A Comparison
of the Environmental Wave Generation
# of Hovercraft and other High-Speed Vessels

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Summary

A series of numerical calculations is performed in order to predict the wave wake generated by a series of six different candidate vessels operating in a river. The vessels all have an overall displacement of 60 t, a length of 30 m, and a nominal beam of 10 m. The vessels are essentially transom-stern catamarans, in which the proportion of the weight of the vessel that is supported by an enclosed air cushion is varied between 0% and 100%.

It is shown that dramatic reductions in the height of the generated wave pattern is possible. This depends on the speed of the vessel and the depth of the water. In the case of deep water, a reduction of 54% is possible at a speed of 40 knots, when the cushion supports 60% of the weight. Under the same conditions, in water of depth 7.5 m, the expected reduction is 59%.

1 Introduction

1.2 Background

In the last decade there has been an upsurge of interest in the wash, or wave wake, generated by fast river ferries. The source of this interest is the desire to operate such ferries at considerably greater speeds than those that would have been previously contemplated. These new ferries operate in a speed regime near the vicinity of the primary hump, at which the Froude number $F = U/\sqrt{gL}$ is of the order of 0.6 to 0.8. At such high speeds of perhaps 25 knots, the wavemaking can be an order of magnitude greater than that occurring at the more traditional speeds, which might be as low as 10 knots. Here, U is the vessel speed, g is the acceleration due to gravity, and L is the vessel length.

The main concern with these vessels is the environmental impact due to the wave system impinging on the river banks and retaining walls and thereby possibly causing erosion in extreme scenarios. A secondary consideration is the unwanted motion induced on moored vessels in the vicinity of the ferry routes.

Surprisingly, there appears to be less concern with the power required to drive these vessels. Unnecessary power leads to increased aerial pollution, noise, and fuel consump-

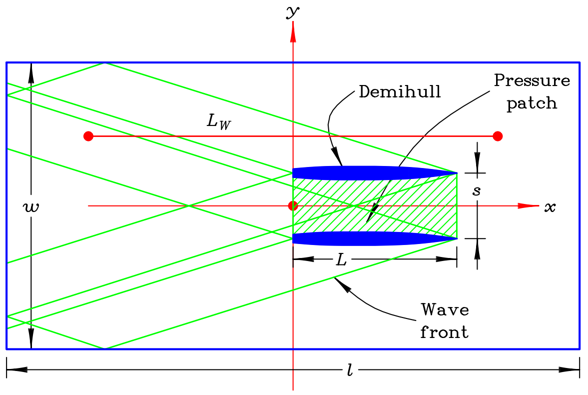

Figure 1: Features of the Problem
(a) Characteristics of the Waterway

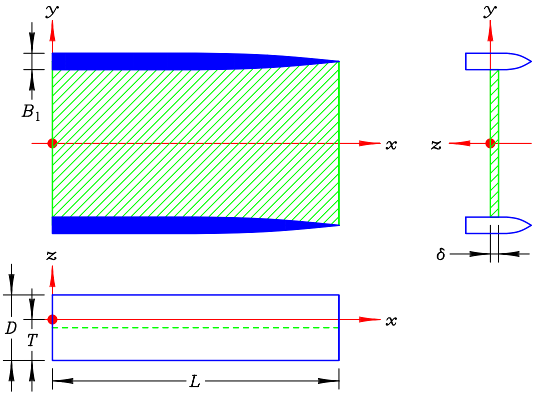

Figure 1: Features of the Problem
(b) Dimensions of the Vessel

tion. Consequently, a vessel that creates a low-impact wave system is likely to require less propulsive power, so that it seems very desirable to minimize the wavemaking.

The damage caused to the foreshores clearly depends also on the nature of the banks, such as the material composition and topology. This second part of the engineering problem is not considered in this paper, but should be the subject of a separate in-depth study.

