SENSITIVITY STUDY OF WAKE WASH TO HULL FORM VARIATIONS

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ABSTRACT

One of the reasons put forward for preferring a multihull over a monohull is minimization of the ship's wake wash. But what are the limits of monohull wash performance? Before choosing one form over another shouldn't one know the relative sensitivities of each type? This paper addresses the monohull half of this question.

The Washington State Ferries "SUPER" class is perceived to be the lowest wash ferry in the WSF fleet. WSF has stated that they are interested in extending and evolving this hull form to be the foundation for a new class of slightly larger, slightly faster ships. As a first step in that program John J. McMullen Associates (JJMA) undertook a parametric study to assess the sensitivity of the SUPER hullform to variations in length, draft, and speed.

Using the SHIPFLOW CFD tool JJMA ran predictions of the wake wash of the baseline SUPER hull at two drafts, and two speeds. We then modified the hull to represent a length change required to carry 30 extra cars, and predicted the wash of the lengthened hull. The results show the sensitivity of the hull to some fairly modest changes in parameters, and in particular point out the need for caution when evolving from one well-known datapoint: The offspring form may have surprisingly different behavior.

This is offered as one portion of understanding the relative merits of the monohull and catamaran hull forms.

DISCLAIMER

The work described herein is the work of the authors and of John J. McMullen Associates, Inc. It was neither requested nor funded by the Washington State Ferries, nor are the assumptions or conclusions herein to be construed as the opinions of WSF, its parent organization, or any of its branches.

The authors are grateful to WSF for permitting this work, and permitting its publication.

INTRODUCTION & BACKGROUND

Washington State Ferries has, at least in casual conversation, discussed the idea of developing a ferry for the Seattle to Bremerton route which would be slightly faster and of slightly greater capacity than the ships presently serving that route. The Seattle to Bremerton ferry run is a heavily used route, with many thousands of commuters making the 16 mile daily trip. The trip runs through the narrow waterway of Rich Passage, an area where vessel wake wash is of great importance.

WSF believe their four SUPER class ships to have the best wake wash performance of any of the car ferries in the fleet. This then suggests that these would be a good point of departure in development of a new ship. The hypothetical new ship would be somewhat larger in capacity than the SUPERs, say about 20 cars more. In addition, there will certainly be pressure to make them faster than the SUPERs' 18 knot speed.

The question that arises, then, is whether the hull's wake wash performance would be severely degraded by either of these evolutionary steps.

John J. McMullen Associates, Inc. (JJMA) uses the SHIPFLOW computational fluid dynamics (CFD) software for analyses of this type. As a marketing exercise, to demonstrate our proficiency with this type of analysis, we undertook a sensitivity study of the SUPER class hull form.

We performed, first, a baseline prediction, establishing the predicted wash level for the unmodified SUPER class. We then made a second run at a one-foot-deeper draft. This establishes the effect of draft upon wash.

The next series was the effect of speed. The baseline case is a ship at 17 feet draft and 18 knots. We re-ran this case for 17 foot draft and 20 knots, a 2 knot speed increase.

Finally, we investigated the effect of length, running wash predictions for versions wherein the ship has been lengthened some 35 feet.

All of the runs were made with the ship fixed in heave and trim. A one-case investigation showed that this simplification had no impact on the results for the baseline case. All of the runs were performed using a linearized free surface solution. A one-case investigation showed this to have an effect of about 20% on the wash height, but we believed this "error" would be uniformly present in all of the cases, and we therefore economized by repeating this simplifying assumption in all runs.

In addition, an obvious question is whether the particular CFD tool yields reliable results. This was investigated by means of a "blind test" prediction of the wash of the newly launched JUMBO MK II class. The results of the CFD prediction are compared with measurements in the Appendix to this paper.

SHIPFLOW THEORY AND MODELING TECHNIQUES

SHIPFLOW uses a zonal approach with the flow field divided into three zones. The potential flow part (zone 1) is computed using a second order panel method satisfying the exact free-surface boundary conditions. An integral boundary layer method (zone 2) is used for computing the viscous flow over the forward and middle parts of the hull. The method uses the pressure distribution from the potential flow calculation as input. A Reynolds averaged Navier-Stokes method (zone 3) is employed for the stern flow. The numerical method is of the finite-difference type employing the SIMPLER algorithm for the pressure / velocity coupling. Wall functions are used and the turbulence is modeled by the k-ε equations. Boundary conditions on the inlet and the outer borders are taken from the calculations in zones 1 and 2 [1].

The models of the hull geometries were made in the lines drawing program FastShip. The hull forms were then exported to an IDF file and thereafter converted into a SHIPFLOW geometry input file. The ferry hulls in this investigation were mirrored in the center plane and fixed in trim and sinkage. The free water surface was modeled with a dense grid exceeding 15 panels per wavelength. This ensures that the surface is smooth and correctly represented for the wake comparison. The SHIPFLOW runs used an iteration method to solve the free surface, fully accounting for the non-wall-sided shape of the ship, etc. The ship is also free in sinkage in trim, this being resolved during the iteration process.

In the present work we made a few simplifying assumptions in the modeling of the hulls. The hull form models have blended the rudders into the ship's skeg. Put another way, the propeller aperture has been filled in. This probably has no great effect on the wake wash, and considerably simplified the hull form modeling.

BASELINE WASH PREDICTIONS

The first analysis case was the baseline hull (M/V ELWHA) at 17 feet draft, 18 knots. A graphical map of the free surface is reproduced in Figure 1. The figure shows contours of surface (wave) height. The contours are taken at 5cm intervals[1]. The ship is the lens-shaped object, and it is moving to the left.

Longitudinal wave cuts were taken through the free surface. Wave cuts were taken 45m, 50m, and 55m off the ship's centerline. The wave cuts are presented in Figure 2.

There are several noteworthy elements to this first set of results. First, note that there are two groups of waves present in the wave cut. The first group, which shows on the plot from zero to approximately 650 feet aft of FP, is the bow wave. Then, aft of this, is the region where the transverse waves are encountered. This becomes more clear by considering Figure 3, which depicts this in simplified style.

Notice in Figure 2 that three contours are drawn, corresponding to 45, 50, and 55m distance between the wave cut and the ship's centerline. As may be seen, in the bow wave group there is a rapid drop off of wave height with distance. This is not evident in the second wave group.

The second wave group does not depend as strongly on distance. It is this group that forms most of the wash perceived at great distances.

Close observation of Figure 2 will also show that the wave crest located just forward of 1000 feet aft of FP is the tallest of the waves in this second group.

THE EFFECT OF DRAFT

The first parametric investigation run was the effect of draft. What is the effect upon wake wash of a one-foot draft increase? The results of the investigation are presented in Figures 4 and 5 below. As may have been expected, there is a slight but not dramatic increase in wash height.

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[1] SHIPFLOW expresses heights - as in the legend on the plot - as fractions of the ship's LBP. In the given case the specified interval (4.320×10^{-4} x LBP) has been selected such that the contours are at 5 cm intervals.

