Hull Form Considerations in the Design of Low Wake Wash Catamarans

by
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ABSTRACT

During the past four years, the authors have measured the wake wash characteristics of numerous aluminum catamarans of various displacements, lengths and hull forms. Some of these vessels were designed with low wake wash as a goal and some were not. Hull form characteristics that contribute to low wake wash become apparent when the wash characteristics are correlated with Froude Number (waterline length) and length to beam ratio. This paper:

- *Briefly reviews the techniques of wake wash measurement and analysis presented in an earlier paper,*
- *Presents the results of wake wash measurements of various vessels,*
- *Shows why minimizing the waterline length (LWL) is important to low wash catamaran design, and*
- *Suggests design goal parameters for achieving the lowest possible wake wash for a given vessel displacement and service speed.*

This paper is intended to act as feedback to the design community to communicate the results of wake wash measurements and give the designers the benefit of comparison of various hull form characteristics that contribute to low wake wash.

INTRODUCTION

Wake Wash issues continue to take a prominent role in the design and operation of high speed vessels, particularly those operating in congested waters, those near environmentally sensitive areas, and industrial property. During the past four years, the authors have measured the wake wash characteristics of numerous aluminum catamarans of various displacements, lengths and hull forms. Some of these vessels were designed with low wake wash as a goal and some were not. In this paper we hope to briefly review the techniques of wake wash measurement and analysis presented in an earlier papers, present the results of our recent work, and discuss how the results of this work can help naval architects set wake wash mitigation as a design criteria.

THE STATE OF THE SCIENCE OF WASH TECHNOLOGY

To set the stage for understanding the state of wake wash technology, let us suppose that the protection of shorelines and wetlands assumed the same national priority and the same funding level as the exploration of space did in the 1960s. We would have an integrated program that included topographical charting of an entire route, including beach slopes, bottom contours, bottom composition and frictional factors. We would have a total tide and current program as another component of this integrated program. We would have wind generated wave profiles for every meteorological condition that exists, has existed, or will possibly exist in this area. We would have variations in sea water composition, biological and intertidal marine growth diurnal cycles, throughout the route, and existing man made structures would be included. On this complex program we could

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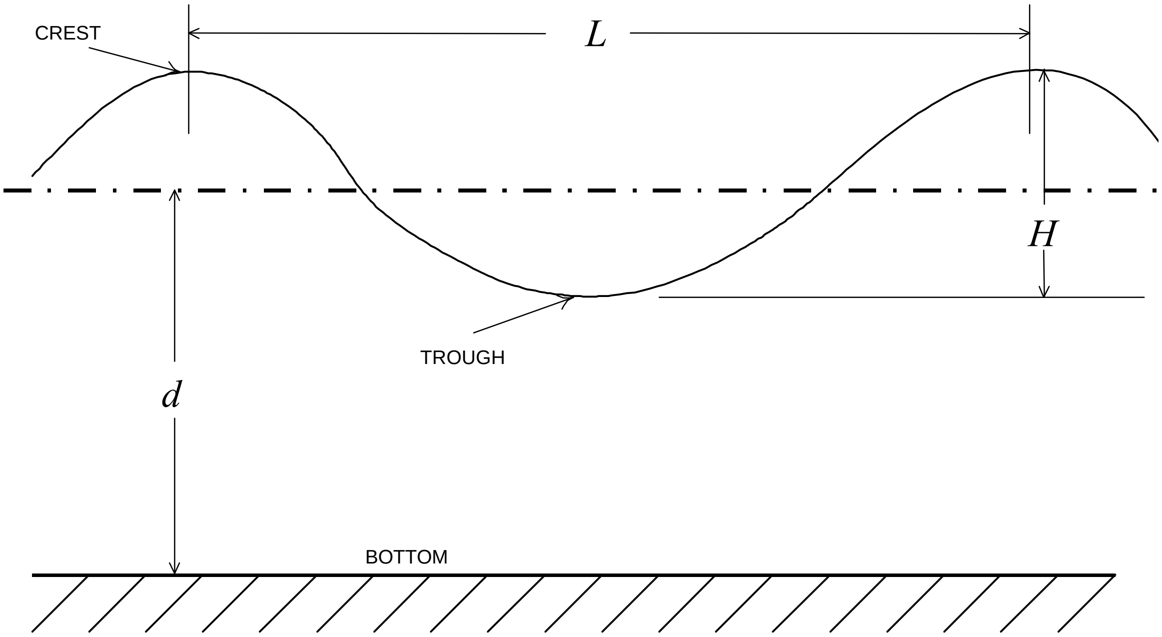

