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Comparison of Proposed Stability Criteria with the Results of Model Tests

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Comparison of Proposed Stability Criteria with the Results of Model Tests.

This report contains the results of a series of capsizing tests with a fishing vessel. The outcomes of the tests are compared with the requirements contained in Regulations 2 and 4 of Chapter IV of the Draft Text of the 1977 Convention as given in IMCO Document PFV XIX/2/4.

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1. Introduction

The mechanism of capsizing of ships in waves is not yet fully understood. Therefore stability criteria can be determined on an empirical base only. For that purpose ship characteristics as e.g. righting levers, differences between the righting levers and the levers of heeling moments, areas under the righting lever curve etc. have to be defined which are supposed to assume different values for ships which are safe or unsafe with regard to capsizing. In order to judge the discriminating efficiency of such criteria information on the real behaviour of ships is necessary. It can be get from the casuality history of ships as well as from model experiments. Information on real ships has the advantage to include - at least in principle - realistic combinations of all capsize hazards. But practically it is impossible to get sufficient full scale data for a systematic investigation of stability criteria. Capsizing experiments with ship models are necessarily restricted to less realistic situations but can provide systematic information on the relationship between ship characteristics and occurrence or non-occurrence of capsizing in defined situations. Therefore they are suited to define efficient measures of stability rather than the required level of such measures. It seems that the combined use of model experiments and full scale information is the best way to develop criteria for the safety against capsizing: the first to establish formulations for the criteria, the latter to determine a sufficient level of safety.

In this paper stability criteria contained in Chapter IV of the draft text of an International Convention for the Safety of Fishing Vessels (IMCO-Documents PFV XIX/2/4 and PFV XVI/8) are compared with the results of model tests in order to state their relevance with respect to a situation which relatively often has been observed at actual casualties.

2. Investigated Capsize Situation and Ship Conditions.

The model tests have been carried out with the model of a fishing vessel operating in long-crested irregular quartering waves at a Froude number of about 0.3. The sea-state has been kept constant during the whole test series. The model was investigated at three freeboards (created by draft variation at unchanged depth) and with three variants of the deck well (1. completely free deck aft of the forecastle; 2. with a transverse squared volume body extending from side to side in the middle of the deck aft of the forecastle and 3. with a longitudinal squared volume body not extending from side to side; the area covered by the volume body was about 20 % of the free deck area in both cases). For each freeboard and each variant of the deck well the GM-value has been varied in order to determine the limiting values at which just capsizing occurs.

Details of the model, of the waves and of the testing procedure as well as information on each of 128 runs are given in the Appendix.

3. Results of Capsizing Tests.

Capsizing of ships in irregular seas is a random event. Therefore the safety against capsizing should be stated in terms of probability. Because of the big number of runs that would have been necessary to determine significant values of the probability of capsizing the decision whether a model is to be considered safe or unsafe against capsizing was based on its behaviour during several runs: A model condition was labelled "safe" if the model did not capsize in a series of four to eight runs. It was labelled "unsafe" when capsizing did occur.

In Fig. 1 the lowest righting arm curves of "safe" cases and the highest righting arm curves of "unsafe" cases are shown. In the following the curves of the "safe" cases are taken as capsize limits. This choice has been made because righting levers derived by interpolation between those of unsafe and safe cases would not have differed much from the chosen levers. It should also be kept in mind, that the tests did not include heeling moments from wind or gusts. Therefore acutal stability criteria should be based on even higher righting levers. In spite of this fact it seems fully justified to use the capsize limits for comparisons of the investigated model conditions.

It can be seen from Fig. 1 that the righting arms which are necessary to prevent capsizing increase with increasing freeboard (or decreasing draft). This holds for the ship with free deck area behind the forecastle as well as for the ship with volume bodies on the deck. The ship where the volume body on deck extends from side to side needs higher righting levers in order to be safe than the ship without or with a longitudinal volume body. There is no significant difference in the righting levers of the ship with free decks and of the ship with the longitudinally arranged volume body on deck.

4. Comparison of Proposed Stability Criteria with the Results of Model Tests.

For the capsize situation for which the model tests have been carried out only Regulations 2 and 4 of Chapter IV - Stability - of the draft text of an International Convention for the Safety of Fishing Vessels (IMCO-Document PFV XIX/2/4) apply.

In Fig. 2 the area under the righting lever curve up to 30^0 angle of heel as required in Regulation 2 (1) (a) is compared with the corresponding values which have been found necessary in the model tests in order to prevent capsizing. It can be seen that compliance with the requirement of the Regulation would not prevent capsizing in all investigated cases. The same holds with respect to the area under the righting lever curve up to 40^0 angle of heel as can be seen from Fig. 3.

When considering the curves derived from the model tests in Fig.2 and 3 it should be kept in mind that they do not provide any allowance for wind heel and other influences not present in the model tests. If an allowance for influences not present in the model tests is made, the requirements of Regulation 2 (1) (a) can be considered sufficient for cases with low freeboard (or deep draught) only.

A comparison of the required righting lever at an angle of heel of 30^0 according to the model tests on the one hand and according to Regulation 2 (1) (b) on the other hand is shown in Fig. 4. For small freeboards the righting lever required by the Regulation seems to provide a sufficient safety margin; but this margin decreases with increasing freeboard.

The provision of Regulation 2 (1) (c) with respect to the angle of heel at which the maximum righting lever shall occur is more severe than has been found necessary in the tests for the cases with low freeboard. But it hardly suffices in the low draft conditions.

The GM requirement in Regulation 2 (1) (d) is far below what has been found necessary in the model tests.

Regulation 4 requires that every vessel shall be able to withstand the effect of water on deck to the satisfaction of theAdministration. As guidance for the investigation of this effect the method described in PFV XVI/8, Annex II p. 47/50 has been used. The levers GZ_W of the heeling moment due to water on deck determined according to this method are shown in Fig. 5. There is not much difference between the heeling levers GZ_W for the case without and with a longitudinal volume body on deck. As to be expected the minimum righting levers necessary to prevent capsizing are about the same for both these cases. The heeling levers GZ_W for the case with the transverse volume body on deck are significantly lower than those for the other two cases. The corresponding minimum righting levers however are higher than those for the other two cases. This unlogical result can only be explained by the fact that the method for the determination of the heeling moment due to water on deck is not realistic enough. The same conclusion is reached if the difference between the area under the righting lever curve up to 40^0 angle of heel and the area under the heeling lever curve is considered (this difference is equal to the area under the righting lever curve between the dynamic heeling angle due to water on deck and 40^0 angle of heel). Fig. 6 shows that the excess area under the righting lever curve which is necessary to prevent capsizing is much higher in the case with the transverse volume body on deck than in the cases without or with the longitudinal volume body on deck. Therefore, the proposed method is - at least for the investigated capsizing situation - not suited to take account of the effect of water on deck.

5. Conclusions

- Regulation 2 (1) (a) and (b) does not provide sufficient safety against capsizing in cases of high freeboard (or low draught). As yet it is not possible to state the limits of applicability of these requirements. For vessels similar to the investigated one some information on the dependency of the stability criteria on the freeboard can be taken from the test results reported above.
- The GM requirements of Regulation 2 (1) (d) do not directly influence the safety against capsizing. But they limit the initial heel due to wind or other moments and may thereby prevent the generation of situations from which it is more likely that a ship capsizes. In this connection it does not make sense that the GM can be reduced for vessels with complete superstructure (for which the heeling moment due to wind is usually higher than for a single deck vessel).
- With respect to Regulation 4 - Effect of water on deck - it has to be stated that at the time being, no method is available to judge reliably the effect of water on deck. Therefore, it is not possible to demonstrate compliance with this regulation. As a consequence this regulation should be deleted.

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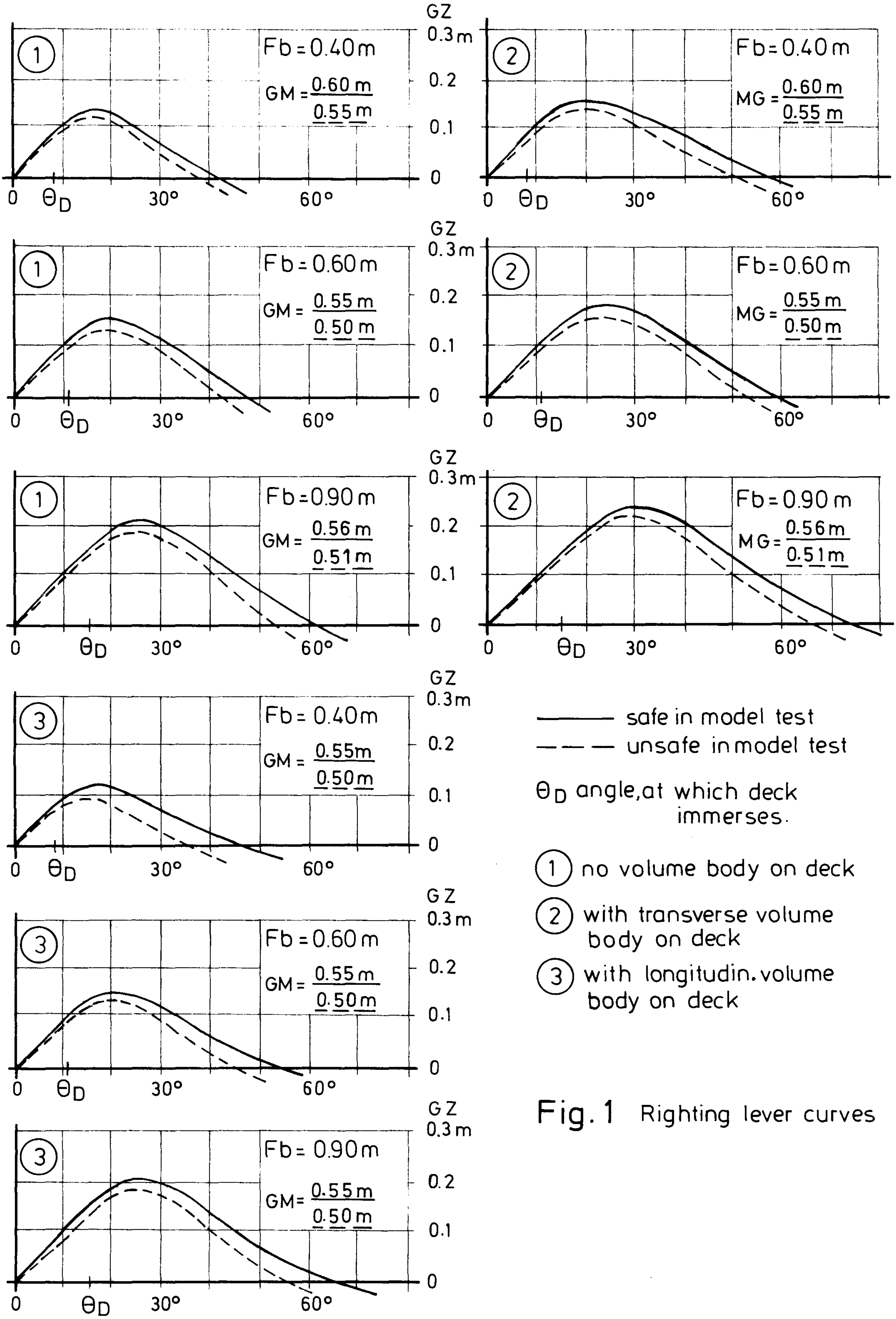


Fig. 1 Righting lever curves

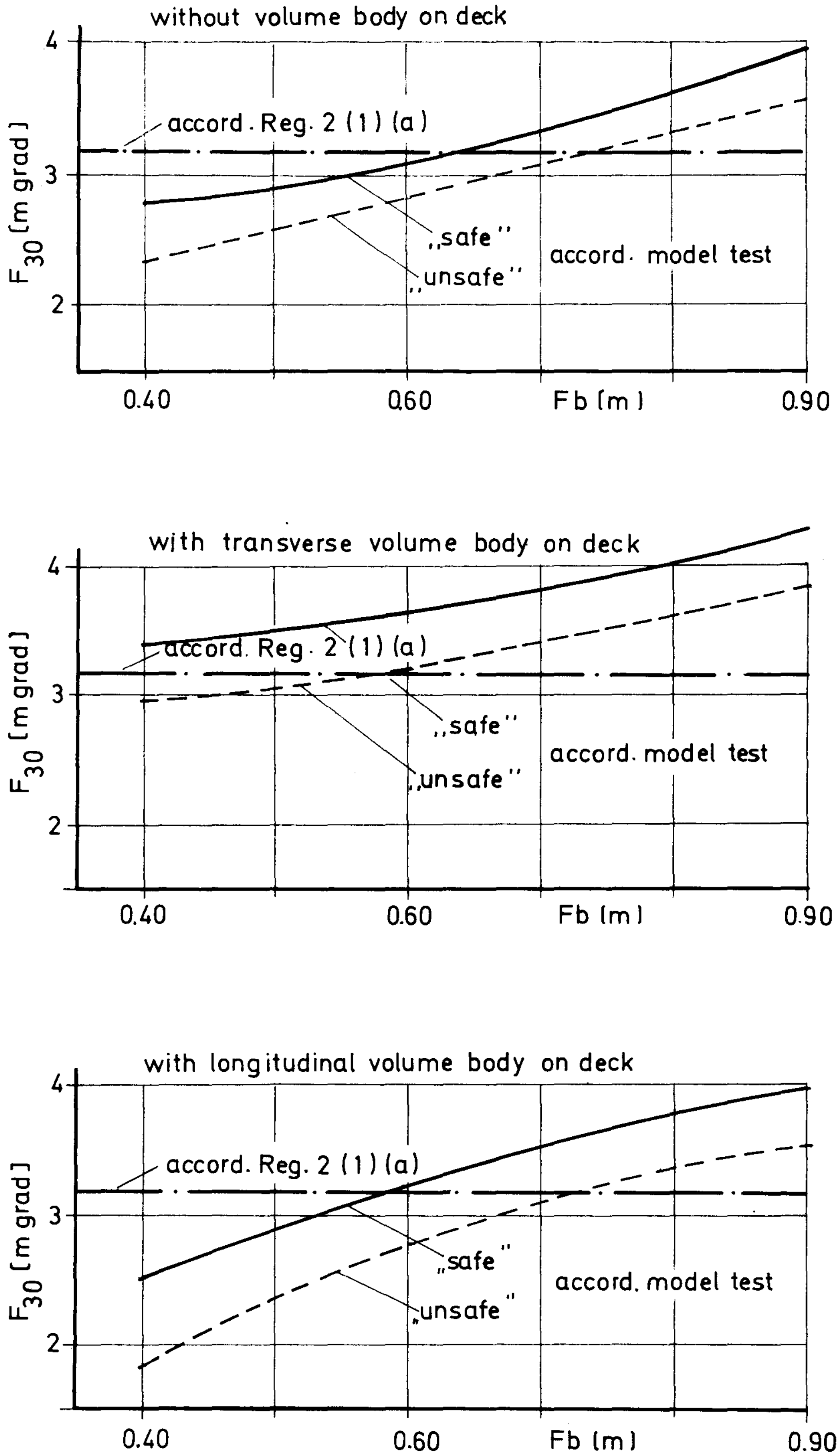
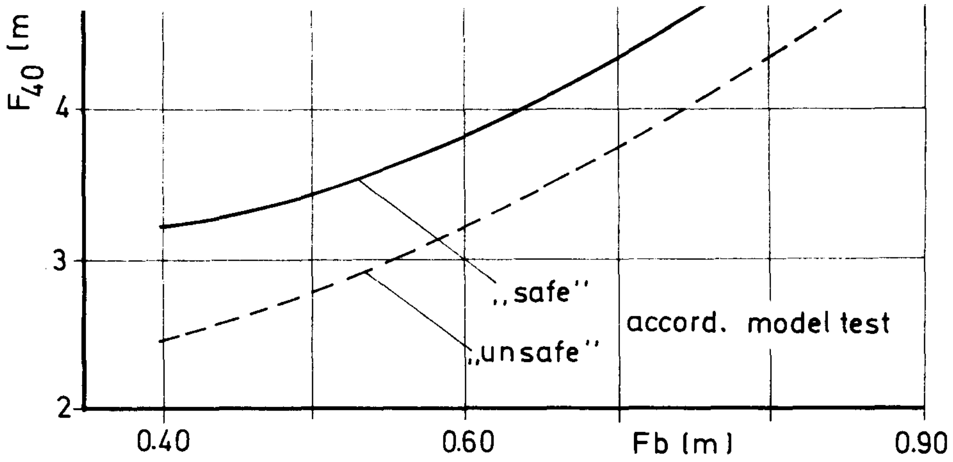
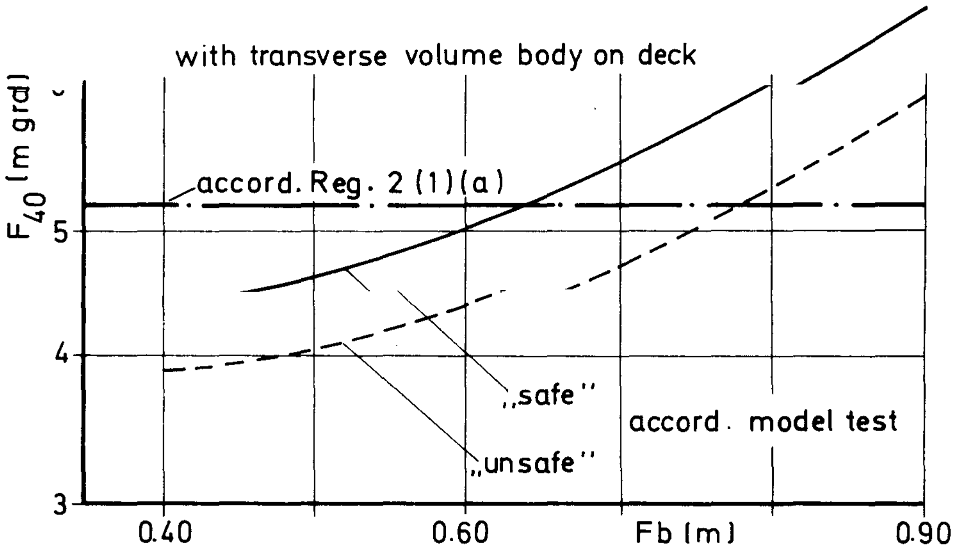