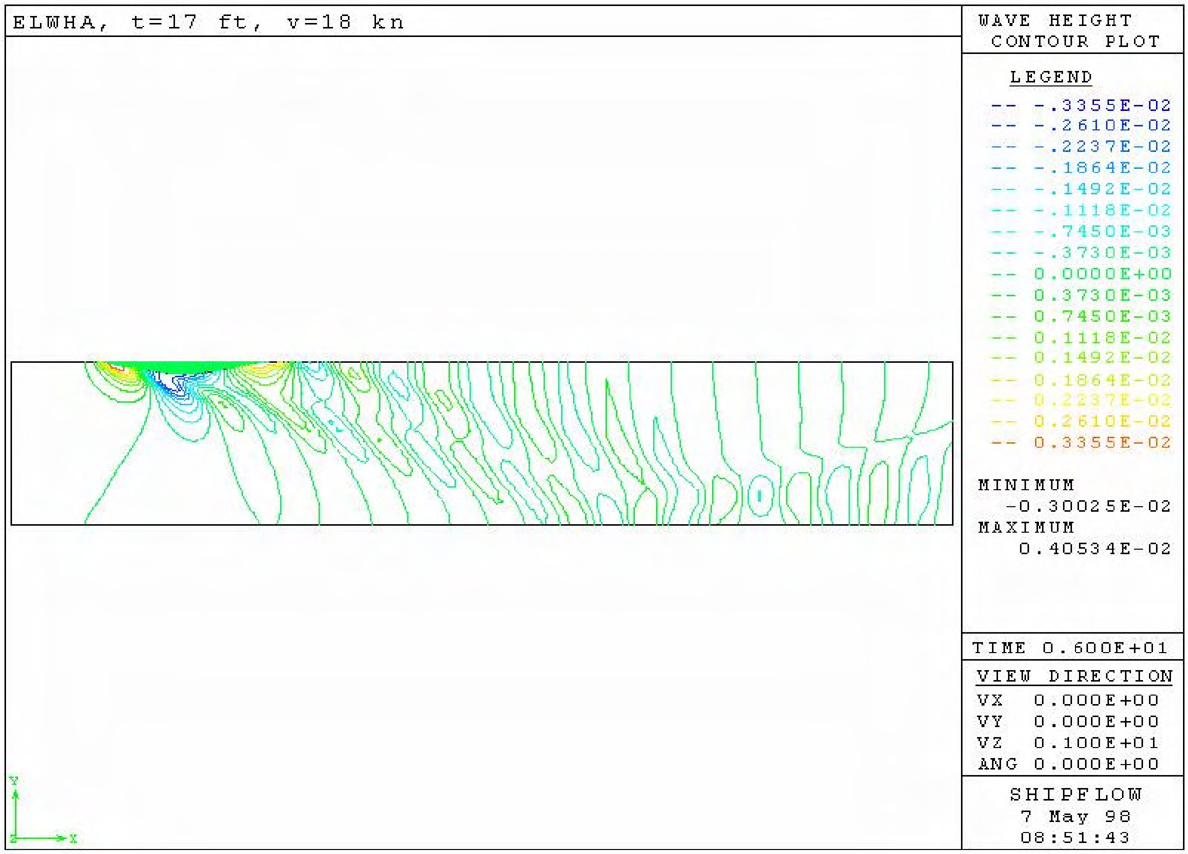

Figure 1 - M/V ELWHA free surface contours, Draft=17 feet, Speed=18 knots.

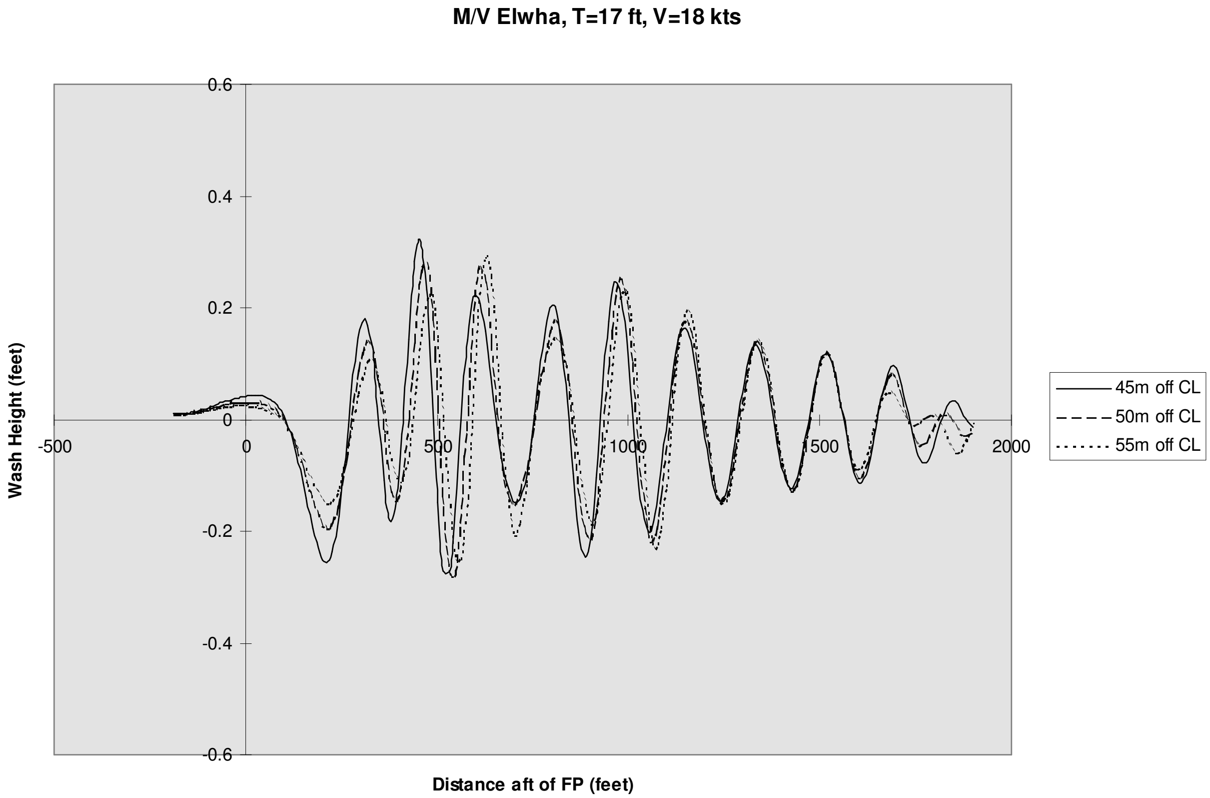

Figure 2 - M/V ELWHA Wave Profile, Draft=17 feet, Speed=18 knots.

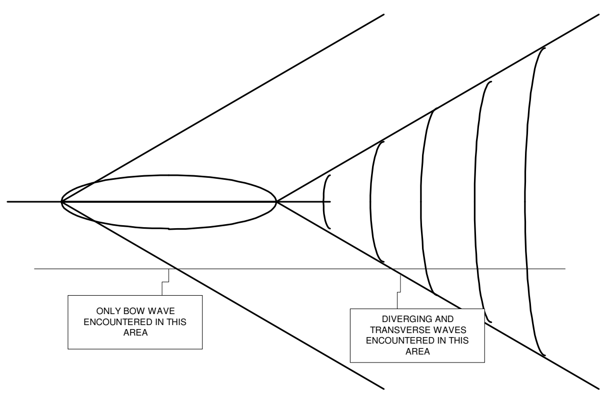

Figure 3 - This crude illustration shows that the first waves on the wave cut will contain only the ship's bow wave. The stern wave group is the group that contains both diverging and transverse waves.