1.4 Literature Review

Research on a modern ferry, the RiverCat, used on the Parramatta River leading into Sydney Harbor, was reported by Doctors, Renilson, Parker, and Hornsby (1991). In that work, both theoretical predictions of the wave resistance and measurements of the total drag on a scale model were made. It was demonstrated that there was excellent correlation for the resistance between the theory and the experiments. In addition, the wave elevation was measured along a set of longitudinal cuts in the towing tank. The maximum trough-to-peak height for each cut, averaged over the set of cuts, was used as a measure of the height of the wave system. This average “wave height”, plotted as a function of the vessel speed, correlated well with the corresponding wave-resistance calculations.

However, the question was naturally raised whether one should consider computing the wave elevation itself, rather than the wave resistance. The aim, then, when evaluating or optimizing a vessel, would be to seek those designs which produce a low-amplitude wave system. The question of the precise measure of the wave system to be minimized is still open. For example, it is not clear whether a small number of large-amplitude waves is preferable to a large number of small-amplitude waves with the same total energy.

The results of several recent studies on the environmental aspects of fast ferries have been made available. These include the work of Fox, Gornstein, and Stumbo (1993) and Kofoed-Hansen (1996). Most of these studies were of an experimental nature, in which measurements of the wave wake of full-size vessels were undertaken.

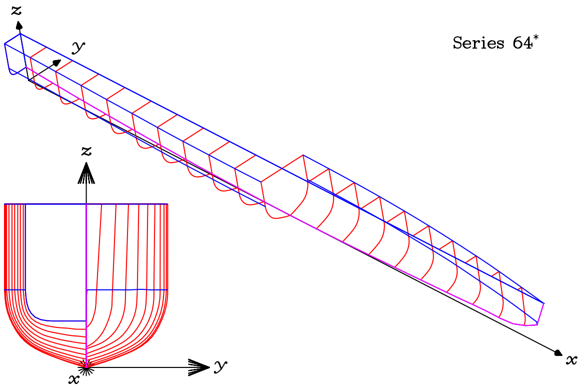

Figure 2: Subject Vessels
(a) Modified Series 64 Demihull

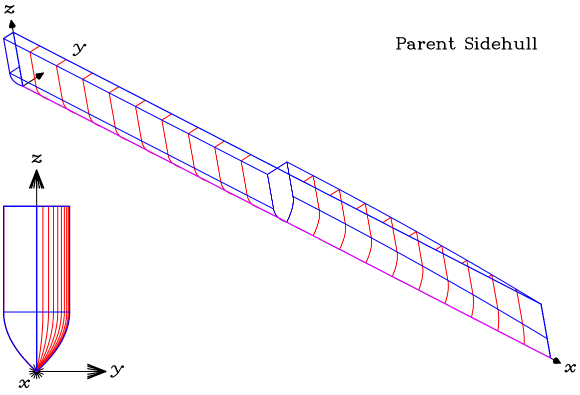

Figure 2: Subject Vessels
(b) Modified Wigley SES Sidehull

The purpose of this present study is to exercise a computer program described previously by Doctors (1997). The origins of the theory behind this program are in the pioneering work of Michell (1898) and Sretensky (1936). This theory is based on the assumption of the vessel possessing thin hulls giving rise to a relatively mild wave system. Hence, this theory is particularly applicable to the present case of interest, in which such highly efficient hullforms are considered.

The wave-generation computer program has been described by Doctors (1997) and has undergone considerable development since that time. Publications presenting numerical predictions of the wave pattern have been presented by Doctors (1998) and Doctors and Day (2001). A particular point of interest has been the matter of the rate of decay of the wave system with respect to the position of the point of measurement (that is, the lateral offset of this point from the track of the vessel).

A general, and not particularly startling, conclusion of this work is that vessels possessing slenderer hulls create a wave system with a lower characteristic height. It can also be shown that, in the case of a catamaran, the characteristic wave height is reduced as the spacing between the demihulls of the vessel is increased. These results have been verified experimentally as well.

Amongst the naval architecture community, there is some confusion about wave generation and decay. In response to this confusion, Doctors (2002) discussed the question of the rate of lateral wave decay. It can be shown that the rate of decay is strongly dependent on the Froude number of the vessel. This rate of decay reaches a value of $-\frac{1}{2}$ at very high speeds. That is, the characteristic wave height varies with the inverse square root of the transverse offset y. The mathematics behind this analysis were presented by Wehausen and Laitone (1960) and Stoker (1966).