Fig. 2 Required area under righting lever curve up to $\theta = 30°$





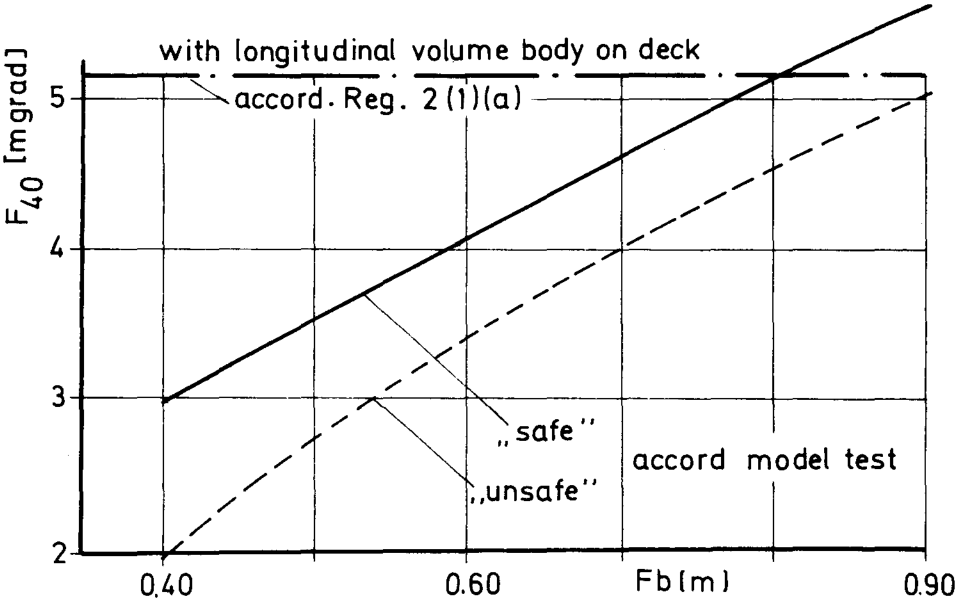


Fig. 3 Required area under righting lever curve up to $\Theta = 40°$

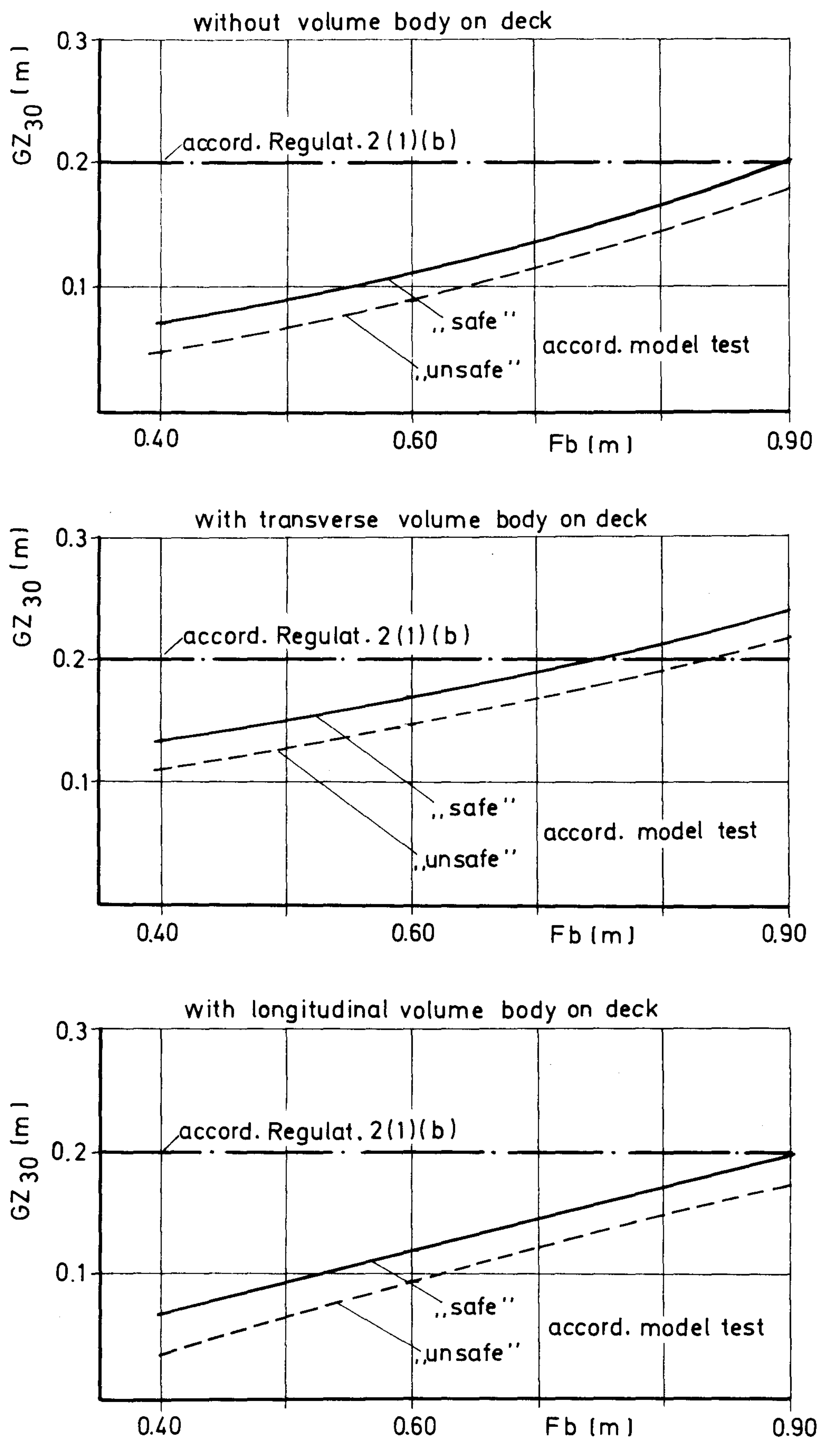


Fig. 4 Required GZ at $\Theta = 30°$

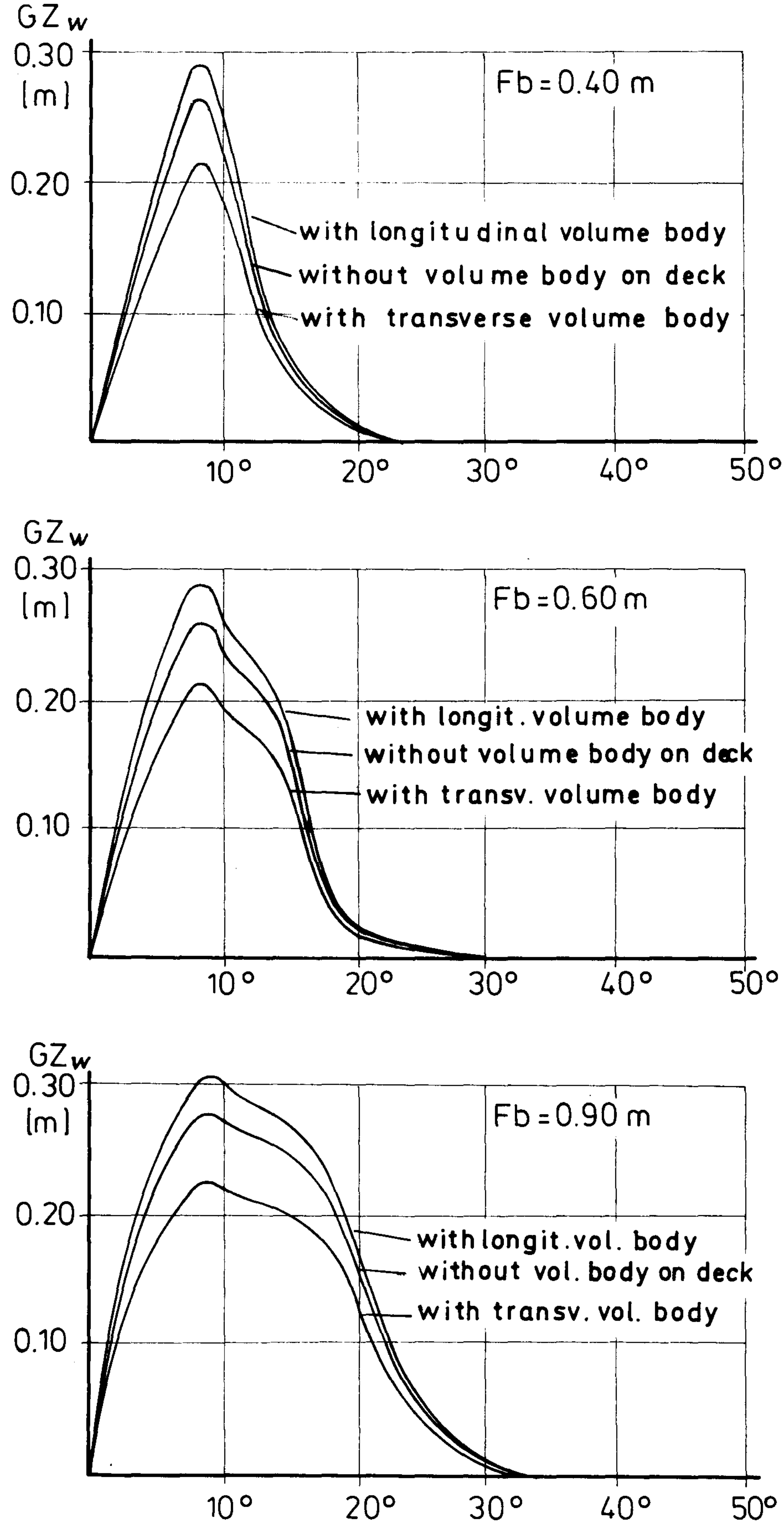


Fig. 5 Heeling lever curves due to water on deck (accord. IMCO-proposal)

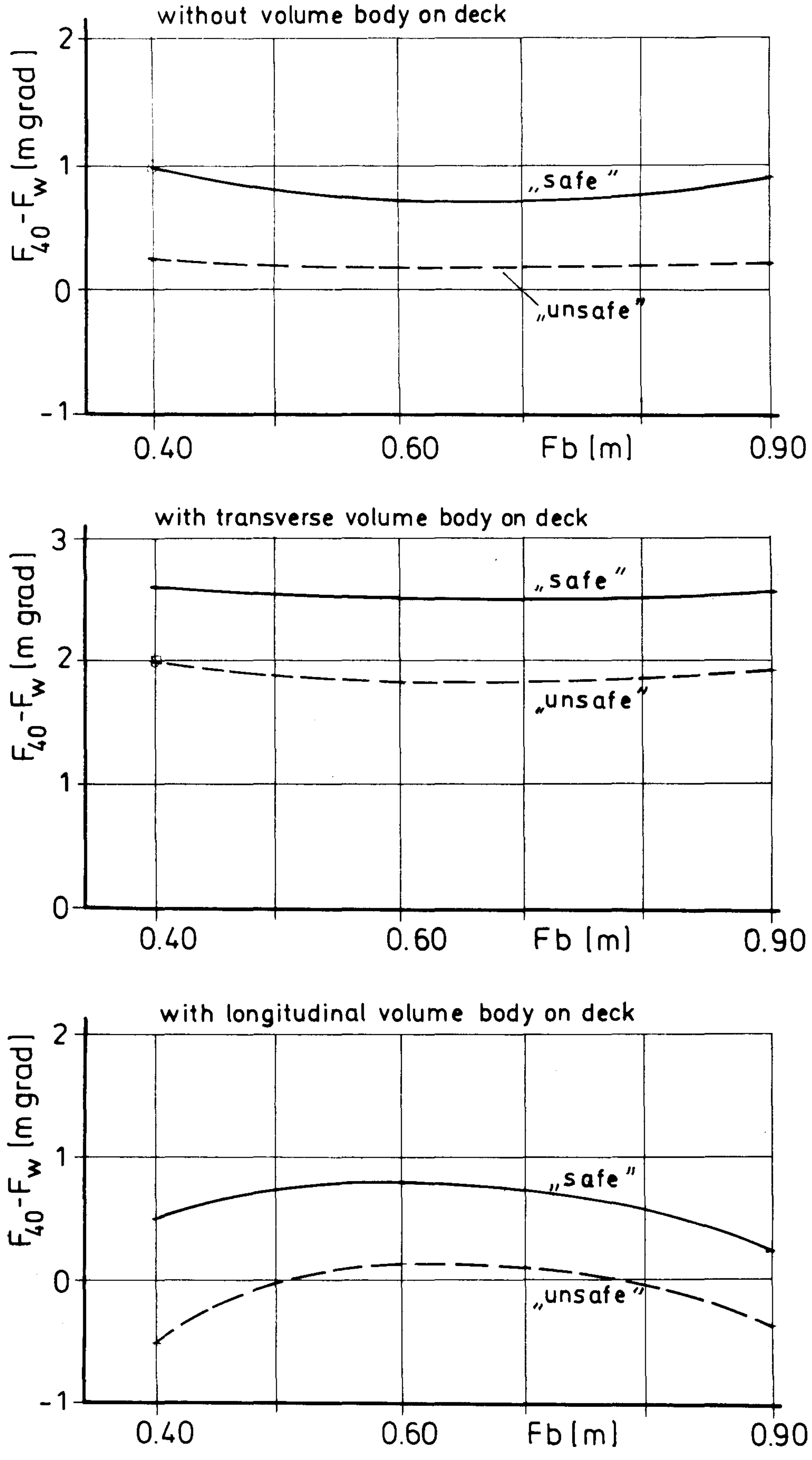


Fig. 6 Difference area between area under righting lever curve up to $\theta = 40°$ and under heeling lever curve

Seakeeping Tests with the Model of a 30 m Cutter carried out in the Hamburgische Schiffbau-Versuchsanstalt GmbH. (Hamburg Ship Model Basin Ltd.)

Contents :

1. Ship data, model Nr. 2651 (ex. 1603)

Length o.a.	30.00 m
Length in the CWL	27.38 m
Length b.p.	26.00 m
Beam mld.	6.80 m
Hight of the bulwark	0.75 m
Area of freeing ports on each side (corresponding to IMCO-Rules : 1.27 m^2)	6 x 0.217 = 1.272 m^2
Longitudinal gy-radius	0.252 .L b.p.
Bilge keels length	10.4 m
width	0.3 m

Ship condition I

Freeboard	0.40 m
Draught related to top of keel (0.35 m above base line)	
before	2.62 m
midship	3.00 m
aft	3.38 m
Volume of displacement	271.50 m^3

Ship condition II

Freeboard	0.60 m
Draught before	2.42 m
midship	2.80 m
aft	3.18 m
Volume of displacement	242.16 m^3

Ship condition III

Freeboard		0.90 m
Draught	before	2.12 m
	midship	2.50 m
	aft	2.88 m
Volume of displacement		200.15 m^3

Metacentric heights GM_o for the three ship conditions are given in table No. 2 (survey of trials) page 6 and in the tables page 10 to 38.

Length of the deck behind the forecastle	22.50 m
Area of the deck behind the forecastle	143.50 m^2 ($=A_o$)

Transverse volume body (volume body I)

Breadth (from side to side)	6.80 m
length	4.20 m
height	0.75 m
area (=19.90 % of A_o)	28.56 m^2
Length of the deck in front of volume body I	8.67 m
behind volume body I	9.63 m

Longitudinal volume body (volume body II)

Breadth	3.15 m
length	9.00 m
height	0.75 m
area (= 19.76 % of A_o)	28.35 m^2
length of the deck in front of volume body II	6.27 m
behind volume body II	9.63 m

- 4 -

Forecastle in all cases closed

Propeller data propeller model No. 1198

Diameter D	2000 mm
Pitch P	1500 mm
Pitch ratio P/D	0.75 m
Disc area ratio	0.40
Blade number	4

model scale 1 : 9

Side view of the cutter see Fig. A 1

Body plan see Fig. A 2

2. Procedure of Tests and Measuring Technique

The self-propelled model was hand operated by a helmsman being accommodated on a subcarriage, which can move across the basin in front of the main carriage.
The model was connected to the control platform by light and flexible "fishing line" cables to supply the electric current to the propelling motor and to the steering engine and, in addition, to transmit the telemeasured values from the model to the recorders carried on the sub-carriage. During the tests carriage and sub-carriage were following the model so, that the cables fall down vertically and did not influence the motions of the model.
The course actually steered was measured with the aid of a gyroscope fitted to the model and recorded on a luminous point recorder (visicorder) together with the rolling motions measured by means of a built-in horizontal gyro.
During the tests a propeller speed was chosen which provided a corresponding ship's speed of about 9,5 knots in calm water.

All tests were carried out in a irregular seaway which occurs in the Northsea at wind forces of abt. Beaufort 8 to 9. The wave heights and periods of the sea conditions are given in the following Table No. 1

Mean wave height	3.50 m
Significant wave height	4.70 m
Maximum wave height	6.60 m
Mean wave period	7.0 s
Significant wave period	7.9 s
Maximum wave period	9.1 s

Table No. 1

Data of the (full scale) seaway for the tests

The tests were carried out mainly on courses of 30^{o} (thereby means course 0^{o} stern sea and 180^{o} head sea). Because of the large heeling angles mainly of the model with small GM_{o} - values greater course deflections could occasionally not be avoided.

For a more reliable statement whether the model is endangered or not a greater number of test runs were carried out as originally intended. Table No. 2 shows a survey of the tests carried out.

GM_o (cm)	Course (Degs)	Quantity of runs and run numbers (in brackets) without volume body on deck		with transverse volume body on deck		with longitudinal volume body on deck	
Freeboard 0.90 m		**Volume of displacement 200.15 m^3**					
60	30	5	(49 to 53)	4	(54 to 57)	5	(58 to 62)
56	30	4	(29 to 32)	5	(33 to 36,80)		
56	180			1	(37)		
56	90			1	(37a)		
55	30					8	(63 to 70)
51	30	7	(22 to 28)	6	(15,16,18 to 21)		
51	0			1	(17)		
50	30					7	(71 to 77)
45	30	5	(4,5,7,8,9)	5	(10 to 14)	2	(78 to 79)
45	0	3	(1 to 3)				
45	90	1	(6)				
42	30			5	(81 to 85)		
Freeboard 0.60 m		**Volume of displacement 242.16 m^3**					
60	30	3	(86 to 88)				
55	30	4	(89 to 92)	4	(98 to 101)	3	(111 to 113)
50	30	5	(93 to 97)	4	(102 to 105)	5	(106 to 110)
45	30					3	(114 to 116)
Freeboard 0.40 m		**Volume of displacement 271.50 m^3**					
69.3	30	2	(40, 41)				
69.3	0	2	(38, 39)				
60	30	4	(42 to 45)	4	(131 to 134)		
55	30	3	(46 to 48)	2	(129 to 130)	4	(117 to 120)
50	30			3	(126 to 128)	5	(121 to 125)

Table No. 2

Test survey

3. Results

The results of all test runs are presented on pages 10 to 38, collected according to test groups. On these pages the following data are given:

1. the main data of the cutter
2. the actual righting arm courve of static stability (GZ over Θ)
3. the maximum heeling angle which has been found during the individual run
4. a judgement of the safety against capsizing
5. a short comment to the stability behaviour.

The data in the table are valid for courses of about 30° stern sea if not specially marked by *) and a footnote.

For the purpose of an objective judgement of the safety against capsizing, the area under the righting lever curve between the maximum angle of heel (which was measured for each run) and the vanishing point of the righting lever curve has been used. During former capsizing experiments**) a good correlation between the subjective judgement of the danger of capsizing and this area which is proportional to the remaining working capacity has been found. This correlation is shown in the following Table No. 3. The judgements have been marked by numbers. This scale for judgement is also shown in the Table No. 3

Remaining working capacity (RW) in radian measure x righting arm (rad x cm)	Judgement	Scale
$7{,}5 < Rw$	not endangered	6
$6 < Rw \leqslant 7{,}5$	somewhat endangered	5
$5{,}5 < Rw \leqslant 6{,}0$	endangered	4
$3{,}0 < Rw \leqslant 4{,}5$	very endangered	3
$1{,}5 < Rw \leqslant 3{,}0$	very strong endangered	2
$0 < Rw \leqslant 1{,}5$	extremely endangered	1
---	capsized	0

Table No. 3

Scale for judgement

**) HSVA-Report S 57/74 "Untersuchung der Stabilität schneller Linienfrachter"

HSVA-Report S 62/74 "Stability of Supply Ships" Results presented by the Norwegian delegation to the IMCO in January 1975

Remark : The judgement on the basis of the remaining working capacity corresponded in about 2/3 of all runs to the subjective impressions gained during the tests concerning the danger of capsizing.
In one third of all runs the spontaneous judgement during the tests differed more or less from the later analysis.

Summary of the main test impressions

1. In all cases it was rather difficult to keep the course of the model. The difficulty of course keeping increased with decreasing initial stability. The model yawed strongly, heeled at smaller GM_o-value more leeward and threatened to get out of station in these cases.

2. The danger of broaching appeared to be greater for the model with the small draught than for the model with the larger draught. The model with the small draught appeared to be more a "plaything" during the overtaking through the powerful waves.

3. In general, surprisingly little water came onto the deck which run off quickly at the rerighting up of the model mostly over the back part of the bulwark, and the remaining water run through the freeing ports, which were dimensioned according to the IMCO-rules. The running off of the water appeared to be not so quickly with the transverse volume body on deck as at the model without or with the longitudinal volume body.
   Only in very few cases it was observed, that a small quantity of water gushed against the opposite bulwark at the change of the heeling direction.

4. With only few exceptions the capsizings turned out similarly. The stern was grasped by a high powerful wave, the model nearly broached, heeled strongly leeward, turned back to the original course and in the direction of the wave propagation respectively; and yet the model heeled even stronger and capsized.

5. At the same model condition and at the same sea condition the danger of capsizing was partly remarkably different. Even under omission of the less successful runs there was partly a relatively large spread of the danger of capsizing. Less succeful runs were

- 9 -

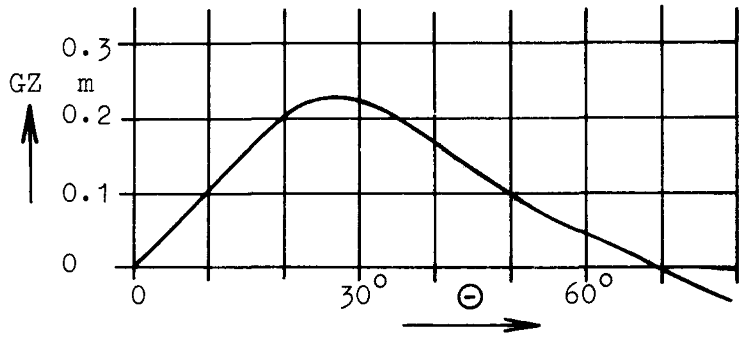
for instance:
tests in which the model did not encounter the high powerful waves,
tests where the high powerful waves were encounted near the wall of the basin,
tests where the cables tangled with the weight rod.
This spread might be caused by the imponderables concerning capsizing in model tests as well as at full scale.

6. In some cases the maximum heeling angle in the high powerful waves was partly much greater (up to 17^{o}!) than the point of vanishing stability in smooth water. Because these "over-angles" not only occurred when the model was in a wave trough there might have been hydrodynamic moments acting on the model which prevented the capsizing. (When the model is in a wave trough a greater stability is expected than in smooth water).

The fig. A 3 to A 14 show some traced records of the tests. For a better understanding of the given parts of the records the actual courses of the model over ground has been reconstructed from the course records and the actual headings of the model relative to the wave propagation has been drawn into the curves of overground course.
Fig. P 1 to P 7a show some photographs of the model in stern sea.

Ship data:

Freeboard	0.90 m
Draught	2.50 m
Displacement	200 m^3
GM_o	0.60 m
Natural roll period	6.07 s
Volume body on deck:	-



Run No.	49	50	51	52	53
Max. heeling angle (degs)	32	49	33	45	47
Remaining working capacity (rad · cm)	6.5	1.6	6.3	2.5	2.0
Judgement	5	2	5	2	2

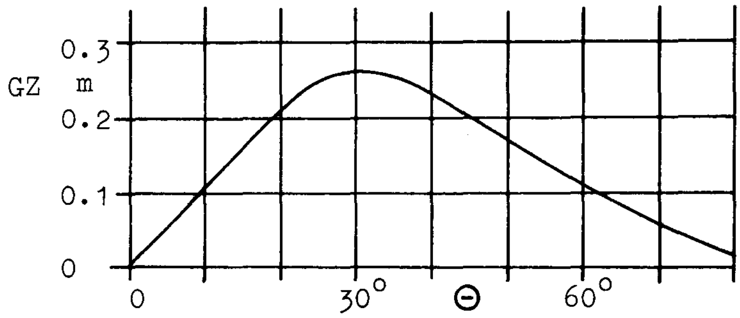
Ship behaviour with respect to stability

In general small to moderate, when passing the high breaking waves large yawing and rolling motions. Because the high powerful waves coming from behind firstly grasped the stern, the model threatened to broach. It heeled partly strongly leeward, water came on deck over the dipped bulwark but run off relatively quickly after righting up of the model.

In consequence of the one-sided increase of resistance caused by the heeling the model turned back comparatively quickly to the original course and even across it, respectively.

Ship data:

Freeboard 0.90 m
Draught 2.50 m
Displacement 200 m^3
GM_o 0.60 m
Natural roll period 6.10 s
Volume body on deck: transverse



Run No.	54*	55	56	57
Max. heeling angle (degs)	25	55	36	39
Remaining working capacity (rad · cm)	14.9	3.4	9.9	8.6
Judgement	6	3	6	6

Ship behaviour with respect to stability

*) Test did run not very good because only driven for a short time in the region of powerful waves.

During overtaking through the high breaking waves strong yawing motions and danger of broaching. Thereby partly large leeward heelings, water came onto the deck over the dipped lee-bulwark, spray also over the weather-side bulwark. At running off the water stopped in front of the volume body extended from side to side (the water appeared to run off not as well as at the model without volume body).