Figure 1. -- Basic Wave Characteristics

superimpose the wake wash profile of a new ship design in each configuration of loading, speed, propulsion combination, hull surface, and track adherence. From this program we would know precisely what effect a particular vessel would have on the ecology of the area, short term and long term, seasonal and instantaneous.

Absent this national priority, absent the funding for the enormous research required to plan such an operation, we have come to treat wake wash impact as a tenuous and often temporary meeting of several technologies on a disputed beach on which we attempt to define a "worst case" scenario and predict what can possibly be the worst thing that the wash from a particular vessel will do under particular extreme conditions. It is far from being an exact science at the current state of the art. It is a combination of fundamental naval architecture, empirically based technology, the observations and knowledge of experienced ferry operators, the contribution of coastal engineers, marine biologists, and the application of modern computer technology to each of these areas.

In previous papers[4] the authors have provided a comprehensive discussion of wake wash technology and described the methods used to predict and measure wash. We can briefly summarize this work by accepting that the behavior of waves, whether wind or vessel generated, has been well studied and documented in deep water and, for *comparison* purposes, it has been found best to perform measurements in deep water[5]. An assumption is made that in deep water, after a wave travels a certain distance from the point of generation, gravity will have caused the wave to assume a sinusoidal wave profile and then wave theory can be applied.

THEORY OF WAVE FORM AND PROPAGATION

Most waves that we observe in the ocean are wind generated waves and wind generated waves are often confused by several factors such as fluid motion beneath the wave surface and the confusion of several sets of wave patterns merging. However a simple wind generated wave is similar in format to a vessel generated wave that has traveled a distance from the vessel. These waves eventually assume a sinusoidal or simple harmonic form and can be analyzed with classic sinusoidal theory. The terms and measurable criteria are illustrated in Figure 1.

Without significant interference from other wave systems, a vessel generated wave that has traveled a few ship lengths from the point of generation will assume a form so close to that of the sinusoidal wave, that we can use classic wave theory to quantify and characterize the wash generated by various hull forms and specific vessels. This wave theory is defined by the following basic characteristics, illustrated in Figure 1:

L	The length of the wave from one point to the same point on the next wave.
H	The height of the wave from crest to trough

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[4] See the bibliography at the end of this paper.

[5] "deep" in terms of vessel length and Depth Froude Number, both of which are defined later in this paper.

T The time that it takes for two successive wave crests to pass a given point.

Although we often note steeper and sharper waves closer to the line of travel of the vessel, if we get several vessel lengths away, the sinusoidal theory gives us a good basis for comparison of waves characteristics between various vessels.

Vessel Generated Waves:

With few exceptions (and those are weird shapes), every vessel moving through the water generates two sets of waves, *divergent waves* which move out at an angle from the centerline of travel and *transverse waves* (Kelvin wake) which move out from the stern perpendicular to the centerline of travel. These are easily noticed when viewed from above in an airplane or from a bridge as a vessel passes beneath. They are illustrated in Figure 2.