The techniques employed in these programs were later subjected to an optimization process described by Day and Doctors (2001), in which the wave generation was the object function. The very effective genetic algorithm (GA) was used for this purpose.

Table 1: Measures of the Wave System

Item	Symbol
Minimal wave elevation	ζ_{min}
Maximal wave elevation	ζ_{max}
Range of wave elevation	ζ_{range}
RMS wave elevation	ζ_{RMS}

Finally, the pioneering work of Tuck and Lazauskas (1998) and Lazauskas and Tuck (1998) must also be referred to. These researchers employed the same thin-ship theory and similar optimization procedures to arrive at efficient hullforms, applicable to the design of multihull vessels and resulting in low wave resistance. This work was continued by Tuck, Scullen, and Lazauskas (2000 and 2002).

1.6 Current Work

It is well known that the hovercraft has a very low wave resistance in comparison to a displacement craft. The primary reason for this is that, even though the weight supported by the water may be the same, the extent of the lateral distribution of this weight is large — typically up to one half of the length of the craft. The nearly two-dimensional wave system that is generated suffers a relatively large wave cancellation. Secondly, the level of the pressure is low. Accordingly, the wave generation (which is essentially proportional to the pressure) is also low.

This idea was exploited in the work by Doctors and Day (2000), who demonstrated that a multi-cushion hovercraft could generate an almost zero-height wave system provided the pressure in the individual cushions could be chosen according to the desired speed of travel.

In the research to be reported here, we shall examine the possibility of minimizing the wave generation in a very practical manner, by considering a surface-effect ship (SES). This vessel is just a combination of a catamaran and a pressure distribution. This design represents a good candidate for operation on calm rivers. This is because of the following advantages:

1. The low cushion-air requirements implies low noise levels emanating from the lift system.
2. The sidehulls permit excellent maneuvering characteristics.
3. The problem of speed drop-off in waves, typical of the SES, would be absent in this scenario.

The principal features defining the vessel and the waterway can be seen in Figure 1(a). The main geometric dimensions are detailed in Figure 1(b).

Table 2: Particulars of Parent Demihull

Item	Symbol	Value
Displacement mass	Δ	30 t
Waterline length	L	30 m
Waterline beam	B_1	1.000 m
Draft	T	1.500 m
Demihull spacing	s	10 m
Waterplane-area coefficient	C_{WP}	0.8333
Maximum section coefficient	C_M	0.8000
Block coefficient	C_B	0.6667
Prismatic coefficient	C_P	0.8333
Slenderness coefficient	$L/\nabla^{1/3}$	9.655

2 Computer Program

2.2 Description

The computer program utilized here has been described by Doctors (2003). In essence, the program computes far-field wave functions which depend on the geometry of the source disturbance, that is, the demihulls of rhe vessel and/or the pressure distribution acting on the free surface due to the presence of the air cushion.

These wave functions have been developed by Michell (1898) for a ship traveling in deep water and by Sretensky (1936) for the case of water of finite depth. Corresponding wave functions for the pressure distribution were published by Newman and Poole (1962).

A very efficient recursion algorithm is employed in the computer program for evaluating the wave elevation of the free surface. It takes advantage of the fact that the vast majority of the calculation is common for all the points on the free surface and that the intermediate results can be stored for repetitive use.

2.4 Analysis of Statistics

As well as specific wave profiles (usually longitudinal wave profiles), one often characterizes the wave system in a statistical manner. Table 1 lists the four characteristic wave heights considered in this work.

Another wave parameter, namely the “wave height”, has also been used by some researchers. This is the maximum trough-to-peak height for each cut. While it has been argued that this parameter is important in terms of the potential damage that can be inflicted by the waves, there is no scientific basis for this statement. Additionally, the value of this parameter is very sensitive to the accuracy of either the numerical calculations or experimental measurements, as the case may be.

