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National Maritime Institute

Report

Experiments with a model of MFV TRIDENT
and an alternative round-stern design

Project No SH P/23.41

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REFERENCE SH P/23.41
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for Director

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N A T I O N A L   M A R I T I M E   I N S T I T U T E

Project No 23.41

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NATIONAL MARITIME INSTITUTE

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1. INTRODUCTION

In October, 1974, MFV TRIDENT, a seine-net trawler was lost with all hands off Duncansby Head in a near Northerly gale.

As part of the Inquiry set up to investigate the cause of the loss, Ship Division, NPL (now NMI) were asked by Marine Division, Department of Trade, to carry out model experiments in an effort to discover if there were any obvious hydrodynamic reasons for the casualty. In addition the experiments were intended to form part of an investigation into the characteristics of stability that contribute to the safety at sea of inshore fishing vessels of TRIDENT's type.

To help in an assessment of TRIDENT, an alternative design having similar overall dimensions was selected and model experiments conducted on this to provide a basis for comparison. A round-stern design having a reputation for good seakeeping was chosen and thus two models made to the same scale were available for test.

This report describes the calm and rough water experiments that have been carried out on both models. In seas approximating to those that are thought to have existed at the time of the casualty, the TRIDENT model has capsized. This has been avoided by stiffening the hull (increasing its transverse metacentric height at rest) or by increasing both the loading and stiffness of the hull.

IMCO regulations concerning stability criteria look, for the two designs investigated at least, to be in doubt and evidence leading to this conclusion is presented in this report.

2. DESCRIPTION OF HULLS AND REPRESENTATIVE MODELS

(a) TRIDENT

TRIDENT was a single screw seine-net trawler built in steel. Above decks she consisted of a whaleback forward, abaft which a well extended aft to a transom stern. A steel deckhouse was positioned within the well and aft of amidships. A steel hatchway to the fish hold was arranged about midway between the whaleback and the deckhouse front. Freeing ports consisted of a slot running continuously for about half the length of the ship. TRIDENT was registered at Peterhead (official number PD 111) and her principal particulars together with the assumed ship condition at the time of loss are given in Tables 1 and 2. A general arrangement drawing is shown in Fig 1 and a photograph of TRIDENT at sea in Fig 2.

The model was made in wood to a $^1/15$th scale. Hull lines were not available but the Napier Company of Arbroath had lifted offsets from the sister vessel SILVER LINING and these were used and faired to provide the ship lines from which the model was constructed. They are shown in figs 3A, B and C. Deckhouse, whaleback, bulwarks etc were added in polyurethane and aluminium, and freeing ports were reproduced exactly from information provided by the Department of Trade in their letter dated 24th December, 1974. Details of stern frame, rudder and bilge keels were reproduced from data supplied in DOT letter dated 15th May, 1975. A photograph of the completed model is shown in Fig 4.

The model was only 1.7 m long (a $^1/15$th scale was required to match the capability of the wavemaker in the test tank). This length limited the inclusion of certain measuring equipment and once gear was installed to provide remotely controlled drive to the model there was insufficient room for the installation of pitch and roll recording equipment. It was however possible to arrange a moving weight mechanism which could be operated remotely, the aim of which was to simulate the effects of a sudden gust of wind striking the ship. A photograph of the inside of the model showing instrumentation in place is given in fig 5.

(b) Round-stern design

The model of this representative design was made to a $^1/15$th scale in similar fashion to the TRIDENT model. Principal particulars of the ship are given in Table 3 and include conditions similar to those for TRIDENT i.e. for the ship newly arrived at fishing grounds. Hull lines and general arrangement are shown in Figs 6A, B, C and 7 and a photograph of the completed model in fig 8. Comparative body sections of the two designs are shown in fig 9.

The model was installed with duplicate measuring equipment as arranged in the TRIDENT model.

3. STABILITY AT REST IN CALM WATER

Using DOT's computer program SIKOB hydrostatic particulars were computed from the hull offsets of both designs and stability curves obtained. For TRIDENT the assumed condition when lost was taken. Details of this were taken from the report on the formal investigation dated 12th September, 1975 (ref. 1) and are reproduced in Table 2. Table 4 gives details of the condition selected for the round-stern design.

As a check, the TRIDENT model was fitted to a GZ apparatus, which for any angle of toll measures the hydrostatic moment acting to restore a freely floating model to the upright. Figs 10 and 11 give stability curves for both hulls and a comparison between calculated and measured GZ values can be seen. A close comparison cannot be expected at angles beyond which the deck edge becomes immersed and this for TRIDENT occurs at about 16 degrees. The minimum stability required by the current IMCO regulations (ref. 2) is also indicated in figs 10 and 11.

4. ROLL CHARACTERISTICS IN CALM WATER

Since the motion of roll will have an important bearing on the chances of capsize, knowledge of the roll characteristics of TRIDENT would throw valuable light on the reasons for her loss. Also some reservations exist as to whether the roll characteristics of a ship are truly represented in a model. Any discrepancy would place doubt on the conclusions drawn from model tests. In the absence of TRIDENT the opportunity was taken to measure the roll decrement of the sister vessel SILVER LINING lying at Peterhead. Fortunately SILVER LINING was found to be in a condition close to that of TRIDENT when lost and experiments in which SILVER LINING was excited in roll were put in hand. Roll period was measured and the roll damping coefficients deduced following the equation:-

$$-\frac{d\phi}{dn} = a\phi + b\phi^2 \qquad \ldots (1)$$

ϕ being roll angle and a and b damping coefficients.
In the laboratory similar tests were conducted on the TRIDENT model and the results of both tests are shown in fig. 12. Using Froude scaling, the predicted roll period of the ship becomes:-

$$\text{model period} \times \sqrt{\text{scale}}$$

and from fig. 12, measured model period = 1.58 seconds

$\therefore$ predicted ship period = $1.58\sqrt{15} = 6.12$ seconds

which compares reasonably with 6.5 seconds measured on SILVER LINING bearing in mind her condition was not precisely that of TRIDENT.

Using the same measured data, roll decrement curves were drawn and linear damping coefficients deduced following the equation:-

$$\text{linear damping ratio,}\quad c = \frac{T \log_e 2}{2\pi t_{\frac{1}{2}}} \qquad \ldots (2)$$

where T is roll period. (This assumes exponential decay of amplitude; a more approximate treatment than equation (1), but convenient for comparing ship and model.)
$t_{\frac{1}{2}}$ is the time for roll to decay by half.

Here, for the model to behave exactly as the ship, c should be the same. From fig. 13 c for model is 0.0528, and for SILVER LINING it is 0.0512. No great error is indicated and thus roll motions at the model can fairly be regarded as closely representative of TRIDENT's behaviour at sea.

5. MODEL MANOEUVRING EXPERIMENTS IN CALM WATER

Before embarking on seakeeping tests it was thought desirable to examine the manoeuvring characteristics of the hulls since if caught in an unfavourable position to the sea with waves present, lack of positive rudder response would increase the vulnerability of the ship.

Conventional manoeuvring experiments conducted in No 4 tank, NMI, were carried out on both models each being fitted with remote control drive which operated both propeller and rudder. The models were ballasted to reproduce the conditions given in Tables 1 and 3, care being taken to set the correct transverse metacentric height. Turning circles at various rudder angles were conducted at the normal ship operating speed, the path of each model being recorded photographically. Ratios of ship length to turning circle were deduced and are shown in fig. 14. They reveal no abnormalities. A slight bias due to the single propeller is present but there is no evidence of any instability at small rudder angles.

6. CHOICE OF SEA STATE FOR SEAKEEPING EXPERIMENTS

The sea state reported at the time of TRIDENT's loss is quoted in reference 1 as ".... wind NNE force 5-6; sea from NNE, fairly rough; tide ebbing northwards at about 1.2 knots". TRIDENT was apparently only a few miles off Duncansby Head.

The characteristics of typical coastal waters are given by Darbyshire (ref. 3). They are commonly used in model experiments for the prediction of the performance of ship designs expected to operate in near coastal waters. As a starting point, therefore, irregular waves as defined by Darbyshire were generated in the test tank.

The wave height at the time of loss is not known. For wind forces 6 and 7 Darbyshire quotes significant heights of 2.35 and 3.2 m respectively. With the tide against the wind it is probable that the waves became shorter and steeper and it is not unreasonable to surmise that the highest of these (3.2 m) could have obtained. The sea area concerned is well known for its freak seas and it is unlikely that pure coastal-type waves were present. Thus an alternative sea state was sought for the model tests. Taking waves which corresponded full scale to significant heights of 3.2 m, their lengths were shortened in the test tank and after a prolonged run, reflection from the tank walls produced areas of breaking waves which were found to be repeatable over short periods of time. These waves appeared very realistic and were used for most of the model tests.

Breaking waves defy exact definition, but an approximate analysis of their characteristics is shown in fig. 15 and for comparison, Darbyshire type waves for wind forces 7 and 8 are included in this diagram. The maximum wave height produced by these breaking waves in any given sample corresponded to 4.9 m full size.

7. MODEL SEAKEEPING EXPERIMENTS

Both models were free running and remotely controlled through radio link from the NMI No 3 tank carriage. Corresponding ship speeds of up to 10½ knots were possible. The bulk of the data collected was entirely visual and to support these, ciné films were taken of most of the experiments. The test procedure was as follows:-

Waves were first generated in the tank and each model in turn driven through them, the carriage following behind to maintain close contact. Once in the area of breaking waves the carriage was stopped and the model manoeuvred in various courses such as head to sea, following, beam, continuous circular manoeuvres, etc. When desired the roll of the model in waves was accentuated by operating the moving weight mechanism in the model thus simulating a sudden gust of wind striking the ship. This mechanism was also controlled remotely from the carriage.

The tests conducted can be conveniently considered in three parts as follows:-

(a) Tests in coastal-type waves according to Darbyshire

Both models were ballasted to reproduce the conditions given in Tables 1 and 3 and two sea states relevant to Beaufort wind forces 7 and 8 were set.

The behaviour of each model was perfectly satisfactory in such waves. TRIDENT shipped a little water over the whaleback in force 8 and during ircular or zig zag manoeuvres rolled considerably more than the round-stern design. In following seas little difference was noticed and certainly the transom stern in TRIDENT did not appear to handicap progress in such waves. There was however in both models a tendency to broach. Although the models were of almost the same displacement (see Tables 1 and 3), the transverse metacentric heights were considerably different. The value for TRIDENT (0.732 m) was much less and produced a much more tender hull in the water and this was responsible for the greater roll experienced. The application of the gusting wind mechanism had little effect on behaviour.

There was no reason to suppose that TRIDENT in the "as lost" condition would have experienced any real difficul y in Darbyshire coastal-type waves up to force 8 in strength.

(b) Tests in breaking waves

The models were ballasted to the conditions given in Tables 1 and 3.

In heads seas the motions of both models were severe. Considerable water was shipped in both and sometimes it struck the deckhouse front. TRIDENT rolled more and proved harder to keep on course.

In following seas both models broached with TRIDENT rolling severely when caught in a quartering sea position.

The freeing port arrangements in the two models differed significantly. TRIDENT's were of the slot type whereas those in the round-stern consisted of hinged doors. The doors worked better. TRIDENT's arrangement allowed water to flood on to the deck as the vessel rolled into a wave and the time taken to discharge water from the deck was considerable. This of course depended on the amount of water shipped but periods equivalent to 2 minutes (full scale) were noted.

Once circling manoeuvres were attempted the TRIDENT model was immediately at risk. The model capsized on a number of occasions usually when it was caught in a beam to sea position.

There were two distinct types of capsize; the classic case, in which the hull when balanced on the crest of a wave and without water on deck, immediately loses waterplane inertia and hence stability, and the case where a wave overwhelms the bulwarks and produces a rolling moment greater than the restoring moment naturally present in the hull. These types of capsize have been filmed and for this report several frames have been reproduced photographically from the cine negative. Unfortunately the quality of the prints suffers but figs 16 and 17 show sequences of the two types of capsize discussed.

It is significant to note that the elapsed time for each capsize was only a few seconds (full scale) and this was even less when the model was kept stationary in beam seas. Fig. 18 shows the sequence of events when the model was struck by a breaking wave in such seas.

In contrast, the round-stern model survived circular manoeuvres in the breaking waves with comparative ease. Nevertheless motions were severe and considerable quantities of water were shipped. On several occasions the model survived a test period equivalent to about 1 hour full scale. Every attempt was made to bring about a capsize such as allowing the model to hold station in beam seas, but the extra stiffness inherent in the hull due to the larger GM clearly contributed to survival.

(c) Tests in breaking waves with both models having modified conditions at rest

The aim of these experiments was to discover the loading or stability changes that were needed to enable the TRIDENT model to survive the breaking waves or alternatively find the condition for the round-stern design which would bring about capsize.

As a first simple step, TRIDENT's GM was altered to that of the round-stern design. This was achieved quite easily by rearranging the ballast inside the model and carrying out an inclining experiment to check the new GM. Experiments in the breaking waves were repeated and no capsize was obtained. Test periods of up to 1 hour full scale were carried out. Motions were extremely severe and decks very wet and an impression was gained that limiting conditions for survival had been reached.

This simple device of increasing the hull stiffness thus proved successful and the differences in performance between the TRIDENT and the round-stern model now appeared to be due to the nuances of the respective hull shapes.

DOT were anxious to explore further since modifications to the sister vessel SILVER LINING were being actively considered. Three further conditions were tried, details of which were supplied by DOT in their letter dated 2nd March, 1976. They are outlined in Table 5. Essentially they increased the displacement of TRIDENT and as a consequence the GM also changed. All three cases resulted in increased hull stiffness.

Tests in the breaking waves were carried out with the model set in these three conditions in turn. At no time did the model capsize. The higher displacements (conditions (b) and (c) in Table 5) reduced freeboard considerably yet despite shipping considerable amounts of water, the model survived test periods of 80 minutes full scale. There were two occasions when the model after being struck beam on by a wave developed loll but it recovered fairly quickly. In condition (d) of Table 5 rolling was more noticeable and this appeared consistent with earlier experience since the GM in this condition was the lowest of the three modifications tried (0.875 m). Film records exist for all conditions tested.

Referring to Table 5, there are four alternative conditions for the TRIDENT model all of which survived the breaking waves. Their relevant stability curves are plotted in fig. 19 together with the "as lost" condition which produced capsize and it is significant to note that IMCO recommendations lie close to this latter curve.

The round-stern design was tested in four further conditions its displacement being kept constant. Variations were thus restricted to changes in GM and these are set out below:-

CONDITION	DISPLACEMENT (tonnes)	GM (m)
Newly arrived at fishing grounds (initial tests)	160	0.908
(e)	160	0.732
(f)	160	0.574
(g)	160	0.504
(h)	160	0.4

Corresponding stability curves are plotted in fig. 20 together with the IMCO recommendation.

