The Specialist Committee on Safety of High Speed Marine Vehicles

Final Report and Recommendations to the 22nd ITTC

1 GENERAL

1.1 Membership and Meetings

The 22nd ITTC Specialist Committee to study the Safety of High Speed Marine Vehicles initially comprised eight members and had four recommendations from the 21st ITTC on which to base its work.

Three of the members (Dand, Doctors and Keuning) had served on the High Speed Marine Vehicles Committee of the 21st ITTC, the remainder being newcomers. Dr. Ian Dand was appointed Chairman by the 21st ITTC and the Committee elected Dr. Lex Keuning to be the Secretary. Unfortunately, due to ill health, Dr. Keuning had to withdraw from the Committee towards the end of its working life, and Dr. Dand assumed the dual role of Chairman and Secretary for the time remaining.

The membership was therefore:

Dr. I. W. Dand, UK (Chairman)
Dr. J. A. Keuning, Netherlands (Secretary)
Prof. H. H. Chun, Korea
Prof. L. Doctors, Australia
Prof. G. Grigoropoulos, Greece
Mr. P. Grzybowski, Poland
Prof. M. Takaki, Japan
Dr. S. Vogt Andersen, Denmark.

The Committee met four times in the three year period since the last conference as shown in Table 1.

Other communications between members were accomplished by means of e-mail, fax and telephone.

TABLE 1

Date	Place	No. Attending
April 1997	London	5
July 1997	Sydney	4
December 1997	Lyngby, Denmark	8
November 1998	Athens, Greece	6

1.2 Recommendations from the 21st ITTC

The following recommendations for the work of the Committee were made by the 21st ITTC:

- Study the dynamic instabilities of high speed craft and develop procedures to solve problems relating to high speed roll, pitch and directional stability anomalies.
- Develop by means of test procedures and computer codes, information on dynamic instability which can be used to improve coverage of this topic in the IMO High Speed Craft Code.
- Catalogue incidents and accidents to high speed passenger-carrying vessels to identify trends and areas of hydrodynamic inadequacy

- Develop full-scale test procedures to define and determine high speed craft safety.

2 THE SAFETY OF HIGH SPEED CRAFT AND THE ITTC

In the short period of time since the last ITTC the fast ferry has established itself as a fixture in the maritime scene. While there are still technical challenges to be solved in its design and operation, the concept is now sufficiently mature to warrant a comprehensive overview of its impact on the maritime population. It is the impact on safety which has received the most attention, reflecting a worldwide concern about safe practices, safe operations, indeed the growth of the safety culture.

National administrations have carried out Formal Safety Assessments of fast ferry operation and the International Maritime Organisation, IMO, is already in the process of reviewing and revising its Code of Safety for High Speed Craft. In view of the fact that this Code was published comparatively recently, the fact of its review is a measure of both the speed at which this sector of the marine community is developing and also concerns for the consequence of any accident involving such a vessel.

Two disciplines are involved in any safety assessment, one being technical, the other operational. The link between them is sometimes hard to see, but it is clear that more and more hydrodynamic test establishments are becoming directly involved with the relationship between safe operation and design. The Committee is therefore of the opinion that, whereas some of the disciplines used in the study of safety may be foreign to ITTC members, they nevertheless have a place in its deliberations. The Committee therefore saw its role as:

- indicating some broad areas of study in which operational safety and vessel dynamics combine,
- helping to forge the links between the various disciplines involved. This may be done by providing information for those involved in model experiments to determine whether a given craft design will be operationally safe or not.

In our deliberations, aimed at satisfying these goals, it became apparent that the recommendations made by the last Committee had, in some degree, been overtaken by the pace of development. Some were no longer appropriate, while others needed more work, due to inadequacies in present databases. (Relevant accident statistics are the prime example.) In what follows, therefore, attempts will be made to adhere as closely as possible to the guidelines provided by the Recommendations, but some deviation will be inevitable.

We have assumed safety to embrace the complete avoidance, (or minimising the consequences) of an accident, where an accident is defined (Werenskiold 1998) as

"A sudden unintended event that could result in serious injury, or death, to passengers, crew or third parties".

It is well known that the main cause of most accidents in transport systems is human error and it has been shown that accidents in the operation of fast ferries are no exception. Therefore, in order to minimise accidents, the operation, as well as the design of the vessel must receive detailed consideration.

As an example of this, it has been found (IMO 1997) that of the accident types to which a fast craft is likely to be exposed, that of collision is by far the most serious. To avoid a collision some fundamental features of the vessel are needed:

- it must be sufficiently controllable to be predictable in its response and behaviour so that not only the crew, but also approaching vessels must be easily able to deduce its behaviour in the short term,
- as a corollary of this, the vessel must be sufficiently dynamically stable,
- it must have sufficient power to be able to make an appropriate speed in the prevailing conditions,
- it must be sufficiently manoeuvrable.

In addition it must have a sufficient reserves of stability to survive should a collision occur.

Virtually all of these points come within the ITTC area of expertise. Therefore they must be of interest to the members. But the demands of safe operation go a little further than mere study of the technology behind collision avoidance. In the above test, judgmental words such as “sufficient” and “adequate” occur without any definition. It is easy to conduct a tank test to demonstrate manoeuvrability, but it is more difficult to demonstrate whether the degree of manoeuvrability is satisfactory, sufficient or adequate.

It was on this crucial point that the Committee agreed that a worthwhile part of its output would be a list of criteria which helped to define the words “sufficient” and “adequate”. This would allow the results of experiments (the techniques for which are being studied by another committee) to be assessed from a safety perspective.

A final general point to be made relates to an awareness of the safety of the environment which has intensified since the recommendations for this committee were formulated. For high speed vessels this impacts two main areas:

- the power required to attain the service speed and hence the type of fuel used and the exhaust emitted,
- the wash generated.

Both of these come directly or indirectly within the remit of this Committee, and hence the ITTC. Exhaust emissions can be harmful in the long term and wash from fast vessels has become a significant nuisance at best, and danger at worst, to those on or near the shore when a fast craft passes. Hydrodynamic establishments have been in the forefront of studying wash, both to understand and minimise it. By the use of model tests, an efficient vessel design can be obtained which can significantly affect the power used and, therefore, the exhaust emitted.

With these considerations in mind, the main body of this report was produced. An attempt has been made to adhere to the original recommendations, but some additional matter has been added.

Accordingly, the main body of our report comprises the following sections:

- an assessment of the types of accidents to which fast vessels are prone, to discern any obvious trends,
- an overview of the important aspect of human factors and their relation to safety. This involves internal and external vessel control, communications and navigation equipment,
- theories related to dynamic stability. The hope is that, with such theories, craft may be designed that behave in a safe and predictable manner in order to minimise unwanted problems for the human operator,
- the behaviour of vessels in extreme situations. This is the ultimate test of safe vessel design and links directly to its dynamic stability,
- full scale tests, in recognition of the requirement of the IMO High Speed Craft Code that compliance with the code must be demonstrated at full scale,
- wash, including the studies that have been made both to understand and minimise it by design and operation,
- criteria to link model and full scale tests to acceptable levels of safety.

In compiling this, the Committee has taken note of the following Conferences:

- FAST 97, Sydney, July 1997,
- SURV IV
- High Speed Marine Craft, Safe Design and Operation, NSF, Bergen, 1996,
- HSMV 99, Capri, March 1999

3 RESEARCH INTO THE SAFETY OF HIGH SPEED CRAFT

3.1 Casualty Analysis

Introduction

Any discussion of safety-related matters must be based on of the magnitude of the problem, and indeed, if there is presently a problem at all. The way in which this is done is frequently by the assiduous collection of casualty data followed by its detailed analysis. This provides information on casualty rates, numbers of fatalities, type of vessel involved etc. It can also, in some cases, give indications of what was the main technical cause of an accident.

The fact that fast passenger-carrying vessels are comparatively new on the maritime scene means that little historical casualty data is available. This problem is compounded by the fact that there does not appear to be many organisations collecting, collating and publishing such data on a regular basis.

However it is also becoming clear that high speed passenger-carrying vessels have to date maintained a generally good safety record, their casualty rates in port and harbour areas often being an order of magnitude less than those of conventional ocean-going vessels.

It is against this background that this section of the report is presented. It had been hoped that an analysis of casualties to high speed craft would reveal particular problems of dynamics and hydrodynamics which would lend themselves to research and solution by ITTC members. The lack of much relevant data made this an impossible goal in the life of this committee. However, some relevant data were found, and these are now discussed.

Categorisation of Accidents

It is clearly important to catalogue accidents to high speed passenger-carrying vessels so that trends and areas of hydrodynamic inadequacy may be identified.

In Figure 1 the worst passenger ferry disasters are categorised by cause (Lloyds Maritime Information Service 1997). It is apparent that wrecks and strandings dominate. Figure 2 shows cruise ship total losses for the same period. The greatest number of accidents are due to fire, while those due to collision and capsizing are reduced. Accidents to conventional ships such as tankers and cargo vessels exhibit almost the same trends.