Ship data:

Freeboard 0.90 m

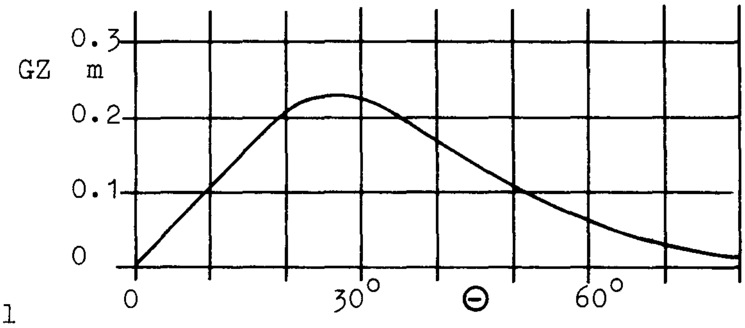
Draught 2.50 m

Displacement 200 m^3

GM_o 0.60 m

Natural roll period 6.08 s

Volume body on deck: longitudinal



Run No.	58	59	60*	61	62
Max. heeling angle (degs)	41	65	36	90	35
Remaining working capacity (rad · cm)	5.0	0.9	6.6	-	6.9
Judgement	4	1	5	0	5

Ship behaviour with respect to stability

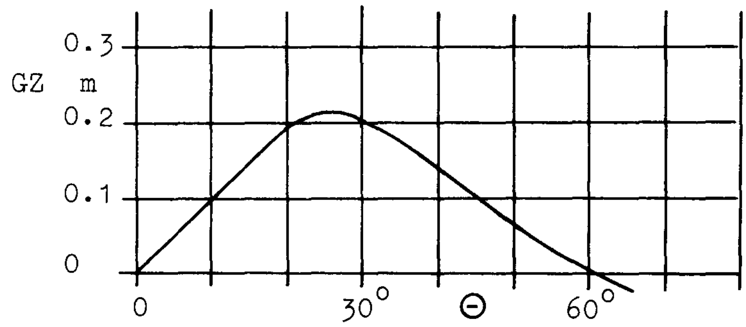
*) In the region of the powerful waves the model run only for a short time near the wall of the basin.

Passing the high powerful waves large yawing motions and partly very large leeward heelings occurred. At two runs (No. 59 and 61) the model was grasped by a very high breaking wave, it broached nearly and heeled very strongly leeward.

When turning back, in one case, the model was righting up to the original running direction. In the other case (run No. 61) the model persisted at a heeling angle of about 80°, turned into the wave direction under increasing of the heeling angle to about 90°, persisted also at this heeling for about 5 to 6 sec (full scale) and capsized to starboard.

Ship data:

Freeboard	0.90 m
Draught	2.50 m
Displacement	200 m^3
GM_o	0.56 m
Natural roll period	6.40 s
Volume body on deck:	-



Run No.	29	30	31	32
Max. heeling angle (degs)	34	45	60	56
Remaining working capacity (rad · cm)	4.1	1.3	~ 0	0.1
Judgement	3	1	1	1

Ship behaviour with respect to stability

When overtaking through high powerful waves large yawing motions and large, partly very large leeward heeling angles. The situations of risk of capsizing were always initiated through a high wave coming up from behind which grasped firstly the stern. Thereby the model broached nearly, the leeward heeling angle increased, the deck was dipped partly more than the midship, spray came over the weather-side of the model. Together with the passing of the powerful waves the model turned back into the direction of wave propagation (partly even more) and righted up again.

Ship data:

Freeboard 0.90 m

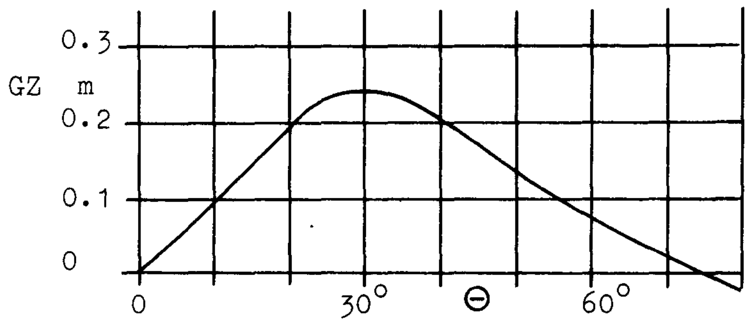
Draught 2.50 m

Displacement 200 m^3

GM_o 0.56 m

Natural roll period 6.42 s

Volume body on deck: transverse



Run No.	33	34	35	36	80	37*	37 a**
Max. heeling angle (degs)	58	47	47	38	43	25	16
Remaining working capacity (rad · cm)	1.3	3.6	3.6	6.6	4.7	11.9	15.0
Judgement	1	3	3	5	4	6	6

*) abt. 30° head sea **) abt. beam sea

Ship behaviour with respect to stability

Test runs in about 30° stern sea :

During overtaking through the higher waves larger yawing motions and larger leeward heeling angles. Partly, the model surged with the waves coming up from behind. When a high breaking wave grasped the stern the model threatened to broach. Thereby the model heeled partly strongly leeward, the deck dipped partly more than 50 %. At turning back to the direction of wave propagation the model righted up rather quickly and the water run off quickly. In some cases at large heeled model a water stagnation was observed in front of the volume body extended from side to side.

Test run in about 30° head sea :

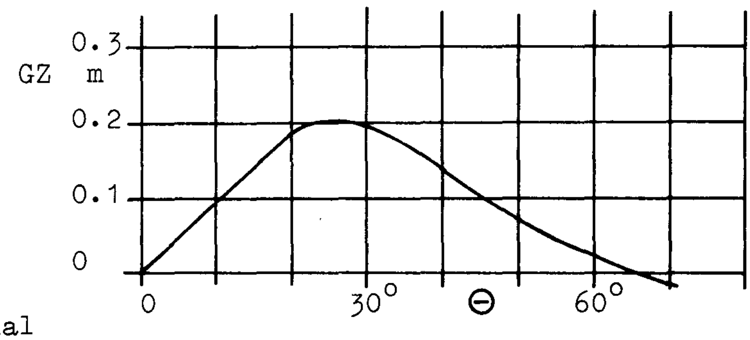
In general, only small to moderate rolling motions, at course alterations partly somewhat larger heeling angles. Practically no water on deck.

Beam sea, ship at rest :

Only small to moderate, in the high and breaking waves somewhat larger rolling motions and spray on deck.

Ship data:

Freeboard 0.90 m
Draught 2.50 m
Displacement 200 m^3
GM_o 0.55 m
Natural roll period 6.50 s
Volume body on deck: longitudinal



Run No.	63	64	65*	66	67	68*	69	70
Max. heeling angle (degs)	49	44	36	43	27	33	45	61
Remaining working capacity (rad · cm)	1.1	1.9	3.8	2.1	6.6	4.7	1.7	0.1
Judgement	1	2	3	2	5	4	2	1

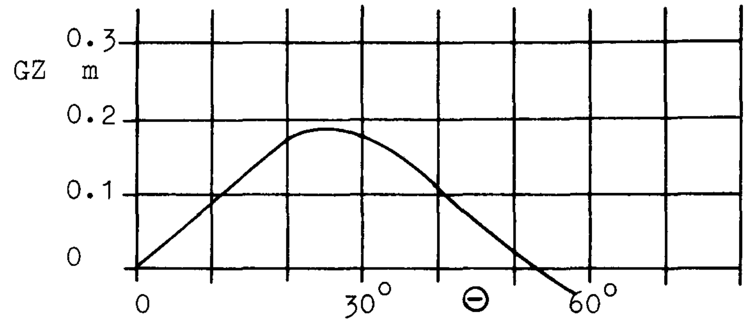
Ship behaviour with respect to stability

*) Model not run in the region of high powerful waves.

When running in the region of the high waves large yawing motions combined with large leeward heeling angles.
The largest heeling angles occurred when the stern was grasped by very high breaking waves, the model run out of the rudder and threatened to broach. During increase of the off-course also increasing of the heeling angle which was smaller when the model turned into the direction of the wave propagation. In one case (run No. 67) the model kept the course also when overtaking the powerful waves and heeled only relatively little leeward.

<u>Ship data:</u>

Freeboard	0.90 m
Draught	2.50 m
Displacement	200 m^3
GM_o	0.51 m
Natural roll period	6.81 s
Volume body on deck	-



Run No.	22	23	24	25	26	27	28
Max. heeling angle	59	48	41	> 90	40	38	> 90
Remaining working capacity (rad · cm)	- 0.2	0.2	1.2	-	1.3	1.6	-
Judgement	1	1	1	0	1	2	0

<u>Ship behaviour with respect to stability</u>

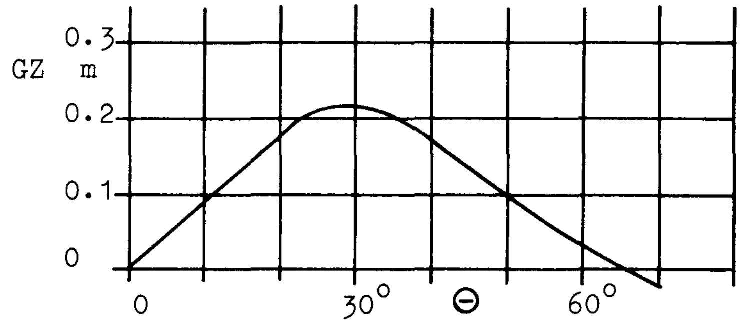
At running in the region of the higher waves larger yawing motions and partly large leeward heeling angles.
Also at this stability condition the largest heeling angles occurred when the stern was grasped by a very high wave, the model deviated from the course and threatened to broach.

At one case (run No. 25) the model capsized at broaching, in another case (run No. 28) the first high wave of a powerful group of waves initiated a large yawing motion (in derection to broaching) the model yawed back and was grasped by the next high breaking wave and capsized leeward ar broaching. During the increase of the capsizing angle beyond 90° the model turned into the direction of waves propagation.

It should be mentioned that in one case (run No. 22) the maximum heeling angle was larger than the statical capsizing angle.

Ship data:

Freeboard	0.90 m
Draught	2.50 m
Displacement	200 m^3
GM_o	0.51 m
Natural roll period	6.84 s
Volume body on deck:	transverse



Run No.	15	16	18	19	20	21	17*
Max. heeling angle (degs)	> 90	57	61	> 90	49	50	18
Remaining working capacity (rad · cm)	-	0.5	0.2	-	1.4	1.3	11.4
Judgement	0	1	1	0	1	1	6

*) abt. 0° stern sea

Ship behaviour with respect to stability

When running in the region of high waves large yawing motions and partly also large heeling angles. Like all in all case mentioned up to now also at these test runs the large heeling angles occurred when the stern was grasped by a high wave coming up from behind and the model threatened to broach.

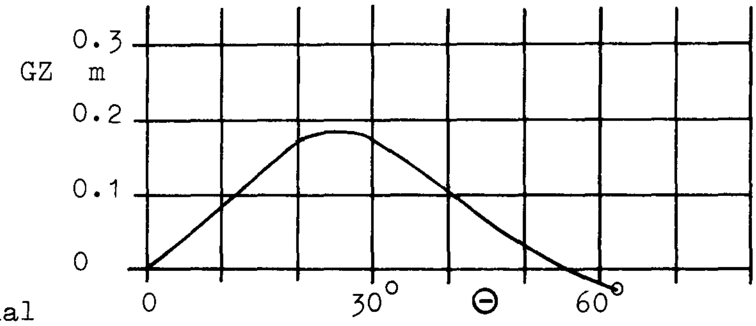
Both capsizing cases were initiated during broaching. When the heeling angle increased over about 45° the model turned back to the direction of wave propagation.

In one case the model persisted for about 5 to 6 sec (full scale) at a heeling angle of about 90°, in other case the model capsizing quickly up to 180° (leeward).

At the test run in 0° stern sea the model was very unsteady. It always threatened to run out of the rudder, especially when overtaking the high and breaking waves.

Ship data:

Freeboard	0.90 m
Draught	2.50 m
Displacement	200 m^3
GM_o	0.50 m
Natural roll period	6.93 s
Volume body on deck:	longitudinal



Run No.	71	72	73	74	75	76	77
Max. heeling angle (degs)	68	72	63	59	44	68	>90
Remaining working capacity (rad · cm)	- 0.6	- 1.0	- 0.3	- 0.1	0.7	- 0.6	-
Judgement	1	1	1	1	1	1	0

Ship behaviour with respect to stability

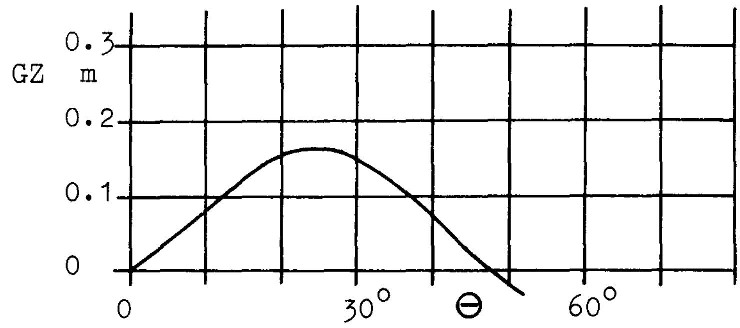
When running in the region of the high waves larger yawing motions and also large leeward heeling angle. In all cases, in which the maximum heeling angles occurred, the model was grasped by high powerful waves, broached nearly and the heeling increased up to the values (given in the above table) during turning back in the direction of the wave propagation.

In two cases (run No. 71 and 76) the capsizing was obviously prevented by the flexible "fishing line" cables (to supply the electric current and to transmit the telemeasured values) between the model and the subcarriage, which were entangled with the rod on which a weight could be displaced for changing the stability.

At nearly all cases the maximum heeling angles were larger than the statical capsizing point.
In one case the model capsized to starboard (leeward).

Ship data:

Freeboard	0.90 m
Draught	2.50 m
Displacement	200 m^3
GM_o	0.45 m
Natural roll period	7.40 s
Volume body on deck:	-



Run No.	1*	2*	3*	6**	4	5	7	8	9
Max. heeling angle (degs)	5	6	19	26	54	>90	52	48	>90
Remaining working capacity (rad · cm)	7.7	7.6	5.4	3.5	-0.2	-	-0.1	~0	-
Judgement	6	6	4	3	1	0	1	1	0

*) abt. 0° stern sea **) abt. beam sea, model at rest

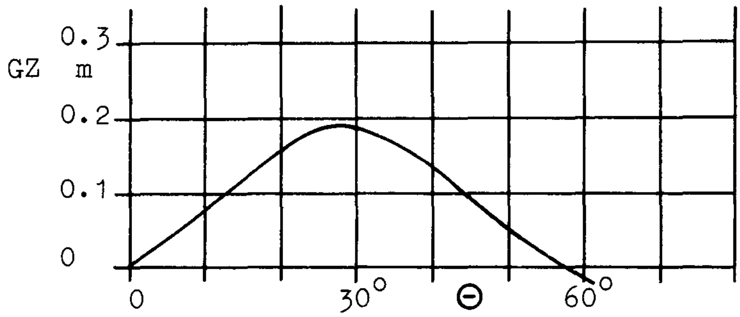
Ship behaviour with respect to stability

At the test runs in about 0° stern sea the model was very unsteady, it surged partly with the high waves coming up from behind.
In one case (run No. 3) the propeller speed was reduced down to zero, even though the model surged with one high wave crest about half of the basin length until it finally run out of the rudder. At this course deflection the heeling angle of 19° occurred (listed above).

In beam sea (model at rest) in general moderate, when passing the high waves also large rolling motions. Thereby relatively little water came onto the deck, first over the weather-side then over the dipped leeward bulwark.
In all cases the water run off relatively quickly over the bulwark and through the freeing ports respectively.
Test runs in about 30° stern sea :
At running in the region of the higher waves large yawing and rolling motions. The maximum heeling angles (listed above) occurred when the stern was grasped by a high powerful wave and the model broached with simultaneous increase of the heeling. Later on the model turned back into the direction of wave propagation, at a further increase of the heeling.
In two cases the model capsized (beginning with a leeward heeling). In the other cases the maximum heeling angles were equal or even larger than the statical capsizing angle in smooth water.

Ship data:

Freeboard	0.90 m
Draught	2.50 m
Displacement	200 m^3
GM_o	0.45 m
Natural roll period	7.43 s
Volume body on deck:	transverse



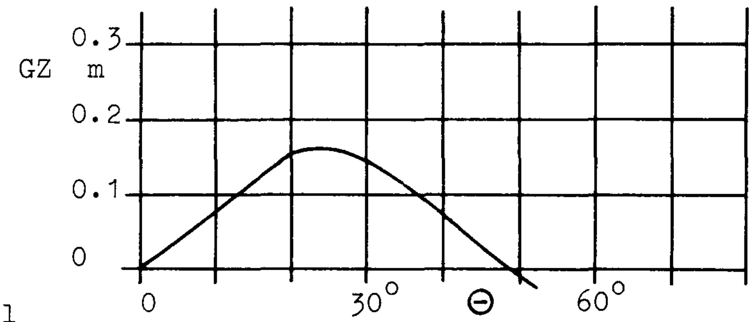
Run No.	10	11	12	13	14
Max. heeling angle (degs)	49	45	37	>90	> 90
Remaining working capacity (rad · cm)	0.5	0.9	2.6	-	-
Judgement	1	1	2	0	0

Ship behaviour with respect to stability

When running in the region of the higher waves larger rolling and yawing motions.
The character of the capsizing cases was similar to the cases already mentioned, i.e. at first grasping of the stern by a very high wave, then nearly broaching with simultaneous leeward heeling, futher increase of the heeling angle and capsizing during turning back to the direction of wave propagation. For the capsizing itself the water, which came onto the deck, seemed to be unimportant.
It was clearly observed that practically no water was on deck, before the model capsized. The water came firstly on deck when the freeing ports and the top of the bulwark respectively dipped into the water.

Ship data:

Freeboard	0.90 m
Draught	2.50 m
Displacement	200 m^3
GM_o	0.45 m
Natural roll period	7.41 s
Volume body on deck:	longitudinal



Run No.	78	79
Max. heeling angle (degs)	>90	44
Remaining working capacity (rad · cm)	-	0.1
Judgement	0	1

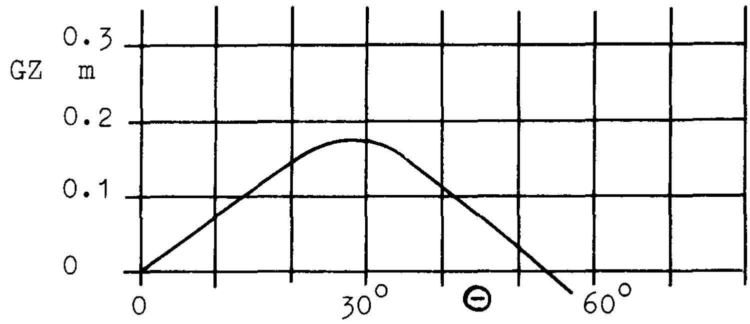
Ship behaviour with respect to stability

Also at this model condition the capsizing proceeded as in the cases mentioned before, i.e. when the model was grasped by a very high wave it nearly broached; thereby large leeward heeling and capsizing during turning back into the direction of wave propagation.

During the test run No. 79, the model also nearly broached in a very high wave. But apparently the energy of the wave was not sufficient for capsizing of the model. It was righted up during turning back to the original course.

Ship data:

Freeboard 0.90 m
Draught 2.50 m
Displacement 200 m^3
GM_o 0.42 m
Natural roll period 7.77 s
Volume body on deck: transverse



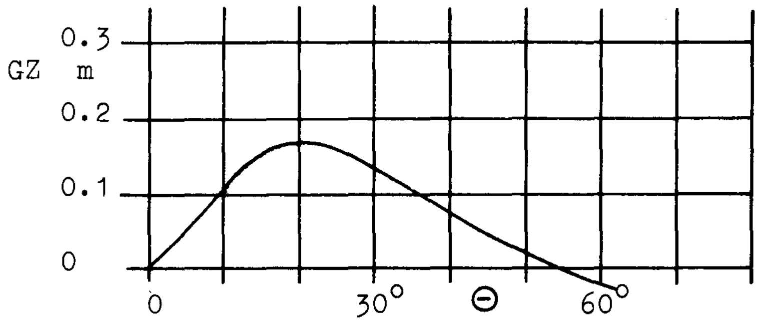
Run No.	81	82	83	84	85
Max. heeling angle (degs)	46	>90	76	> 90	>90
Remaining working capacity (rad · cm)	0.4	-	-2.7	-	-
Judgement	1	0	1	0	0

Ship behaviour with respect to stability

At two test runs the model capsized under similar circumstances as described before.
At the run No. 83 capsizing was apparently prevented by the "fishing line" cables which became antangled with the weight rod.
The capsizing at the test run No. 82 was somewhat different. In this case the model was grasped by a high powerful wave, deviated much from the course (but without broaching) heeled largely to starboard (leeward), turned back to the direction of wave propagation with simultaneous increase of the heeling angle to about 60° (model in direction of wave propagation). The next wave grasped the stern, the model turned over the direction of wave propagation and righted up again. When passing the second high breaking wave the model heeled to port, turned back again into the wave direction and capsized at last to port (neither leeward nor weather side).

Ship data:

Freeboard 0.60 m
Draught 2.80 m
Displacement 242 m^3
GM_o 0.60 m
Natural roll period 6.25 s
Volume body on deck: -



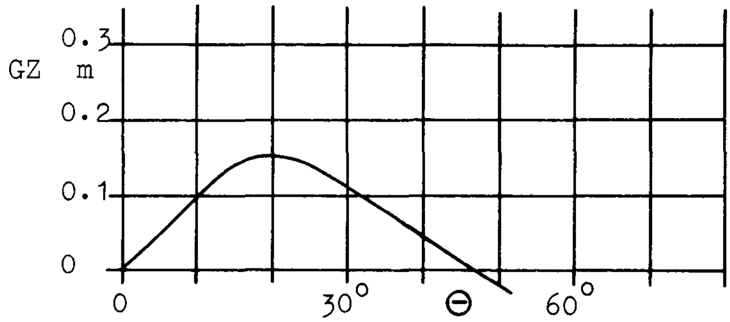
Run No.	86	87	88
Max. heeling angle (degs)	30	41	41
Remaining working capacity (rad · cm)	2.9	0.9	0.9
Judgement	2	1	1

Ship behaviour with respect to stability

In general, moderate, in the higher waves larger rolling and yawing motions. During overtaking by the high and breaking waves the risk of broaching was apperently smaller than at the smaller displacement. Also at the larger heeling angles relatively little water came onto the deck, which run off quickly.

Ship data:

Freeboard	0.60 m
Draught	2.80 m
Displacement	242 m^3
GM_o	0.55 m
Natural roll period	6.70 s
Volume body on deck:	-



Run No.	89	90	91	92
Max. heeling angle (degs)	32	53	27	36
Remaining working capacity (rad · cm)	1.3	- 0.2	2.3	0.7
Judgement	1	1	2	1

Ship behaviour with respect to stability

During overtaking by the high powerful waves very large yawing motions and partly large heeling angles. But in general less risk of broaching.
At the run No. 90 the maximum heeling angle occurred in connection with a large yawing motion. The model turned back into the direction of wave propagation under retention of the large heeling angle (larger than the statical capsizing angle in smooth water!) and then righted up again.