Of the four further conditions tested in the round-stern design two produced capsize. These were conditions (g) and (h) where GM was 0.504 and 0.4 m respectively. It was noticeable in the experiments that as the model stiffness reduced through reduction in GM the incidence of rolling in breaking waves increased. Condition (e) was selected with GM = 0.732 m to agree with the value for TRIDENT in the "as lost" condition and the model survived. This showed that survival did not depend solely on the absolute value of GM or some non-dimensional derivative of it, but rather the character of the stability curve played an important part. Figs. 19 and 20 indicate that condition (e) produces greater dynamical stability than TRIDENT in the "as lost" condition despite having the same GM and this is brought about by differences in the hull shapes. Conditions (g) and (h), both capsize cases, have curves roughly equal to or below the IMCO minimum.

8. CONCLUSIONS

The model experiments have shown that it is quite possible that TRIDENT in a condition as assumed when lost could have capsized in breaking waves of modest height. The sequence of events during capsize occur so rapidly that there would have been little opportunity to raise an alarm.

Reasons for capsize suggested by the results of the model experiments are:-

(1) TRIDENT in the assumed as lost condition had insufficient stability at rest. This was soon appreciated in the model where roll, even in a modest sea state, was excessive. Lack of sufficient hull stiffness is suggested

as the main cause contributing to capsize and later experiments in which either displacement or GM was increased proved conclusively that the hull shape itself was not at fault but rather its weight distribution which produced an unfavourable value of GM.

(2) Discharging water from the decks through the freeing ports, although of great importance, does not appear to influence the possibility of capsize significantly. In case (c), see Table 5, where the freeboard was very low, water was constantly on deck in such quantity as to overwhelm the freeing ports yet the model survived, this being entirely due to increased stiffness brought about by the higher GM.

(3) It is difficult to assess accurately the effect of TRIDENT's transom stern on performance. It appeared slightly inferior to the round-stern design in following seas, water at times flooding on to the after deck. Both hulls tended to broach in following seas.

(4) The "as lost" condition assumed that 5 tonnes of oil fuel was aboard TRIDENT. Alternatively the amount may have been 8 tonnes. This larger amount would have increased displacement by less than 2% and the evidence of the experiments suggest that it is extremely unlikely that this increased amount would have reduced the chances of capsize.

(5) The effect of a sudden gust of wind striking TRIDENT cannot be ignored, but when tried during the experiments it had little effect. The worst case would be with the hull balanced momentarily on the crest of a wave but in the cases where the hull was adequately stiff the model was relatively undisturbed. Only a very large gust is likely to prove dangerous. The moving weight mechanism in the model was designed to simulate the effects of a 40 knot wind gusting to 60 knots and this was thought amply representative of the conditions thought to be prevailing at the time of loss.

On the evidence of the behaviour of these two models alone, the margin of stability for the small inshore fishing vessel as indicated by the IMCO criteria seems insufficient. Referring to figs 19 and 20 both models experienced capsize when their stability at rest was close to the IMCO minimum. For the round-stern design a survival case was obtained with the max GZ fractionally above the IMCO value but greater stability was present due to an angle of vanishing stability higher than that implied by IMCO.

If IMCO recommendations for minimum stability are to be reconsidered then greatest emphasis should be placed on the maximum GZ value and its position in the stability curve. A higher GZ will in most cases lead to larger dynamical stability. Also a stated minimum value for the angle of vanishing stability should be considered.

9. RECOMMENDATIONS FOR FUTURE WORK

It was not possible to test the models in waves of Darbyshire coastal water type above force 8. Information at higher wind forces would be useful and could be obtained by experimenting at sea. However this can be an expensive and time consuming exercise.

The conclusions drawn from the model experiments concerning IMCO recommendations are based on the evidence of two hull designs only. Clearly more data are required. These could be obtained from further model experiments on different designs within the inshore fishing vessel field and in particular, cases that are recorded in casualty lists could be examined. Ideally those chosen would have the conditions of loss reliably documented.

With regard to SILVER LINING, the additional tests carried out on the TRIDENT model described under section 7(c) of this report indicate that case (c), displacement = 239.5 tonnes, GM = 0.981 m, is perhaps the best since the higher displacement allows a larger catch of fish to be carried.

10. LIST OF REFERENCES

1. MFV TRIDENT (ON PD 111) Report of Court No S 497. Formal Investigation Published by HMSO, 1976.

2. Recommendation on intact stability of fishing vessels. IMCO, London, 1968.

3. The one dimensional wave spectrum in the Atlantic Ocean and in coastal waters. Ocean Wave Spectra by J. DARBYSHIRE New Jersey: Prentice-Hall Inc., 1963.

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Experiments conducted by: R. Jacob assisted by
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Planning and Commercial Manager: James Dawson

TABLE 1

Principal particulars of TRIDENT as thought at time of loss

Model number		5320
CONDITION		5 tonnes oil fuel aboard
LENGTH OVERALL	(m)	25.91
LBP	(m)	22.09
BREADTH mld	(m)	6.86
DEPTH mld	(m)	3.35
Draught amidships	(m)	2.48
Displacement	(tonnes)	167.6
Transverse GM	(m)	0.732
Radius of gyration in pitch		29% LBP*
Propeller		Fixed 4 bladed, dia = 1.78 m pitch = 1.35 m
Rudder		Semi balanced, area = 2.77 m^2

*Achieved at model. Normally 25% LBP is assumed.

TABLE 2

TRIDENT

ESTIMATED CONDITION AT TIME OF LOSS
(taken from reference 1)

ITEM	TONNES	VCG (m)	VMT	LCG (m)	LMT
'Lightship'	149.83		478.99		160.99A
Stores in Lower Focle	1.0	2.74		8.84F	
Stores in Upper Focle	1.5	4.88		10.97F	
Fresh Water	1.5	1.07		8.78F	
Hyd. Oil Drum on Deck	0.18	4.57		7.92F	
Fish Boxes in Hold	3.37	2.29		5.33F	
Lub. Oil Drums in ER	0.14	1.37		4.42A	
Nets	1.27	3.96		1.22A	
	0.92	4.27		11.43A	
	0.92	4.18		6.4 F	
	0.15	4.18		6.4 F	
	0.23	5.94		7.62A	
	0.11	4.11		11.58A	
Chain at After Gallows	0.27	3.81		8.69A	
Dog Rope	0.10	4.11		11.58A	
Stores	0.05	4.27		4.57A	
Crew and Effects	0.52	4.57		3.66A	
Oil Fuel	5.08	-		-	
Tyres (6 OFF)	0.30	3.96		-	
	167.6	3.153	528.44	0.797A	133.6A

KM 3.89 m
GM 0.74 m (solid)
FS -0.008 m
GM+ 0.732 m (fluid)

MLD drafts F = 1.68 m
@ Perps A = 2.98 m   Trim = 1.3 m by Stern

Full drafts F = 1.83 m
@ Perps A = 3.13 m

Free surface (IMCO)
Bunkers (P&S) 0.52
FW tank 0.76
DS tank 0.06
1.34

$$= \frac{1.34}{167.6} = 0.008 \text{ m}$$

TABLE 3

Principal particulars of round-stern design

Model number		5321
CONDITION		Newly arrived at fishing grounds
LENGTH OVERALL	(m)	24.36
LBP	(m)	21.44
BREADTH mld	(m)	6.71
DEPTH	(m)	3.35
Draught amidships	(m)	2.49
Displacement	(tonnes)	160
Transverse GM	(m)	0.908
Radius of gyration in pitch		27% LBP*
Propeller		Dia = 1.75 m, variable pitch (1.27 m for seining, 1.17 m for trawling), 4 blades
Rudder		Semi balanced, area = 2.41 m^2

*Achieved at model. Normally 25% LBP is assumed.

TABLE 4

Round-Stern Design

Condition when newly arrived at Fishing Grounds

ITEM	TONNES	VCG (m)	VMT	LCG (m)	LMT
Lightweight - seiner	115.58		304		148A
Diesel Oil Fuel	9.14	1.37		4.21A	
Lub. Oil	0.60	2.19		6.34A	
Hydraulic Oil	0.40	2.59		3.96A	
Fresh Water	2.79	1.68		8.23F	
Crew & Stores	0.98	3.66		4.88A	
Nets on Deck	0.50	3.96		6.1A	
Warps - 14 coils per side	2.44	4.15		3.51F	
Gear in Store	1.50	3.05		8.84F	
Ice	12.20	2.12		2.07F	
Empty Boxes - approx 600	6.71	2.41		4.21F	
Fish on deck 2.3m off ℄	7.11	3.81		3.05A	
	160.0	2.58	412.8	0.77A	123A

KM	3.53 m	
GM	0.94 m	(solid)
FSC	-0.032 m	
GM	0.908 m	(fluid)

Mean draught amidships - 2.49 m
Trim - 0.33 m by stern

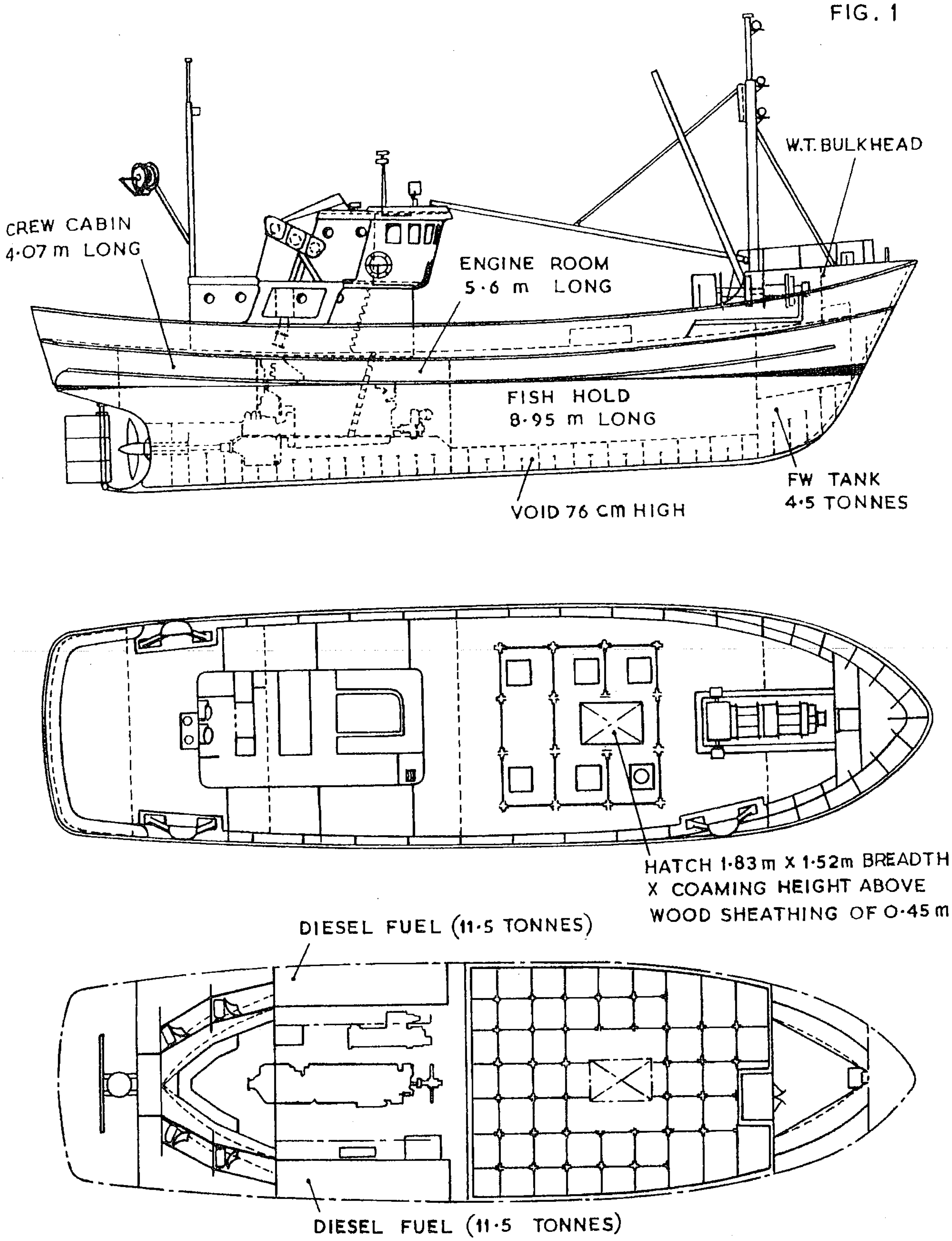
Draughts F = 1.79 m
A = 3.19 m

TABLE 5

Additional conditions in which TRIDENT model was tested

(a)	CONDITION		5 tonnes oil fuel aboard	
	DISPLACEMENT	(tonnes)	167.6	
	MEAN DRAUGHT	(m)	2.48	
	Transverse GM	(m)	0.908	
(b)	CONDITION		Departure from grounds with 35.6 tonnes boxed fish and 50% consumables	As requested by DOT in their letter dated 2nd March, 1976 (applies to (b), (c) and (d))
	DISPLACEMENT	(tonnes)	222	
	MEAN DRAUGHT	(m)	2.79	
	Transverse GM	(m)	0.948	
(c)	CONDITION		Arrival condition with 10% consumables	
	DISPLACEMENT	(tonnes)	239.5	
	MEAN DRAUGHT	(m)	2.92	
	Transverse GM	(m)	0.981	
(d)	CONDITION		Arrival with no fish and 10% consumables	
	DISPLACEMENT	(tonnes)	178.5	
	MEAN DRAUGHT	(m)	2.44	
	Transverse GM	(m)	0.875	