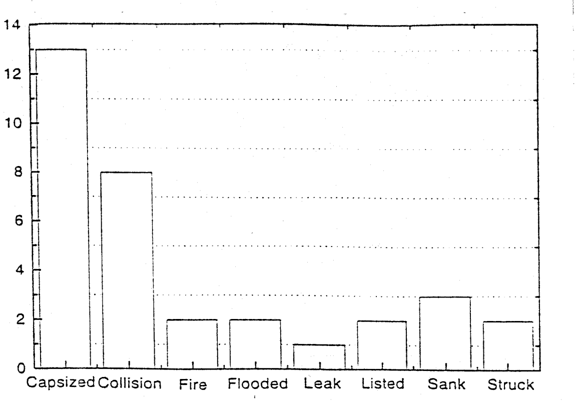

Figure 1. Major Passenger Ferry Accidents, 1963-1996.

Therefore, it appears that accidents to high speed passenger ferries are related to their dynamics and operation. Unfortunately this casualty data did not reveal the mechanism behind the accidents and/or the relationship between them and the hydrodynamic forces acting on the vessels.

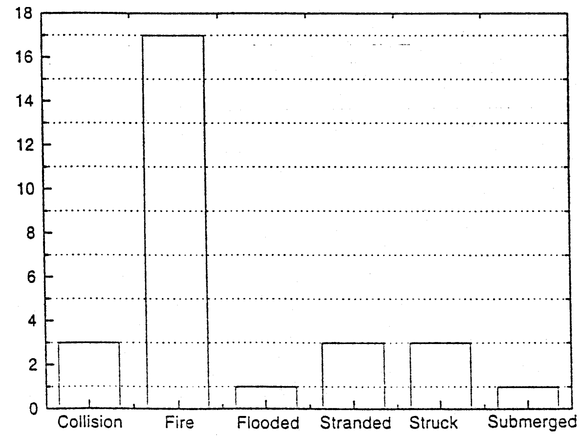

Figure 2. Cruise Ship Total Losses, 1963-1996.

Fast Ferry Casualties

Some fast ferry casualties have occurred since the last ITTC; a sample is given in Table 1.

TABLE 2

Vessel(s)	Date	Type	Craft Type
Hai Yang and Man Boon	April 1997	Collision	Catamaran/ conventional ferry
Superferry 2	October 1997	Multiple collision	Monohull
Flores	May 1998	Mechanical failure	Jetfoil
Laura	June 1998	Grounding	Hydrofoil
Sunnhord-land/Kingtor	June 1998	Collision	Catamarans

It is of interest to note that several of these accidents were collisions, emphasising the conclusion drawn by IMO (1997) that the risk of collision is the most significant hazard faced by high speed ferries. The chance of severe injury is emphasised by the accident to the Jetfoil which stopped abruptly from speed causing injuries to 122 passengers.

3.2 Human Factors and Navigation Equipment

Human Factors

Introduction. Due to its very nature, high speed navigation sets demanding requirements for the crew. Fast ferries often operate in areas of high traffic density and in restricted waters, while patrol boats and SAR vessels usually navigate close to the shore, factors which make the stress on navigators high. The person in command of a HSMV has less (often much less) time to take an appropriate action than that of a conventional displacement vessel.

Dynamically supported craft (planing, hydrofoils, air-cushion vehicles), multiple hulls, and atypical propulsion and steering devices (e.g. waterjets) aggravate the problem further. Navigating an HSMV is not like navigating an "ordinary" vessel – it is a different skill. Thus, in the interests of safety, special attention must be paid to suitable training for HSMV crews.

Simulators in Training. Ship handling simulators are extremely useful in training navigators of fast craft (Hagman and Ahlman, 1996, Kaplan, Römeling and Tveit, 1995). An example of such a simulator was presented by Kaplan, Römeling and Tveit (1995). The functioning of a simulator can be based on either model test data or a mathematical model describing the hydrodynamic forces acting on a vessel. The latter solution requires good qualitative and quantitative understanding of the hydrodynamic phenomena associated with HSMV operation, but is not limited to the particular vessel for which model tests were performed.

Apart from its flexibility, cost saving and ease of use, simulator training makes it possible to create dangerous emergency situations or to simulate unusual events likely to occur during normal ship operation. Trainees can be given the opportunity to cope with them by proper instruction.

Simulators in Behavioural Studies. Ship handling simulators may also be used to acquire knowledge of shiphandling and the decision-making processes of fast craft navigation (Hara, 1991, Nagasawa, Hara, Nakamura and Onda, 1993, Hammer and Hara, 1990, Imazu, 1995).

In the study presented by Hara (1991) the importance of various factors affecting the safety of navigation was determined by applying the Analytic Hierarchy Process to the results of interrogations of a number of HSMV navigators. The subjective level of difficulty of different encounter situations was assessed and showed large individual differences in navigators' reactions. During simulation they paid particular attention to other high speed vessels.

Hammer and Hara (1990) indicate that knowledge of the intention of another vessel is the most important factor in assessing the risk of collision. Thus communication directly between vessels, or via a VTS centre, must be considered as very important. Transponders may be used to interchange such information automatically.

An interesting approach is presented in a paper by Nagasawa, Hara, Nakamura and Onda (1993) where navigation is treated as a trade-off between risk of collision and physical loss and the navigator's reaction is a result of a trade-off between his mental and physical loads. Suitable measures are proposed to present these notions quantitatively. The term Blocking Coefficient is introduced, which presents the overall risk of collision taking into account all possible manoeuvres in a given situation. Physical losses are assessed by the navigators subjectively by the application of their preferred order of manoeuvres.

Results of the aforementioned studies can be used to elaborate suitable training procedures for both navigators and VTS operators or even influence the present regulations.

HSMV Safety Reporting System. Human errors are the cause of many accidents; information on these is vital and must be collected and analysed. This can be done by the collection and analysis of incident data. Navigators should be encouraged voluntarily to report all safety incidents and hazardous situations, not necessarily attributed to human errors. In return, confidentiality should be guaranteed. Such a system to record aviation safety incidents has existed for many years and proved to be useful (Rosenthal, 1997).

Team Work and Man-Machine Interface. Since the workload on a HSMV navigator is very large, one person cannot deal with all aspects of ship handling. Hagman and Ahlman (1996) state that the bridge should be "manned with two experienced officers, one who pilots the ship while the other assists and closely follows progress on the route. The piloting officer should always see that the co-pilot is well informed continuously about planned actions."

The efficiency of crews can be increased during Bridge Resource Management courses (Wahren, 1996, Huth and Firnhaber, 1997) concentrating on communication, team building, workload management and bridge resources. Their main target is to use all available technical resources and to deploy human resources in an optimal manner. A similar kind of training is commonplace in commercial aviation.

Navigation Equipment

Integrated Bridge Systems (IBS). Integrated Bridge Systems were created as a result of the application of Risk Analysis and Man-Machine Interface principles together with methods of ergonomics. Systems of this kind are described by Kristiansen and Tomter (1992), Lazarevic, Kuzmanic and Lakos, (1997), Pedersen, Ljungberg, Franck and Brathen (1992) or Kaplan, Römeling and Tveit (1995). The basic idea of their design is that the navigator has all the controls and displays related to all aspects of ship operation easily accessible from his seat. Information from many sources is processed and filtered adequately for the current mode of operation (open water navigation, docking, evacuation etc.) and only the relevant portion is presented to the navigator in an easy to perceive form. Time consuming activities, such as determination of position and course, route planning, position prediction, plotting of other vessels positions and courses, are made automatically or are computer-supported.

Controllers and Predictors. Some high speed passenger-carrying vessels now carry sophisticated controllers, some of which have a predictive capability. Kallstrom (1996, 1997) describes the system developed for the Stena HSS vessel which provides a high degree of automatic control almost up to the berth. Even swinging manoeuvres are controlled automatically. The controller also has a predictive capability which shows, on a screen, the probable path the vessel will take if the present control state remains unchanged (Figure 3). With the ability to "look ahead" from 30 to 120 seconds, such a system makes a significant contribution to safety by giving an early indication of whether the vessel is standing into danger.

