

**Appendix D**  
**RISK ASSESSMENT OF THE PASSAGE PLAN**  
**IN RELATION TO WAKE WASH WAVES**

**1. Introduction**

The waves generated by high-speed craft have been identified as a potential hazard to shorelines, structures, other marine vessels and people along the shoreline, particularly when operating in relatively shallow water.

MCA requires Owners to undertake a risk assessment of the passage plan as part of the requirements for issue of the Permit to Operate certificate. This guidance is provided on the processes and documentation that is required of the risk assessment.

**2. Risk Assessment Applies to all High-Speed Craft**

MCA require a Risk Assessment of the passage plan with reference to wake wash which should provide a route and speed profile that minimises the effects on the local shore line and to local users. The risk assessment is to be applied to all HSC operating in UK waters and should highlight any areas likely to be affected by wash and any subsequent action taken to reduce it.

Where wake wash is of concern, the master of an HSC undergoing any transit voyage or scheduled voyage should be responsible for having a passage plan in place which includes a risk assessment with respect to wash wake.

**3. Guidance**

Guidance is given below on how to conduct such an assessment.

Attention is also drawn to:

- (a) MCA Research Project 420 – “Investigation of High-Speed Craft on Routes near to land or enclosed Estuaries” and in particular Table 8.1 of the report Wash Characteristics gives four types of Wash Classification.
- (b) MCA Research Project 457 – “A physical study of Fast Ferry Wash Characteristics”.
- (c) PIANC Project Guidelines for Managing Wake Wash for High-Speed Vessels. Marcon Report of WG 41, 2003.
- (d) UK Engineering and Physical Sciences Research Council report GR/R21165/01 - Ship’s Wash Impact Management.

**4. Outline Form of Assessment**

The HSC Code is a risk-based document and the solution to managing wake wash is identifying an appropriate risk based solution. The Guidelines for the Application of Formal Safety Assessment for use in the IMO Rule-Making Process (MSC/Circ. 1023) offer a structured methodology for undertaking the risk assessment. These guidelines offer an overview of the techniques involved and a format for a final report. The format of the report is that which the IMO require and should provide a useful guide.

## 5. Wake Wash Background

Wake Wash - means the waves produced by the vessel due to its movement through the water. These waves are associated with the transmission of energy away from the vessel. For HSC operating at high speed their generation takes place in a different speed-length regime than for conventional ships and their generation, propagation and impact are affected more by water depth than those typically produced by conventional ships.

The common factor for HSC is that the power propulsion system delivers a considerably higher engine output per person transported compared to the slower previously deployed conventional ferries. The need for higher power has the consequence of a new type of wake wash which may lead to increased hazards to shorelines, structures, other marine vessels and activities of people, e.g., bathing beaches. When a craft makes way through the water, wake wash is generated as a result of the change in pressure along its hull. The actual wave pattern, height and frequency, depend on the craft hull form, size, depth of the water, topography of the seabed and the speed. When undertaking a risk assessment of the passage plan consideration should be given to the vessels speed through the water and not just the speed over the ground when route planning through shallow tidal waters, the difference between the speed over ground and speed through the water may bring the vessels operation into the transitional zone.

The waves are largest at the so called "critical speed" (a ratio between the ships speed and the depth of water) which should be avoided. A HSC should operate at a speed above or below critical speed as the waves at these levels are more moderate. In shallow water, wake wash produced by the HSC distinguish themselves significantly from those generated by the conventional ships in that they have a much longer period and appear very suddenly along the coastline. HSC typically generate a wave pattern comprising of groups of long period bow divergent waves and short period stern divergent waves.

The long periodic waves cannot normally be observed near the route of the craft due to the flatness of the wave profile, but these waves usually cause problems in the shallow water near the coasts because their height increases when the depth decreases. At the same time, the wavelength decreases resulting in increasing the wave steepness and when it exceeds a certain limit, the wave will break. Although the highest wave produced by a fast ferry is at the depth critical speed, operators minimize the time spent in this region and by carefully selecting the locations for acceleration and deceleration, the impact on the shore can be localised and the position of contact controlled. However, if a ferry operates at super-critical speed in a confined estuary, the inherent characteristics of the initial waves are unavoidable, potentially affecting substantial lengths of coastline.

Wake wash is classified as subcritical, critical or supercritical in terms of the depth Froude number  $F_{nh}$  which describes the ratio of the vessels speed to the wave propagation velocity in shallow water and  $F_{nh} = V_s/\sqrt{g \cdot h}$  where  $V_s$  is the ship speed in metres per second,  $g$  is the acceleration due to gravity in  $m/s^2$  and  $h$  is the water depth in metres: for the purpose of classification "sub-critical" means approximately  $F_{nh} < 1$ , "critical" means the band approximately between  $F_{nh} = 0.85$  to  $1.15$  and "supercritical" means approximately  $F_{nh} > 1$ .

Small HSC, primarily passenger-only vessels typically have service speeds above a length Froude number ( $F_{nl}$ ) of 1.0. As these vessels accelerate and decelerate they pass through a transition speed (sometimes referred to as "hump speed") where wake wash is at a maximum for conditions other than operating in critical depth. For most vessels, this occurs at a  $F_{nl}$  between 0.55 and 0.6. At speeds above this transition speed, wake wash wave heights decrease with increasing speed.

It can be shown that operation at a length Froude number of 0.9 or more corresponds to critical water depths greater than about half the length of the vessel. With respect to the generation of critical waves at such water depths, the shallow water effect for typical HSC

becomes negligible. However this does not mean that the subsequent propagation of these wash waves into shallow water should be ignored.