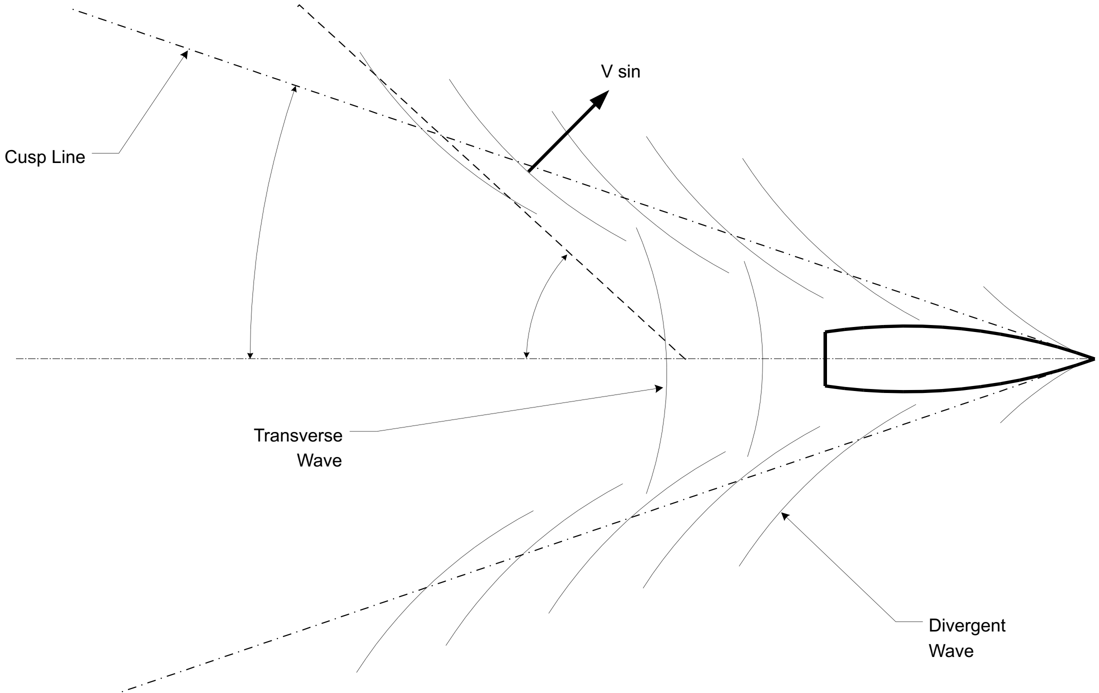

Figure 2
Vessel Generated Waves

The generation of the divergent waves is a function of hull form (Prismatic coefficient), angle of entry, speed, and speed-length ratio (V/ g*LWL) and is significant in the development of the height and energy of the wave train, particularly at low or intermediate speeds. The transverse wave form is usually negligible at low speeds but increases with speed and at hump speed the transverse wave form is the significant component of wave resistance. Above hump speed, the transverse waves disappear and the divergent waves become the principal component of the wave train.

The angle in salt water develops to be 19.46° initially for all ships but the angle of obliquity , varies with hull form and speed, being lower at higher speed length ratios (4° -10°) and higher for lower speed length ratios and fuller hull forms (20°-30°).

Wave Energy:

The energy in a wave front is the sum of the potential and kinetic energy and is given by:

$$E \quad E_{kinetic} \quad E_{Potential}$$

$$E \quad \frac{gH^2 L}{16} \quad \frac{gH^2 L}{16}$$

$$E \quad \frac{gH^2 L}{8}$$

where g is acceleration due to gravity and is the density of water.

Using the relationship for wavelength as a function of period for open ocean waves of $L \quad \frac{gT^2}{2}$ *, then*

$E \quad \frac{g^2H^2T^2}{16}$, which in metric units can be expressed as $E \quad 1961H^2T^2$

MEASUREMENT OF WAKE WASH

Measurement of Wash energy has been accomplished in essentially the same way in areas of the world where wash is being analyzed. A submerged pressure sensor is used to record wave height and wave period and with these two components, wash height and wash energy density can be determined for various vessel speeds. Summary plots can then be constructed showing height or energy density against speed or Froude number.

A number of such tests have been performed by the authors and it has proven useful to combine the results on a series of graphs to analyze the differences in the wash characteristics of several vessels.

Most of these vessels compared in this paper are high speed aluminum catamaran passenger ferries or tour boats. Some were designed with low wake wash as a specific criteria and some were not.

