On Wave-Wake Interaction Near A Ship Stern

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1. Introduction

When we conducted a resistance test of a trimaran Wigley model to investigate a blockage effect, as seen in Fig.1, a spot off the line at around Fn=0.26 of the trimaran made us wonder whether it is a reasonable spot or due effect of an experimental error. If we look the move of resistance dynamometer in precise, there have been two stationary values in a run and the starting point of ship stern waves followed to these movements. We immediately supposed that this may be a feature of wave-wake interaction worthwhile to study.

As to the wave-wake interaction of S103, Doi of Hiroshima Univ. presented a short note with the present author to this past MIT-workshop where we have given a global view on this problem. The present paper is just complementary to this work that came up close to the present author.

2. Starting point of stern waves

We observed a Fn effect on the generating location of stern waves of Wigley models(Fig.2) to compare with that of S103 model(Fig.3). The model S103 is an Inuid, stream-traced from a simple source distribution $m(\xi)=0.4\xi$ $(|\xi|\leq 1)$, the draft of which is assumed to be infinite - so 2-D form in an analytical sense.

From these figures we find that

① the forward shift is almost periodical based upon $1/Fn^2$ and the amounts increase with Fn, which are common to all cases.

② but their shape of the variation is quite different between Wigley models and S103 model.

The above first point is acceptable, but the second point seems to need a little consideration. Perhaps the flow around Wigley model is 3-dimensional so that a complicated interaction between bow waves & the boundary layer(BL) might have occurred. While in case S103, the flow is 2-dimensional, so that the simplified or idealized interaction occurred. It is easy to imagine that the BL growth is smooth along framelines, and the transverse wave system is more prominent near the BL with respect to model S103.

3. A mechanism of interaction to be postulated

These results reminded us a former study carried out on S103 and make us consider the mechanism of the interaction between bow waves and the boundary layer. Fig.4 is an overview of S103 wave profiles measured by Doi where the starting point of stern waves is notified.

It may be not difficult to postulate the interaction mechanism as follows. The generating point of stern waves moves fore and aft depending on Fn in accordance with oncoming bow wave phase at the stern. This periodical movement is closely related to the Cw curves. The increase in advanced start of stern waves appears at the hollow zone of Cw curves, while its gradual retardation occurs with increasing Fn until to the most delayed start, close to AP(stern position), which corresponds to the hump zone in the Cw-curves.

If we accept once the above relation, two prospects are expected.

(1) One is a kinematical relation to be required on the shape of Cw curves.

(2) The other is a physical relation concerned with stable or unstable stern flow.

With regard to (1), there exists an effective ship length defined by the distance from bow to the starting point of stern waves. This effective ship length varies with geometrical Fn (defined by invariant ship length). With the elongation of the effective ship length, Fn based on this effective ship length does not proceed so fast as geometrical Fn, so the Cw curves is elongated or give rise to a longer rising slope, while the shrinkage of the effective ship length, so called effective Fn proceeds faster than the geometrical Fn, so the Cw curves is pressed into a short range, that means a short falling way. It is illustrated in Fig.5 which the author prospected in some places. Actually we see such tendency on the usual Wigley resistance curves (Fig.6).

With regard to (2) prospect, we imagine that there is stable or unstable flow condition regarding stern wave generation. As well known the flow is accelerated at wave trough due to the wave orbital motion which suppresses the BL-growth, while it is decelerated at wave crest that assists the BL-growth. If we look Fig.4, the stern waves are always born on the steep rising wave slope near the stern where the vertical upwards flow component or so called a kind of flow separation is most probable. At special Fn, such as Fn=0.22, 0.26, 0.35, stern waves hesitate to start or consider at a loss which of the two probable points (one is just around AP, the another is far front rising slope) is suitable for start. Just after this speed, stern waves jump up to start at most probable ahead position of the ship side as we see in Fig.3. The jump should be reflected on Cw or resistance curves. But in the former research(Fig.7) we could not find such special jump on the Cw curves. We carried out a more careful resistance test around these two Fn ie 0.22 and 0.27 (we excluded 0.35 because of the strong disturbance flow) and found experimentally a small but certain discontinuous resistance curves (Fig.8). Note that Cw in Fig.7 is expressed in a form of $R_w/1/2 \cdot \rho U^2 L^2$, but Ct is in a different form. Two jumping Fn difference is almost 2π in the sense of $1/Fn^2$ expressions. It is regrettable that the present author does not yet try numerical analysis.

4. Conclusions

Through experiments and imaginations we learned two prospects on wave-wake interaction. One is a special feature of Cw curves - long rising slope around hump and short falling way around hollow. Another is resistance discontinuity happens at specialized Fn on an idealized 2-D flow model where the vertically smooth BL and the rich transverse bow waves interact each.