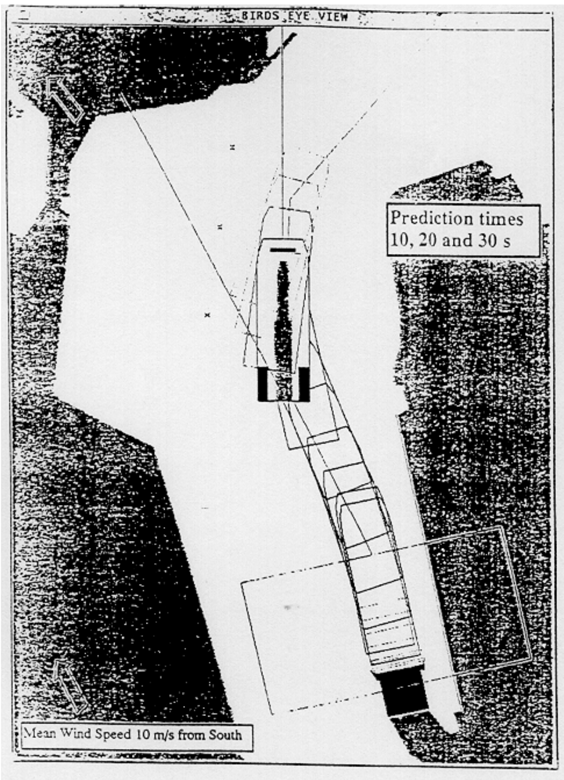

Figure 3. HSS Track Showing Predicted Positions.

The speed at which a navigation situation can change in a fast vessel and the need to be appraised of potential hazards in its path have led to research into intelligent navigation aids which combine prediction with an expert system and chart information. Of particular value in shallow and congested waters, such a system gives the operator of a fast craft warnings of not only potential collisions, but also hazards such as shoal waters, piled beacons and other fixed structures. Use of electronic charts and a mathematical model of the vessel's behaviour combine to produce a safety tool which owes much to tank test results. Such a tool formed one output from the Brite Euram SPAN (**S**afe **P**assage **a**nd **N**avigation) project described by Doyle (1999).

Electronic Chart Systems (ECS). Although ECS are standard components of IBS, Hughes (1997) points out that according to the present regulations they cannot replace paper charts and therefore should not be used as prime aids to navigation. He also draws attention to deficiencies of existing ECS and lists requirements for the reliable operation of such systems.

Observation and Detection. Apart from X and S band radars, Hellström, Blount, Ottosson and Codega (1991) include image intensifiers and an infrared gyro-stabilised camera in the necessary observation equipment.

Transponders. Shipborn transponders (Automatic Identification Systems) may be used to provide automatic data transfer between ships and between ship and shore (e.g. VTS centre). It is especially important with fast craft that information relevant to navigation is quickly and reliably transferred to all interested parties without putting an additional workload on navigators.

Some benefits of using transponders are as follows:

- Ships can broadcast their intentions, thereby eliminating the danger of misinterpretation (Crichton and Redfern, 1996). (See also Section 3.2.1.3).
- In the areas where VTS radar coverage is hindered by the geography of the area ships may continually broadcast about their position (Foxwell, 1995).
- All traffic participants may share the same radar picture, transferred to them from the VTS centre (Foxwell, 1995).
- GPS corrections may be transferred to ships (Foxwell, 1995).
- When a ship is lost in an accident the recording of transmitted data may be treated as a remote "black box" providing information for SAR operations and enabling later analysis of events (Heikkilä, 1996).

So far two systems of marine transponders have been tested (Heikkilä, 1996):

- Digital Selective Calling (VHF DSC).
- Ship-Shore Ship-Ship transponder (4S).

Virtual Prototyping (VP). Virtual prototyping can model and visualise the process of building, testing and operating a prototype system. Jons and Schaffer (1995) point out that this technology might be applied during the development of fast ferries (and possibly any HSMV).

For instrumentation VP might be used to test different bridge configurations in order to select the best solution.

VP would be also an ideal tool during initial crew training by providing the means to test bridge procedures before the actual ship is constructed.

Vessel Traffic Services (VTS)

The IMO guidelines for VTS define it as follows:

"Any service implemented by a competent authority, designed to improve safety and efficiency of traffic and the protection of the environment. It may range from the provision of simple information messages to extensive management within a port or waterway."

VTS cover areas of high marine traffic density, quite often with additional navigational difficulties (e.g. due to geographical features).

No extensive research on VTS with HSMV particularly in mind has been done; nevertheless VTS applicability in the areas where such vessels operate seems obvious.

According to the findings of the COST 301 project carried out by the EEC countries, VTS should be designed to collect, process, present to operators, disseminate to users, store and print out data of all types relating to the marine traffic situation which it monitors (Degré, 1995). A broad description of many aspects of VTS operation is provided by Bell (1990).

Moore (1993) draws attention to some problems associated with VTS operation, namely communication with the ship's crew and operation procedures.

Training of VTS Operators.

Many aspects of training are dealt with by Barber (1990). Simulators of VTS centres may be used during training. These simulators might be linked to ship handling simulators (Distributive Interactive Simulation might be used for this purpose - Jons and Schaffer, 1995) in order to provide both VTS operators and navigators with suitable feed-back during training and to smooth their co-operation. The need for a proper training may be illustrated by the fact that, during one series of simulator tests, all situations leading eventually to grounding were assessed too optimistically by the trainees (Heikkilä, 1996). This would have produced disastrous consequences in real life. The same source points out that ship performance *may* deteriorate with the presence of VTS advice.

Mariner's Reluctance

Many mariners see VTS as detracting from their authority (Boisson, 1994, Zade, 1994). For many, VTS conflicts with the powerful traditions of the freedom of usage of the seas (Degré, 1995).

Shore-Based Pilotage

Since it would be highly impractical for a HSMV to take a pilot on board in situations when his advice is desirable, the concept of Shore-Based Pilotage may be applied (Huth and Firnhaber, 1997). According to the definition adopted by the International Maritime Pilots Association "Shore-Based Pilotage is an act of pilotage carried out in a designated area by a pilot licensed for that area from a position other than on board the vessel concerned to conduct the safe navigation of that vessel".

Marine Traffic Simulation

Marine traffic simulation is a valuable tool used to investigate the marine risk, and hence safety, levels in congested waters. Traffic is randomly generated at one or more 'gates' and caused to move along prescribed routes within prescribed speed bands. Each vessel is assumed to be within a domain which moves with it. If another vessel enters this domain an "encounter" is deemed to have taken place and is logged. Encounter statistics may be used to indicate levels of marine risk and the effects of changes in operation on safety may then be judged by carrying out "what if" scenarios on the simulator.

Various operating rules are built into such simulators and many of these relate to the safety of low speed manoeuvres in wind, waves and current. The link to ship hydrodynamics occurs at this point and increasing use is now made of manoeuvring simulation with traffic simulation in marine safety studies.

Conclusions

The following conclusions are drawn with regard to human factors and HSMV safety:

- There is a need to interchange information between ships about their intentions.
- Training of navigators and VTS operators with the use of simulators will become more common. Thanks to Virtual Prototyping, the training of navigators may start before the actual ship is constructed.
- Connecting bridge simulators with VTS centre simulators would provide both navigators and VTS operators with realistic feedback and refine their co-operation.
- An HSMV bridge should be manned with no less than two officers.
- The training of HSMV navigators should not be limited to navigation skills only but should encompass team work, communication skills, coping with difficult and stressful situations, optimum use of available technical means etc. (these being the aim of Bridge Resource Management training). The same applies to VTS operators.
- Time-consuming activities of HSMV navigators should be automated (or be computer supported) in order to allow the navigators more time for assessment of the situation and decision-taking.
- Electronic Chart Systems should be made sufficiently reliable to be approved as the prime aids to navigation.
- Vessel Traffic Services will develop and become more common for HSMV.

As a result of these conclusions, the following is recommended:

- A Navigation Safety Reporting System should be set up in order to improve operational procedures, and identify areas needing investigation, by studying incidents and accidents in which fast craft were involved.

3.3 Dynamic Stability

Introduction

In the report of the HSMV Committee to the 21st ITTC, a substantial section was devoted to the dynamic stability of high speed craft. Some types of instability were identified and model test techniques to study them were outlined.

The connection between dynamic stability and safety is so self-evident that it was believed by this Committee that an analysis of high speed marine accidents would soon reveal dynamic instability as a major cause. With the limited information that the Committee has been able to obtain, it has become clear that this is not the case. It has further become clear that only limited research has been carried out on the topic worldwide since the last ITTC.

This suggests that either:

- dynamic stability problems are not a major cause of accidents, or
- they are captured at the design and model test stage, or
- they are eliminated by the provisions of the HSC Code (IMO 1996).

It is suspected that the last two of these assumptions are correct in that dynamic instabilities can (and should) be identified during the design and testing process and the operational and other limits imposed by IMO should prevent the vessels operating in extreme conditions.

The 21st ITTC High Speed Marine Vehicle Committee identified some dynamic instabilities and listed them in its report (ITTC, 1996).

In addition, Dand (1995, 1998) listed the following:

- Loss of GM due to Wave System
- Course Keeping
- Bow Diving and Plough-In
- Porpoising
- Chine Tripping
- Take Off
- Spray Rail
- Effect of Critical Speed.

Dand (1998) discussed the physical meanings of these and they are listed here in accordance with his definitions.