FIG. 1



GENERAL ARRANGEMENT — MFV TRIDENT

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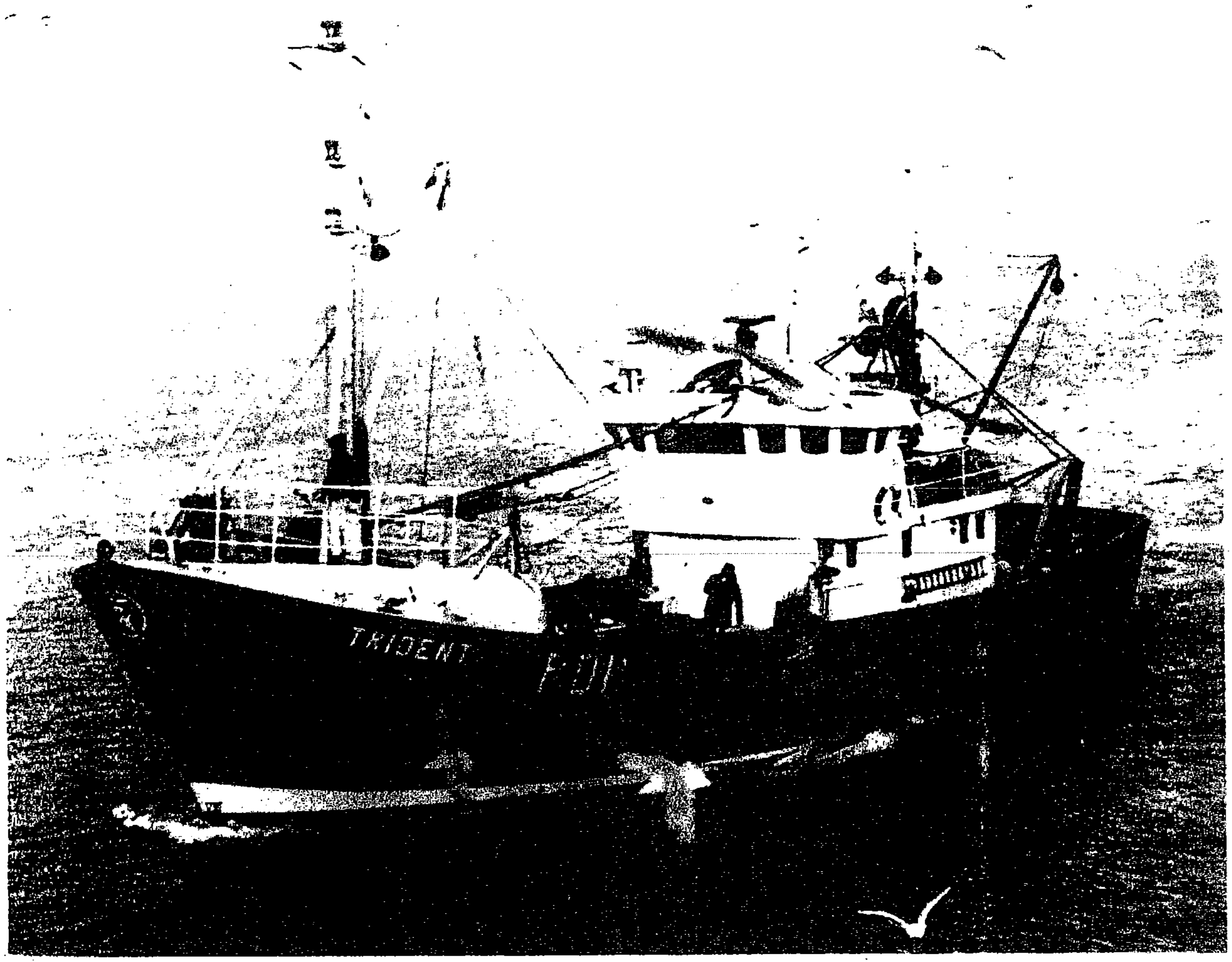
FIG. 2



MFV TRIDENT

REGISTERED DIMENSIONS :-

LENGTH	=	23·99 m
BREADTH	=	6·86 m
DEPTH	=	2·59 m
TONNAGE	=	68·82 TONNES

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FIG. 3A BODY SECTIONS
(TRIDENT)

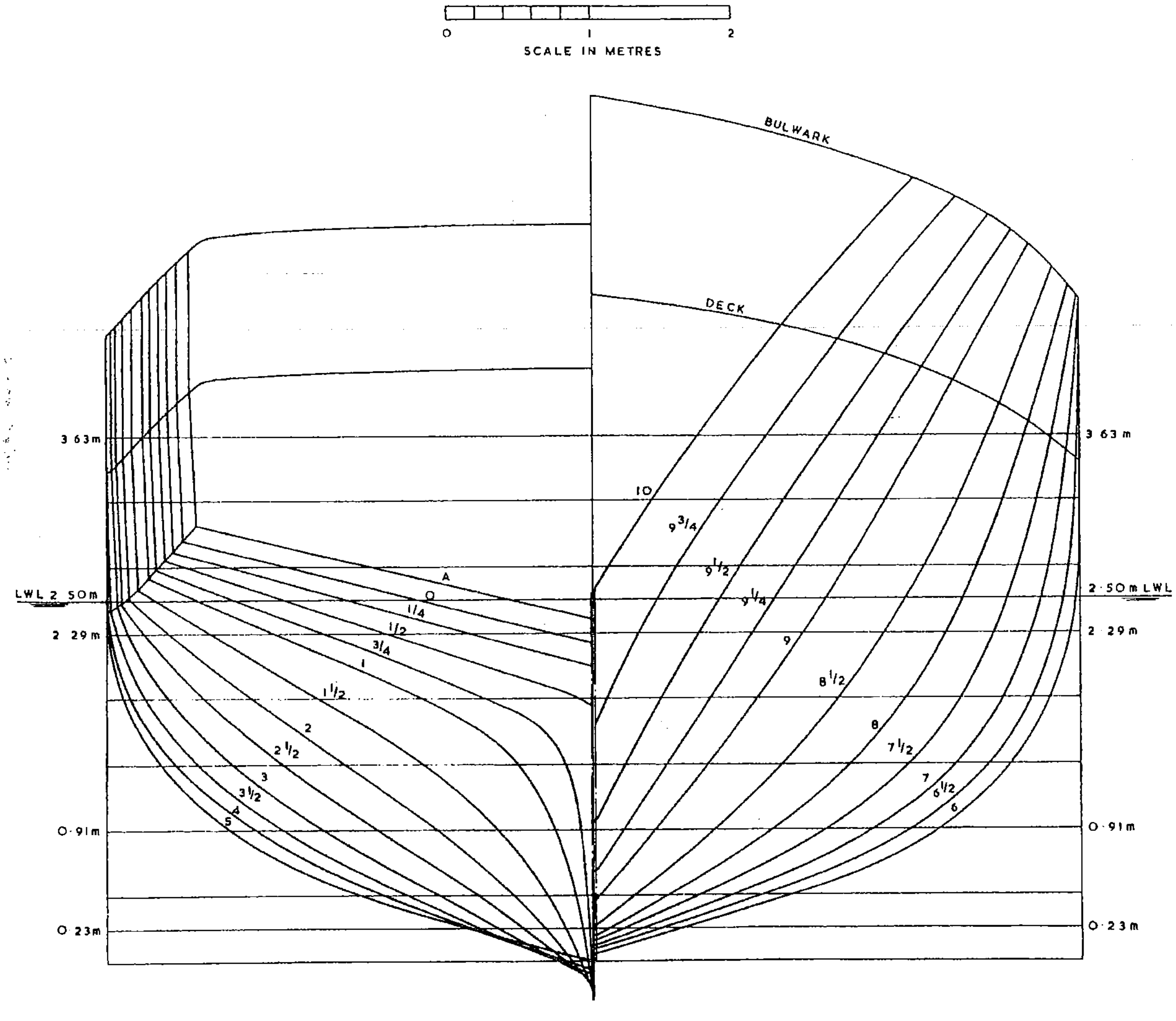


FIG. 3B STERN CONTOUR AND WATERLINE ENDINGS
(TRIDENT)

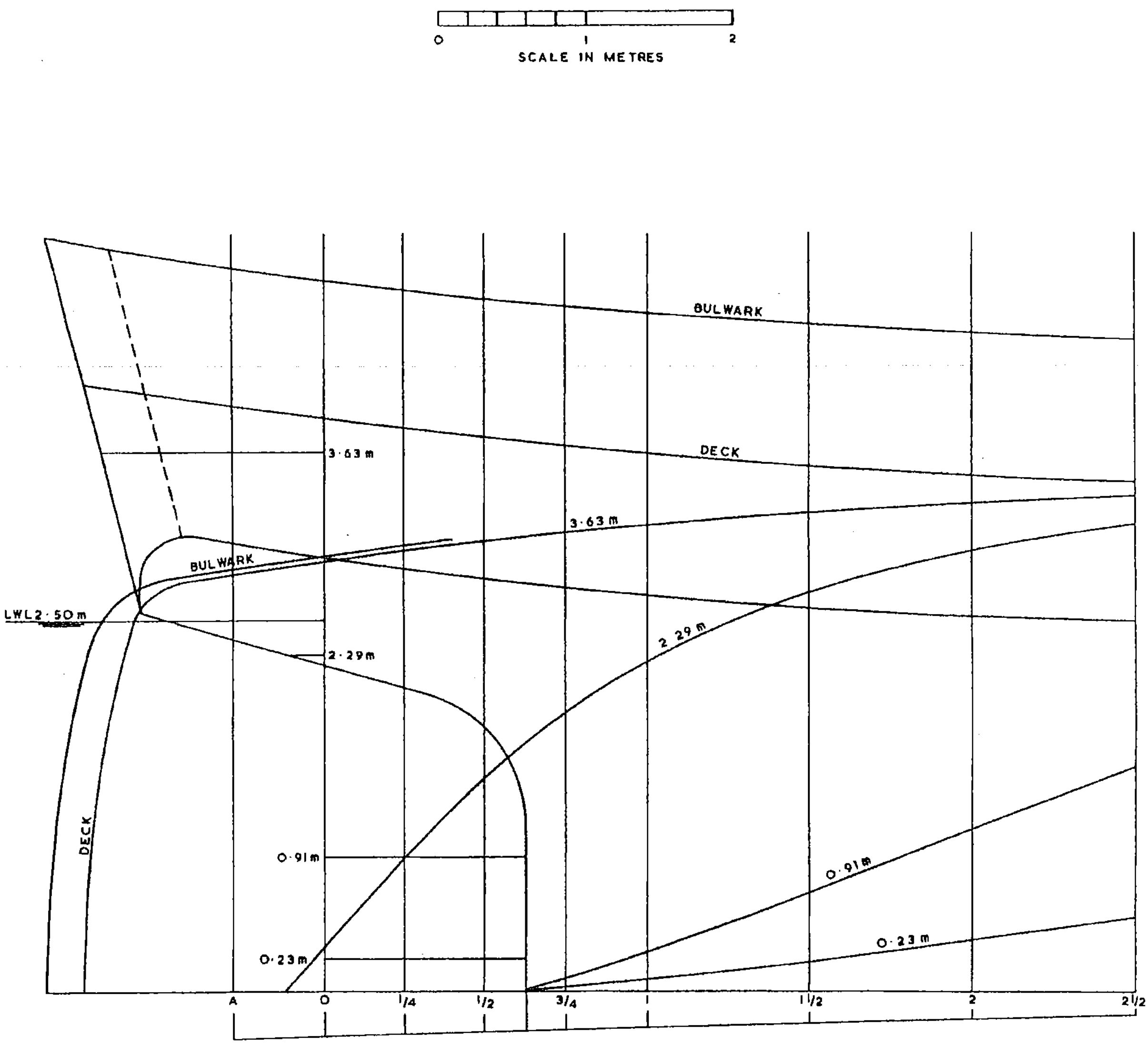


FIG. 3C BOW CONTOUR AND WATERLINE ENDINGS
(TRIDENT)