MCA requires Operators to review each area of the passage plan and the various risks (including such issues as the change in waves generated by operating on reduced number of engines) using a form similar in content to the example sheet of a risk assessment, below.

It is known that turning in shallow water (causing wake wash to be focused at the inside of the turn), acceleration and deceleration through the transition speed as well as changes in speed, can cause potentially hazardous wake wash. It is also known that the effects of these powerful waves can become focused by HSC vessels crossing paths, e.g. sister-ships on the same route. These known factors can be used to an advantage in the risk assessment and the approach angle (with respect to the coastline and seabed topography etc.) can be modified, the vessel can be stopped, a change of speed can be used, timetable adjusted, etc. to minimise the effects of the wash.

From experience It is known that wake wash from vessels operating at reduced power, e.g. on 3 of their normal 4 engine capacity (asymmetric powering), are prone to generating an increased wash. This is not due to speed reduction alone but also to the “crabbing” motion of the hull when asymmetric powering is used. When considering way-points to reduce speed the following should be considered:

- because of the reduced thrust available the vessel will take longer to transit the critical depth speed range or may be unable to pass through this range and become trapped near the critical speed. In the latter case, speed should be reduced to a sub-critical depth Froude number zone below 0.8.
- the vessel may be operating at less than the optimum hull resistance.

It is important to note that the potentially hazardous wake wash generated by high speed craft is not unique to HSC and conventional hull forms can be prone to the phenomenon also.

## **6. Hazard Identification and Risk Assessment Format**

The hazard identification process for wake wash from HSC will need to consider:-

- Where a (geographically) a hazard occurs;
- Over what timeframe the hazard occurs;
- The physical properties of the hazard;
- Who is at risk from the hazard (data on other craft population, shorelines, structures and activities on the coastline);
- Coarse analysis of possible outcomes of hazards to other craft;
- Ranking of hazards: and
- Identify highly sensitive areas, e.g. bathing beaches, marinas, vulnerable coastline, etc.

The risk assessment should identify the distribution of risk (frequency and consequence) across the already identified hazards and identify those areas of high risk, which need addressing.

When conducting route planning and risk assessment, operators should:

- Identify and document control measures to restrict the hazard from wake wash
- Accelerate and decelerate through the transition speed as rapidly as possible.

- Choose locations and courses for acceleration and deceleration such that transition speed wake wash will be directed into minimally harmful areas.

Risk assessment may be performed on the basis of operational experience on the route in question, assisted by theoretical investigation, where appropriate.

## 7. The Permit to Operate

The Operational Criteria of the Permit to Operate may include:

1. A full Risk Assessment of the Passage Plan with reference to wake wash must be carried out.
2. Any likely areas of adverse wake wash impact to be identified and action taken to reduce it.
3. The vessel to be operated in accordance with the control measures identified in the risk assessment.

## 8. Pro Forma for letter of Acceptance of the Risk Assessment for Passage Plan

It is recommended that the MCA Lead Surveyor uses the following wording in a letter to the vessel's Operator to confirm acceptance of the risk assessment of the passage plan with respect to wash and wake:

"The Risk Assessment for the Passage Plan of Vessel .....

On Route of .....to.....

Has been noted and fulfils the requirement of Clause Number ..... of Operational Criteria of the Permit to Operate.

If there are any or a number of complaints of wake wash noted in a particular area the Operator will be approached and requested to revisit and modify as necessary that part of the Risk Assessment for the Passage Plan. "

## 9 Training Aspects

The MCA now require that the Master and all officers having an operational role of an HSC (comments apply generically to either 1994, 2000 HSC Code or DSC Code) vessel must complete detailed training with respect to wake wash generation in order to gain Type Rating. See guidance notes under 18.1.3, 18.3.2 and 18.6.1 of the Code for further information. This training should enable them to fully understand the possible impact of inappropriately operating at speed in shallow water; of operating at a course and speed different from the approved risk assessment of the passage plan; the possible hazards caused by turns; and operating under asymmetric powering.

## ANNEX

### Example Sheet of a Risk Assessment

<b>HIGH SPEED CRAFT ROUTE RISK ASSESSMENT</b>					
Assessment Number.....					
This record considers the above named vessel route plan from ..... to .....					
And assesses the risk to other mariners, persons on the shoreline and the environment as a result of waves or wash generated by the vessel.					
Date.....Assessment Leader .....					
Passage Plan sector from ..... to.....					
<b>PERCEIVED HAZARD OR RISK</b> <i>(example) Critical waves onto Killiney beach, Bullock Harbour, Sandycove, Fortyfoot.</i>					
<b>RISK ASSESSMENT (TICK LEVEL)</b>					
<b>HAZARD SEVERITY</b>			<b>LIKELIHOOD OF OCCURRENCE</b>		
	5 VERY HIGH	Multiplied By		5 VERY LIKELY	= <span style="border: 1px solid black; padding: 2px;">16</span>
X	4 HIGH		X	4 LIKELY	
	3 MODERATE			3 QUITE POSSIBLE	
	2 SLIGHT			2 POSSIBLE	
	1 NIL			1 UNLIKELY	
<b>CONTROL MEASURES NECESSARY OR IMPLEMENTED</b> <i>(example)</i>					
1 Follow course line via South Burford Buoy for bank to absorb wave/wash					
2 Operate Craft with minimum trim					
3. Reduce speed quickly to minimise time in critical speed zone					
4. Avoid course alteration during slowdown					
5. If speed below 34kts at 1 mile from Kish maintain speed at subcritical					
6. Make early speed reduction if exceptional conditions prevail					
<b>RESULTS AFTER RECOMMENDATIONS IMPLEMENTED</b>					
<b>HAZARD SEVERITY</b>			<b>LIKELIHOOD OF OCCURRENCE</b>		
	5 VERY HIGH	Multiplied By		5 VERY LIKELY	= <span style="border: 1px solid black; padding: 2px;">4</span>
	4 HIGH			4 LIKELY	
	3 MODERATE			3 QUITE POSSIBLE	
X	2 SLIGHT		X	2 POSSIBLE	
	1 NIL			1 UNLIKELY	
<b>REMARKS</b>					