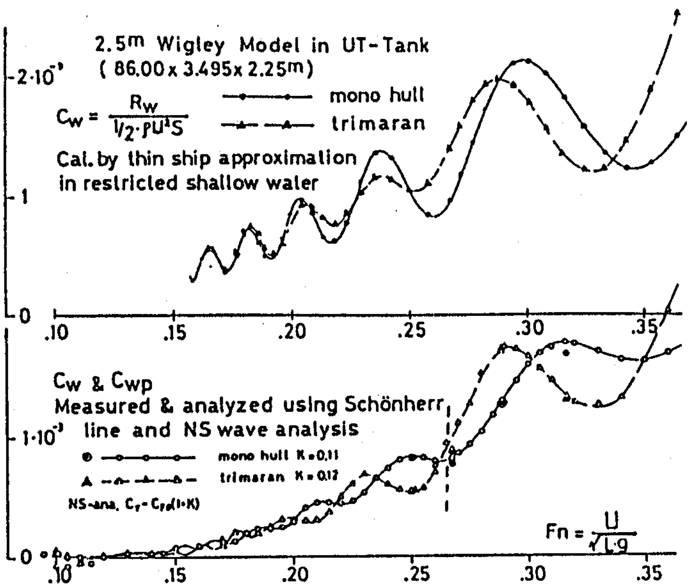

Fig.1 Wave resistance coefficient in restricted water

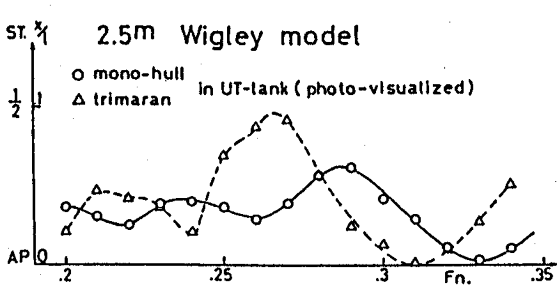

Fig.2 Starting point of stern waves

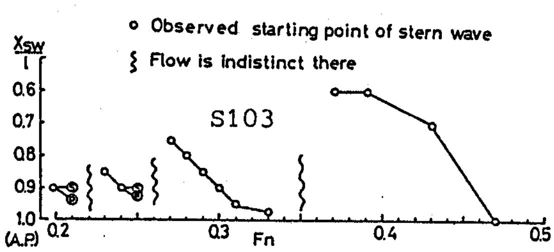

Fig.3 Starting point of stern waves

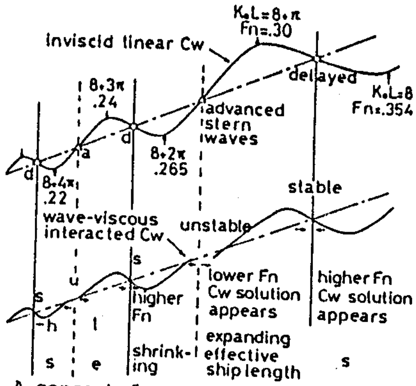

Fig.5 A concept for change of Cw phase due to wave-viscous interaction at stern

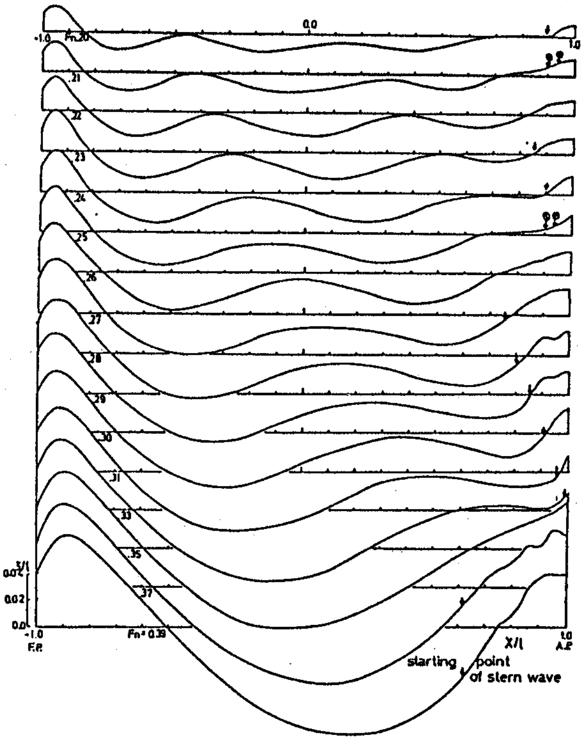

Fig.4 Observed wave profile (S103)

