Bow Waves on Fine Ships - Nonlinear Numerical Studies

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A detailed numerical study has been carried out of the divergent wave field produced by the bow of ships with small entrance angle. Two specific families of shapes have so far been treated: inclined slender wedges, and slender Wigley hulls. Some calculations are also made on a frigate.

The calculations are carried out with high resolution in two dimensions (the cross flow plane) and in time, i.e. 2D+T. The full nonlinear free surface boundary conditions are applied within the 2D+T approximation.

The calculations so far carried out show that the flow at the bow of slender hulls at normal ship speeds involves: 1) a rising spray sheet, which eventually decelerates due to the action of gravity, 2) a strong divergent gravity wave (A) originating aft of the stem, and which leaves the hull travelling outward, eventually breaking, followed in same cases by 3) another divergent gravity wave (B), usually weaker than (A). Further waves do not seem to arise. See Figure 1.

In same cases one or both of these divergent waves break, see Figure 2. The breaking of these divergent waves creates substantial white water and vorticity, which trails aft and joins ship's wake.

As seen in the case of the Wigley hull, the strong wave (A) originates further aft of the stem as the speed increases, and at its origin has a substantial angle to the hull, see Figure 3.

These two waves (A) + (B) shed light on the ship's actual divergent wave spectrum, which plays a very important role in the resistance of ships at high speeds, according to thin ship theory; but the latter is certainly inadequate for the prediction of a significant part of the divergent wave spectrum. The question therefore arises as to the actual divergent waves produced by slender ships at high speeds.

It was the conclusion by Ogilvie [1] (see the comment of Tuck in [1]) that 2D+T theory is an adequate approximation for the treatment of slender bows at normal ship speeds; the same conclusion is implicit in the analysis of Maruo [2] with regard to the treatment of the bow splash due to motion in oncoming waves. These conclusions could seem especially valid with regard to the treatment of bow splash (which we show is directly related to water impact) and of the divergent waves which follow.

The inclined wedge, for which a length scale is absent, offers an important opportunity for understanding the morphology of bow waves of fine ships. For an inclined wedge (wedge angle α, stem angle β) at speed U, the wave height η, at any longitudinal location $\vec{x}$, from the wedge stem, must obey the scaling law:

$$\kappa\eta=f(\kappa\vec{x};\ \alpha;\ \beta), \qquad \text{where } \kappa=g/U^2$$

As a result, it is obvious that the flow near the bow begins as a self-similar spray, just as in gravity-free water entry. This is confirmed in the present calculations, which then show that for sufficiently large values of $\kappa\vec{x}$, the effect of gravity causes the spray to decelerate, fall and eventually break over; meanwhile, the divergent gravity waves (A) and (B) arise. For very large $\kappa\vec{x}$ the influence of gravity dominates, and waves seem suppressed.

Finally, these calculations shed light on the wave resistance originating at the bow. In the case of inclined wedges, the bow resistance, R_b, is:

$$R_b \sim C_D \cdot \rho U^6/g^2$$

where C_D depends only on the wedge angles. Values of C_D are calculated and presented.

References

1. Ogilvie, T.F., " The wave generated by a fine ship bow", Proceedings of the 9-th ONR symposium on Naval Hydrodynamics, 1972.

2. Maruo, H., " Prediction of deck wetness: A Theoretical Development", Technical Report 90-53, Ocean Engineering Laboratory, UCSB,1990.

