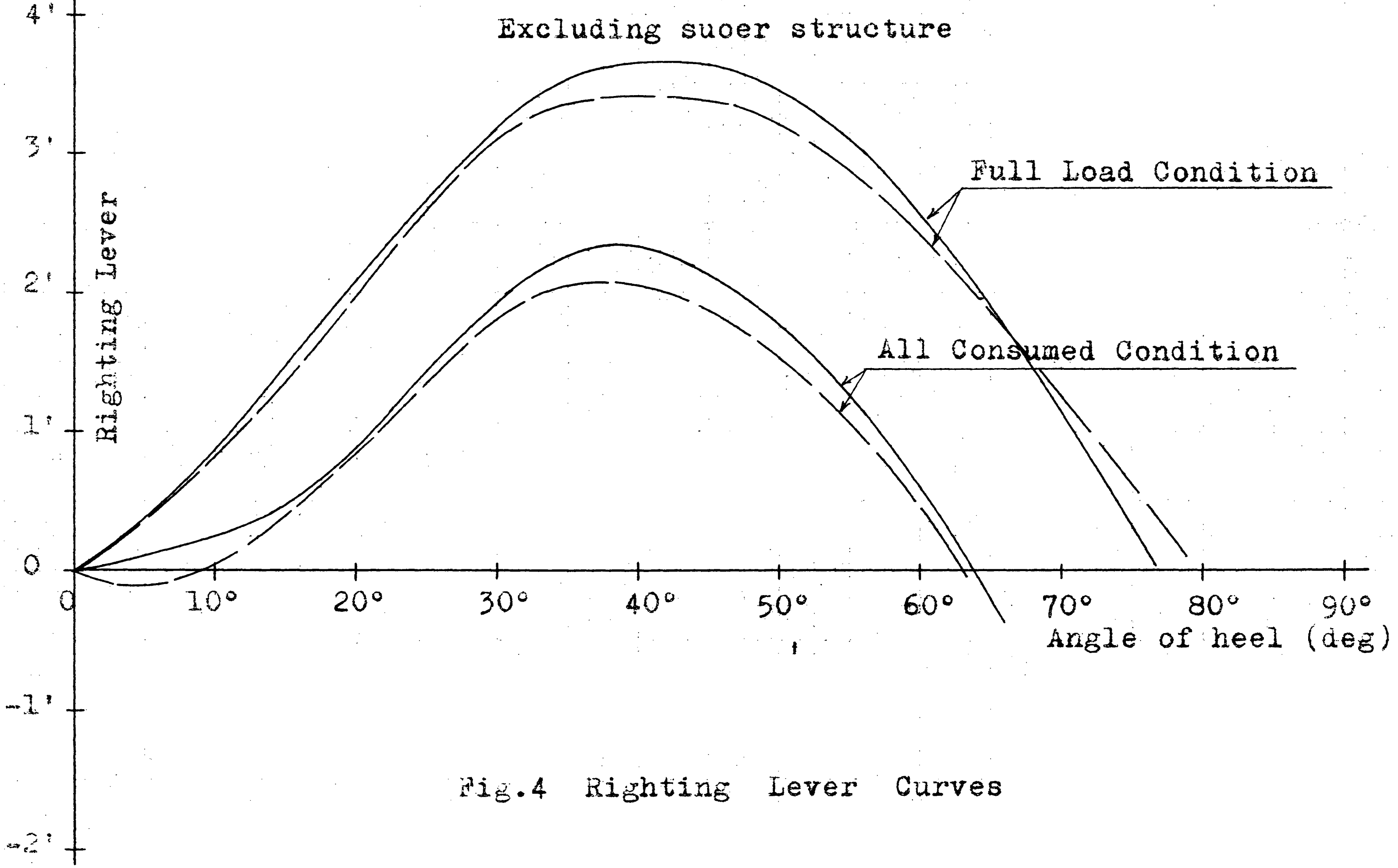

Fig.4 Righting Lever Curves

RESISTANCE TESTS ON 2.5 METER MODELS AND EHP ESTIMATION

THE UNIVERSITY OF TOKYO
SHIP MODEL BASIN LABORATORY

— Third Report —

Resistance Tests on 2.5 meter Models and EHP Estimation

By

Project Director :
Takao Inui, Prof., Dr. Eng.,
Superintendent, Ship Model
Basin Laboratory, The University
of Tokyo.

University of Michigan,
ORA Project 05589,
Maritime Administration
Contract MA-2564,
Task Order 111,
Change No.1.

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—— Contents ——

Introduction

In the Introduction of the preceding report (Second Report, March 1964), it was stated that this Third Report would treat the two kinds of tank experiments —— resistance tests and wave observation tests —— on a 2.5 meter model of the Mariner "as built" alone. However, for better comparison's sake, an amendment was made as follows :

(a) The resistance tests both on the Mariner "as built" and on the Alternative Mariner (with-bulb) will be summarized in this Third Report.

(b) The investigation into the wave-making characteristics of the mentioned models, including the models' side wave profiles as well as the bird's eye view pictures and their stereo-analysis of the wave patterns as a whole, will be treated in the Final Report (Fourth Report).

(c) Both in (a) and (b), comparisons would be made not only on the mentioned two models ; i.e. the Mariner as built and the alternative Mariner (with-bulb), but also on the alternative Mariner main-hull alone (without bulb). A lot of color slides will also be furnished in (b), which will be useful to give a clear contrast of the simple characteristics of the wave configuration of the mathematically obtained fore half body (the alternative Mariner without bulb) against of the conventionally obtained hull form (the Mariner "as built").

In accordance with the above-mentioned line, the present report (Third Report) will give the details and the discussions about the resistance tests carried on the three 2.5 meter models, i.e. one "as built" model and two "alternative" models, with and without bulb.

For simplicity's sake, the following notations are adopted for identifying the model numbers and the design numbers of these three models.

Corresponding Hull Geometry	(a) Mariner "as built"	(b) Alternative Mariner (main hull alove)	(c) Alternative Mariner (with-bulb)
Design Number	M-0	M-5 (*)	M-5
Model Number	MR-1	MR-2	MR-2xA4

Section 1 Description of the Models

Design M-5, our final proposal, was accepted by Mr. R. J. Taylor's letter dated April 15, 1964, Reference (7).

In Table 1 the principal dimensions and the hull coefficients of the mentioned three different forms are given for the full-scale ships (Lpp = 528'-6").

Two wooden models MR-1 and MR-2 (without bulb) were made with Lpp = 2.5 meters (8.202 feet). The Scale of these two models to the full scale ships is $\frac{8.202}{528.5} = 1/64.435$.

For the alternative Mariner model MR-2, four bulbs were designed and tested as shown in Table 2. Among these four tested bulbs, it has been ascertained that A-4 Bulb is the best. Therefore, hereinafter we denote the final alternative Mariner model (with-bulb) as MR-2 x A4 as shown in the Introduction.

The profile, bottom plan and front view pictures of these three models are shown in Photos 1 - 3 .

The principal particulars and off-sets of the two models MR-1 and MR-2 x A4 are shown in Tables 3, 4 and 5, while (a) their body-plans and profiles of bow and stern, and (b) the detailed plan of the optimum bulb A4 are shown in Figs. 1 - 3.

The corresponding sectional area curves, the designed load-waterlines, and the hydrostatic curves are also given in Figs. 4 - 6.

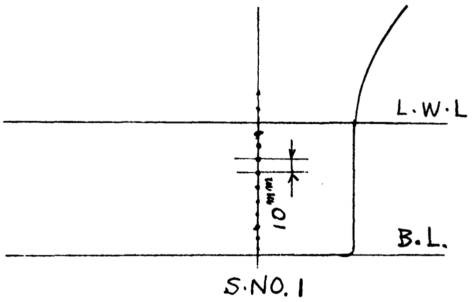
Section 2   Test Conditions for the Resistance Tests

The usual EHP tests or the resistance tests were carried on these three models for two kinds of loading conditions, i.e. (a) the designed condition, and (b) the full-loaded condition. In Table 6 the hull particulars and coefficients, the displacement and wetted surface, etc. are given both for 2.5 meter models and for full-scale ships.

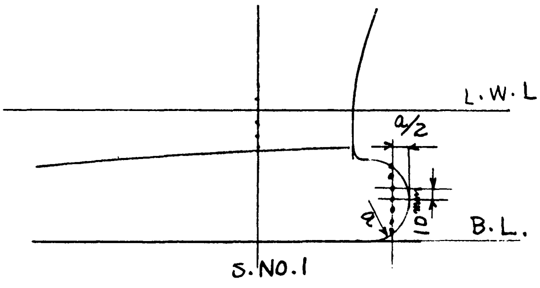
Section 3   Turbulence Stimulation

As the turbulence stimulators, the plate studs of 1.3 mm height were adopted with constant intervals of 10 mm. The location of the line of the mentioned plate studs are shown in the following sketches.

(a) Case "without bulb"



(b) Case "with bulb"



Refer to Dr. Tagori's papers, References (8), (9), (10).

Section 4   Analysis of the Test Results

The first model MR-1 (Mariner as built) was early prepared in December 1963, and some preliminary towing experiments on this first model were carried out from time to time for the period January through March 1964. The water temperature was between 8°C and 10°C for this period.

The second model MR-2 (alternative main hull) was then built in April 1964 after the final approval was given to the proposed design M-5. The towing tests on the second model MR-2 and those on the final model MR-2 x A4 were carried out for the period April through May 1964, when the water temperature had gone up to 20°C. To avoid any small measuring errors which may occasionally come from the fairly large difference of water temperature between these two tested periods, the first model MR-1 was again tested in parallel with the other two alternative models during the latest two months. In this report these latest results were finally adopted for the model MR-1.

In the analysis of these resistance tests, two different ways were adopted, as follows.

(A) Hughes' Method :

In Figs. 7 and 8, the total resistance coefficient curves of these three models were given for the tested two loading conditions, i.e. the design condition and the full-loaded condition, respectively. Here, the resistance coefficient

$$Ct' = Rt / (\frac{1}{2}\rho V^2 Lpp^2) , \quad \ldots\ldots\ldots\ldots \quad (1)$$

and Froude number

$$Fn = V / \sqrt{Lpp\, g} , \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

were adopted for conveniense of absolute comparison, resistance as well as speed.

In these figurs (Figs. 7 and 8) the mean sinkage curves as well as the trim curves were also given for reference.

From the results at the very low Froude number range, it can be safely concluded that the stimulator adopted was appropriate. The form factors based upon Hughes' (1954) basic line were found as K = 0.27 for the model MR-1 (Mariner "as built") and K = 0.29 for the model MR-2 (alternative, without bulb), where Hughes (1954) basic line is given as follows :

$$C_f = R_f / (\frac{\rho}{2} V^2 S) = \frac{0.066}{(\log_{10} R_n - 2.03)^2} , \quad \cdots\cdots (3)$$

where R_n = Reynolds number

Therefore, we have

$$C_f' = R_f / (\frac{\rho}{2} V^2 L_{pp}^2) = (1 + K)C_f', \qquad (4)$$

$$C_f' = C_f \times \frac{S}{(L_{pp})^2}, \qquad (5)$$

And finally, the wave-making resistance coefficients are given as

$$C_w' = R_w / (\frac{\rho}{2} V^2 L_{pp}^2) = C_t' - (1 + K)C_f', \qquad (6)$$

The above-mentioned method of analysis is known as "three-dimentional" extrapolation method, which have widely been adopted in Japan because of its superiority in the accuracy of prediction as well as in the scientific basis.

The obtained values of the form factor (K = 0.27 and K = 0.29) look like quite reasonable, when we consider the fairly large value of the beam-draft ratios, especially for the model MR-2. (Appendix C).

Figs. 9 and 10 show thus obtained wave-making resistance coefficients, which will be very close to the net wave-making resistance in the true meaning of the word.

Here, it will be interesting to notice in Fig. 9 (the designed condition) that

(a) the second model MR-2 (main hull alone) is a little bit superior to the first model MR-1 (as built), and that

(b) the final reduction per centage in wave-making resistance (the difference in Cw' between MR-1 and MR-2xA4) is about $\frac{0.102 - 0.044}{0.102} \times 100 = \frac{0.058}{0.102} \times 100 = 57$ (%) .

However, in Fig. 10 (the full-loaded condition) this per centage reduction is smaller, because the optimum bulb A4 was designed not for the full-loaded condition but for the designed condition.

In the following table a comparison is made in the Cw' value, expressed in Equation (6), of these three models at the designed speed of Vs = 20 knots.

Table A —— Comparison in C_w' (Hughes' Method)

Model	MR-1 Mariner	MR-2 Alternative	MR-2xA4 Alternative
Loading Condition	(as built)	(main hull)	(with bulb)
Designed	$.102 \times 10^3$	$.102 \times 10^3$	$.044 \times 10^3$
Full Loaded	$.120 \times 10^3$	$.100 \times 10^3$	$.062 \times 10^3$

(B) Schoenherr's Method;

Secondly, the well-known ATTC method of analysis based upon Schoenherr's basic line, was adopted. This method of analysis admits the classical Froude's assumption that the frictional resistance of a ship's model can be replaced by that of the "equivalent" plate, whose length and wetted surface are same with those of the model.

The thickness of this "equivalent" plate is mathematically null. Thus the displacement is also null , while any ship's model has a certain thickness or a finite displacement, more or less, as denoted by the volume-length ratio ∇/L^3 .

It is quite natural therefore to conclude that the residual resistance

$$C_r = R_r / (\frac{\rho}{2} V^2 S) = C_t - C_f , \qquad (7)$$

$$\text{where} \quad C_t = R_t / (\frac{\rho}{2} V2S) \qquad (8)$$

$$C_f = R_f / (\frac{\rho}{2} V^2 S) = \text{Schoenherr's friction line}, \cdot\cdot \qquad (9)$$

would involve a part of viscous resistance, which may not follow Froude's law of comparison, but will follow Reynold's law.

Anyway, the Cr-curves thus analysed are obtained from the total resistance coefficient curves (Figs. 7 and 8) for two loading conditions as shown in Figs. 11 and 12.

Although the residual resistance does not mean at all the net wave-making resistance, it will still be of some practial interests from design's point of view to make a comparison of the three models in the term of residual resistance. However for an absolute comparison, we had better adopt another kind of residual resistance coefficient, like

$$C_r' = R_r / (\frac{\rho}{2} V^2 L_{pp}^2) , \qquad (10)$$

The reason for this is quite clear, because Lpp (= 2.50 meter) is absolutely constant for these three models.

The following table, Table B, gives a comparison in the form of Cr' at Vs = 20 knots, in contrast with Table A.

Table B —— Comparison in C_r' (Schoenherr's Method)

Model	MR-1	MR-2	MR-2xA4
Loading Condition	Mariner (as built)	Alternative (main hull)	Alternative (with bulb)
Designed	$.212 \times 10^3$	$.210 \times 10^3$	$.175 \times 10^3$
Full Loaded	$.230 \times 10^3$	$.225 \times 10^3$	$.180 \times 10^3$

Section 5 EHP Estimation

The estimation of the effective horse power (EHP) for the full-scale ships, the mentioned two methods of analysis, (a) Hughes' and (b) Schoenherr's, or more exactly, (a) a three-dimensional exprapolation method, and (b) a two-dimensional extrapolation method, were also adopted.

Herein, the main concern is concentrated to the selection of most reliable valuses for the roughness allowances, or

$$\Delta C_f = \Delta R_f / (\frac{\rho}{2} V^2 S) , \qquad (11)$$

In ATTC standard method, a well known value of Δ Cf = 0.0004 has been widely adopted. However, the recent experiences especially in Japan, show that this value of roughness allowance is too large not only for the two-dimentional extrapolation (in this case a "negative" roughness allowance needed), but also for the three-dimentional extrapolation.

In this report it was intended to give, at first, the most reliable abosolute value of EHP by adopting the three-dimensional extrapolation (Hughes' method). Then, secondly, for more practical or statistical comparison's sake, the two-dimensional extraplolation was made by adopting Schoenherr's friction line and by assuming,

$$C_f = 0.0004 \qquad (12)$$

(A) Three-Dimensional Extrapolation Based on Hughes' Basic Line :

The total resistance of the corresponding full scale ships is given as,

$$C_{ts} = C_w + (1 + K)C_{f,s} + \Delta C_f \qquad (13)$$

Herein, the roughness allowance of $\Delta C_f = 0.0002$ was adopted as the average mean of a lots of speed-trial data recently analyzed with a lots of high speed cargo liners built in Japanese shipbuilders. (On this matter, refer to Appendix D). Thus obtained EHP curves are shown in Fig. 13, for the mentioned two loading conditions.

In the following table (Table C), a comparison in EHP (three-dimensional), at Vs = 20 knots, of the three models is given.

Table C —— Comparison in EHP (three-dimensional)

Model	(1) MR-1 Mariner	(2) MR-2 Alternative	(3) MR-2xA4 Alternative	(4) Per cent reduction
Loading Condition	(as built)	(Main hull)	(with bulb)	$\frac{(1)-(3)}{(1)} \times 100$
Designed	8300 PS	8250 PS	7350 PS	11.5 %
Full Loaded	8960 PS	8500 PS	8040 PS	10.1 %

(B) Two-Dimensional Extrapolation based on Schoenherr's Line :

By this method of extrapolation, the total resistance of the ships is given as

$$C_{ts} = C_r + C_{f,s} + \Delta C_f \qquad (14)$$

where ΔC_f is given by Equation (12) by ATTC standard method.

These EHP curves are given in Fig. 14, again for the two loading conditions.

The table, similar to Table C, is also prepared for a comparison of EHP (two-dimensional) of the three models at the speed of Vs = 20 knots, as follows :

Table D —— Comparison in EHP (two-dimensional)

Model	(1) MR-1 Mariner	(2) MR-2 Alternative	(3) MR-2xA4 Alternative	(4) Per cent reduction
Loading Condition	(as built)	(main hull)	(with bulb)	$\frac{(1)-(3)}{(1)} \times 100$
Designed	10420 PS	10380 PS	9760 PS	6.4 %
Full Loaded	11110 PS	10920 PS	10400 PS	6.4 %

The per cent power (EHP) reduction in the Table D shows the values fairly smaller than those given in the preceding Table C.

However, it can be safely concluded that the actual features are very close to Table C rather than to Table D.

x x x x x x x

There remain further two points of interest concerning the resistance tests on Model MR-1, the Mariner "as built". The first point is to check our results of the 2.5 meter (8.202 feet) model with those of DTMB 20 feet model. Appendix A is prepared for this comparison.

The second point of interest is to study or to confirm the actual level of wave-making resistance of the Mariner "as built". This is especially so because the Mariner "as built" is widely known as the near best among the existing conventional fast cargo liners.

As discussed in Appendix B, the mentioned reputation about the Mariner "as built" was definitely demonstrated by the wave-pattern pictures.

Here it will be important to notice that a lots of systematic series models must have been tested before the Mariner "as built" hull form was finally adopted.

In contrast to this, the main hull of the alternative Mariner (MR-2) was determined by a direct procedure without taking any detour.

Although the detailed discussions on the wave pictures and their stereo-analysis will be given in the Final Report (Fourth Report), it will still be useful, even indispensable, to give, in this report, some idea about the wave-making characteristics of the three models. For this purpose, the models' side wave profiles were prepared from the elongated pictures which were taken during the runs. (Appendix E)

Conclusion

As far as the resistance tests on 2.5 meter models are concerned, it has been ascertained that the mathematically designed Model MR-2xA4, Alternative Mariner (with bulb), is superior, in EHP at 20 knots to the conventional Model MR-1, Mariner as built, by about 12 per cent (at the designed load condition) and by 10 per cent (at the full loaded condition).

In this comparison it was aimed to keep the block coefficient strictly same, and the detailed calculation shows that the alternative model has C_B a little bit larger (C_B = 0.6169) than the original one (C_B = 0.6125). The size of the optimum bulb (A4) is 1.6 per cent of Lpp (= 528'-6") in its effective radius, which means that its effective diameter is about 16.9 feet (the designed draft for this alternative model is 25.95 feet). The maximum forward projection of this bulb, measured from F.P., is about 16.4 feet.

It must be noticed here that before reaching any final conclusion, it is of greatest importance to study in details the over-all effects of the large bulb upon the self-propulsion factors by carring out the self-propulsion tests of highest accuracy on large models (say, L must be 4 meters or 12 feet at least) as well as the flow measurements (or the stream-line observations) especially in the vicinity of the stern.

With respect to this, the following two points should be carefully taken into considerations.

(a) The type and configuration of the stern :

Although our experiences on the bulb effects upon propulsive efficiency are limited in the variation of the stern configurations, it looks like that with the ordinary cruiser stern the hull efficiency is kept approximately same, while with the transom stern or the Hogner's stern a further improvement in DHP of considerable amount is realized by adopting a large "waveless" bulb in addition to the previously obtained improvement in EHP. (DHP is equivalent to PHP, the power delivered to the propeller).