The Catamaran Ferries International (CFI), PACIFICAT, designed by Incat Designs of Sydney, Australia, and Robert Allan Ltd. of Vancouver, B.C. is an 1886 tonne 245 car, 1200 passenger ferry.

The FBM Tricat SASSACUS, designed by FBM, Isle of Wight, Great Britain, and built by the Pequot River Shipworks of New London, CT is a 400 passenger excursion boat.

The AMD 385 CHINOOK is a 196 tonne, 350 passenger ferry designed by Advanced Multihull Designs of Sydney, Australia and built by Dakota Creek Industries of Anacortes, WA.

The ECat is a 175 tonne prototype ferry or excursion boat designed and built by Halter Marine of Gulfport, MS.

The New York Fast Ferry, BRAVEST, is a 149.87 tonne, 350 passenger ferry designed by Nigel Gee of Great Britain and built by Robert E. Derecktor Shipyard of Mamaroneck, NY.

The SLICE is a 184 tonne prototype multipurpose stable sea-platform vessel designed by Lockheed Marine, Sunnyvale, CA. and Art Anderson Associates of Bremerton Washington, fabricated by Nichols Brothers Boatbuilders of Whidbey Island Washington and assembled in Honolulu Hawaii.

Some key characteristics are given in Table 1:

Table 1
Key Characteristics

VESSEL	LWL (METERS)	L/B	SERVICE SPEED (KNOTS)	DISPALCEMENT (TONNES)
PACIFICAT	96	16.00	35	1886
SASSACUS	42.01	14.41	45	
Ecat	38.6	18.34	31.6	175
CHINOOK	38.5	13.05	34.7	196
BRAVEST	38.0	16.17	32.4	149.87
SLICE *	21.34	28/8.75	27	185

* Waterline length given is from the bow of the forward pod to the stern of the after pod. L/B is LWL/strut beam followed by LWL/pod diameter.

Figures 3 and 4 plot the wake wash height and energy densities of these vessels for comparison. All plots are adjusted to a standoff distance of 300 meters from the line of travel of the vessel. Please note that the wash height of PACIFICAT, a much larger vessel than the others, has been halved and its energy density has been divided by 10 all for clarity of presentation and comparison. For benchmarking purposes, the wash standard used by Washington State Ferries for sensitive areas in Puget Sound is also shown on the graphs. We hasten to point out that this standard was developed empirically for a particular beach area and a different standard will be appropriate for each area of operation.

A number of characteristics of the vessels become immediately apparent:

The vessels reach hump speed (for wake wash) at different speeds. SLICE reaches hump speed earliest at about 16 knots and PACIFICAT reaches it latest at about 34 knots.

