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Dr. Ian W Dand, BSc PhD FRINA FRSA FREng

The Wash of Surface Ships

ABSTRACT

Wash is the inevitable consequence of a vessel moving on the surface of a river, canal, lake or the sea. In this paper the principal features of wash are considered, as are the factors causing them. Some consideration is then given to the reduction of wash nuisance by design and operation after which the paper concludes with a brief excursion into wash criteria.

The main conclusion reached is that, while wash of surface vessels cannot be eliminated entirely, its nuisance to other waterway users can be reduced to acceptable levels by suitable design and operational measures.

INTRODUCTION

All vessels, moving on the surface of the sea, create wash. Indeed, they must do so because the characteristic wave pattern made by a moving ship is simply one manifestation of the pressure changes over its hull.

In recent years, wash has received more attention than usual and it is perhaps no coincidence that this has gone hand-in-hand with the increase in the service speed required of certain vessels. New advances in lightweight, powerful propulsion machinery, coupled with a greater range of propulsor types and capabilities, have enabled vessels to achieve speeds in excess of what was considered the norm a comparatively short time ago.

These advances have certainly brought benefits to operators and the public at large because cargo, passengers and services can be delivered more rapidly, or in greater bulk, than before. But such advances come with a cost. The wash of some high speed vessels can cause damage and may endanger life. At the very least, it can, in some cases, constitute a significant nuisance to other waterway users. High-speed vessel wash contains a significant amount of energy and if this is dispersed in shallow water near a beach or a river bank, people on the beach may be inconvenienced or the bank may be eroded away.

In this paper we explore the factors relating to wash which the quest for speed, facilitated by increased propulsive power and efficiency, have brought into prominence. We then go on to suggest how design and operation can help to minimise its unwanted effects and conclude by considering criteria which result in acceptable levels of wash.

FACTORS AFFECTING WASH

A number of factors are crucial in determining the character and extent of a vessel's wash. These are:

- Speed
- Water depth
- Hull design and type
- Propulsor type
- Proximity of channel banks and their type

We consider these individually.

Speed

Speed, of course, is crucial to the generation of wash. With no speed, there is no wash.

It might be supposed that the greater the speed, the greater the wash height, but this is not necessarily so. Waves are created, at low speeds, by the bow and stern with, in some vessels, other, lesser, wave systems arising from idiosyncrasies in the hull design. As the waves are created, they will superimpose, resulting in interference between the main wave systems. The result is that, at some speeds, wave height is augmented, while at others it is reduced. These wave interactions in the wash lead, at comparatively low speeds, to humps and hollows in the resistance (and wash height) curves, these being defined not solely by speed, but by the relationship between speed, vessel length and, in shallow areas, water depth.

These links between speed and length or depth lead to the well-known Froude Length and Depth Numbers:

$$F_{nl} = v / \sqrt{gL}; \quad F_{nh} = v / \sqrt{gh} \qquad \ldots(1)$$

where v is vessel speed
L is vessel length
h is water depth

These help to define the characteristics of wash and wave resistance, the humps and hollows in the wash height and resistance curves being related to the appropriate Froude Number, rather than speed on its own. This explains why, when two vessels are moving at the same speed in deep water, the shorter of the two may make the most wash because it is operating at the higher Froude Length Number. In shallow water, it may be the larger of the two that makes the most disturbance because of the relationship of ship length to water depth. This is discussed further below.

Not only does interference between wave trains emanating from different parts of the hull affect wash height, so does interference between different wave components in a wave train. At low, "displacement" speeds there are diverging and transverse components in a surface ship's wave system (see Figure 1). At the cusps of this system, wave heights may be enhanced by interference, whereas in other areas, where diverging and transverse wave components cancel, wave height is diminished.