Loss of GM due to Wave System

If a displacement vessel moves fast enough, its wave system can be characterized by crest at bow and stern combined with a trough amidship. If the hull form is fine enough, the loss of buoyancy and waterplane area caused by the trough can cause an apparent loss of transverse GM. The vessel may then loll over to one side or other. In some cases this heel may couple into yaw and the vessel begin to turn. The turn may induce further heel, which induces further yaw and so on. Taken to extremes, the vessel may suffer a catastrophic heel and turn, leading to capsize.

Many researchers have been studying this instability for both HSMV and conventional ships, Washio and Doi (1991) studied the dynamical stability characteristics of HSMV running in calm water and in waves. Furthermore, they proposed a hull form with improved transverse instability developed from the experimental results.

Lewandowski (1998) showed that coupled roll-yaw-sway dynamic stability of hard chine hulls in the planing regime developed at Fnv>2 (Fnv: Volume Froude Number). He found that the traditional transverse stability involving the metacentric height GM or the righting arm GZ is meaningless, because the centers of dynamic and hydrostatic force are distinct.

Afremov and Smolina (1995) performed systematic model tests and analytical studies on relevant hydrodynamic characteristics of a ship series. They also provided a mathematical model of a ship's lateral motion in a seaway. They provided a reliable prediction of high-speed ship performance and found ways of ensuring stability and eliminating the possible development of dangerous roll angles.

Course Keeping

Poor dynamic stability about the vertical axis gives rise at best to poor course-keeping and at worst to loss of control. Although problematic in themselves, these tendencies become more serious from a safety perspective as speed increases. In extreme cases "a calm water broach" can occur if the yaw instability couples into heel.

Rutgersson (1998) proposed test procedures originally used to characterize the calm water maneuvering performance of ships. This study of stability problems in following waves for high speed monohulls will be carried out as a joint Finish and Swedish research program. The test results will be used for validation of mathematical models.

Bow Diving and Plough In

Bow diving and plough-in at wave speed occur when a vessel, moving into or with a wave system, comes off one wave and ploughs into the next. For a high speed passenger ferry carrying vehicles, the need for adequate buoyancy forward (possibly a problem for catamarans with fine fore-bodies) together with adequate bow door arrangements is essential if the vessel is not to be engulfed.

Porpoising

Porpoising is a well-known pitch instability which affects high speed planing craft. It is now amenable to elimination by design, but was the cause of catastrophic accidents to some early high speed vessels.

Chine Tripping

Chine Tripping is experienced on planing hard chine monohulls when turning. The chine may dig in and cause a powerful and sudden heeling moment. In extreme cases the vessel could roll over at high speed. No references to work on this topic have been found.

Take Off

High speed catamarans may experience large aerodynamic lift forces and pitch moments at speed or in waves. This is caused by air flow over and under the bridge deck which, in extreme cases, could cause the vessel to lift from the water and rotate in pitch. At present such behavior is confined to high speed, light weight, vessels. No references to work on this topic have been found.

Spray Rail Engulfing

A high speed vessel receives a not inconsiderable amount of lift forward from the spray rails, which, on some designs, may double as fenders. Tank tests have shown that, once a certain speed is exceeded, these may cease to deflect the bow wave or spray and become engulfed. When this happens the bow may drop, to the accompaniment of large sheets of green water thrown into the air in the region of the forebody. Speed may reduce at the same time. In extreme cases bow diving may occur. No references to work on this topic have been found.

Effect of Critical Speed

Recent tank tests and full scale trials on a high speed passenger catamaran in shallow water have identified some loss of directional stability when moving at or near the critical speed. This speed is defined as

$$\sqrt{gh}$$

where h is the water depth. It is about the speed at which solitary waves or solitons are shed and hydraulic jumps created. Whether or not solitons are shed, it is common for the vessel's own wave system to be characterized at such speeds by a high, and often breaking, following wave, similar in form to a hydraulic jump. This is situated just astern of the vessel and its upstream influence gives a tendency to broach. This is perhaps analogous to the loss of directional stability experienced by aircraft flying through the transonic speed range, and has been felt not only by the present day vessels in shallow water, but also by high speed torpedo boats passing through a narrow, shallow, harbor entrance at speed in World War 2.

Dynamic Stability of Multihulls

Renilson and Anderson (1997) developed a mathematical model to predict the behaviour of a high speed catamaran in following seas, with particular reference to bow diving. The surge force from the wave, and the vessel's heave and trim in the wave, were calculated using a quasi-steady assumption. These calculations, together with the validity of the quasi-steady assumption for this situation, were checked using a partly captive model. In addition, model tests were conducted to determine how the resistance, heave and trim varied with speed in calm water. From the results of the mathematical model, situations where bow diving would occur were identified. The effect of the additional drag of the submerged cross structure was included and the resulting motions studied.

Dynamic Stability of Monohulls

Renilson and Tuite (1996) proposed a four-degree-of-freedom model, accounting for surge sway, roll and yaw, which incorporated the effect of heel. They calculated the coefficients required to simulate the behaviour of a high-speed round-bilge planing hull in following seas, including roll/yaw coupling. They concluded that the region of broaching of a fast planing vessel decreases as the vessel's metacentric height is increased.

Spyrou (1996a, b) analysed the dynamic stability of displacement ships in quartering regular waves focusing on the specific conditions leading to broaching. He carried out steady-state and transient analyses in the system's multidimensional state-space in order to identify all existing limit sets and locate attracting domains. Then he focused on the development of roll and the eventuality of capsizing and set out a multi-degree method of global analysis based on transient maps. His study established a connection between speed, heading, automatic control parameters and capsizing. In a more recent paper, Spyrou (1997) devised an elaborate nonlinear model for manoeuvring in waves to identify nonlinear phenomena that govern large-amplitude horizontal ship motions. His analysis unveiled a sequence of phenomena leading to cumulative broaching, which involves a change in the stability of the ordinary periodic motion on the horizontal plane, a transition towards sub-harmonic response and, ultimately, a sudden jump to resonance.

Lewandowski (1998) developed a method to predict the dynamic roll stability of hard chine planing craft. Starting with the equations of motion, an equation governing small roll perturbations is developed. The roll restoring moment acting on the hull is evaluated by considering static and dynamic contributions. The contribution of rudders and skegs, which is significant for this type of craft, is also determined. Lewandowski(1997) also developed a method to evaluate the coupled roll-yaw-sway dynamic stability of hard chine hull in the planing regime. Expressions for the linear stability derivatives are presented as functions of geometry and loading, speed, trim angle, and wetted keel and chine lengths. A stability criterion is derived, and the effects of length/beam ratio, loading, LCG position, deadrise, and appendages on stability are examined. A simple method to check the transverse dynamic stability of a proposed design is presented.

Katayama and Ikeda (1995, 1996c) investigated experimentally transverse stability loss and the dynamic instability of pitch-excited rolling in planing craft advancing in calm water. Using a database of measured three-component hydrodynamic forces they concluded that although the period of rolling induced by pitching is almost constant, roll becomes unstable when the pitch is a multiple of half the roll period.

Celano (1998) recently investigated the porpoising stability of planing craft experimentally. His tests included hulls with higher deadrise angles, more typical of craft now employed for high-speed military purposes. Two models of actual full-scale craft, complete with performance enhancing features such as lifting strakes, trim tabs and variable drive angle were tested. These additions were found to have a profound effect upon conditions for the inception of porpoising. Established planing hull analysis methods were augmented with techniques developed during the course of the study to provide a basis from which to design and outfit high-speed, heavily laden planing hulls with respect to porpoising stability. The longitudinal dynamic instability in calm water, (porpoising), of a personal water craft was investigated experimentally at up to Fn=6.0 by Katayama and Ikeda (1996a, 1996b, 1997). The criteria of occurrence of porpoising are predicted using a linear stability theory. Porpoising motion is also estimated using a non-linear time domain simulation method. Measured restoring, added mass and damping coefficients are used in these methods and the predicted criteria and simulated motion are in good agreement with the measurement.

To reveal the cause of porpoising instability, the measured forces are analysed. The results show that coupled heave and pitch restoring coefficients have a different sign and are of the same order as the other coefficients in the high speed range. This means that porpoising is caused by a self-excited oscillation due to the energy exchange between heave and pitch motions.