(b) The selection of the optimum revolution of the machinery :

As well-known, the selection of the type of machinery, especially the well balanced relation between power and revolution of the propeller is indispensable for attaining the possiblly highest propulsive efficiency. This is especially so in case of Diesel engines.

With the design of the waveless hull forms of any kind, the revolution of the propeller must be reduced, more or less, in accordance with the reduction in DHP. Otherwise, the smaller diameter of propeller must be adopted by trying to adjust to the unreasonally high revolution of propeller under the lower DHP.

This, of course, means to sacrifice the propulsive efficiency more or less.

With the steam-turbine engine, there will be no difficulties, because the ratio of the reduction gear can be easily adjusted, while with the diesel engine, this problem must be carefully treated.

Appendix A Comparison between Two Similar Models of Mariner "as built"

In Mr. R. J. Taylor's (MARAD) letter (Reference 6) were enclosed two data-sheets on the DTMB tank test results, carried out on the 20 feet Mariner "as built" Model (DTMB Model 4414, Propeller 3249). The first sheet (Test 10) is for the designed load condition with draft 26.96 ft (dated on 16 April, 1952), while the second sheet (Test 12) is for the full loaded condition with draft 29.71 ft (dated on 29 April, 1952).

The two models of the Mariner "as built", one is the 20 feet model tested in DTMB in April 1952, the other is the 2.5 meter model tested in the Ship Model Basin of the University of Tokyo, April through May in 1964, are quite similar except that the large model alone was fitted with the bilge keels.

In Figs. A-1 and A-2, the comparisons in C_w' (net wave-making resistance) as well as in C_r' (residual resistance) were given, respectively. From these figures the coincidence between the two similar models is better in term of C_w' than in term of C_r', which also acertains that the three-dimensional extrapolation is superior to the two-dimensional one. Herein it should be noted that the water temperature for the two DTMB tests was assumed as 59°F (15°C), because of lack of any informations on this matter.

In Fig. 14 of the text, Section 5, a comparison is also made in term of EHP. The conclusion with these figures are quite similar to those discussed in the above with respect to either the wave-making or the residual resistance.

Appendix B Wave-Making Resistance Level of the Mariner "as built"

We must confess that we had a strong impression with the very low level of wave-making resistance of the model MR-1 (Mariner "as built").

This impression was further doubled when we actually investigated its wave patterns in details later on.

Herein, a comparison was made with a certain Japanese fast cargo liner model (Model SR-452), which were known as near best among the SR-45 series models of conventional hull form (Refer to the 1962 Annual Report of "Investigation into the Propulsive and Steering Performances of High Speed Liners "published by the 45th Research Committee in the Shipbuilding Research Association of Japan.).

Fig. B·1 shows the Cw(= Rw $/(\frac{\rho}{2}V^2\nabla^{2/3})$)curves for the two models MR-1 and SR-452, Reference (14), Fig. 16.

Figs. B·2 ~ B·4 are for the comparison in the bird's eye view wave patterns, while Figs. B·5 ~ B·7 show the model's side wave profiles.

From these figures and wave pictures, the superiority of the Model MR-1 (Mariner "as built") to the Japanese Model SR-452 is definitely demonstrated.

Appendix C Discussions on Form Factors

As stated in the text, Section 4, the form factor based upon 1954 Hughe's line was found as K=0.27 (Mariner as built) and as K=0.29 (Aeternative Mariner).

The form factor is affected principally by the volume ratio ∇/L^3, secondly by L/T. To check the reliability of the mentioned K-values, Figs. C·1 and C·2 are prepared. These figures show that these K-values are quite reasonable if we consider fairly large B/T ratio.

Appendix D Discussions on Roughness Allowance

Concerning the prediction of the roughness allowance for the full scale ships of fast cargo liners, Reference (15) is prepared. This is the extracts from the 1962 Annual Report of "Investigation into the Propulsive and Steering Performances of High Speed Liners" by the 45th Research Committee in the Shipbuilding Research Association of Japan.

The speed trial results were analysed with the four fast cargo liners, Yamanashi-maru, Yamatoshi-maru, Richmond-maru and another ship named "A". In this analysis, three kinds of analysis; (a) I.T.T.C. 1957 line, (b) Schoenherr line, and (c) Hughes line were adopted. The first two are the two-dimensional extrapolation methods without adopting any "form factor", while the last one is a three-dimensional extrapolation.

As stated in the text, Section 5.4 on page 3, the weather and sea condition was best for the Yamanashi-maru.

Therefore, the most reliable value of ΔC_f would be very close to that of the Yamanashi-maru (Refer to Table 5.3), $\Delta C_f = 0.172 \times 10^{-3}$.

In this report, however, $\Delta C_f = 0.0002$ was adopted for Hughe's three-dimensional extrapolation method.

Appendix E Wave Profile Measurements alongside the Models

During the every run of the resistance tests with the three models, MR-1, MR-2, and MR-2xA4, the wave-profile pictures were automatically taken by a specially designed camera. In this appendix E, those at six different speeds Vs = 17, 18, 19, ..., 22 knots were selected for comparison, as shown in Figs. E·1 ~ E·6 (designed load condition) and in Figs. E 7 ~ E 12 (full loaded condition), respectively.

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Figures E.1 ~ E.6 — Measured wave profiles (Designed condition); for Vs = 17 ~ 22 knots

Figures E.7 ~ E.12 — Measured wave profiles (Full loaded condition); for Vs = 17 ~ 22 knots

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(14) T. Inui : Wave-Making Resistance of Ships, T.S.N.A.M.E., Vol.70 (1962), p.283.

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Table 1 — Principal Dimensions for Full Scale Ships

Ship Items	MR - 1 (Mariner "as built")	MR - 2 (Alternative Mariner without Bulb)	MR-2 x A4 (Alternative Mariner with Bulb)
Lpp	528'6"	528'6"	528'6"
L	520'0"	520'0"	520'0"
Bm	76'0"	79'0"	79'0"
dm	27'0"	25.95'	25.95'
Δ	$18{,}655^T$	$18{,}078^T$	$18{,}797^T$
Cb	.6125	.5933	.6169
Cp	.6246	.6050	.6290
C⊗	.9807	.9807	.9807
Cw	.7236	.6965	.6965
l.c.b.	1.47%L	2.10%L	0.32%L

Table 2 — Bulb Characteristics

Bulb Number	a/Lpp	f/Lpp	h/Lpp	Ab/A⊗
A 1	1.8 %	2.82 %	+ 1 %	14.3 %
A 2	1.8	2.82	0	14.3
A 3	1.8	2.82	- 1	16.5
A4 (optimum)	1.6	2.92	+ 1.5	11.3

Notes : a = Radius of the bulb

f = Immersion of the bulb center

h = Longitudinal location of the bulb center from F.P. (+) denotes fore, (-) denotes aft

Ab = Maximum sectional area of the bulb

A⊗ = Midship sectional area

Table 3

Principal Particulars

Model

Model No. (Design Number)	Mariner "as built" MR-1 (M-0)	Alternative (with-bulb) MR-2xA4 (M-5)
Length between perpendiculars	2.5000 m	2.5000 m
Length on 20 stations	2.4600	2.4600
Breadth moulded	.3595	.3737
Draft moulded	.1277	.1228
Rise of floor	0	0
Bilge turn radius	.0454	.0454
Stations apart	.1230	.1230
Water lines apart	.0378	.0300
Bow & buttock lines apart	.0378	.0300

Ship

Model No. (Design Number)	Mariner "as built" MR-1 (M-0)	Alternative (with-bulb) MR-2xA4 (M-5)
Length between perpendiculars	528'6"	528'6"
Length on 20 stations	520'0"	520'0"
Breadth moulded	76'0"	79'0"
Draft moulded	27'0"	25.95'

Note : Symboles in parentheses denote the design name for respective ships.

Table 4 — Offsets of MR-1 (M-0), Mariner "as built"

(unit in mm)

Half Breadth

S.No.	B.L.	1/4W.L.	1/2W.L.	1W.L.	1.5W.L.	2W.L.	2.5W.L.	3W.L.	3.5W.L.	4.5W.L.	5.5W.L.	top of model	S.No.
F.P.	-	(11.8)	(14.4)	(12.7)	(8.7)	(4.8)	(2.1)	(1.0)	1.1	4.2	13.5	38.5	F.P.
1/2	2.8	14.9	18.2	18.2	15.2	12.0	9.9	9.4	9.9	16.2	29.3	60.6	1/2
1	4.7	17.7	22.4	24.0	22.2	20.4	19.1	19.2	20.7	29.3	44.9	80.8	1
1^{1}/2	5.8	21.3	27.1	30.4	30.2	29.7	29.6	30.6	33.3	43.8	61.2	98.6	1^{1}/2
2	6.8	25.1	32.4	37.7	39.4	40.3	41.5	43.8	47.2	59.3	77.3	114.6	2
3	8.4	36.1	46.0	56.4	61.5	65.1	68.8	72.9	77.7	91.0	108.2	141.8	3
4	11.0	51.6	64.6	79.4	87.8	93.4	98.4	103.4	108.6	120.6	135.0	161.5	4
5	20.8	73.1	88.3	105.0	114.7	121.4	126.8	131.5	136.1	145.5	155.5	171.3	5
6	43.4	98.4	113.9	130.8	139.8	146.0	150.6	154.6	158.0	163.9	169.3	175.3	6
8	100.9	145.6	157.3	168.8	173.7	175.9	177.1	178.0	178.7	179.4	179.8	179.8	8
10	134.7	162.3	171.4	179.1	179.8	179.8	179.8	179.8	179.8	179.8	179.8	179.8	10
12	109.1	152.5	164.0	175.4	178.9	179.7	179.8	179.8	179.8	179.8	179.8	179.8	12
14	64.1	112.7	128.3	147.7	160.4	168.7	174.2	177.1	178.9	179.7	179.8	179.8	14
15	39.0	83.9	100.2	122.4	138.2	150.5	160.2	167.6	178.0	179.2	179.8	179.8	15
16	21.0	57.9	71.1	91.2	108.4	123.9	137.8	150.2	160.6	173.8	178.0	179.0	16
17	10.6	37.6	47.1	61.4	74.6	89.8	106.3	122.6	137.4	159.9	170.7	176.8	17
18	7.2	22.7	28.7	36.9	43.8	53.0	66.9	85.5	104.5	136.3	156.2	174.0	18
18^{1}/2	6.7	17.6	21.0	26.1	30.1	35.8	46.1	64.2	84.8	121.0	145.5	171.0	18^{1}/2
19	5.8	10.3	13.0	15.8	17.6	20.1	30.4	41.1	63.2	103.4	132.5	165.8	19
19^{1}/2	-	-	5.6	3.2	3.8	4.6	6.5	16.5	40.0	83.6	116.5	153.7	19^{1}/2
20	-	-	-	-	-	-	-	-	16.2	61.4	95.7	135.8	20
Y	-	-	-	-	-	-	-	-	-	41.3	75.2	116.5	Y
Z	-	-	-	-	-	-	-	-	-	13.7	47.2	98.8	Z

Note : The values in parentheses denote the cross point of F.P. station and extention of respective water lines.

Table 5 —— Offsets of MR-2xA4 (M-5), Alternative Mariner (with-bulb)

(unit in mm)

Half Breadth

S.No.	B.L.	.5W.L.	1W.L.	2W.L.	3W.L.	4W.L.	5W.L.	6W.L.	7W.L.	8W.L.	9W.L.	L.W.L.	S.No.
F.P.	-	-	-	-	-	-	1.8	5.5	15.0	28.8	44.5	0	F.P.
1/2	-	1.2	4.7	6.7	6.9	6.9	10.3	18.4	30.7	46.3	66.3	7.0	1/2
1	-	5.7	10.2	15.0	16.5	17.5	22.2	32.5	46.2	62.9	80.4	17.7	1
$1^{1}/_{2}$	-	10.6	16.7	24.5	28.6	30.7	36.1	47.0	61.6	78.7	96.6	30.9	$1^{1}/_{2}$
2	.9	15.1	23.6	35.2	42.2	45.8	50.8	61.2	76.5	93.1	111.0	46.1	2
3	2.0	27.0	42.3	60.7	70.6	76.5	80.8	89.6	103.8	118.9	134.2	76.8	3
4	7.6	50.6	69.6	90.3	99.9	103.9	107.6	115.3	126.7	139.3	151.7	104.1	4
5	25.5	81.8	100.8	118.5	125.7	128.1	131.1	137.6	146.3	154.8	163.3	128.2	5
6	57.5	114.4	129.2	142.3	146.3	147.8	150.2	154.8	160.8	166.6	171.6	147.8	6
8	120.0	158.3	167.5	174.5	175.9	176.5	176.5	176.8	179.0	181.2	183.4	176.5	8
10	141.2	174.8	183.7	186.6	186.6	186.6	186.6	186.6	186.6	186.6	186.7	186.6	10
Max.	141.3	175.2	184.2	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	186.9	**Max.**
12	124.4	165.4	176.0	184.4	186.1	186.5	186.9	186.9	186.9	186.9	186.9	186.3	12
14	71.8	129.0	145.7	165.4	174.9	179.7	182.5	184.4	185.9	186.4	186.8	180.0	14
15	44.4	100.0	120.2	146.0	161.3	171.5	177.3	181.6	184.2	185.6	185.9	172.0	15
16	25.0	69.1	89.5	118.0	140.9	157.7	169.0	176.5	181.0	183.2	184.0	158.4	16
17	13.3	45.4	59.6	83.1	109.0	134.8	154.9	167.4	175.0	178.7	180.4	136.8	17
18	6.9	27.4	36.0	48.8	67.3	99.3	130.8	150.0	160.7	167.3	171.6	102.3	18
$18^{1}/_{2}$	4.5	19.3	25.5	33.1	46.1	77.4	114.2	136.7	149.0	157.4	162.4	80.9	$18^{1}/_{2}$
19	2.9	11.1	15.2	18.3	25.8	53.0	94.0	119.9	134.3	143.9	149.5	56.7	19
$19^{1}/_{2}$	-	1.2	3.0	4.5	6.5	26.9	70.5	100.6	116.6	126.8	133.5	31.2	$19^{1}/_{2}$
20	-	-	-	-	-	-	44.1	76.5	94.9	105.9	113.2	0	20
Y	-	-	-	-	-	-	22.0	54.0	73.8	85.9	93.5	-	Y
Z	-	-	-	-	-	-	-	23.9	45.5	59.5	69.0	-	Z

Table 6

Test Conditions of Models

Model No.	MR-1 (M-0) Mariner "as built"				MR-2 (M-5) without bulb Alternative Mariner				MR-2 (M-5) with A-4 bulb Alternative Mariner			
Condition	Designed condition		Full loaded condition		Designed condition		Full loaded condition		Designed condition		Full loaded condition	
	model	ship	model	ship	model	ship	model	ship	model	ship	model	ship
Lpp	2.500^{m}	528'6"	2.500^{m}	528'6"	2.500^{m}	528'6"	2.500^{m}	528'6"	2.500^{m}	528'6"	2.500^{m}	528'6"
L (20 stations)	2.460^{m}	520'0"	2.460^{m}	520'0"	2.460^{m}	520'0"	2.460^{m}	520'0"	2.460^{m}	520'0"	2.460^{m}	520'0"
L$_{wl}$	2.475^{m}	523.3'	2.475^{m}	523.3'	"	"	"	"	"	"	"	"
Bm	.3595^{m}	76'0"	.3595^{m}	76'0"	.3737^{m}	79'0"	.3737^{m}	79'0"	.3737^{m}	79'0"	.3737^{m}	79'0"
dm	.1277^{m}	27'0"	.1407^{m}	29'10$\frac{1}{16}$"	.1228^{m}	25.95'	.1358^{m}	28.71'	.1228^{m}	25.95'	.1358^{m}	28.71'
trim	0 %L		0 %L		0 %L		0 %L		0 %L		0 %L	
displacements	.06910m^3	18655^{T}	.07740m^3	20896^{T}	.06697m^3	18078^{T}	.07515m^3	20289^{T}	.06963m^3	18797^{T}	.07788m^3	21025^{T}
Wetted surface	1.0757m^2	48083ft^2	1.1442m^2	51151ft^2	1.0587m^2	47329ft^2	1.1167m^2	49923ft^2	1.1124m^2	49709ft^2	1.1704m^2	52321ft^2
Cb	.6125		.6220		.5933		.6020		.6169		.6238	
Cp	.6246		.6331		.6050		.6130		.6290		.6352	
C⊗	.9807		.9825		.9807		.9820		.9807		.9820	
l.c.b.	1.47 %L		1.68 %L		2.10 %L		2.34 %L		.32 %L		.84 %L	

Note : Symboles in parentheses denote the design name for respective ships.