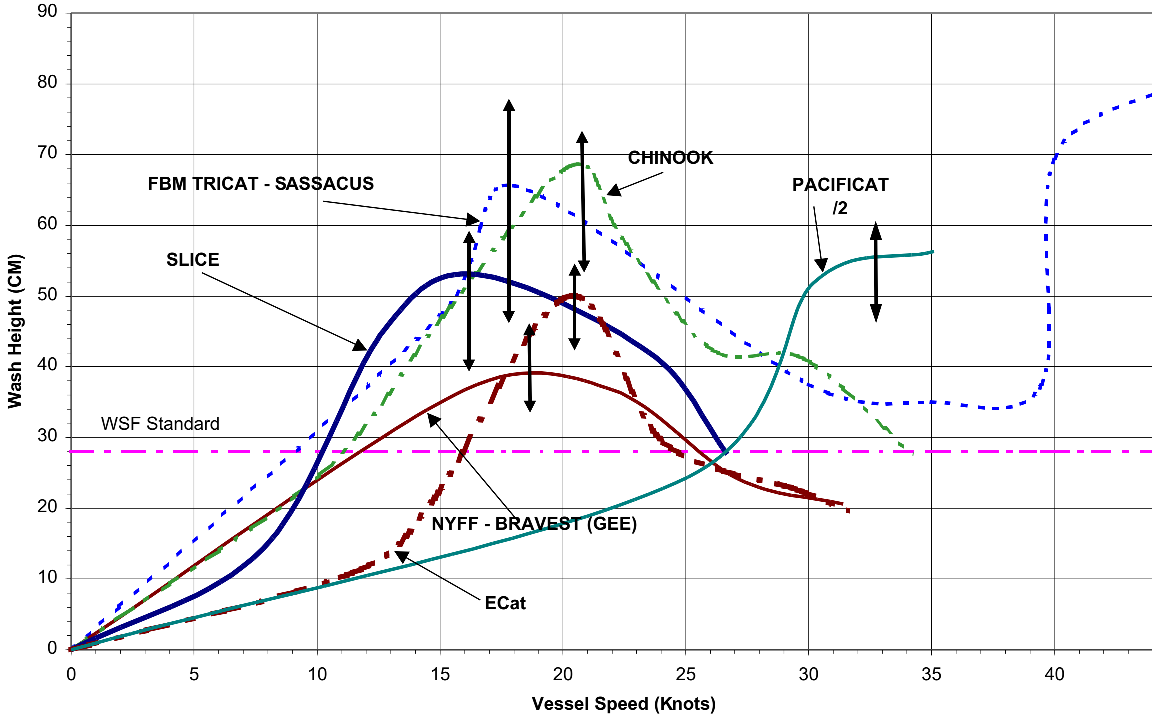

Figure 3: Comparison of Vessel Wash Height at 300 Meters

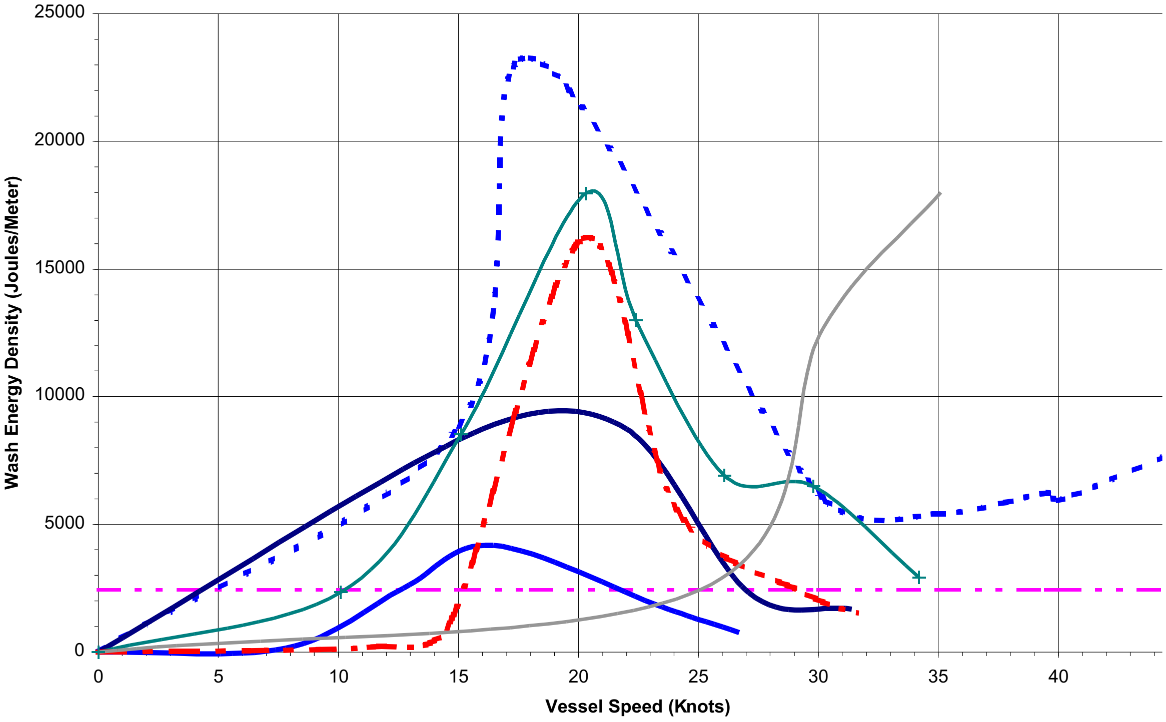

Figure 4: Comparison of Vessel Wash Energy Density

ECat gets through the hump region the fastest and CHINOOK takes the longest.