RISK RATING	ACTION AND TIMESCALE
<b>1 – 5 TRIVIAL</b>	No action is required
<b>6 – 10 TOLERABLE</b>	No additional controls are required. Monitoring is required to ensure that the controls are maintained
<b>11 – 15 MODERATE</b>	Efforts should be made to reduce the risk, but the costs of prevention may be taken into account. Risk reduction measures should be implemented within a defined time period. Where the moderate risk is associated with extremely harmful consequences, further assessment may be necessary to establish more precisely the likelihood of harm as a basis for determining the need for improved control measures.
<b>16 – 20 SUBSTANTIAL</b>	Voyage should not be started until the risk has been reduced. Considerable resources may have to be allocated to reduce the risk. Where the risk involves work in progress, urgent action should be taken.
<b>21-25 INTOLERABLE</b>	Voyage not to be started or continued until the risk has been reduced. If it is not possible to reduce the risk even with unlimited resources, passage has to remain prohibited.

# MARINE INFORMATION NOTE

MIN 48 M+F

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## **RESEARCH PROJECT 420: Investigation of High Speed Craft on Routes near to Land or enclosed Estuaries**

Note to: Ship owners, HSC operators, port and other relevant authorities, research and further education institutes.

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### *Summary*

#### **INFORMATION ON COMPLETED PROJECT 420 - Investigation of High Speed Craft on Routes near to Land or enclosed Estuaries**

**RESEARCH CONTRACTOR: KIRK McCLURE MORTON, CONSULTING ENGINEERS**

**TIMESCALE: September 1997 to September 1998**

#### **EXECUTIVE SUMMARY:**

This project was commissioned by The Maritime and Coastguard Agency to investigate the wash of high speed ferries operating in Belfast Lough. This was in response to public concern regarding the size of wash waves produced along the shoreline of the Lough. The principal rationale behind this study has been to combine the expertise of naval architects and coastal engineers to study the fundamental generation of wash from fast ferries and the propagation of the resulting waves.

The study utilized mathematical and physical modelling along with site measurements to determine the far field wave characteristics of the ship generated wave. Mathematical models confirmed by site measurements were used to confirm the impact of the waves on the shoreline.

The fundamental difference between the super-critical, critical and high speed sub-critical wash produced by a fast ferry compared to the low speed sub-critical wash of a conventional ship is the presence of long period waves which were not previously described in published technical literature. Areas at risk from these waves are identified in the report.

The study has revealed the limitations of the current mathematical models but it has been demonstrated that it is possible to assess the impact of High Speed Craft operated on routes near to land or enclosed estuaries.

## NOMENCLATURE

g	acceleration due to gravity, 9.81 m/s <sup>2</sup>
h	water depth, m
V <sub>s</sub>	velocity of ship, m/s
F <sub>n</sub>	Froude number, a non-dimensional number relating speed to a linear dimension.
F <sub>n<sub>h</sub></sub>	Froude depth number
knot	1 nautical mile = 1852 metres
wash, wash wave	waves generated by the forward motion of marine vessels
critical speed	the maximum speed a wave can travel in a given depth of water , $F_{n_h}=1$
critical wash	wash created by vessel speed operating at or near critical speed
supercritical wash	wash created by vessel speed in excess of critical speed, $V_s > \sqrt{gh}$ .
sub-critical wash	wash created by vessel speed less than critical speed, $V_s < \sqrt{gh}$ .
high speed sub-critical wash	significant wash created by vessel operating at high speed in a water depth such that at all times the speed is less than critical speed, $V_s < \sqrt{gh}$ . {Subject proposed for further research see 7.8.1}
non-dispersive wave	a wave which cannot feed its energy back to create further waves.
SHIPFLOW©	Computational Fluid Dynamics code developed by Flowtech International AB.
Z <sub>raise</sub>	a software control coefficient used in SHIPFLOW©

## 1. Background

1.1 High Speed craft have been operating between Belfast Lough and Loch Ryan in Scotland since 1992 when the “Seacat Scotland”, a 74 metre INCAT wave piercer was introduced. In 1996 the “Stena Voyager”, a HSS 1500, was introduced into the same route and the monohull vessel “Jetliner” was introduced from Loch Ryan to Larne. The arrival of the larger High Speed Craft (HSC) caused a number of new problems as well as reviving other older ones. The wash wave produced by the heavy displacement craft travelling at some 40 knots created a number of serious wash related incidents which caused damage to ship's moorings, yacht moorings and knocked people off their feet on the beach and drew an unacceptable level of complaint.