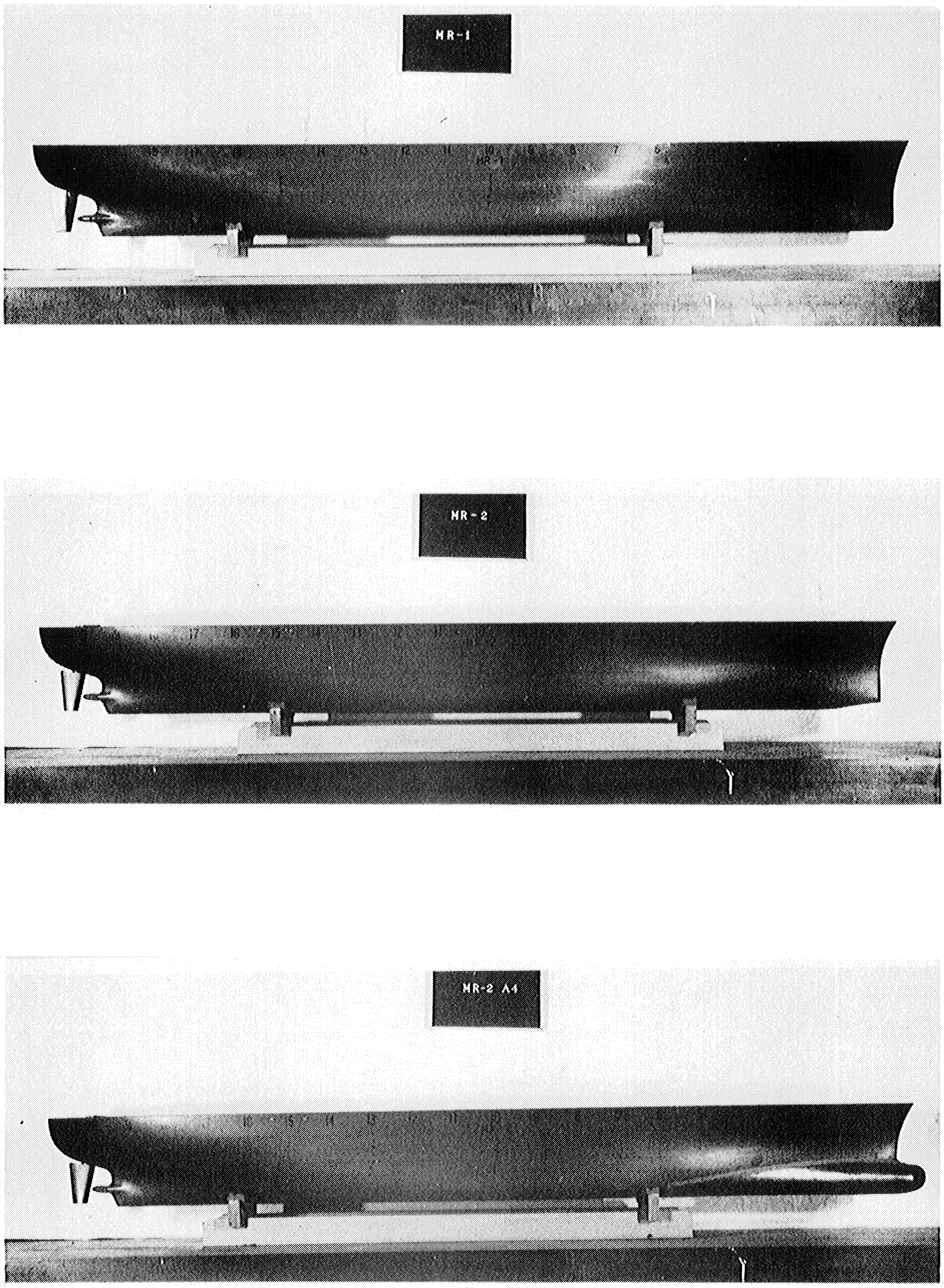


Photo 1 Profiles of the models

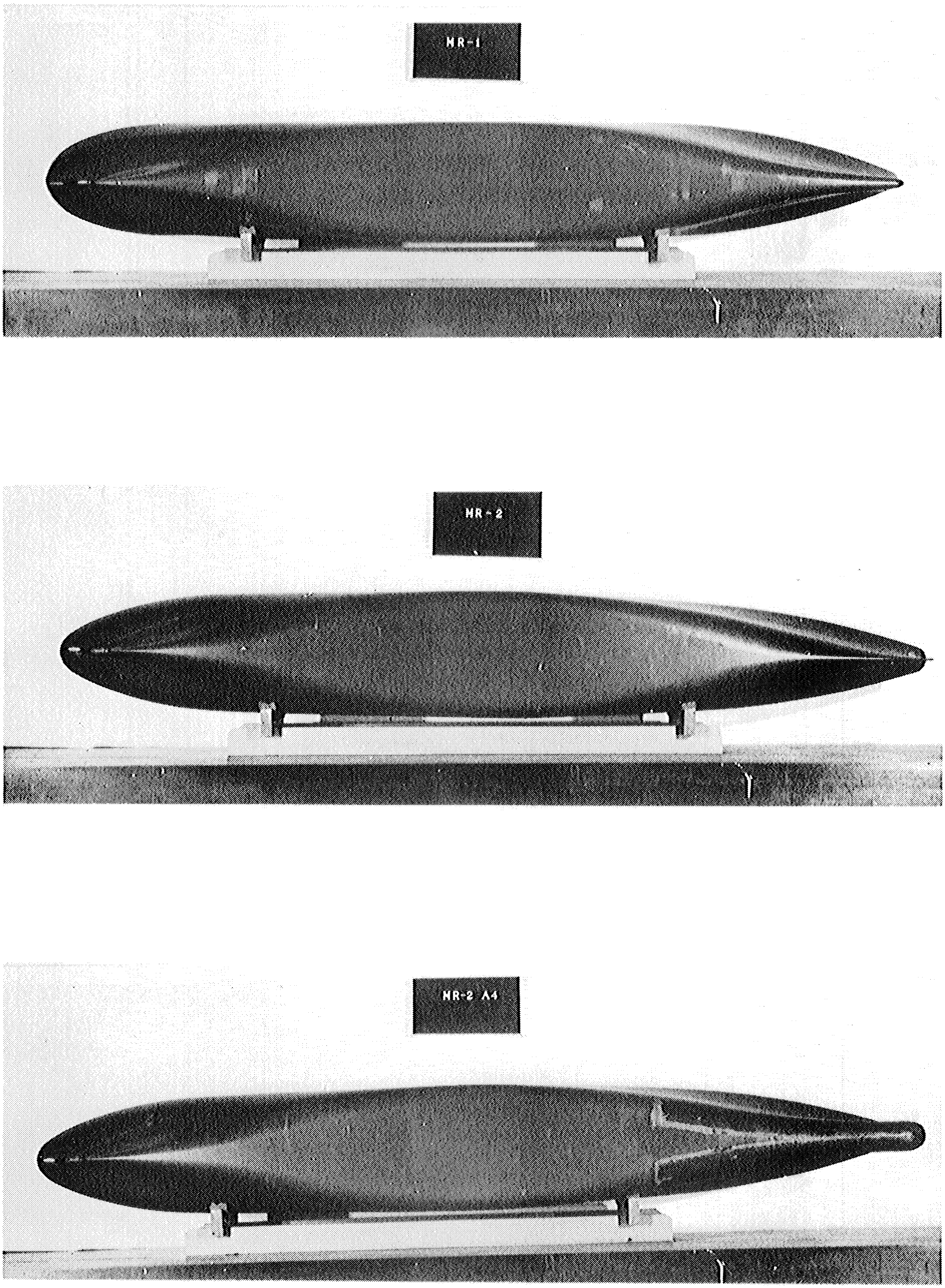


Photo 2 Bottom plans of the models

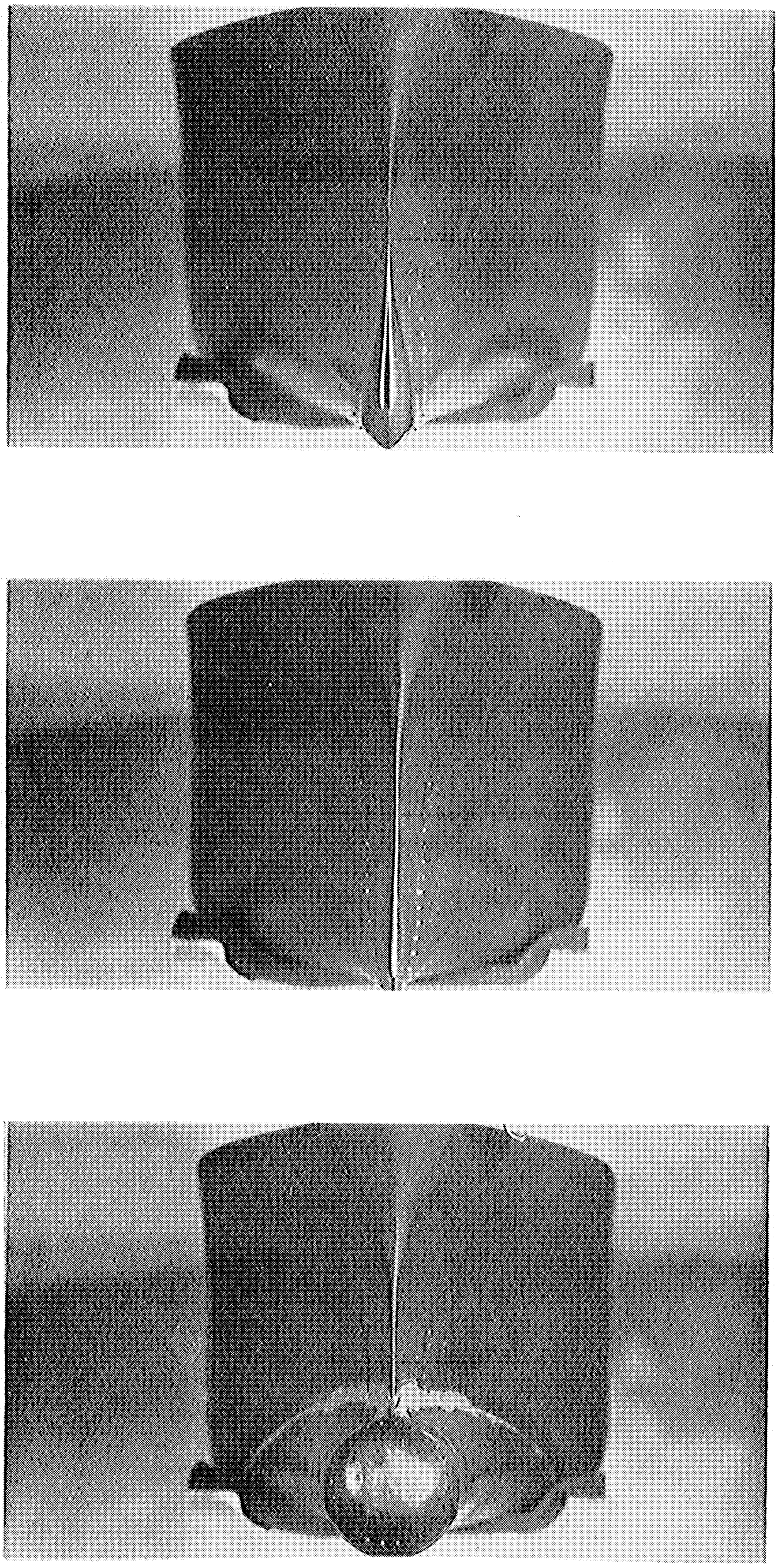
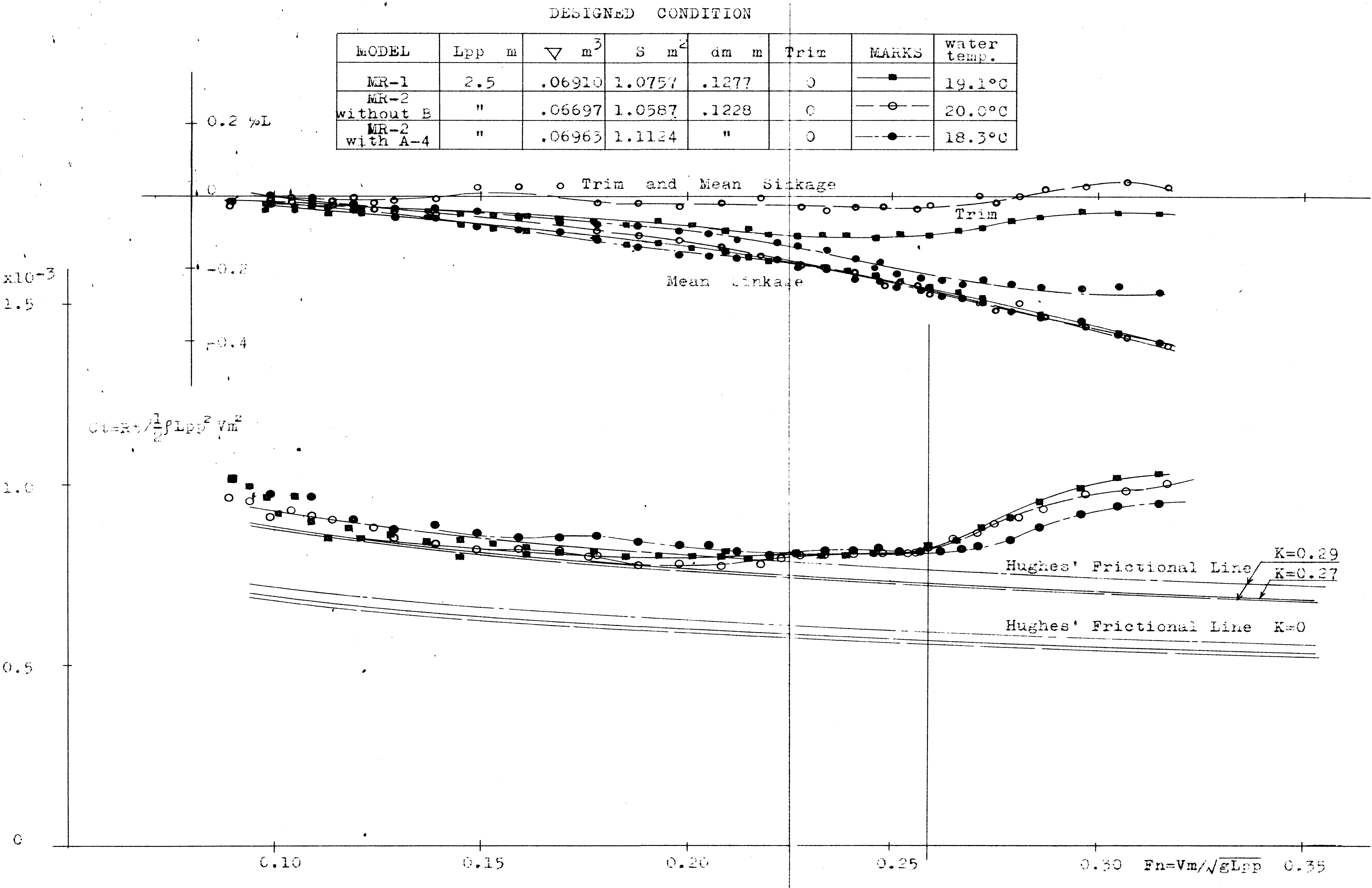
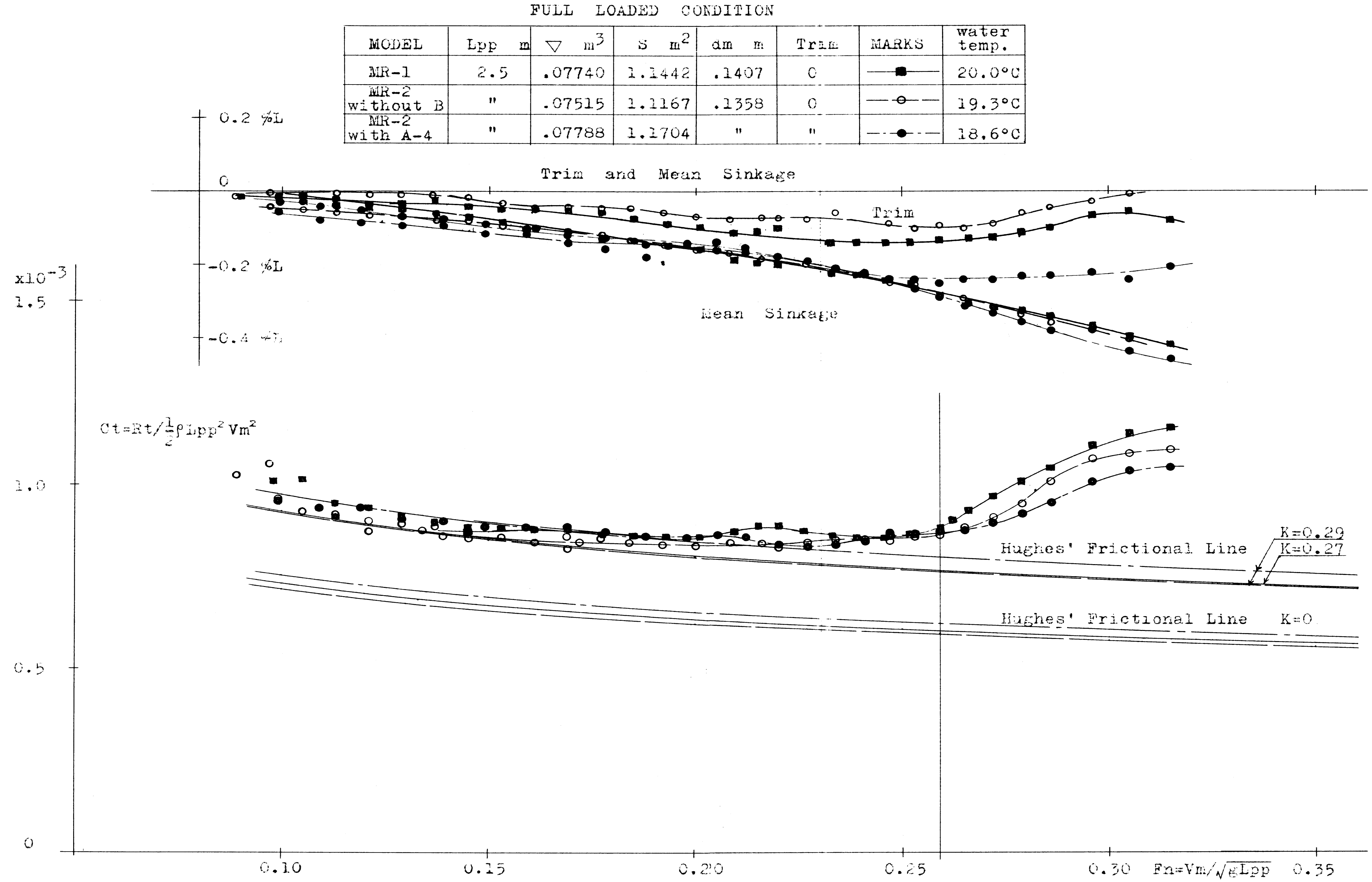


Photo 3 Front views of the models



MODEL	Lpp m	▽ m^3	S m^2	dm m	Trim	MARKS	water temp.
MR-1	2.5	.06910	1.0757	.1277	0	—■—	19.1°C
MR-2 without B	"	.06697	1.0587	.1228	0	—○—	20.0°C
MR-2 with A-4	"	.06963	1.1124	"	0	-·-●-·-	18.3°C

Fig. 7 Total Resistance Coefficient and its Curves



FULL LOADED CONDITION

MODEL	Lpp m	▽ m^3	S m^2	dm m	Trim	MARKS	water temp.
MR-1	2.5	.07740	1.1442	.1407	0	—■—	20.0°C
MR-2 without B	"	.07515	1.1167	.1358	0	—○—	19.3°C
MR-2 with A-4	"	.07788	1.1704	"	"	-·●·-	18.6°C

Fig. 8 Total Resistance Coefficiemt and etc Curves

DESIGNED CONDITION

MODEL	Lpp m	∇ m^3	dm m	L/B	B/dm	MARKS
MR-1	2.5	.06910	.1277	6.84	2.82	—■—
MR-2 without B	"	.06697	.1228	6.58	3.04	— ○ —
MR-2 with A-4	"	.06963	"	"	"	-·●-·

Remark; Obtained by Hughes' frictional method.
Form factor
$K = 0.27$ for MR-1
$K = 0.29$ for MR-2

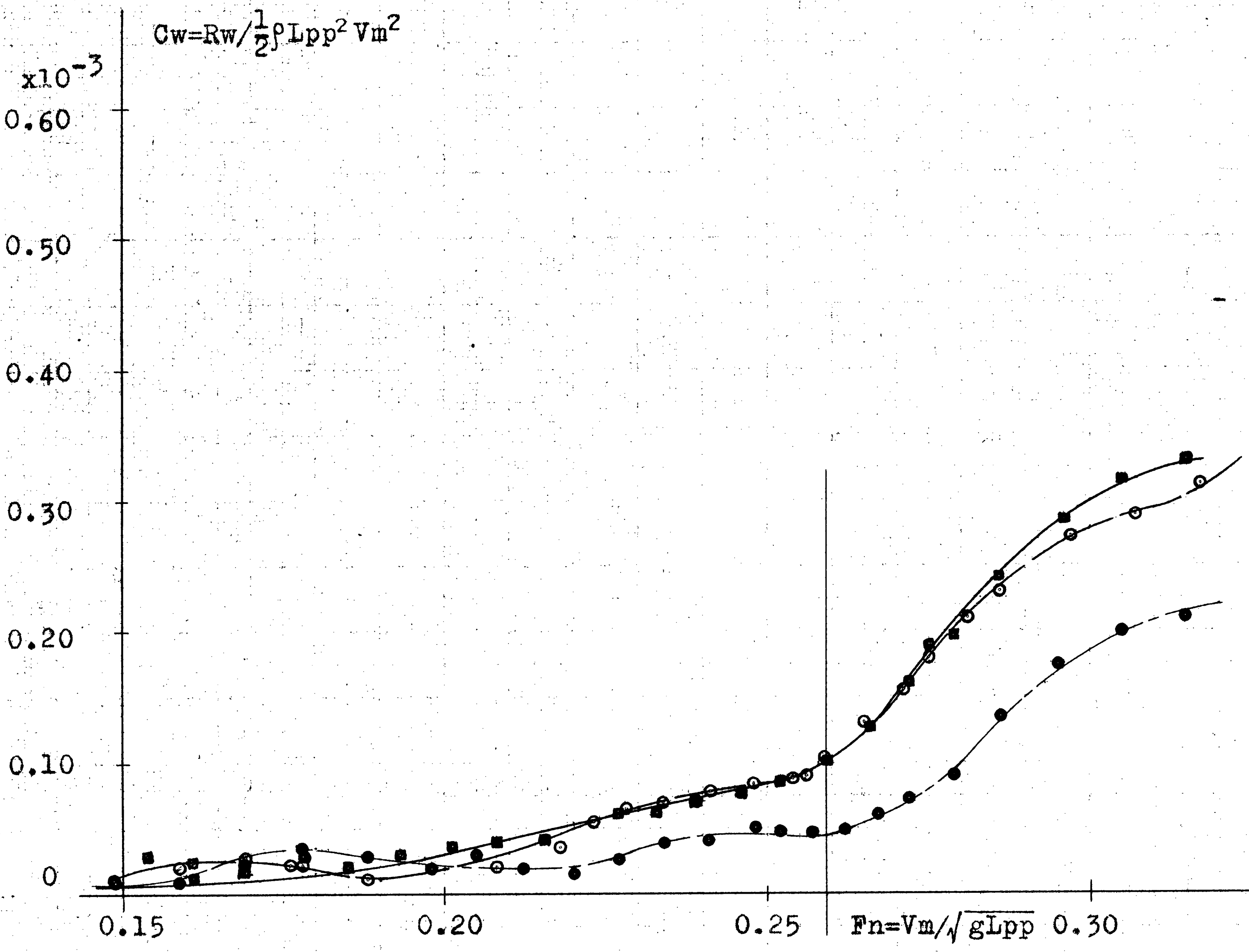


Fig. 9 Wave Making Resistance Coefficient Curves

FULL LOADED CONDITION

MODEL	Lpp m	∇ m^3	dm m	L/B	B/dm	MARKS
MR-1	2.5	.07740	.1407	6.84	2.56	—■—
MR-2 without B	"	.07515	.1358	6.58	2.75	—⊙—
MR-2 with A-4	"	.07788	"	"	"	-·●·-

Remark; Obtained by Hughes' frictional metod.
Form factor
K = 0.27 for MR-1
K = 0.29 for MR-2

