The Generation and Decay of Waves behind High-Speed Vessels

Lawrence J. Doctors
The University of New South Wales, Sydney, NSW 2052, Australia
Alexander H. Day
The University of Glasgow, Glasgow, G12 8QQ, Scotland

Summary

The inviscid linearized wave pattern generated by high-speed monohulls and catamarans is investigated theoretically with a particular view to determining the rate at which the maximal wave range on a longitudinal cut drops off with transverse offset from the track of the vessel. It is shown that the maximal wave range varies approximately with the offset raised to an exponent. The value of this exponent generally lies between -1.06 and -0.20, depending upon the speed of the vessel.

1 Introduction

The subject of the present investigation is the matter of the rate of decay of the waves generated by high-speed vessels. In the past, it has been suggested by some persons concerned with the damage caused by the waves behind river vessels, that the wave height varies with the inverse cube root of the transverse offset from the track of the vessel. This misconception presumably has its origins in a misunderstanding of the work of Wehausen and Laitone (1960, p. 487, Equation (13.42b)) and of Stoker (1966, p. 242, Equation (8.2.40)). Those equations are only applicable for the variation along the Kelvin angle in the linearized far-field wave system generated by a point source traveling in deep water.

This rate of decay has also been investigated by Day and Doctors (2000), with some emphasis being placed on an elementary tent-like element. In the current work, we shall investigate the effect of some fundamental parameters, such as the length of the vessel and the choice between monohull and catamaran.

2 Mathematical Formulation

The coordinate system and principal parameters defining the problem are shown in Figure 1(a). The vessel has a length L, a draft T, and the beam of the hull or demihull is B_1. The spacing between the demihulls, in the case of a catamaran, is s. The width of the river or the canal is w and the depth of the water is d. The density of the water is ρ, the acceleration due to gravity is g, and U is the speed of the vessel.

The formulas of Newman and Poole (1962) have been used to compute the wave resistance of the vessels. Regarding the wave elevation, one may consult the work of Tuck, Scullen, and Lazauskas (2000) and Doctors and Day (2000).

3 Computer Program

Advantage was taken of the obvious spatial recursion relationship between two corresponding terms in the summation for the wave elevation, for two points in the wave field. In this way, considerable computational effort was saved.

Calculations were extended to a distance of at least 30 fundamental wave lengths downstream of the vessel. It was also important to ensure that the downstream distance was sufficient in order to capture the relevant data for the longitudinal wave cuts with the greatest lateral offsets. At least 30 points were computed for each wave length.

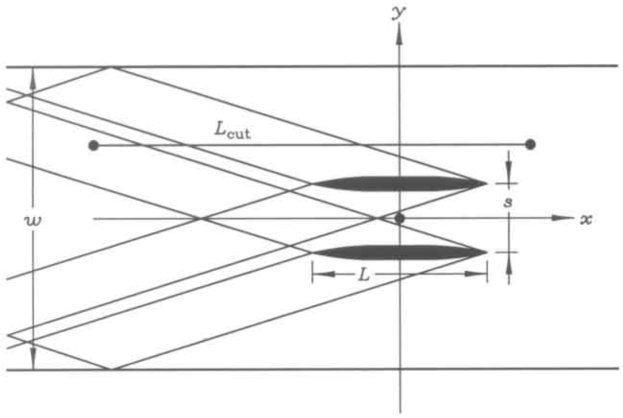

Figure 1: Definition of the Problem
(a) Coordinate System

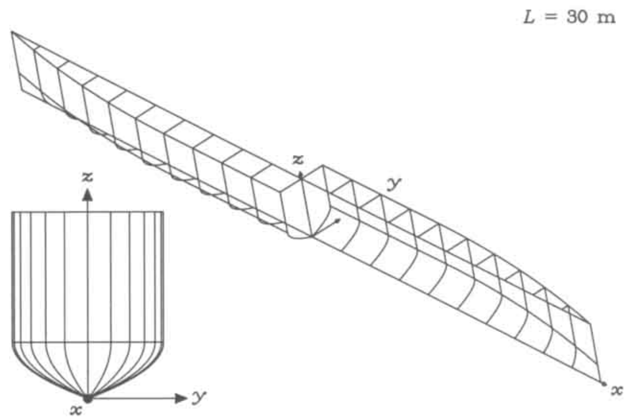

Figure 1: Definition of the Problem
(b) Modified Wigley Hull

In the case of deep water, it was found that the width of the canal could be chosen on the basis of the well-known Kelvin angle in order to avoid reflections from the side of the canal. Thus, in some cases, a width of up to 5000 m was chosen, in order to limit this source of error in the wave elevation to less than than 1 mm.

