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Design of a High Speed Foil-Assisted Catamaran for Low Wake

By

by Nic de Waal

Fast passenger ferry operations that reduce travel time for commuters are often fundamental to the development and economic well-being of water-based communities. However, surface waves (wakes) generated by high speed ferries can potentially cause adverse impacts to shorelines and properties in confined waterways and environmentally sensitive areas. In Puget Sound for example, repeated attempts to establish passenger fast ferry service over the past two decades on the Seattle-Bremerton route that passes through Rich Passage have met with limited success as a result of such impacts.

The Rich Passage Passenger Only Fast Ferry Study was designed to investigate the feasibility of restoring a passenger only fast ferry (POFF) service between Seattle and Bremerton with particular focus on Rich Passage, the

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Inside this Issue

President's Message

2010 sees our Institution celebrate its 150th Anniversary which is a milestone to be proud of and to provide some reassurance of our strength and resilience.

2009 has been a difficult year for many in our industry and has led to the unfortunate closing of a number of local boat yards, with many others struggling for new orders. The worst appears to be over and orders and inquiries seem to be picking up for some.

The Institute has remained strong and active with regular members meetings around

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companies of note in the Auckland area.

We have an active committee who give their time enthusiastically to the institution for the good of the members and of our profession and I thank them for their support.

Membership numbers are strong (around 240) which are buoyed by the regular intake of student members from Auckland University and Unitec. Both Auckland University and Unitec courses continue to be recognised by RINA and both institutions were visited again this year by Trevor our Chief Executive as part of the ongoing accreditation process. Members of the RINA NZ committee continue to work with Auckland University and Unitec to assist in the ongoing development of their course and maintenance of the quality of graduates. This is something we feel to be vitally important to our industry and the long term future of the profession.

RINA is represented on the executive committee of the MIA and take an active role in ensuring that our voice is heard during discussions regarding the marine industry nationwide. Further members are involved in the ongoing discussions with NZTE, Auckland Plus and the various industry bodies promoting the marine industry and significant development projects within the Auckland region.

Like many of our membership, especially overseas, I am a member of both RINA and IMarEST and throughout the year we have formed closer relations with the local branch of the Institute of Marine Engineers. As well as co-hosting social functions we are opening our technical meetings and talks to members of both institutions. This should benefit the members of both institutions with a greater number and range of technical and social occasions being presented.

Great opportunities exist for our industry with the resurgence of the global economy and the additional exposure and opportunities that will be presented by the Rugby World Cup next year.

I look forward to another exciting year ahead and to doing my best to promote the institution and our industry as a whole.

Ian McLeod

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narrowest section of the waterway constrained by landmass points to the north and south. The objective of the study was to establish criteria necessary to minimize wake damage from potential POFF operations with crossing times of less than 35 minutes and to develop a design which would not only be acceptable to the landowners in terms of its impact on the shoreline, but a design which would set a benchmark for future high speed craft in terms of low wash.

Pacific International Engineering (PIE), a company in Seattle was tasked with finding a design which could be developed to achieve the requirements of low wake and high speed. Having studied a great number of potential designs and many vessels in operation, they selected a Teknicraft hydrofoil supported catamaran as the design which showed the best potential of all vessels. This was followed by Teknicraft and PIE conducting detailed seatrials of two vessels in operation to establish a data set of wave height and energy characteristics which would be used to validate computer predictions.

Teknicraft was tasked to design the vessel, and collaborated with the Institute of Hydraulic Research at Iowa University (IHHR) to do the computational fluid analysis, since they were in the process of developing a very advanced code for wake prediction. The IHHR code is a URANS (unsteady Reynolds-averaged Navier-Stokes) code which demands huge computing resources and is expensive to execute. A decision was therefore made to first do sensitivity analysis using a potential flow code to optimize the hull shape and the hydrofoil profile.

The design of a vessel hull needs to be such that it balances the specific requirements in the most optimum way possible. The first requirement for the vessel was to have a wake signature compliant with a newly developed wake criterion.