Ship data:

Freeboard 0.60 m

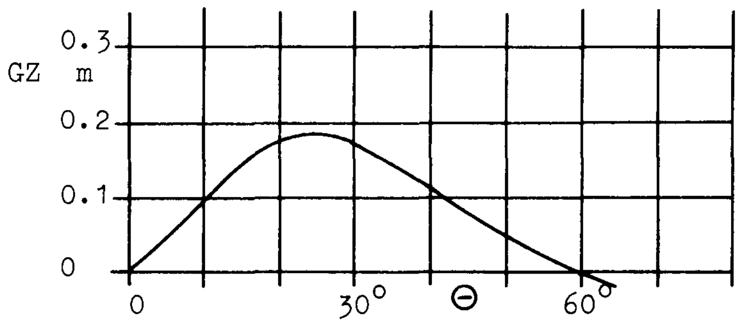
Draught 2.80 m

Displacement 242 m^3

GM_o 0.55 m

Natural roll period 6.75 s

Volume body on deck: transverse



Run No.	98	99	100	101
Max. heeling angle (degs)	45	43	36	43
Remaining working capacity (rad · cm)	1.0	1.3	2.7	1.3
Judgement	1	1	2	1

Ship behaviour with respect to stability

Very strong yawing motions and heelings leeward at overtaking by high and powerful waves.

The largest heeling angles occurred in connection with large course deviations. The model righted up when it turned back to the original course and in the direction of wave propagation respectively. The water which came on deck seemed to run off less well because of the volume body extended from side to side, it was partly dammed in front of the volume body.

Ship data:

Freeboard 0.60 m

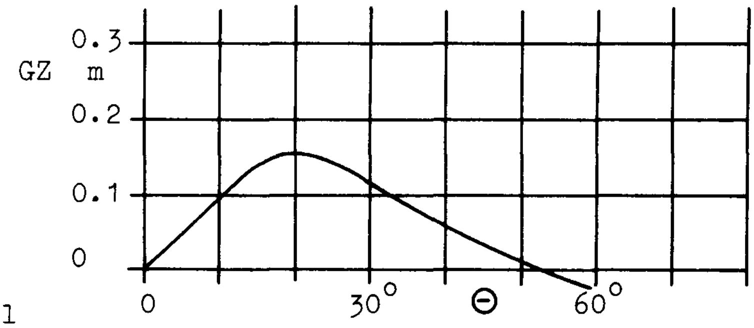
Draught 2.80 m

Displacement 242 m^3

GM_o 0.55 m

Natural roll period 6.73 s

Volume body on deck: longitudinal



Run No.	111	112	113
Max. heeling angle (degs)	52	36	34
Remaining working capacity (rad · cm)	~0	1.2	1.5
Judgement	1	1	1

Ship behaviour with respect to stability

The model yawed and rolled very strongly during overtaking by high powerful waves. In one case (test run No. 111) the model nearly broached in a high breaking wave turned back in a heeled position into the wave propagation and righted up again in this heading. During the main phase of righting up the model was located in a wave trough. The water which was came on deck at large heeling angle run off relatively quickly through the freeing ports.

Ship data:

Freeboard 0.60 m

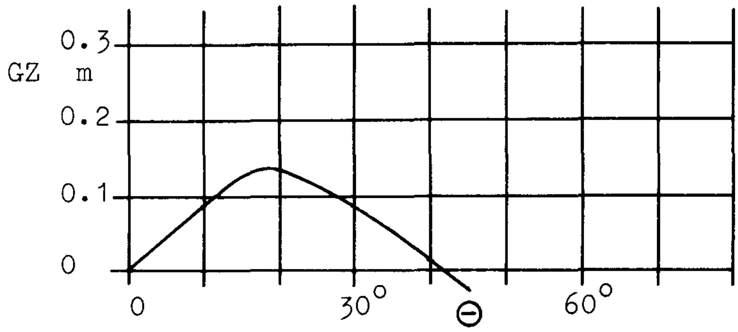
Draught 2.80 m

Displacement 242 m^3

GM_o 0.50 m

Natural roll period 7.22 s

Volume body on deck: -



Run No.	93	94	95	96	97
Max. heeling angle (degs)	30	47	46	40	> 90
Remaining working capacity (rad · cm)	0.9	-0.2	-0.1	0.1	-
Judgement	1	1	1	1	0

Ship behaviour with respect to stability

The model yawed and rolled very strongly during overtaking by the high powerful waves.
The water coming onto the deck through the freeing ports and over the dipped bulwark at large heeling angles run off again rather quickly through the freeing ports.
Especially at the runs No. 94 and 95 large heeling angles occurred at large course deviations. But during turning back into the direction of wave propagation the model righted up again in these cases.
At run No. 97 the model was grasped by a high breaking wave, it nearly broached, heeled very strongly leewards and capsized at turning back into the direction of the wave propagation.

Ship data:

Freeboard 0.60 m

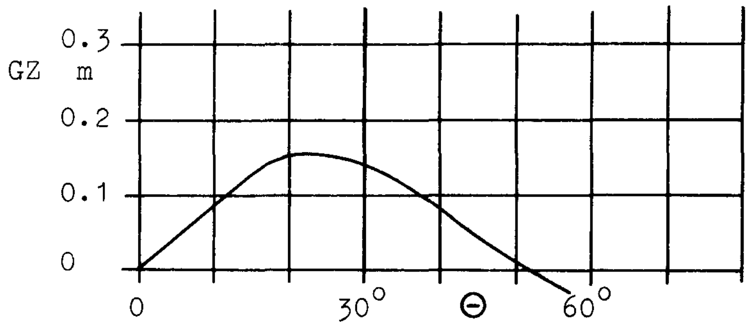
Draught 2.80 m

Displacement 242 m^3

GM_o 0.50 m

Natural roll period 7.25 s

Volume body on deck: transverse



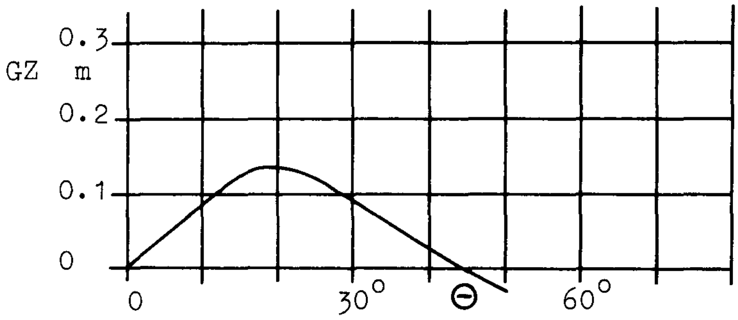
Run No.	102	103	104	105
Max. heeling angle (degs)	> 90	43	59	56
Remaining working capacity (rad · cm)	-	0.5	-0.3	-0.1
Judgement	0	1	1	1

Ship behaviour with respect to stability

When the stern of the model was grasped by high and breaking waves the model nearly broached in connection with a simultaneous leeward heeling. There after it turned back into the direction of wave propagation under slow increase of the heeling.
In one case the model capsized to starboard, in two cases the maximum heeling angles were larger than the statical capsizing angle in smooth water. In the last two cases the model righted up before it was grasped by the next high wave. Only in one case (run No. 103) the heeling decreased at turning back into the direction of wave propagation. The water which came on deck apparently run off less well compared with the model without or with the longitudinal volume body on deck.

Ship data:

Freeboard 0.60 m
Draught 2.80 m
Displacement 242 m^3
GM_o 0.50 m
Natural roll period 7.25 s
Volume body on deck: longitudinal



Run No.	106	107	108	109	110
Max. heeling angle (degs)	56	53	41	49	32
Remaining working capacity (rad · cm)	-0.5	-0.3	0.1	-0.1	0.9
Judgement	1	1	1	1	1

Ship behaviour with respect to stability

When the model was grasped by the waves coming from behind it nearly broached and thereby heeled very strongly leeward. In one case (run No. 106) capsizing was prevented by the fishing line cables. The cables became entangled with the weight rod and thus prevented an increase of the heeling.

The heeling angle measured in this situation was much larger than the statical capsizing angle in smooth water. Also at the runs No. 107 and 108 the maximum heeling angles were larger than the statical capsizing angles.

At the run No. 110 the model surged with a high breaking wave, thereby it yawed and rolled strongly. But larger continuous heelings did not occur.

Ship data:

Freeboard 0.60 m

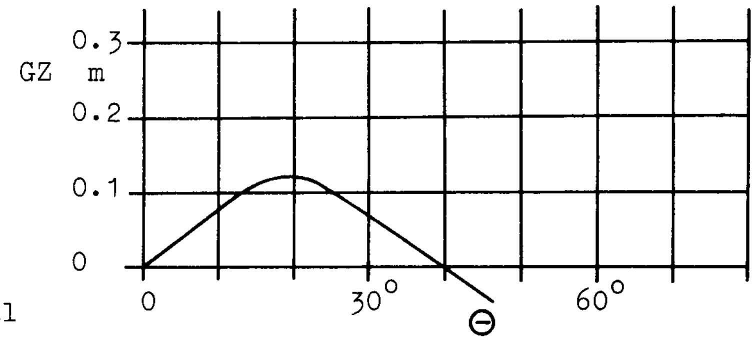
Draught 2.80 m

Displacement 242 m^3

GM_o 0.45 m

Natural roll period 7.83 s

Volume body on deck: longitudinal



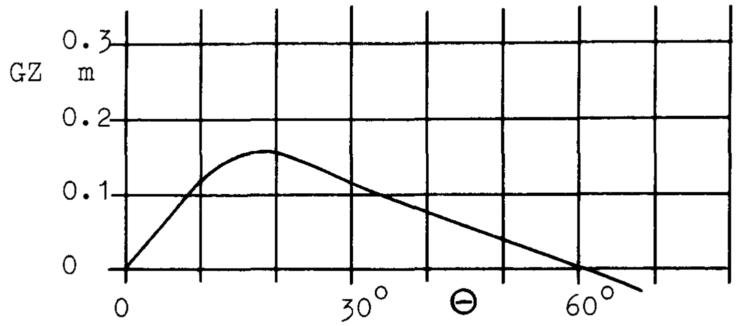
Run No.	114	115	116
Max. heeling angle (degs)	37	52	> 90
Remaining working capacity (rad · cm)	0.1	-0.9	-
Judgement	1	1	0

Ship behaviour with respect to stability

When the stern was grasped by ligh waves coming up from behind the model nearly broached and thereby it heeled very strongly leeward. Partly, the model remained in this heeled position for a longer time and turned back into the direction of wave propagation. Thereby the model righted up again at the runs No. 114 and 115. At run No. 116, the model righted up at first in the same way after passing a very high wave. Later on, the model was overtaken by a wave being not very high, deviated only a little, heeled strongly leeward and capsized on the original course. After increase of the capsizing angle over 90° the model turned into the direction of wave propagation.

Ship data:

Freeboard	0.40 m
Draught	3.00 m
Displacement	271.5 m^3
GM_o	0.69 m
Natural roll period	5.53 s
Volume body on deck:	-



Run No.	38*	39*	40	41
Max. heeling angle (degs)	9	10	18	22
Remaining working capacity (rad · cm)	8.2	8.1	6.1	4.9
Judgement	6	6	5	4

*) abt. 0° stern sea

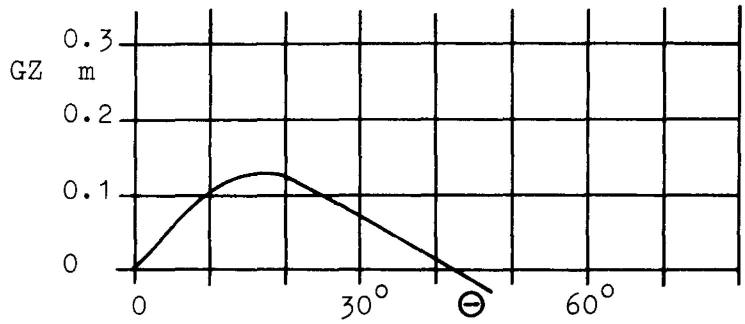
Ship behaviour with respect to stability

At running in about 0° stern sea the model partly surged with high waves. In general small, seldom moderate in harmonious heeling motions. Practically no water came on deck.

At the runs in about 30° stern sea in the region of high powerful waves moderate rolling, occasionally somewhat larger heeling motions and also strong yawing motions. No risk of broaching. The water coming partly on deck over the bulwark run off quickly through the freeing ports.

Ship data:

Freeboard 0.40 m
Draught 3.00 m
Displacement 271.5 m^3
GM_o 0.60 m
Natural roll period 6.35 s
Volume body on deck: -



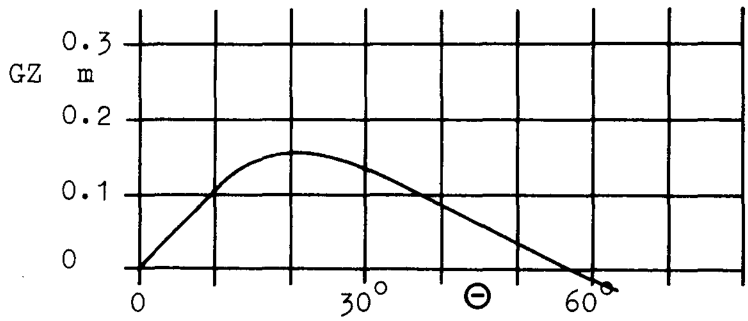
Run No.	42	43	44	45
Max. heeling angle (degs)	19	30	27	29
Remaining working capacity (rad · cm)	2.8	0.9	1.4	1.1
Judgement	2	1	1	1

Ship behaviour with respect to stability

At running in the region of high waves generally the model heeled moderately leeward, yawed strongly, but was kept on course relatively well. When the stern was grasped by a high breaking wave the model deviated, heeled leeward somewhat stronger and righted up again at turning back to the original course. Partly relatively much water come onto the deck as well as over the weather-side and over the leeward bulwark, but mostly it run off quickly and only little water gushed against the opposite bulwark when changing the direction of heeling.

Ship data:

Freeboard	0.40 m
Draught	3.00 m
Displacement	271.5 m^3
GM_o	0.60 m
Natural roll period	6.35 s
Volume body on deck:	transverse



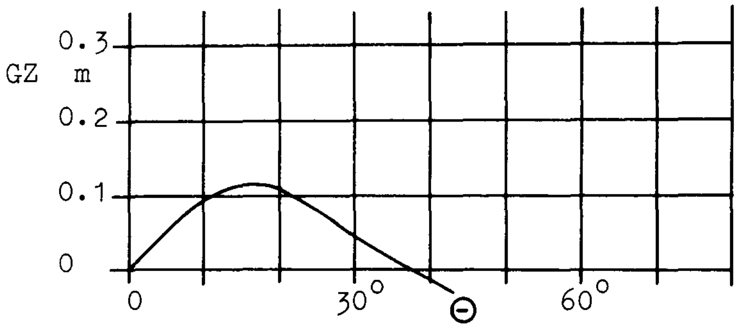
Run No.	131	132	133	134
Max. heeling angle (degs)	48	29	20	21
Remaining working capacity (rad · cm)	0.4	3.5	5.9	5.4
Judgement	1	3	4	4

Ship behaviour with respect to stability

At running in the region of high waves partly larger yawing motions and heelings. At the runs No. 133 and 134 the model surged with high breaking waves without being overtaken by them. During run No. 131 the maximum heeling angle (listed above) occurred when the model was grasped by a very high breaking wave. It deviated stronger, heeled strongly leeward, turned back to the original course with slow increase of heeling and righted up again at turning further into the direction of wave propagation. Generally the water coming onto the deck seemed to run off less well than at the model without volume body on deck. In front of the volume body the water was somewhat dammed.

Ship data:

Freeboard	0.40 m
Draught	3.00 m
Displacement	271.5 m^3
GM_o	0.55 m
Natural roll period	6.80 s
Volume body on deck:	-



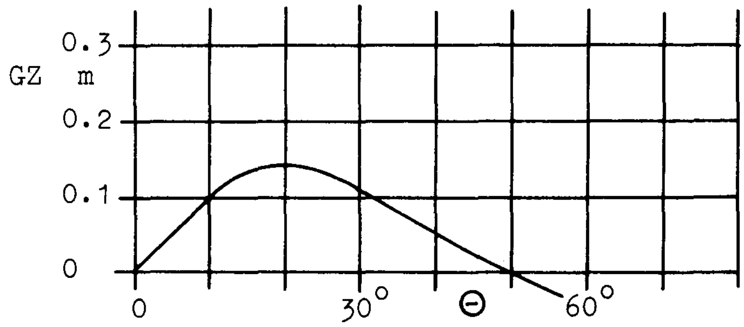
Run No.	46	47	48
Max. heeling angle (degs)	39	31	>90
Remaining working capicity (rad · cm)	-0.1	0.2	-
Judgement	1	1	0

Ship behaviour with respect to stability

At running in the region of high and breaking waves the model rolled and yawed partly very strongly, partly it also remained in a heeled position (run No. 46) and righted up at turning back to the original course. At run No. 48 the model capsized after it was grasped by the second high breaking wave of a wave group (after passing of the first wave the water coming on deck has nearly completely run off again).
At first, the model deviated stronger from the course, thereby it heeled strongly leeward, heeled stronger at turning back into the direction of wave propagation, turned beyond that direction under retention of the large heeling (dipped side now weather-side), righted up a little and capsized a short time later when passing the next relatively small wave.

Ship data:

Freeboard 0.40 m
Draught 3.00 m
Displacement 271.5 m^3
GM_o 0.55 m
Natural roll period 6.84 s
Volume body on deck: transverse



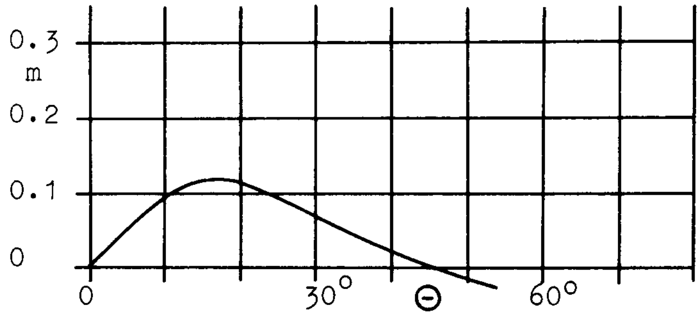
Run No.	129*	130
Max. heeling angle (degs)	49	> 90
Remaining working capacity (rad · cm)	~ 0	-
Judgement	1	0

Ship behaviour with respect to stability

The model yawed very strongly in the high breaking waves and thereby it heeled leeward very strongly. The capsizing (run No. 130) was initiated by a large course deflection (nearly broaching). Thereby the model heeled leeward up to about 45°, then it turned into the direction of wave propagation under slow increase of the heeling angle and capsized to starboard.

Ship data:

Freeboard 0.40 m
Draught 3.00 m
Displacement 271.5 m^3
GM_o 0.55 m
Natural roll period 6.82 s
Volume body on deck: longitudinal



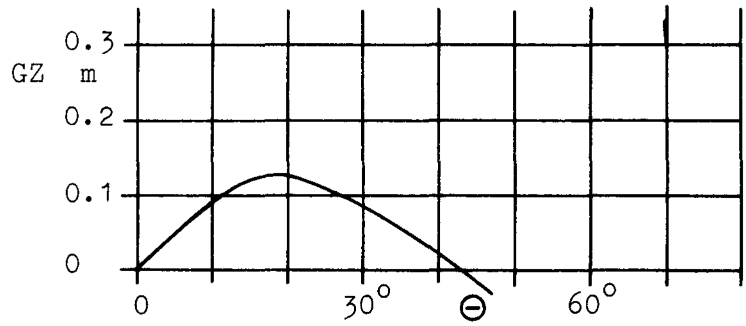
Run No.	117	118	119	120
Max. heeling angle (degs)	24	47	32	29
Remaining working capacity (rad · cm)	1.8	-0.1	0.7	1.1
Judgement	2	1	1	1

Ship behaviour with respect to stability

At running in the region of high partly breaking waves the model rolled and yawed strongly, partly also larger heelings occurred lasting a short time, at a somewhat larger course deviation.
In these cases the model righted up when turning back to the original course and into the direction of wave propagation respectively.

Ship data:

Freeboard	0.40 m
Draught	3.00 m
Displacement	271.5 m^3
GM_o	0.50 m
Natural roll period	7.37 s
Volume body on deck:	transverse



Run No.	126	127	128
Max. heeling angle (degs)	> 90	43	> 90
Remaining working capacity (rad · cm)	-	0	-
Judgement	0	1	0

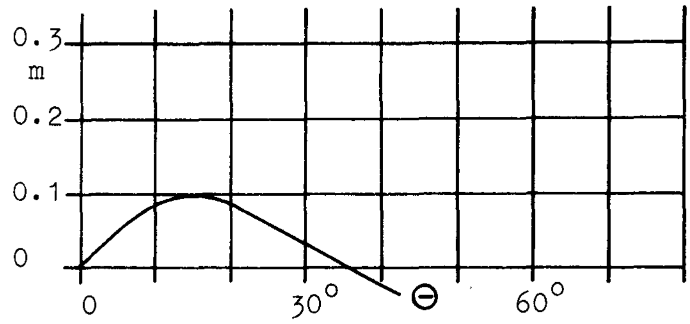
Ship behaviour with respect to stability

In both cases of capsizing the model nearly broached by a high breaking wave coming up from behind. Thereby it heeled strongly and capsized at turning back into the direction of wave propagation.

At the run No. 127 the model deviated not so strongly as at the other two runs, but heeled very strongly. Also the heeling increased with turning into the direction of wave propagation. In this position the model righted up again.