PACIFICAT never gets over the hump.

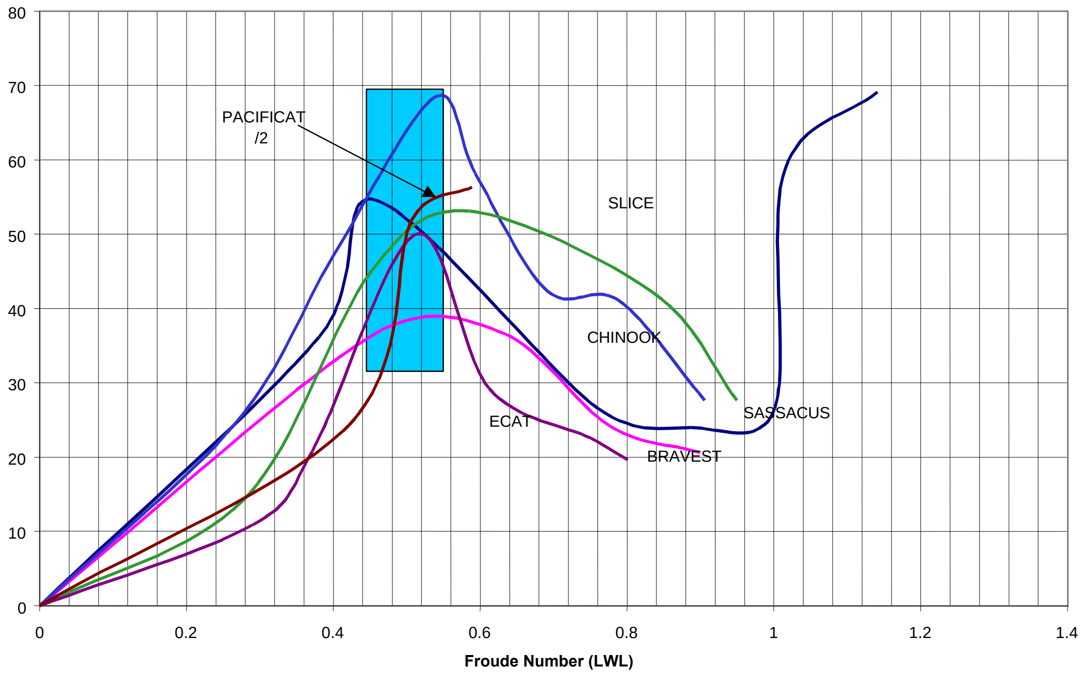

Figure 5: Wash Height vs. Froude Number (LWL)