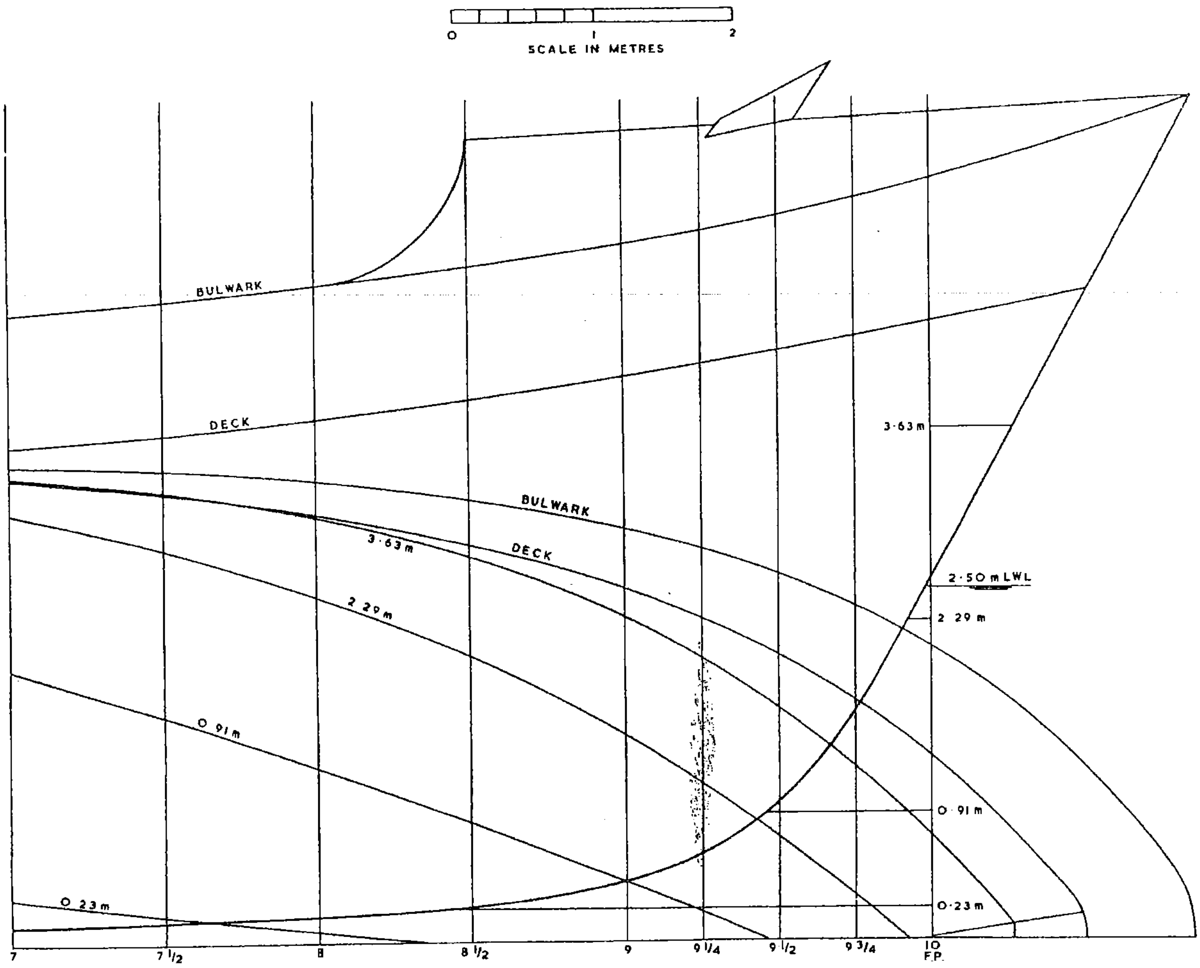
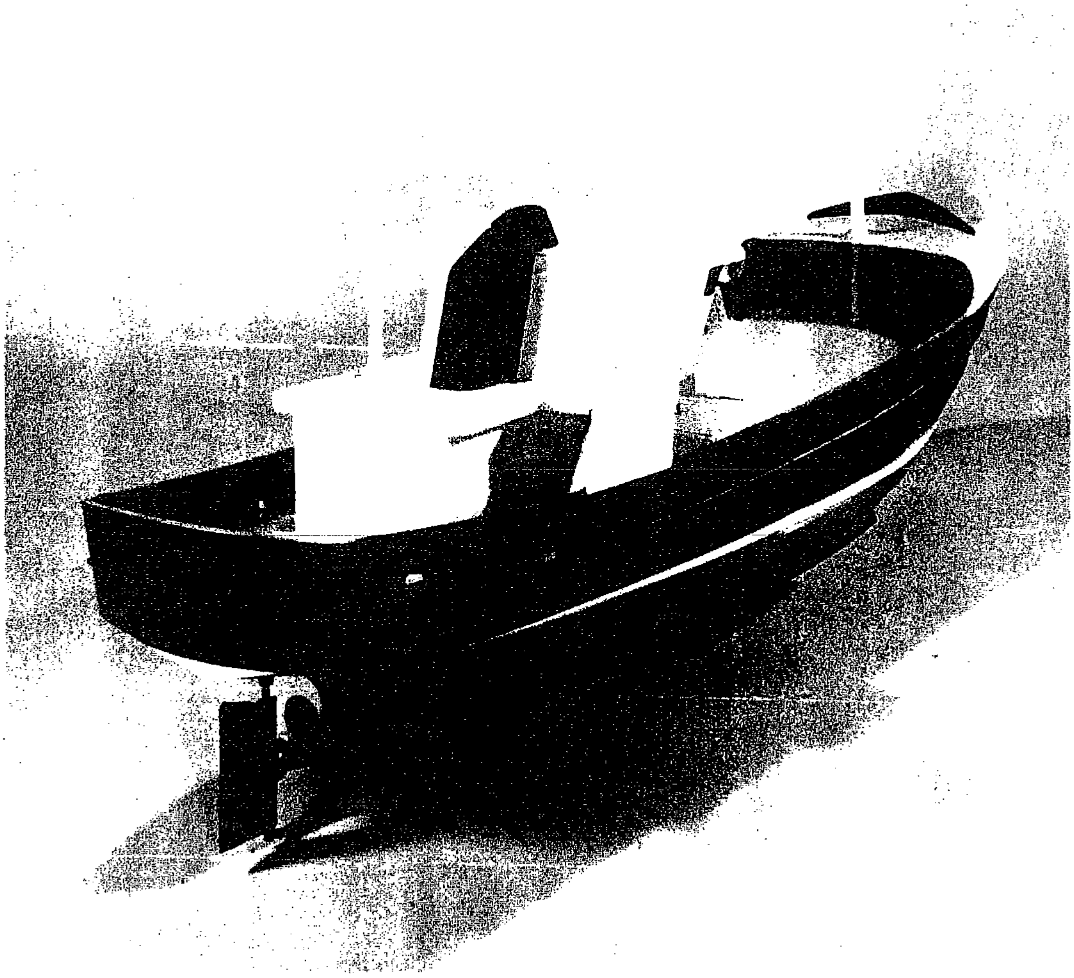
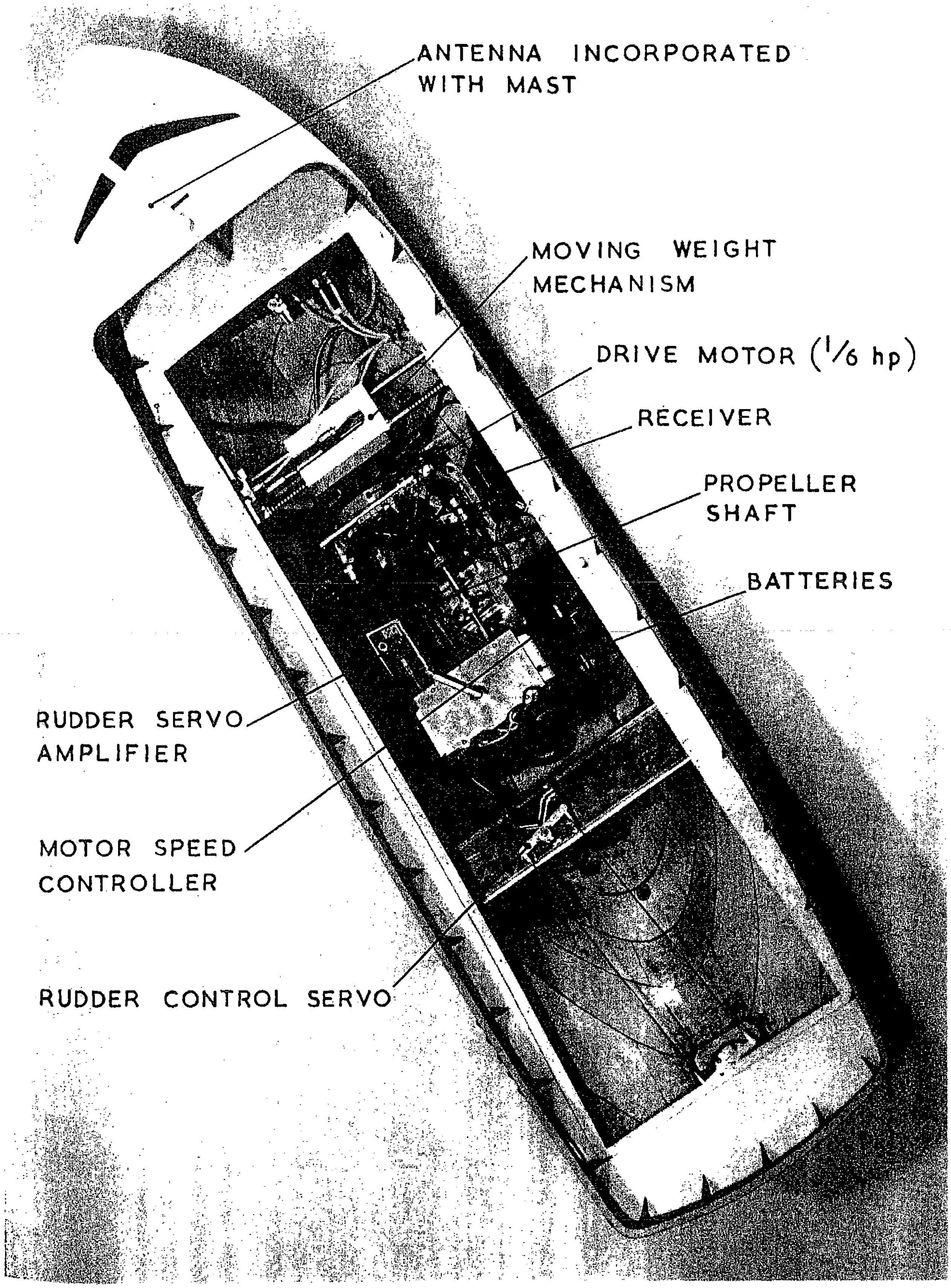


FIG. 4



TRIDENT MODEL

FIG. 5



INSTRUMENTATION IN MODEL

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FIG. 6A BODY SECTIONS

(ROUND-STERN DESIGN)

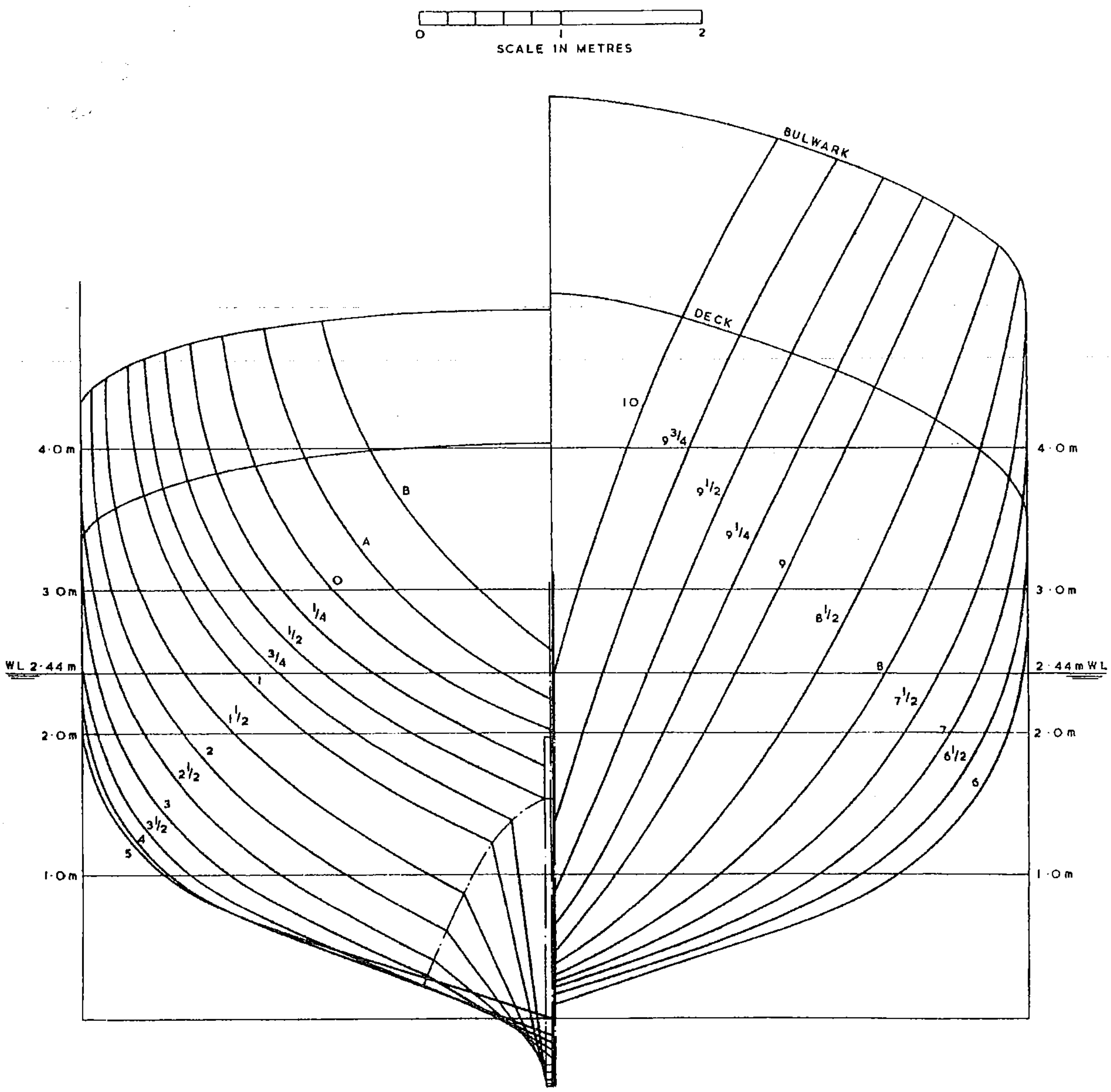


FIG.6B. STERN CONTOUR AND WATERLINE ENDINGS
(ROUND-STERN DESIGN)