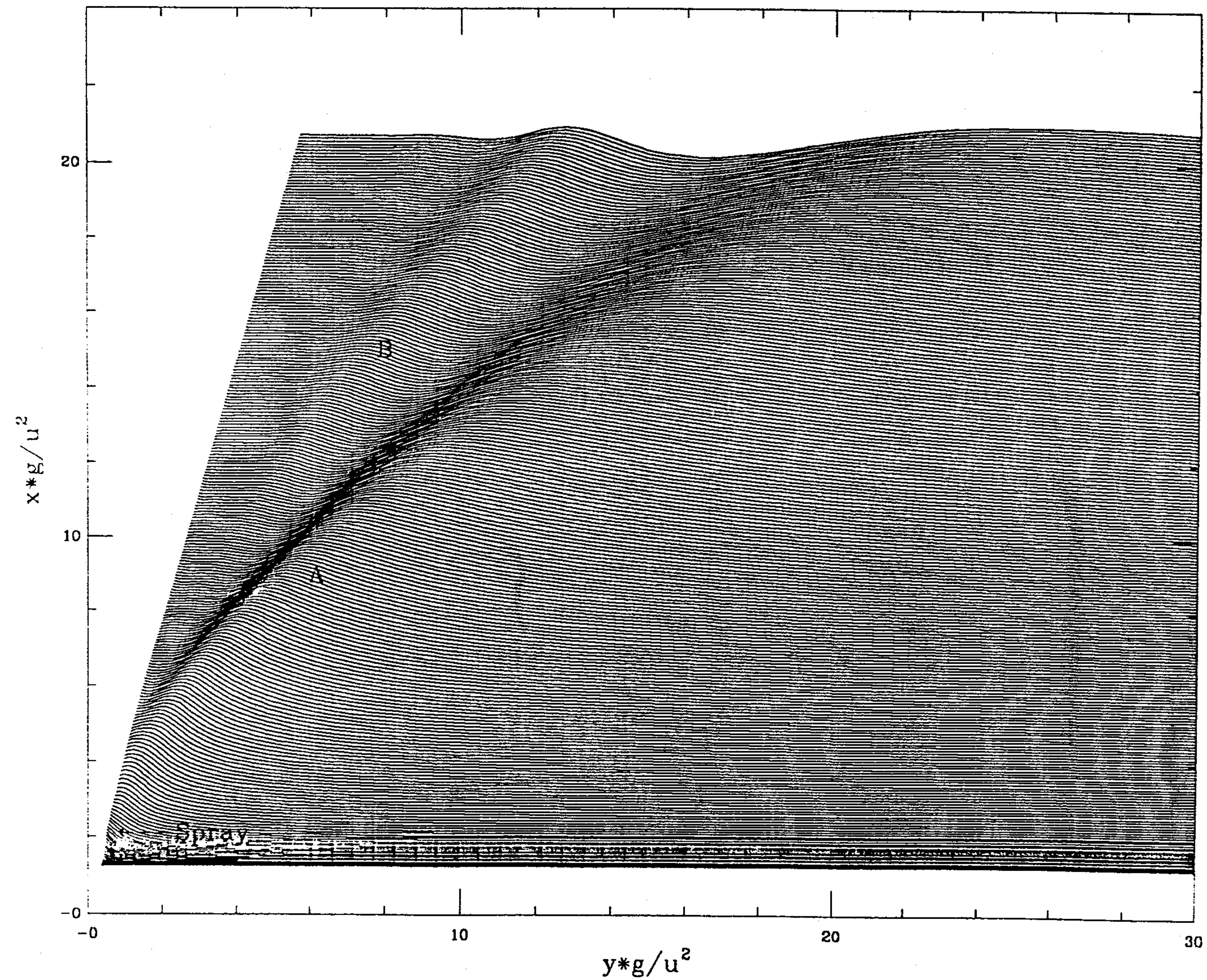

Figure 1. The Waves Field Produced By a Wedge of Angle 18°, Stem Angle 45 °, Traveling at Speed U