4 Test Vessels

A modified version of the hull defined by Wigley (1934) was used here to create a parent hull. The hull has parabolic section bilges and parabolic waterplane ends, as shown in Figure 1(b). The vessel has a variable amount L_1 of parallel middle body, which allows one to choose the prismatic coefficient. The vessel can also have a wall-sided region of draft T_1 near the waterplane.

All six of the vessels possess a displacement of 60 t and draft of 1.5 m in fresh water and have a maximal section coefficient of 0.8333. The three monohulls have a beam of 2.0 m. The three catamarans have a demihull beam of 1.0 m and a demihull spacing of 10.0 m. Overall vessel lengths of 24 m, 30 m, and 36 m were selected.

The analytic expressions for the wave functions for this vessel were presented by Doctors (1995).

5 Wave Resistance and Wave Elevation

The wave resistance for the three monohulls is plotted in Figure 2(a) and for the three catamarans in Figure 2(b). One should observe that selecting a series of vessels with the same effective wavemaking length $L_W = C_P L$ causes the humps and hollows of the curves to align horizontally. At the same time, the greater lengths lead to dramatic reductions in wave resistance.

The wave contours for a monohull are depicted in Figure 3(a). The different character of the wave pattern for the catamaran is noted in Figure 3(b).

6 Wave-Decay Curves

Four measures of the wave system were considered in this work. The "wave height", which is the greatest difference between a consecutive trough and a peak, is often used in practice to indicate the magnitude of the wave. For our principal measure, we shall use the "wave range" $\zeta_{\rm range}$. This is simply the difference between the highest and the lowest points in the wave cut.

Figure 4 shows the transverse decay of these wave measures for a monohull and for a catamaran. A curve of the type

$$\zeta/\zeta_1 \quad = \quad A(y/y_1)^N$$

has also been fitted; it is seen that the fit is excellent for these cases.

