On Unusual Phenomenon in Manoeuvrability and its Successful Countermeasure of a Fishery Research Vessel*

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These days we sometimes have experienced or heard of full-bodied ships with so-called "unusual phenomena" in manoeuvrability, and these ships seem to increase in number rapidly because of growing the fullness of hulls.

Herewith in this paper an example of such a phenomenon appeared in a fishery research vessel is dealt with. Turning tests and zig-zag tests were conducted, using both the ship and its 1/10 scale model. Oblique towing tests, β-varying tests (in which the drift angle is changed slowly) and observation of the stern flow, furthermore, were made in a towing tank using the model.

In consideration of these experiments, a center fin shutting the large clearance above the propeller and the rudder was fitted to both the ship and the model. The results were satisfactory and the unusual phenomena no longer appeared. Therefore, the course stability recovered almost completely and both the model and the ship could keep the course without any difficulty.

1. Introduction

Generally, a fishery boat has a comparatively large deck area and a smaller value of L/B (length-breadth ratio), so that she can keep stability and permits deck works. In spite of a smaller C_B (block coefficient) boat, the engine room tends to be arranged as backwards as possible and the ship form is rather fat locally in aft body.

In such a fishery boat, strange behaviours are often observed and called "unusual phenomena in manoeuvrability"[1)-4),7)].

In this paper "unusual phenomena" appeared on a fishery research vessel and also on its model ship are investigated. In the results, strange behaviours in this ship and her model are explained as "two states of flow field corresponding to one state of ship motion". To eliminate the unusual phenomenon and to improve course stability of the ship, a simple and effective countermeasure was found.

2. General view of the ship

In Table 1 the principal particulars of the ship and her model are listed. She is a fishery research vessel with an ordinary fishery boat form, though her L/B is a little bit smaller than usual.

Fig. 1 shows her form. The remarkable features of her form are the fat stern, especially of the upper-fore part of the propeller, the small curvature of 2.0 m water line, and the large clearance and the flat frame lines adove the rudder and the propeller.

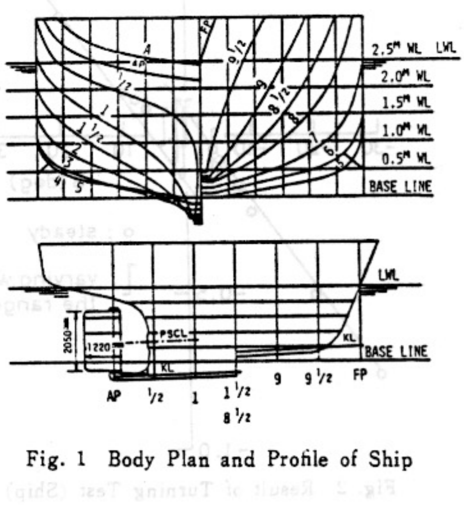

Fig. 1 Body Plan and Profile of Ship

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Table 1 Principal Particulars of Ship and Model

			SHIP		MODEL
			original	with fin	free running and PMM tests
Length × breadth × depth		(m)	27.8 × 6.00 × 3.00		2.78 × 0.6 × 0.4
Mean draught		(m)	2.55	2.50	0.2668
Draught at FP		(m)	1.71	1.61	0.2168
Draught at AP		(m)	3.39	3.38	0.3168
Block coefficient			0.638*		0.638
Displacement		(ton)	272.80*		0.26615
Rudder area ratio			1/27.8		1/27.8
Ship speed		(m/s)	5.04*		1.30
Propeller	Diameter	(mm)	1600		160
	Blade number		3		4
	Pitch (angle)	(mm)	960(15°) : CPP		96
	Revolutions	(rpm)	370		890

*) designed

3. Result of free running tests

The tests of the ship were held under the condition of Table 1. As the tests of the model were held at the designed draught, the ship is comparatively stern-trimmed.