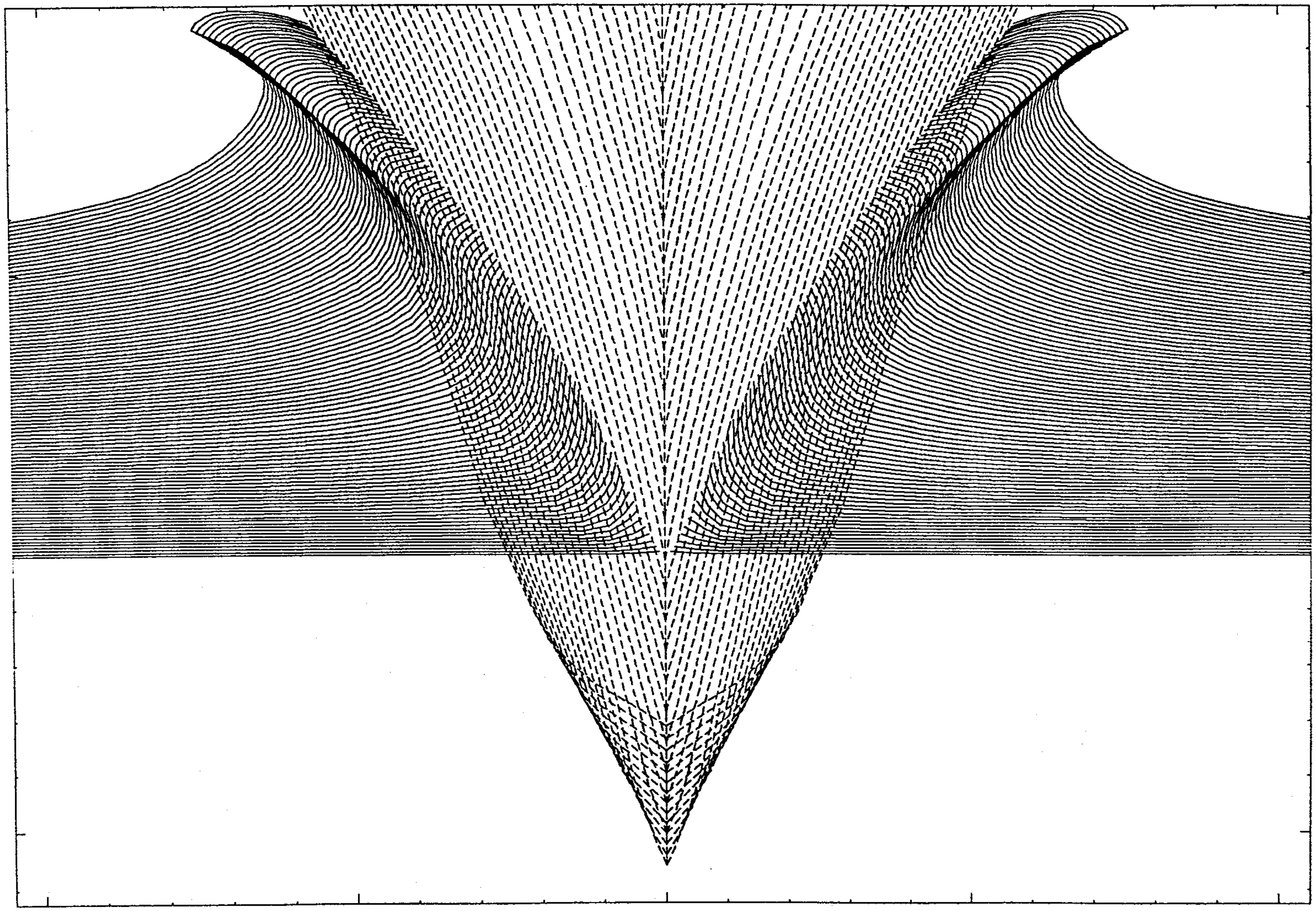

Figure 2. Bow Wave Produced by Frigate Hull, F_L=0.5

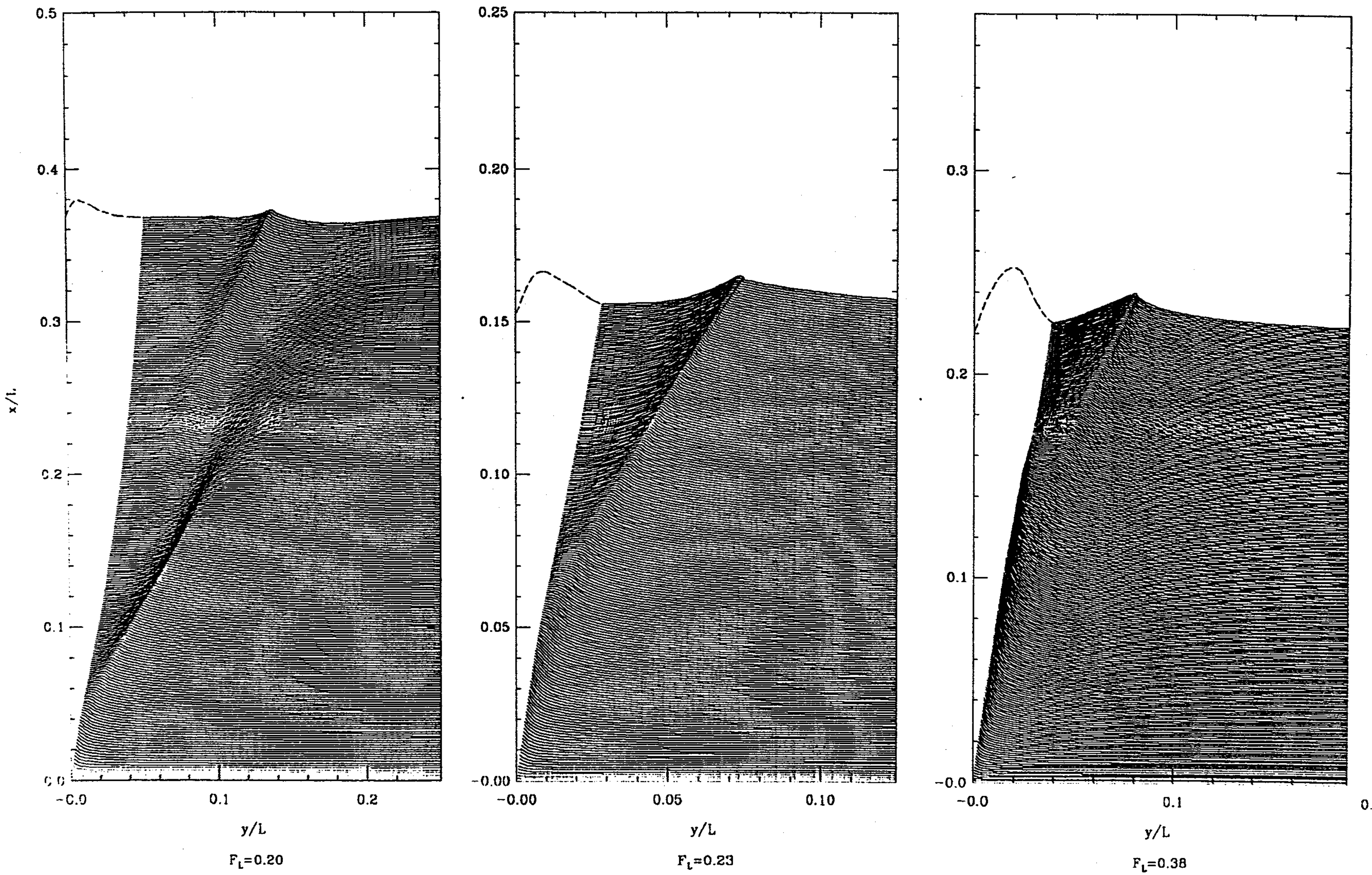

Figure 3. Bow Waves Produced By Wigley Hull (B/L=0.11) Moving Through Still Water

DISCUSSION

Roberts A.J.: An alternative description of "waves" A and B is that they are just different crests of the one wave. Water waves are dispersive and so we expect crests to move through the region of the wave energy which propagates at half the speed of the crests.

Tulin M.: Basically agreed.

Mori K.: According to my observation, the free surface around steep crests are fluctuating with rather high frequency. I think the fluctuation may be an important factor. How do you think about its effects?

Tulin M.: In these calculations we did not observe fluctuations such as you described. Neither have we observed them with our LONGTANK calculations of overturning waves. I would be interested to know whether such fluctuations have been observed in other high resolution calculations.

Kajitani H.: What is the physical difference between Bow Waves and Body Waves? Is it acceptable that body waves are generated from some non smooth ship sides? If so, can we assume that the existence of such body waves appeared on the numerical evaluation for Wigley Hull may be due to the numerical disturbance along hull?

Tulin M.: Definitions: Bow waves (A and B) seem to originate near the stem; Body waves may be traced back to some point on the curved (smooth) hull far out of the stem. No, I do not think at the present time that these body waves are due to numerical disturbances. However, we need to study the maths further.

Yue D.K.P.: A clarification question: You mentioned obtaining spurions wave with excessive grid sizes – you mean excessively large grid sizes of course?

Tulin M.: Yes, of course

Choi H.S.: Would you comment on any differences in the wave field downstream between the cases if the stem angle is less than and greater than 45°? With this question I mean any possible connections to the nonlinear diffraction or the so-called Mach reflection.

Tulin M.: We have not yet done calculations for the stem angle greater than 45°, and I do not know what effects might arise. However, if the opening angle of the wedge is increased, I expect the divergent waves would disappear (this was shown by both Maruo and Tulin). We cannot, however, consider large opening angles using 2D+T.

Cao Y.: 1) Have you plotted the wave profile on the ship hull surface and compared it to the experimental results? It would be interesting to see the comparison.

2) There is a water surface rising ahead of the bow in the 3D case. The 2D+T approximation however does not predict that. Could you comment on the effect of the surface rising ahead of the bow on the bow wave system?

Tulin M.: 1) It is a good suggestion. Thank you.

2) We have not evaluated that effect, which disappears as the Froude number increases. The 2D+T computaion is powerful, but we must learn its limitations, and how to use it for lower Froude numbers.