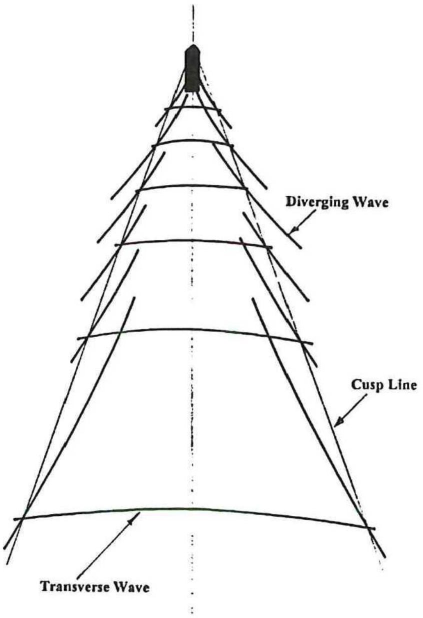

Figure 1. Sub-critical Wave System

At high enough speeds, the transverse wave system cannot keep up with the vessel and disappears. The remaining wash consists solely of the diverging system which stays with the vessel as speed increases further. Such waves have quite high energy and are very persistent. They may perhaps be the source of the wave "packets" seen moving over coastal or harbour waters on a calm day with few, if any, vessels in the vicinity.

It is important to remember, however, that speed affects not only the height of waves in a ship's wave system, but also their period. Frequently, wash nuisance is due as much to the periodicity of the wave system as to wave height. As will be seen, at certain combinations of speed and water depth, long period waves can be formed.

Water Depth

Depth of water is relevant to any discussion of wash. It is known that dispersive waves steepen and increase in height when they enter shallow water and it is well-known that the resistance to motion increases. Much of this increase is

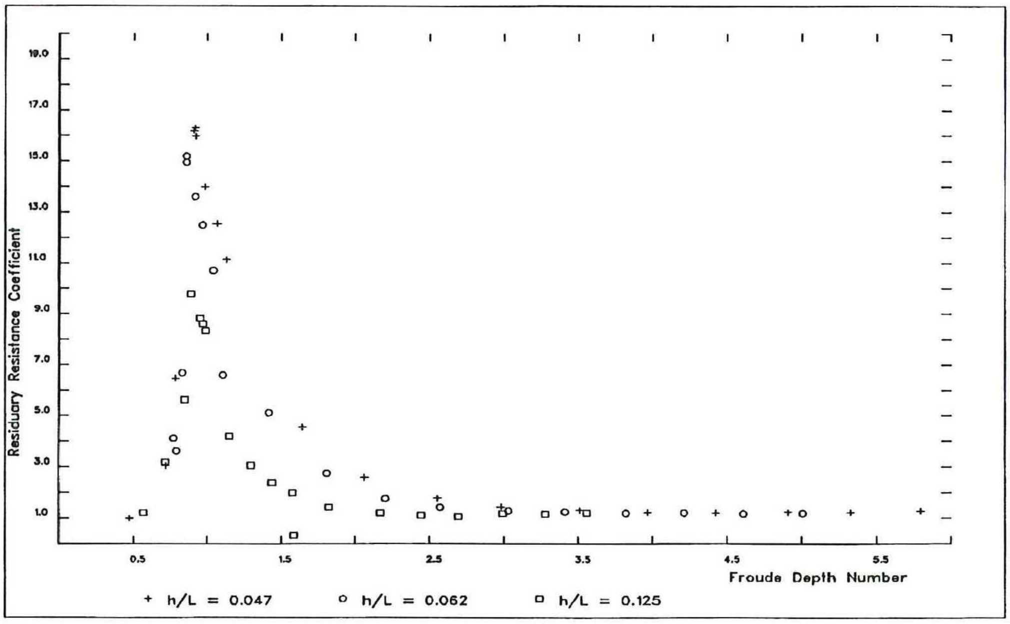

Figure 2 Residuary Resistance

in the wavemaking component of resistance and it is well-known that, for displacement ships, speeds will be limited in certain depths of water because the vessel simply does not have enough power to overcome the resistance increase.

Nowadays, however, we have seen the rise in popularity of craft which have sufficient power, and are designed, for high speeds. This has two consequences in terms of wash generation:

- Vessels can move at much higher speeds in shallow harbours, rivers and estuaries than has been the norm in the past
- Waters which were once considered to be deep are now, as far as wash generation iS concerned, to all intents and purposes, shallow

These two consequences alone have caused wash to assume a higher profile in the consciousness of the maritime world in recent years and it is perhaps relevant to consider why this should be.