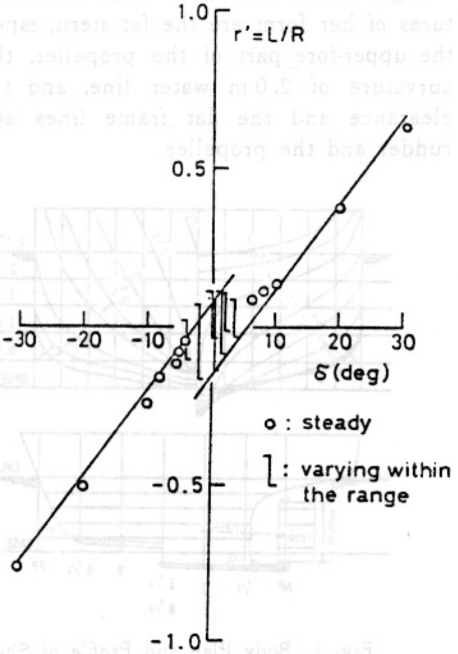

Fig. 2 Result of Turning Test (Ship)

Fig. 2 shows the turning characteristics of the ship, where δ is rudder angle, r' is non-dimensional rate of turn, L is the ship length and R is the turning radius. In the large range of rudder angle, it shows fairly stable. Within the smaller rudder angle, however, it looks quite strange. Fig. 3 is the record of yaw rate ($\dot{\psi}$) with constant rudder angle, and the record looks like as if the rudder angle has changed alternatively, though the hydrodynamic forces acting on the ship are supposed to change stepwise instead.

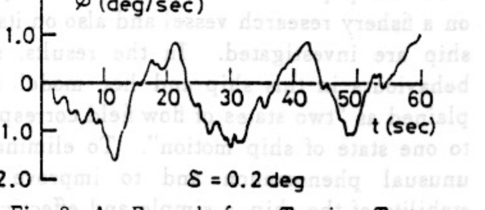

Fig. 3 An Example from Turning Tests (Original Ship)

The condition and the result of the model tests are also shown in Table 1 and Fig. 4. In this case, the turning characteristics is almost divided into two curves and the gap between them corresponds to about 10° in rudder angle. However, as to the frequency of appearance,

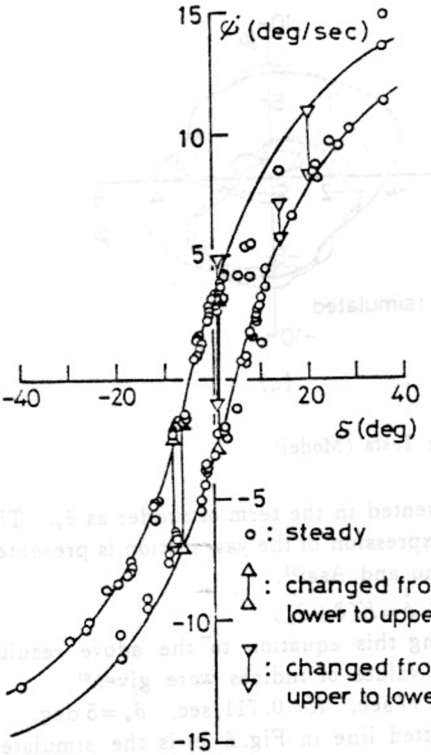

Fig. 4 Result of Turning Tests (Model)

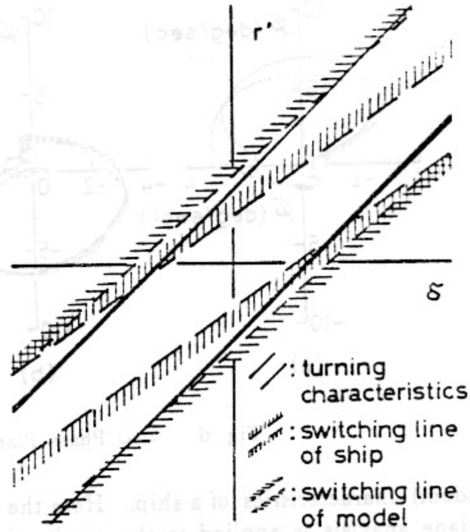

Fig. 5 Sketch of Turning Characteristics and "Switching Line"

there is a difference between the two lines.