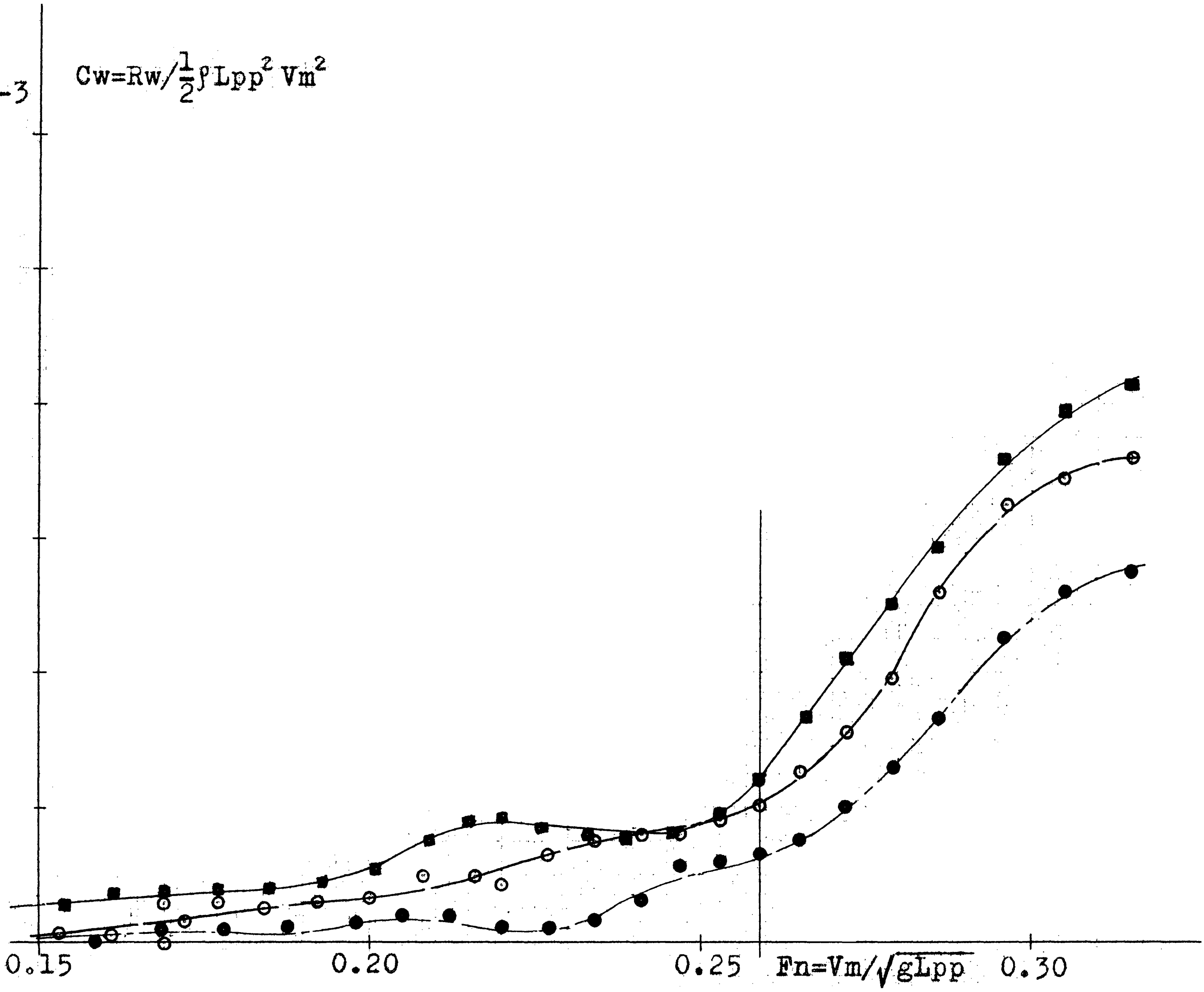


Fig. 10 Wave Making Resistance Coefficient Curves

DESIGNED CONDITION

Model	Lpp m	▽ m³	dm m	L/B	B/dm	Marks
MR-1	2.5	.06910	.1277	6.84	2.82	———
MR-2 without B	"	.06697	.1228	6.58	3.04	— — —
MR-2 with A-4	"	.06963	"	"	"	—·—·—

Remark; Obtained by Schoenherr's frictional method.

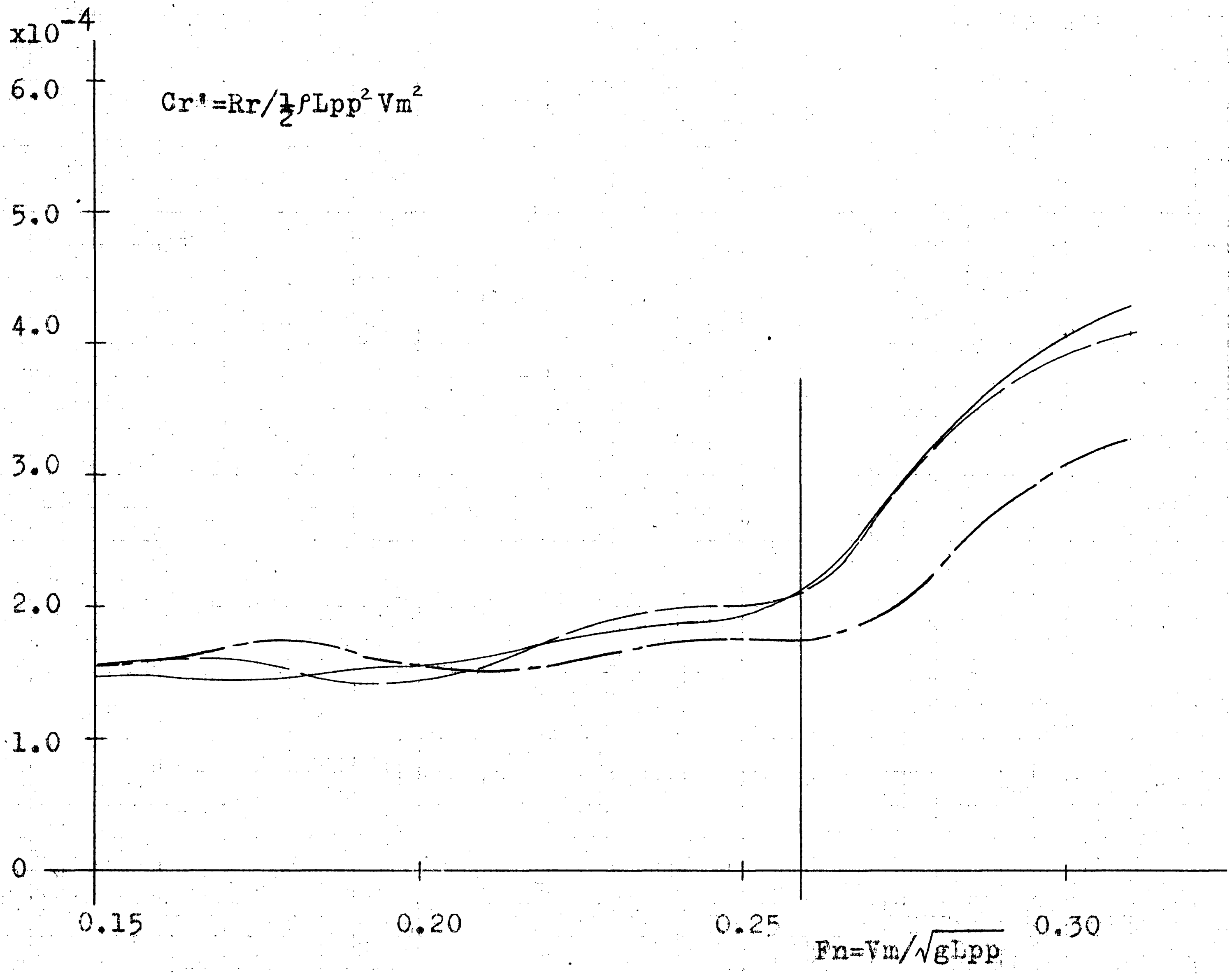


Fig. 11 Residual Resistance Coefficient Curves

FULL LOADED CONDITION

MODEL	Lpp m	∇ m^3	dm m	L/B	B/dm	MARKS
MR-1	2.5	.07740	.1407	6.84	2.56	———
MR-2 withoutB	"	.07515	.1558	6.58	2.75	— — —
MR-2 with A-4	"	.07788	"	"	"	—·—·—

Remark; Obtained by Schoenherr's frictional method.

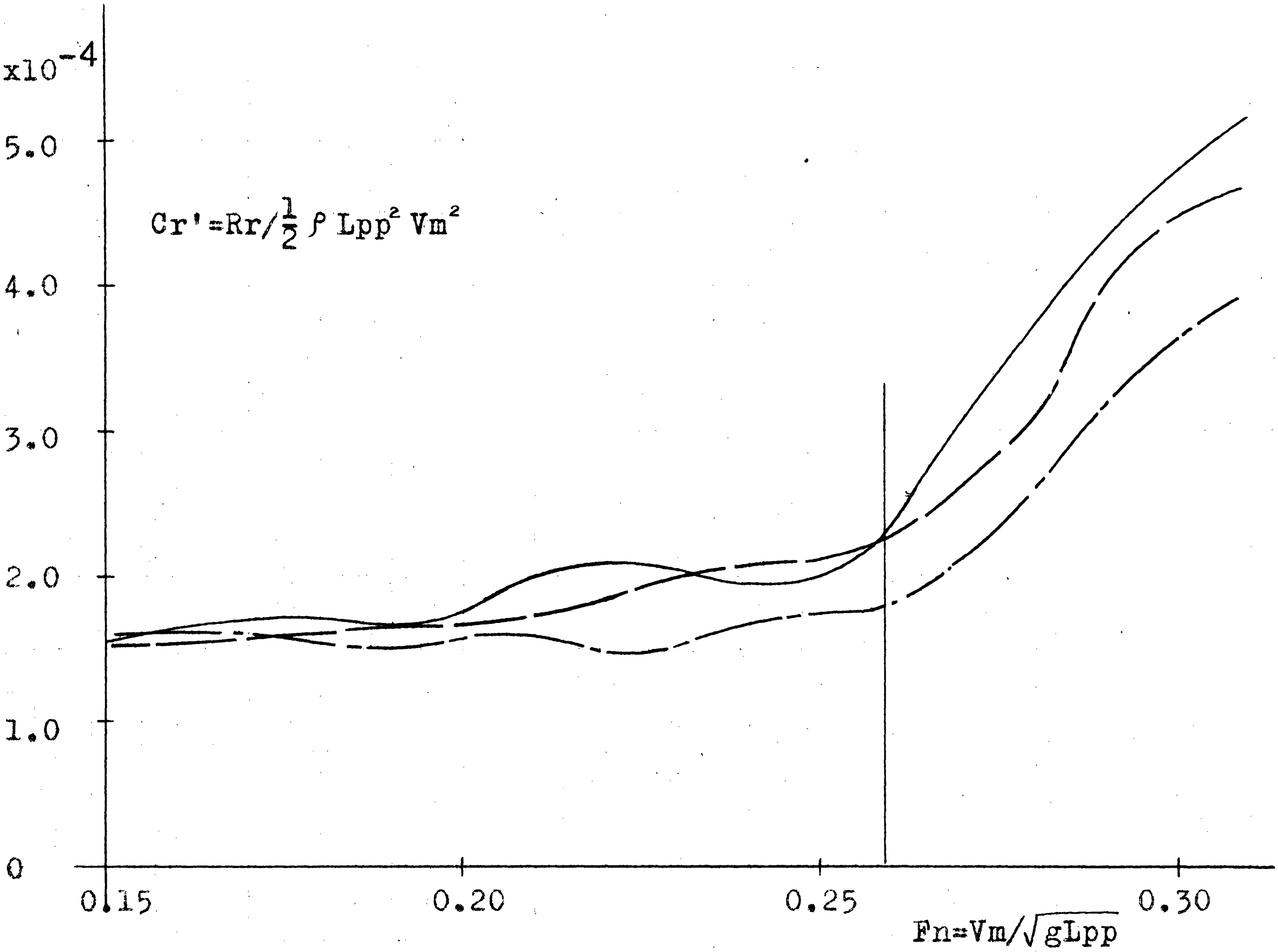


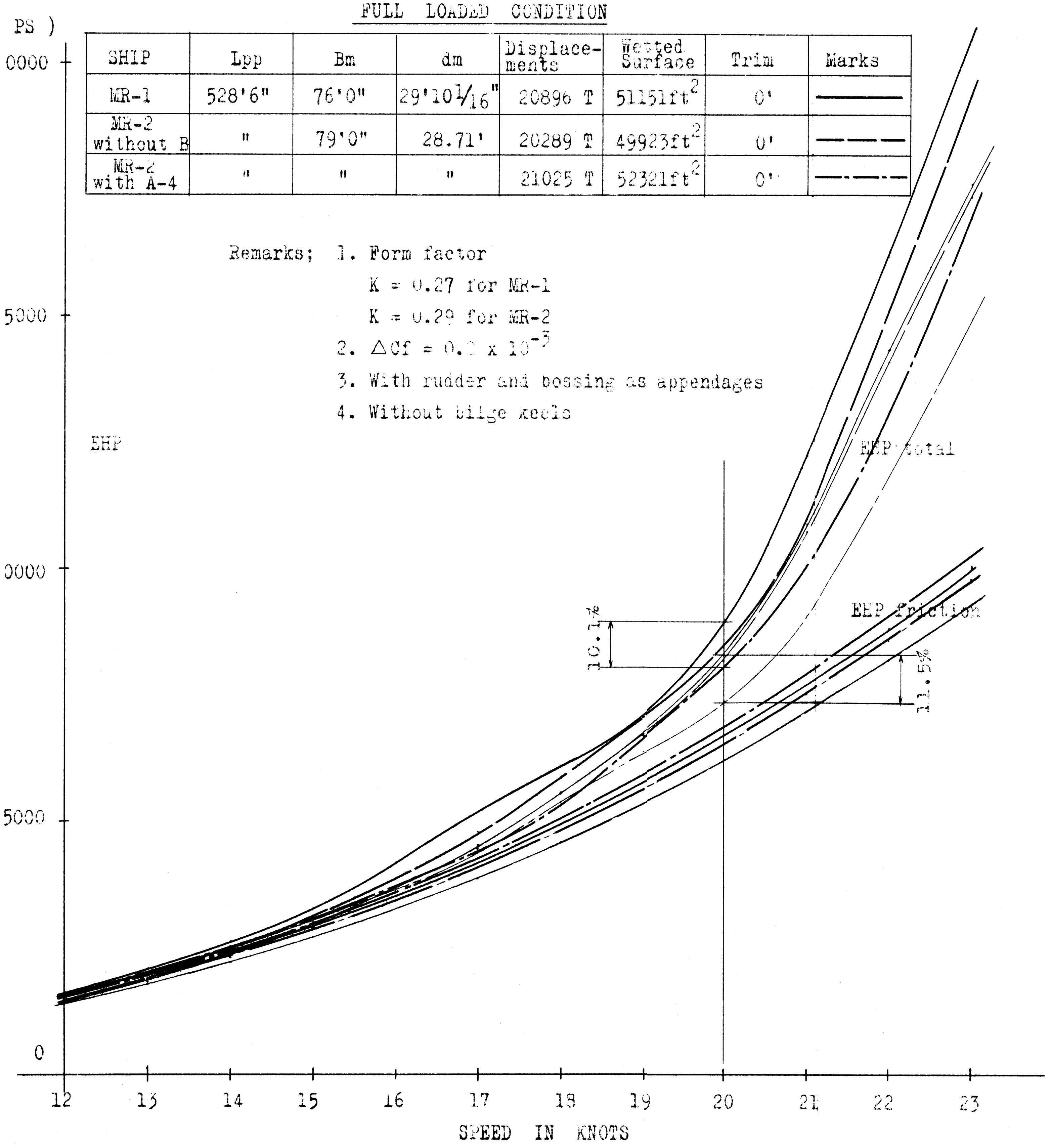
Fig. 12 Residual Resistance Coefficient Curves

DESIGNED CONDITION

SHIP	Lpp	Bm	dm	Displace-ments	Wetted Surface	Trim	Marks
MR-1	528'6"	76'0"	27'0"	18655 T	48083ft^2	0'	———
MR-2 without B	"	79'0"	25.95'	18078 T	47329ft^2	0'	— — —
MR-2 with A-4	"	"	"	18797 T	49709ft^2	0'	—·—·—

FULL LOADED CONDITION

SHIP	Lpp	Bm	dm	Displace-ments	Wetted Surface	Trim	Marks
MR-1	528'6"	76'0"	29'10$\frac{1}{16}$"	20896 T	51151ft^2	0'	**———**
MR-2 without B	"	79'0"	28.71'	20289 T	49923ft^2	0'	**— — —**
MR-2 with A-4	"	"	"	21025 T	52321ft^2	0'	**—·—·—**



Remarks; 1. Form factor

K = 0.27 for MR-1

K = 0.29 for MR-2

2. $\Delta Cf = 0.2 \times 10^{-3}$

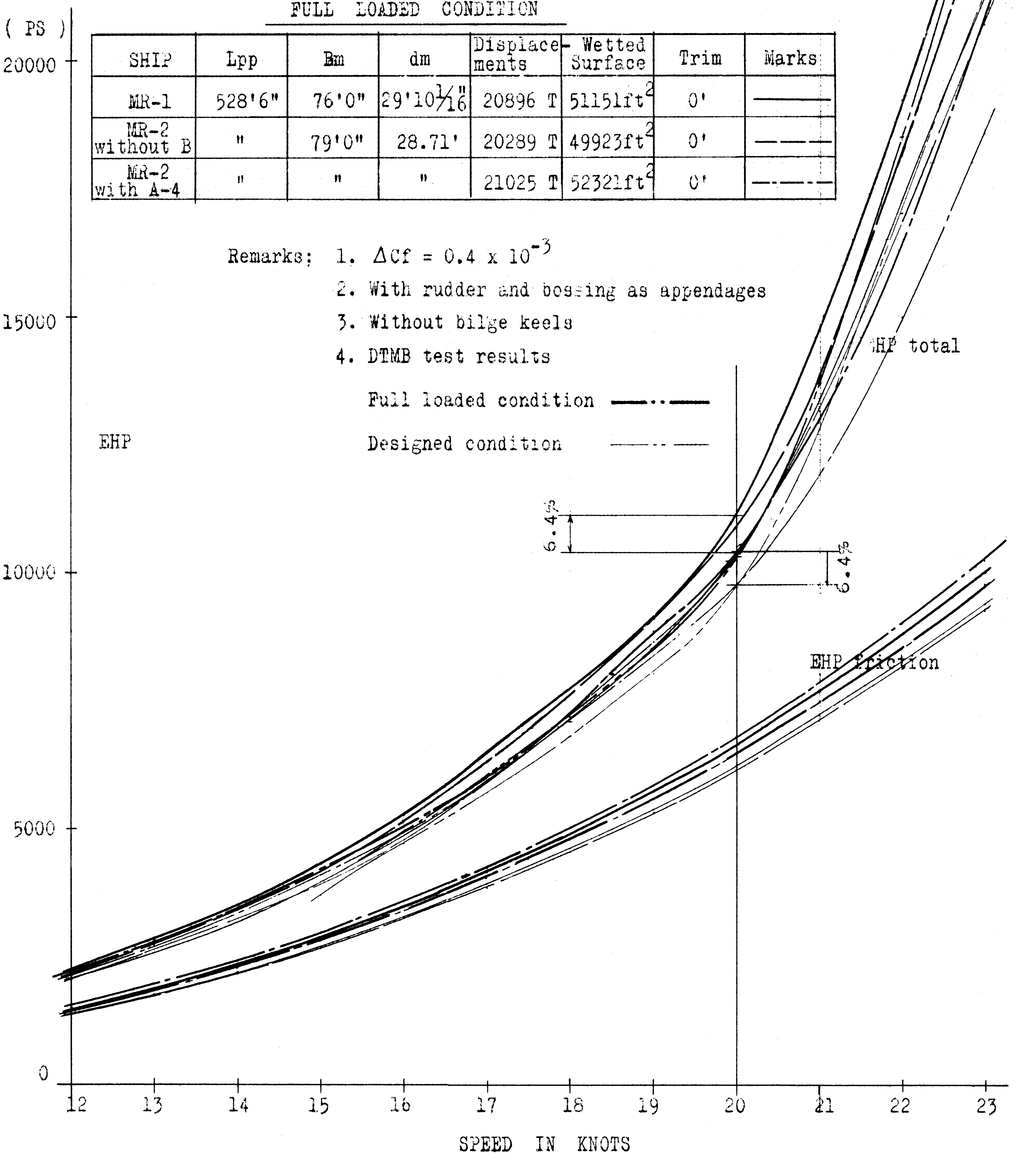
3. With rudder and bossing as appendages

4. Without bilge keels

Fig. 13 EHP Curves Calculated by Hughes' Frictional Method

DESIGNED CONDITION

SHIP	Lpp	Bm	dm	Displacements	Wetted Surface	Trim	Marks
MR-1	528'6"	76'0"	27'0"	18655 T	48083ft^2	0'	—·—
MR-2 without B	"	79'0"	25.95'	18078 T	47329ft^2	0'	— — —
MR-2 with A-4	"	"	"	18797 T	49709ft^2	0'	—·—·—