If a ship is moving at a speed through the water that makes the Froude Depth Number of equation (1) equal to unity, it is said to be moving at the critical speed for that depth of water. If this is combined with a water depth, h, which is small in relation to the length, L, of the vessel (say less than 50%), large increases in residuary resistance and wash height will occur. Figure 2 demonstrates this for a model catamaran for three small values of the ratio h/L; values of residuary resistance coefficient show a pronounced peak at or near unity Froude Depth Number.

Figure 3 shows the effective power curves deduced from the results in Figure 2 and demonstrates the following:

- At or near unity Froude Depth Number the effective power curve steepens and then flattens out before adopting a more normal shape at high speeds
- As h/L is reduced, effective power drops at low Froude Depth Numbers, but less so, or not at all, at some supercritical values

These two observations relate to practical, operational, consequences:

- If a craft gradually builds up speed in sufficiently shallow water, it will experience a rapid increase in resistance in the transcritical range. This may limit its speed as it tries to get over the "hump" and will generally be accompanied by an

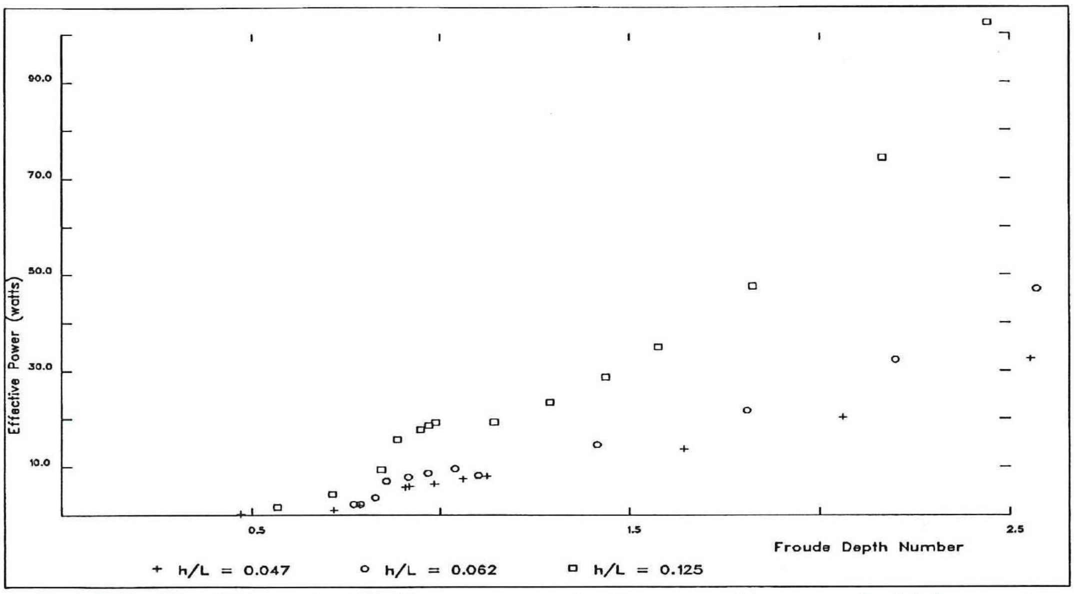

Figure 3. Effective Power in Shallow Water

increase in wash height, as Figure 4 demonstrates
- If the vessel has enough power to “get over” the hump, it may suddenly increase speed to a much higher value, due to the levelling off of the effective power curve seen in Figure 3
- Furthermore, other model results have shown that, if the vessel then moves into deeper water, it may not increase its speed much (depending on Froude Depth Number) because shallow water resistance in super-critical conditions may be less than that in deep.

Hull Design and Type

The hydrodynamic design of hull forms to keep residuary resistance (and, as a consequence, wash) to acceptably low values has long exercised the minds of naval architects. Wave cancellation, or tuning, devices have been, and are still, in vogue and the bulbous bow and, to a lesser extent, the bulbous stern, have both been used for this purpose. Although the bulbous bow, if properly designed, will reduce residuary resistance, it can only do so over a limited speed range. It is, in effect, tuned to the wave pattern of the hull at a given speed. This is ideally suited to a merchant vessel which operates for most of its life at its service speed; significant fuel savings can accrue from a well-designed bulb.