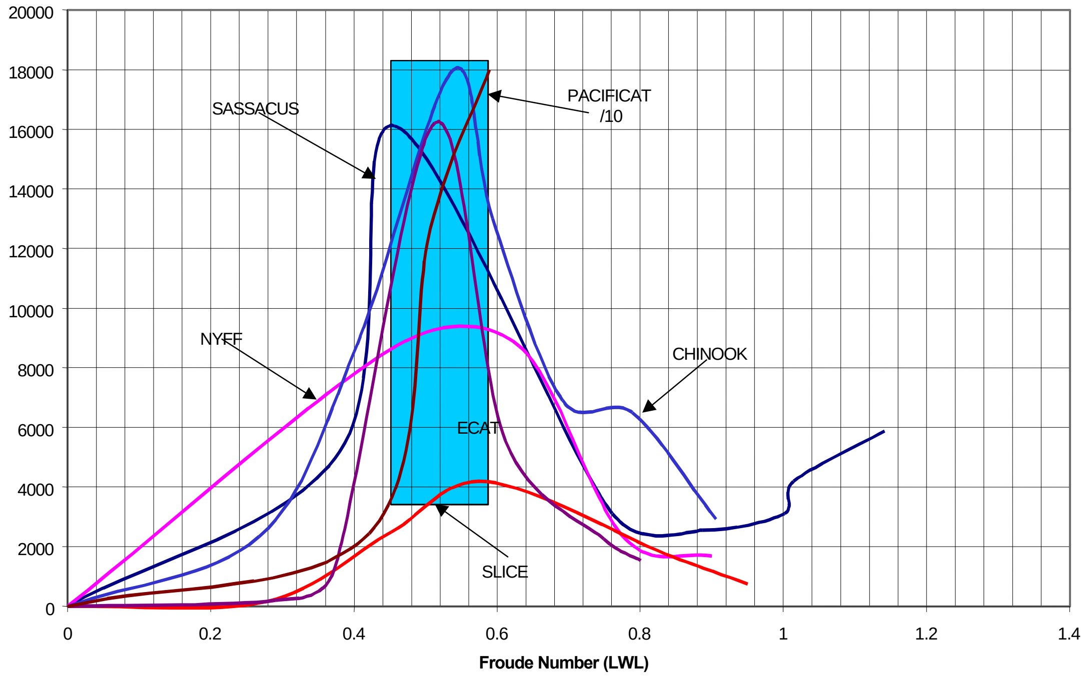

Figure 6: Energy Density vs. Froude Number (LWL)

- The sooner a vessel gets over the hump and the faster it does so, the lower the wake wash at higher speeds.

Froude Number (F_n) can use any convenient relevant dimension and in this study is based on each vessel's waterline length (LWL):

$$F_n = V \Big/ \sqrt{g(LWL)}$$

Replotting this data against Froude Number (LWL) reveals that for all the vessels in this study, the wake wash hump for both height and energy density occurs between a Froude Number of 0.45 and 0.58. It should be noted that the propulsion (or powering) hump normally occurs at a Froude Number of about 0.6. The difference was particularly notable during SLICE trials where the propulsion hump was definitely at 12 knots but the wake wash hump was just as clearly at 16 knots.

DESIGNING FOR MINIMUM WAKE WASH

A design goal of low wake wash can be achieved by designing a vessel that achieves hump speed as early as possible and with the lowest possible hump wash height and energy density.

Hump speed (for wake wash) increases with waterline length. Therefore, minimizing waterline length in a given design will reduce the hump speed.

In general, wash height and energy density at hump speed are inversely proportional to length-to-beam ratio (LWL/B). Also, high LWL/B seems to contribute to getting through the hump more rapidly.

Therefore, reduction of waterline length without reduction of the demihull beam in a catamaran will decrease the length-to-beam ratio and minimizing the hump in both height and energy density depends on the highest possible length-to-beam ratio. So, to maintain length-to-beam ratio as the waterline length is reduced, the beam must also be reduced. The only way, then to maintain displacement is to increase draft as conceptually illustrated in Figure 7.

Increasing draft to maintain displacement will increase the wetted surface of the vessel and therefore, may significantly raise the powering requirements for a given service speed. If wake wash is the paramount criteria or a very important one, the added power and fuel consumption may be a price worth paying.

There are, like all such tradeoffs, limits. For example, the width of major machinery components and their requirement for maintenance access will limit the reduction of beam and operational limitations on proposed operating routes may limit draft.

On the other hand, new opportunities arise. Gas turbine engines, because of their compact size, could be very attractive in a narrow beam vessel.

From the foregoing, several points become very clear:

- Making a catamaran shorter to reduce wake wash is counter-intuitive but appears to be correct.
- When the design goals change, the design process must change. The traditional minimizing of total resistance in the quest for economy and efficiency may need to be rethought in some cases.
- Though SLICE is a unique concept, it's wash performance may lead designers toward semi-SWATHs as a possible optimum low wake wash vessel.