FULL LOADED CONDITION

SHIP	Lpp	Bm	dm	Displacements	Wetted Surface	Trim	Marks
MR-1	528'6"	76'0"	29'10$\frac{1}{16}$"	20896 T	51151ft^2	0'	———
MR-2 without B	"	79'0"	28.71'	20289 T	49923ft^2	0'	— — —
MR-2 with A-4	"	"	"	21025 T	52321ft^2	0'	—·—·—

Remarks; 1. $\Delta Cf = 0.4 \times 10^{-3}$

2. With rudder and bossing as appendages

3. Without bilge keels

4. DTMB test results

Full loaded condition ——·· ——

Designed condition —·· —

Fig. 14 EHP Curves Calculated by Schoenherr's Frictional Method

Remarks;

1. Marks

Condition	Full	Design
2.5^{m} Model	━━━━	────
DTMB	━ ━ ━ ━	─ ─ ─ ─

2. Obtained by Hughes' frictional method.
Form facter ; 0.27
Values of DTMB were estimated from EHP curves of C4-S-1a, attached to the letter from Washington.
(assumed Water Temp. = 15.0°C)

3. Appendages
2.5^{m} Model; rudder and bossing.
DTMB ; rudder , bossing and bilge keels.

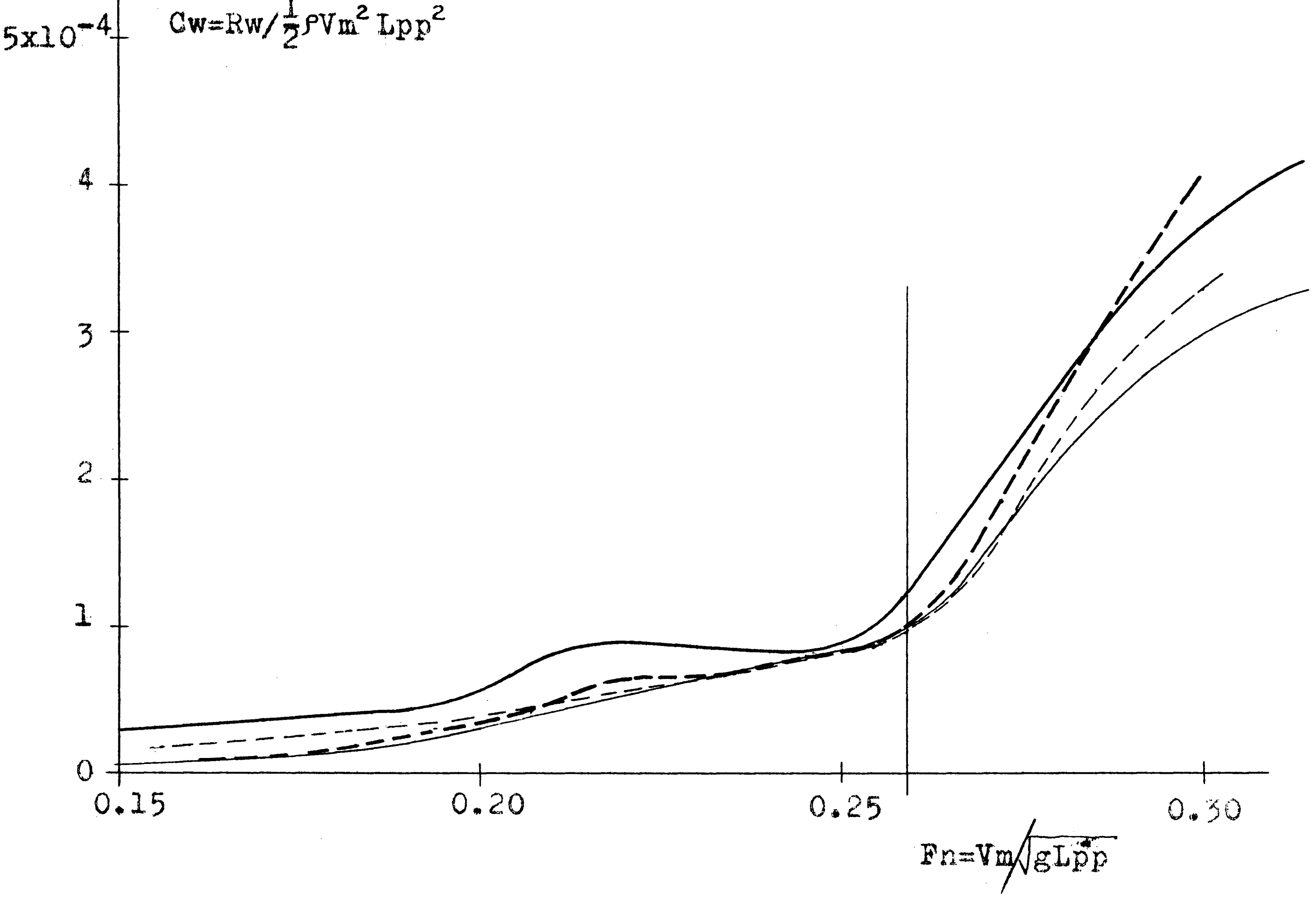


Fig. A1 Comparison with DTMB test results in Cw

Remarks ;

1. Marks

Condition	Full	Design
2.5^{m}Model	━━━━	────
DTMB	━ ━ ━	— — —

2. Obtained by Schoeherr's frictional method.

Values of DTMB were estimated from EHP curves of C4-S-1a, attached to the letter from Washington. (assumed WaterTemp.=15.0°C)

3. Appendages

2.5^{m}Model; rudder and bossing.
DTMB ; rudder, bossing and bilge keels.

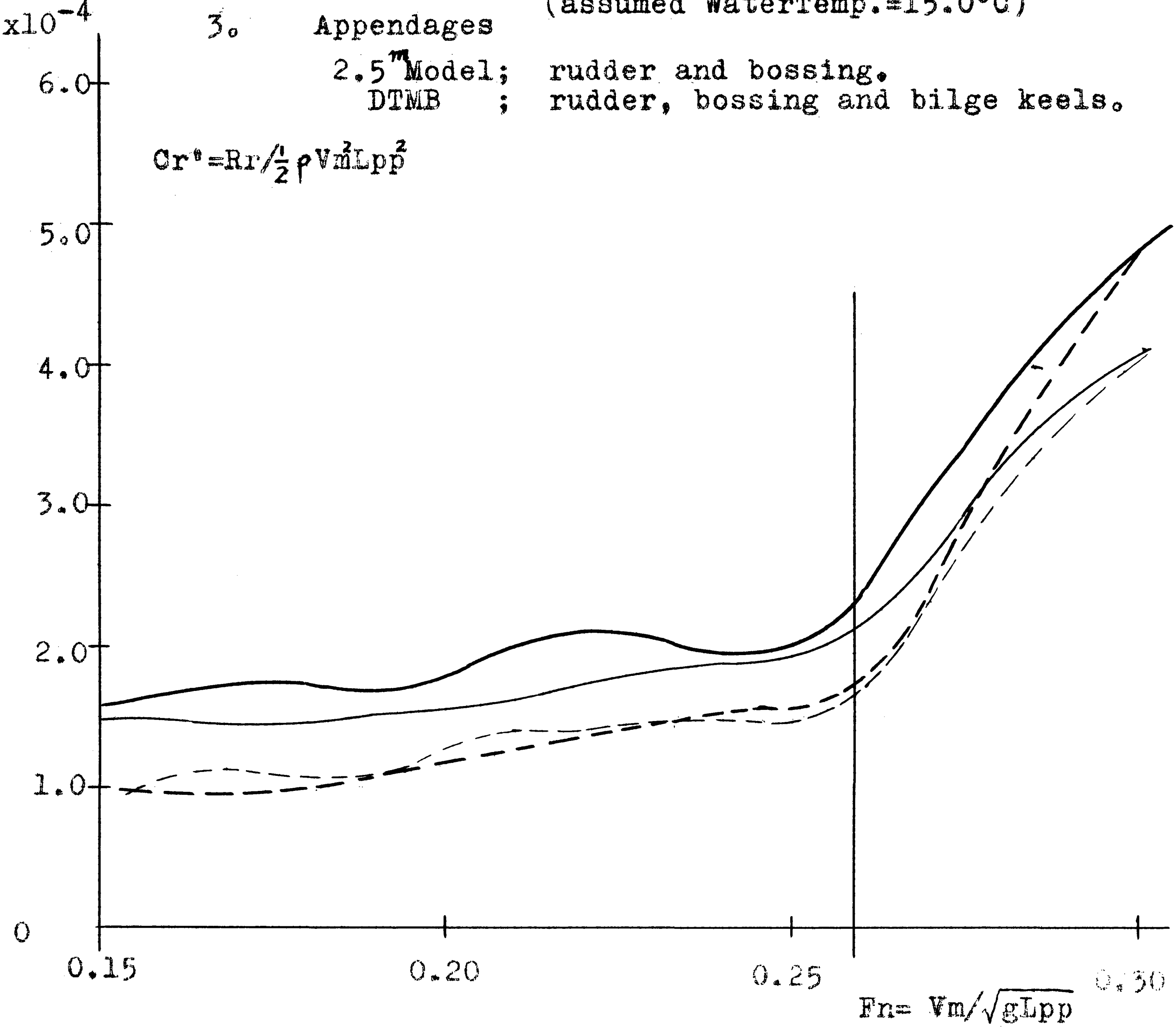


Fig. A2 Comparison with DTMB test results in Cr

MODEL	Lpp m	m^3	dm m	L/B	B/dm	MARKS
MR-1	2.50	.06910	.1277	6.84	2.82	———
SR-452	"	.05810	.1100	7.00	3.27	- - - -

REMARKS; 1. Obtained by Hughes' frictional method.
Form factor K=0.27
2. Trim
MR-1 Even keel
SR-452 1% Lpp trim by stern
(½ Load)

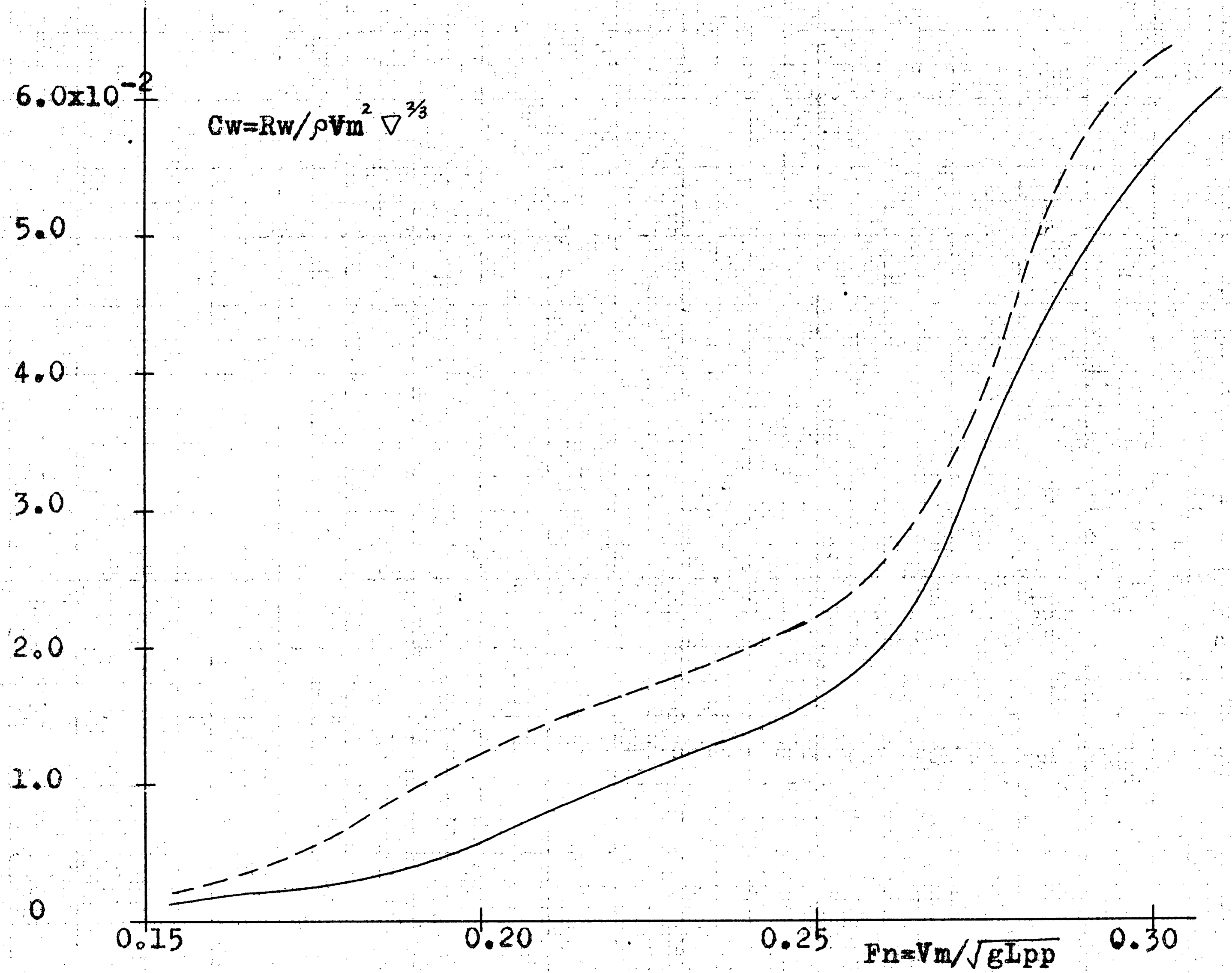


Fig. B.1 Comparison with a Japanese Liner Model SR-452 in Cw

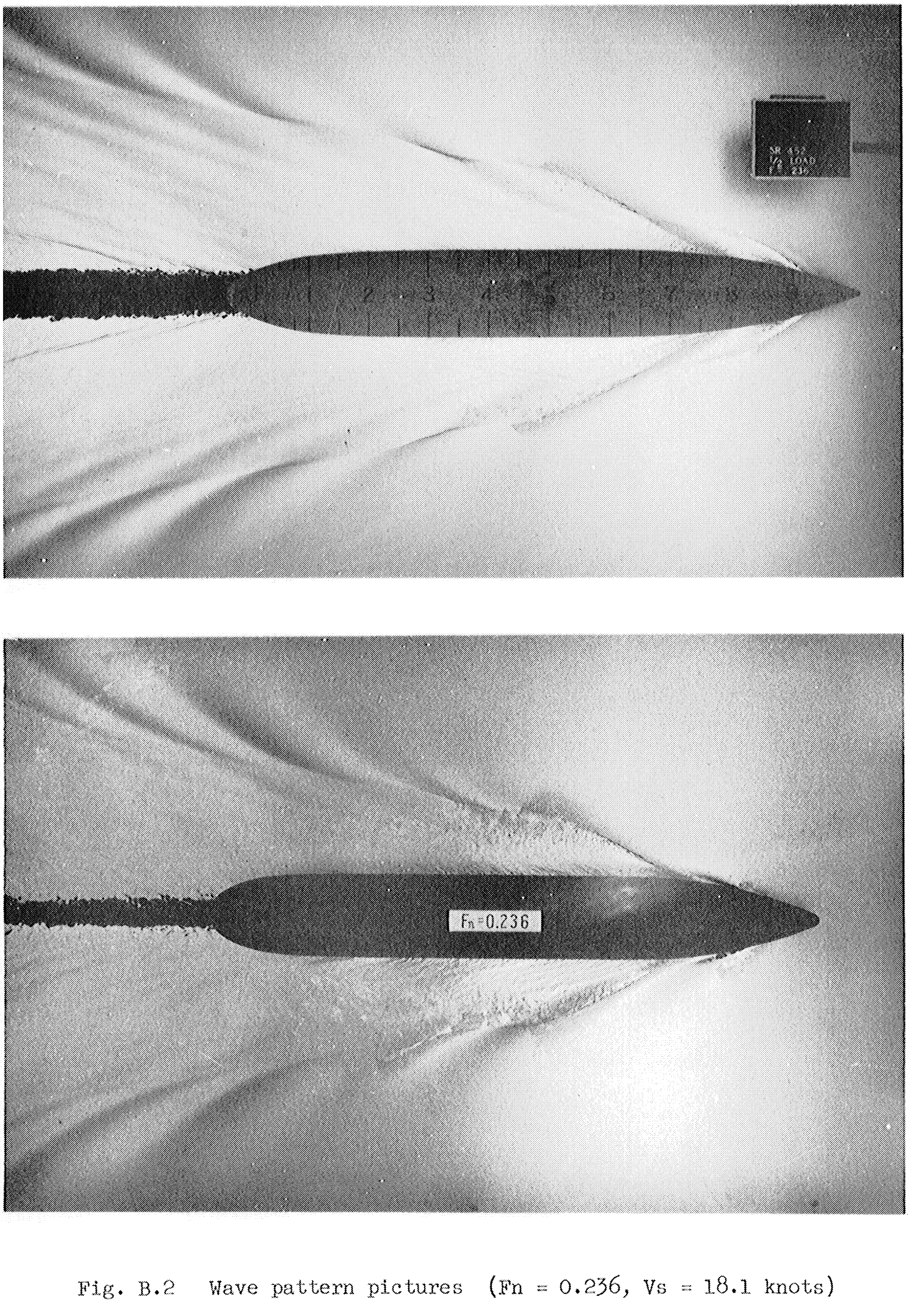


Fig. B.2 Wave pattern pictures (Fn = 0.236, Vs = 18.1 knots)

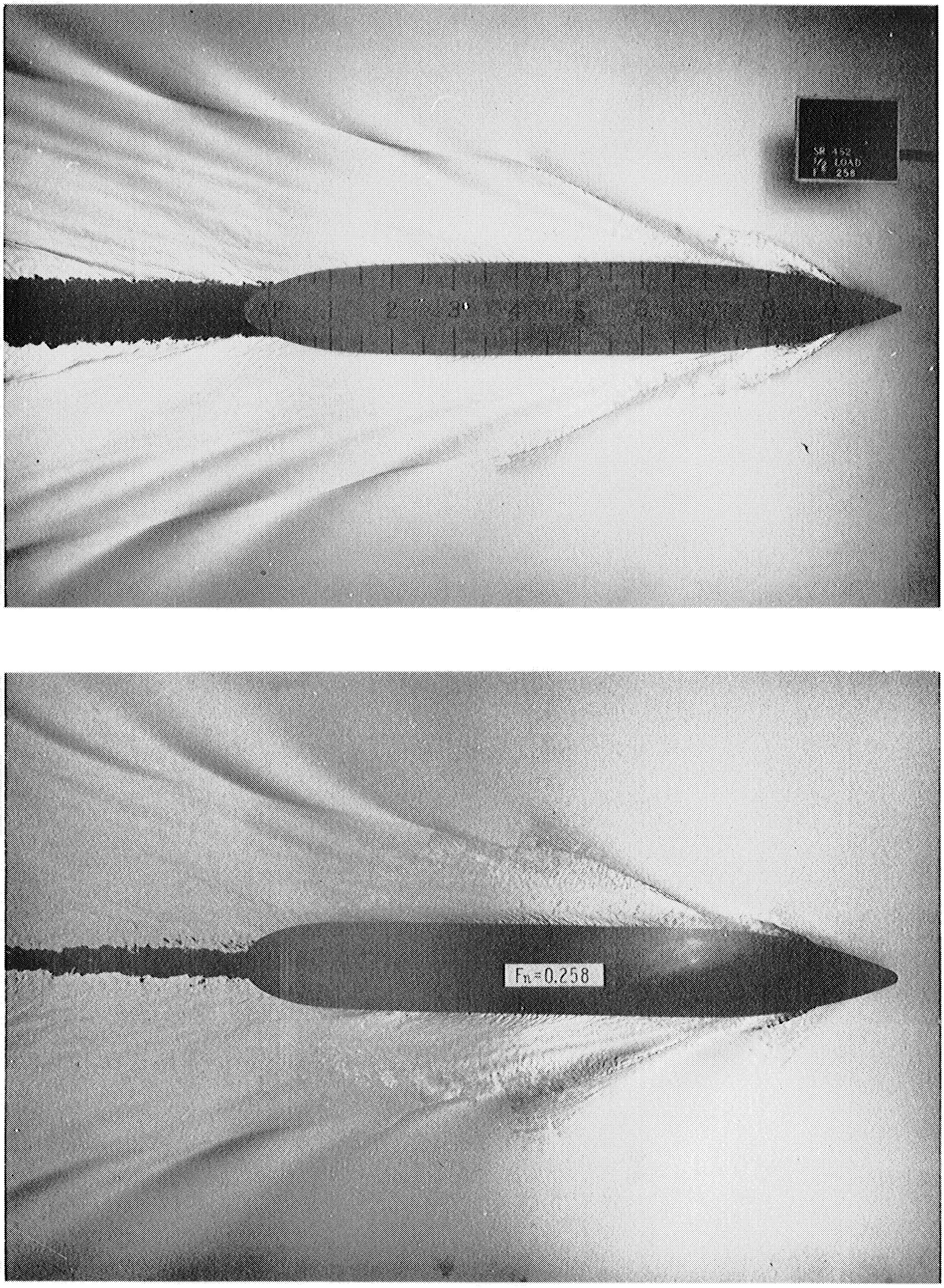


Fig. B.3 Wave pattern pictures (Fn = 0.258, Vs = 19.8 knots)