There was clearly a need to study the underlying root causes of the pressure wave generated by the wash of High Speed Craft and the transformation effects in enclosed and sometimes sheltered waters. The MCA recognized there were safety benefits for all users of the sea and foreshore in such a study. The study could be used as a sound technical basis for the inclusion of operation parameters in the High Speed Craft Code or the High Speed Craft Permit to Operate.

## 2 Project Objectives

1. review the current state of knowledge on wash from fast ferries,
2. both measure and calculate the wash profiles from different types of fast ferry,
3. mathematically model the wash wave propagation and transformation process,
4. produce recommendations to reduce the problems of wash,
5. produce a standardized methodology for assessing fast ferry wash.

## 3 Methodology

3.1 The starting point for the study was an extensive literature review of technical publications, research reports and books on

the fundamental physics of ship wash, the results of tank tests, field measurements and coastal processes. The objective was to assess the current 'state of knowledge' on the subject and identify the areas where further information was required to conduct the study.

3.2. The second stage was the determination of the wash characteristics of the various highspeed craft using Belfast Lough. Unfortunately detailed information on tank tests, numerical simulations and prototype evaluation was not available as it is commercially sensitive and is the property of either the ship owner, the ship yard which developed and built the craft or the design team.

Consequently it was necessary to establish the wash characteristics of the fast ferries using Belfast Lough independently. This was achieved in three ways:-

- the wash waves were monitored at a range of locations around Belfast Lough
- the wash characteristics of four ships using the Lough were determined mathematically using Shipflow©.
- free running generic models of a high speed monohull, a wave-piercing catamaran and the catamaran SWATH hull configuration, similar in concept to Stena HSS, were constructed and tested in a large shallow pool.

3.3 The third stage involved using the data acquired on the wash characteristics close to the ship as input to a range of mathematical models. These describe the wave transformation processes which influence the wash wave patterns which spread across the Lough. The wash wave predictions from the mathematical models were then compared with measured data at selected locations around the Lough. This process of verification was used to calibrate the models so that they could be used to predict the wash wave properties at other locations, which were not monitored.

## 4 Summary of Results

4.1 An extensive literature review revealed that although there was extensive fundamental work on wash wave characteristics in water of

various depths dating back to 1906, there is relatively little published work on the wash produced by large fast ferries, as they are a relatively recent innovation. Wash waves are classified in terms of the depth limited Froude

number  $F_{nh} = V_s / \sqrt{gh}$ , which is the ratio of ship speed to the wave propagation velocity in shallow water. The wash is defined as sub-critical, critical or super-critical if  $F_{nh} < 1$ ,  $=1$ , or  $>1$  respectively. The classification is purely a function of ship speed,  $V_s$ , and water depth,  $h$ .

4.2 The mathematical modelling highlighted the limitations of the current software available. A comparative study for one of the hulls in question was performed to ensure that the wave heights and pattern are modelled correctly in SHIPFLOW©. This study has shown that the wash wave height (but not the wave pattern) is very sensitive to a software control coefficient,  $Z_{raise}$ , in shallow water analysis. An appropriate value of this coefficient has been determined by comparing model tests and SHIPFLOW© calculations and it has been used in all SHIPFLOW© calculations in order to ensure consistency in the results. The analysis method using SHIPFLOW© has been compared with model test results on earlier occasions and generally these comparisons show good correlation for the results. Typical differences in measured wave amplitudes are of the order of 5-10% at subcritical and supercritical Froude numbers while at critical Froude number the difference may be about 40%. A limitation in the comparison is however, that only a few wave measurements are made sufficiently close to the model to be within the area analyzed by SHIPFLOW©.

4.3 The physical measurement of the wash waves in Belfast Lough produced the most significant new observations. There are several aspects of the wash of a fast ferry, which are fundamentally different from that of a conventional ship. An overview of the main risks and the ship operational categories is given in tables in the report. It should be noted that the wave heights and periods presented are for a particular ship and are used as an example. They will vary with vessel speed, length, displacement, hull configuration and water depth.

4.3.1 A super-critical wash measured several kilometres from the track of Stena HSS displays in the initial wave group, waves which do not exist with a conventional ferry. Typically in a super-critical wash the first wave in the group has a period of 40 seconds and a height of 0.4m. The second and third waves are the highest at 0.7m with periods of 20 seconds and 14 seconds respectively, followed by 8 waves which steadily reduce in height and wave period to 0.2m and 8 seconds respectively. The second zone of waves with periods of between 6 seconds and 3.5 seconds is similar to the complete wash produced by a conventional ferry of similar displacement. The third zone has a small group of very steep waves with a period of 3 seconds and is peculiar to fast ferries. In previous studies it was concluded that the height of waves produced by fast ferries was less than that of conventional ships. The presence of the world's largest fast ferry, Stena HSS, has resulted in the conclusion that the heights can be similar, but the periods are substantially longer. The 40 seconds time span between the first two wave crests in a super-critical wash result from the wave being non-dispersive. This is due to the restricted water depth and the observation that the divergence angle of between 10° and 12° is maintained with distance from the track.

4.3.2 A wave pattern identified as a high speed sub-critical wash is produced by high speed operation in the deep waters of the North Channel. This wash pattern is dominated by a 14 seconds wave which persists for 17 minutes initially with a height of 0.7m but subsequently reducing to between 0.3m and 0.2m. This is the transverse wave which is generated behind a ship, with a principal direction equal to the ship's heading and spreading at about 20° on either side of the track.