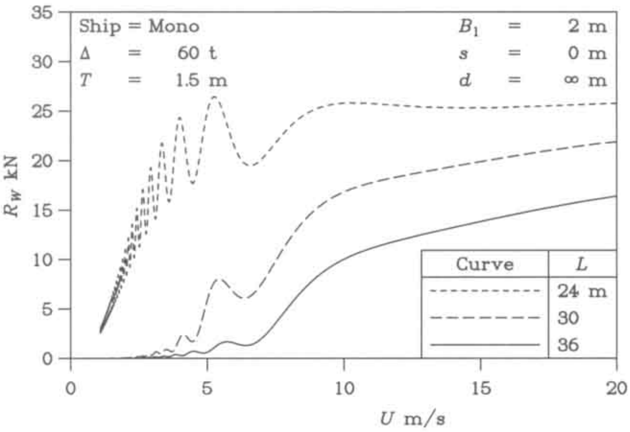

Figure 2: Wave Resistance
(a) Three Monohulls

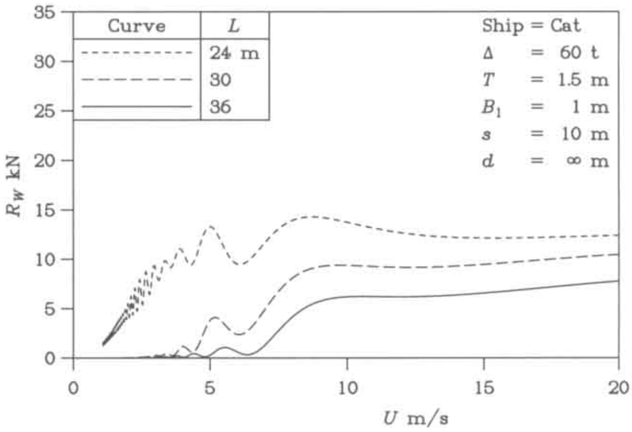

Figure 2: Wave Resistance
(b) Three Catamarans

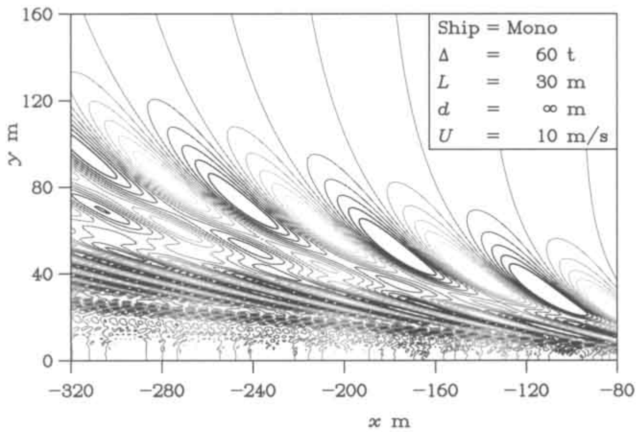

Figure 3: Wave Contours
(a) Monohull at a Speed of 10 m/s

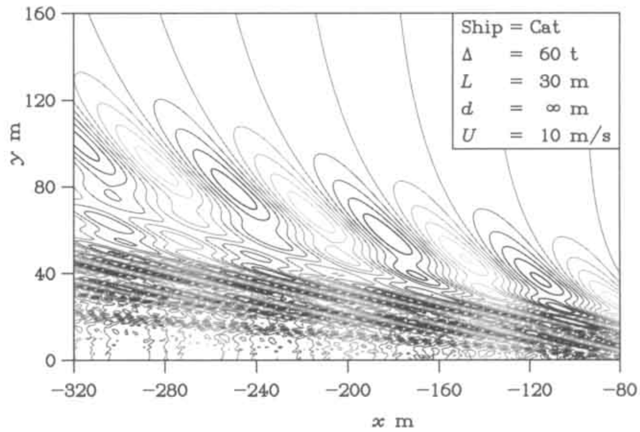

Figure 3: Wave Contours
(b) Catamaran at a Speed of 10 m/s

Finally, the "fitted" wave range ζ_1^* for all six vessels is shown in Figure 5(a). One can see, again, that the longer vessels always generate a lower wave range at the close cut where $y_1 = 100$ m, while catamarans generate smaller waves than monohulls do. This is particularly true at the lower speeds. The corresponding exponent N is shown in Figure 5(b). Here, it can be seen that a value of around -0.33 would actually be representative for speeds between 8.0 m/s and 13.0 m/s. However, a value of around -0.50 is certainly more applicable at the higher speeds. On the other hand, at some of the lower speeds, this exponent can reach values as low as -1.06.

7 Conclusions and Acknowledgments

Future work should include an extension of the numerical investigation to include the effects of finite depth. In this case, it will be necessary to take care regarding the spatial applicability of the simpler far-field wave elevation that was utilized.

The authors gratefully acknowledge the assistance of the Australian Research Council (ARC) Large Grant Scheme (via Grant Number A89917293).

8 References

Day, A.H. and Doctors, L.J.: "Rapid Estimation of Near- and Far-Field Wave Wake from Ships and Application to Hull-Form Design and Optimization", *J. Ship Research*, Accepted for publication, 28+ii pp (February 2000)