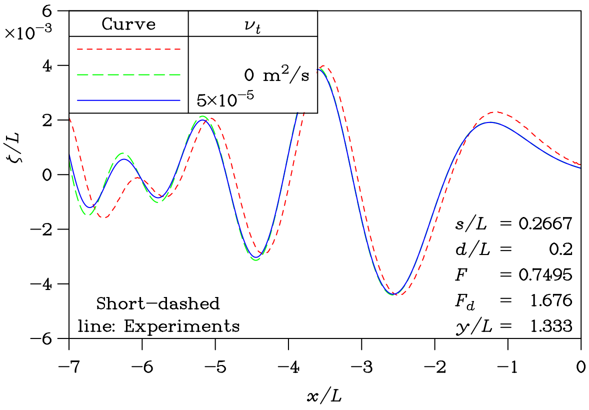

Figure 3: Longitudinal Wave Profiles (a) Effect of Eddy Viscosity

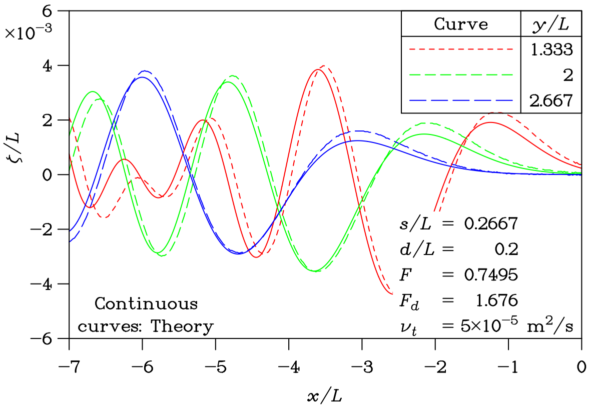

Figure 3: Longitudinal Wave Profiles (b) Effect of Transverse Offset

2.6 Validation

By way of validation of the computer program, we reproduce here some results published by Doctors (2003). These results pertain to a catamaran based on a modified Series 64 hull, described by Yeh (1965). It is shown in Figure 2(a).

The waterline length of the model was 1.500 m and the three demihull spacings that were considered were 0.300 m, 0.400 m, and 0.500 m. The width of the tank for the experiments was 12.0 m and the four water depths employed were 0.300 m, 0.450 m, 0.600 m, and 0.900 m.

The two parts of Figure 3 show a comparison of experimental and computed longitudinal wave profiles. Figure 3(a) demonstrates the effect of introducing viscosity into the calculation, a factor that has been traditionally ignored in such calculations. The effect of viscosity on the short-wavelength waves is thought to be significant for small ship models; this is demonstrated here. However, at prototype scale, one can ignore the influence of water viscosity on wave generation. This matter was investigated theoretically by Basset (1888) and Lamb (1961).

Next, Figure 3(b) also shows excellent correlation between the predictions and measurements for three longitudinal wave cuts.

Figure 4 presents a comparison between the root-mean-square wave elevation for all the eight longitudinal wave cuts used in the model tests. Results are shown for two depths of the water in the two parts of the figure. The very good agreement between the theory and the experiments is demonstrated, except in the vicinity of the depth Froude number of unity. The depth Froude number is defined as $F_d = U/\sqrt{gd}$, where d is the water depth.

This disagreement is partly caused by the rather restricted width of the model basin which makes it difficult to extract steady-state data from the tests.