4.3.3 As stated in paragraph 4.3.1 this study has identified a third problem area produced by the small group of waves with a period of 3 seconds at or close to the breaking wave limit. These form the *last* wave group in the wash pattern and can arrive 30 minutes after the first wave. Small craft such as speedboats and open boats drifting for the purposes of fishing could be vulnerable to swamping or capsizing.

4.3.4 Critical wash is a special case and can be minimized by going between sub critical and super-critical as quickly as possible. At the shore it is difficult to identify the critical wave in isolation and it is usually recognized by a magnification of the leading waves in the super-critical wash. It was calculated and observed that the outer edge of the critical wave spreads at the same rate as its forward velocity  $\sqrt{gh}$  and can quickly fill the width of the inner part of Belfast Lough. Operating at depth limited Froude numbers as low as 0.9 for a sustained period of time, can still generate waves up to the breaking limit and can be achieved with fast conventional ferries.

4.3.5 In comparing the wash for the two types of High Speed Craft it was noted that the wave pattern was similar in all wave classifications, with the exception of the highspeed sub critical transverse wave which is believed to be related to the ship length. The wave energy was observed to be dependent on power and displacement.

4.4 Wash modelling in Belfast Lough was demonstrated to produce useful results. The wash prediction models and the wave transformation models still require considerable development. In order to produce the necessary wave data and to automatically cope with the complex spreading wave patterns respectively, it is not possible to produce a normalised model which is applicable to all fast ferry configurations and sea bed topographies. Nevertheless the existing models are sufficiently adaptable to enable environmental impact statements to be prepared for particular ferry operations on a site-specific basis. An analysis of model results has been supported by actual site measurements.

## 5 Conclusions:

5.1. The fundamental difference between the super-critical, critical and high speed sub-critical wash produced by a fast ferry compared to the low speed sub-critical wash of a conventional ship is the presence of long period waves producing a range of risks to Lough users and the general public.

5.2. The long period waves at the start of the super-critical wash are intrinsic to high speed vessels.

5.3. Both the wash prediction models and the wave transformation models still require considerable development in order to produce the necessary wave data and to automatically cope with the complex spreading wave patterns respectively. As such, it is not possible to produce a normalised model which is applicable to all fast ferry configurations and sea bed topographies. Nevertheless the existing models are sufficiently adaptable to enable environmental impact statements to be prepared for particular ferry operations on a site-specific basis.

5.4. Visual observation of wash waves is insufficient and should be supported by physical measurement particularly when assessing the affect of different operational strategies.

## **6 Recommendation**

6.1 As the long period waves at the start of the super-critical wash are intrinsic to the operation of HSC. An environmental impact statement should be produced for each new proposal for a fast ferry to operate in shallow coastal waters to assess the level of risk for different users. To facilitate this, the wash characteristics should be assessed by physical and mathematical modelling during the design process. The predictions should be verified during commissioning trials. This information should be made available to the assessors and form an integral part of the classification process.

6.2. In view of the foregoing, it is recommended that Belfast Lough users in particular are made aware of the risks by e.g. Port Operators or relevant authorities.

6.3. Fast ferries should not plan to alter course inside the mouth of the Lough as super position of the initial super-critical waves on high speed sub-critical wash can occur on the outside of the bend on an inbound course. Course changes while at super-critical speed can cause wave super position of waves from

different frequency zones on the inside of the bend.

*(This recommendation does not override a Master's Prime Responsibility to comply with the Regulations for Preventing\_Collisions at Sea)*

## **7 Implementation**

7.1 The MCA will disseminate the information derived through publications in the professional press and presentations at professional fora.

7.2 The project for making the public aware of the effects will be re-emphasised and Masters and Watch Officers of High Speed Craft will also be included.

7.3 Prior to the introduction of new vessels and before a High Speed Craft Permit to Operate will be issued Operators will be requested to provide an impact assessment verified by a third Party, as evidence that they have taken into consideration the wave making potential of the vessel and the areas at risk identified. Such information is to be included in the Craft operating Manual and the Route Operating manual respectively.

7.4 Software programmers for modelling ship generated waves are to be encouraged to extend their calculation field boundaries.

7.5 A Marine Guidance Note is to be produced for Operators specifying the aspects of the High Speed Craft wash to be modelled by liaison with Industry.

7.6 Marine Guidance note to be produced for the benefit of Master's and Navigators by liaison with Industry.

7.7 Ship designers to study the wash wave signature of their vessels.

7.8 Suggested areas for further research are;

7.8.1 Identify the break point between high and low speed in the sub-critical range and the influence of ship length in high speed sub-critical wash.

7.8.2 Assign a numerical value to the risks identified so that they can be evaluated in accordance with probability concept as defined in Annex 3 of the High Speed Craft Code.

## **8 Further Information**

8.1 For further information contact Mr Keith Patterson, Project Manager, on 029 9147 5307

8.2 A copy of the summary report can be viewed on the MCA website at

[www.mcga.gov.uk](http://www.mcga.gov.uk)