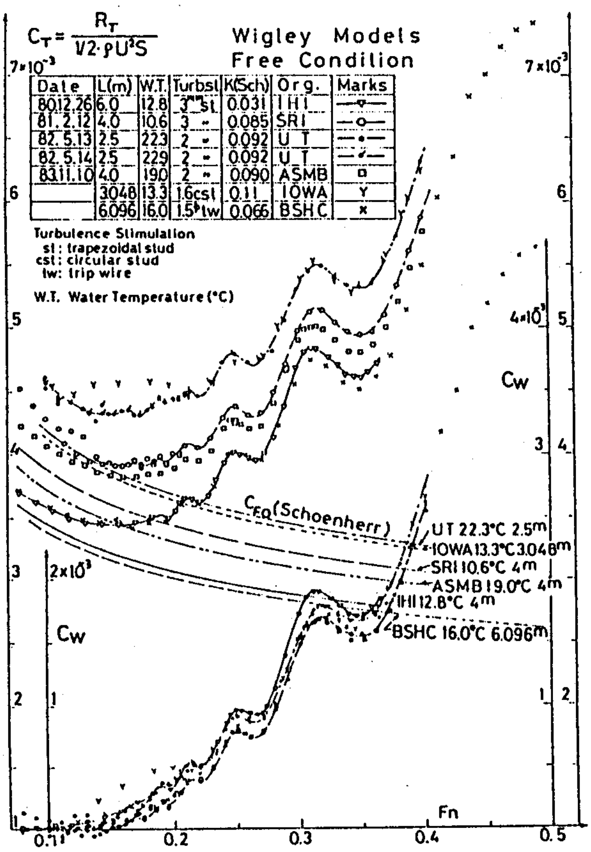

Fig.6 Resistance test results, a work of ITTC cooperative experiments

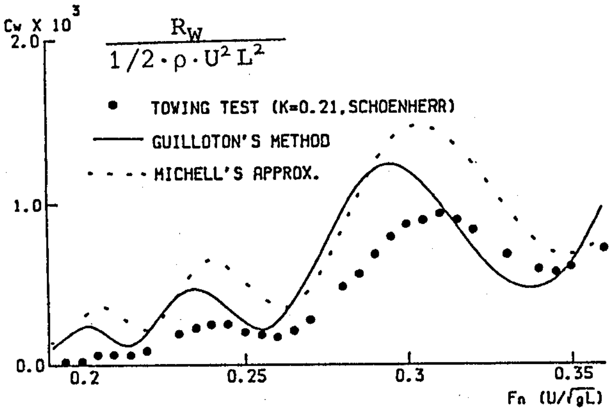

Fig.7 Wave resistance curves of S103

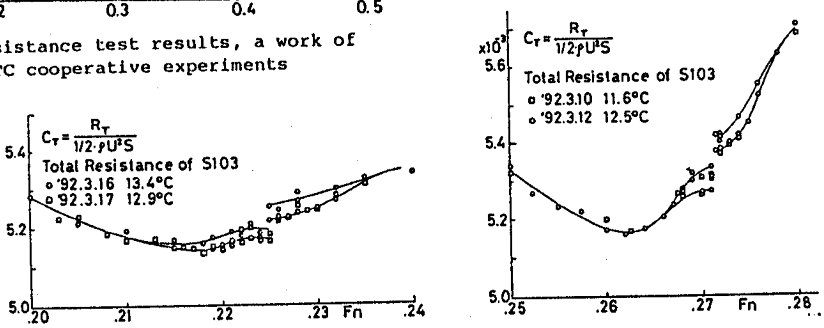

Fig.8 Discontinuity of resistance curves (S103)

DISCUSSION

Clement A.: Do you know any case of such a phenomenon (i.e. discontinuity in resistance curve) for actual ship (real size)?

Kajitani H.: This may not happen with actual ships. Because the flow around the actual stern is different from that of scaled down model. Immediately three reasons come out.

1) As Prof. Tulin pointed out in his discussion, propeller suction makes the flow faster, so that we may not expect such stern wave movement.

2) Even if we assume the without propeller case in a real size ship, such interference occurs in most probable condition, only when BL and wave action are in each balanced strength. BL is relatively small in real size due to the high R_n, so that the flow approaches ideal flow where the interaction bacomes impossible. Of course you may agree to that the objective of the present talk is to show how to look and synthesize many experimental results in a single rational stream.

3) As mentioned in my talk, actual commercial hull is complicated so called 3-D shape, quite different from S103 2-D model, even different from high level wave making Wigley hull. We can't see hump and hollow Cw curves in most commercial ships. So, may not. I thank you very much for your discussion. But this does not the guarantee of discontinuity in resistance of real size. There may be such phenomena by many other reasons of which I 'm not aware.