Ship data:

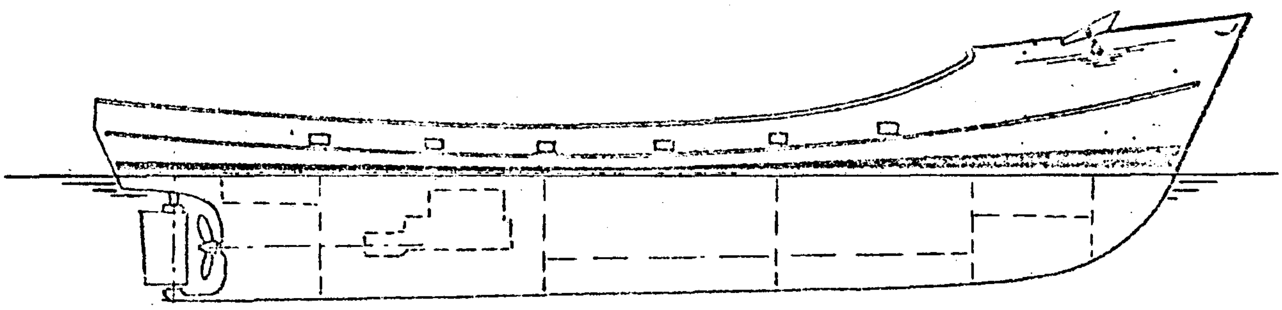
Freeboard	0.40 m
Draught	3.00 m
Displacement	271.5 m^3
GM_o	0.50 m
Natural roll period	7.36 s
Volume body on deck:	longitudinal



Run No.	121	122	123	124	125
Max. heeling angle (degs)	> 90	30	30	34	48
Remaining working capacity (rad · cm)	-	0.2	0.2	~0	-0.7
Judgement	0	1	1	1	1

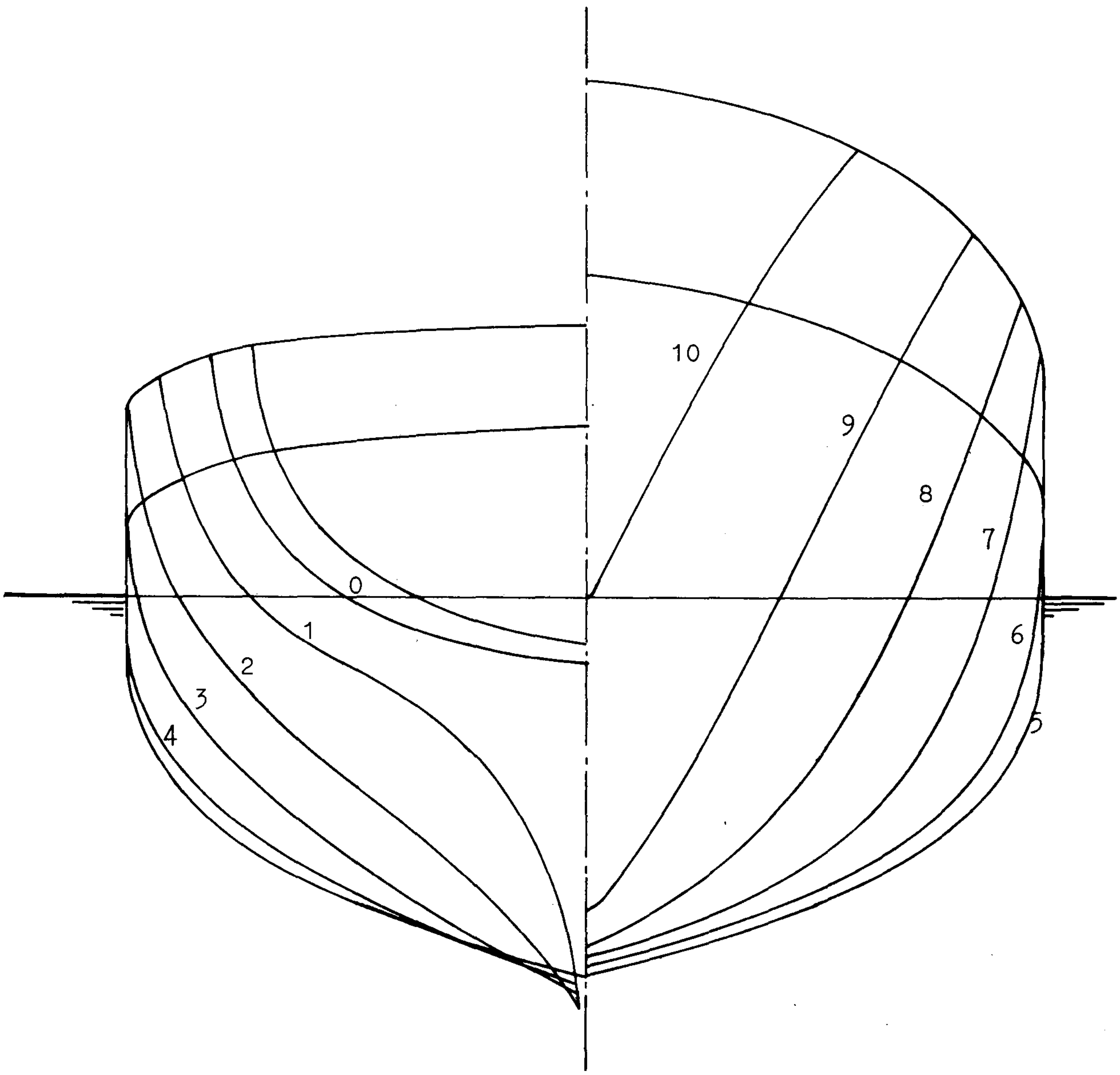
Ship behaviour with respect to stability

At running in the region of high and partly breaking waves large yawing and rolling motions, partly also somewhat larger leeward heelings occurred. The water which came onto the deck as well over the weather-side and over the leeward bulwark run off quickly.
Only very little water gushed against the opposite bulwark when changing the direction of heeling.
At the run No. 121 the stern was grasped by a high and breaking wave, the model deviated more (but not broaching), heeled strongly leeward, turned into the direction of wave propagation thereby righting up again, turned further beyond this direction, heeled again leeward when passing the next wave crest, turned back into the direction of wave propagation with simultaneous increase of heeling and capsized finally to starboard when passing the third wave crest.