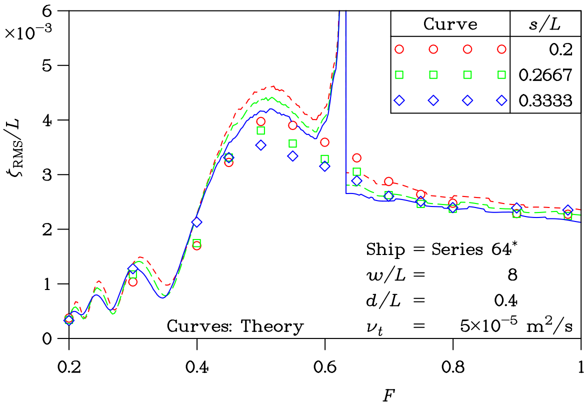

Figure 4: Demihull Separation on RMS Wave Elevation (a) $d/L = 0.4$

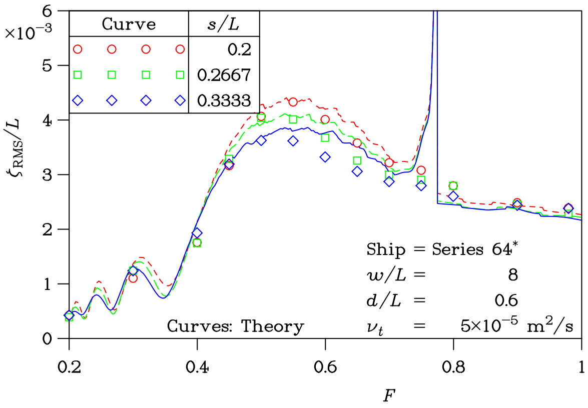

Figure 4: Demihull Separation on RMS Wave Elevation (b) $d/L = 0.6$

3 Computer Predictions

3.2 Parent Test Vessel

The chosen parent demihull can be seen in Figure 2(b). For the sake of simplicity, this was based on the classic Wigley (1934) hull. To be specific, the bow half of the demihull possesses parabolic waterlines and its sections are also parabolic, but with some wall-sided portion below the waterline. The stern half of the demihull possesses parallel waterlines and its sections blend in with the sections of the bow.

The stern, having a transom, is typical of the SES, because this permits the traditional waterjet installation. The geometric data of the parent demihull is given in Table 2.

A family of surface-effect ships was created by considering six different values of the vessel demihull beam (less than the parent value of 1.000 m). The consequent loss in displacement was compensated for by means of the cushion pressure. This is detailed in Table 3. The new demihulls were created from the parent demihull by means of a simple affine transformation, as described by Doctors (1995).

3.4 Sample Wave Cuts

We start by showing some sample longitudinal wave cuts for the pure catamaran in Figure 5. Hence, for this example, the demihull beam B_1 is 1.000 m and the static cushion depression is zero. Two different speeds are shown in the two parts of the figure. The wave elevation ζ as a function of the longitudinal coordinate x is plotted for a total of four cuts. That is, four different values of the transverse offset y are considered. It can be seen that the wave curves “start” at progressively more negative values of x for larger values of y. The rather steep appearance of the waves is due to the distorted vertical scale of the plot.

Table 3: Particulars of the Six Vessels

Vessel Type	Demihull Beam B_1 (m)	Cushion Depression δ (m)	Total Displacement Δ (t)
Catamaran	1.000	0.000	60
SES	0.800	0.040	60
SES	0.600	0.080	60
SES	0.400	0.120	60
SES	0.200	0.160	60
Hovercraft	0.000	0.200	60

Similar results are presented for the pure hovercraft in Figure 6. In this example, the demihull beam is taken to be zero, while the static cushion depression δ is 0.200 m. Particularly noteworthy is the low wave height in Figure 6(b), corresponding to a speed of 40 knots.

3.6 Wave-Decay Curves

Four measures of the wave system were considered in this work. For our principal measure, we shall use the "wave range" ζ_{range}. This is simply the difference between the highest and the lowest points in the wave cut.

Figure 7 shows the transverse decay of these wave measures for the pure catamaran. The same two speeds as before are considered. A regression curve of the type

$$\zeta/\zeta_1^* \;=\; (y/y_1)^N$$

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

In a similar manner, the wave-decay curves for the pure hovercraft are plotted in Figure 8

3.8 Wave-Decay Coefficients

Finally, we present in Figure 9 the two decay coefficients in Equation 1. The fitted wave height ζ_1^* for the six vessels is plotted as a function of the speed in Figure 9(a). It is most interesting to observe that the optimal craft appears to be the SES in which the sidehull beam B_1 is 0.4 m. The reduction in the wave height is more than 50% in comparison with the catamaran.

Care must be taken when drawing conclusions, because the exponent N also varies from one craft to the other, as seen in Figure 9(b). This is mainly true at the lower speeds.