Secondly, the vessel needed to be able to maintain a cruise speed of at least 35 knots. The distance between the ports is 13.5 nm, and a crossing time of no more than 35 minutes is required to meet the service schedule. Considering that 4-6 minutes are spent at either end of the route at very low speed whilst approaching the terminals, the average speed to traverse the remaining 13nm is 35 knots. Further important requirements included for the vessel to have low fuel consumption, carry up to 150 passengers, have good sea keeping to ensure a comfortable ride for passengers in all weather conditions, have a cost in the same order of conventional high speed ferries which would not meet the requirements, and meet all US Coastguard requirements for a commercial passenger vessel.

Considering the requirements for this application it was clear that there were conflicting criteria in terms of hull design. For instance a hull that would produce a low wake at high speed with low resistance would not normally be a hull with good seakeeping in adverse sea conditions. Teknicraft provided three different hull shapes which emphasized different characteristics in terms of low wake, low resistance and good sea keeping, as well as a number of foil profiles. Through the potential flow CFD analysis an optimized hull shape and foil profile was developed.

The URANS code was then used to further enhance the hull shape, optimize demi-hull spacing, foil location relative to centre of gravity, and trim angle of the vessel. Once optimized, the wake predictions were calculated. Due to the very large grid which is required to obtain the necessary accuracy, only the near field wake data was predicted using the URANS code. However, a Havelock source code was used to propagate the near field data to wave height and wave energy properties at a distance of 300m from sailing line. The results were checked against the measured field data of the catamarans, whereby the code was validated.

The service speed of 35 knots or more was not only dictated by the commercial aspects of the route and scheduling times, but more importantly by the geographical features, and in particular the water depth in the passage area.

For any given vessel and constant water depth, an increase in speed will lead to an increase in the height of the maximum wave in a wake train (H_{max}) up to a certain speed. Beyond that speed, the maximum wave height will decrease. The speed at which H_{max} occurs is often referred to as the hump speed. The hump occurs when the ship produces a wake with a wavelength that is one-half the length of the ship.

The vessel speed at the hump (V_{hump}) can be derived from the dispersion relation (the relationship between wave speed and wave length) for linear waves substituting the length of the ship (L) for wavelength and the local water depth (h):

$$V_{hump} = \sqrt{\frac{gL}{\pi} \tanh \frac{\pi h}{L}} \qquad (1)$$

Note that V_{hump} occurs at a *vessel length Froude number* (F_L) of 0.56 where F_L is defined as:

$$F_L = \frac{V}{\sqrt{gL}} \qquad (2)$$

According to eq. 1, V_{hump} becomes constant as the water depth h becomes large for a vessel given L. Also, shorter vessels get over the hump and begin to show a reduced wake at lower speeds than longer vessels.

For the case of the Seattle to Bremerton ferry route, water depths vary between 20 and 30m, and typical passenger only vessels have lengths that vary over a similar range. Therefore hump speeds are typically in the range of 15 to 25 knots for most conventional commercial catamaran craft in this area. In general, it is important to avoid operations around the hump speed in cases where wake minimization is an objective, because the vessel will, in general, produce it largest wakes around these speeds. Fuel consumption is also very high at the hump speed.

Super-critical and sub-critical wakes

The term super-critical is sometimes used to describe high-speed vessels while the term sub-critical is used to describe displacement vessels travelling at slow speed. Super -critical refers to the state where the vessel is moving faster than the speed at which a wave of the same length can travel in that depth of water. The wake produced by a super-critical vessel is different from that produced by a vessel moving at sub-critical speed. The super-critical condition occurs when the speed of the vessel exceeds that of a long wave in the same depth of water. It can be determined using the depth Froude Number (F_h):

$$F_h = \frac{V}{\sqrt{gh}} \qquad (3)$$

Figure. 1a illustrates an example wake pattern generated by a vessel moving at 38 knots in water that is infinitely deep. Since h is infinite, F_h = 0 and the condition is sub-critical. The wake is composed of two parts: diverging wakes that move away from the vessel at an angle of up to 35.27° and transverse wakes that move in the vessel's direction. Both types of wakes theoretically exist only within a cone set at 19.47° from the vessel.