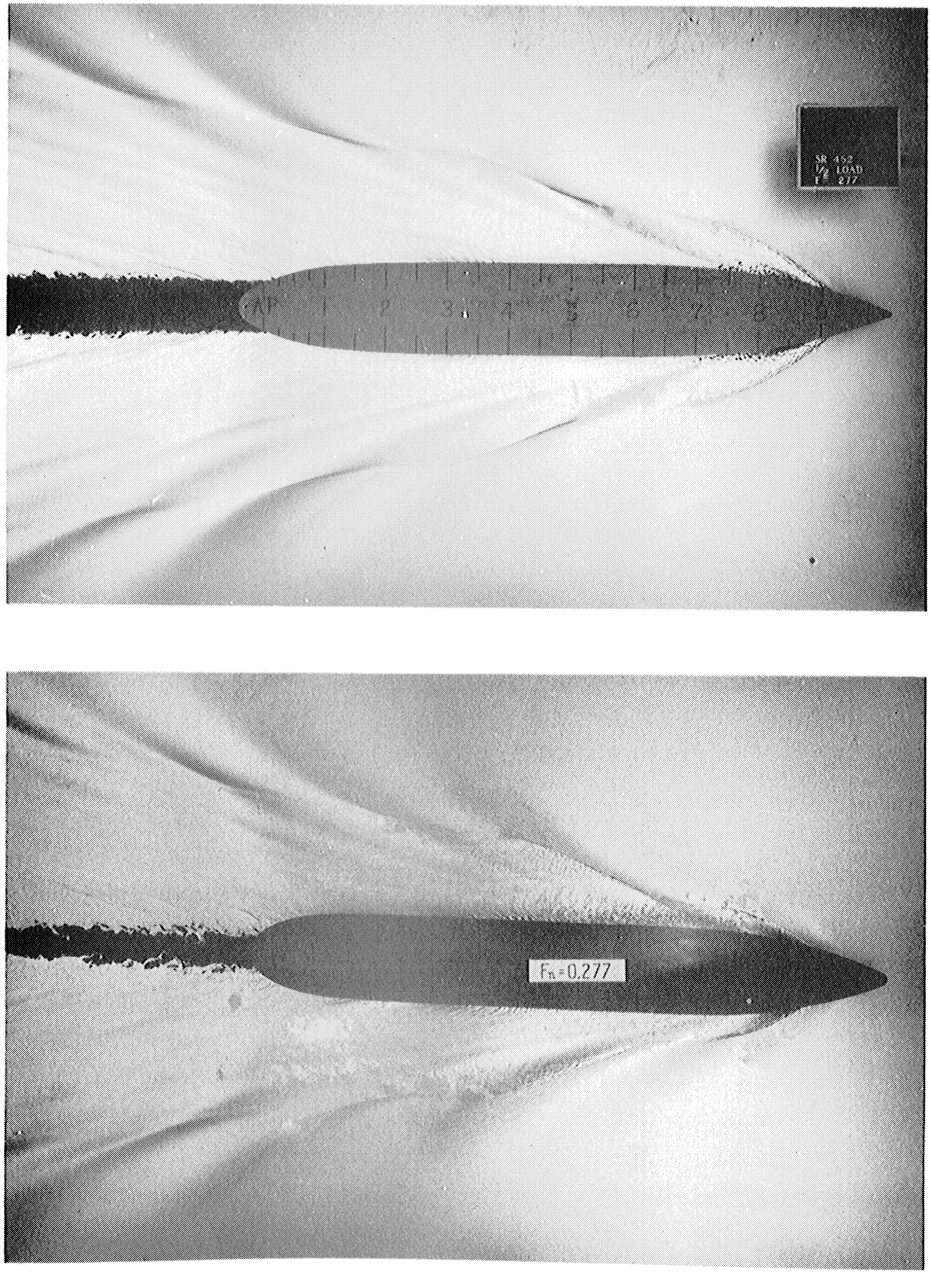


Fig. B.4 Wave pattern pictures (Fn = 0.277, Vs = 21.3 knots)

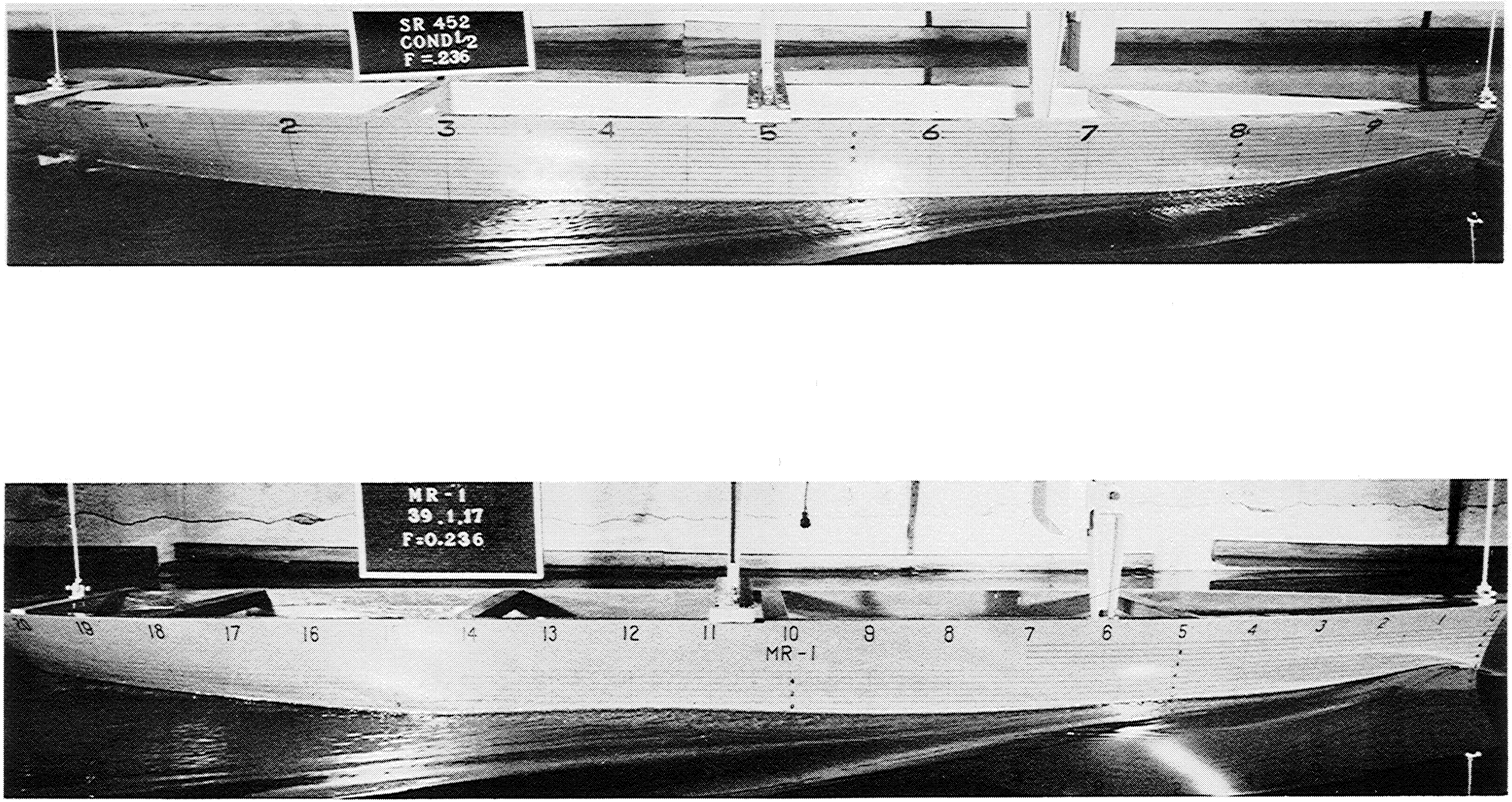


Fig. B.5 Wave profile pictures (Fn = 0.236, Vs = 18.1 knots)

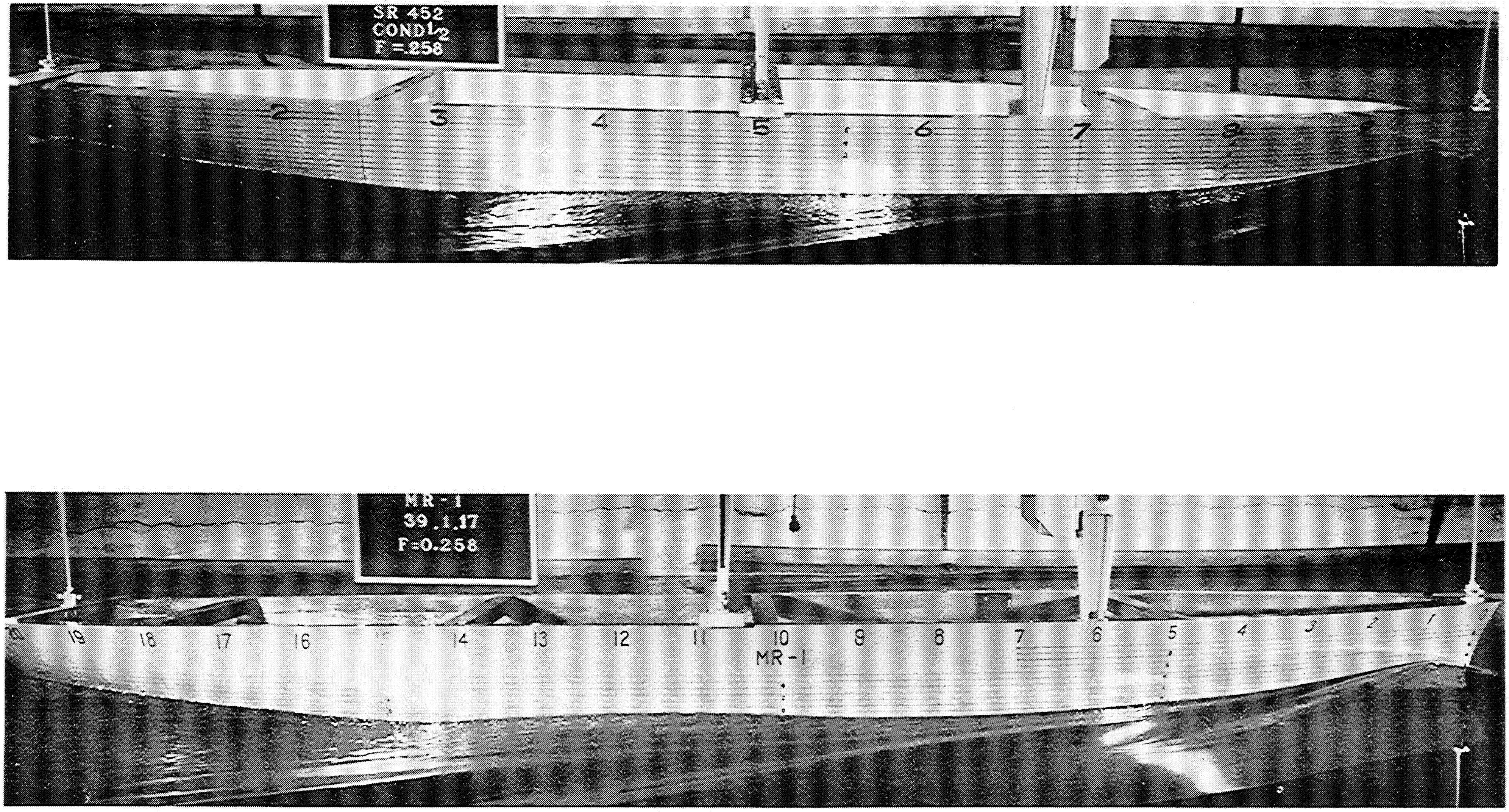


Fig. B.6 Wave profile pictures (Fn = 0.258, Vs = 19.8 knots)

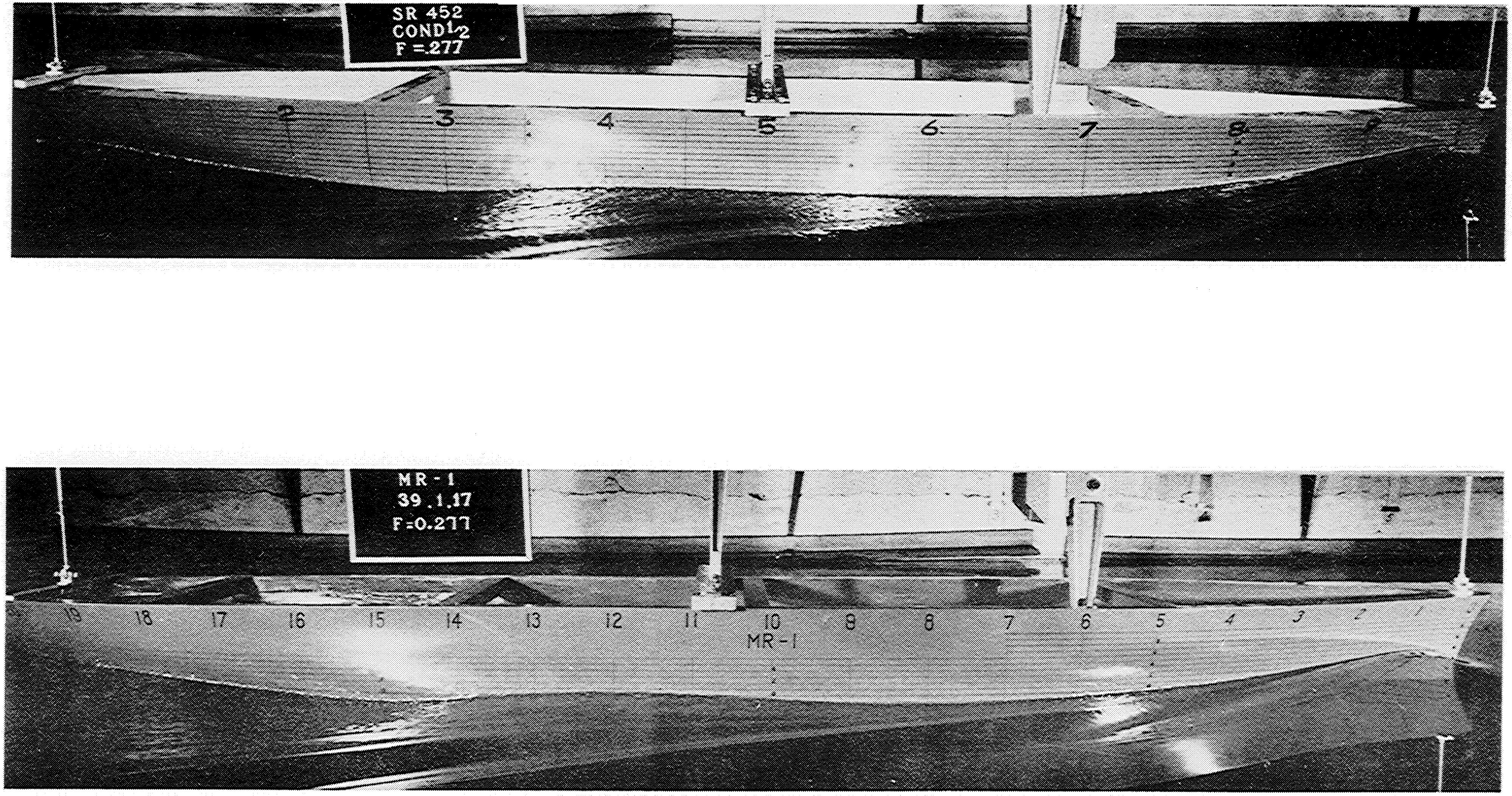


Fig. B.7 Wave profile pictures (Fn = 0.277, Vs = 21.3 knots)