But, although the bulb reduces waves, and by implication, wash, it is not an ideal solution if wash levels must be reduced over a range of speeds. Similar considerations apply to wave cancellation plates at the bow, a device seldom used these days and likely to be of very limited use in the reduction of wash.

Other features of hull geometry affect wash, and most naval architects are aware of the changes in residuary resistance that can be brought about by:

- Prismatic coefficient
- Displacement/length^3 ratio
- Beam/draught ratio

for displacement ships. These are also drivers of wash generation and some will be re-visited below.

However, hull type can also affect wash. By this is meant whether a vessel is a monohull or a multihull and whether it is a displacement, semi-displacement or planing type. It is known that multihulls can generally produce more acceptable

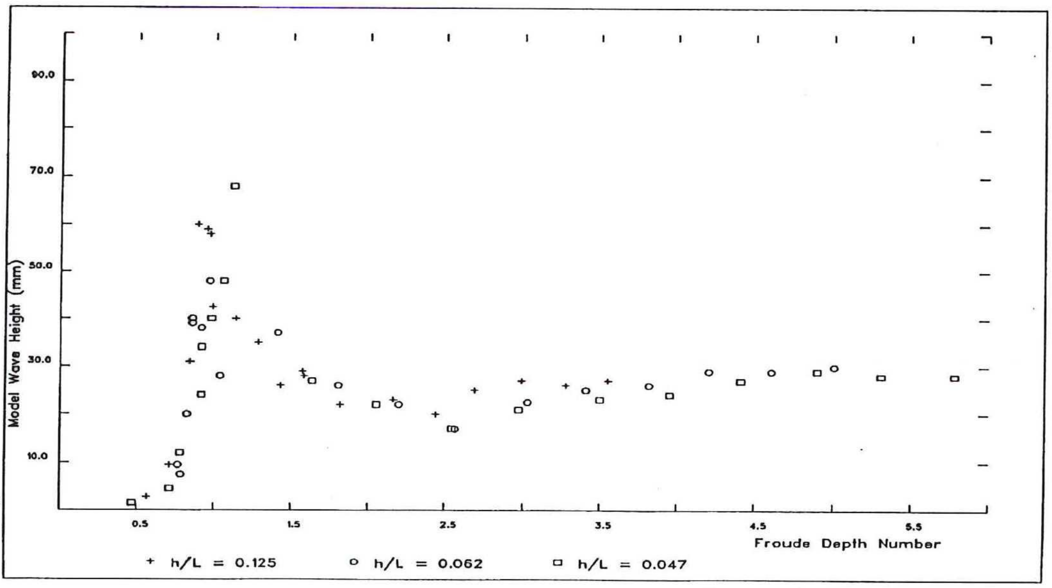

Figure 4. Wash Heights

wash than a monohull of the same displacement, but this is not an inviolate rule. A badly-designed multihull can still produce poor wash characteristics.

A feature of semi-displacement or planing vessels (as well as multi-hulls) is that they are able to move at supercritical speeds in a wide range of water depths. They therefore have the potential to create significant wash. They also have the ability, because of their speed, to re-define waters (which were considered as deep for slower-moving vessels) as shallow. For example, a vessel able to move at 40 knots is doing so at around the critical speed in the southern North Sea. For such vessels, this sea area may therefore be regarded as shallow.

When high speed is desired, there are of course a number of vessel types which do not fit into the definitions used above. Notable among these are the air cushion vehicle, the surface effect ship and the hydrofoil. In terms of wash the last generally has the most favourable characteristics, but only when foil-borne, much of the energy then being translated into spray and underwater turbulence, rather than surface waves. Air cushion vehicles can have acceptable wash characteristics, but surface effect ships may not, due to those parts of the vessel which penetrate the sea surface.

Propulsor Type

The effect of propulsors on wash is, for obvious reasons, confined to a discussion of those which work on or under the water surface. Propulsion by air-screws is, of course, not included.

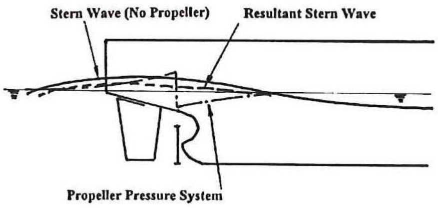

Figure 5. Effect of Propeller

Conventional submerged propellers have long been known to affect the stern wave system of displacement ships, as shown diagrammatically in Figure 5. This is related to the well-known phenomena of thrust deduction and resistance augment, but, from a wash point of view, the effect is small. The greatest environmental effects of such propellers is more likely to be from scour of the sea, or waterway, bed in shallow and confined waters. Such locations occur in berthing pockets, locks, fairways and canals.