Comparing the turning tests of the ship with the model, the apparent features are somewhat different, although the basic character is the same: Two hydrodynamic forces act in each turning motion. In the case of the ship, one of the curves fades away in the larger range of rudder angle and the self-oscillating alternation of yaw rate occurs in the smaller range. In the case of the model, there exist two steady states of turning.

Fig. 5 is a sketch prepared for the explanation of the difference between the ship and the model. The full lines mean two turning characteristic curves, which can be regarded as the same between the ship and the model. The "switching lines" described in broken lines are defined that, if the turning motion (in this figure it corresponds to the yaw rate, but, strictly speaking, it may correspond to the apparent drift angle at the stern) grows across the line to the hatched side, the flow field alternates with another.

In the ship, within the smaller rudder angle each turning characteristic cruve exists in the outsides of the switching lines, and therefore the motion oscillates between the switching lines. The difference between the maximum and minimum value in Fig. 2 corresponds to the gap of the switching lines. In the larger rudder angle, as one of the two turning characteristic curves is placed between the two switching lines each, only one state of motion is allowed.

Contrary in the case of the model, below the medium value of rudder angle, switching lines surround turning characteristic curves, hence each state of motion is realizable. In the larger rudder angle, switching lines and turning characteristic curves seem to be adjacent to or coincide with each other, and therefore two states of motion are not always coming up.

The "switching line" is conceived through the observation of the unsymmetrical stern flow separation, which will be described later in this paper. It might be reasonable to consider the slope or the gap of the switching lines is not the same between the ship and the model in consideration of Reynolds number etc. However, the fundamental feature of the turning characteristics of this ship/model—two hydrodynamic forces act on the ship in each motion of turning —is still persuasive.

In the followings, the results of zig-zag tests are described. Nomoto's K–T analysis is well-known as a method of Z tests analysis. (K and T are gain and time constants of ships' yaw motion respectively.) But for ships having such a phenomenon, it is not convenient to apply it, because it provides merely the average (time-

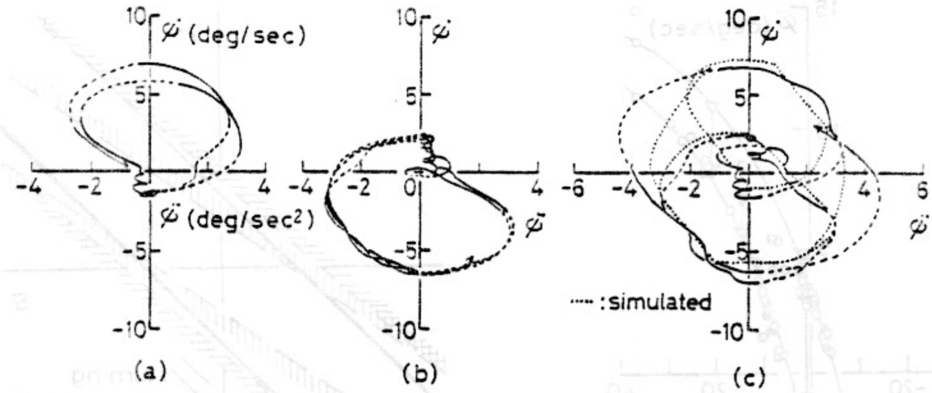

Fig. 6 $\dot{\psi}$-$\ddot{\psi}$ Phase Planes of Zig-Zag Tests (Model)

.ndependent) characteristics of a ship. Here the phase plane anaylsis is applied to the results of the model (see Fig. 6: $\ddot{\psi}$ and $\dot{\psi}$ denote yaw acceleration and yaw rate respectively).

The full lines in the figures mean that the rudder angle is kept constant, and the broken lines in the figures mean under steering. All the figures of Fig. 6, i. e., (a), (b) and (c) are odtained from the same 7.5° Z tests, though they seem to be very curious. In Fig. 6 (a) starboard rudder works well and port-side less. In (b) vice versa and in (c) both cases happen to occur. These results correspond to the two turning characteristic curves in Fig. 4 : (a) shifts on the upper line, (b) on the lower line and in the case of (c) at the very time when the 3rd rudder is commanded, the motion moves from the upper to the lower suddenly and consequently both trajectories are piled upon (c).