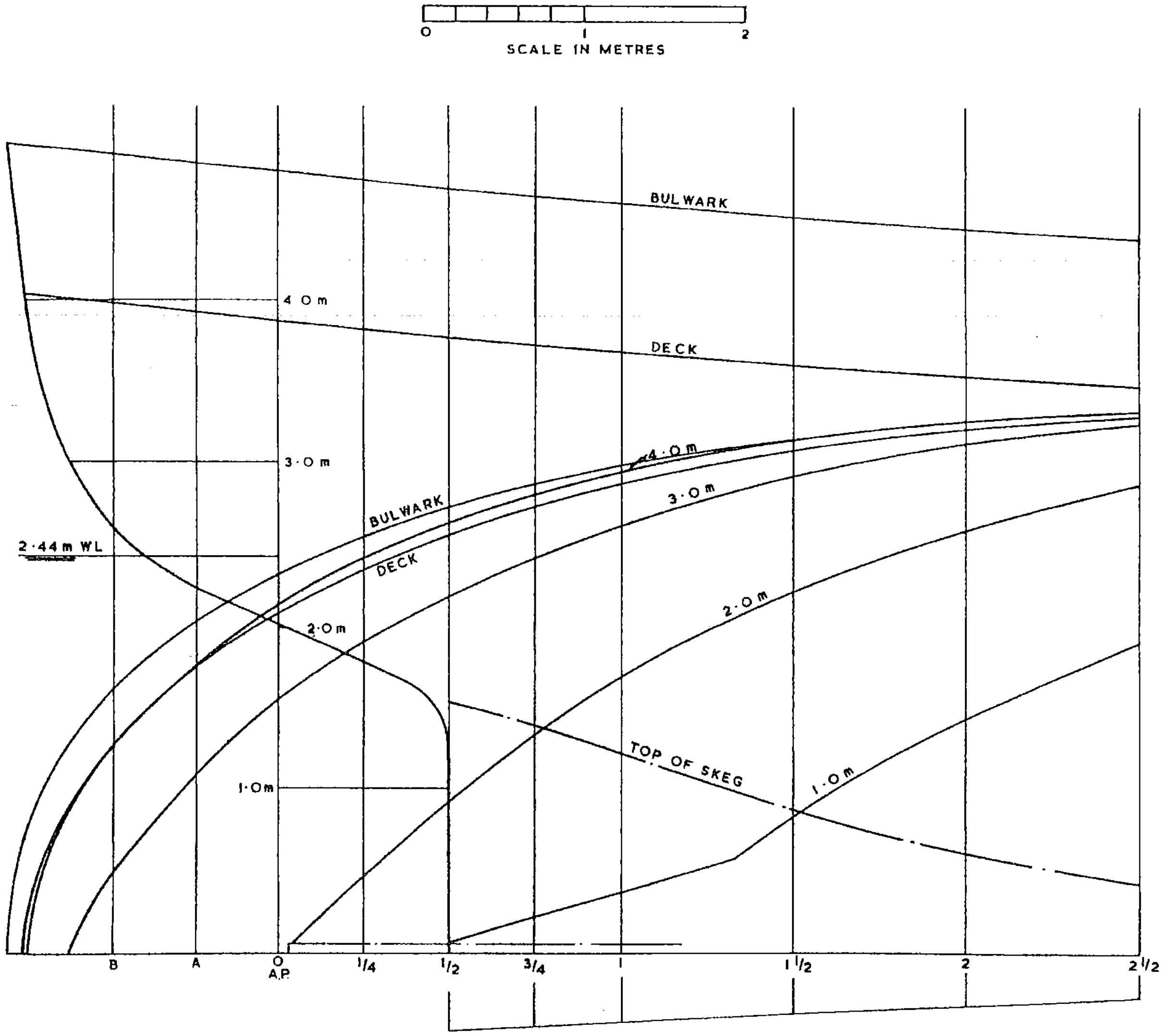
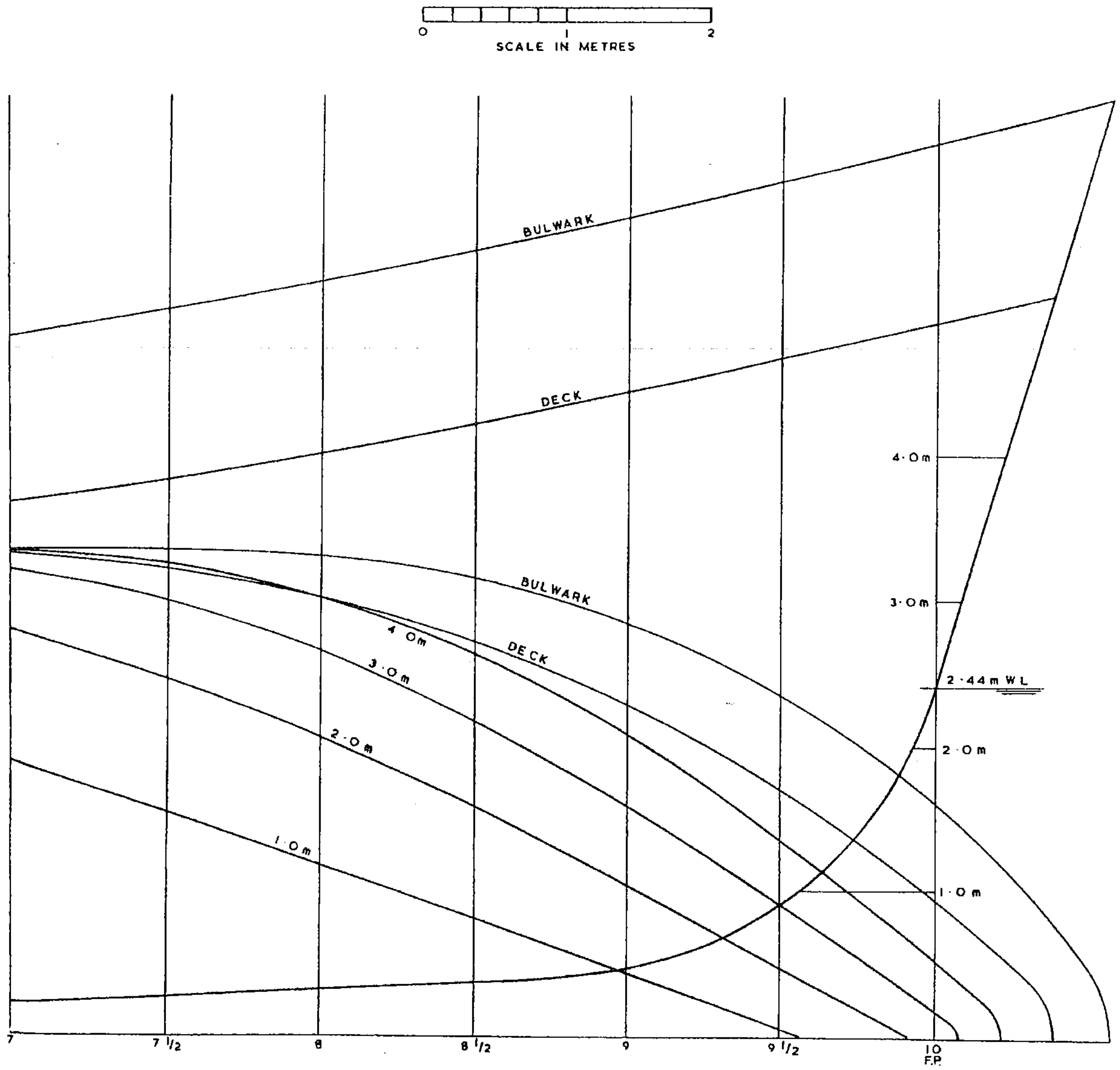


FIG.6C. BOW CONTOUR AND WATERLINE ENDINGS

(ROUND-STERN DESIGN)



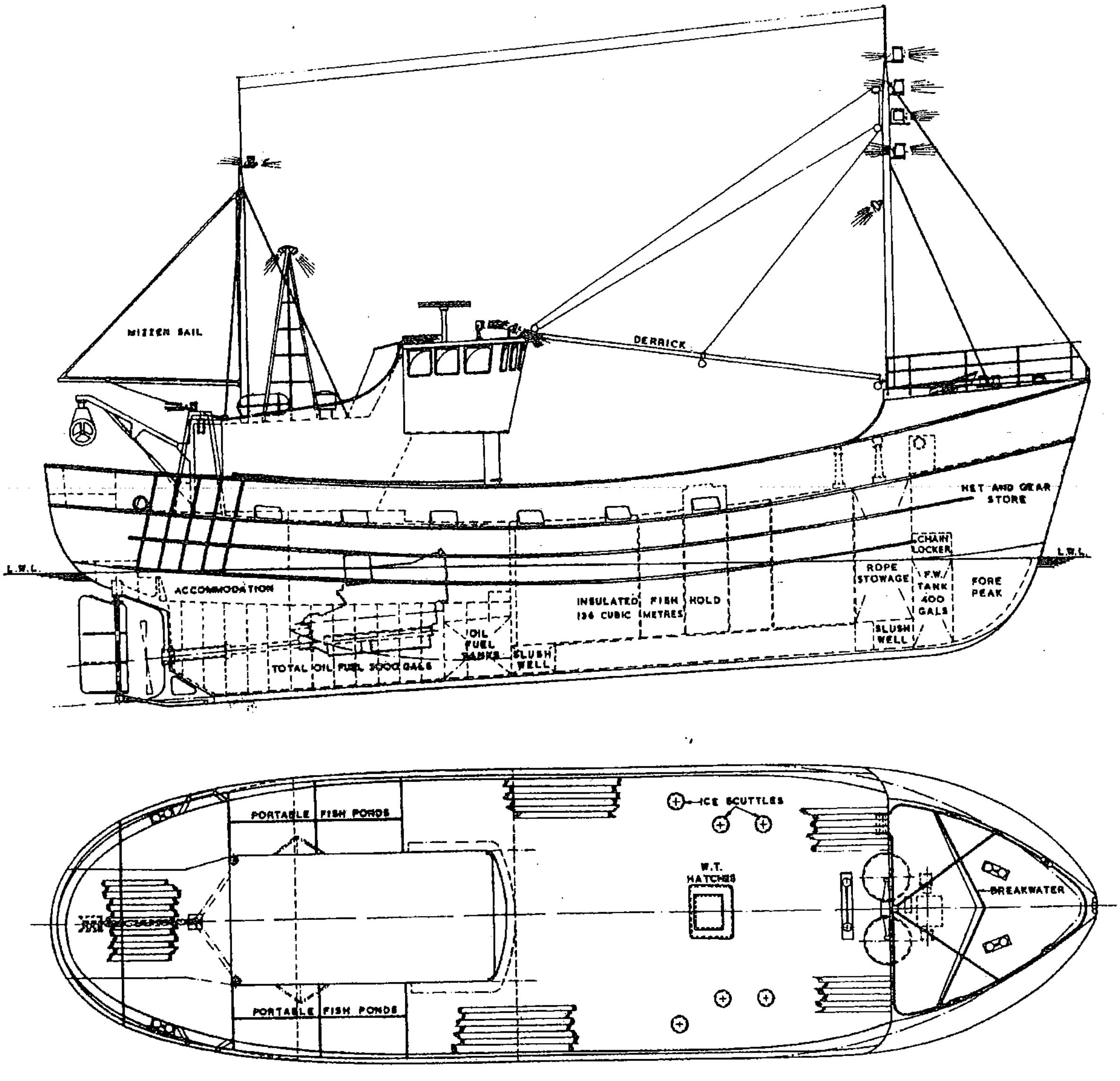
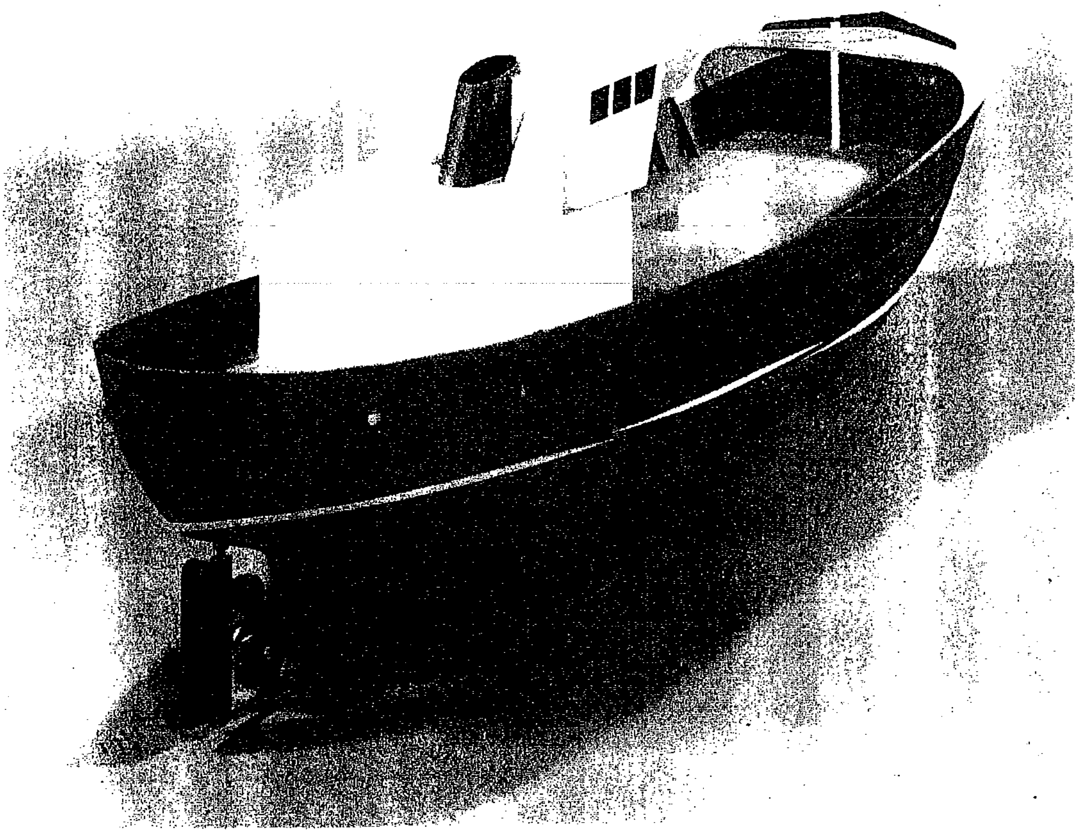