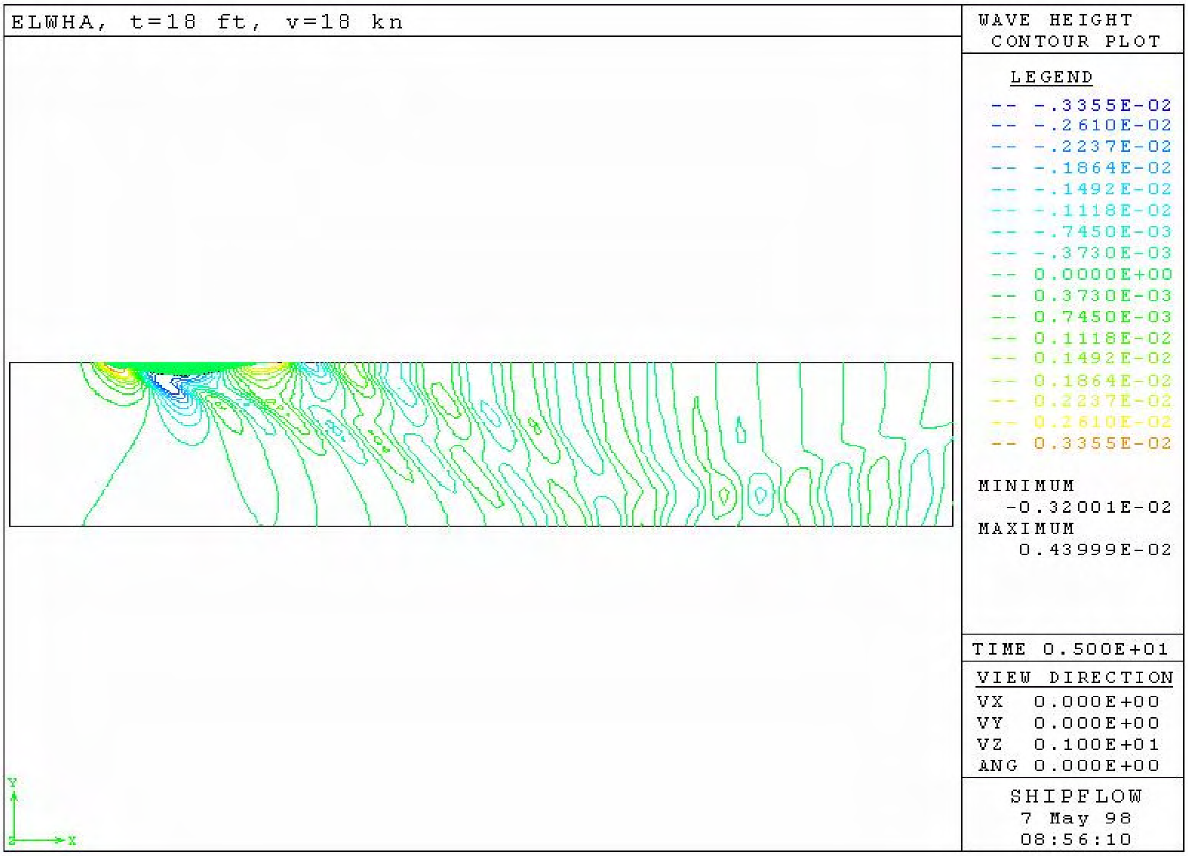

Figure 4 - M/V ELWHA free surface contours, Draft=18 feet, Speed=18 knots.

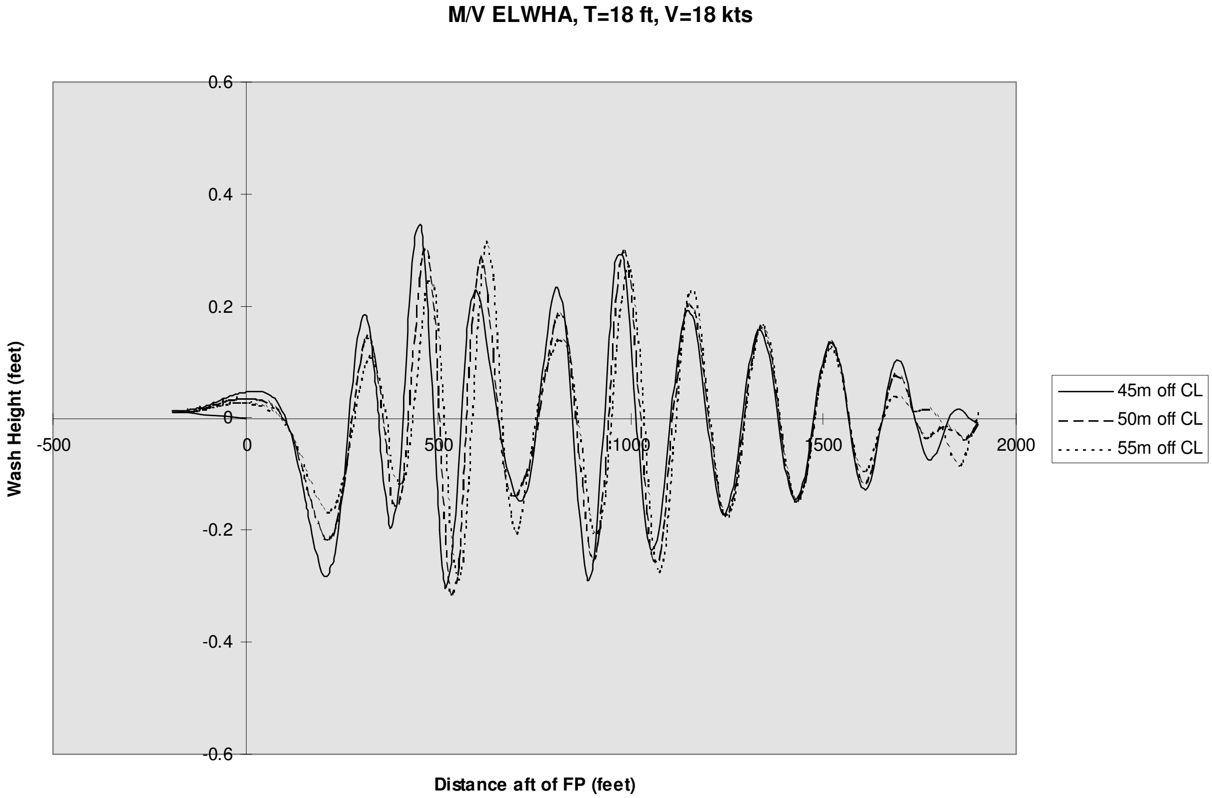

Figure 5 - M/V ELWHA Wave Profile, Draft=18 feet, Speed=18 knots.