## Investigation of HSC on Routes near to Land or enclosed Estuaries. Extract from Project 420

### Table 8.1 - Wave Wash Characteristics.

Wash Classification	Wave Component Characteristics
<b>Super – Critical</b> <b><math>F_{nh} &gt; 1</math></b> <b><math>V_s &gt; 35</math> knots</b>	<b>Zone 1</b> Long period waves, initial waves non-dispersive, 1 <sup>st</sup> two crests diverge $\cong 10^\circ - 12^\circ$ , initial period 40s 3km from track. 2 <sup>nd</sup> wave highest in group, waves more dispersive as period reduces to 8s, direction dependant on ratio of ship velocity and individual wave velocity. <b>Zone 2</b> Medium period waves, 6s – 3.5s, similar to conventional ship wash. <b>Zone 3</b> Short period waves, 3.0s – 2.5s, breaking/near breaking at end of wash.
<b>Critical / Near Critical</b> <b><math>0.85 &lt; F_{nh} &lt; 1.1</math></b>	Two non dispersive waves generated at bow and stern, travel in the direction of and at the speed of the ship, spread laterally at the same velocity, sustained generation of constant depth can build height to breaking limit.
<b>High Speed Sub - Critical</b> <b><math>F_{nh} &gt; 0.85</math></b> <b><math>V_s &gt; 20</math> knots</b>	Classical Kelvin Ship Wash Pattern <b>Zone 1</b> Long period waves, 12s – 8s gradually building in height over a number of waves before reducing with reducing period. <b>Zone 2</b> Medium period waves, 6s – 3.5s, similar to conventional ship wash. <b>Zone 3</b> Short waves, 3.0s – 2.5s, breaking/near breaking at end of wash. <b>Zone 4</b> Transverse waves, 14s – 13s period for 40 knot vessel > 100m long.
<b>Low Speed Sub – Critical</b> <b><math>V_s &lt; 20</math> knots</b>	<b>Zone 2</b> Medium period waves 6s – 3.5s, cusp waves in Kelvin Ship Wash Pattern <b>Zone 4</b> Transverse waves $\cong 5$ s for 15 knot vessel.

**Note-** with the exception of super critical (Zone 1) and critical waves direction is a function of ship velocity and wave group velocity.

# MARINE INFORMATION NOTE

MIN 118 (M+F)

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**RESEARCH PROJECT 457: A Physical Study of Fast Ferry Wash Characteristics in Shallow Water**

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## *Summary*

**INFORMATION ON COMPLETED PROJECT 457 – A Physical Study of Fast Ferry Wash Characteristics in Shallow Water.**

**RESEARCH CONTRACTOR:** Queen's University of Belfast in association with Belfast Harbour Commissioners

**TIMESCALE:** September 1999 to April 2001

**EXECUTIVE SUMMARY:** Following on from Research Project 420, an extensive programme of model testing and field monitoring of the wash wave characteristics of fast ferries operating at speed in shallow water has been undertaken at The Queen's University of Belfast. Solitary like wave crests of very low amplitude have been observed travelling up to four ship lengths ahead of the ship whilst operating in very shallow water however, it has also been observed that the crests have been followed by long period troughs of very small amplitude.

The most significant conclusion is that the leading long period waves in the super-critical wash are significantly more important than the solitary waves with respect to risk for users of the coastal zone. The presence of very long wave periods, sometimes in excess of 40s, at the start of the super-critical wash has been explained. This is due to divergence in the direction of travel of the leading wave crests, which is maintained with distance from the ship. The divergence angle is primarily a function of depth Froude number and to a lesser extent water depth.

The decay rate of the wash in shallow water was observed and quantified. The impact on shoreline and other vessels is discussed.

## NOMENCLATURE

g	acceleration due to gravity, 9.81 m/s <sup>2</sup>
h	water depth, m
Vs	velocity of ship, m/s
x	distance from vessels track
Fn	Froude number, a non-dimensional number relating speed to a linear dimension.
Fn <sub>h</sub>	Froude depth number
Fn <sub>l</sub>	Length Froude number
knot	1 nautical mile = 1852 metres
wash, wash wave	waves generated by the forward motion of marine vessels
critical speed	the maximum speed a wave can travel in a given depth of water, Fn <sub>h</sub> = 1
critical wash	wash created by vessel speed operating at or near critical speed
supercritical wash	wash created by vessel speed in excess of critical speed, Vs > √(gh).
sub-critical wash	wash created by vessel speed less than critical speed, Vs < √(gh).
high speed sub-critical wash	significant wash created by vessel operating at high speed in a water depth such that at all times the speed is less than critical speed, Vs < √(gh).
non-dispersive wave	a wave which cannot feed its energy back to create further waves.

### 1. **Background**

- 1.1 Fast ferries produce very long period waves at super-critical speed when operating in shallow water typically found in many estuaries.
- 1.2 These waves produce significant surge effects at the shoreline that can cause damage to ships moored at open quays and are potentially dangerous to small craft at or near the shore and the general public using beaches and low coastal paths.
- 1.3 Fast ferries operating at speed in confined channels also pose steerage problems for other ships when in close proximity with the potential risk of collision or running aground on shallow banks outside the channel.
- 1.4 The largest wash height is produced at the critical speed.
- 1.5 Further work is required to understand how the critical wave spreads and how the leading waves in the super-critical

wash diverge. It is important to identify how these phenomena are influenced by hull configuration and water depth.

- 1.6 The long-term impact of fast ferry operation on the environment requires consideration.
- 1.7 The work is complimentary to research project 420.

### 2. **Project Objectives**

- 2.1 Study the transverse spreading velocity of the critical wave group,
- 2.2 Study the divergence of the leading long period waves in the super-critical wash,
- 2.3 Determine how the above is influenced by hull configuration/future designs, speed and water depth,
- 2.4 Provide more detailed information to improve the mathematical models of the wave transformation processes in estuaries used in research project 420 which in future would be used to produce environmental impact statements for fast ferries,

- 2.5 Research and demonstrate some remedial measures for reducing the surge effect on shorelines, moored ships and passing vessels in confined channels,
- 2.6 Generally improve the understanding of the very long period waves in a super-critical wash.
- 2.7 Study the influence of wash induced currents and pressure fluctuations on the seabed and on the shoreline.
- 2.8 To determine if the solitary type wave is an effect solely restricted to fast ferries and to ascertain if it is significant when undertaking risk assessments of fast ferry operation.

