



Maritime and Coastguard Agency

---

---

## **Research Project 502: High-Speed Craft Dynamic Stability in Following & Quartering Seas - Operational Guidance**

Notice to all **Owners and Masters of high-speed craft**

*This notice should be read with the applicable High Speed Craft Code*

---

---

**PLEASE NOTE:-**

Where this document provides guidance on the law it should not be regarded as definitive. The way the law applies to any particular case can vary according to circumstances - for example, from vessel to vessel and you should consider seeking independent legal advice if you are unsure of your own legal position.

### **Summary**

**RESEARCH PROJECT 502 – HSC Dynamic Stability in Following & Quartering Seas**

**RESEARCH CONTRACTOR: BMT SeaTech Ltd**

**TIMESCALE: 2.7 years**

**EXECUTIVE SUMMARY:**

Many high-speed craft (HSC) are known to suffer some degree of difficulty control in following and quartering seas, including behaviour such as surfing, bow diving and broaching. The purpose of this research project was to study the currently available literature on the subject, and identify and conduct further research where this was considered necessary, concentrating on the dominant types of HSC currently in service.

Captive and free-running tests were conducted on a models of monohull, and conventional and wavepiercing catamaran HSC. These have been used to develop a mathematical model to aid understanding, and develop guidelines for the design and operation of HSC to minimise vulnerability to loss of control and/or stability.

The purpose of this Information Note is to summarise the guidance to craft operators.

### **1 General**

- 1.1 When sailing in severe following or stern quartering seas, a high-speed craft may, in extreme cases, experience deck immersion or extreme angles of heel. Recent research has been aimed at studying the behaviour of high-speed craft in such situations with a view to understanding the physics, identifying critical conditions and providing some practical information and guidelines.

- 1.2 The principal hazards likely to be experienced by a high speed craft in severe following or stern quartering seas are:
- Surfing
  - Bow diving
  - Broaching
- 1.3 This note has, as its primary aim, the provision of advice to mariners on what to expect and what to do when handling a high-speed craft in severe following and stern quartering seas. The guidance offered here is based, not only on the recent research, but also on the accumulated experience of mariners.
- 1.4 The master may be assisted in the avoidance of dynamic problems if there are instruments that inform on the behaviour of the vessel and information on the sea states likely to be encountered. These parameters include vessel's speed, heading, vertical acceleration, longitudinal acceleration, wave forecasts and current sea state.
- 1.5 It should be noted that *following seas* refer to seas which are dead astern while *stern quartering seas* refer to wave directions between dead astern and 45° from dead astern.

## 2 Caution

- 2.1 It should be noted that the advice given in this note is for guidance only; it is intended to augment and not replace the skill and judgement of the mariner, or the tenets of good seamanship.

## 3 Critical Behaviour in Following and Stern Quartering Seas

Possible forms of critical craft behaviour are described, following which advice is given on warning signs to show that they maybe imminent, followed by the suggested corrective action.

### 3.1 Trapping

#### **Description:**

Trapping can occur when the vessel is moving directly down-wave in waves whose length is roughly equal to the waterline length of the vessel. When cresting one wave, the craft will experience a reduction in resistance, which will cause it to accelerate into the trough ahead and immerse its fore-body in the next wave. If this does not result in a bow dive, the craft will experience a significant increase in resistance that will slow it down to the speed of the waves. It can be the precursor to a bow-dive.

#### **Warning Signs:**

- moving at the speed of the wave, see Figure 1 and Table 2, and
- one wave crest at the stern and another at the bow, and
- wave height greater than 4% craft waterline length
- craft becomes trapped between two successive crests

#### **Corrective Action:**

- slow down and allow the waves to draw ahead.

### 3.2 Surging and Surfing

#### **Description:**

When a high-speed craft is moving in following seas which are directly astern and where the wave length is about the same as or greater than the vessel length, it may accelerate and decelerate in surge as the crests pass. Such surge velocities may differ by as much as 50% of the average speed and are caused by significant changes in resistance and propulsive efficiency as the waves pass. Without warning the craft may accelerate rapidly to the speed of the wave and surf.

Surfing is best avoided if at all possible because of the almost total loss of control that occurs while it is in progress. Surfing can be the precursor to a bow-dive, or a broach.

**Warning Signs:**

- large variations in craft speed at constant throttle
- craft is moving at wave speed plus or minus 10% ( $1/10$ th), see Figure 1 and Table 2, and
- the wave length is between 1 to 2.5 times craft waterline length, and
- the craft has a slight bow-down pitch attitude, with a wave crest abaft amidships
- response to steering controls is poor
- breaking waves increase the tendency to surf

**Corrective Action:**

- avoid running at wave speed (see Figure 1 and Table 2) in waves of dangerous length
- if caught in a surf wait until the critical wave has passed without attempting any major helm action
- afterwards, slow down

### 3.3 Bow-Diving

**Description:**

Bow-diving occurs when a high-speed craft buries its bow into a wave in following or stern quartering seas. This causes all way to be lost, the vessel experiences a severe bow-down pitch and the bow becomes submerged, sometimes resulting in structural damage and injury to personnel. It is particularly severe for vessels such as catamarans with a cross deck and limited residual buoyancy forward. It is different to bow immersion in head seas as the wave behind lifts the stern and worsens the situation.