The following expression of the yaw motion ıs provided to describe the above ship motion. In the equation, an additional turning resistance acting on the hull is considered as well as usual turning resistance. This additional constant can be represented in the term of rudder as δ_a. The similar expression of the yaw motion is presented by Tagano and Asai[5].

$$T\ddot{\psi}+\dot{\psi}=K(\delta\pm\delta_a)$$

Applying this equation to the adove results, following values of indices were given[6].

$$T=1.77\text{ sec},\quad K=0.711/\text{sec},\quad \delta_a=5\text{ deg}.$$

The dotted line in Fig. 6 (c) is the simulated trajectory, using the obtained values of K, T and δ_a, and is in a fairly good coincidence with the observed one. The steady turning characteristics is, of course, able to be taken into account by this equation too.

Motore et al. presented several models of unusual phenomena[7] and the model, namely "system with abnormal moment around the origin" may correspond to the present case.

4. Hydrodynamic forces and flow field around stern

It is doubtless that the additional hydrodynamic force exists as well as usual hydrodynamic forces, as explained above.

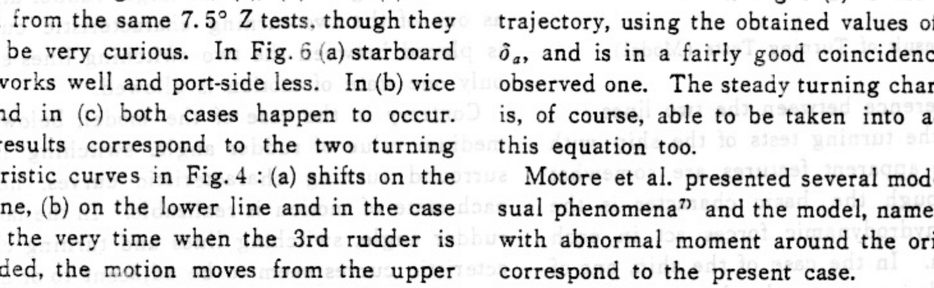

Fig. 7 Results of Oblique Towing Tests

In this section, the results of Planar Motion Mechanism (PMM) tests and of stern flow observation are presented.

Fig. 7 shows the results of oblique towing tests. In the figure Y' and N' are non-dimensional forms of lateral force (Y) and moment (N) around the center of gravity respectively. From the results the stepwise alteration of hydrodynamic forces could be observed about at $-8°$, $+1°$ and $+8°$ of drift angle (β) and this fact verifies the idea mentioned in the first paragraph of this section and also corresponds to the results of free running tests dealt with in the former section.

Are hydrodynamic forces acting on the hull affected by the past history of the ship motion? Sometimes yes, and sometimes no. To certify the question in this case, a kind of tests in which the drift angle is very slowly (about 0.5 deg/sec) changed by PMM was carried out. Fig. 8 is the results of the tests. The broken lines in the figure represent the results of oblique towing tests and the arrows attaching on the full lines mean the direction of the alteration of drift angle respectively.

Within 10° of drift angle, it is obvious that two hydrodynamic forces work on the hull. Because of the initial condition of setting or the different provability of occurence of two values, in the oblique towing tests, both values do not appear at the same drift angle. If the drift angle is over 10°~12°, only one of them acts.

Concerning to the working position of the additional hydrodynamic force, which does the force act on, the hull or the rudder? To certify it, the nominal rudder force was also measured in the tests, and it enables to separate the lateral force and moment acting on the whole ship into two parts each; on the hull and on the rudder. After this separation, it made clear that to a large extent the additional force works on the hull, though to a little extent it does on the rudder, and the apparent point of acting is found around A. P.

The flow field around the stern was observed to investigate the mechanism of generation of the additional force. The flow was visualized mainly by air bubbles getting out from the hull surface and auxiliarily by tufts setting on the hull surface. Owing to the buoyancy, the tracer bubbles are apt to float. This fault can be covered up, when smaller bubbles are used in higher towing speed. This method still has many merits such that it is easy to make and to keep the tank clean.