FIG. 7 ROUND-STERN DESIGN
GENERAL ARRANGEMENT

FIG. 8



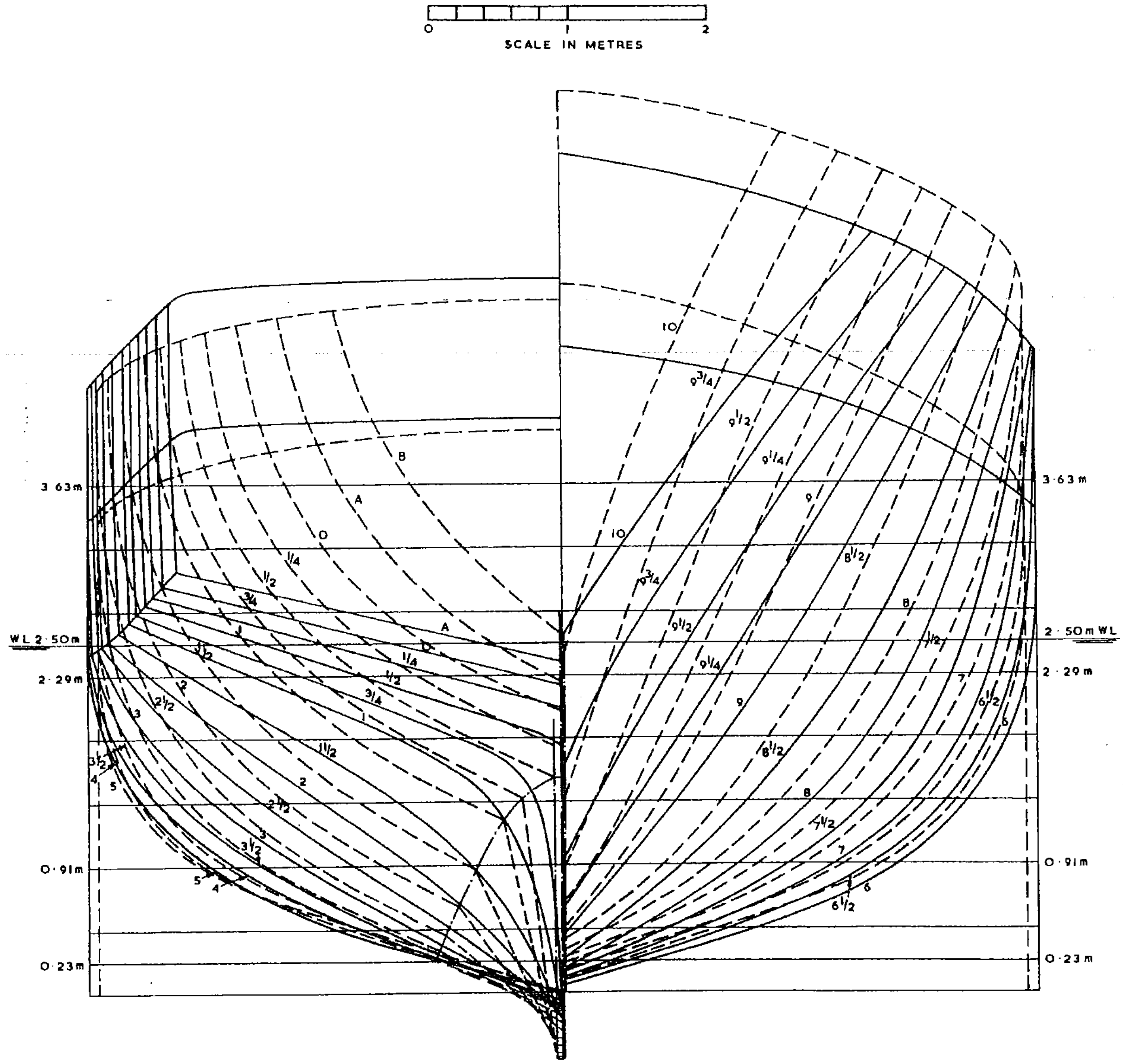
ROUND – STERN MODEL

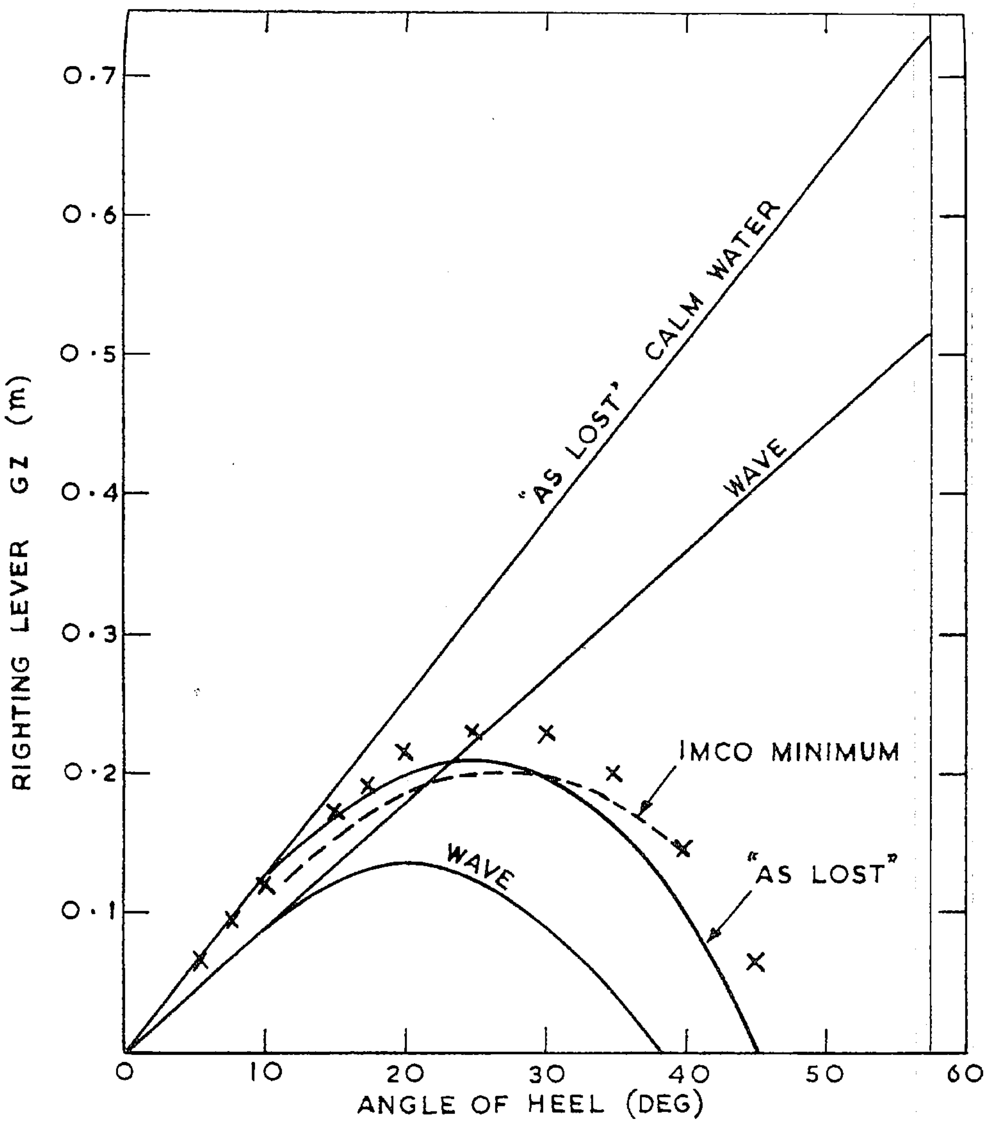
FIG. 9

FIG. 9. BODY SECTIONS

TRIDENT ————

ROUND-STERN DESIGN — — — — —





STABILITY CHARACTERISTICS

	CALM WATER	IMCO MINIMUM	ON CREST OF WAVE
AREA 0-30° (m RAD)	0·075	0·055	0·05
AREA 0-40° (m RAD)	0·10	0·09	0·057
AREA 30°-40° (m RAD)	0·026	0·03	0·007
MAX GZ (m)	0·21 AT 24°	NOT STATED	0·14 AT 20°
GZ AT 30° (m)	0·196	0·2	0·088

X MEASUREMENTS OBTAINED FROM GZ APPARATUS
(FOR "AS LOST" CONDITION IN CALM WATER)

FOR WAVE CURVE, TROCHOIDAL WAVE
(H = 4 m, L = 70 m) HAS BEEN ASSUMED

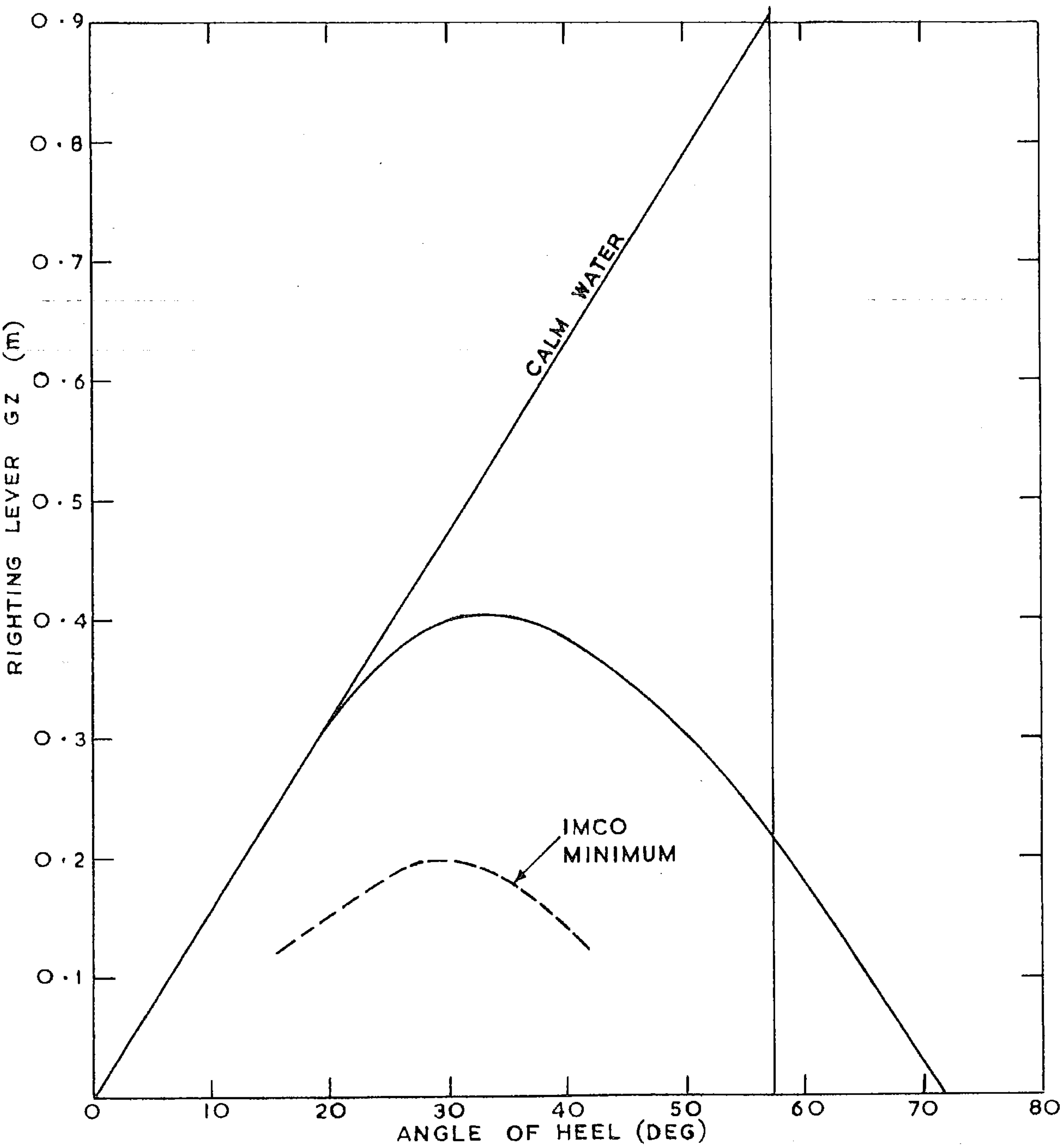
FIG. 10

STABILITY CURVES FOR TRIDENT

FIG. 11

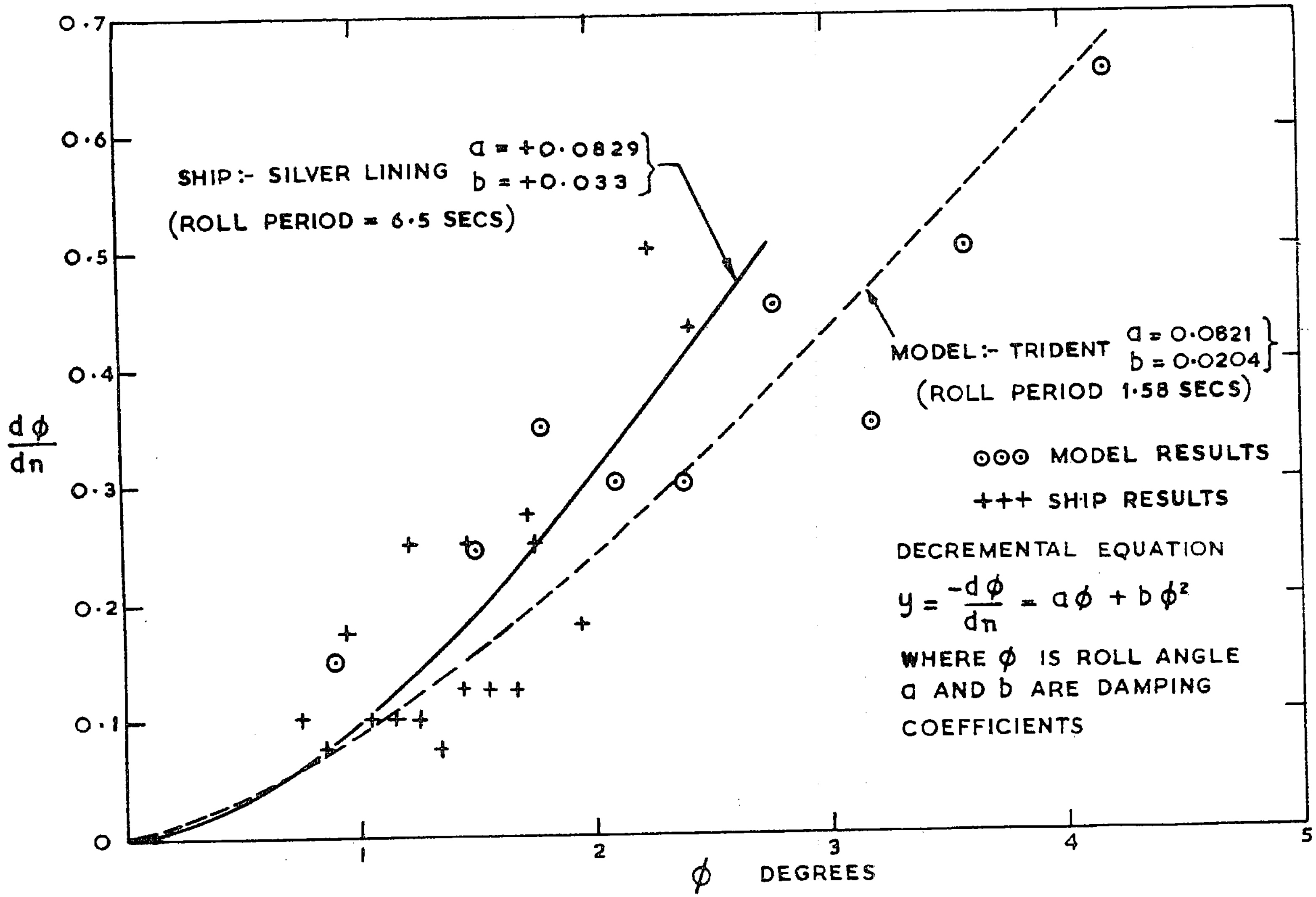
STABILITY CHARACTERISTICS

	CALM WATER	IMCO MINIMUM
AREA 0-30° (m RAD)	0·074	0·055
AREA 0-40° (m RAD)	0·126	0·09
AREA 30-40° (m RAD)	0·052	0·03
MAX GZ (m)	0·405	NOT STATED
GZ AT 30° (m)	0·399	0·2