Dynamic Stability of Wing-in-Ground Effect Craft

With recent political changes in the Eastern Bloc countries, WIGs, or ekranoplans, were revealed to the western world. Since then, the recasting of a rather old WIG concept received much interest worldwide in the last few years, this being reflected in a series of four international conferences, see Proceedings (1995, 1996, 1997, 1998). Recently, the commercialisation of WIGs has been explored in a number of countries such as Russia, Australia, Taiwan, Germany, USA and Korea. Bogdanov (1995a) noted that legislation for ekranoplans could fall under the jurisdiction of either or both of the International Maritime Organization (IMO) and the International Civil Aviation Organization (ICAO), depending on the mode. There seems to be little open literature available on the subject of the safety of wing-in-ground-effect (WIG) craft, or ekranoplans. The vast majority of the published research is centred on the aerodynamics of these craft, concentrating on the question of the increased aerodynamic efficiency when operating close to the "ground" or the surface of the sea. However, there are a number of papers on the stability of WIGs, see Kumar (1972), Staufenbiel and Schlichting (1988), Gera (1995), Fuwa et al (1995), Riley (1995), Hall (1994), Rozhdestvensky (1996), Delhaye(1997), Chang, Paik and Chun (1998). Chang et al (1998) derived the static and dynamic longitudinal stability equations and the stability of a 20 passenger WIG design, based on a number of wind tunnel experiment data. A general conclusion from these references on the stability is that due to the very proximity to the free surface, a WIG can be inherently unstable if the aerodynamic centers are mismatched. For stability, the vertical aerodynamic centre of a WIG should be ahead of its aerodynamic centre in pitch.

Some publications address the question of the optimal shape of a WIG.Rozhdestvensky and Savinov (1998) investigated the optimal design of 2-D wing sections in extreme ground effect. Suzuki et al produced 2-D optimal wing shapes with a high lift performance and satisfactory longitudinal static stability using a potential panel and SQP method. Kim and Chun (1998) developed a method to produce optimal 2-D wing sections in a tail wing combination with the design constraints which satisfy static stability and showed that an optimal wing section could have a larger lift force than that of the original wing.

3.4 Seakeeping and Extreme Motions

Introduction

The dynamic behaviour of high speed craft in a seaway is directly related to its safety. Accordingly a separate section has been prepared in which recent advances, both theoretical and experimental, in the behaviour of fast craft in a seaway are presented. This supplements the discussion of dynamic stability given in section 3.3 above.

Analytical Modelling of HSMV Seakeeping Responses

Although, during the last decade, much effort has been directed toward developing analytical tools for the reliable estimation of HSMV motions, there is still a long way to go to devising an adequate standard. There are two major problems in this respect:

- the appropriate modelling of all the factors that affect the dynamic behaviour of modern types of HSMV at the higher speed range
- their non-linear behaviour.

Furthermore, lateral motion responses are highly influenced by the strongly non-linear behaviour of roll, while viscous effects should be taken into account for its estimation.

The current trend in the analytical modelling of HSMV seakeeping responses is the development of time-domain computer codes, which take into account some of these factors analytically, empirically or semi-empirically. Disregarding some of these factors should be carried out with great care, however, but advances in computer speed and power provide a powerful tool for this approach.

Monohulls. De Kat and Paulling (1989) developed a time-domain numerical model based on the impulse response function procedure proposed by Cummins (1962) to determine the large amplitude motions of steered vessels subjected to severe sea conditions. De Kat, et al (1994) used this model to investigate intact ship survivability of frigates in extreme waves and concluded various criteria should supplement those currently in use; these are listed in Section 3.7 below.

Payne (1990) developed a three-dimensional time-domain computer program for planing hulls in random, head or following seas. His hydrodynamic coefficients are based upon a two-dimensional strip theory for standard displacement vessels.

Lai (1994) developed a linearized vortex-lattice method with special epsilon-model treatment for jet spray and presented an extensive study of three-dimensional planing hydrodynamics.

Wang (1995) used the mixed Eulerian-Langragian scheme developed by Longuet-Higgins and Cokelet (1976) to simulate numerically fully non-linear, free-surface flows in the time-domain. He used an Eulerian Boundary Element Method, with a desingularized source distribution to handle the boundary-value problem. Both this method and the source-doublet panel method developed by Markew (1991) have been proven to be stable, efficient and robust time-stepping schemes for fully non-linear free surface problems. In the sequel, a Lagrangian Finite Difference Scheme was used to satisfy the dynamic and kinematic free-surface conditions. The author compared the proposed numerical simulation with experimental results for the case of flare slamming and deck wetness. Finally, he used the source-doublet method to study the problems of the free drop of a flared body in calm water and of three-dimensional planing. Zhao and Faltinsen (1993) proposed a similar method to study water entry of two-dimensional bodies.

Ulstein and Faltinsen (1996) generalised Sedov's (1940) two-dimensional theory for the unsteady problem of a flat plate that enters water with constant fall velocity to cope also with a heaving planing plate. They proposed a time-domain theory under the assumptions that gravity can be neglected in the near field and the immersion of the flat plate is small.

Wu and Moan (1996) presented a linear and non-linear hydro-elastic analysis of the seakeeping responses of semi-displacement vessels using appropriate body boundary conditions of flexible modes. The total response was decomposed into linear and non-linear parts. The linear part was evaluated by an extension of the high-speed strip theory for non-planing ship hulls presented by Faltinsen and Zhao (1991). The non-linear part came from the convolution of the impulse response functions of the linear ship-fluid system and the non-linear hydrodynamic forces. It was concluded that the hydro-elastic effect in linear extreme responses is insignificant and that the non-linear influences are more significant the larger the Froude Number.

Bertram and Yasukawa (1996) overviewed the currently available Rankine Source Methods (RSM) and compared them with Green's Function Methods (GFM). They concluded that hybrid methods matching a RSM near-field solution to GFM far-field solutions are attractive for overcoming problems in the frequency domain for encounter frequencies lower than 0.25g /U (where g =9.81 m/sec^2 and U =ship speed).

Jiang et al (1996), applied and extended recent developments in dynamic system analysis to the study of highly non-linear ship rolling motion and capsizing in random beam seas. They also defined safe and unsafe areas in the phase plane of the unperturbed system model to distinguish the qualitatively different ship motions of capsize and non-capsize. The correlation between phase space flux and capsize was investigated through extensive simulation

Savander (1997) expanded the two-dimensional impact model of Vorus (1996) to a three-dimensional steady planing formulation. In both models, gravity was excluded from the free-surface boundary conditions. In addition, this model could be interfaced to a seakeeping simulation model.

Multihulls. Chan (1994) presented two models for the calculation of ship motions and wave loads acting on high-speed catamarans. He used both a three-dimensional oscillating and a three-dimensional oscillating-pulsating source distribution method. Although both methods provide similar results, only the latter predicts some experimentally-observed wave load phenomena.

Fang and Her (1994) described a time-domain method to model non-linear SWATH ship motions in large longitudinal waves. They took into account both large non-linear motions of the ship and non-linear viscous force. The time simulation technique was handled by a fourth-order Runge Kutta method and the cubic spline method was used to interpolate the corresponding hydrodynamic coefficients at each time step. The analytical results were experimentally verified.

Kvaeldvold (1994) investigated, analytically and numerically, slamming against the wetdeck of a multihull vessel in head waves. He used a two-dimensional, asymptotic method valid for small local angles between the undisturbed water surface and the wetdeck in the impact region. The disturbance of the water surface and the local hydro-elastic effects in the slamming area were accounted for. Interaction effects between local loading and global rigid ship motions were partially investigated. He concluded that loads and stresses on the wetdeck are strongly influenced by the elasticity of its structure.

Van't Veer (1997) devised a three-dimensional Rankine panel method to calculate the steady and unsteady velocity potential around a twin-hull vessel. He compared his method with experimental and numerical results, using a two-dimensional strip theory, up to a Froude Number of 0.60. He concluded that trim and sinkage should be included in the motion calculations if they are significant.

Kring et al (1997) used the non-linear, time-domain, three-dimensional Rankine Panel method to simulate the seakeeping behaviour of semi-displacement monohulls and catamarans. They took into account the transom flow of semi-displacement hulls and the flow interaction effects between catamaran demihulls, as well as the non-linear effects of flare and the submergence of overhanging structures, which can also be significant. Furthermore, their code can predict extreme statistics, and model passive and active ride control systems.

SES. Ulstein (1995) studied numerically and theoretically in the time domain the vertical plane motions of a SES in low sea states, focusing on non-linear air leakage underneath the seals and the coupling between the flexible stern bag and the air cushion pressure. He assumed a large forward speed compared to the relative vertical velocity between the bag structure and the water surface. He then calculated in a simplified way the hydrodynamic coefficients due to the side-hulls and, since the flexible bag behaves hydrodynamically as an unsteady 2-D planing surface, he solved the problem by combining the solution for that surface with an integral equation for the wetted length of the bag. The latter is a generalisation of what Wagner (1932) did for slamming. He concluded that the increase in the height to length ratio of the flexible stern seal bag reduces the vertical accelerations.

Sebastiani and Valderazzi (1997) formulated a computational procedure for the time-domain simulation of a SES moving in waves. Among the main innovations of their seakeeping procedure is a detailed treatment of the non-linear dynamics of the air cushion, accounting for its interaction with the flexible seals, developed on the basis of experiments.