The effect of draft becomes slightly more pronounced when considered in terms of wash energy. Wash energy is a function of wave height squared multiplied by wave period squared. This relationship has been captured by integrating wave height squared over wave length. The integration was performed numerically over three wave cycles. The comparison of the resulting values, see Table 1, shows in general a 33% increase.

It is interesting to compare this with the increase in the ship displacement represented by the one foot draft change. The displacement as calculated by SHIPFLOW changes from 3040 LT to 3411 LT, a 12% change. Thus wash energy increases significantly faster than displacement.

Table 1 - Comparison of wash energy with change in draft.

Distance off Centerline	Energy @ T=18' vs T=17'
45m	136%
50m	134%
55m	130%

Wash energy is related to ship wavemaking drag. Thus we are in effect predicting that Rr increases faster than displacement. Or, put yet another way, Rr-per-ton increases with Displacement.

THE EFFECT OF SPEED

The effect of a speed increase was studied by running the baseline hull at 20 knots. The effect on wash height is dramatic, as shown in Figures 6 & 7 below.

The Wash height has increased by fifty percent or more. This represents more than a doubling of wash energy, see Table 2.

Table 2 - Comparison of wash energy with change in speed.

Distance of Centerline	Energy @ 20 knots vs 18 knots
45m	242%
50m	229%
55m	220%

It is again interesting to check this prediction by considering what it implies about resistance. The wake data suggest that Rr increases by a factor of two. Since speed has also increased, this corresponds to a Cr change by a factor of 1.86. Certainly the total ship drag does not double with a two knot speed increase.

But the Rr is not the total ship drag. Much of the ship drag is due to friction. Indeed, a simplified calculation suggests that 4000 SHP may be consumed by friction at 18 knots. Since the total propulsion power at 18 knots is also about 4000 HP, this means that virtually all of it is consumed by friction. This, in turn, means that a two-fold increase in Rr might be a negligible increase in SHP. For a 2 knot speed increase this seems reasonable.

The practical implication of this is that it may well be within the marine engineer's power to increase the ship's speed by a mere ten percent. Little does one realize that such a modest speed increase would more than double the wash energy, perhaps changing the performance all the way from "excellent" to "unacceptable."

THE EFFECT OF LENGTH

We have seen, or gained evidence, that there is a strong impact of speed upon wash. If we wish to increase service levels using a ship based on M/V ELWHA, then it appears that increasing ELWHA's speed is a bad way to go - at least from a wash point of view. What about increasing capacity? What if we increase the ship's length by 35 feet, equivalent to carrying approximately two more cars in each lane (22 cars total.)

Figures 8 & 9 present the results for wash predictions for a version of ELWHA which has been "scaled in length" to 415 feet LBP. This was accomplished by simply changing the X scale factor in the program, using the same offsets as the baseline ship. As may be seen the impact of this length change is small, and indeed favorable: Per Table 3 the wash energy actually decreases by 45%.

Table 3 - Comparison of wash energy with change in length, due to 35 foot "stretch".

Distance of Centerline	Energy @ 415' LBP vs 380' LBP
45m	58%
50m	54%
55m	51%

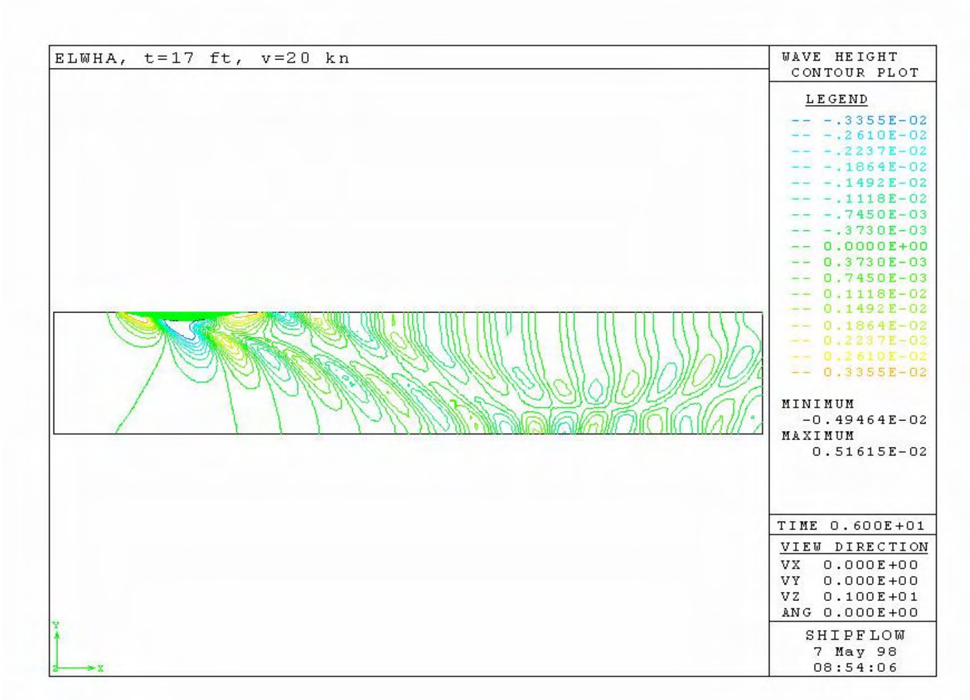

Figure 6 - M/V ELWHA free surface contours, Draft=17 feet, Speed=20 knots.