It is verified from the observation of the flow field that the unsymmetrical separation obviously occurs in the stern of this model. In the case of a usual slender ship the face side flow and the back side flow join at the center line of the stern and pass backward by the action of the propeller through the rudder. But in this ship, to some extent, flow crosses from starboard to port or vice versa over the rudder and the propeller. Owing to the crossing flow, the flow pattern differs between the starboard side and the port side. In one side, it flows smoothly, but in the other side, a separated flow accompanied with

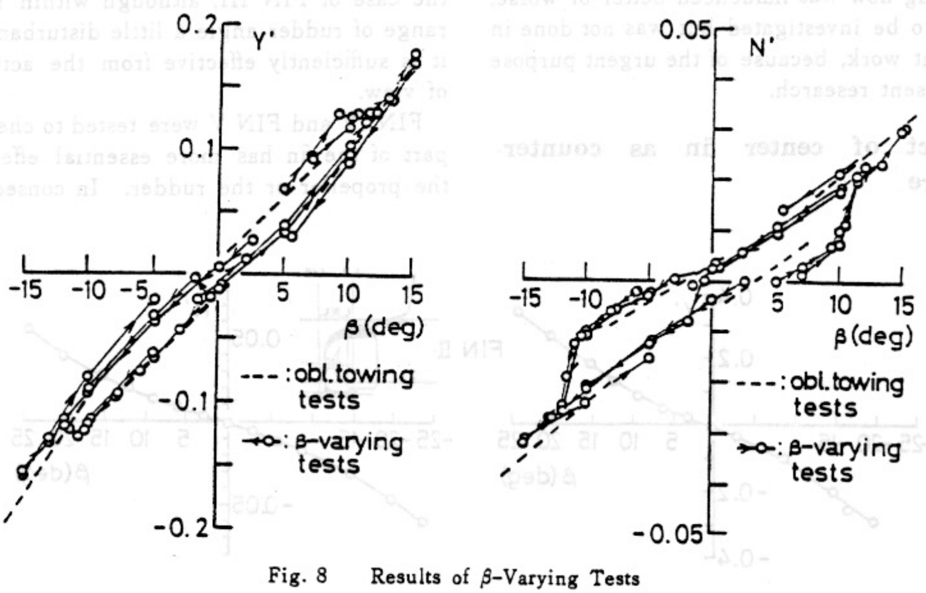

Fig. 8 Results of β-Varying Tests

vortices is produced.

Explaining about the flow pattern versus the drift angle more in detail, an example that the drift angle increases slowly from starboard 4° is examined. Until the drift angle increases about 9°, a large separation of flow is observed around the port-side stern (face side), when the crossing flow from starboad (back side) to port (face side) is produced in the clearance above the propeller and the rudder. But if the drift angle reaches near 10°~12°, the direction of the crossing flow suddenly alters and the flow passes through the clearance from port to starboard. This abrupt change of flow pattern does occur only near the critical drift angle. Of course, at the same time when the sudden alternation of flow happens, the hydrodynamic forces acting on the ship vary stepwise as shown in Fig. 8.

Considering the outstanding fatness around the s.s. 1/2 at 2.0 m water line in Fig. 1, the lines of this ship, it may be possible that the flow around this part separates. Separation itself, if it occurs symmetrically in both sides of a hull, does not produce any lateral force on a hull and has almost nothing to do with manoeuvrability. In this ship, however, the crossing flow through the aperture induces rather larger unsymmetrical separation, which is the problem. In spite of some change in drift angle, this unsymmetrical separation and also the value of the additional hydrodynamic forces do not vary.

Besides, it was observed that by steering or by the propeller loading, the sudden alternation of the crossing flow was influenced better or worse, which is to be investigated but was not done in the present work, because of the urgent purpose of the present research.

5. Effect of center fin as countermeasure

Through the results of the several tests mentioned adove, the countermeasure to be taken is almost arising. The fundamental measure is to alter the fat stern or frame lines, but it is more actual to equip a proper fin on the hull without changing the hull itself.