### 3. **Methodology**

A shallow wide towing tank measuring 50m x 17m with a maximum water depth of 400mm was built in a warehouse provided by Belfast Harbour Commissioners. A cable-way towing system with a computer controlled variable speed motor was installed to tow a variety of models with a scale of between 1:50 and 1:80 at speeds up to 4.5m/s. Loose stone beaches with a slope of 1:3 were used to minimise reflections around the tank. As the models were towed close to one side in order to maximise the measurement area, a very low reflection coefficient was essential. This was achieved locally by placing variable density foam blocks in a chevron formation on top of the stone beach.

An array of 12 resistance probes was used to measure the wash wave profiles produced by the different models. To measure the surface elevation parallel wire resistance wave probes were used. Before starting a new measurement task the probes had to be calibrated. The probes were positioned and the output signal of the amplifier was zeroed. The probes were then lifted 50mm and a measurement taken. These values were then used for calibration.

Models of both catamaran and monohull fast ferries were towed at a range of constant speeds in water depths ranging from 100 to 400mm equivalent to between 5m and 32m at full size. The various speeds resulted in wave heights

and patterns being measured at depth limited Froude Numbers ranging from 0.8 to 2.6.

Experiments were conducted in which the models were accelerated and decelerated at different locations in the tank relative to the wave probe arrays. This was particularly important to ascertain how the super-critical wash decays after the ship has slowed down and is no longer energizing the leading long period waves.

In addition to the scale models of fast ships a series of generic models were also tested. The hull shapes comprised a flat bottom in the longitudinal and transverse directions, vertical sides, a 10mm radius curve between the sides and the bottom. In plan view the sides had a constant curvature from the stem to the point of maximum beam which in all cases was 0.5m from the stem. Adding rectangular sections lengthened the hulls. The hulls were tested in both monohull and catamaran form and at different drafts.

A qualitative assessment was made of the effect of super-critical wash produced by fast ferries on,

- other ships either approaching or travelling in the same direction,
- moored vessels at open quays in estuaries.

These tests were conducted at model scale and the observations were verified using data obtained from field measurements taken as part of other studies.

For field measurements to track the wash of fast ferries, the wave power research group developed two types of measurement equipment:

- an ultrasonic measurement system which worked on the time taken for a sound signal to be emitted by a transducer and reflected back by the air-water interface, and,
- a sea bed pressure transducer system used to measure the pressure of the water column overhead.

The output from the physical modelling programme supplemented with field measurements from other studies were

used to improve the input data to the Mike 21 software which has been adapted to model the transformation of fast ferry wash in the coastal zone in MCA project 420. The refined input data included the range of wave periods used, the direction of travel of the different wash wave components and the attenuation of height with distance from the ship's track. In addition some preliminary calculations were undertaken on sediment transport in very shallow water and at the shoreline.

The Environmental Impact of High-Speed Ship Wash part of the research project had an initial look at the environmental impact of high-speed wash. A case study was chosen to illustrate a possible procedure for such an investigation and to show the various difficulties in assessing the impact of high-speed craft.

#### **4. Summary of Results**

- 4.1 The crest length increases at the same velocity as the critical speed. The critical wave is also an unsteady process. As the ship remains at the critical speed the wave crests tend to move forward and propagate in a direction almost parallel to the track of the ship and the leading wave crests tend to straighten out.
- 4.2 The angle between the leading wave crests is primarily a function of depth Froude Number with a secondary dependence on water depth.
- 4.3 Catamarans tend to produce wash with distinct wave frequency groups due to phase cancellation of some waves from each hull. This varies with hull length and spacing. In comparison monohulls generally produce a continuous spread of wave frequencies from the long initial waves to the short tail waves. It was observed that catamarans operating in the supercritical regime produce less energetic waves than monohulls of similar length and displacement
- 4.4 A mathematical model has been compared to and validated by experimental data. It was found that the model provided a good prediction of the wave patterns, the angle of each wave in the leading group of waves, and the divergence of the wave crests. As a result it was possible to predict the period of the leading waves in the far field and also to calculate the divergence angle between these waves.
- 4.5 Moored ships will surge on the long period super-critical or near-critical waves. As with any damped mass spring system, the response of the ship will depend on size, displacement and the elastic constraint of the mooring system. Large ships will respond to the long period waves, while small vessels will respond to the shorter wave components. Consequently each ship and mooring configuration has to be analysed individually to assess the problems caused by fast ferry wash. As a remedial measure moored ships should avoid unequal lengths for mooring lines.
- 4.6 The effect of the wash of high-speed craft on other moving vessels is dependent on size, displacement and hull form. Consequently the risk to each vessel must be assessed individually. Vessels operating in the transcritical range should not overtake small vessels.
- 4.7 The characteristics of the leading long period waves were explored by studying the decay rates. It was found that as the vessel speed increased in the supercritical range there was a reduction in the initial group wave height but as the wave moved away from the ship track they were more persistent. Decay rates have been determined for different water depth/ship length ratios.
- 4.8 Initial studies were completed and longer term monitoring programmes instigated to determine the environmental impact of wash from fast craft and to make a comparison with other ships. The vulnerability of a coastal zone to wave attack is dependant on the typical particle size and the grading of the material. If fine sediments are interspersed with gravel and small stones, then armouring takes place and the mass transport rate is significantly reduced.
- 4.9 Both conventional ships and fast ferries can produce solitary like waves, which are of very long period and can travel several ship lengths ahead in very shallow open water. Large displacement ships operating in shallow water are

particularly prone to generating this type of wave. However, with respect to fast ferries the following should be noted;

- 4.10 These waves are only generated at sub-critical and near-critical depth Froude numbers when the water is very shallow with a small under keel clearance of 1m to 2m. Consequently they occur when there is a high 'blockage'.