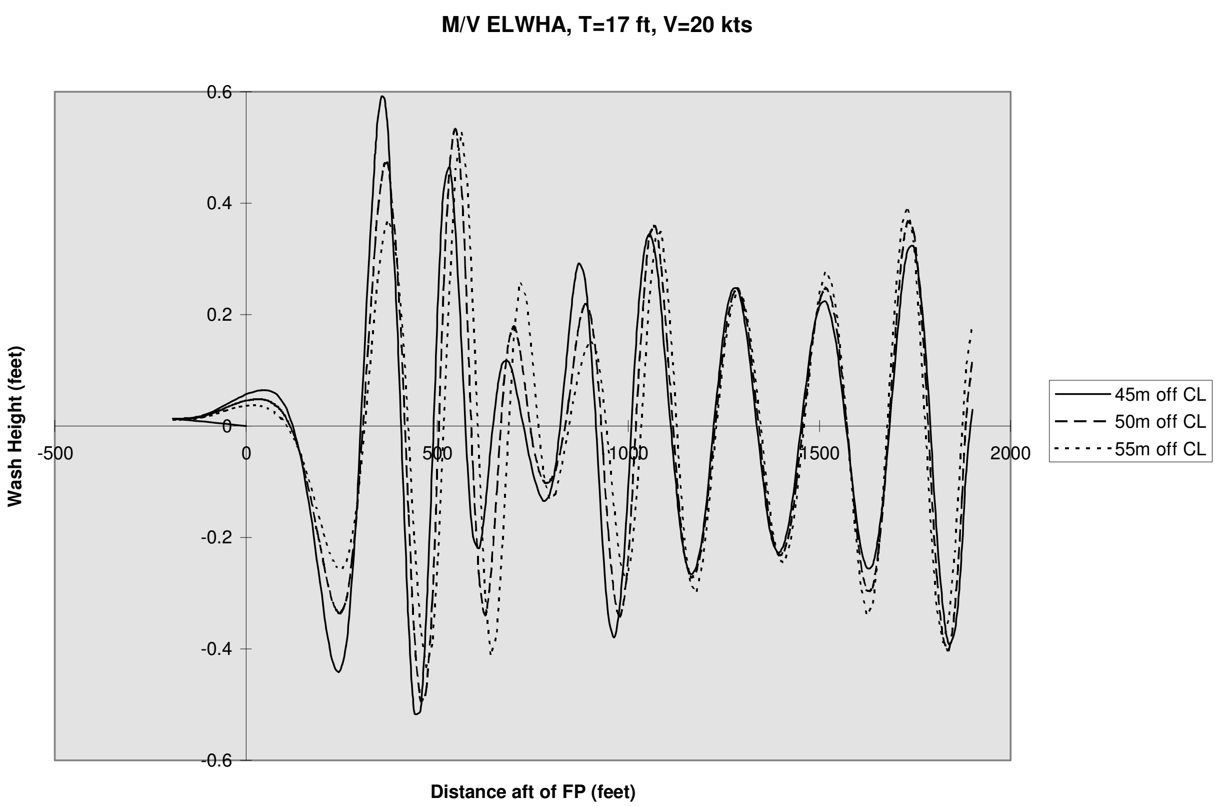

Figure 7 - M/V ELWHA Wave Profile, Draft=17 feet, Speed=20 knots.

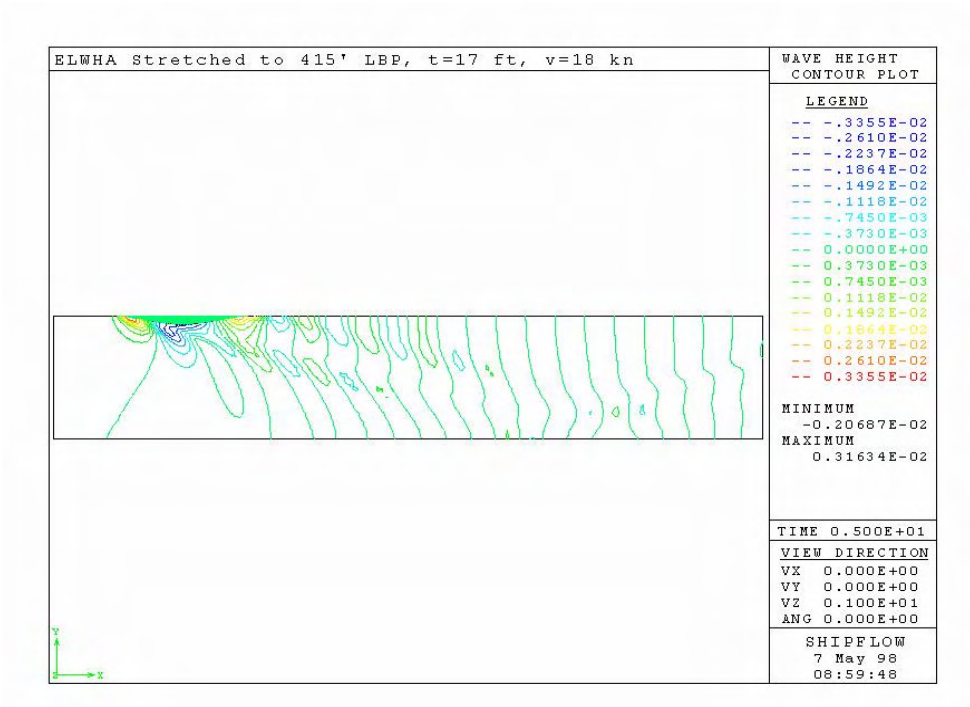

Figure 8 - M/V ELWHA free surface contours, length increased by stretching 35 feet.

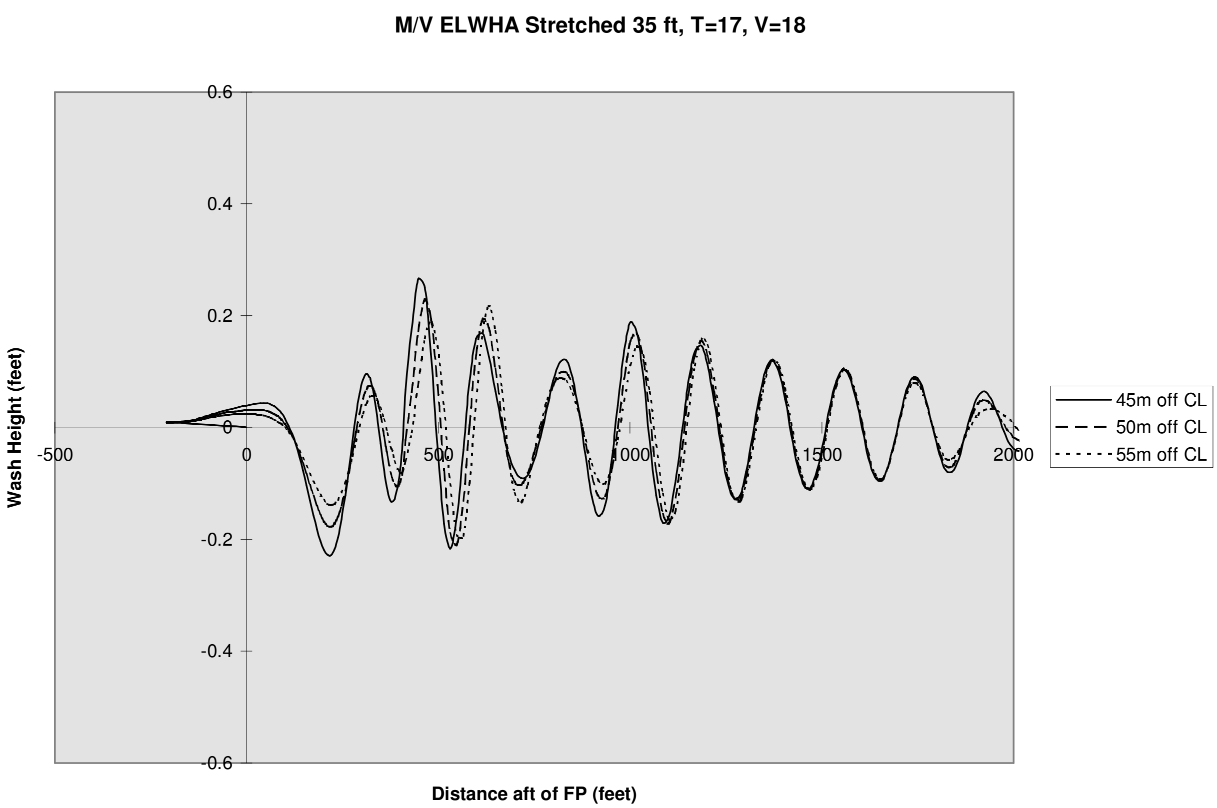

Figure 9 - M/V ELWHA Wave Profile, length increased by stretching 35 feet.