Hydrofoils. Van Walree et al (1991) devised a design tool for hydrofoils encompassing a time-domain simulation of their powering and seakeeping characteristics. The system was linked to a simulation model of the ride control system. The authors announced also the initiation of an extensive experimental research program to determine the hydrodynamic characteristics of the craft.

Ohtsubo and Kubota (1991) presented a new method for calculating vertical motions and wave loads of large high-speed ships with hydrofoils. Ship motion was predicted by a strip method taking into account the effects of the non-linear hydrodynamic forces and dynamic lift of the hydrofoils. They stressed the importance of accurately predicting the dynamic lift of submerged hydrofoils travelling close to the free surface under waves. Experimental verification of the method in the case of a hydrofoil catamaran was provided.

Experimental Investigations

Monohulls. Suhrbier (1978) investigated experimentally, by means of captive and radio-controlled tests, the roll stability of a semi-displacement craft at high speeds. A reduction of roll stiffness at speeds corresponding to Froude numbers above 0.6 to 0.8 was reported. Spray rails can be used to overcome problems of heeling at these speeds if the metacentric height cannot be increased. Tests carried out with two geosims did not produce any indication of scale effect problems on the stability characteristics. In a more recent paper, Suhrbier (1995) investigated the effect of propeller cavitation on propeller/hull interaction and the dynamic stability of planing craft. He found out that loss of running trim due to trim flap ventilation and collapse of suction forces can lead to dynamic instability and possibly broaching. Thus trim flaps should be sealed at their connection to the transom".

Fuwa et al (1982) used a radio-controlled model to reproduce broaching on a small high-speed boat in a model basin. They then carried out a large series of tests with captive models to determine the coefficients of the equations describing manoeuvring motion in waves. A method of system identification was used for this. The optimal form of the maneuvering equation was derived and the dynamic balance of each component of the equation was examined. To carry out the former task they analyzed measured data by minimizing Akaike's Information Criteria (Sagara, 1981) to control the accuracy of the large number of parameters to be identified using limited data. Broaching always occurs when a ship is under surf-riding conditions on the front slope of a wave and the velocity U becomes almost equal to that of the wave propagation V_W. The authors concluded also that the most likely conditions are $\lambda/L=2.0$, heading of encounter $\alpha=20°$ to $30°$ and $U \cos\alpha \approx V_W$. Experimental results have been verified by full-scale tests with satisfactory agreement.

Kan et al (1990) carried out extensive tests of a containership in quartering waves for a set of encounter angles at speeds corresponding to Froude numbers up to 0.37. Most capsizing occurred at encounter angles between 20° and 40°, to the lee side and at high speeds. The latter two conclusions were attributed to surf-riding or asymmetric non-linear surging motion. They also examined numerically non-linear phenomena such as the fractal capsizing boundaries in the initial value plane as well as the control parameter plane.

Lundgren (1993) studied experimentally, (by carrying out captive model tests), and numerically (by using a time-domain computer code), the operational limits for two high-speed monohulls operating in extreme sea conditions. He concluded that modelling of green water on deck is crucial for the accurate calculation of large rolling angles and that capsizing seemed to occur at wave heights causing relative motion to exceed the freeboard midships, even if the metacentric height is sufficient.

Francescutto et al (1994) provided experimental evidence of the strong non-linear effects that are present in the rolling motion of a destroyer in beam seas. A jump from low oscillation to a higher resonant state was obtained by means of a shock while wave excitation was kept constant. The analysis of the phase lag between excitation and rolling confirmed that the jump was due to a bifurcation. These phenomena can be modelled by means of a bifurcated solution of the non-linear rolling equation.

MacFarlane and Renilson (1995) carried out tests on a model of a planing hull form in regular and irregular waves, to investigate the limits of applicability of linear theory for predicting vessel motions in irregular head seas. The experimental results were compared with those calculated using a standard linear strip theory combined with linear superposition theory and with those obtained from linear superposition theory combined with the experimental results in regular waves. They provided plots of the applicability areas for both of the above cases. Grigoropoulos and Loukakis (1995) carried out similar tests for three planing hull forms, concluding that standard strip theories are inadequate to predict the seakeeping behaviour of planing craft.

Keuning and Pinkster (1997) investigated experimentally and analytically variants of a semi-planing fast patrol boat within their "Enlarged Ship Concept". The idea behind this concept is to create variants of a basic design with increased length and with equal payload, in order to improve calm and rough water performance. The results of their concept were confirmed. They concluded that peak values of the vertical accelerations should be used in the limiting criteria rather than significant values.

Grigoropoulos et al (1997) investigated experimentally the seakeeping characteristics of a double-chine parent hull form, (with wide transom, bottom warp and L/B ratio of 5.5), of the NTUA series of planing hulls, extrapolated to a 108-metre car/passenger ferry and to a 65-metre passenger ship. Experimental results for the vertical seakeeping responses in head sea states at Froude Numbers of 0.34 and 0.68 were compared with analytical results based on Salvesen, Tuck and Faltinsen's (1970) strip theory for conventional ships and the time-domain method for planing hull forms proposed by Payne (1990). While strip theory results in an excessive overestimation of the vertical ship responses, Payne's method provides reasonable results. In a more recent paper, Grigoropoulos and Loukakis (1998) presented experimental results for three members of the NTUA series with L/B ratio ranging between 4 and 7 at the same speed in seven sea states. They concluded that vertical ship responses are relatively small overall and do not differ greatly when grouped with respect to Froude Number, despite the large differences in the parameters involved. In addition, they derived two rules of thumb applicable at pre-planing speeds and at the tested sea states: Pitch (RMS) [deg] $\approx 0.22\ H_S$ [m] and

C.G. acceleration (RMS) [g] ≈ 0.03 H_S [m]. Despite the approximate nature of these criteria, they can be useful in determining the operability of a particular ship in a given sea environment. Finally, since mean added resistance in waves seems to be relatively small and relatively constant, a modest increase in resistance at the design speed of the order of 15% is sufficient to account for the added resistance.

Summary

It is clear that the topic of fast craft behaviour in a seaway has received attention in recent years. Its direct relation to safety has not been addressed in all cases, but some information leading to safe design and operation has been revealed.

There is more to be done, however, and it is apparent that more tests, at model and full scale, should be carried out to investigate the effect of GM and CG position on course stability and capsize. This, of course, impinges on the domain of the ITTC Stability Committee and indicates an area of overlap within the ITTC organisation.

3.5 Full Scale Tests

Types of Full Scale Tests

With the emphasis of the IMO Code of Safety for High Speed Craft (the HSC Code (1996)) on the demonstration of a satisfactory level of operational safety on the craft itself, testing at full scale is required in a number of key areas.

The following is a selection of the main types of testing required by IMO:

- manoeuvring and controllability, with particular emphasis on the effects of system failures (Chapter 17 and Annex 8 of the Code)
- conformity with acceptable acceleration limits (Annex 3)
- evacuation trial (paragraph 4.8)
- structural loading trials (paragraph 3.6)
- inclining experiments (paragraph 2.7)
- seat tests (Annex 9)

An overview of the approach to safety adopted in the HSC Code has been given by Werenskiold (1997). In this paper he discussed the parts played in high speed craft safety by the International Safety Management (ISM) Code (which became mandatory for most types of ships in July 1998) and Formal Safety Assessment (FSA). The former is a formal framework for the safe management and operation of ships by setting rules for the organisation of company management in relation to safety and pollution prevention, together with the implementation of a company safety system. The FSA is another formal framework which identifies the hazards to which a vessel is exposed, the risks which this implies and the means to control them.

Werenskiold shows how these concepts and others may be combined with the HSC Code to provide a means for total safety assessment. Central to this is the need to demonstrate that certain safety criteria have been met; the way this is achieved is, in many cases, by means of the full scale tests mentioned above. Those of most interest to members of ITTC are now considered.

Evacuation Trials

Marine evacuation systems (MES) are used on passenger-carrying high speed craft. In many cases they consist of an inflatable slide with some form of floater at its foot to collect the evacuated passengers; a number of these are discussed in Safety at Sea International (January 1997). Regardless of their innovative qualities, they must be able to demonstrate an ability to deploy safely in the prevailing environmental conditions. Tank testing could supplement full scale trials for this, and indeed has been used for this purpose with some offshore escape systems. While tank tests can be used to demonstrate the effects of bad weather on the MES, the Code only requires the full scale demonstration to be carried out in calm conditions within a harbour.

Werenskiold (1996) discusses the application of performance requirements to assess and quantify the safety and reliability of the whole evacuation process of high speed craft. In his opinion, the safety margins proposed, and demonstrated in recent HSMV accidents, are far too small.

Sea Trials

Of direct interest to ITTC members are the sea trials required by the HSC Code to demonstrate, among other things, safe manoeuvring and control together with compliance with safe acceleration limits.