Side view of the fishing cutter
without deckhouse

Fig. A 1



Body plan of the tested model

Fig. A 2

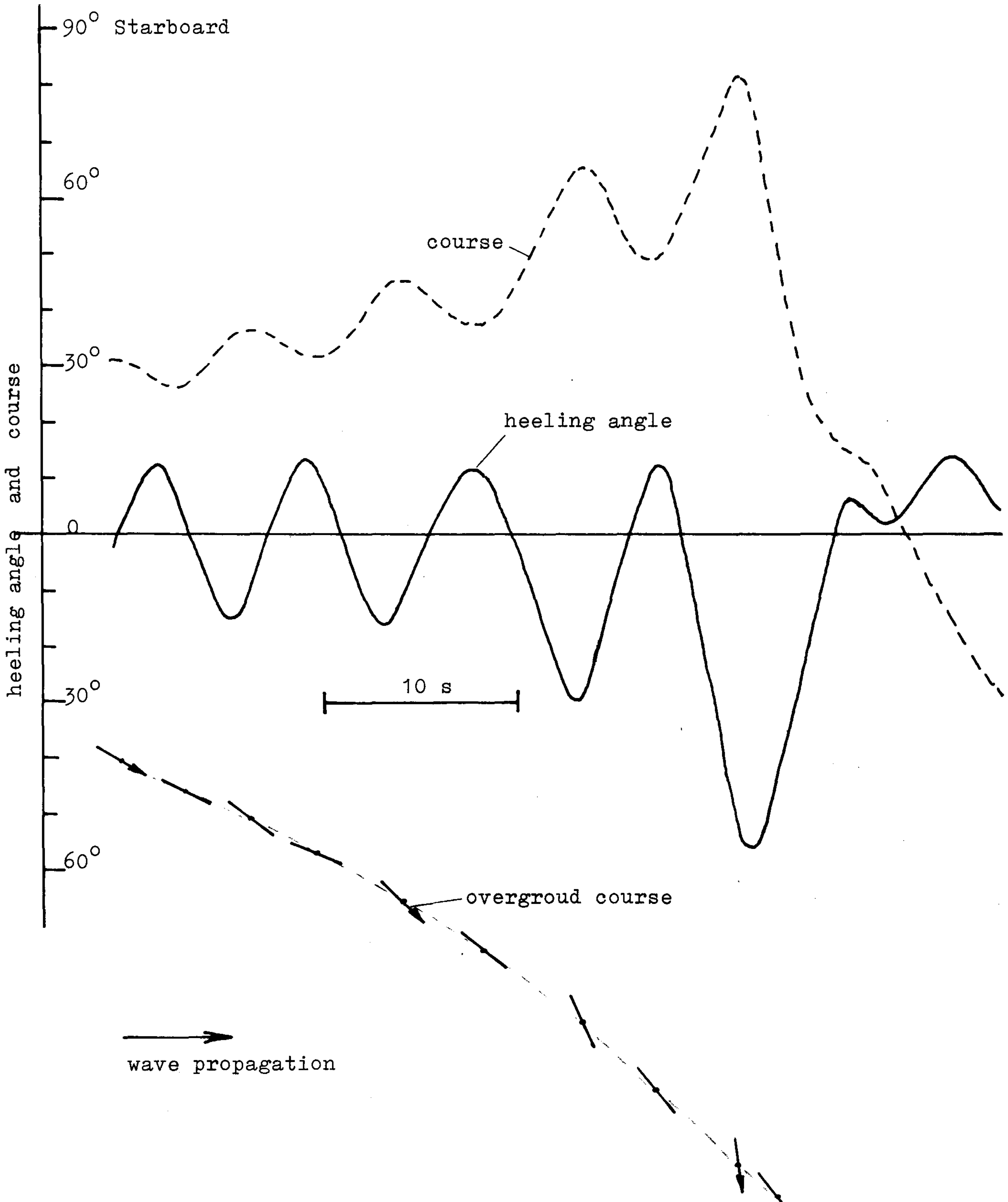


Fig. A 3 Run No. 16

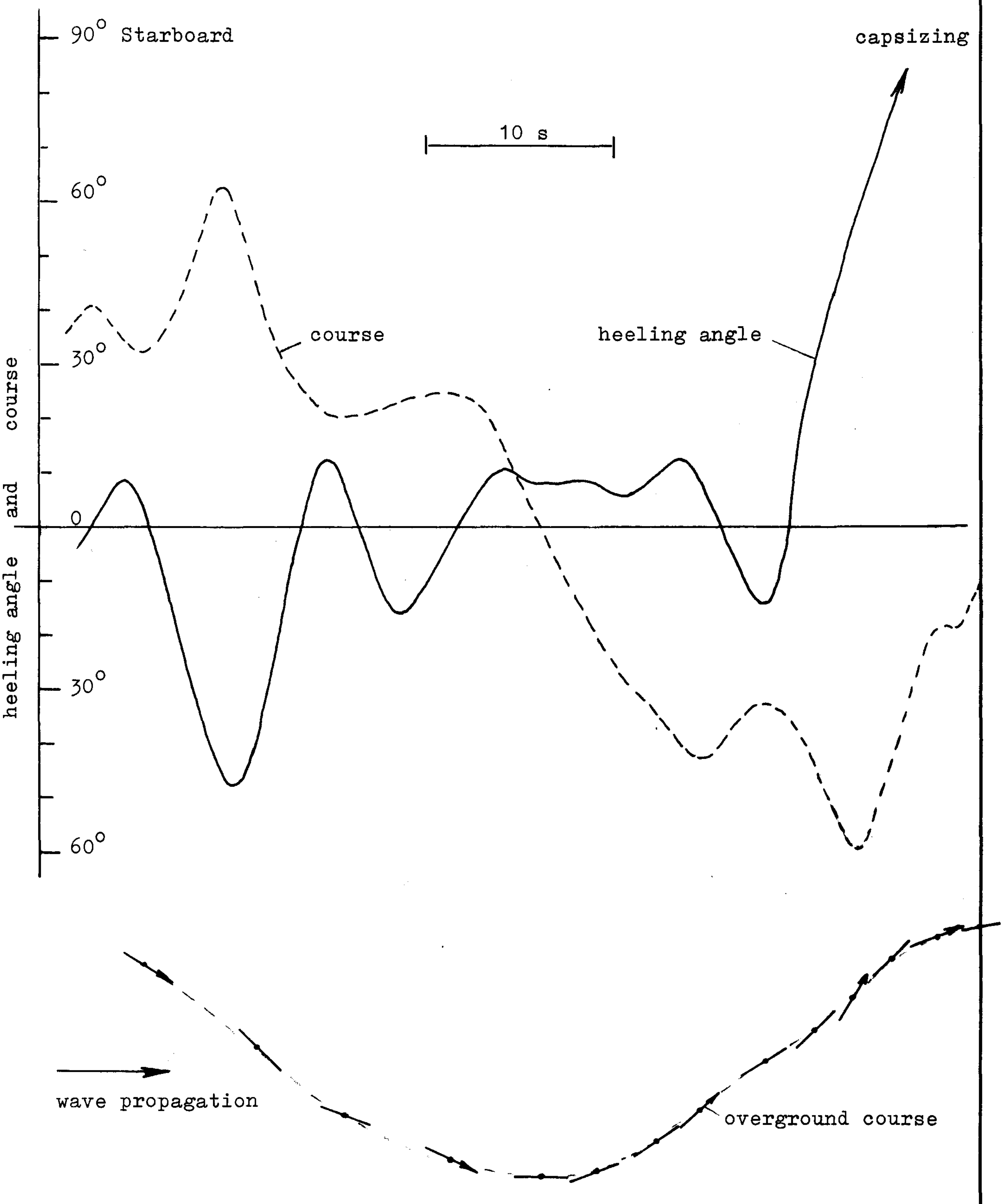


Fig. A 4 Run No. 19

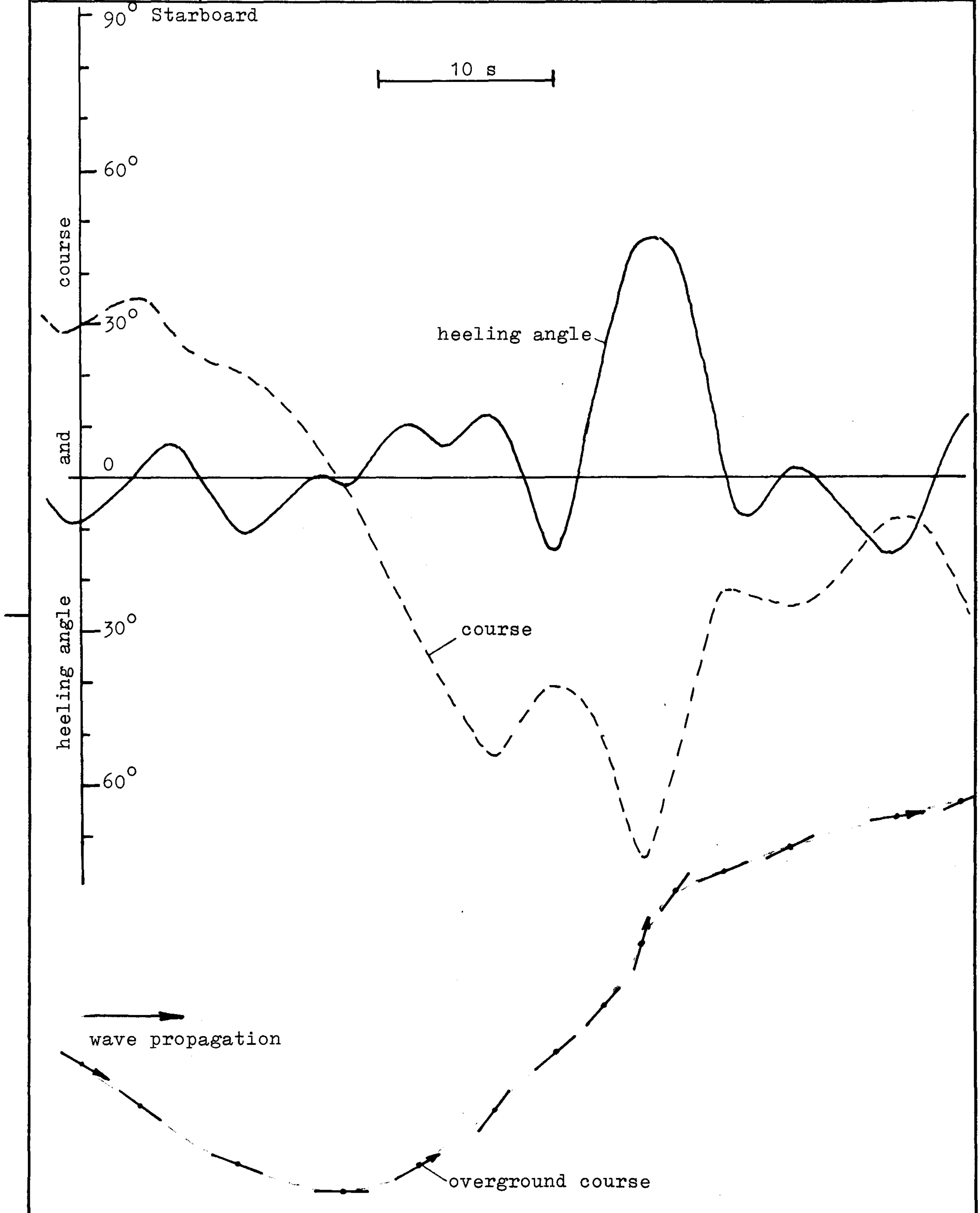


Fig. A 5 Run No. 35

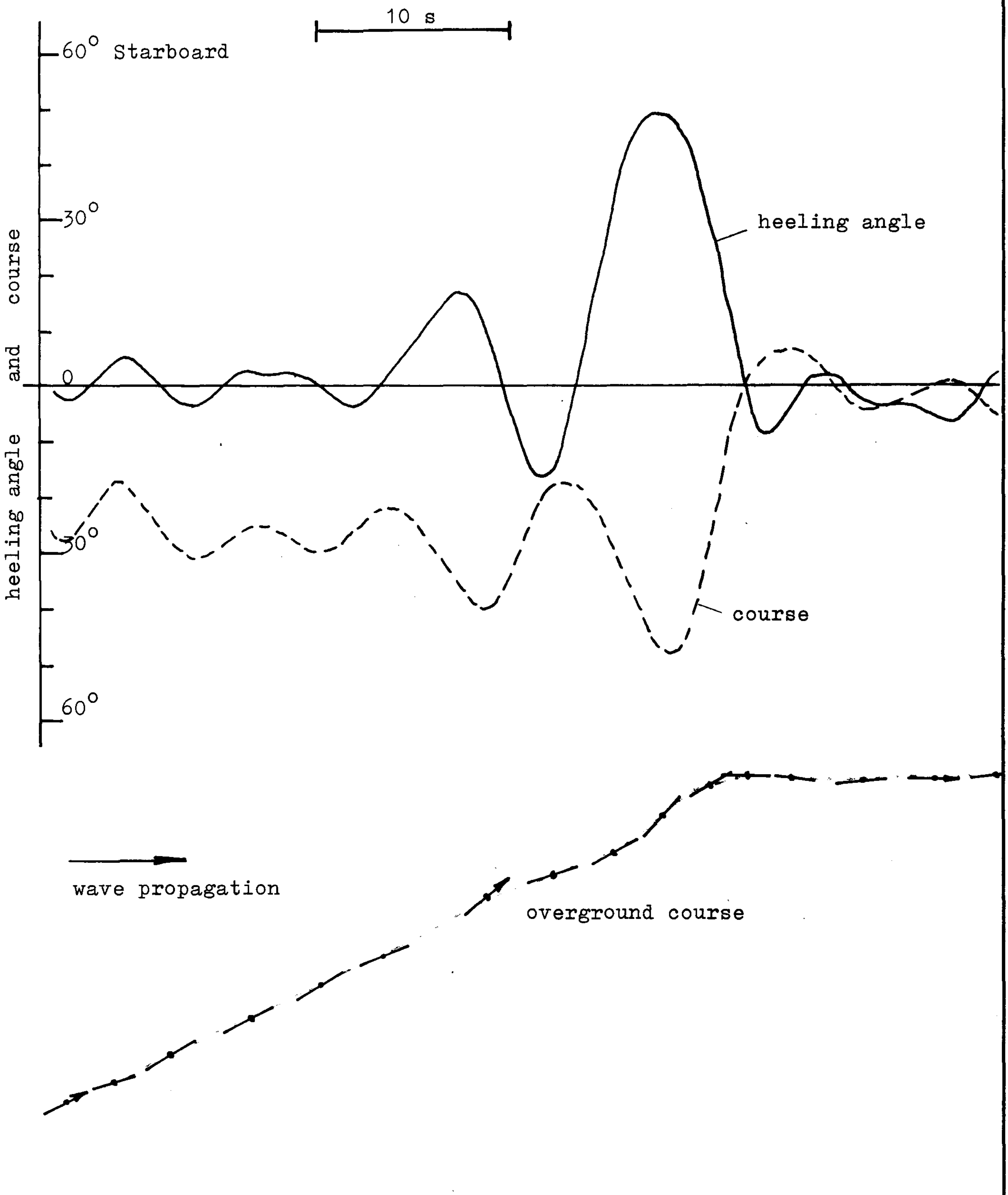


Fig. A 6   Run No. 50

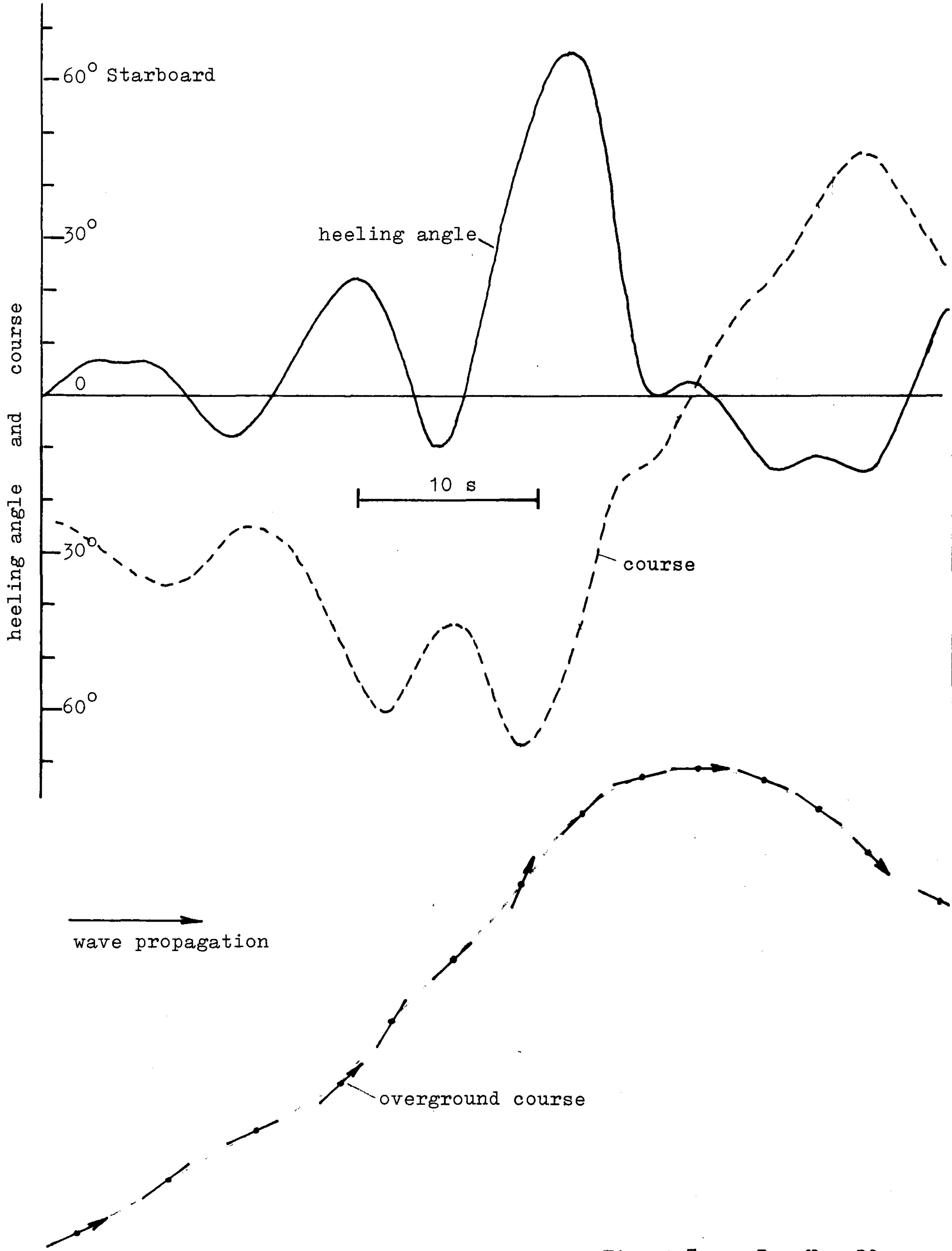


Fig. A 7   Run No. 59

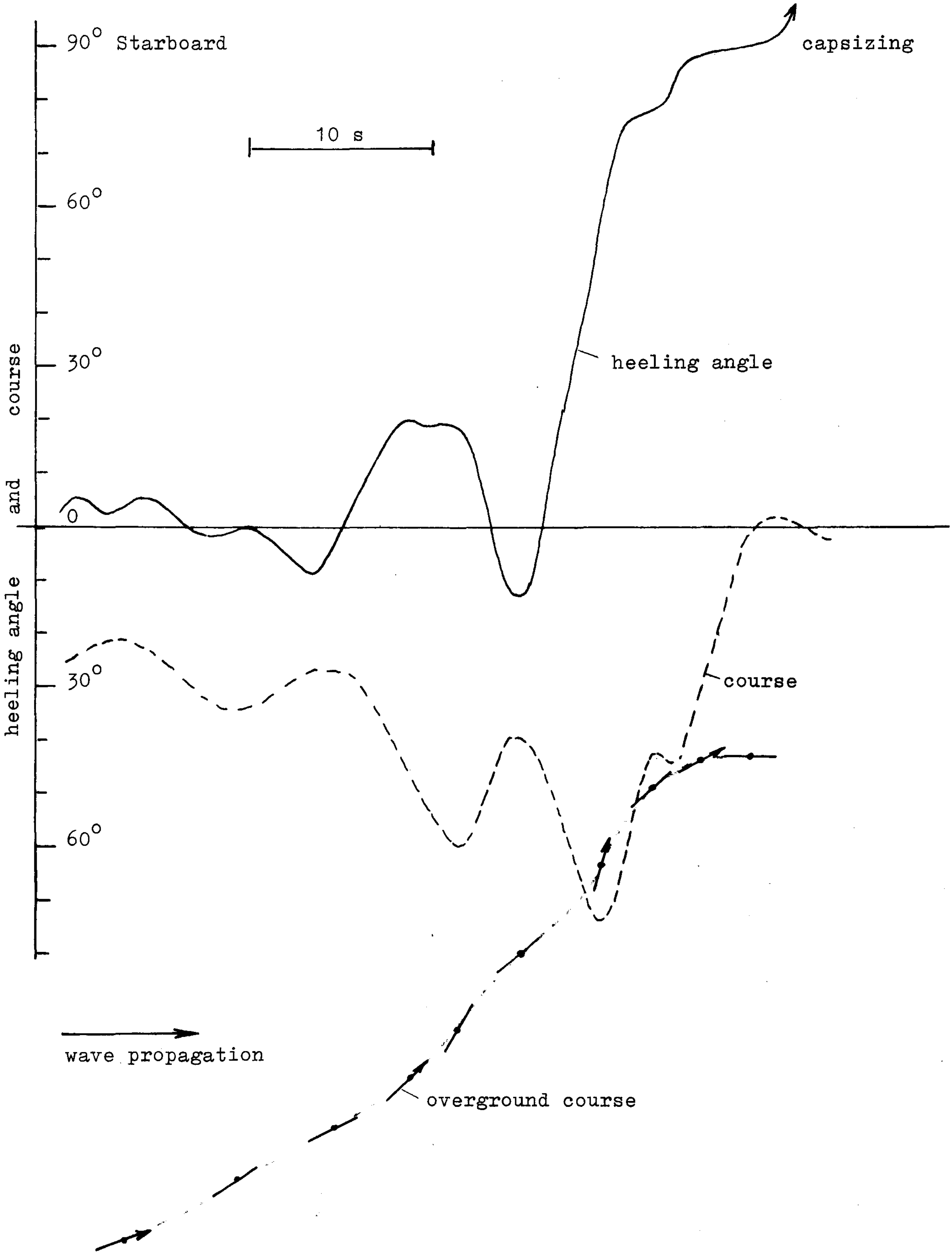