This result is encouraging. Indeed, the wash has gone down. Perhaps it would be possible to physically convert one of these ships to a higher capacity by jumboizing her? In the next run we simulated this approach by inserting 35 feet of parallel mid-body (PMB) into the hull. As may be seen in Figure 10 and 11 this approach is not recommended. Wash height increases in this case, and energy the same.

Table 4 - Comparison of wash energy with change in length, due to 35 feet of parallel mid body.

Distance of Centerline	Energy @ 415' LBP vs 380' LBP
45m	177%
50m	174%
55m	170%

Again, note that the increase in wash would correspond to only a small Rr (drag) increase. Indeed, if the choice between the two length changes was being made based on drag test results, one might be tempted to accept the PMB method. After all, it makes it possible to physically make the new ship out of an existing one, with a very moderate drag penalty. Unfortunately, as the CFD has shown, this "very moderate" drag penalty results in a substantial degradation in wash performance, which might be enough to make the whole exercise worthless.

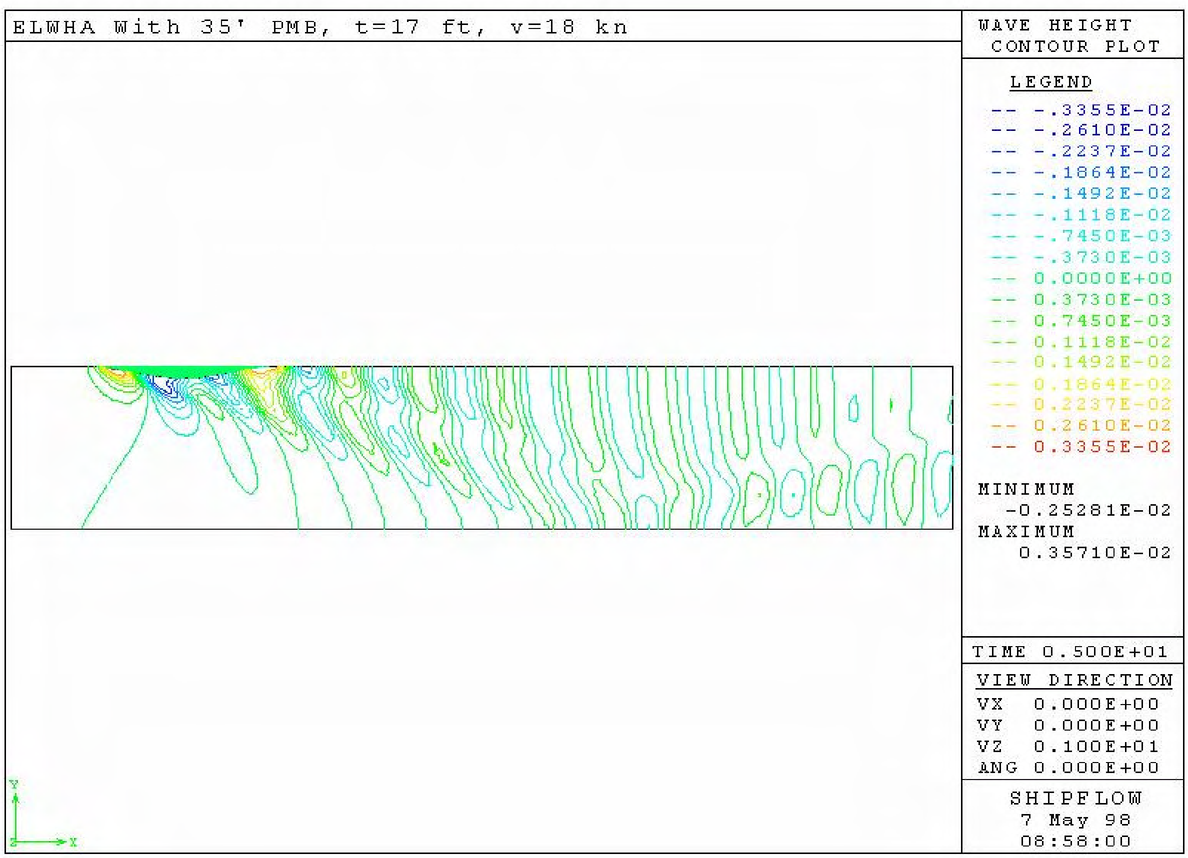

Figure 10 - M/V ELWHA free surface contours, length increased by 35 feet of PMB.

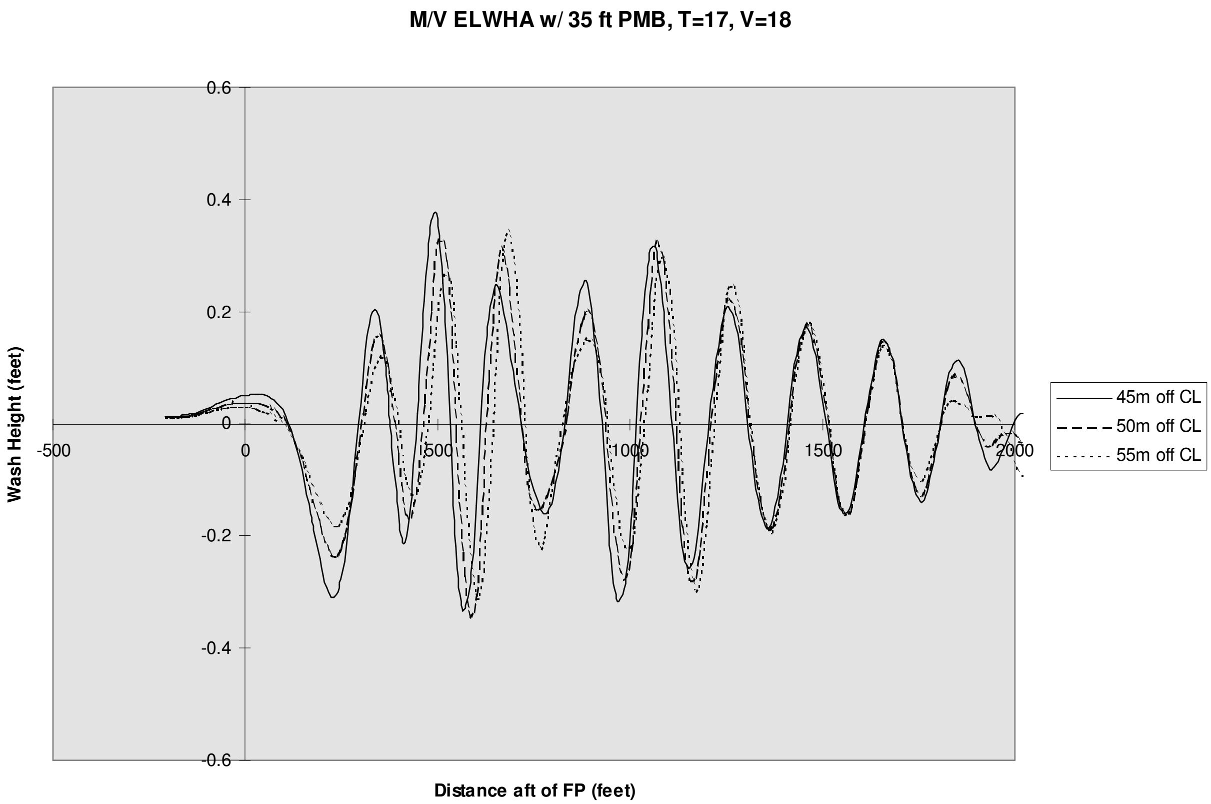

Figure 11 - M/V ELWHA Wave Profile, length increased by 35 feet of PMB.