The wavelength and speed of the wake can be found from linear wave theory. As the vessel speed increases, so does the speed, or celerity, of the wake. A point will be reached where the vessel is moving faster than the celerity of the transverse wake and the transverse wake is shed. Beyond this critical point (i.e., if the vessel maintains a speed equal to or greater than this speed and the depth remains the same or decreases) the wake will assume a super-critical wake pattern, which is composed only of diverging wakes. Figure. 1b shows the wake pattern for the same case as shown in Fig. 1a, but in a depth of 30 m. In this water depth, F_h = 1.14 and the resulting wake pattern is super -critical. The pattern is broader and there is no transverse component following the vessel. The spacing between wave crests in Figure. 1a varies considerably for the diverging wakes, but only slightly for the transverse wakes.

The variable spacing corresponds with a variation in the time it takes for successive wave crests to pass a fixed point, in other words wave period (T). Corresponding wave periods are superimposed on the wake pattern as colour contours in Figure. 1. It can be seen that the transverse wave period is approximately 12 seconds, while the divergent wave periods vary between about 1 second close to the sailing line and 10 seconds away from the sailing line. The speed range around F_h = 1 is known as the trans-critical speed range, which will be discussed below.

Trans-critical wakes

A sub-critical wake pattern contains both diverging and transverse wakes. Below the hump speed, the two wake patterns are not impacted by the depth. Beyond the hump speed, the transverse wakes begin to "feel" the bottom and become less dispersive (i.e., less able to transfer energy from one wave to another). At the critical speed, F_h=1, the vessel and the wake are both moving at the local long wave speed, $\sqrt{gh}$. In reality, this behaviour is not instantaneous but occurs over the trans-critical range. The breadth of this range around F_h=1 is unclear, but estimates vary as broad as 0.84 to 1.15 and 0.85 to 1.1