Fig. A 8 Run No. 61

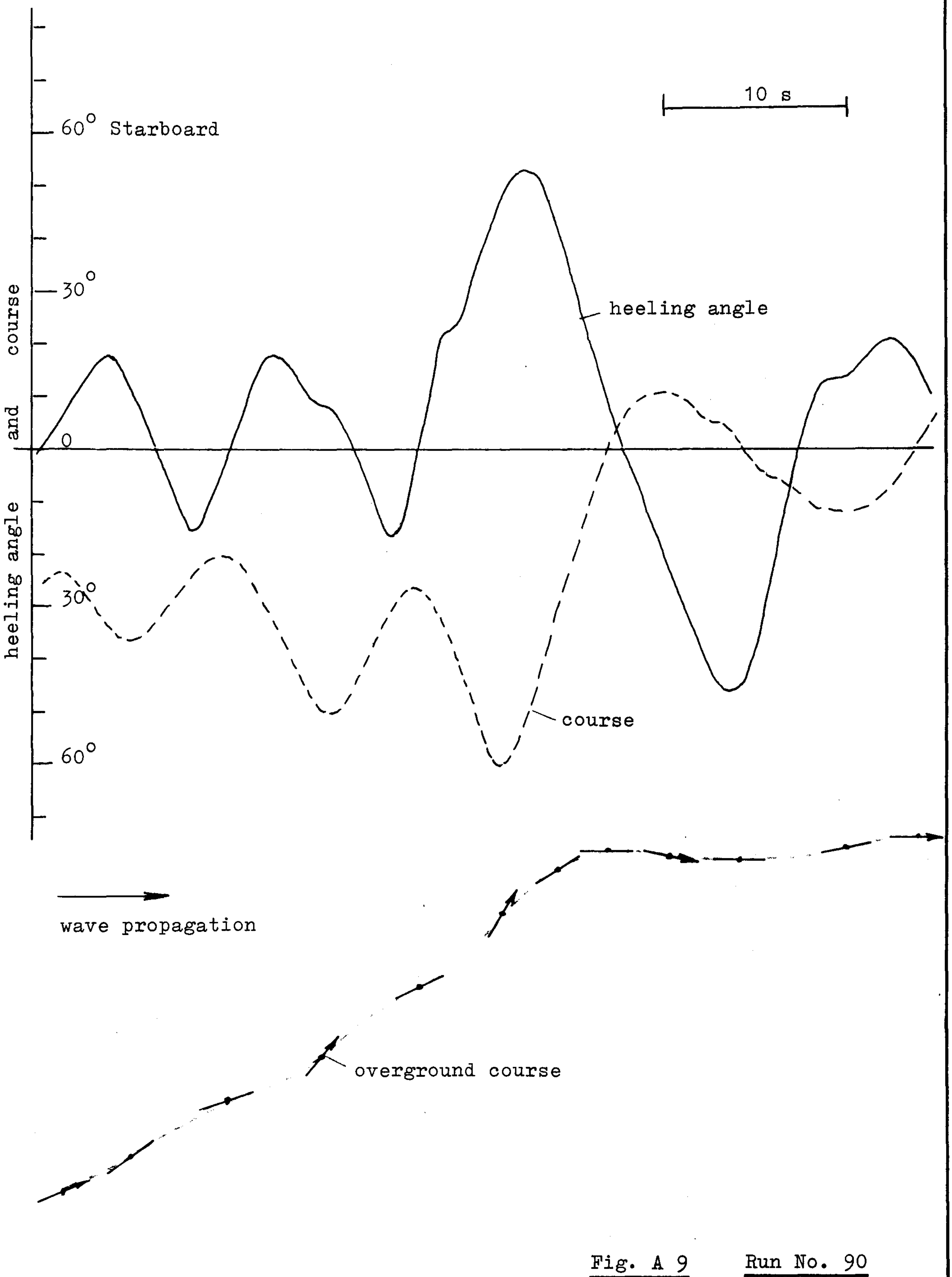


Fig. A 9 Run No. 90

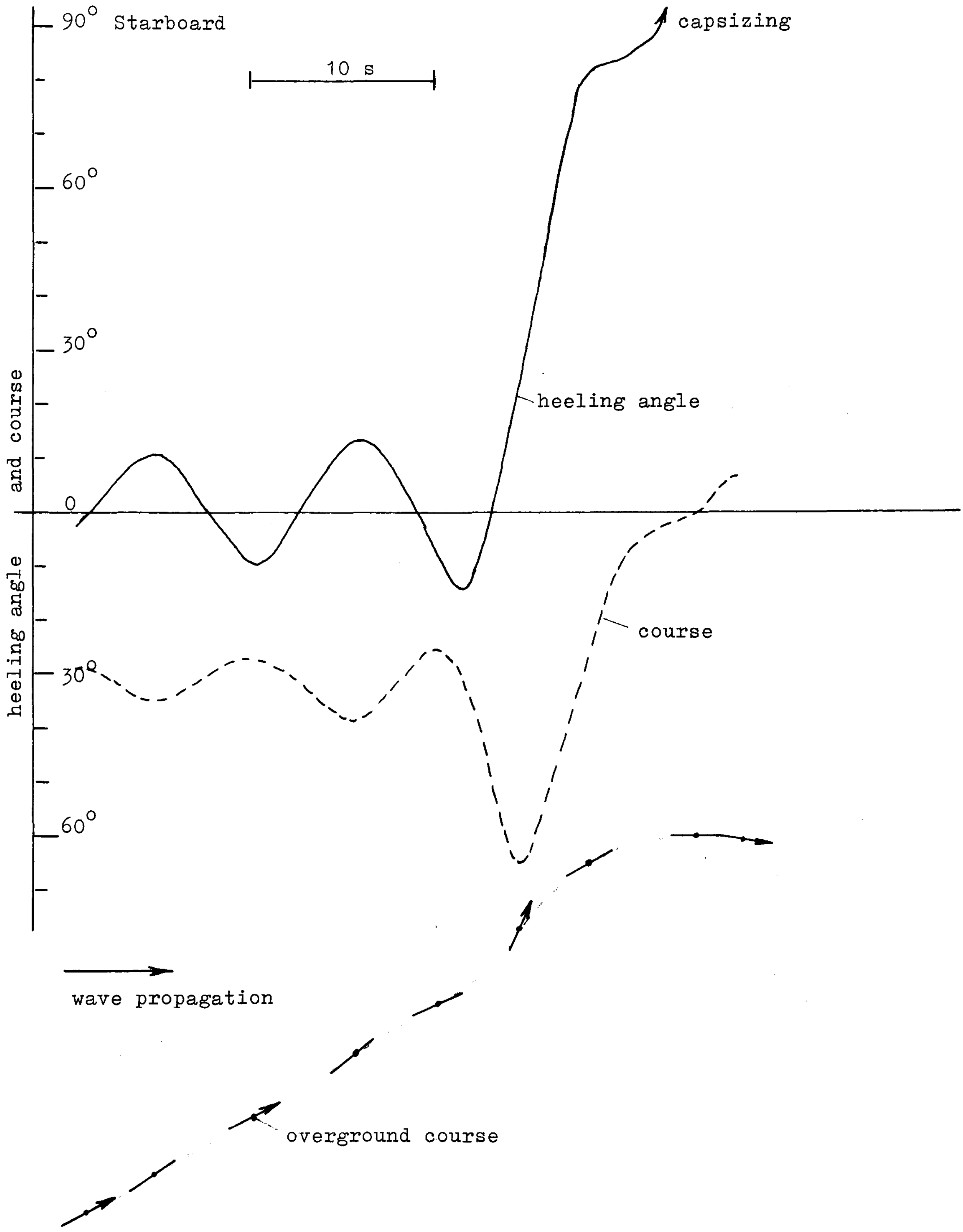


Fig. A 10 Run No. 97

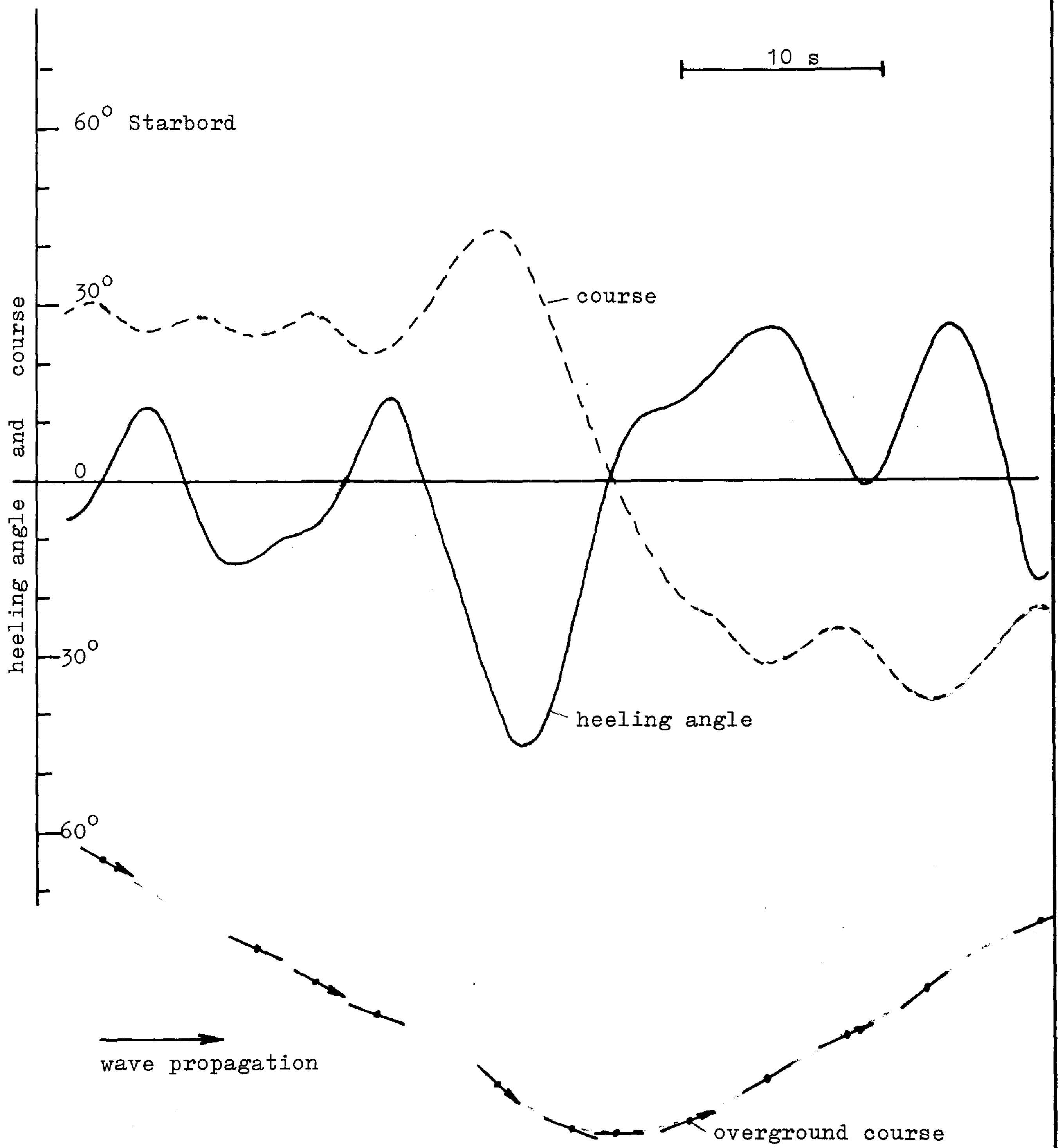


Fig. A 11 Run No. 98

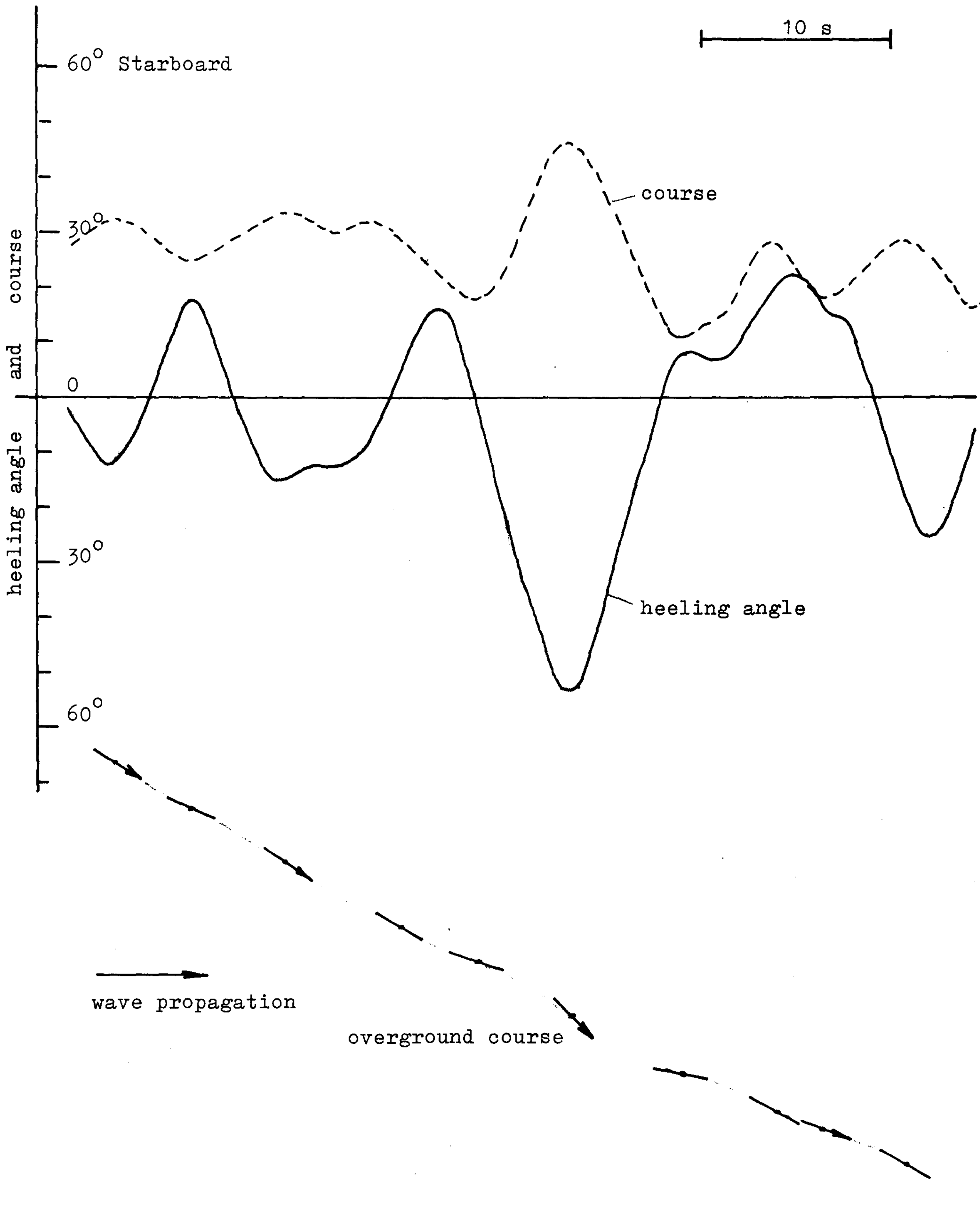


Fig. A 12 Run No. 107

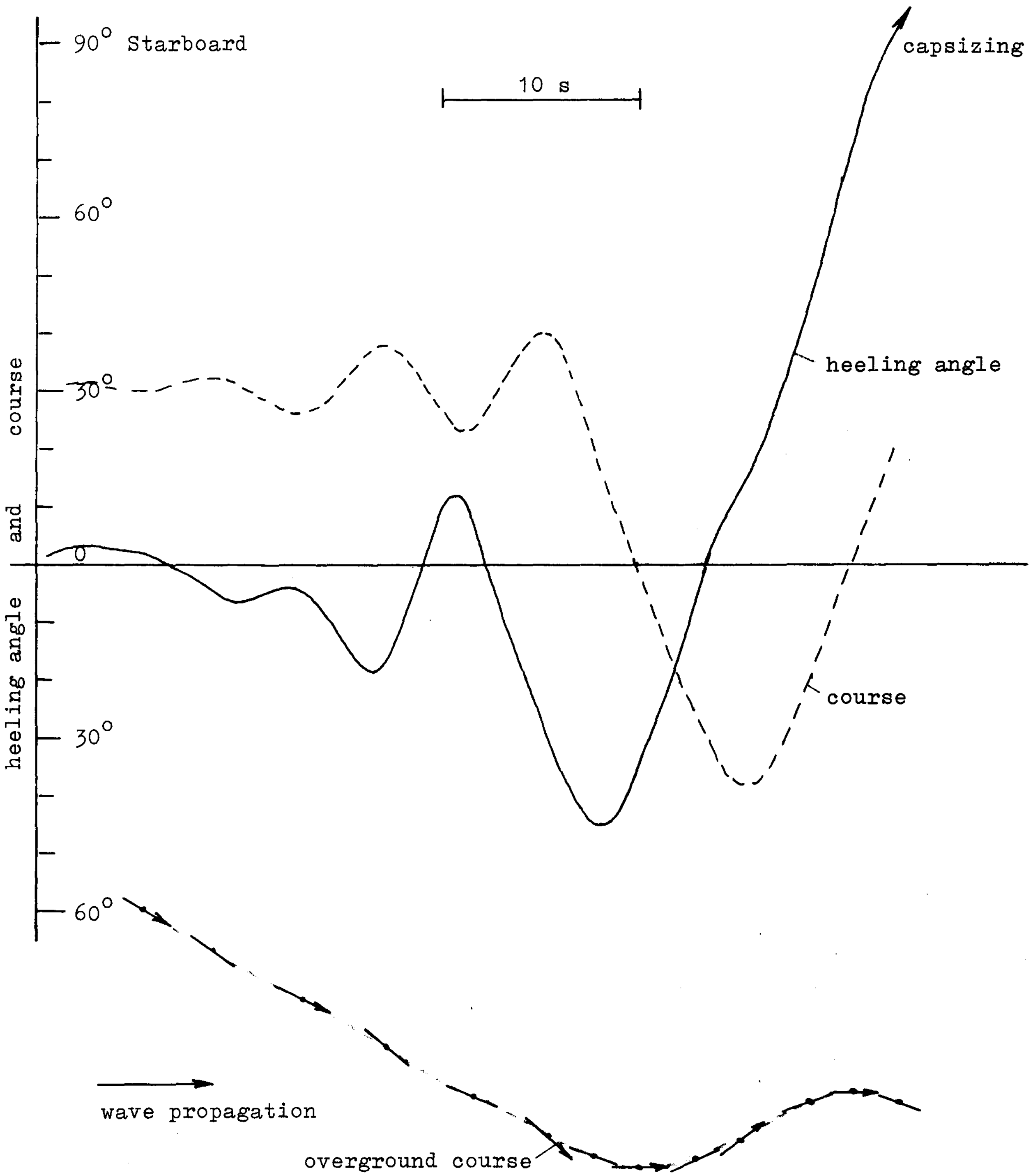


Fig. A 13 Run No. 121

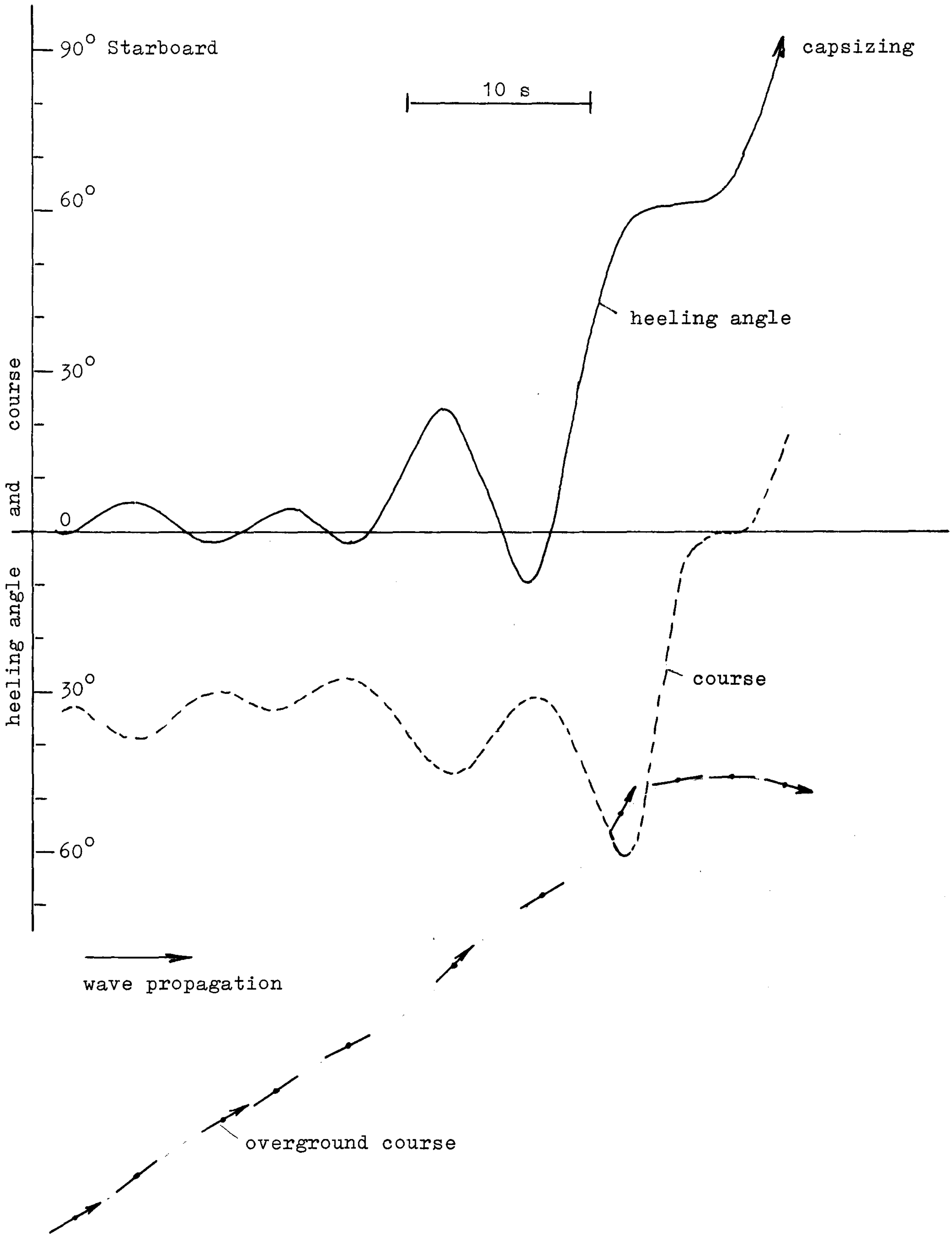
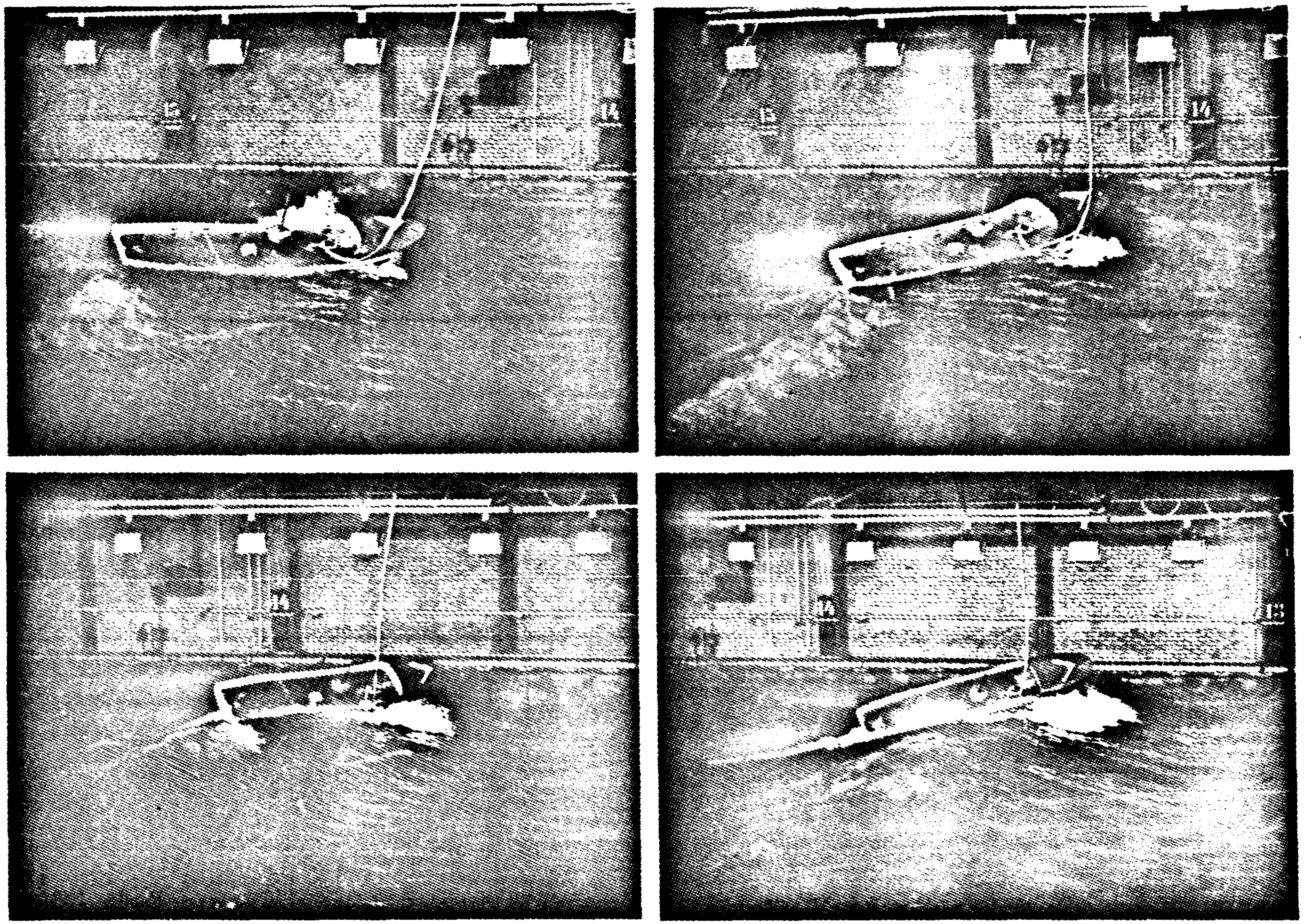