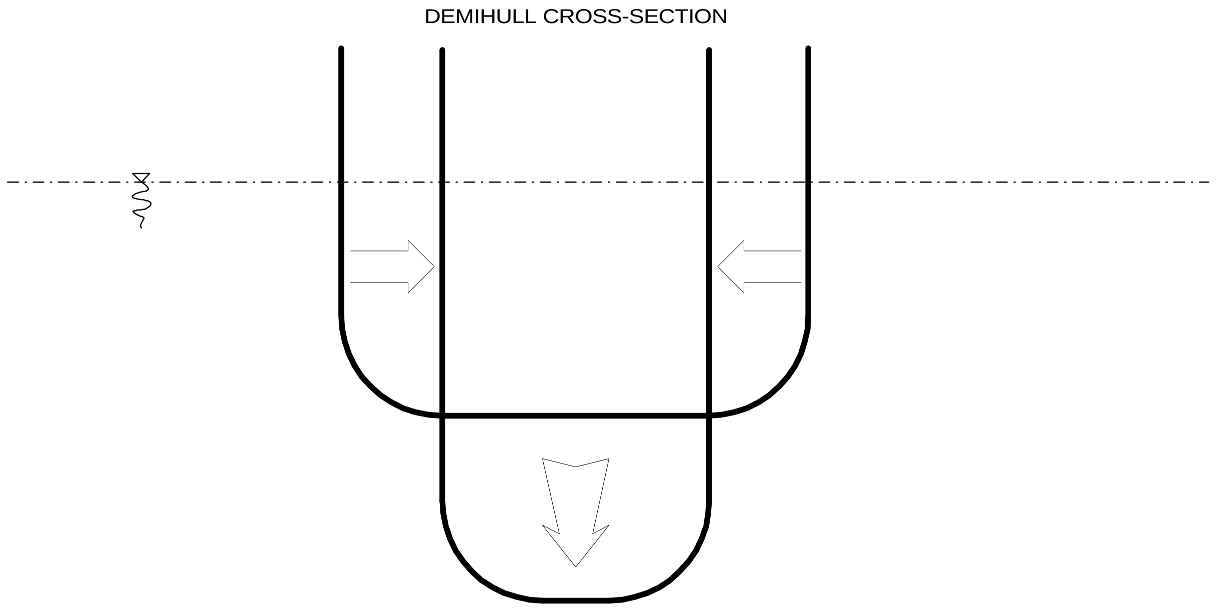

Figure 7: Reducing Demihull Beam and Increasing Draft

THE PRICE TO PAY FOR MINIMIZING WASH:

Naval architecture has been described as a series of compromises to produce a ship that does everything it needs to do but seldom does any one thing as well as we would like. To maximize payload, we sacrifice operational costs in power; to maximize speed we sacrifice payload and economy, etc. The decision to minimize wake wash is no exception. If, as explained above, we choose to limit waterline length (keeping L/B relatively high) to obtain a higher Froude number at lower speeds while maintaining payload, the design may suffer in several other areas:

- Draft increase will somewhat limit the wash reduction and increase propulsion resistance.
- On a catamaran, when demihulls are narrowed, the effect on wash of demihull separation must be recalculated and it may, as well, cause modification of interhull structure which could increase weight.
- Seakeeping in certain sea conditions is sensitive to waterline length and shortening the hull can cause a loss of seakindliness which may cause unacceptable slow downs , to the disadvantage of wash reduction.
- Short waterline lengths may increase pitching and increased bow flare above the waterline may be required.

CONCLUSIONS

- Waterline length and length-to-beam ratio are very important parameters in the design of low wash vessels.
- With increasing awareness and concern about wake wash issues, there is a need for more comparative data on the wake wash profiles of various hulls and hull forms, all prepared to a uniform standard so that they are comparable. The authors have attempted to initiate such a comparison by presenting our observations to date and drawing some preliminary conclusions that may be helpful to designers.

ACKNOWLEDGEMENTS

The authors wish to thank Terry Schmidt, Nigel Gee, Halter Marine Corporation, Advanced Multihull Designs, Nigel Warren, and the British Columbia Ferry Corporation for their kind permission to publish the results of our wake wash measurements of their designs. Without this data, this paper would not be possible.

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