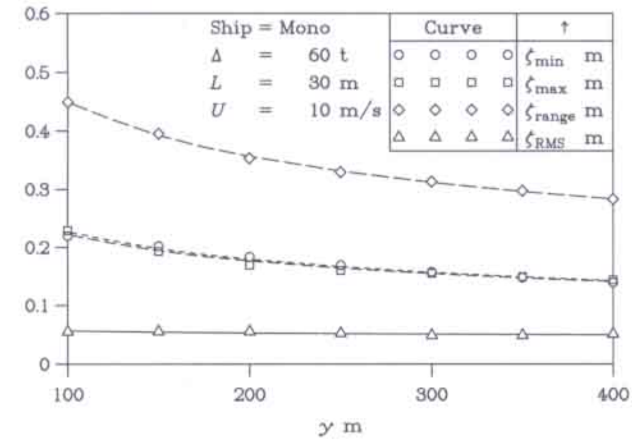

Figure 4: Curves of Wave Decay
(a) Monohull with a Length of 30 m

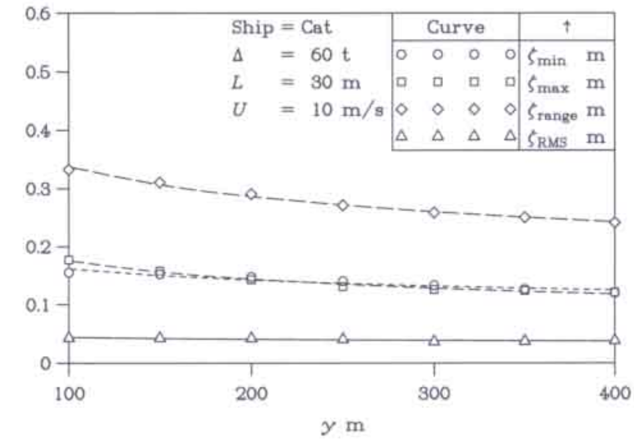

Figure 4: Curves of Wave Decay
(b) Catamaran with a Length of 30 m

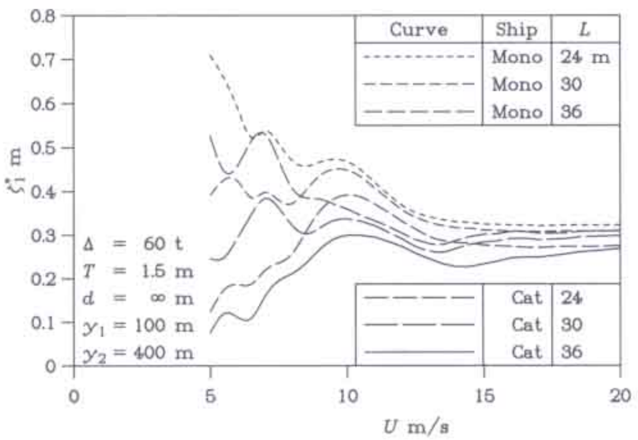

Figure 5: Decay Coefficients
(a) Magnitude of Range

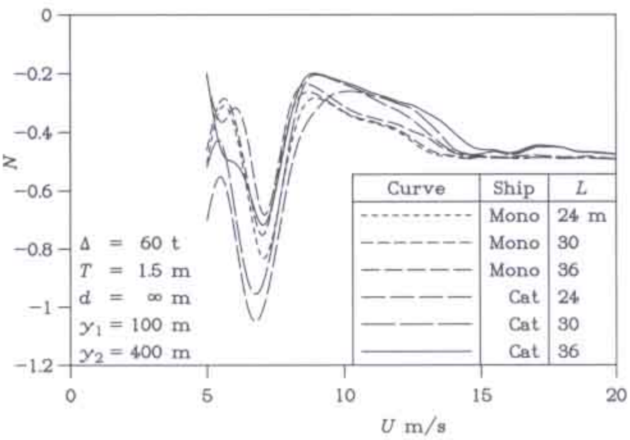

Figure 5: Decay Coefficients
(b) Decay Exponent

DOCTORS, L.J.: "A Practical Method of Prediction of Ship Resistance for Displacement Vessels", *Proc. Sixth International Symposium on Practical Design of Ships and Mobile Units (PRADS '95)*, Society of Naval Architects of Korea, Seoul, Korea, Vol. 1, pp 648–659 (September 1995)

DOCTORS, L.J. AND DAY, A.H.: "Wave-Free River-Based Air-Cushion Vehicles", *Proc. International Conference on Hydrodynamics of High-Speed Craft: Wake Wash and Motions Control*, Royal Institution of Naval Architects, London, England, pp 12.1–12.9 (November 2000)

NEWMAN, J.N. AND POOLE, F.A.P.: "The Wave Resistance of a Moving Pressure Distribution in a Canal", *Schiffstechnik*, Vol. 9, No. 45, pp 21–26 (1962)

STOKER, J.J.: *Water Waves*, Interscience Publishers, Inc., New York, 567+xxviii pp (1966)

TUCK, E.O., SCULLEN, D.C., AND LAZAUSKAS, L.: "Ship-Wave Patterns in the Spirit of Michell", *Proc. IUTAM Symposium on Free-Surface Flows*, Birmingham, England, 8 pp (July 2000)

WEHAUSEN, J.V. AND LAITONE, E.V.: "Surface Waves", *Encyclopedia of Physics: Fluid Dynamics III*, Ed. by S. Flügge, Springer-Verlag, Berlin, Vol. 9, pp 445–814 (1960)

WIGLEY, W.C.S.: "A Comparison of Experiment and Calculated Wave-Profiles and Wave-Resistances for a Form Having Parabolic Waterlines", *Proc. Royal Society of London*, Series A, Vol. 144, No. 851, pp 144–159 + 4 plates (March 1934)