CONCLUSIONS

This study has shown that wash energy does not vary with ship dimensions in a fashion that is intuitive. The effect of a change in draft (or displacement) on energy is fairly straightforward - the heavier ship has higher wash. The effect of speed on wash is dramatic: A ten percent speed increase produces a two-fold wash increase. And the effect of length can only be described as complex: The same change in length, attained by two different techniques, results in different wash results.

As naval architects we are trained to make certain hull form decisions based on drag results. And indeed we see that the wash results parallel the drag results. However, the wash energy is very sensitive to small changes, and responds much more quickly than, say, total drag. If drag results are to be used as harbingers of wash performance, then very close attention must be paid to small changes in Rr.

We caution that these results may be peculiar to the hull in question. However we believe that these results underscore one overriding - albeit simplistic - conclusion: Wash behavior is complex.

Modern CFD tools have come to be accepted for the prediction of wash. In this study we hope that we have shown the need for their use very early in the design process, because very simple decisions can have dramatic effect on the results.

When CFD was an exotic and expensive technique it was used rather akin to model testing: Most of the work was done and CFD was used to confirm and refine predictions made by other methods. In the present study we have seen the inadequacy of this approach, and in the authors' opinion, have shown the desirability of an early application of CFD to the problem, while that question is still in its parametric phase.

REFERENCES

[1] *SHIPFLOW Theoretical Manual, Version 1.3,* FLOWTECH International AB, Gothenburg 1993

APPENDIX: TOOL VALIDATION

In order to accept the results of the ELWHA study, we needed to know if the SHIPFLOW results were credible. SHIPFLOW has been correlated many times with full scale and model basin tests, see for example Figure A1. SHIPFLOW has been used in Europe for many wash studies. Perhaps the most dramatic were the analyses of the STENA HSS 1500 high speed catamaran. Based on these successes we approached the present study with great confidence in the tool.

Nevertheless, we also performed the present investigation as a corporate training exercise, using new staff members who had not participated in the STENA project. This underscored the importance of a validation test.

Washington State Ferries graciously provided the results of wash measurements on the Jumbo Mk II *TACOMA*. These results are presented in Figure A2.

A SHIPFLOW run was made, using the same hull form simplifications as were used for ELWHA. The Jumbo Mk II run was made in deep (infinite) water. The results are presented in Figure A3.

It is clear by comparing these two figures that SHIPFLOW has correctly captured the shape of the wake. Note the presence of the shallow area between the bow wave and stern wave groups. Note also the general trend of the heights of the first two stern waves.

It is the authors' opinion that the degradation after the first two stern waves, seen in the measured data, is attributable to the "noise" in the natural environment, versus the perfect stillness of the computational towing tank. The CFD plot shows a series of stern waves gracefully decaying with distance.

As of the submittal of this manuscript this validation effort has proceeded no further than the comparison of these two curves. We are, however, gratified at the good correlation seen at this level, and are convinced that the trends and comparisons reported in the main body of this investigation are correct. CFD is an appropriate tool for parametric comparative wash analysis.

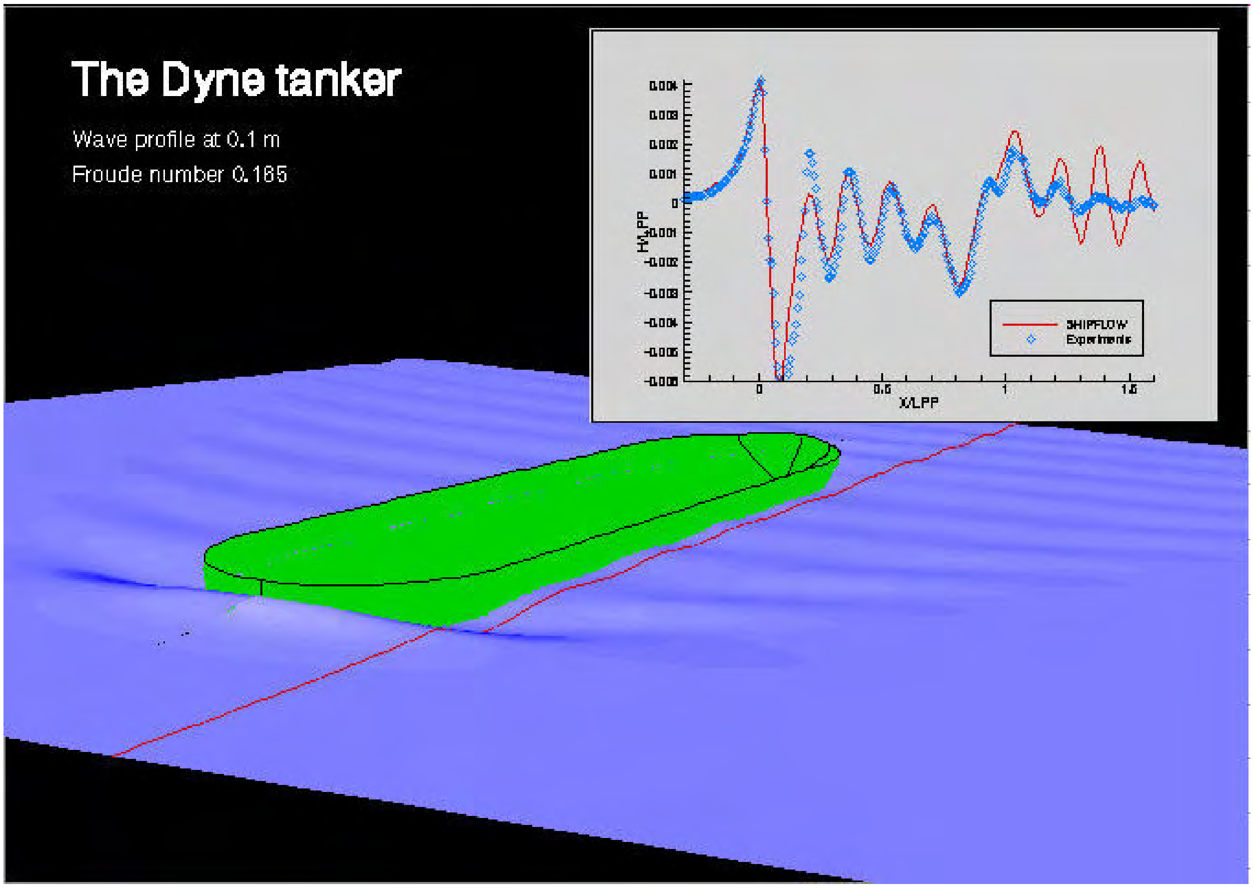

Figure A1 - SHIPFLOW Validation comparison with measurements for a tanker.