## 5. Conclusions

- 5.1 Solitary waves. Both conventional ships and fast ferries can produce solitary type waves, which are of very long period and can travel several ship lengths ahead in very shallow open water. Large displacement ships operating in shallow water are particularly prone to generating this type of wave. These waves are only generated at sub-critical and near-critical depth Froude numbers when the water is very shallow with a small under keel clearance of 1m to 2m. Consequently they occur when there is a high 'blockage'.
- 5.2 Super-critical and Critical Wash Waves. As solitary waves are only generated in very specific circumstances and are very small in height, it is the leading waves produced at super-critical and trans-critical depth Froude numbers in conjunction with the transverse high speed sub-critical waves which are the most significant to users of the coastal environment.
- 5.3 Mathematical model. A mathematical model has been compared to and validated by experimental data. It was found that the model provided a good prediction of the wave patterns, the angle of each wave in the leading group of waves, and the divergence of the wave crests. As a result it was possible to predict the period of the leading waves in the far field and also to calculate the divergence angle between these waves.
- 5.4 Decay. In sub-critical wash the decay of the height of the divergent waves is a function of distance from the track of the vessel,  $x^{0.33}$ , and for the transverse waves  $x^{0.5}$ . In super-critical wash the rates of decay can be substantially less with the lowest decay rate measured being  $x^{0.2}$ . However it was found that the decay rate varied significantly with water

depth/ship length ratio and to a lesser extent with hull configuration. The low height decay rate in the leading super-critical wash is attributable to the waves being largely non-dispersive in that energy is conserved in individual waves. However, the crests diverge with distance from the ship spreading the energy over a larger area hence reducing the wave height. Also there is some dispersion of energy into the subsequent waves.

- 5.5 The rate of decay of the maximum wave height at the critical speed was substantially different to the super-critical decay rates. It was observed that the wave heights were significantly greater around the ship's hull, but were found to decay much faster with distance from the ship's track. However, both the wave height and the decay rate were dependent on the length of time that the vessel spent at the critical speed.
- 5.6 Wash persistence. As the crests of the initial waves in the super-critical wash are continuous the height of the waves already produced will reduce when the ship slows to sub-critical speed. This is due to the lateral spread of energy along the wave as the crest length increases without further input of energy from the ship
- 5.7 Length Froude number,  $F_{nl}$ . The length Froude number is an important parameter in intermediate as well as deep water as it influences the point at which a vessel produces its maximum wash when travelling in the critical speed range. A worst case scenario in terms of wash generation occurs when a ship operates at the 'hump speed' (typically between  $F_{nl} = 0.4$  and  $0.6$ ) and the critical depth Froude number simultaneously.
- 5.8 Hull configuration. Catamarans tend to produce wash with distinct wave frequency groups due to phase cancellation of some waves from each hull. This varies with hull length and spacing. In comparison monohulls generally produce a continuous spread of wave frequencies from the long initial waves to the short tail waves. It was observed that catamarans operating in the supercritical regime produce less

energetic waves than monohulls of similar length and displacement.

5.9 Conventional ships. Wash problems are not solely associated with fast craft. All craft capable of exceeding a depth Froude number of 0.85 enter the trans-critical range. Several new ferries are capable of operating at speeds up to 30 knots. In general they are much larger and heavier than the largest fast ferries and are capable of creating wash problems.

5.10 High Speed Vessels Passing Other Ships. The effect of the wash of high-speed craft on other moving vessels is dependent on size, displacement and hull form. Consequently the risk to each vessel must be assessed individually. There are a number of general observations, which have been made.

5.11 Environmental Impact. Initial studies were completed and longer term monitoring programmes instigated to determine the environmental impact of wash from fast craft and to make a comparison with other ships. Initial general conclusions have been reached and reported on.

## **6. Recommendation**

6.1 That the information produced by this research is made widely available to industry.

6.2 That industry utilises the information when preparing Risk Assessments of Passage Plans for High Speed Craft.

6.3 That it be noted that further research in this area is now conducted through the more widely supported Ship Wash Impact Management (SWIM) project.

## **7. Implementation**

7.1 The MCA will disseminate the information derived through publications in the professional press and presentations at professional forums.

7.2 The results of this research will be incorporated in the SHIPS WASH IMPACT MANAGEMENT (SWIM) project.

## **8. Further Information**

8.1 For further information contact Mr Keith Patterson on telephone number 028 9147 5307

8.2 The summary report can also be viewed on the MCA website: [www.mcga.gov.uk](http://www.mcga.gov.uk) and, also The Queen's University of Belfast Fast Ferry Group website [http://www.qub.ac.uk/waves/fastferry/ferry\\_wash\\_hp.html](http://www.qub.ac.uk/waves/fastferry/ferry_wash_hp.html)