Dogliani, Capizzi and Lauro (1997) discussed this whole area and, by an analysis of the HSC Code, designed new types of test to supplement the more usual manoeuvring trials as described, for example, in the ITTC Codes of Practice. These arose from the following requirements:

- measurement of acceleration in the horizontal plane to verify compliance with criteria in Annex 3 of the code during stopping manoeuvres, slam starts and high speed turns
- measurement of cruise performance during normal operation (low sea states) and worst intended condition (high sea states). The operating levels have to be established by full scale tests in different sea conditions with various headings
- demonstration of the effects of failures or malfunctions according to a Failure Mode and Effect Analysis (FMEA) as specified in Annex 4 of the Code.

These highlighted the need to upgrade and update standard manoeuvring trials codes indicating that additional numbers and types of trial were necessary. The authors split the required full scale trials into four groups:

a) **Speed/Power Trials**

Conventional speed/power trials are unaffected by the new requirements, but the determination of a safe maximum speed with one or more propulsion units disabled is now necessary.

b) **Manoeuvrability Trials**

An increased interest in emergency stops and emergency manoeuvres, with their high attendant acceleration levels, has led to the need to ensure that acceleration levels remain within the limits set in Annex 3 of the Code.

The remaining turning, zig-zag and stopping trials required by the IMO Manoeuvrability Standards (1993) are unaffected, although good instrumentation and control is required if meaningful zig-zag tests are to be carried out at high speed. An alternative practical means to indicate directional stability is the pull-out test. Although more comprehensive information on directional stability is obtained from spiral tests, it may be remarked in passing that the usual drawbacks of spiral tests – long timescales and large amounts of sea-room – would be less likely to apply to high speed vessels.

c) **Seakeeping Trials**

Full scale trials specifically to evaluate seakeeping have been a requirement for naval vessels in the past, but have not usually been common for merchant vessels. This situation is now changed, with commercial high speed vessels being required to satisfy (and demonstrate compliance with) the acceleration limits of Annex 3 of the Code. It is necessary to determine:

- speed/power relations in various seastates, and at various headings
- speed loss at a constant engine setting

- whether motions and accelerations in rough seas satisfy Annex 3.

Dogliani et al propose a test in a given seastate whereby a pentagon-shaped course is followed, a wave-measuring buoy being placed at the centre of the pentagon (Figure 4). This provides responses from seas on the head, beam and quarters with additional measurements being taken in beam seas to assess the effectiveness of any ride control systems. It is recommended by the authors that the vessel should stay on each side of the pentagon for 20 minutes (with at least 10 minutes of data acquisition) before changing heading. Wave data for the complete trial are collected from the central wave buoy.

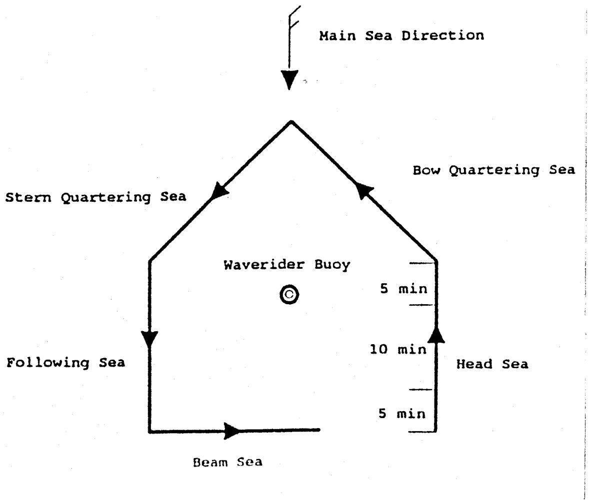

Figure 4. Pentagonal Track for seakeeping Trial.

Similar tests are proposed in the NATO Seakeeping Trials Procedure (1994) while Marintek (Holden, 1991) gives an alternative Trials Procedure for High Speed Craft.

In the former, the pentagonal course of Dogliani et al is extended to an 8-sided course which resembles a straight-sided crescent. In the latter a comprehensive set of trials procedures is given, covering calm water trials manoeuvring trials, rough water trials and analysis/reporting procedures.

d) **FMEA Test**

The purpose of these tests is to determine the safe limits of operation taking account of the possible effects of equipment failure. They can be carried out during the manoeuvring trials by, for example, simulating the sudden failure of the propulsion line, a malfunction in appendage retraction or loss of lift for an ACV. The resultant change in behaviour is measured.

Directional Stability Tests

A simple test, which can be carried at model and full scale, was developed by Werenskiold (1993, 1995). It is discussed at some length in the report of the HSMV Committee of the 21st ITTC and consists of running a model or vessel, at an initial angle of heel, in a straight line. If the heel increased beyond a given limit at speed, then the vessel is likely to be directionally unstable. The detailed criteria are given in section 3.7 below.

Wash Measurements

In Section 3.6 of this report, the problems posed by the wash of HSMV are mentioned. Full scale measurements of wash, while not at present compulsory, have been carried out by a number of investigators as already mentioned.

Tethered or floating wave height measuring devices have not been generally successful for this purpose, and, if possible, wave probes should be attached to a suitable fixed mounting. Care should be taken to measure the wave probe position in relation to the track of the passing vessel; this is usually done using DGPS for both vessel track and probe position. It is important to indicate the time at which some part of the vessel passes the wave probe and its passing speed. Ideally such tests should be carried out at times of slack water, but if this cannot be arranged, the mean water level should be recorded against time. Finally, some idea of the bathymetry local to the test area should be obtained.

Summary

Safety requirements for high speed craft mean that more comprehensive full scale tests and measurements are now required. This means that existing Codes of Practice for trials at sea must be revisited and revised.

3.6 Wash

The Problem

Any vessel moving at high speed on the water surface must inevitably cause a disturbance. This will hold true whether the vessel is of the displacement, semi-displacement or planing type and whether it be hull-borne, foil-borne or supported on a cushion of air. Some of these will cause less disturbance than others, but all will transfer some energy to the water in which they move and various forms of disturbance will result.

By far the most obvious is the wave wash created by all vessels moving on the water surface. The advent of fast passenger-and freight-carrying vessels has brought with it an increase in wash nuisance around the world; in an increasing number of areas this has had an impact on marine safety. This arises when fast vessels pass near to shoaling waters or coastal areas where their wave system comes ashore. There has been an increase in incidents in which long-period waves of large amplitude have come ashore after the passage of a fast vessel on an otherwise calm day. This has caused people on beaches to be knocked down, people in small boats to be inconvenienced, or, in extreme cases, capsized, and, in areas where sea walls abound, has given rise to significant wave reflections and interference. Ships loading or off-loading in harbours have been caused to move excessively (either by the direct effect of the wave wash or by the seiche which they trigger) and large vessels in approach channels can be induced into a noticeable roll motion by their passage (see, for example, Seaways 1998)

All of these manifestations have implications for safety and attempts are being made both to understand the causes of the phenomenon and to minimise its effect by design and operation.

The Cause

The normal free-wave system of low speed surface vessel is well-known; it comprises diverging and transverse wave systems. In shallow water, the following changes occur in this familiar wave system as speed increases:

- the diverging waves may leave the vessel at ever-increasing angles as the critical speed, at a Froude Depth Number of unity, is reached (Havelock 1908)
- the waves increase in height and steepen
- solitary waves ("solitons") may be formed near the critical speed
- at super-critical speeds, the transverse wave system disappears and the diverging system remains
- near the critical speed a large following wave may arise, similar in nature to a hydraulic jump. In some circumstances this can affect handling due to a reduction in directional stability.

A further effect can occur if a vessel is turning, when its wash on the inside of the turn can become steeper due to a "wave focussing" effect.

Wash approaching a beach will also steepen, and possibly break, causing, at best, inconvenience to those on the beach, and at worst, danger to the same people by washing them off their feet.

Although the largest waves are likely to occur when vessels operate in shallow water conditions, it should be noted that waves from high speed vessels in deep water can radiate into shallower water near the coast and still cause wash nuisance. Perhaps the most insidious form of this occurs when large long-period waves ride up a beach unexpectedly on an otherwise calm day. These may have been caused out at sea by a fast vessel which will have long-since disappeared by the time its wash reaches the shore. If the waves reach land where there is no beach, but a rocky shore or seawall, they may reflect, adding to the wave activity just offshore.

Studies of this phenomenon have been confined in the main to vessels whose absolute speed is high and whose Froude Depth Number is around the critical value. However, some investigators have considered lower speed vessels in inland waters whose wash not only causes a nuisance and possible danger, but also erodes the banks of the waterways.

A comprehensive study by the Danish Maritime Authority (DMA) (1998) deals with the former while that of Gadd (1994) deals with both the former and latter with regard to pleasure craft. The DMA report notes that waves from large, fast, ferries are characterised by long periods of around 8 to 10 seconds which may be contrasted to the 4 to 5 second periods of conventional ferries. They also provide a plot (Figure 5) which indicates a zone of speeds near the critical value within which vessels should not operate if they are to avoid excessive wash. It is of interest to note that 40 knot vessels operating in the shallow open waters of some seas (the southern North Sea for example) are operating within this zone.