Bow-diving may have a slow onset if moving at wave speed, but may be dramatic without warning if craft is moving substantially faster than the waves.

**Warning Signs:**

If preceded by trapping (see 3.1 above):

- as for trapping, and
- wave height greater than about 75% ( $3/4$ ) of bow freeboard when stopped, and
- waves from between directly astern and the quarter
- bow almost immersed to the deck or top of cross-structure

If craft moving faster than the waves and:

- waves from between directly astern and the stern quarter, and
- wave height greater than 25% ( $1/4$ ) of bow freeboard when stopped, and
- wave length 100% to 150% of the waterline length of the craft

**Corrective Action:**

- avoidance by attention to the warning signs
- avoiding any trim by the bow
- slow down to less than about 70% of wave speed
- alternatively, if practicable, change course, even to head seas

### **3.4 Broaching**

#### ***Description:***

Broaching is a severe, and often uncontrollable, yawing movement in following seas which turns the vessel beam on to the waves resulting in a dangerously heavy roll, and a sideways sliding motion down-sea. In monohulls with insufficient stability it can result in capsizing. It may be preceded by surfing.

#### ***Warning Signs:***

- desired course slightly or appreciably across the waves, up to 45° from directly down-sea
- wave length similar to craft waterline length, or slightly shorter in quartering seas, and
- craft speed similar to wave speed plus or minus 15% ( $\frac{1}{7}$ th), see Figure 1 and Table 2, and
- wave height greater than 4% craft waterline length, and
- bow-down attitude and bow burying into wave ahead
- up-sea waterjets or propellers beginning to ventilate
- severe yaw motions either side of intended course
- surfing

#### ***Corrective Action:***

- avoid a diagonal course across the waves, ie: up to 45° from directly down-sea
- avoid running close to wave speed (see Figure 1 and Table 2) in waves of dangerous length
- reduce speed to less than about 70% of wave speed
- after a broach, directional control is best reasserted by reducing speed

## **4 Other Behaviour Which May Occur**

### **4.1 Reduction of Intact Transverse Stability**

When a ship is poised on a wave, as it can be in following seas, it may lose transverse stability due to loss of waterplane area. The amount of loss depends on wave height and length, but in following and stern quartering seas, it is more likely to occur with displacement or semi-displacement monohulls than multihulls or planing craft.

### **4.2 Slamming**

Although slamming is more likely in head seas, it can occur with high-speed vessels in following seas if their speed is at least twice the speed of the waves. Its severity will depend on craft speed, wave height and wavelength as well as the design of the bow sections, wet-deck height forward and deadrise. Hard chine planing craft are more likely to be subject to this form of behaviour than displacement or semi-displacement craft.

### **4.3 Synchronous Roll**

Synchronous roll may happen to a high-speed monohull in stern quartering seas when the period of the transverse components of the waves coincides with the natural roll period of the vessel. It is unlikely to occur with catamaran vessels. In any event it is only likely to happen in following and stern quartering seas if the transverse stability of the high-speed craft is marginal.

### **4.4 Parametric Rolling**

Large amplitude roll motion can occur in following seas if the length of time each wave takes to pass the vessel is approximately equal to half the natural roll period of the high-speed craft.

Again, this is unlikely to occur with multihulls and, in following seas, is only likely to occur with monohulls whose transverse static stability is marginal and whose natural roll period is long.

#### **4.5 Combinations of Extreme Behaviour**

The dynamics of a high-speed craft operating in following or stern quartering seas are complex. It is quite possible that various combinations of the behaviour patterns listed above may occur simultaneously. Perhaps the most obvious combinations are those involving surfing which is often the initial stage of a broach or a bow-dive; both of these can lead to further severe events such as fore-deck immersion or capsize.

### **5 Summary**

#### **5.1 Craft Speed**

It is important that speed should be appropriate for the sea conditions. In a following or stern-quartering sea, it is comparatively easy to determine whether the craft is moving faster or slower than the dominant waves in daylight. At night-time, however, such assessments are not so easy.

In such conditions, it is possible that audible cues may be of value. In some catamarans, waves in the tunnel between the hulls may make a “rumbling” noise and a rule-of-thumb may be developed as to the severity of this noise that indicates limiting conditions.

A rough idea of the speed of the dominant waves in a given sea state can be obtained from Figure 1 and Table 2, according to the type of waters in which the vessel is operating.

Craft speed, it is assumed, will be known with some accuracy. If it is not, then, when moving at or near the dominant wave speed (and possibly trapped or in danger of surfing), pitch and heave motions will be considerably reduced, but surge motions will be significantly increased.

#### **5.2 Wave Length**

It can be seen from the advice given above that wave length in relation to the waterline length of the craft is also important in assessing the vulnerability to adverse behaviour. It is therefore important to monitor the length of the waves in which the craft is being operated.