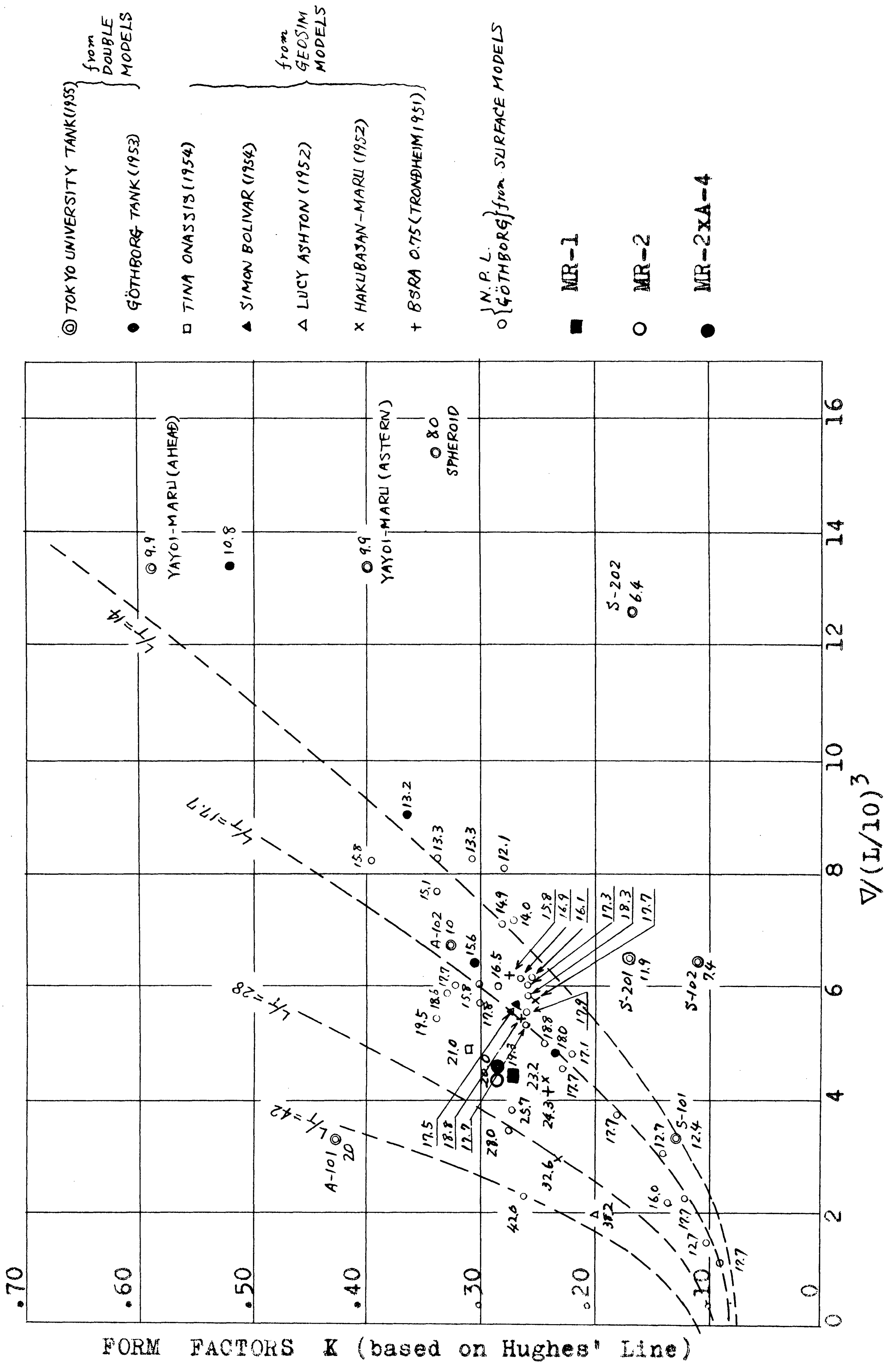


Fig. C1 Form factor K for Various Hull Forms

◎ Fishing Boat ■ MR-1

Tokyo University Tank ○ MR-2

Fig. E1

Wave Profiles

Designed condition

17 knots

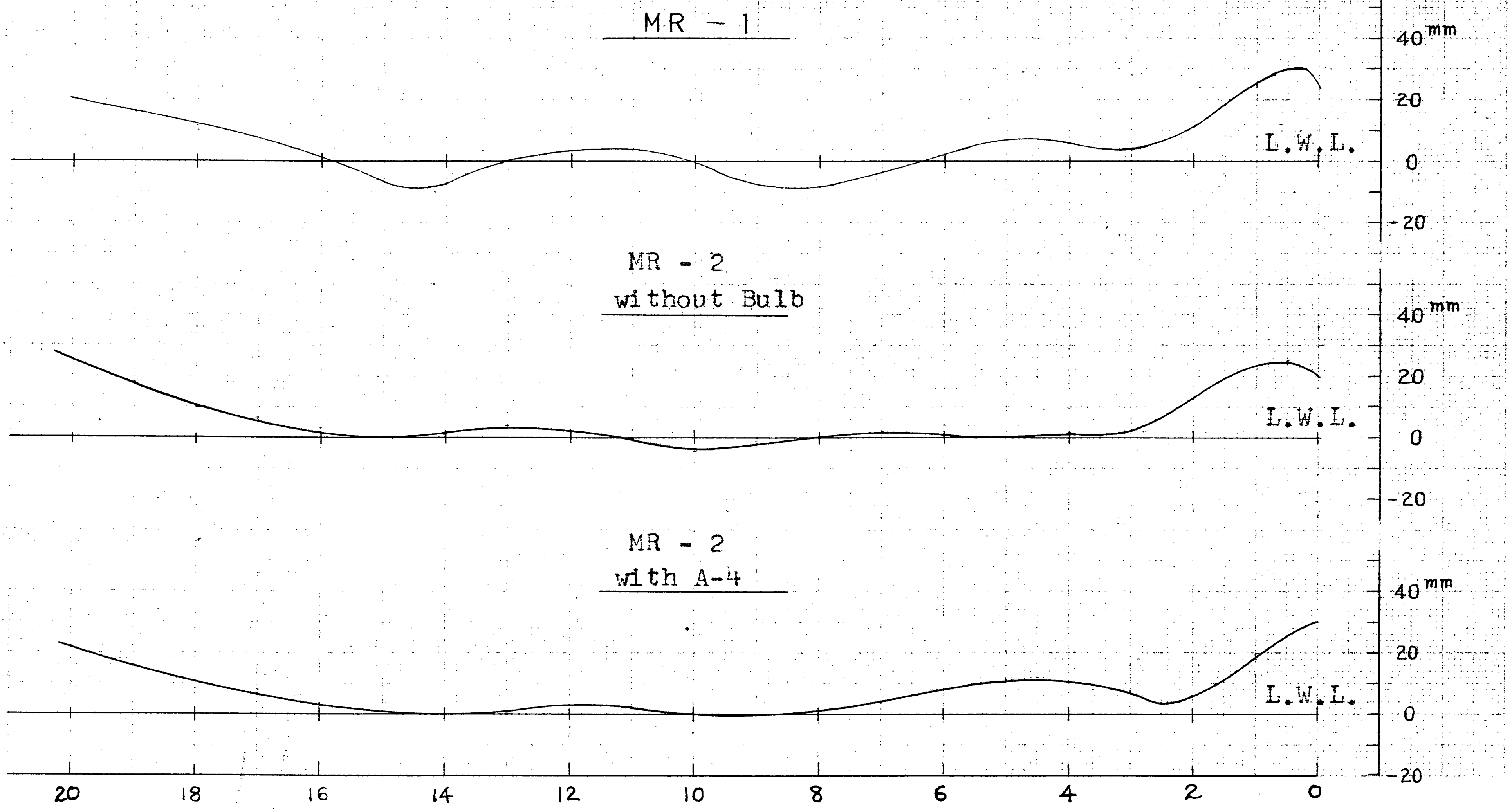


Fig. E2

Wave Profiles

Designed condition

18 knots

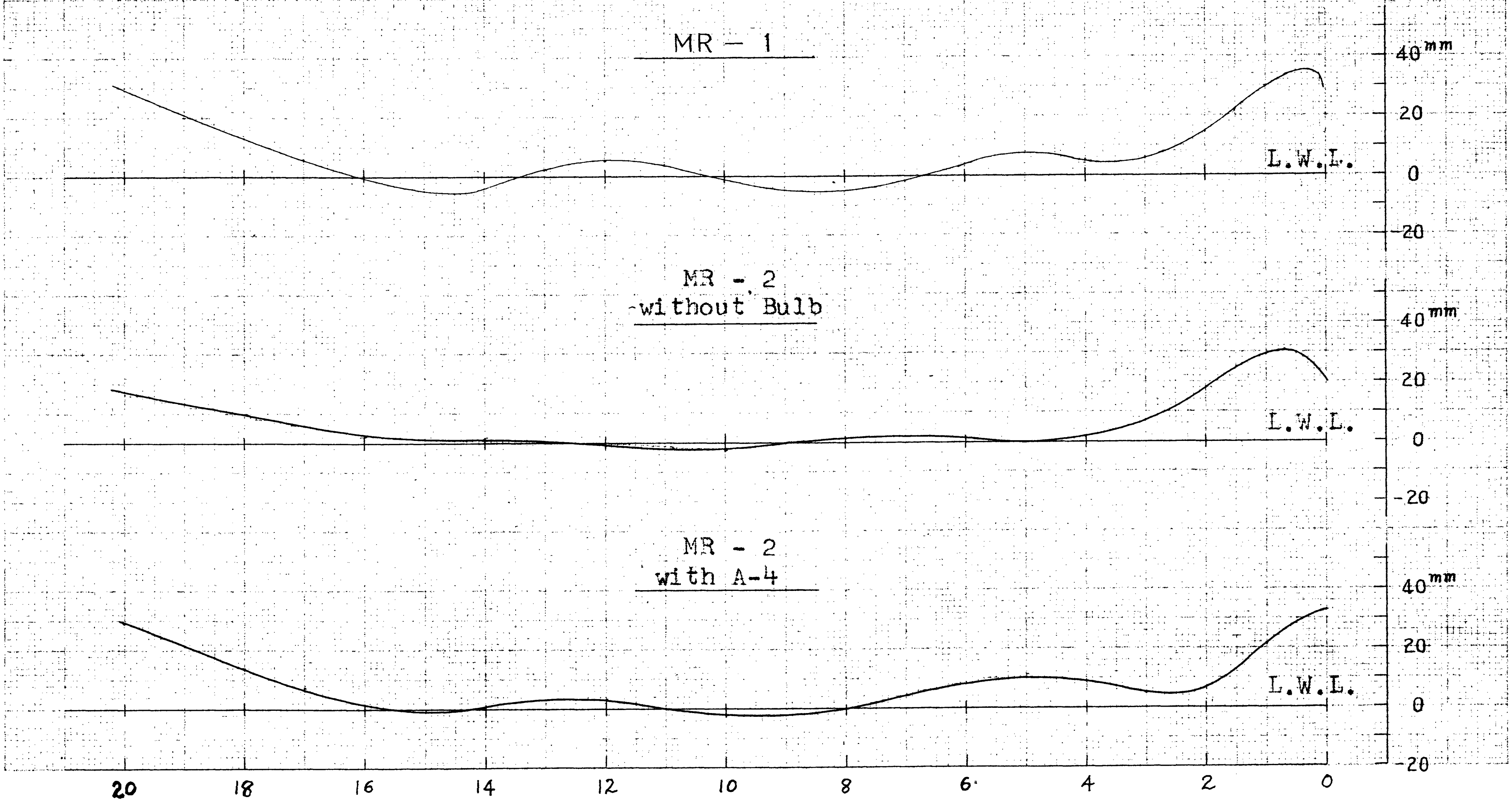


Fig. E3

Wave Profiles
Designed condition
19 knots

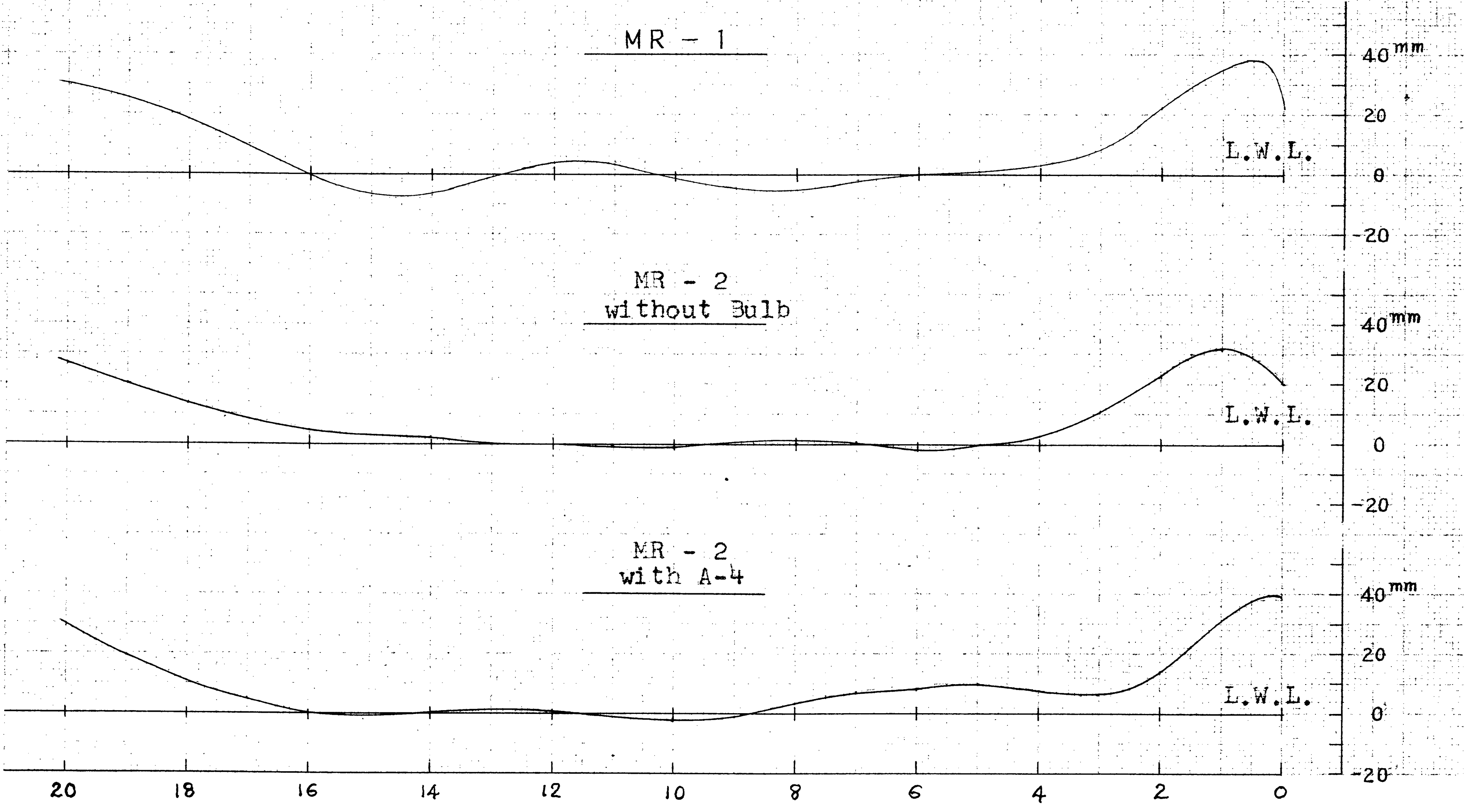
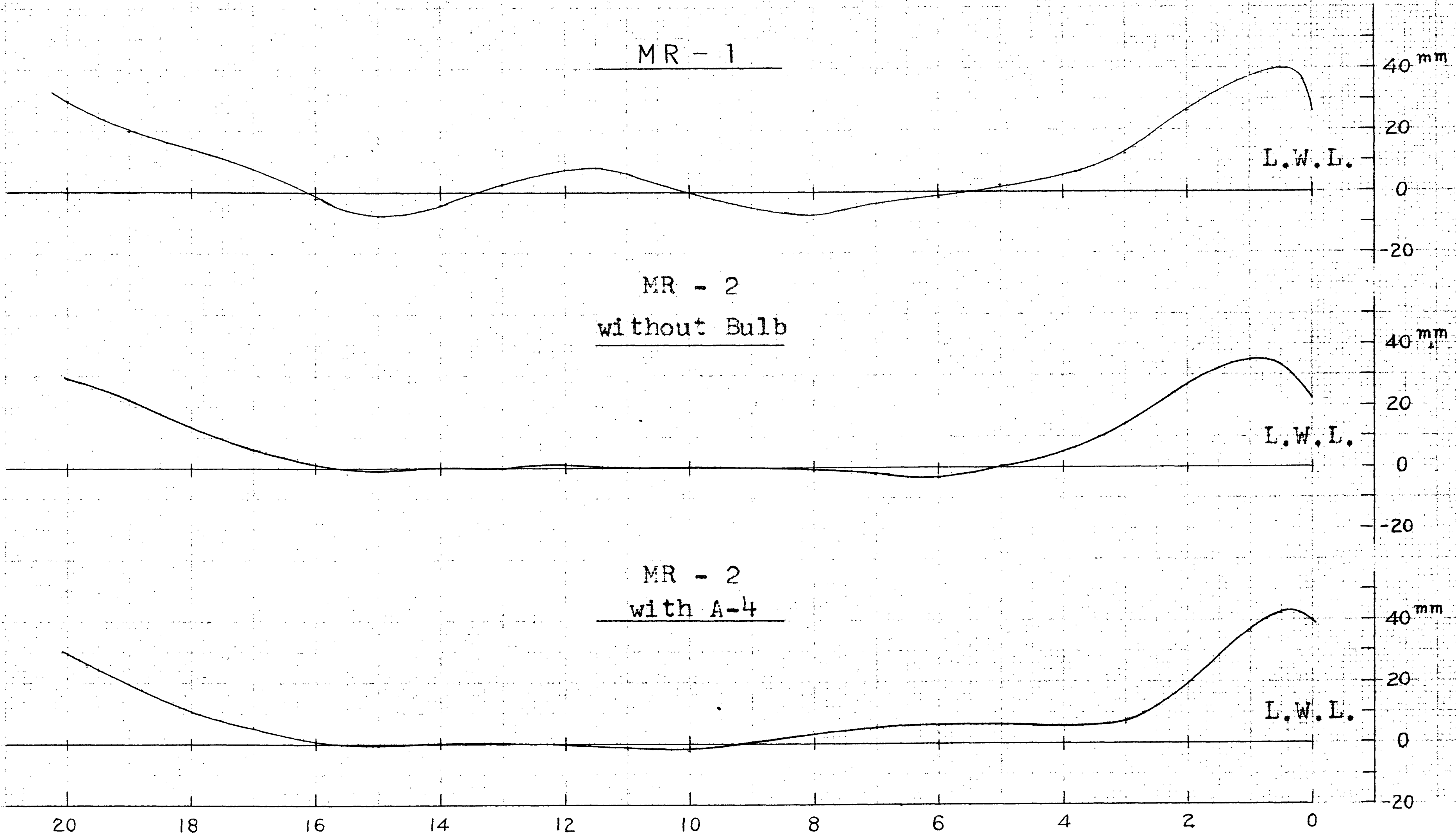