The center fin shutting the crossing flow through the clearance above the propeller and the rudder is to be fitted. By this fin the unsymmetrical separation, at least, may fade away or be weakened. In Fig. 9 an example of the center fin is illustrated.

The results of oblique towing tests and the observation of flow field after fitting the fin on the model were successful as expected: The unsymmetrical separation disappeared and the forces acting on the model both settled along one mean line as shown in Fig. 9.

To determine the shape of the center fin applying to the ship, free running tests, mainly turning tests, were carried out with several types of fins and the results are shown in Fig. 10 respectively. The broken lines in Fig. 10 are the more realizable part of the original model characteristics in non-dimensional form. If the large fin (FIN I) shutting the clearance over the center line almost completely to the stern is equipped, the turning characteristic curve draws nearly a line.

The shutting area of FIN II and FIN III is the same, though the part of the fin above the rudder is attached on the rudder (enlarged rudder) in FIN II and to the hull in FIN III. In the case of FIN III, although within the small range of rudder angle a little disturbance is left, it is sufficiently effective from the actual point of view.

FIN IV and FIN V were tested to check which part of the fin has more essential effect, above the propeller or the rudder. In consequence, it

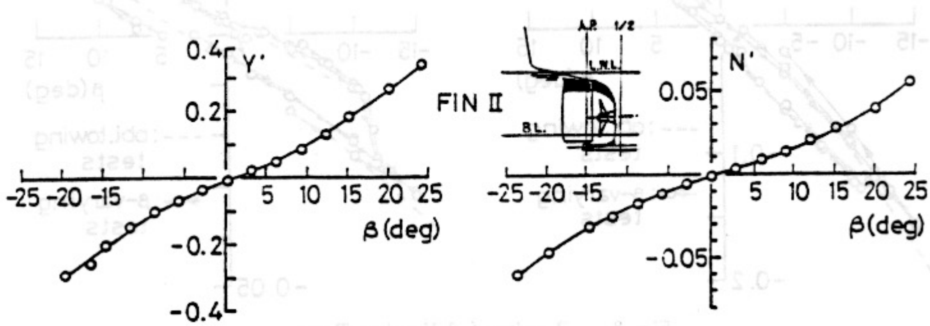

Fig. 9 Fin Profile and Results of Oblique Towing Tests

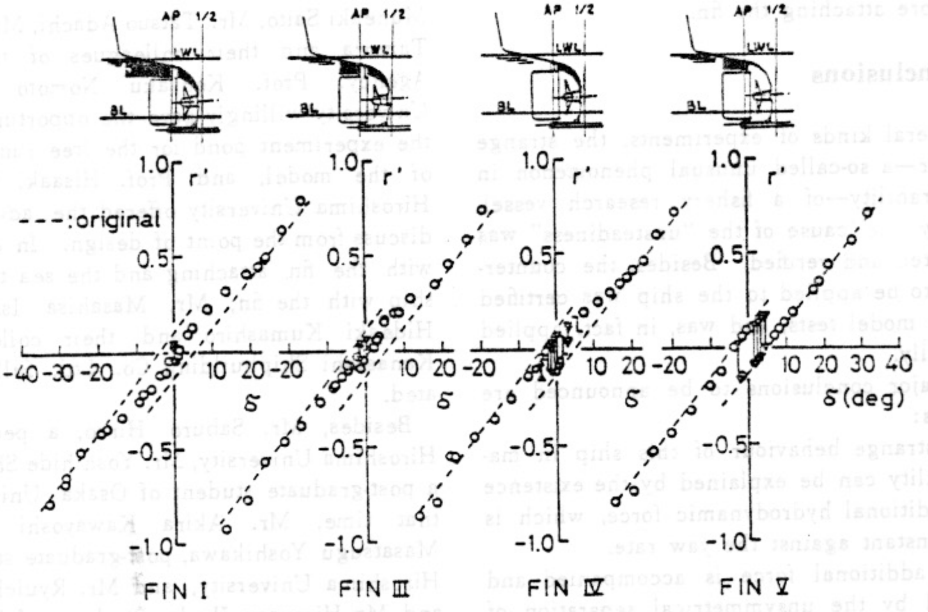

Fig. 10 Fin Profiles and Each Result of Turning Tests (Model)

was found that both parts should be shut and that the part above the propeller is more important to improve the characteristics.