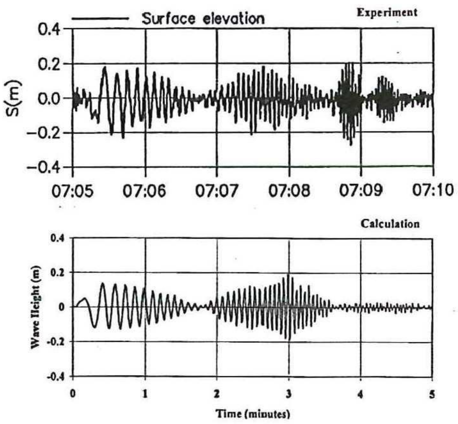

Figure 6. Wash Measurement and Prediction

Waterjet propulsion is much in vogue for high speed vessels, notably high speed ferries. A very comprehensive series of wash measurements for such craft is described by Whittaker (1997), one example of which is shown in Figure 6. Also shown in this Figure is a calculated prediction of this wave trace, carried out by Gadd (2000). The agreement between the two is remarkable, except for a measured high frequency component which was not reproduced in the prediction. Speculation suggested that this component might be due to the jet from the waterjet units of the ferry (or the jet units themselves) impinging on the water surface and making an additional wave system. This was tested at model scale and the results are shown in Figure 7. It is clear that the waterjet in operation had some effect on the wash spectrum.

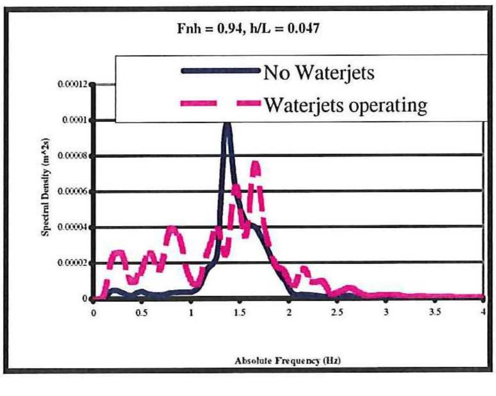

Figure 7. Wash Spectra

Other means of propulsion such as surface-piercing propellers and the submerged jets of jet-foil craft will also have an effect on wash, but their use is not the norm and because of this they do not pose the same potential problems as other more popular means of propulsion.

Having briefly considered the effects of propulsors on wash, it is fair to say that, by and large, their direct contribution to wash nuisance is small. Their indirect contribution, coupled with high-powered diesel or turbine prime movers can be considerable, however. It is they that drive a given hull at certain speeds for which the wash, created by the hull rather than the propulsors, can be considerable.

Channel Banks

When a channel has banks, further changes to the wash regime may occur. Here we discriminate between flooded banks (such as in a fairway) and surface-piercing banks, as in a canal.

Flooded banks often have a shallow area on one or both sides with a comparatively deep channel between. Waves created by a vessel moving along the channel must inevitably travel over the shallow side areas and those waves which are moving at sub-critical speeds in the channel may well find themselves moving at supercritical speeds over the shallows on each side. This will cause such waves to steepen and possibly break, causing nuisance to other water users. If the water over the side banks is especially shallow, and the vessel speed excessive, then the water may be drawn down by the ship in the channel, thereby reducing the depth of water over the side banks. In extreme cases, the side banks may be temporarily drained. If this happens, the water can return with some violence, which, with the attendant breaking waves, could cause some disruption, coupled with damage to the shores of the waterway if they are close to the channel.

Bank damage can also be caused when surface-piercing banks are present. If they are sloping, there will inevitably be a depth near the surface for which the wash speed will be supercritical resulting in waves which steepen and break, as described above for a fairway with flooded banks.