Fig. E4

Wave Profiles

Designed condition

20 knots


MR - 1

MR - 2
without Bulb

MR - 2
with A-4

Fig. E5

Wave Profiles

Designed condition

21 knots

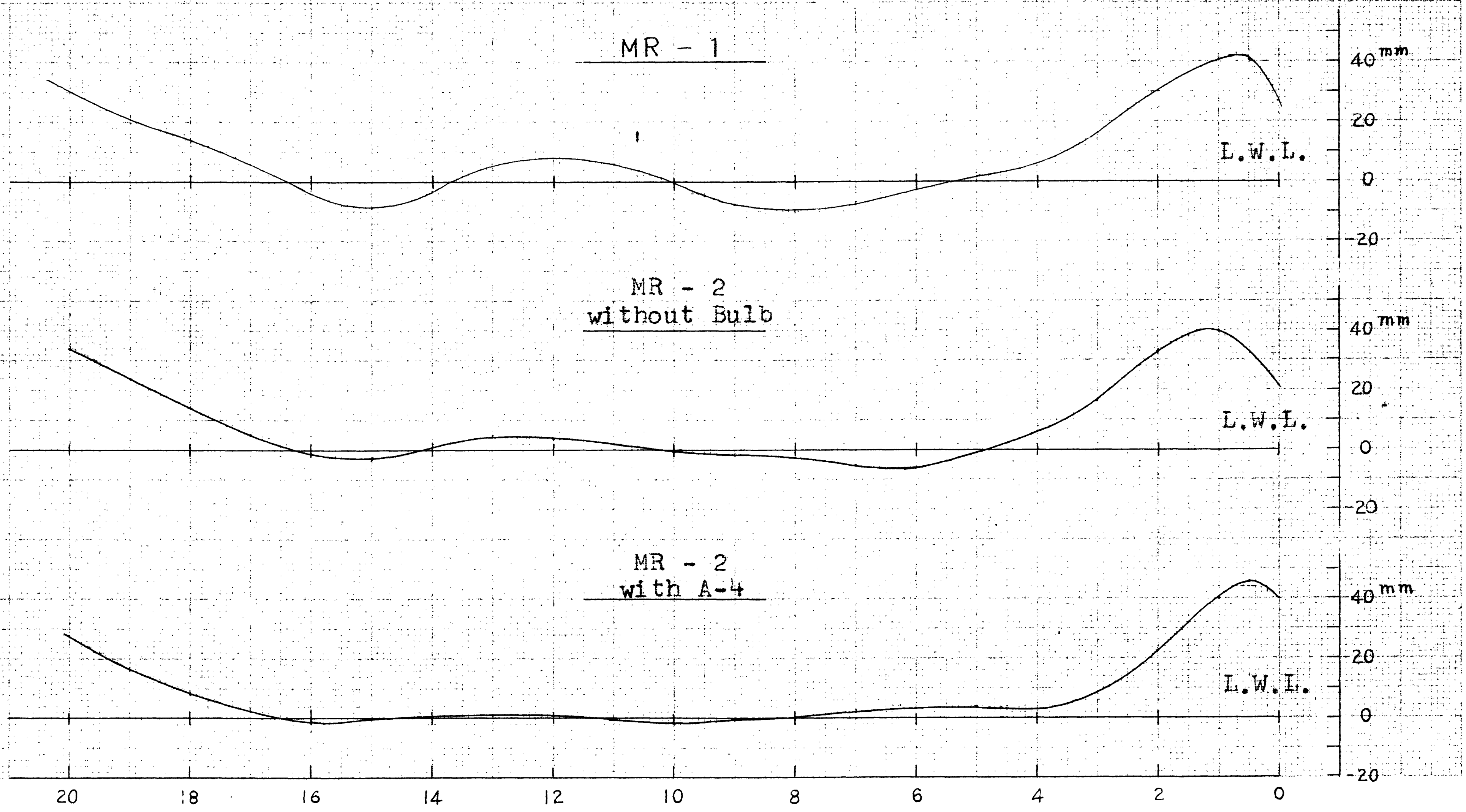


Fig. E6

Wave Profiles
Designed condition
22 knots

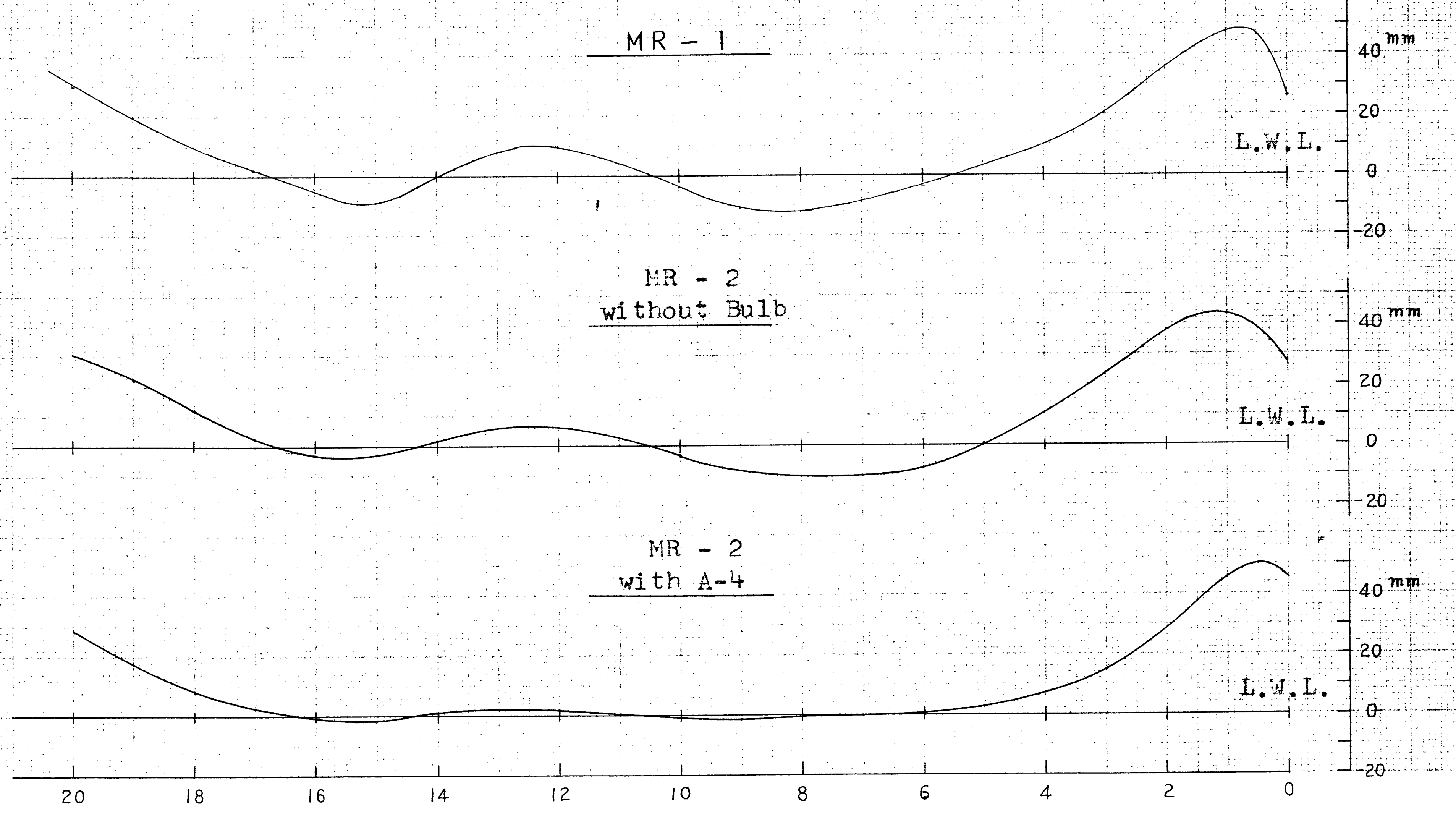


Fig. E7

Wave Profiles

Full loaded condition

17 knots

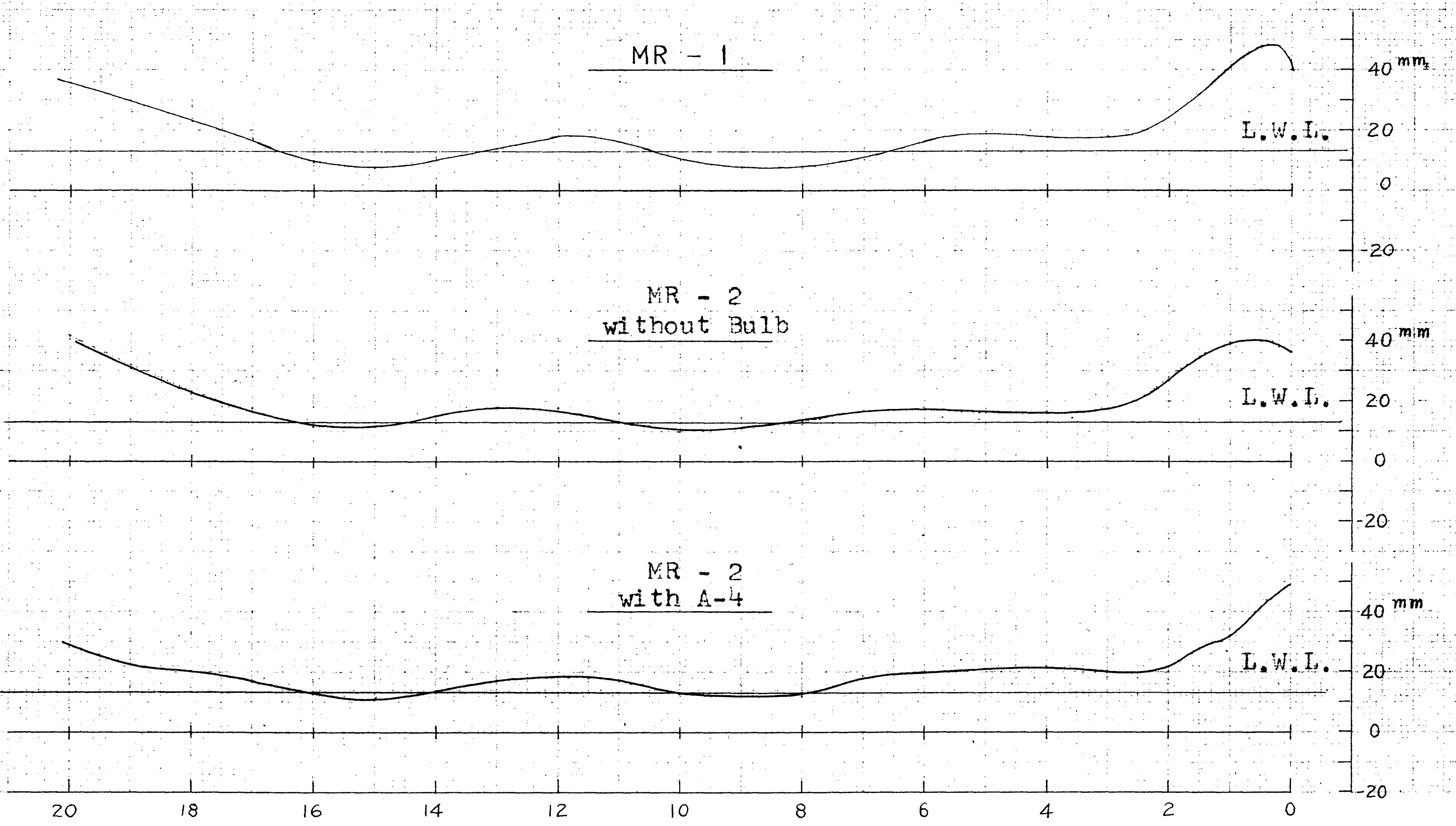


Fig. E8

Wave Profiles

Full loaded condition
18 knots

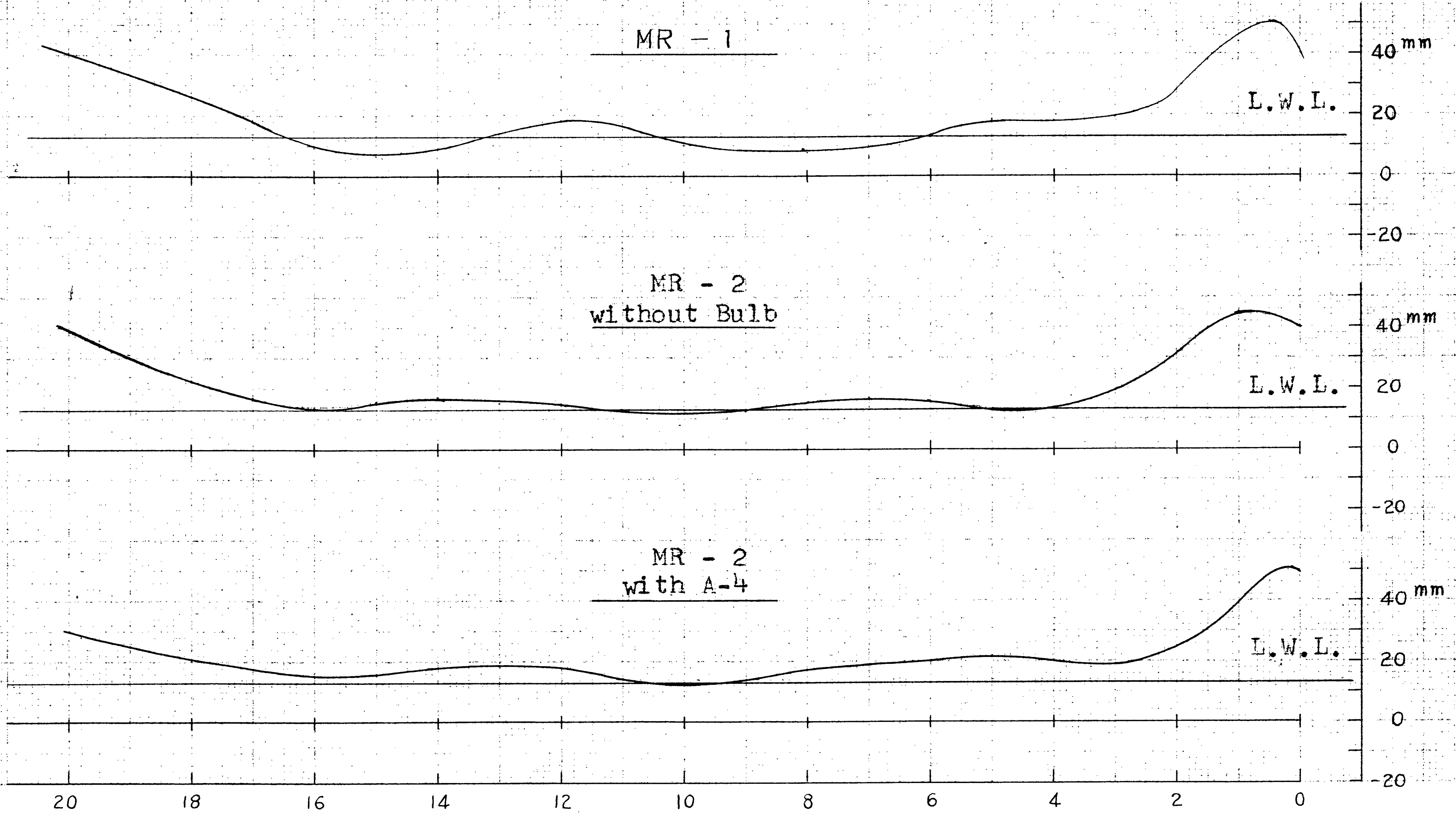


Fig. E9

Wave Profiles
Full loaded condition
19 knots

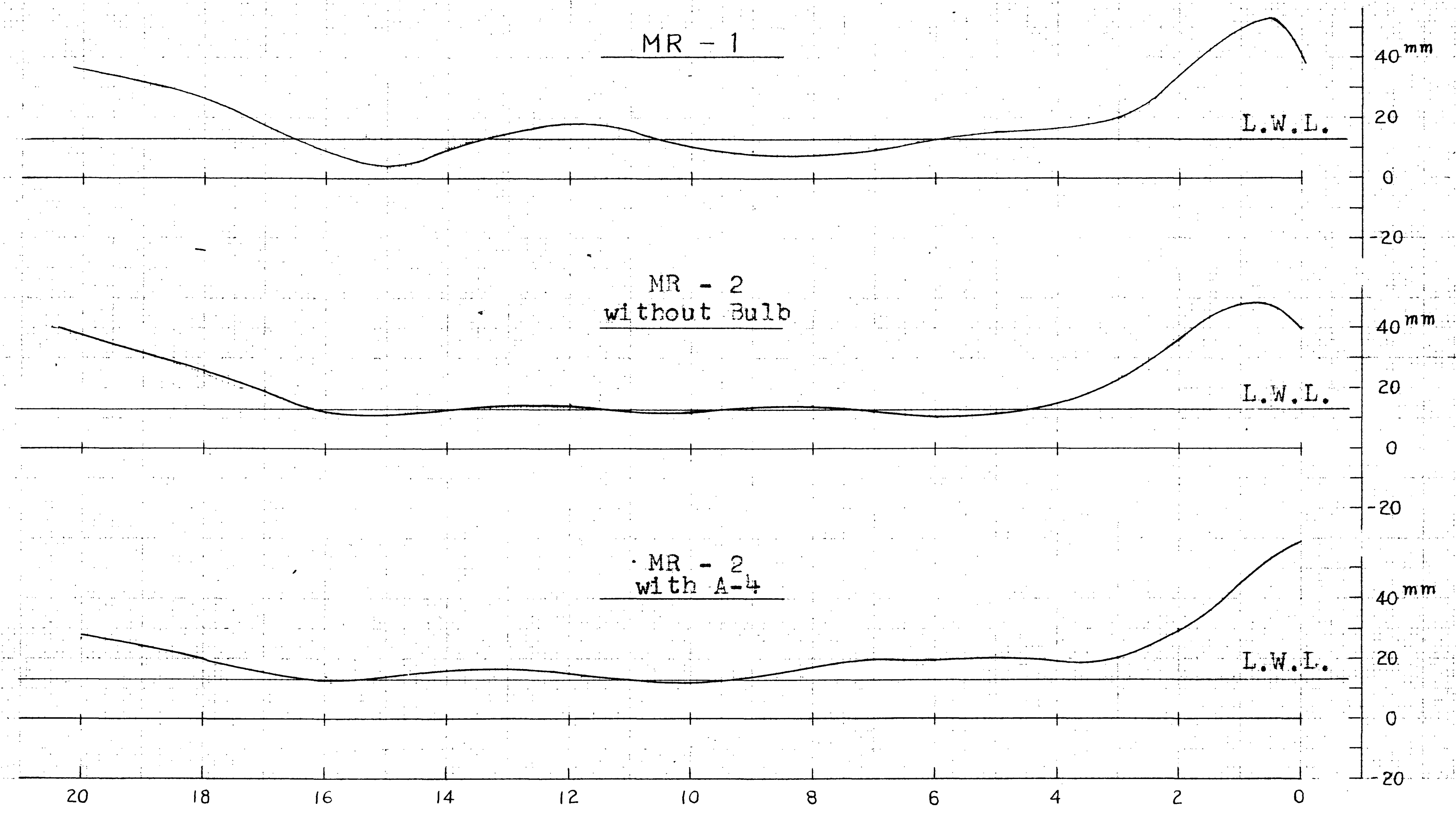


Fig. E10

Wave Profiles

Full loaded condition

20 knots

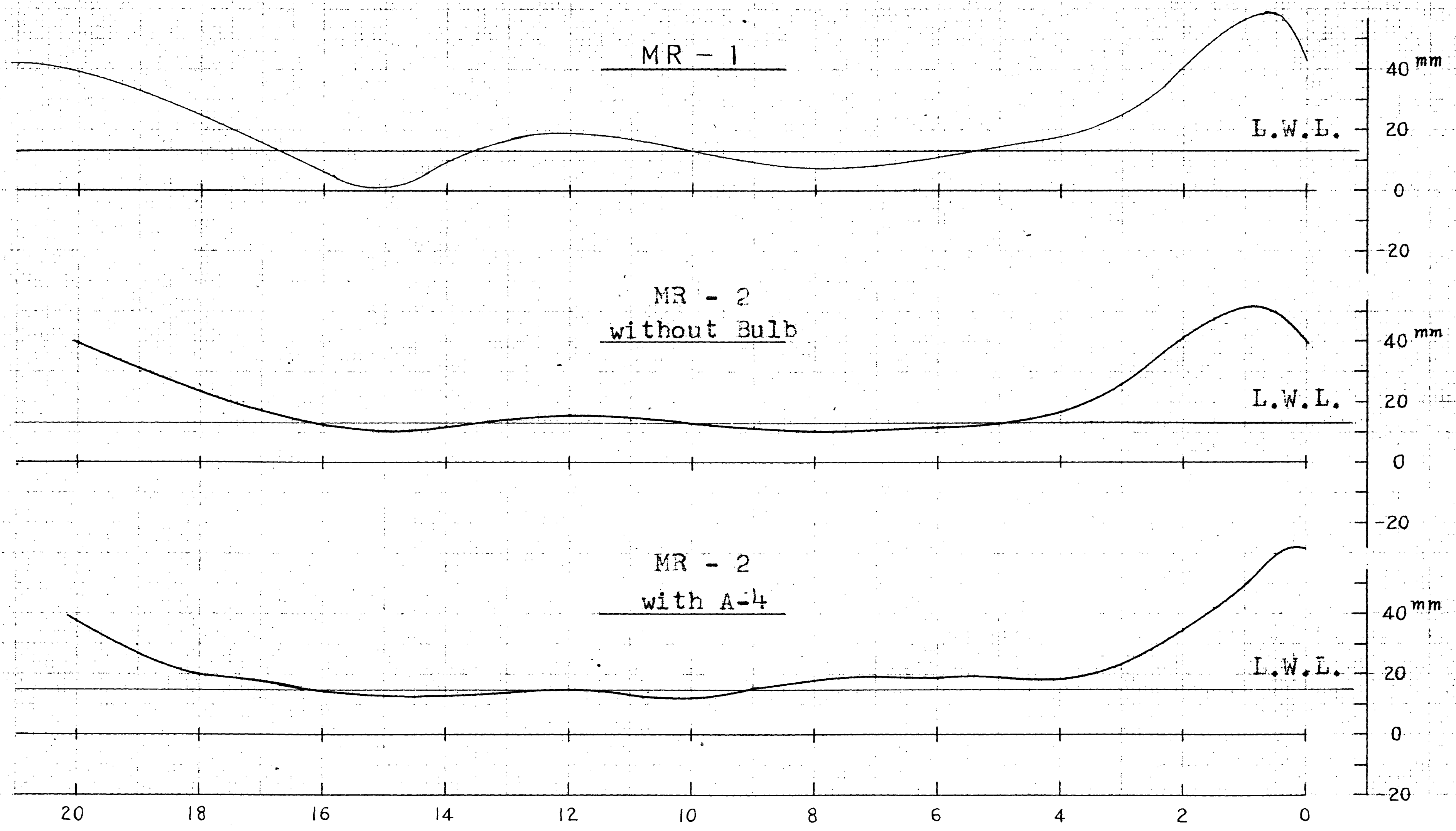
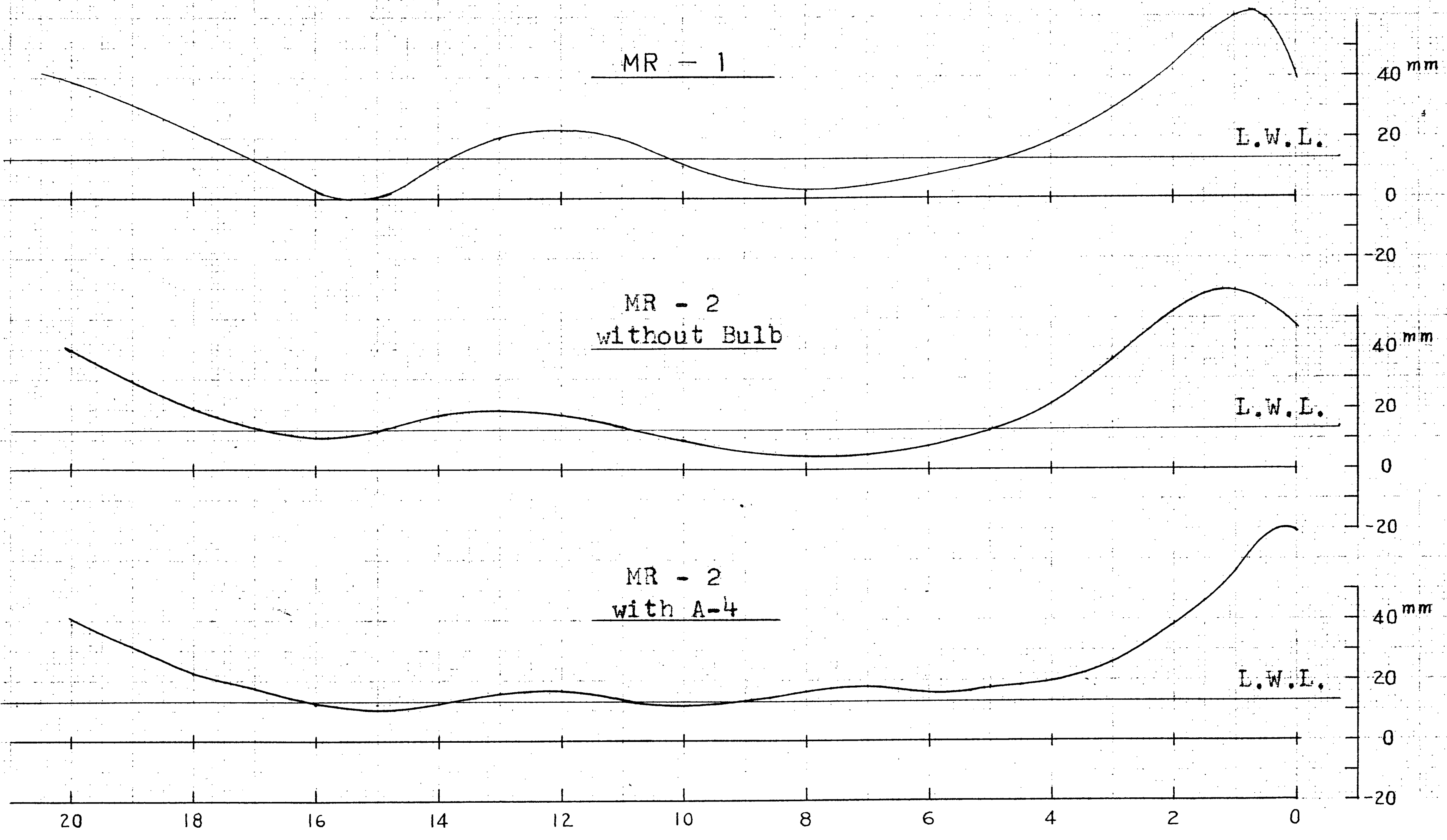


Fig. E11

Wave Profiles

Full loaded condition

21 knots



MR − 1

MR - 2
without Bulb

MR - 2
with A-4

Fig. E12

Wave Profiles
Full loaded condition
22 knots