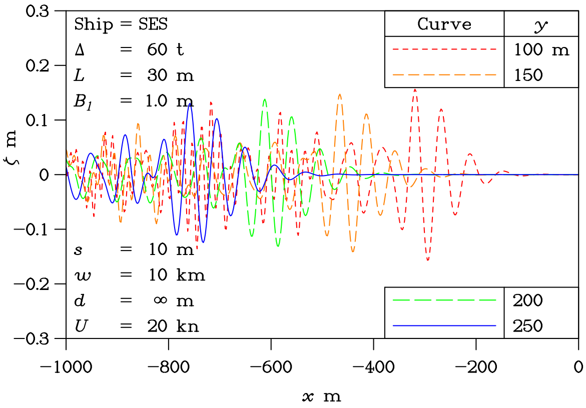

Figure 5: Wave Profiles for Catamaran (a) Speed of 20 kn

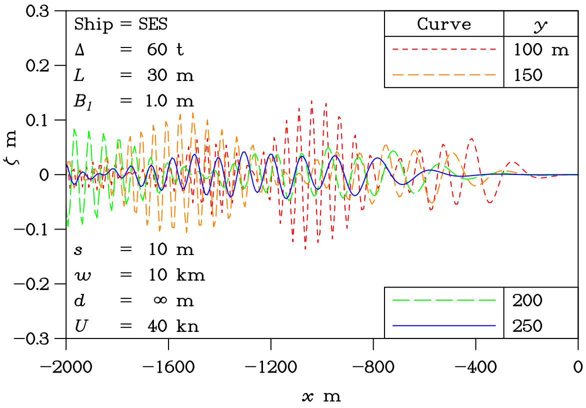

Figure 5: Wave Profiles for Catamaran (b) Speed of 40 kn

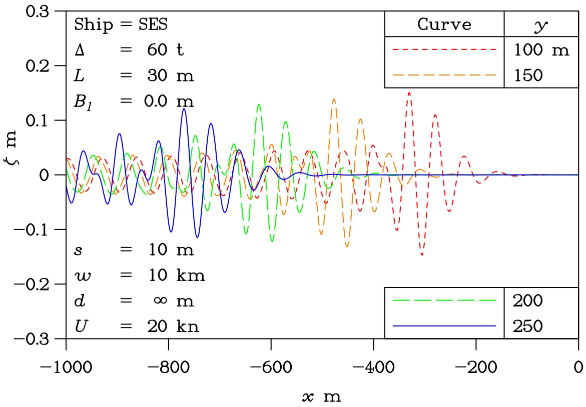

Figure 6: Wave Profiles for Hovercraft (a) Speed of 20 kn

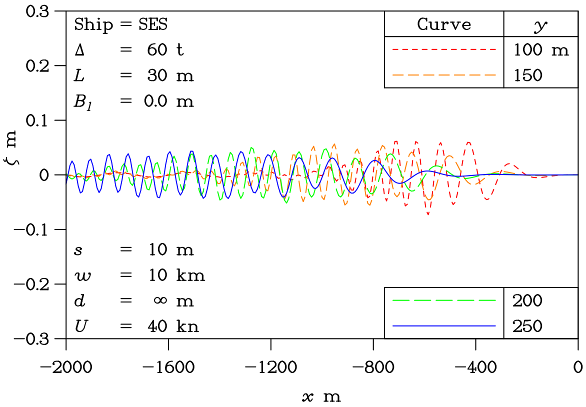

Figure 6: Wave Profiles for Hovercraft (b) Speed of 40 kn

It must be borne in mind that we desire the largest negative value of this exponent. At high speeds, it can be seen, on the other hand, that all the vessels possess the same value of the decay exponent, namely $-\frac{1}{2}$, as already explained.

The case of finite depth is presented in Figure 10. The water depth d is 7.5 m. Two points can be readily seen in Figure 10(a). The first point is the now larger magnitude of the wave generation which occurs at the critical speed of 16.67 knots. Secondly, the relative gain enjoyed by the SES (with a sidehull beam of 0.4 m) is even greater at the highest speed of 40 knots. The approach of the decay exponent N to $-\frac{1}{2}$ at high speeds in Figure 10(b) is more pronounced in this case of finite-depth water.

4 Conclusions

This work has shown that an air-cushion supported river vessel generally creates a much milder wave system than a traditional displacement vessel such as a catamaran.