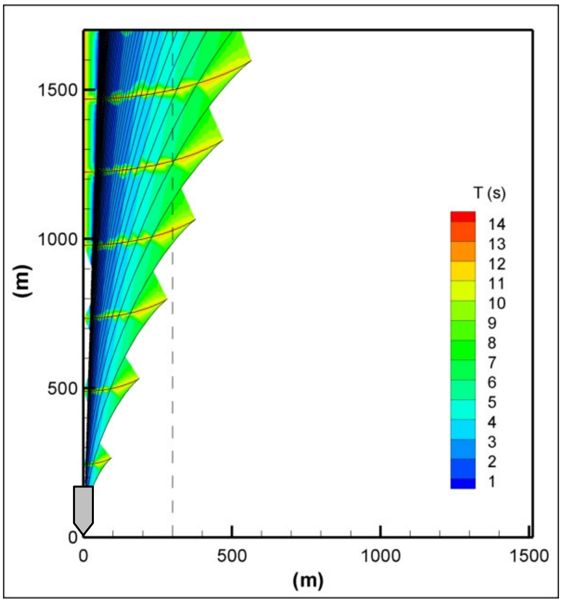

Figure 1a. Wake period for 38 knot vessel in infinite depth water

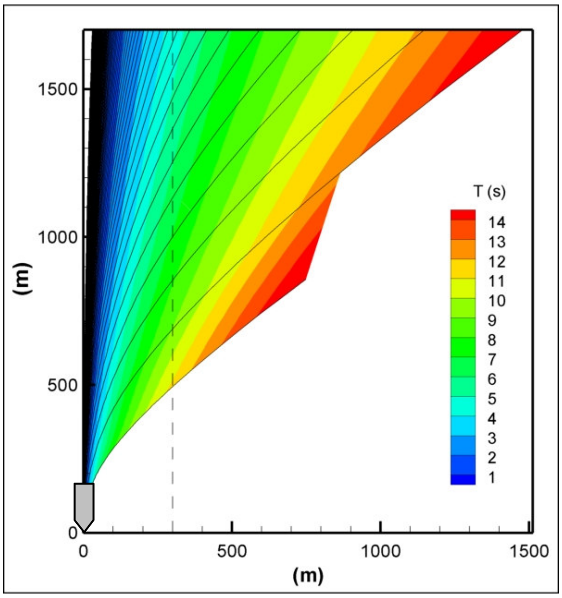

Figure. 1b. Wake period for 38 knot vessel in finite depth water

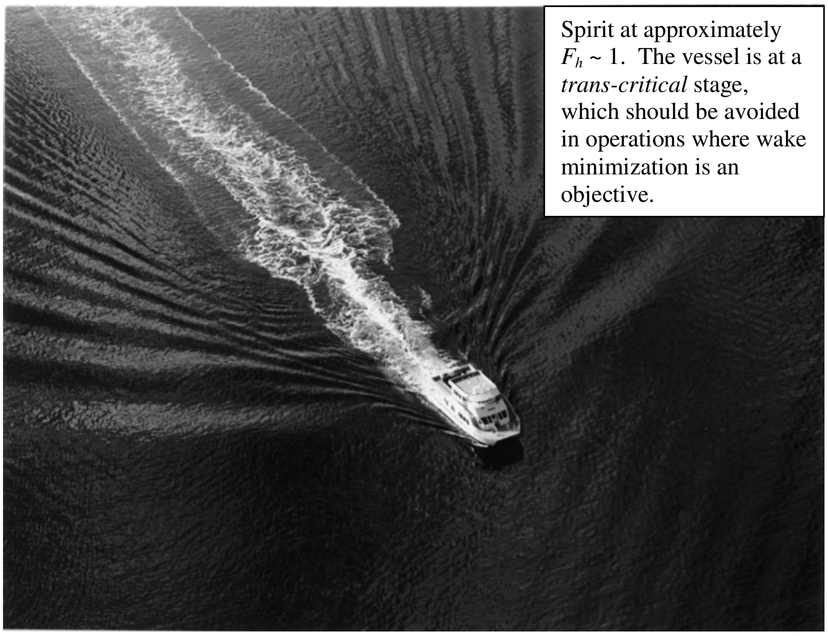

Figure. 3. Photograph of Spirit slowing down and passing through the trans-critical speed. Note the large, long waves building alongside the vessel.

At the critical speed, a single transverse wave will develop parallel to the vessel stern. Since energy is constantly pushed into this wave and the wave cannot disperse, the transverse wave can grow in size very quickly. If a vessel operates at the critical speed for too long the wake will extend further and further out from the sailing line and build in height. The pattern will change depending on the duration of operation at this speed. There will also be a dramatic increase in wave making resistance of the vessel and, consequently, fuel consumption. From both a wake minimization and economic standpoint, it is important that a vessel not be operated at the critical speed for long periods of time. Another effect of these very long trans-critical waves is shoaling in shallow water resulting in an increase in wave height and higher wave energy per unit area of the wave. Figure. 3 shows a photograph of a foil-assisted catamaran slowing down and passing through the trans-critical range; a large, quickly developing wave alongside the ship is clearly visible. For a high speed vessel, the optimum operational range is often the super-critical range, if depths permit. Figure. 4 shows a photograph of the same vessel operating in the super-critical range.

Figure. 5 illustrates the variation in the trans-critical condition with tidal variation. Based on the trans-critical condition, vessel speeds between 26 knots and 36 knots can be potentially problematic for shorelines and waterfront properties depending on tidal elevation. The degree to which operation within and beyond this speed range will be problematic will depend on the wave making characteristics of the POFF vessel in operation for a certain load condition and centre of gravity location.