However, there is another feature of wash in canals and rivers which demands attention. As a ship, having an h/L ratio less than 0.5, increases speed in a canal, (or shallow water) the angle of its diverging waves to the sailing line may increase until, at the critical speed, it is approximately at right angles. In a river or canal the vessel will appear to have a large transverse wave at its bow and, possibly, another at or abaft its stern, with a significant draw-down between. Closer inspection will reveal the fact that the wave at the bow may well be moving ahead of the vessel, its place being taken by another. This process will continue as long as the vessel maintains its speed, a train of waves developing ahead of it, all moving at the same speed.

These waves are called, variously, waves of translation, solitary waves or solitons. They are seen generally in rivers or canals, although there is some evidence that fast ferries may produce "precursor" waves on some occasions. Solitary waves have been caused by large, comparatively slow-moving, vessels, high speed vessels and air cushion vehicles. They are non-dispersive and may travel for many miles along canals and rivers, causing moored vessels to range on their moorings and pontoon jetties to move erratically. They are unusual in that they have a crest, but no trough and are possessed of significant amounts of energy. Finally, they may have very long periods and be difficult to observe until their effect on other waterway users becomes apparent.

MINIMISING WASH BY DESIGN AND OPERATION

Although wash is an inevitable by-product of a vessel operating on the surface of the sea, there are certain things that can be done to minimise its effects. These may be classified broadly into those actions that can be taken at the design stage and those that relate to operation.

Features of Design

The effect of bulbous bows on the wave system of a hull form has already been discussed and leads naturally to consideration of whether, in general, the shape of the hull can be chosen to minimise wash. This has been the goal of naval architects for many years and studies, involving both model tests and calculation, have been carried out on hulls of unconventional shape, invariably for sub-critical speeds. These often have complex geometries, arranged to aid wave cancellation and, although they can be successful in this regard, they are often less successful in terms of build cost and payload carrying capacity.

When speed increases to the transcritical regime, large waves can be produced if the vessel maintains such speeds at certain depth/length ratios. In some parts of the world, route schedules and local harbour water depths can combine to cause vessels to move in this speed regime and create large waves. A model test study (Dand, 2000) explored the relationship between global geometrical hull parameters and wash height in the transcritical regime and concluded that three had the greatest influence. They were, in order of importance:

- Displacement/length^3 ratio
- Transom area ratio
- Prismatic coefficient

Of these, the first was found to be by far the most important. It should be kept as low as possible which drives the designer, not unexpectedly, to long, slender, hull forms. Typical of these are modern catamarans for use on rivers with an extreme example being the rowing eight whose hull produces very little wash.

The desire for waterjet propulsion has led inevitably to the almost universal use of