It is interesting that the optimal craft in this regard, however, is not a pure hovercraft.

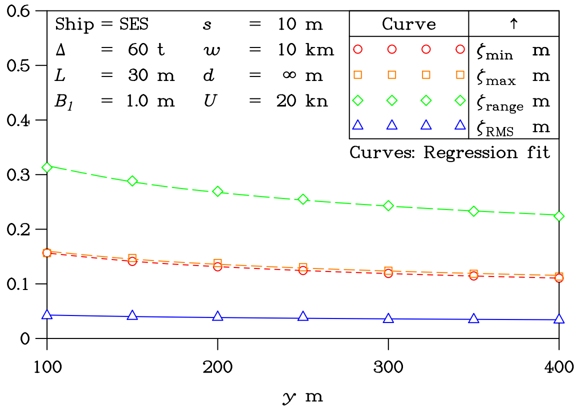

Figure 7: Curves of Wave Decay for Catamaran (a) Speed of 20 kn

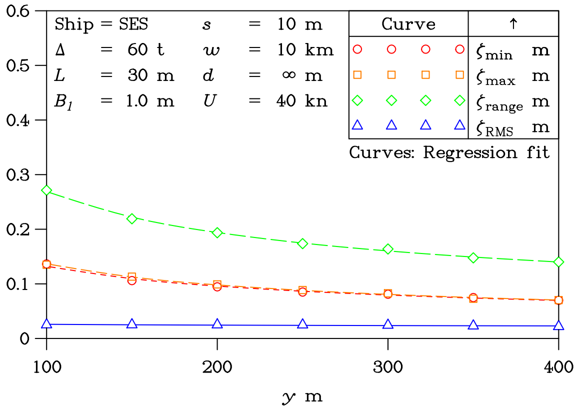

Figure 7: Curves of Wave Decay for Catamaran (b) Speed of 40 kn

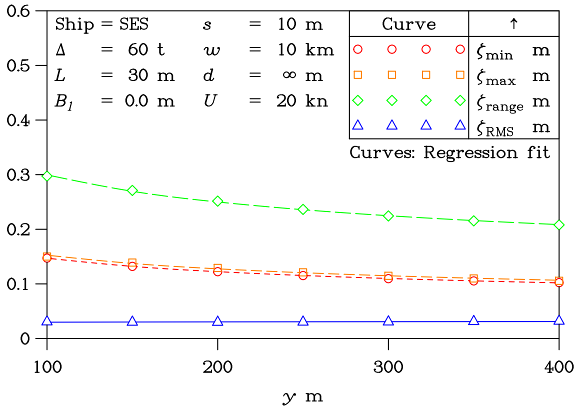

Figure 8: Curves of Wave Decay for Hovercraft (a) Speed of 20 kn

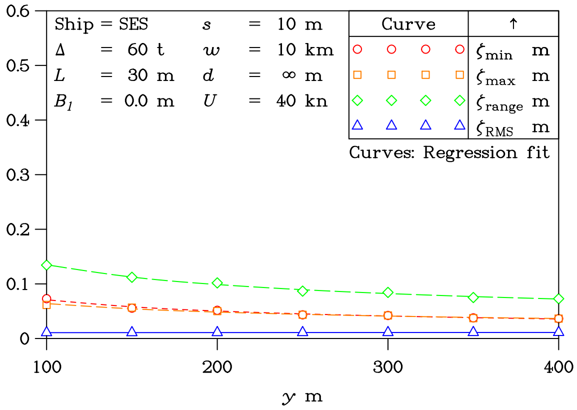

Figure 8: Curves of Wave Decay for Hovercraft (b) Speed of 40 kn

The calculations have shown that a craft in which 40% of the weight is carried by the displacement and 60% is carried by the air cushion results in a configuration that is nearly optimal over the entire speed range. The reduction in wave generation can be around 54% in the case of deep water and up to 59% in the case of a water depth of 7.5 m for the 60 t vessel operating at 40 knots.

Previous experiments on a pure catamaran model have verified the high accuracy of the computer program. It would be the logical next step to perform tests on such models of the SES in order to demonstrate that these theoretical gains can, indeed, be realized in practice.