The results from previous operations and the in-situ trials indicate that beaches in the Rich Passage area respond differently to wakes from both high speed (critical and super-critical) operations and to slow (sub-critical) operations and ambient wind waves caused by storms. Despite small differences in wave height, the wakes from the fast POFF vessels can be significantly more energetic because their periods are longer than wakes from slower vessels. The different wave periods also result in dissimilar wave refraction patterns which produce different quantities of alongshore and across-shore sediment transport. The longer period waves associated with POFF wakes refract more as they enter shallow water and approach the shore with their crests almost parallel to the shoreline. The shorter period

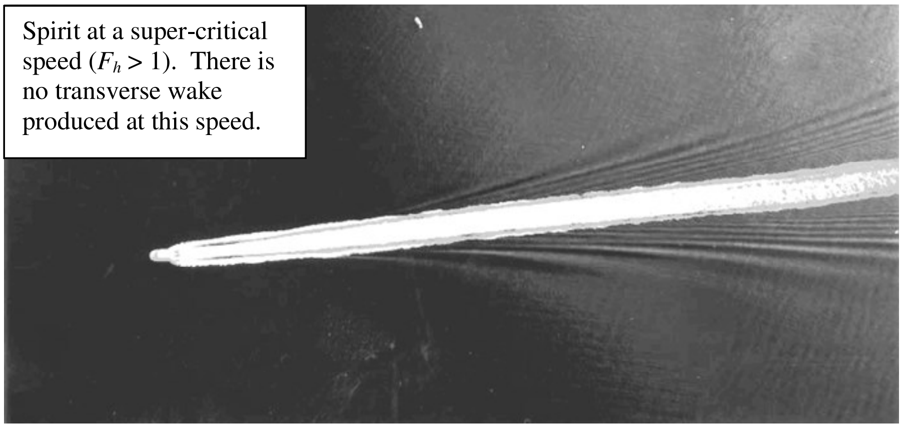

Figure. 4. Photograph of Spirit at a super-critical speed. Note only diverging wakes are present.

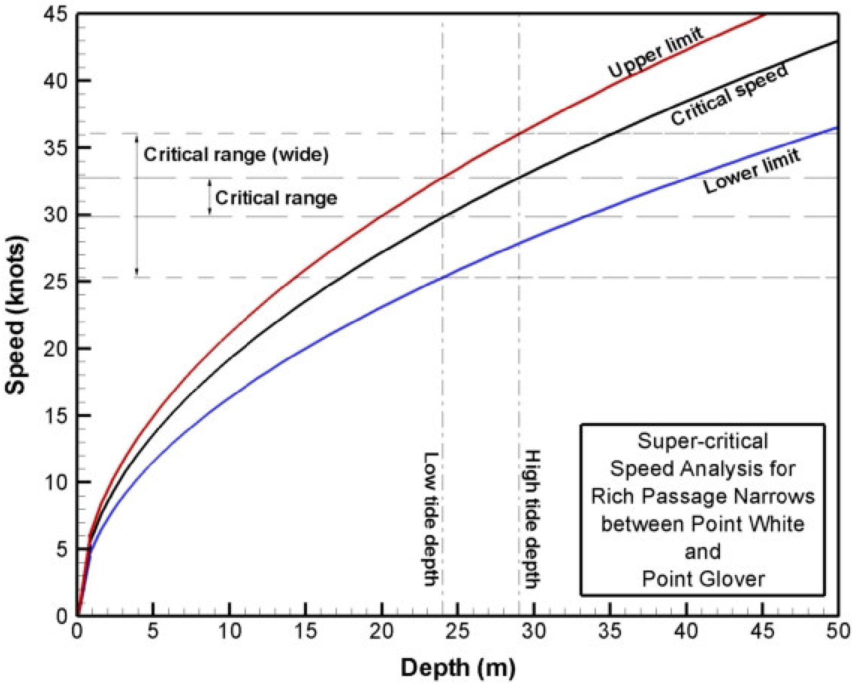

Figure. 5. Critical speeds analysis for Rich Passage Narrows.

wakes from smaller and slower vessels (and also wind generated waves) refract less and approach the shore at larger angles.