STABILITY CURVES FOR ROUND-STERN DESIGN

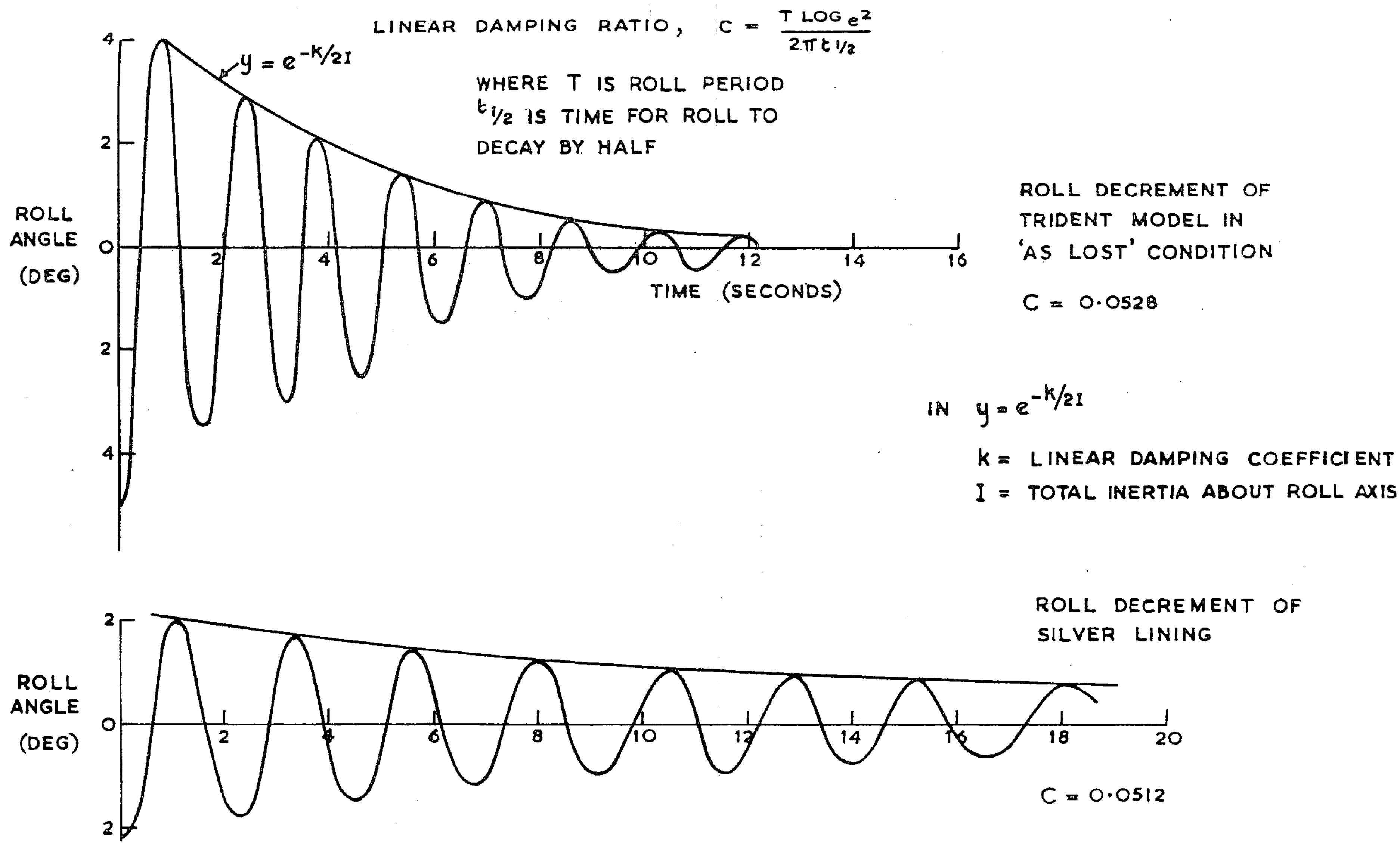
PROJECT N° 23·41



ROLL DAMPING COEFFICIENTS FOR SHIP AND MODEL

FIG. 12

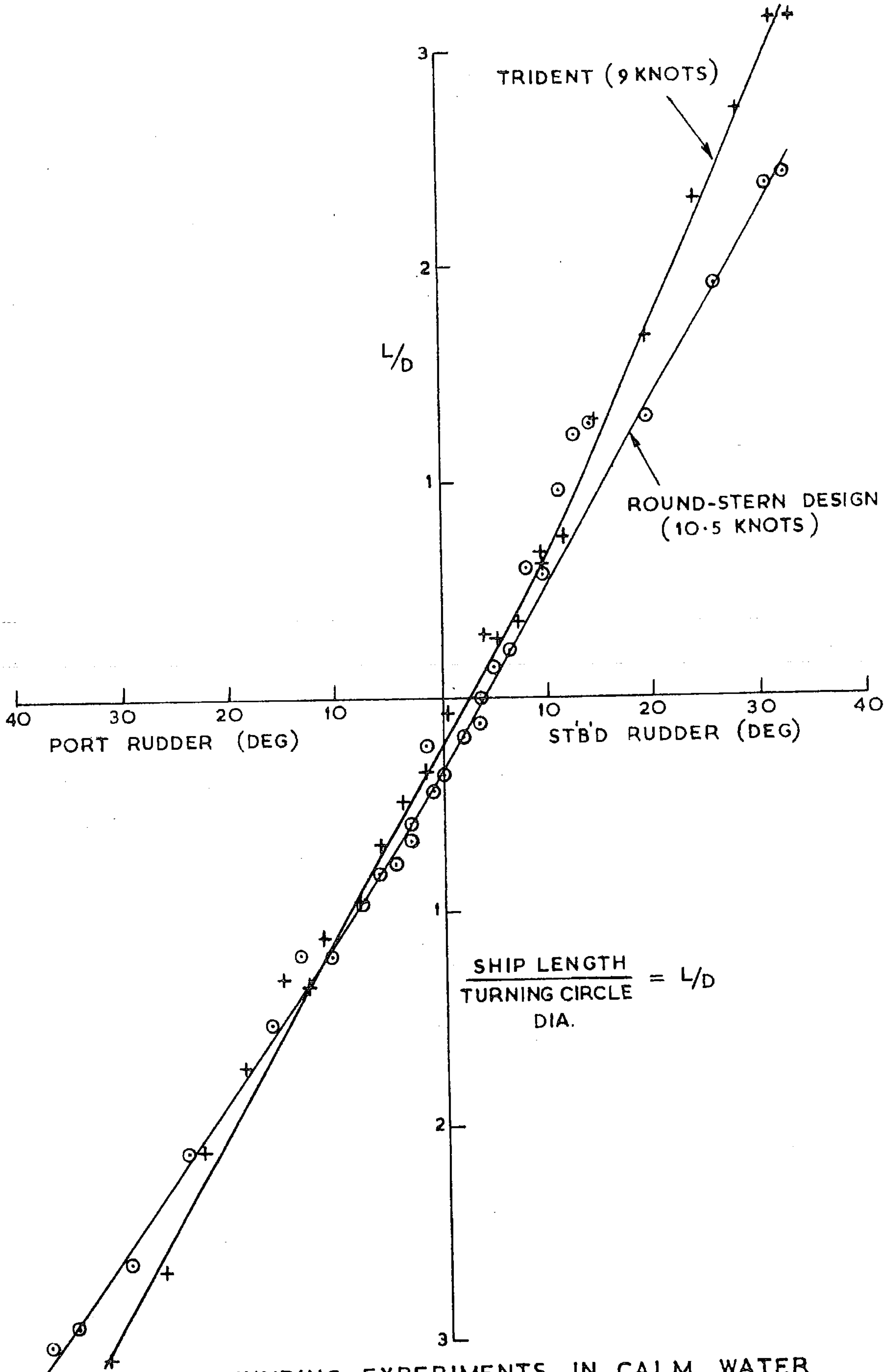
PROJECT N° 23·41



ROLL DECREMENT CURVES FOR SHIP AND MODEL

FIG. 13

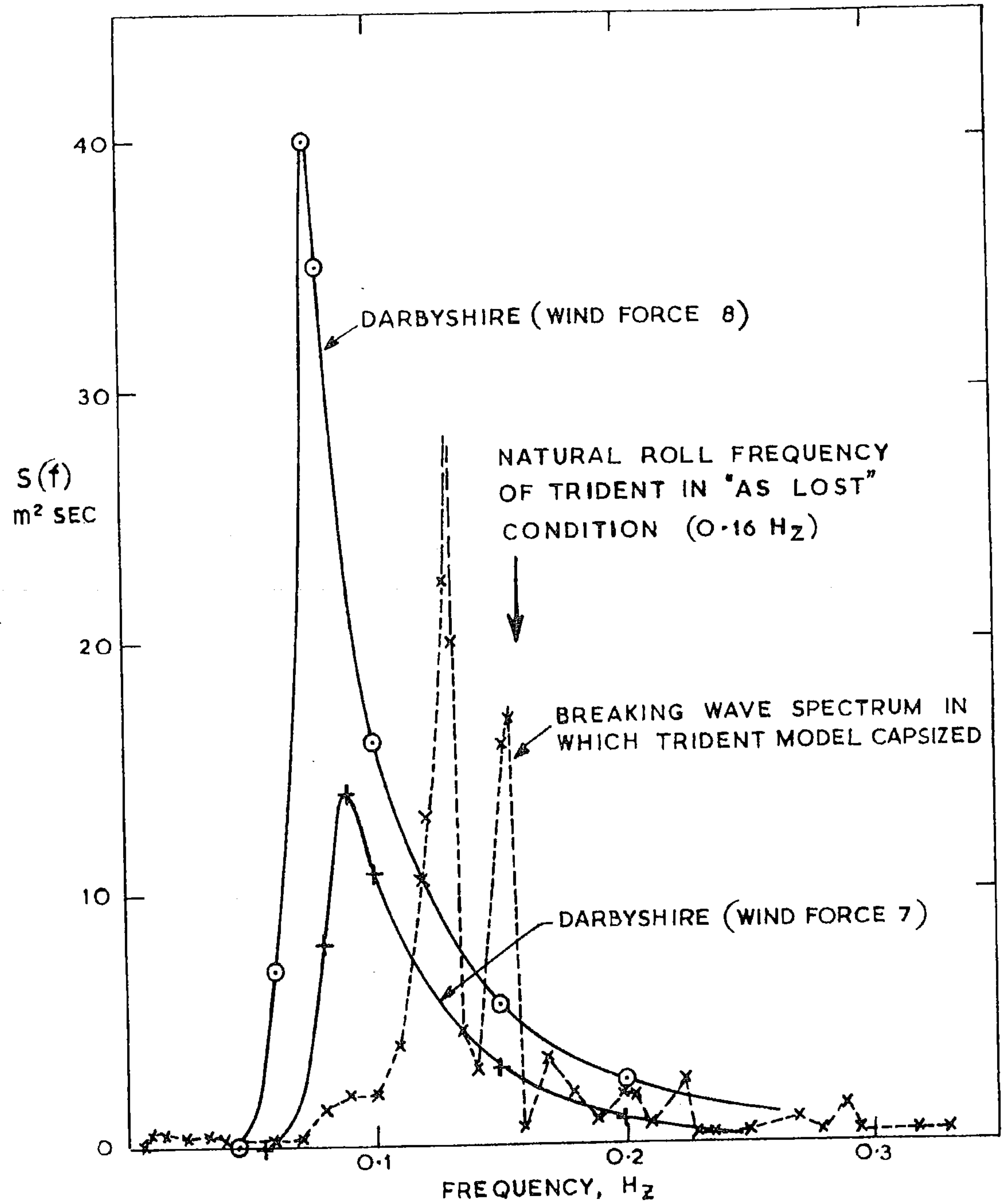
FIG. 14



MANOEUVRING EXPERIMENTS IN CALM WATER

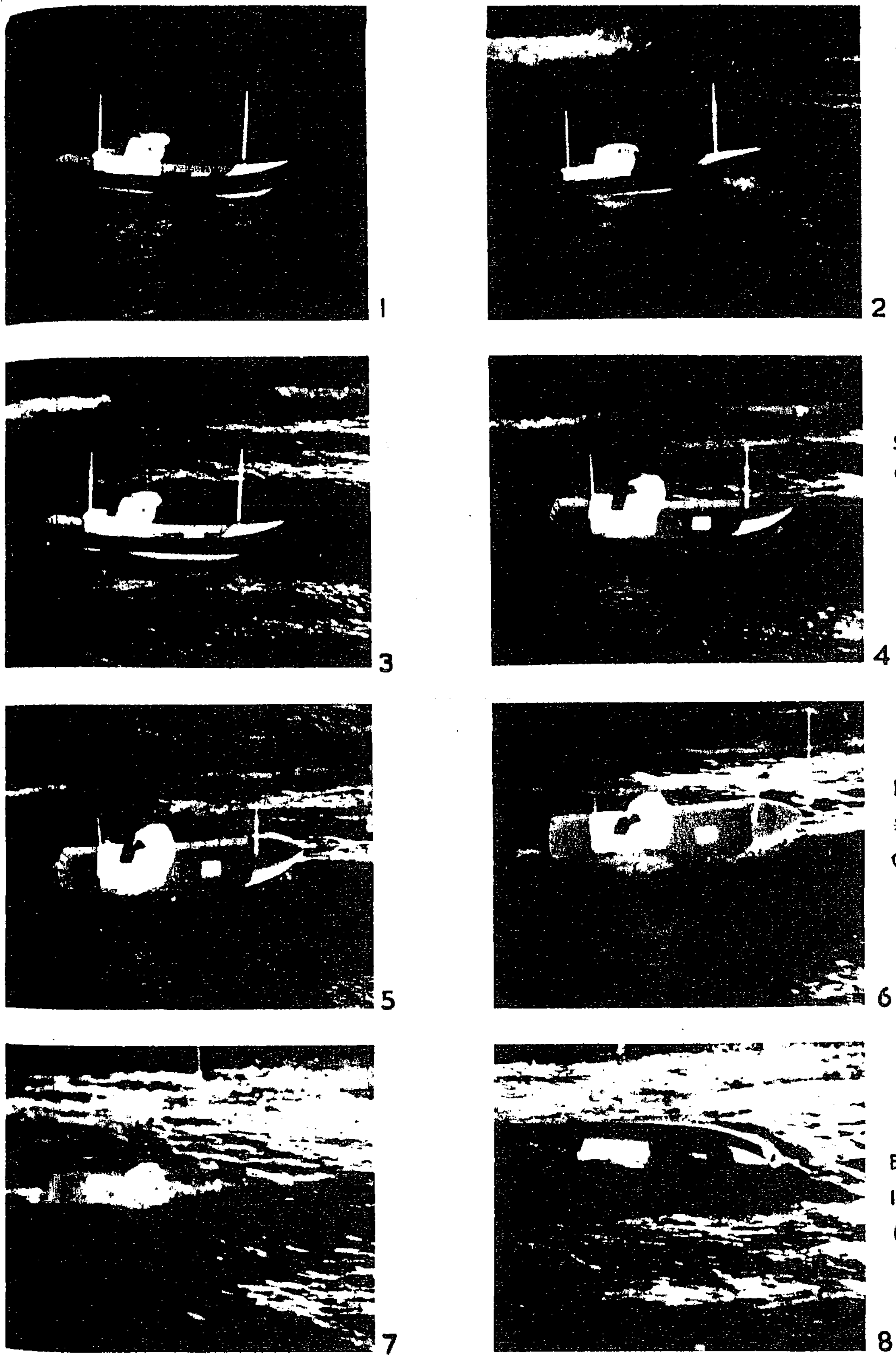
RATIO OF SHIPS LENGTH TO TURNING CIRCLE DIAMETER

PROJECT Nº 23·41



WAVE ENERGY SPECTRA

FIG.16



STERN QUARTERING SEAS

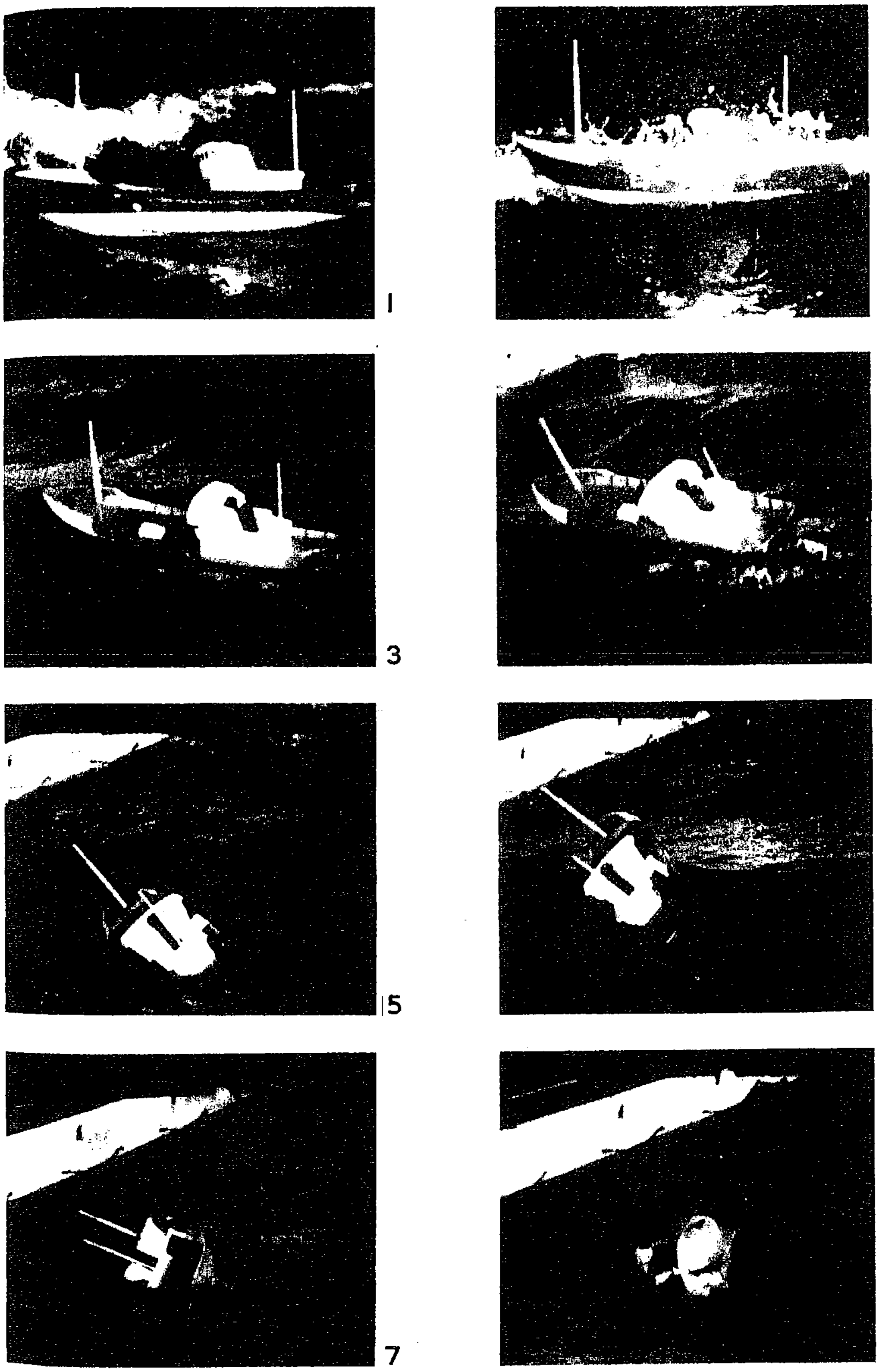
MODEL LOSING STABILITY ON CREST OF WAVE

ELAPSED TIME 13 SECONDS (FULL SCALE)

TRIDENT MODEL CAPSIZING WITH NO WATER ON DECK