5 Acknowledgments

The tests on the model catamaran, referred to here, were performed in the Model Test Basin at the Australian Maritime College (AMC) under the able supervision of Mr Gregor Macfarlane of the AMC.

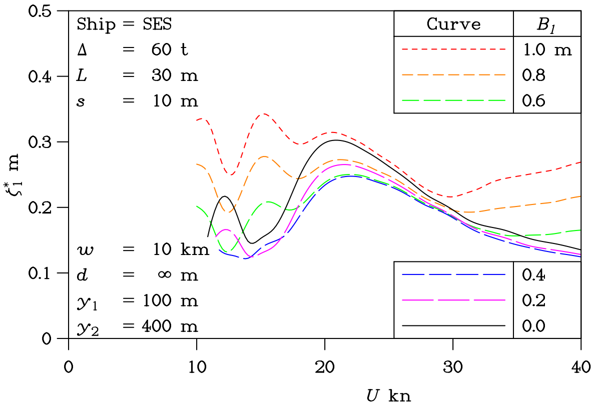

Figure 9: Decay Coefficients in Deep Water (a) Magnitude of Range

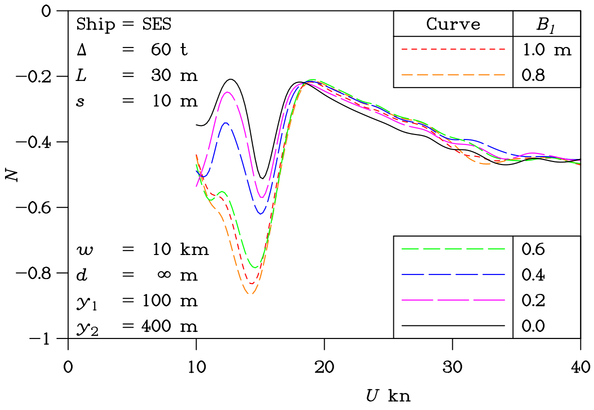

Figure 9: Decay Coefficients in Deep Water (b) Decay Exponent

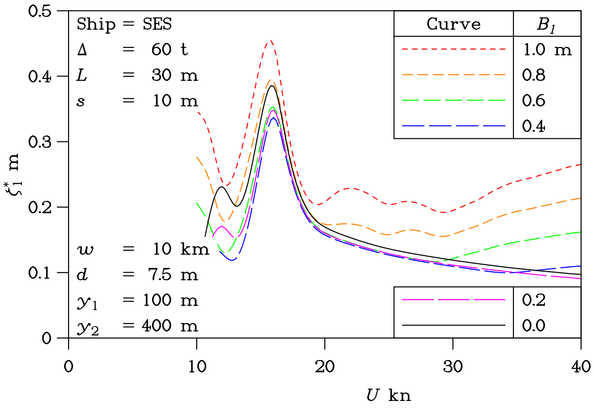

Figure 10: Decay Coefficients in Finite Depth (a) Magnitude of Range

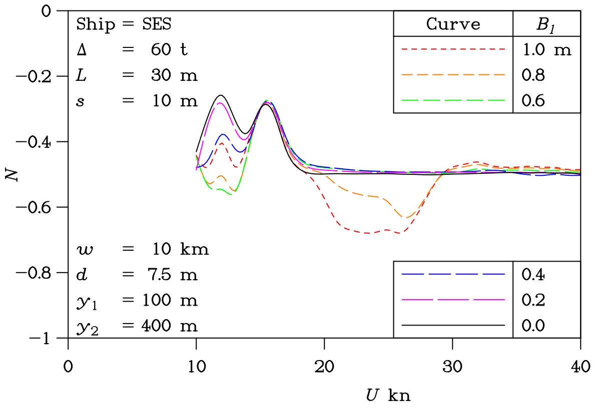

Figure 10: Decay Coefficients in Finite Depth (b) Decay Exponent

The author gratefully acknowledge the assistance of the Australian Research Council (ARC) Discovery-Projects Grant Scheme (via Grant Number DP0209656). He is also appreciative to The University of New South Wales for infrastructure support.

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