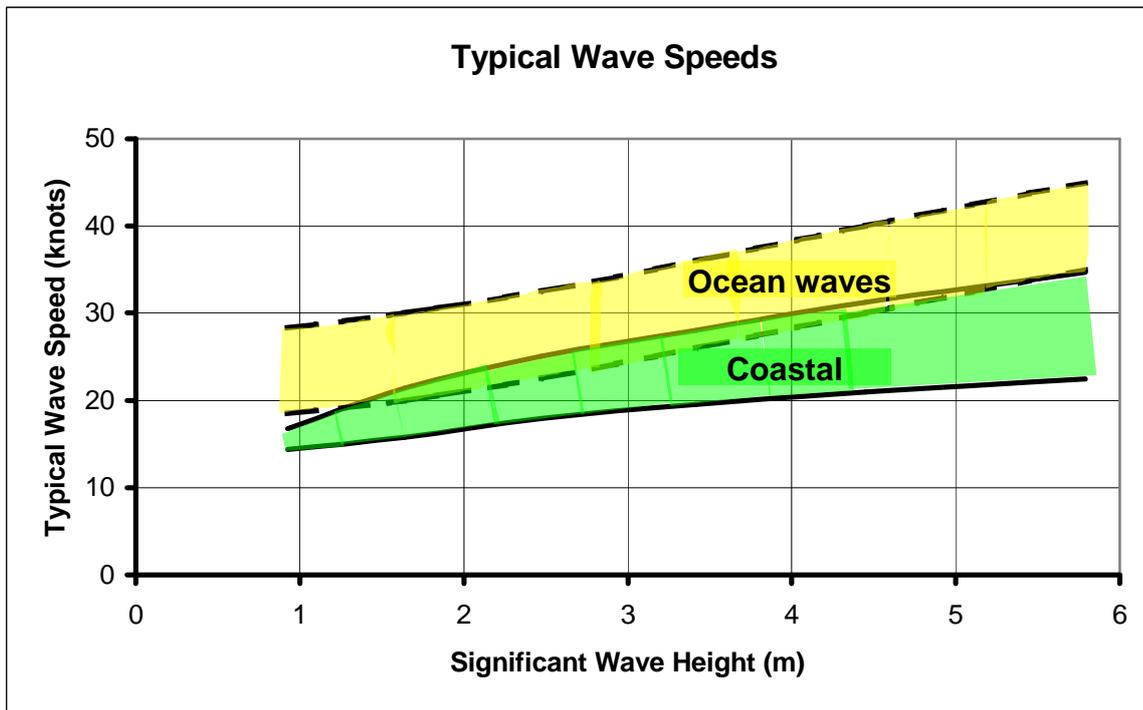
#### **5.3 Seamanship**

Finally, if the craft is severely at risk from its behaviour in following or stern quartering seas, it may be advisable to alter course to a more favourable heading.

Behaviour	Critical craft speed	Critical wave length	Critical wave heights
Trapping	$\approx V_W$	and $\approx L_S$	and $> 4\% L_S$
Surfing	$\approx V_W \pm 10\%$	and $\approx 1 \rightarrow 2.5 L_S$	and $> 4\% L_S$
Bow-diving (slow)	$\approx V_W$	and $\approx L_S$	and $> 75\% F$
Bow-diving (sudden)	$> V_W$	and $\approx 1 \rightarrow 1.5 L_S$	and $> 25\% F$
Broaching	$\approx V_W \pm 15\%$	and $\approx L_S$	and $> 4\% L_S$

**Table 1 – Summary of Guidance in Following & Quartering Seas**

Key:  $\approx$  is approximately equal       $\pm$  is plus or minus  
 $>$  is greater than  $V_W$  is wave speed  
 $L_S$  is ship length  $F$  is bow freeboard when stopped



**Figure 1 – Estimation of Wave Speed**

Enter figure with significant wave height and read off probable range of wave speeds, according to whether navigating ocean or coastal waters.

<b>Sig. Wave Height (m)</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>
<b>Coastal Waves</b>	15 - 18	17 - 23	19 - 27	20 - 30	21 - 33	23 - 35
<b>Ocean Waves</b>	19 - 29	21 - 31	25 - 35	29 - 39	32 - 42	36 - 46

***Table 2 – Tabulated Typical Wave Speeds (knots)***

**More Information**

Shipping Safety Branch  
Maritime and Coastguard Agency  
Bay 2/13  
Spring Place  
105 Commercial Road  
Southampton  
SO15 1EG

Tel : +44 (0) 23 8032 9519  
Fax : +44 (0) 23 8032 9251  
e-mail: [Shipping.Safety@mcga.gov.uk](mailto:Shipping.Safety@mcga.gov.uk)

General Inquiries: 24 Hour Infoline  
[infoline@mcga.gov.uk](mailto:infoline@mcga.gov.uk)  
0870 600 6505

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

File Ref: MS 102/2/53

Published: August 2006

© Crown Copyright 2006

**Safer Lives, Safer Ships, Cleaner Seas**

*Printed on material containing minimum 75% post-consumer waste paper*

*An executive agency of the  
Department for  
**Transport***