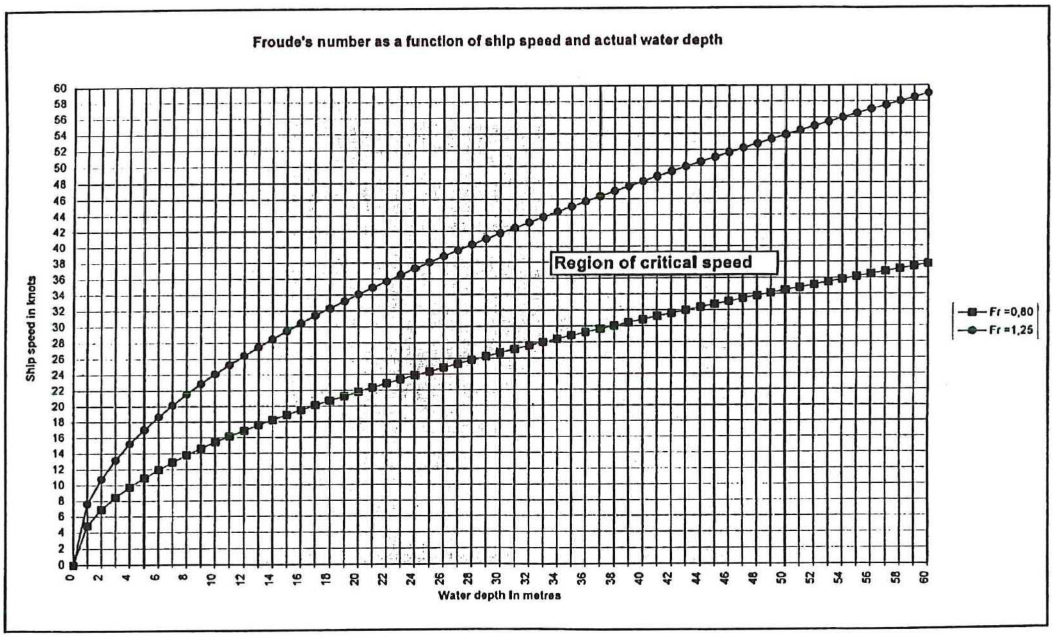

Figure 8. Danish Maritime Authority Speed/Depth Guidelines

transom sterns for high speed vessels. These can bring with them a high resistance penalty and give rise to significant stern waves. Again, the ratio of transom area to midship section area should be kept as low as possible.

Prismatic coefficient is well-known as a hull parameter related to wave generation and residuary resistance and it should be kept as close to the optimum as practicable.

For vessels moving in the supercritical regime, several design options are available:

- Long slender hulls for displacement vessels
- Planing surfaces
- Air cushion vehicles
- Hydrofoils

All will produce wash to a greater or lesser degree, although the hydrofoil option can produce the least wash when foil-borne, albeit at some cost. All vessels moving at supercritical speeds should produce lower wash heights than in the trans-critical regime, but periodicity may be increased. Figure 4 demonstrates the effect on measured wash height on a catamaran model in shallow water.

Features of Operation

Wash can be reduced in nuisance terms by appropriate operating techniques. These relate, in the main, to:

- Speed
- Route
- Manoeuvring

Speed

We have seen that operating in the transcritical regime can produce waves of the greatest height and period. Clearly, it is a regime to be avoided, if at all possible. The matter is complicated because speed and local water depth are connected through the Froude Depth Number of equation (1). A convenient way to avoid operating in this regime is to use the plot of Figure 8 from The Danish Maritime Authority (1997) which shows the range of speeds to avoid for given depths of water.

For vessels operating at speed in comparatively deep water, it may be necessary to pass through the critical regime in the shallow harbour outskirts on the way to the deep water; this should be done as quickly as possible to avoid excessive wash.

Finally, it is clear that service speeds for a given route or harbour area should be chosen to avoid the critical speed region of Figure 8.

Route

If wash is likely to be a problem, choice of route is important. Whittaker (1999) shows how changing a particular fast ferry route in Belfast Lough caused wash to spend itself on a rocky, unused beach, rather than the much-used beach frequented by many people upon which it used to land.

“Shedding the wash” is not unknown as a technique among operators whose route requires them to berth near a beach or shoaling shore-line. When this occurs, the vessel may approach the berth at speed from the sea. It will usually adopt a route which misses the jetty or pier in case a control or other failure would result in collision with the jetty. Because the vessel operator will not wish to be disturbed by motions induced by its wash as he prepares to berth, he may turn just before the final berthing manoeuvres begin. The wash, moving at speed, then heads for the nearby beach or shoreline where its energy is spent. If people are using the beach at the time, they may be inconvenienced, in which case it may be necessary either to prevent people using the beach, warn them of the problem, or re-route the vessel so that wash is spent elsewhere.

Routes which allow high speed vessels to pass close to large, slow-moving, ships in a deep-water channel may also cause wash problems. If the large vessel is constrained by its draught, long period waves created by the fast vessel can cause the larger ship to pitch and heave. If this occurs, it may lose what little underkeel clearance is has and touch the bed of the channel. Re-routing, re-scheduling or curtailing the speed of the passing vessel may be required to prevent such occurrences.

Finally, care should be taken when passing moored vessels. Even comparatively small vessels, whose route takes them past vessels at a jetty, can create sufficient disturbance to cause the other vessels to range on their moorings. This is caused by a combination of wash and ship-ship interaction, and can be alleviated by setting suitable passing speed limits and/or re-routing.

Manoeuvring

Wash and manoeuvring are linked in one important respect. When a vessel turns, its wash may become focussed at the centre of the turn. This can cause large waves to occur locally and, should a small craft be located in this region, it may be in danger.

WASH CRITERIA

We close with a brief consideration of wash criteria. It is fair to say that there is no real consensus on this matter so there is no universal criterion. The result is that there are a number of criteria world-wide, most of them designed for specific locations.