Fig. A 14 Run No. 130

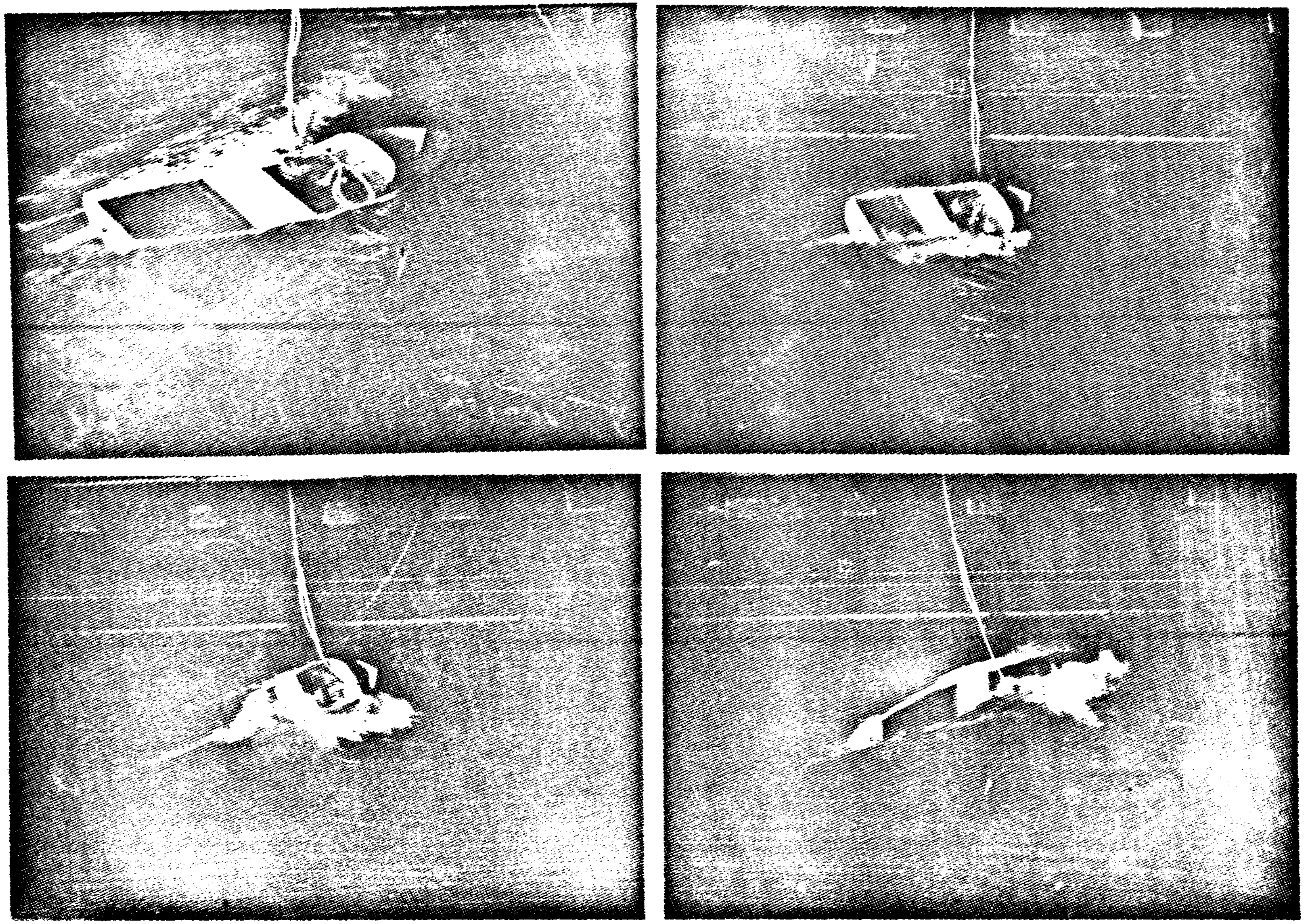


Ship running in abt. 30° stern sea

Freeboard 0,90 m; Volume of displacement 200 m^3; GM_o = 0,45 m

without volume body on deck

Fig. P 1

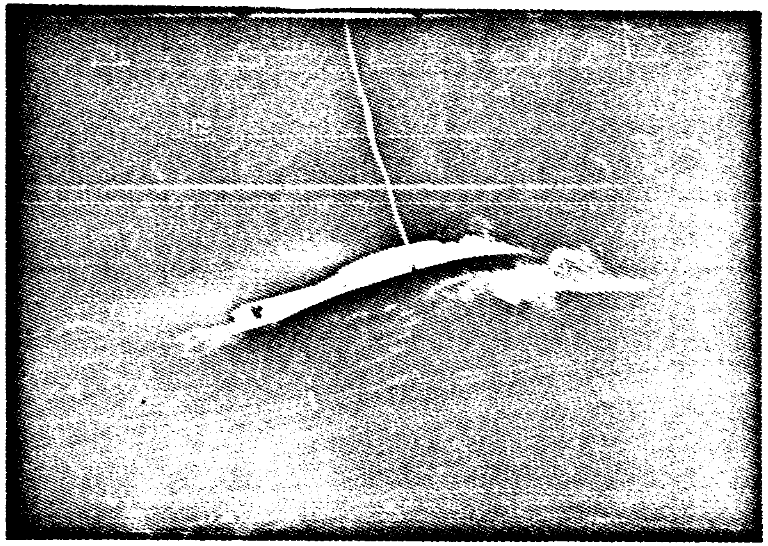


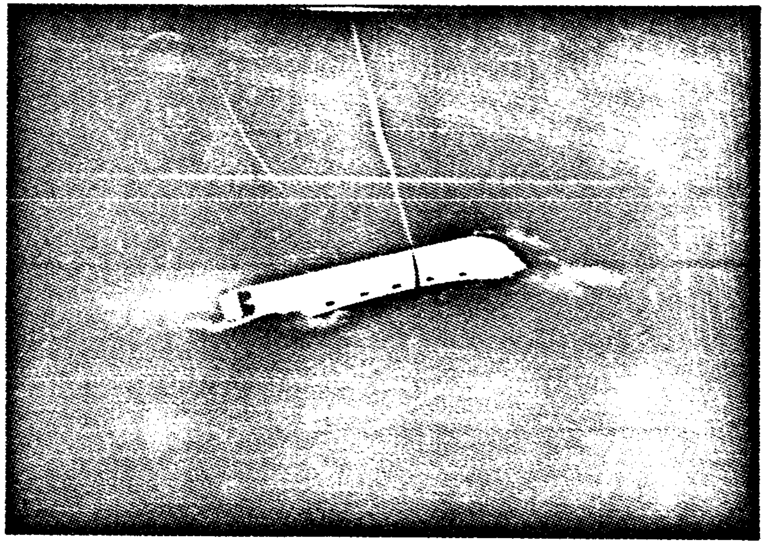
Ship running in abt. 30° stern sea

Freeboard 0,90 m; Volume of displacement 200 m^3; GM_o = 0,45 m

with transverse volume body on deck

Fig. P 2



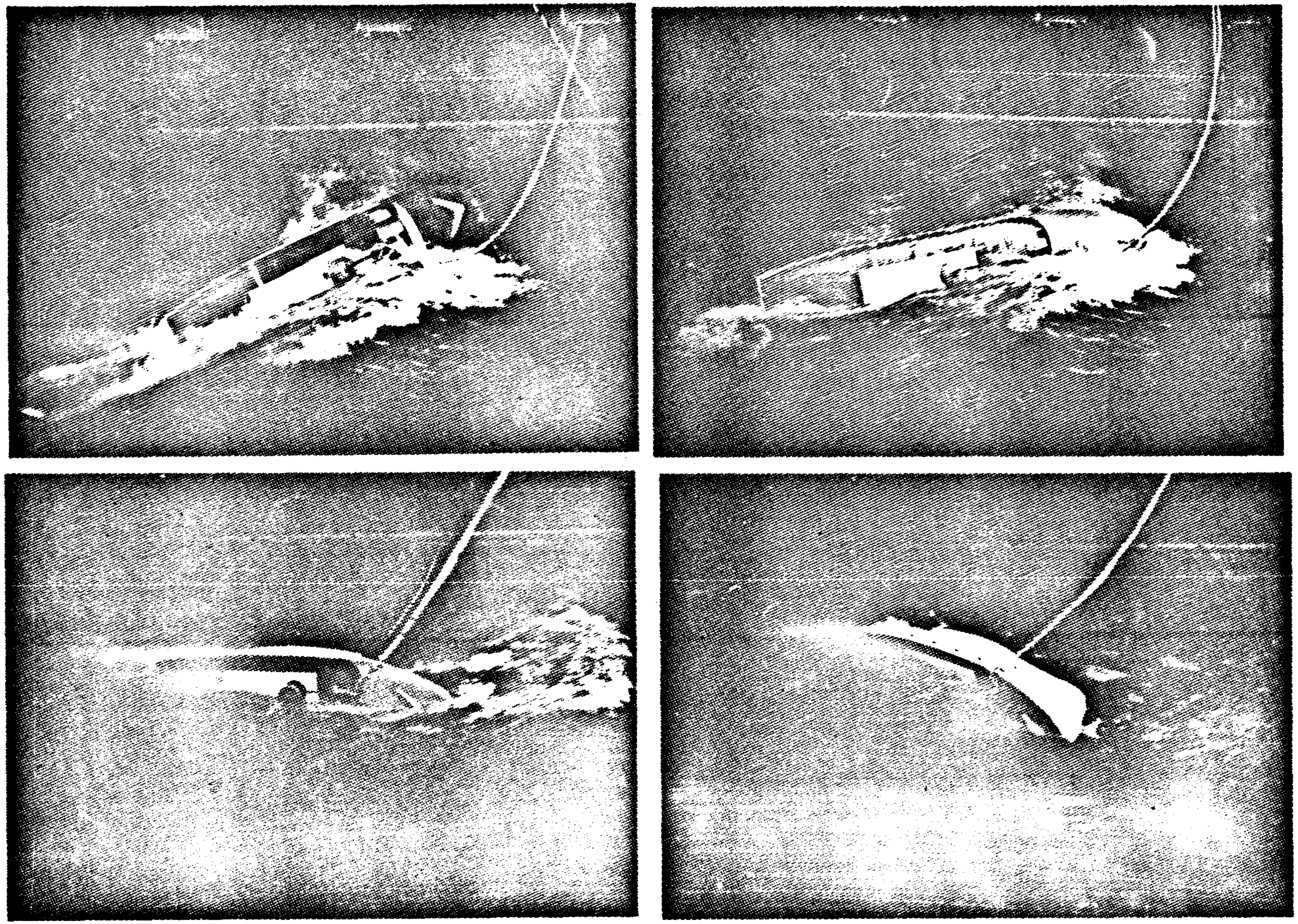


Ship running in abt. 30^{o} stern sea

Freeboard 0,90 m; Volume of displacement 200 m^3; GM_o = 0,45 m

with transverse volume body on deck

Fig. P 2a

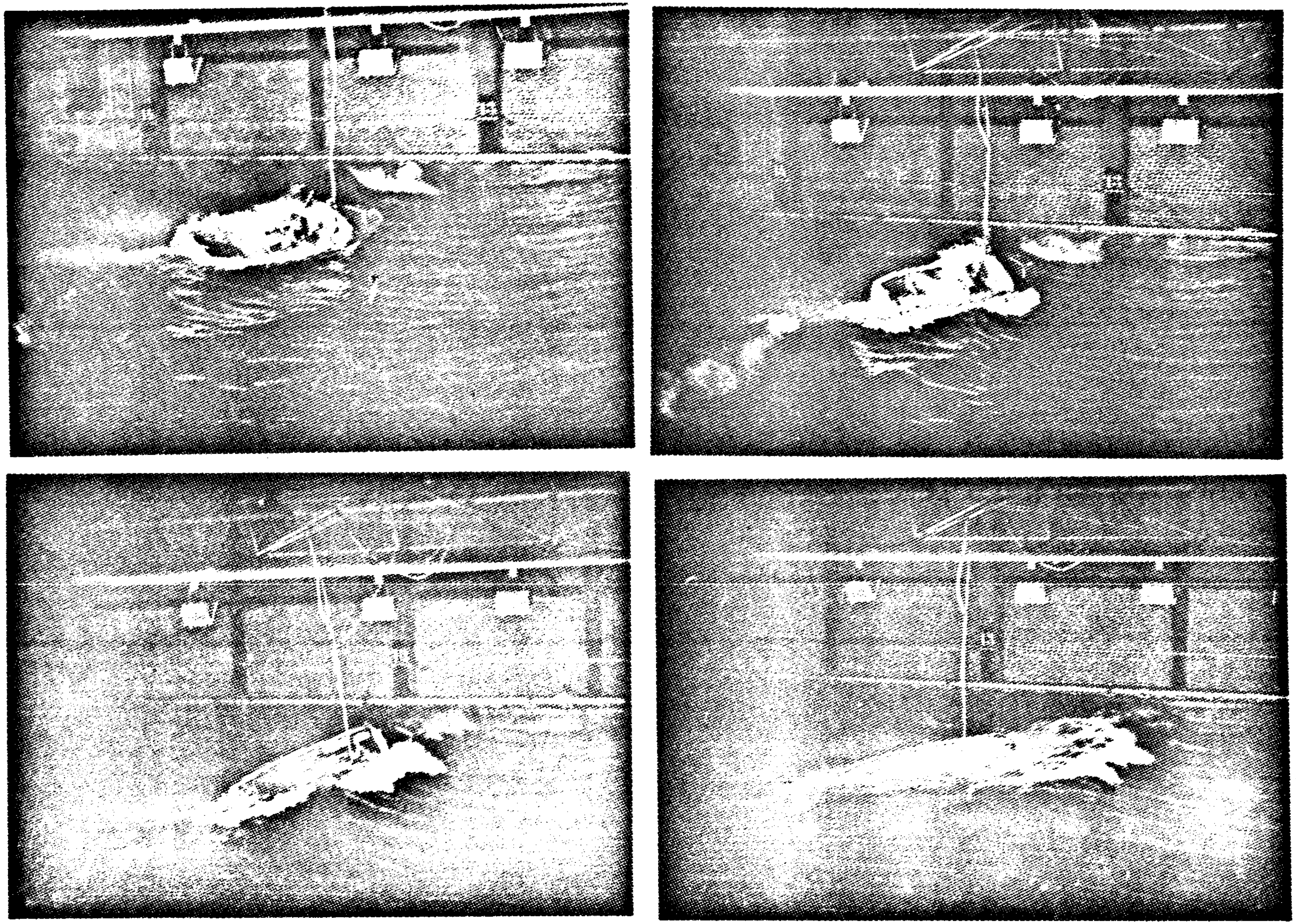


Ship running in abt. 30° stern sea

Freeboard 0,90 m; Volume of displacement 200 m^3; GM_o = 0,45 m

with longitudinal volume body on deck

Fig. P 3

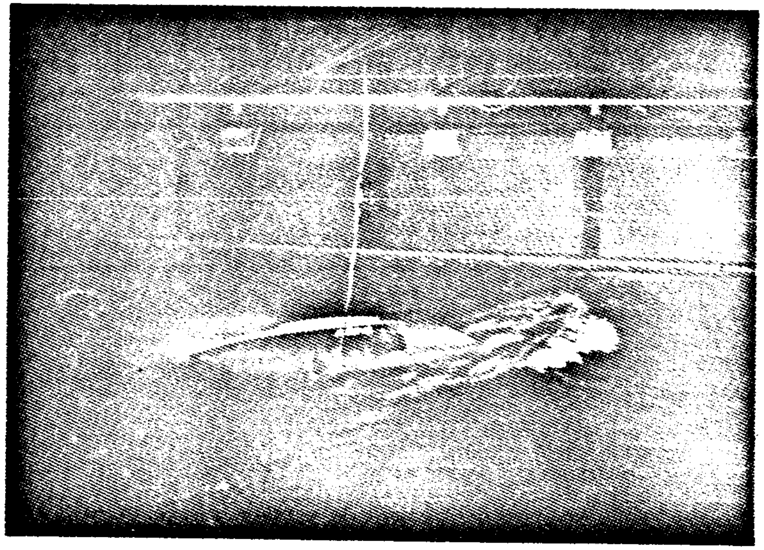


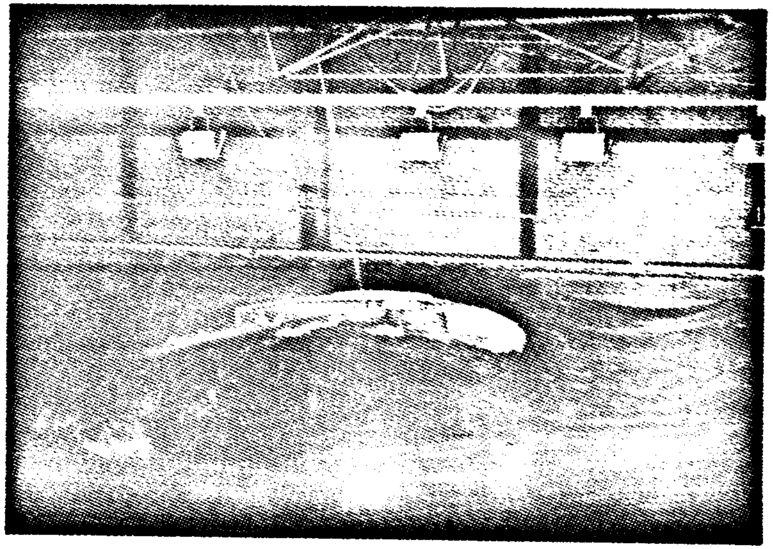
Ship running in abt. 30° stern sea

Freeboard 0,60 m; Volume of displacement 242 m^3; GM_o = 0,50 m

without volume body on deck

Fig. P 4



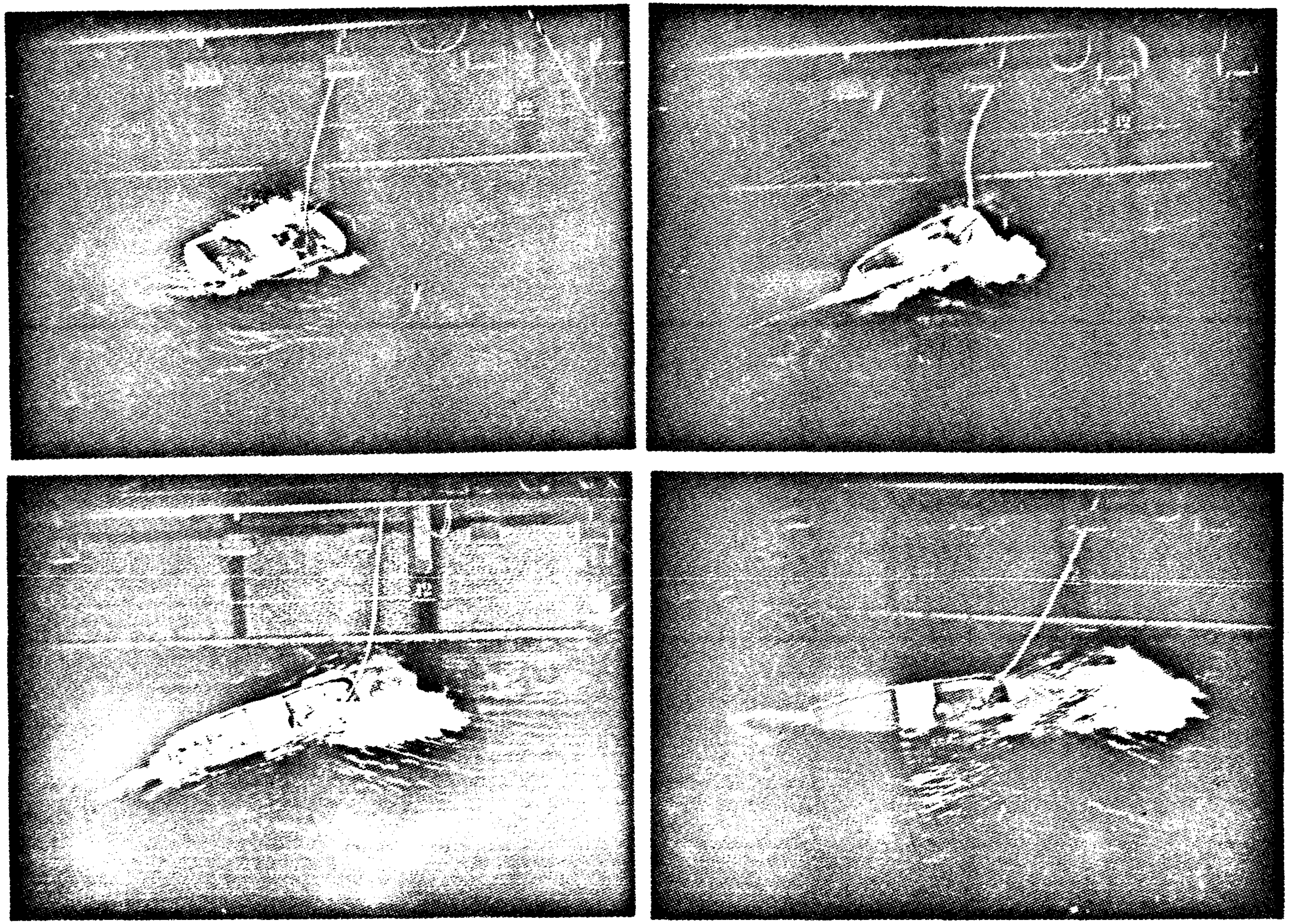


Ship running in abt. 30° stern sea

Freeboard 0,60 m; Volume of displacement 242 m^3; GM_o = 0,50 m

without volume body on deck

Fig. P 4a

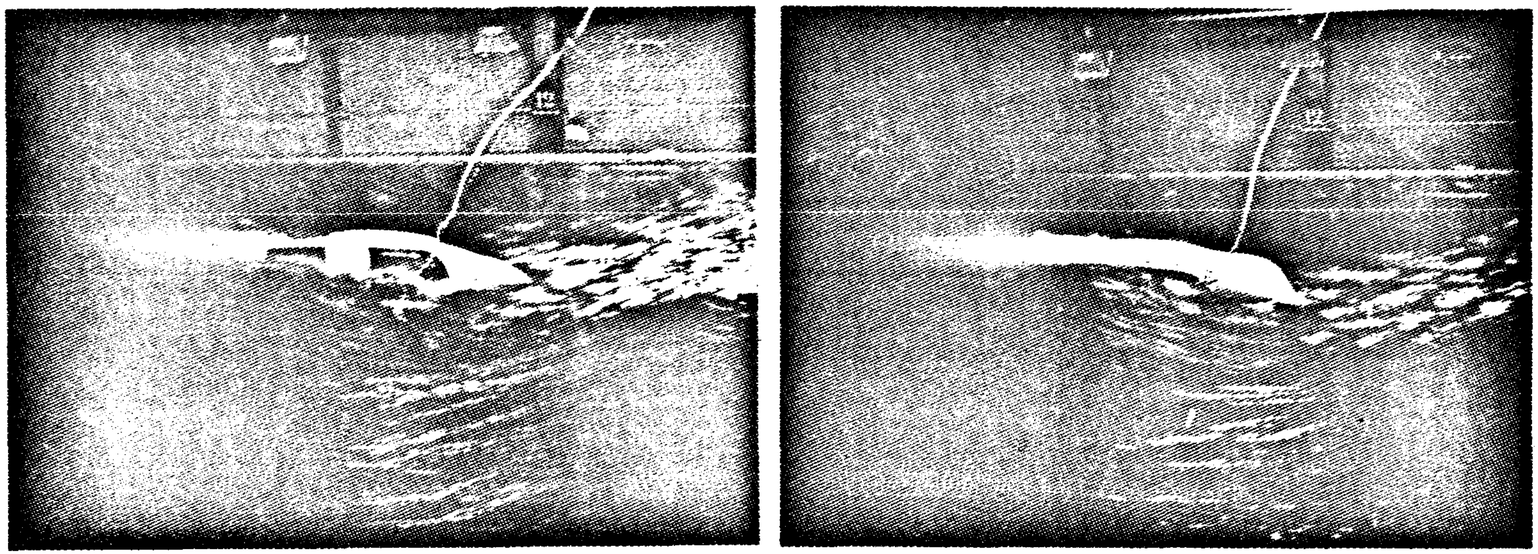


Ship running in abt. 30° stern sea

Freeboard 0,60 m; Volume of displacement 242 m^3; GM_o = 0,50 m

with transverse volume body on deck

Fig. P 5

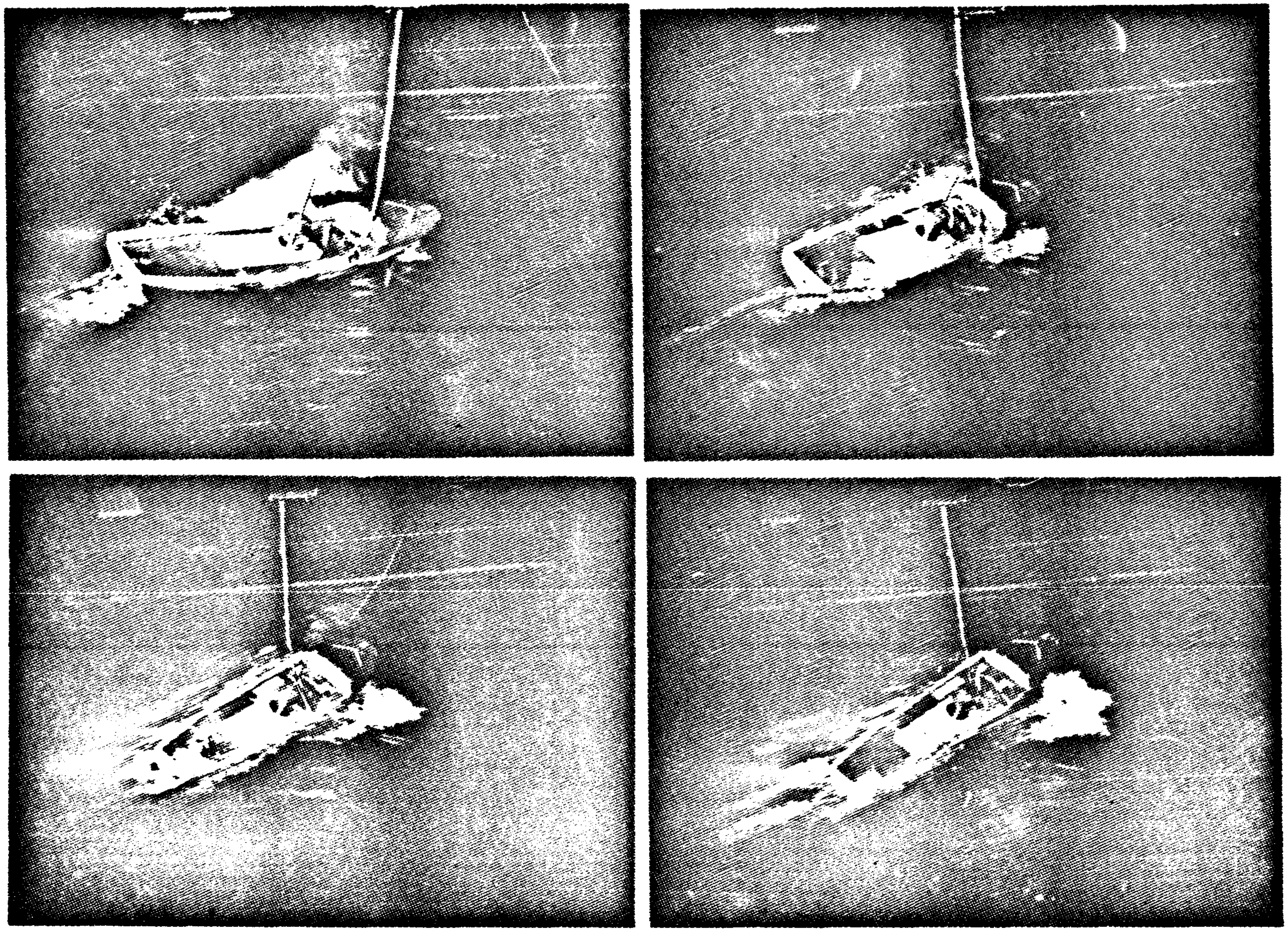


Ship running in abt. 30° stern sea

Freeboard 0,60 m; Volume of displacement 242 m^3; GM_o = 0,50 m

with transverse volume body on deck

Fig. P 5a

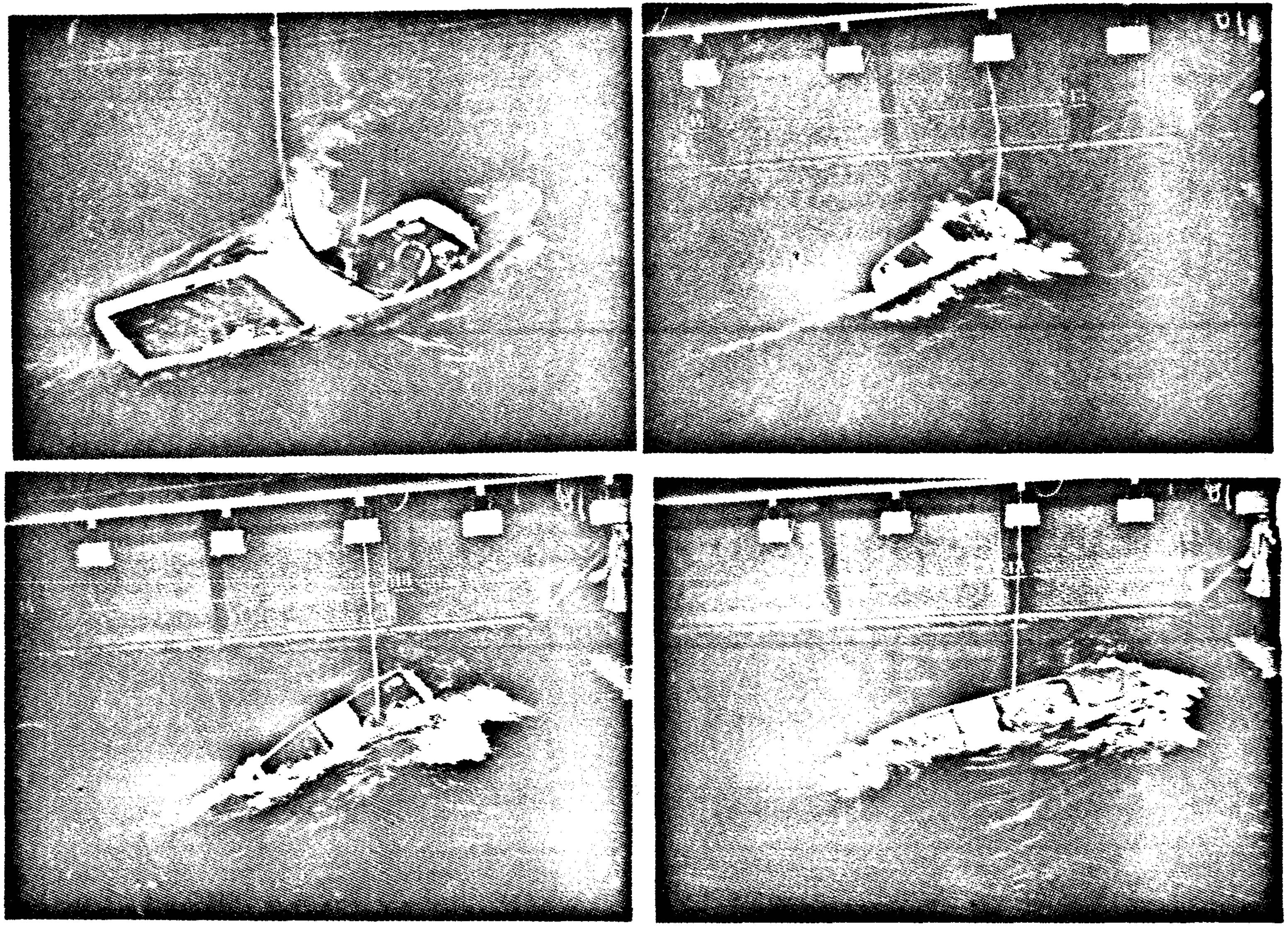


Ship running in abt. 30° stern sea

Freeboard 0,60 m; Volume of displacement 242 m^3; GM_o = 0,50 m

with longitudinal volume body on deck

Fig. P 6

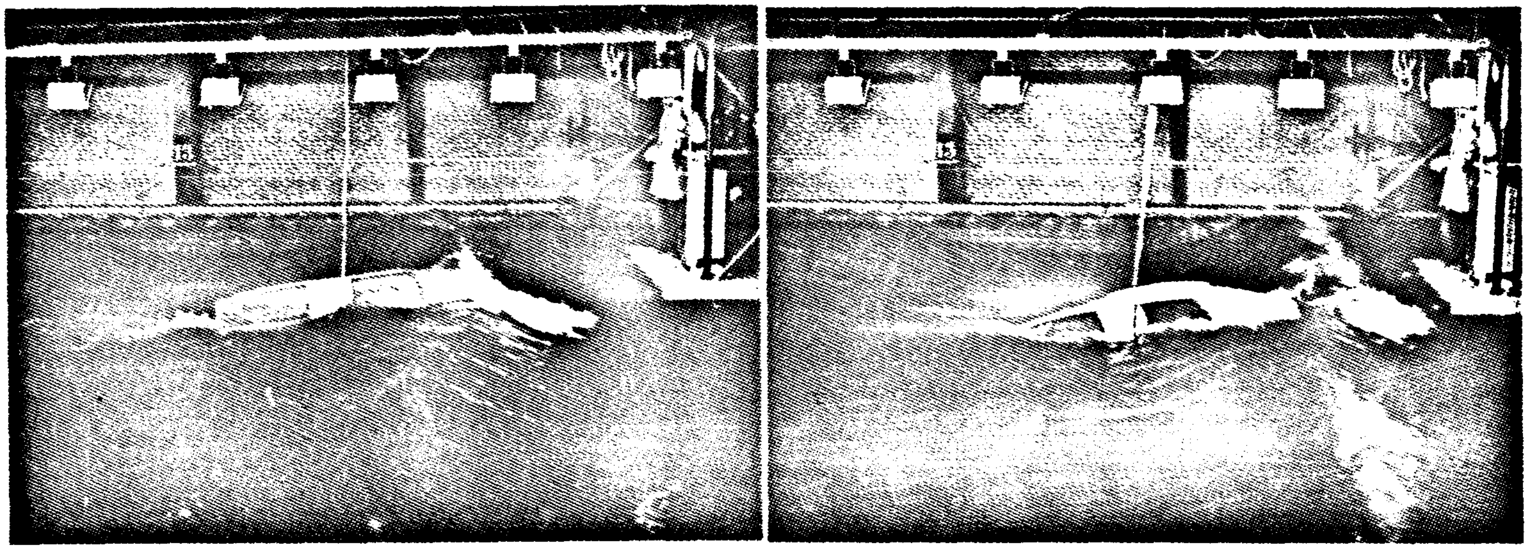


Ship running in abt. 30^{o} stern sea

Freeboard 0,40 m; Volume displacement 271,5 m^3 ; GM_o = 0,55 m

with transverse volume body on deck

Fig. P 7



Ship running in abt. 30° stern sea

Freeboard 0,40 m; Volume of displacement 271,5 m^3; GM_o = 0,55 m

with transverse volume body on deck

Fig. P 7a