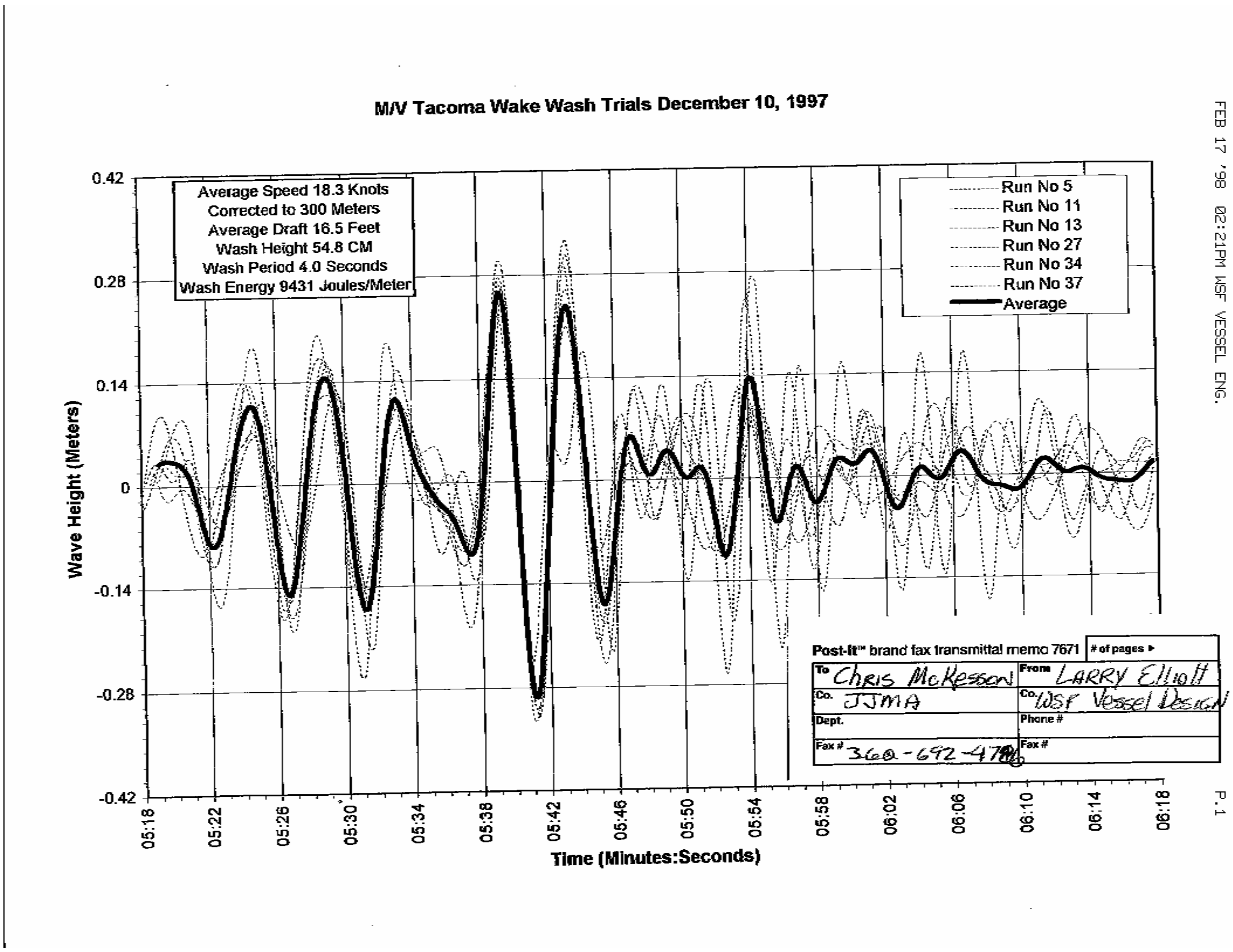

Figure A2 - M/V Tacoma wake wash data from WSF

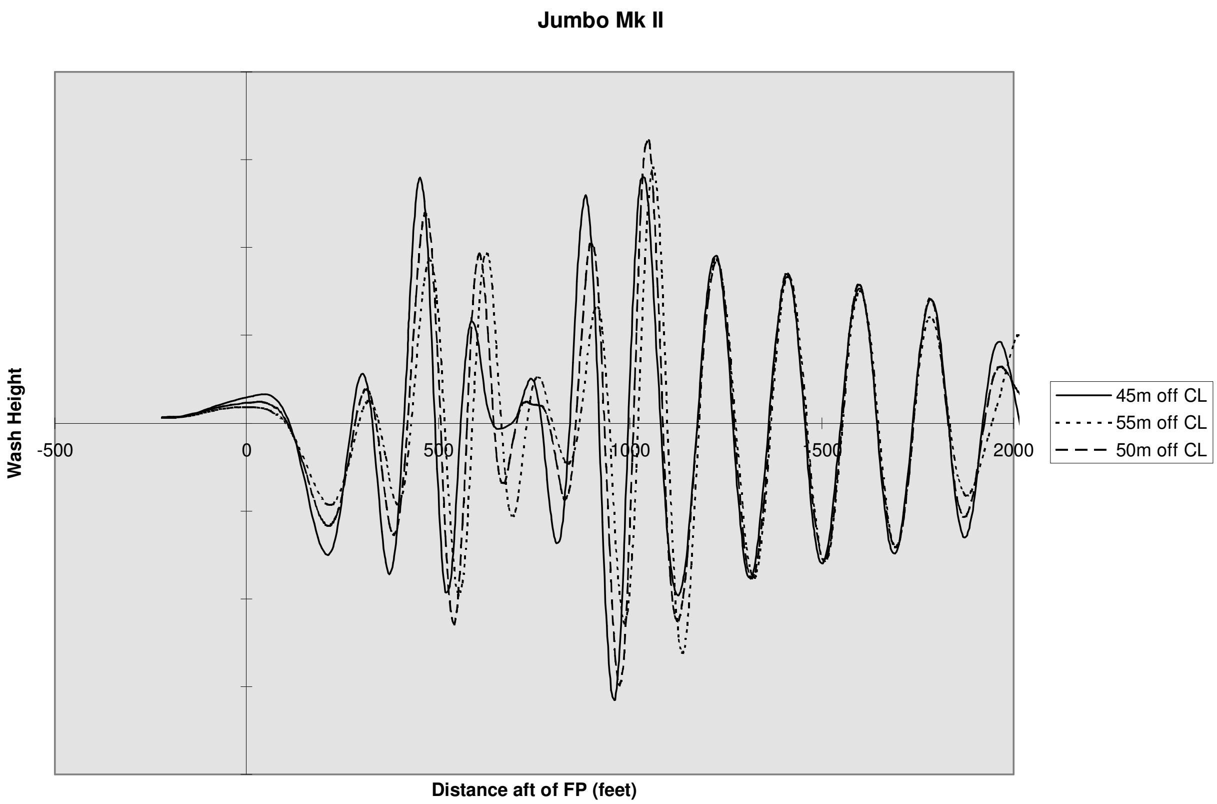

Figure A3 - SHIPFLOW Predictions of Tacoma wake wash.