PROJECT N° 23·41

FIG.17



1, 2: BEAM TO SEA

(MODEL STRUCK BY BREAKING WAVE)

3, 4: SOME WATER ESCAPING FROM FREEING PORTS

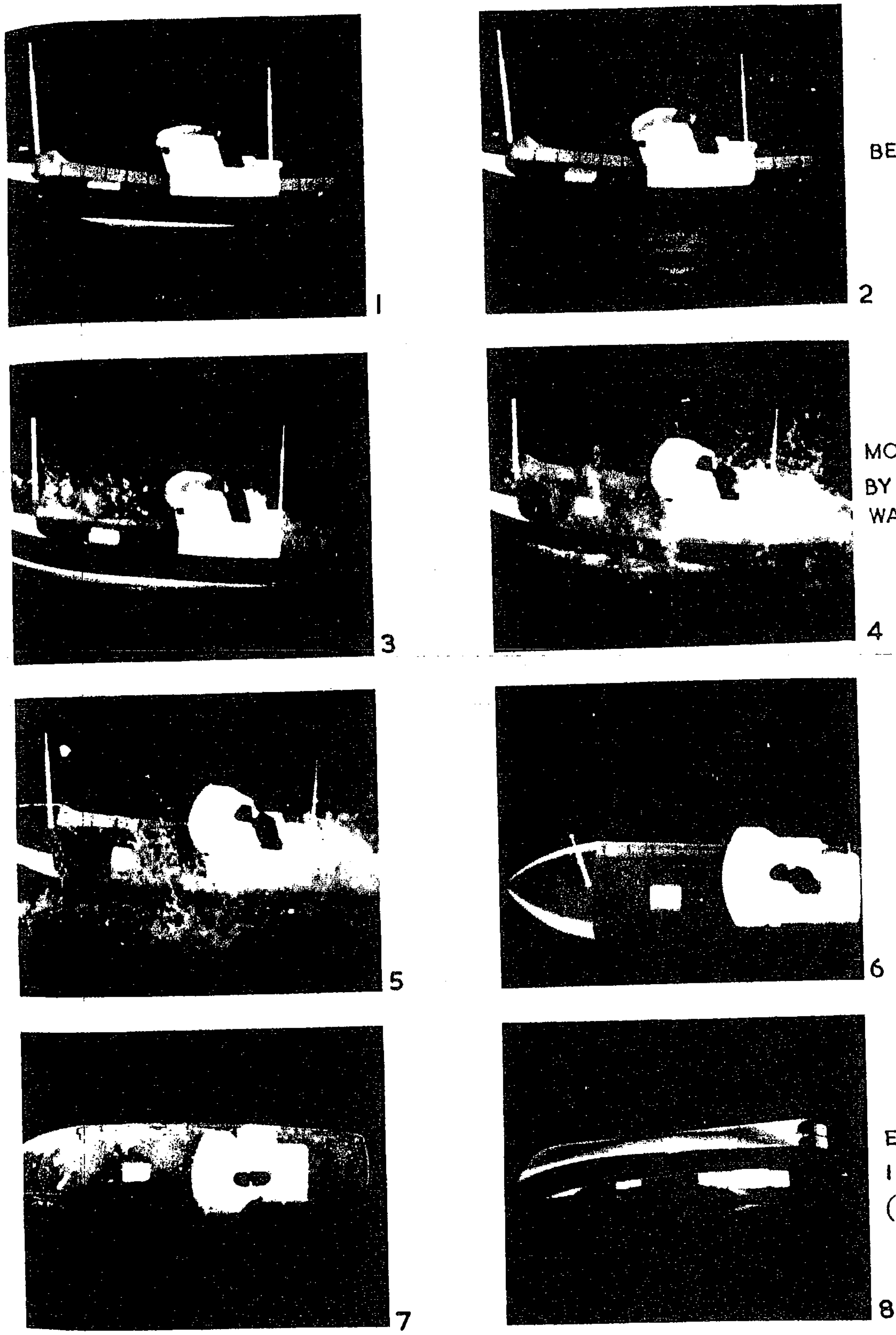
5, 6

7, 8: ELAPSED TIME 17 SECONDS (FULL SCALE)

TRIDENT MODEL CAPSIZING SHORTLY AFTER TAKING WATER OVER BULWARKS

PROJECT Nº 23·41

FIG 18



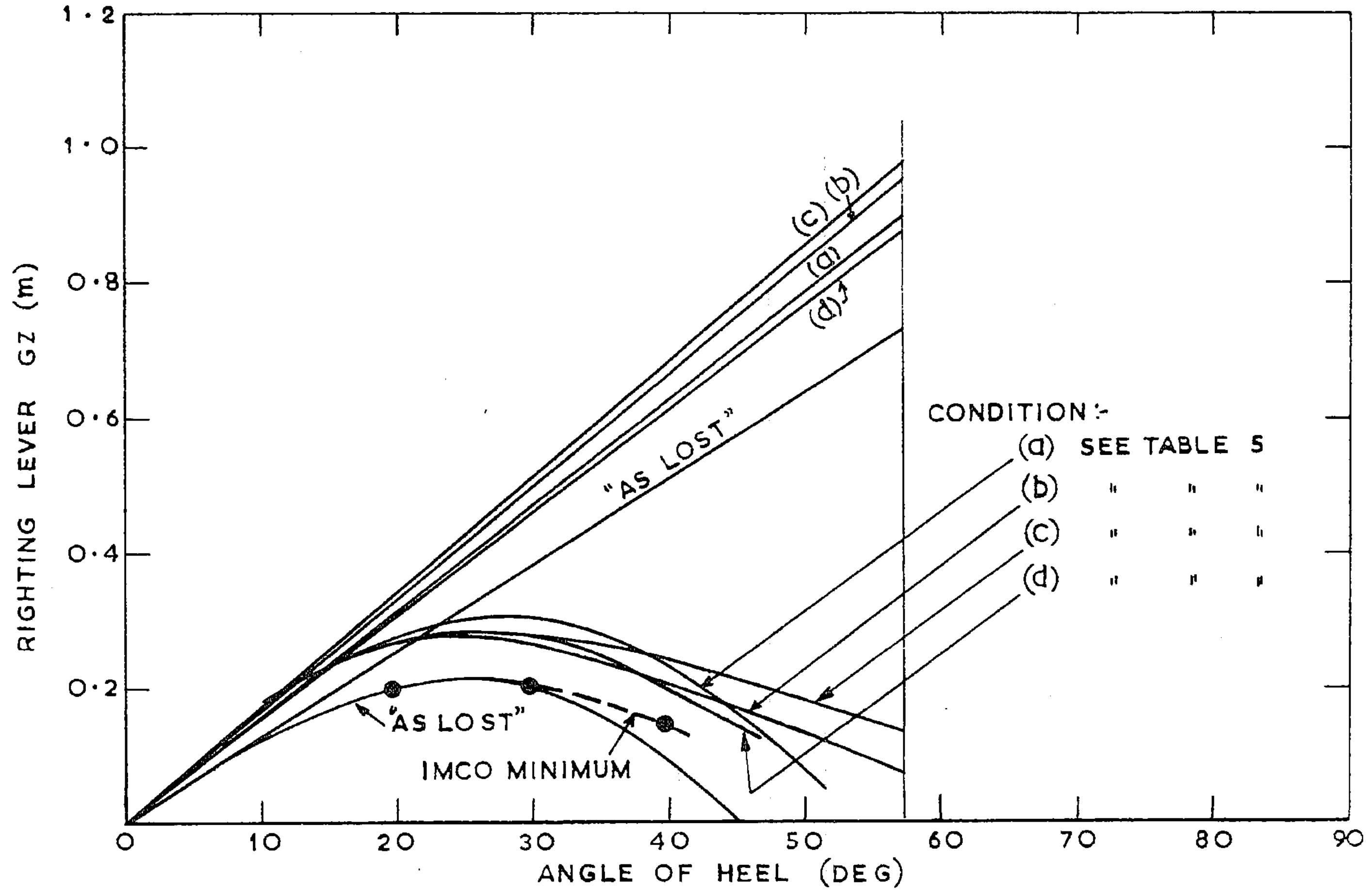
BEAM TO SEA

MODEL STRUCK BY BREAKING WAVE

ELAPSED TIME 12 SECONDS (FULL SCALE)

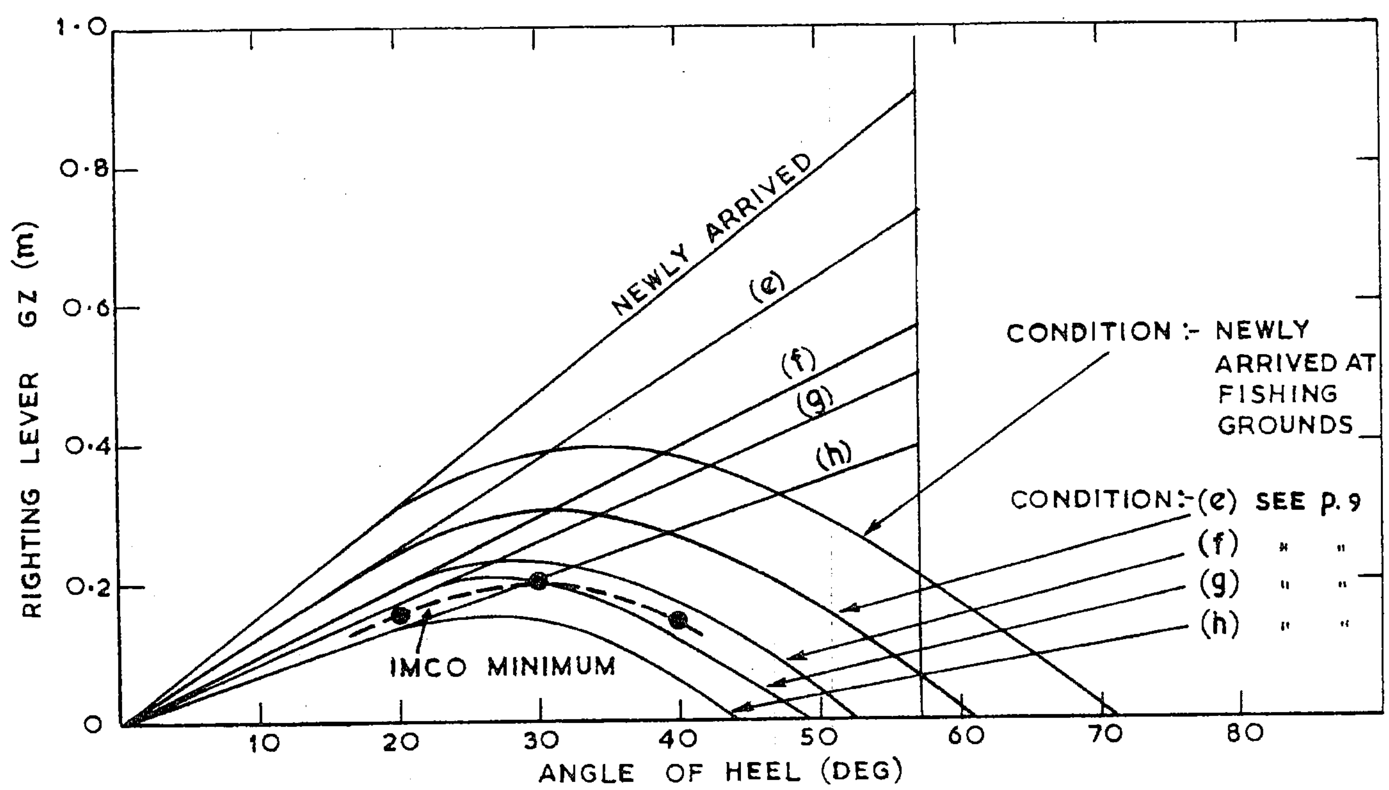
TRIDENT MODEL CAPSIZING WHILST HOLDING STATION IN BEAM SEAS

PROJECT N° 23·41



STABILITY CURVES — TRIDENT

FIG. 20



STABILITY CURVES — ROUND-STERN DESIGN

PROJECT Nº 23·41