In consideration of the above results, FIN III was decided to apply to the ship. To confirm the increase in resistance by the fin, the resistance test was carried out and the value was almost the same as that of the model without the fin. The photo of the fin attaching to the ship is shown in Fig. 11.

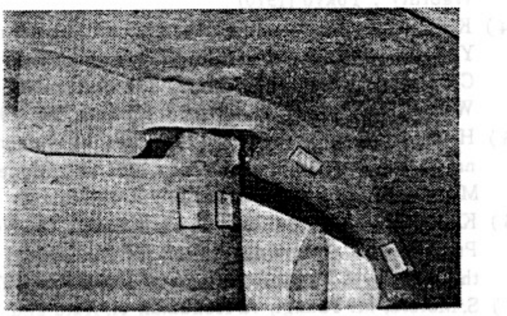

Fig. 11 Fin Profile of Ship

The sea trial of the ship with FIN III was performed in the condition of Table 1 and the result of turning tests is shown in Fig. 12 comparing with that of the ship without the fin. The result is truly satisfactory and the scattering within 10° disappears. In fact, the captain and the officers expressed their appreciations that they can at last navigate her without any anxiety. A little scattering of the values within the small

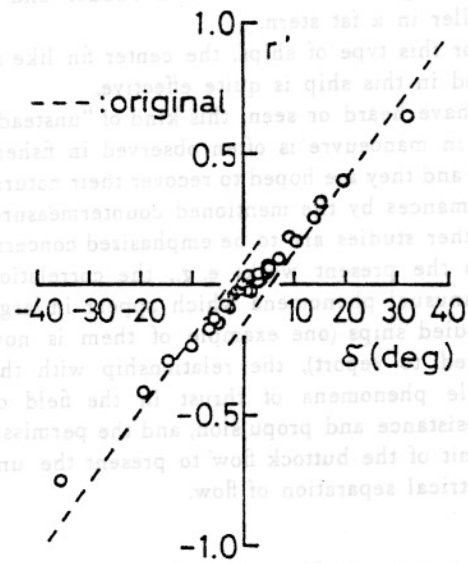

Fig. 12 Result of Turning Tests (Ship with Fin)

range of rudder angle is about the same as that of the model with the fin, and the results of Z tests by usual K-T analysis are not different with those of normal stable ships.

As the fin attaching near the propeller tips sometimes accompanies a severe hull vibration, several attentions as possible were paid for the decision of the sectional form of the fin and the detail works at the construction. Fortunately, the vibration was almost the same as that of the ship before attaching the fin.

6. Conclusions

By several kinds of experiments, the strange behaviour—a so-called unusual phenomenon in manoeuvrability—of a fishery research vessel, especially the cause of the "unsteadiness" was investigated and verified. Besides, the countermeasure to be applied to the ship was certified from the model tests, and was, in fact, applied successfully.

The major conclusions to be announced are as follows:

1) The strange behaviour of this ship in manoeuvrability can be explained by the existence of the additional hydrodynamic force, which is almost constant against the yaw rate.

2) This additional force is accompanied and influenced by the unsymmetrical separation of flow induced by the crossing flow through a rather large clearance above a rudder and a propeller in a fat stern.

3) For this type of ships, the center fin like as applied in this ship is quite effective.

As have heard or seen, this kind of "unsteadiness" in manoeuvre is often observed in fishery boats, and they are hoped to recover their natural performances by the mentioned countermeasure.

Further studies are to be emphasized concerning to the present work; e. g., the correlation with unusual phenomena which appear in large full-bodied ships (one example of them is now prepared to report), the relationship with the unstable phenomena of thrust in the field of ship-resistance and propulsion, and the permissible limit of the buttock flow to present the unsymmetrical separation of flow.

The autors would express their sincere acknowledgement to the many people who have collaborated with them in various stages of the present work.

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