Conclusion

Simulation results show that the final design being built satisfies the criterion for wake energy with powering requirements within range of available commercial engine and waterjet systems.

The conventional method of predicting resistance and wave data comprises of fabricating a physical model and obtaining resistance and wave data by towing the model in a towing tank facility. Potential Flow CFD optimization enabled a hull and foil geometry to be derived, which was morphed from three significantly different hull shapes. Such optimization would not be financially viable using conventional towing tank methods. Even though PF provided optimized geometry, it did not provide accurate absolute data in terms of resistance, wave height and wave length. The URANS-Iowa viscous solver was able to analyze the optimized geometry to obtain data within an accuracy tolerance acceptable for commercial applications. The URANS solver also enabled the design to be further enhanced through the refined optimization of lift components and trim angle, and to find a balanced design which would best meet the original design criteria.

The end result of the optimization was a design with significantly reduced far field wake. The vessel is currently under construction. A detailed testing program will be performed on the full-scale vessel, to validate the results obtained from the URANS solver.

References

Osborne P, de Waal N, Cote J, MacDonald N (2009) 'Impact studies and criteria for high speed operations with foil-assisted catamarans in a wake sensitive area' 10th International Conference on Fast Sea Transportation, Athens, Greece.

Kandasamy M, Ooi SK, Carrica P, Stern F, Campana E, Peri D, de Waal N, Osborne P, Cote J, Macdonald N, "Urans based optimization of a high speed foil-assisted semi-planing catamaran for low wake'' 10th International Conference on Fast Sea Transportation, Athens, Greece.

Nic de Waal is managing director of Teknicraft Design, designers of innovative and functional high performance commercial and recreational power catamarans.

Forthcoming events

Please watch your **Inbox** for the latest events listings. If you do not receive email please pass on your details to to the division and we will ensure you hear about our talks.

Project: **Offshore Patrol vessel visit**

Date: **To be confirmed**

The newest ship in the Royal New Zealand Naval Fleet, Offshore Patrol Vessel HMNZS OTAGO, arrived at the Devonport Naval Base in April. This vessel and the HMNZ WELLINGTON will work with government agencies such as the Ministry of Fisheries, Police, Maritime New Zealand and the Department of Conservation around the New Zealand coast, in the Pacific and Southern Ocean.

Students Receive their Awards

When Trevor Blakely came over to meet New Zealand Division members in February, our student award winners were presented with their prizes.

Congratulations to Kris Decke and John Little (VT Fitzroy- RINA prize for an University of Auckland). Their winning project was summarised in our December newsletter.

Congratulations to our Unitec award recipient Aneel Kesry, who undertook to design a custom, 8.5m sports fisher for a friend and colleague.

RINA NZ Division News

April was a busy month for RINA NZ. We started the month with a dinner cruise on the Waipa Delta to celebrate RINA's 150th Anniversary. 55 people enjoyed a three hour cruise around the Auckland harbour to celebrate this historic event.

A week later, on April 13th the annual general meeting for the New Zealand Division of RINA was held at the MIA. Division Business included accepting the resignation of Chris Moors from council, the election of Rupert Shaw from LOMOcean Design, president's report, and treasurer's report. We would like to pass on our best wishes to Chris and thank him for his contribution to the RINA NZ division.

The AGM was followed by a very interesting talk by LT CDR Simon Fleisher RNZN about HMS NOTTINGHAM Grounding at Lord Howe Island in 2002.

HPYD Update

With the announcement of the Volvo Ocean Race stopover dates the HPYD organizers are planning the dates for the next conference (HPYD4). The High Performance Yacht Design conference is a popular event and is sponsored by RINA. So keep March 2012 free and sign up for an email update at **www.hpyd.org.nz.**

Emails

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