The majority are couched in terms of a limit on wash height. Conceptually, this seems reasonable because it seems intuitively obvious that the higher the wave, the greater the problem. While this may in part be true, it ignores the crucial role played by wave period. Long period waves of comparatively small height can travel at speed, steepen in shoaling waters, and move rapidly up a beach or river bank. Therefore, it is clear that wave period should be included in any sensible wash criterion. Some research work has been carried out in Tasmania on this topic and this has shown that suitable wash criteria can be developed. However, while this is a useful advance, most present-day criteria relate solely to wave height.

For example, a maximum wash height of 300mm was set for vessels on some reaches of the River Thames some years ago at a time when "river buses" were having to ease down repeatedly to minimise wash. Ultimately a new design of vessel, utilising long slender hulls was introduced. Wash was much reduced as a result.

The Danish Maritime Authority (1997) set a similar criterion, but included water depth:

"...when a new high speed ferry is commissioned to operate in a Danish harbour, a Statutory Order sets a limit for the maximum height of the long period waves. This limit should be 0.35m in water 3m deep".

This criterion was developed in the aftermath of a number of wash-related incidents in Danish waterways due, apparently, to high speed ferries. It was supplemented by further recommendations as to the designation of high speed ferry routes on charts, on-board information on speed, position and water depth and a requirement for operators to demonstrate that the consequences on wild-life, banks etc are not detrimental.

In all wash height-related criteria, it must be clear as to what is meant by wash height. There is no universal agreement about this, but a definition that is widely used is that height is the crest-to-trough distance of the highest wave in the first few wave cycles. This is shown in Figure 9 taken from a wave trace of a model catamaran. Wave period is also defined in the Figure.

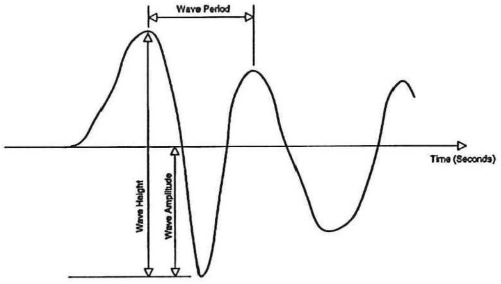

Figure 9. Definitions for Wash Criteria

It may be mentioned in passing that wave traces measured in a towing tank may be contaminated by reflections late in the trace due to the finite tank width. These may cause high waves by superposition; these are generally ignored in defining wash height. However, if a wash criterion has to be set for a narrow waterway with vertical banks (such as a rural canal) then wave reflections may have to be taken into account.

An indirect way of limiting wash is to limit speed. Many waterways, sensitive to wash, have imposed speed limits, causing vessels to ease down. However, in busy waterways (such as those populated by leisure craft), easing down may pose further problems. Vessels may bunch so that, while they are in close proximity, washes from a number of vessels superimpose, thereby creating larger, or longer period, waves. Speed limits must also be chosen with care for a waterway populated by vessels of different sizes. Wash is related to vessel length and water depth, as well as speed, as already discussed. Therefore a limit on speed alone may be a poor substitute for what should ideally be a Froude Number limit in a busy waterway. To give an example, it is often free-running tugs in a commercial ship canal which cause wash damage to banks, rather than large ships, even though both move at the same speed.

Finally, few, if any, wash criteria presently in force include limits on wave periodicity. It is often the cause of nuisance to other waterway users. As already mentioned, some proposals have been made for criteria which include wash period, but these are still at the research stage.

SUMMARY

Wash is an inevitable consequence of a ship moving on the surface of the sea. Although past experience, related to displacement vessels, did not show wash to be a wide-spread problem, the advent of fast vessels in a variety of roles has highlighted wash-related problems. These may stem from the operation of fast ferries at sea, rescue boats on rivers, or leisure craft on rivers, lakes or harbours. Wash can affect the environment (river banks, for example) and other water users. In extreme, and comparatively rare, cases, it can cause loss of life.

In this paper an attempt has been made to explore the question of wash and ways in which its less acceptable characteristics may be ameliorated. However, it is fair to say that the complete elimination of wash is never likely to occur. However, by proper design and operation, coupled with rational criteria, it should be possible to reduce wash problems to an acceptable level.

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