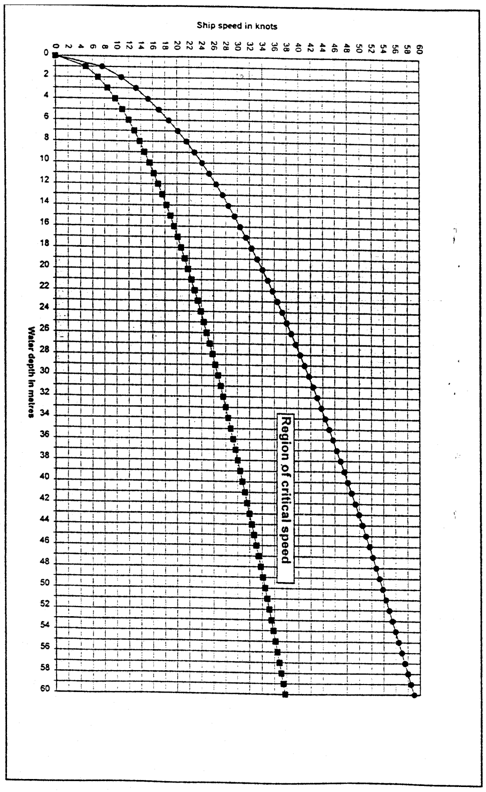

Figure 5. Critical Speed Zone for Excessive Wash.

Gadd (1994) demonstrated a comparatively simple method to compute the wave system of a fast planing vessel. He represented the planing hull by a surface pressure distribution whose length and breadth are such that their product equals the waterplane area of the boat and whose depression, created at rest, equalled the immersed volume of the boat. The resulting wave system (Figure 6) gave remarkably good predictions of measurements made for a variety of pleasure craft (Figure 7).

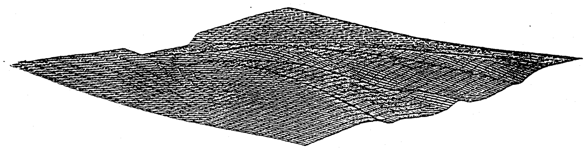

Figure 6. . Predicted High Speed Craft Wave System.

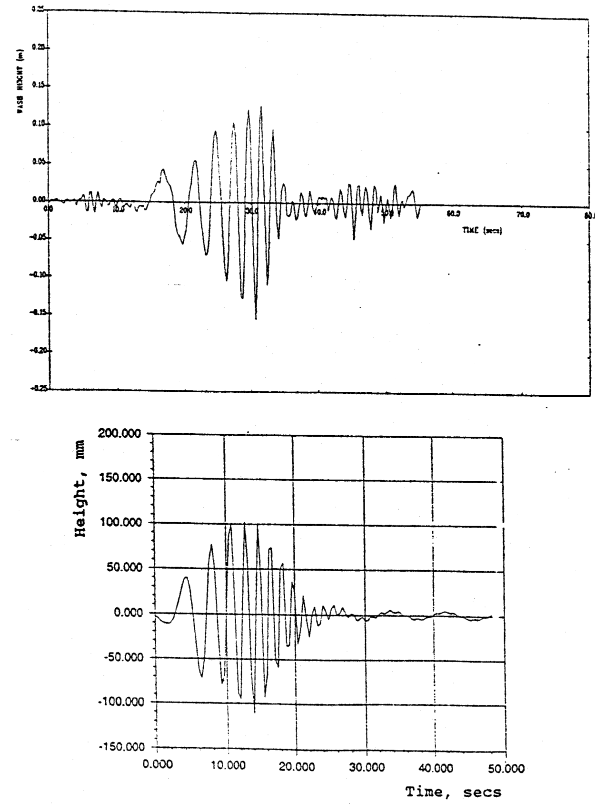

Figure 7. Wash Prediction: Comparison of Full Scale and Computer Results.

Other measurements of wave wash have been made by Renilson and Lenz (1989) who carried out model and full scale experiments to investigate the effect of hull shape on wash height. This was followed (Renilson et al, 1991a, 1991b) by the development of a low wash ferry for service on an Australian River. This demonstrated the value of wave resistance calculations in estimating the importance of the wash generated.

In Europe the SPAN research project has investigated the behaviour of fast catamarans in very shallow water. Wave wash measurements were made with towed models in a tank and were observed with a free-running model in open shallow water. Solitons were observed in the towing tank around the critical speed (Figure 8); they were created at the model and ran ahead of it down the tank. Interestingly, they were also observed in the open water tests when they were shed ahead of the model, their wave fronts forming a circular wave of appreciable energy. Once formed, these moved within the basin independently of the model's wave system and reflected off the walls. Also observed in these tests (and repeated at full scale) was the large following wave at speeds near critical which had similarities to a hydraulic jump.

Possible Solutions

Solutions to the wash problem of high speed craft have been partially successful. It has been found impossible at present to predict accurately the far-field wash climate from near-field measurements taking account of water depth, beach and coastline and the route of the craft. This appears to be a non-stationary Boussinesq (soliton) wave problem which has so far resisted solution.

There is therefore a need, in the first instance, to determine a reliable decay law for the far-field wash of high speed vessels.

Solutions to the wash problem are not comprehensive, but some attempts have been made. These fall into the following broad categories:

- speed and route restrictions
- hull design
- remedial measures on shore, including warnings.

These are now considered by resorting where possible to published information, although at present this is understandably sparse.

However, before going so, it is important to consider by what criteria the adequacy of any remedial measures may be judged.

Wash Criteria

Various authorities are contemplating wash criteria. Usually they are of two main types:

- wash height restrictions
- comparison with already-accepted wash.

Wash height restrictions have been proposed by the Danish Maritime Authority (1998) who set the acceptable height of a long

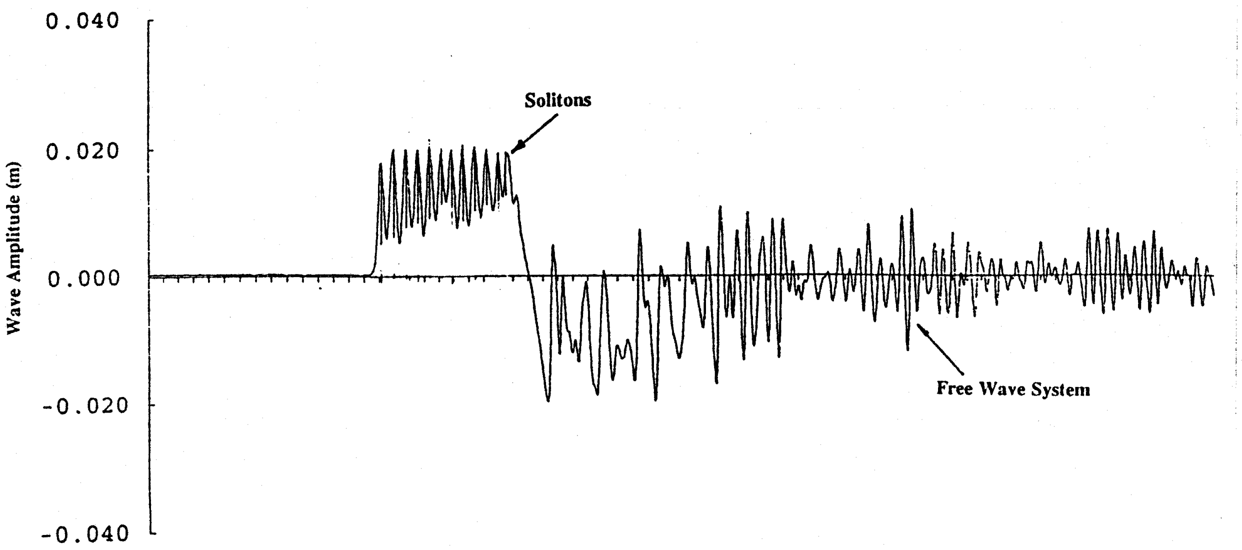

Figure 8. Measured Wash of High speed Catamaran Showing Solitons

period wash wave at 0.35 metres in 3 metres water depth. This has been suggested as a limit for the time being so that future high speed ferry routes can be assessed for both safety of navigation, leisure activities on the coast and protection of coastal structures. A similar criterion was suggested for a high speed catamaran operation on the River Thames.

If an absolute criterion is not set, the wash generated by high speed vessels is often compared with that generated by conventional ferries in the same waters. This is done on the assumption that conventional ferry wash is at best accepted, and at worst tolerated, so that its use as a criterion does not increase marine risk.

Speed and Route Restrictions

Speed and route restrictions are made in the belief that, by changing speed (often by reducing it) and changing the route (often by moving it further offshore), wash problems will be ameliorated.

Unfortunately this is often complicated by the fact that reducing speed may move the vessel from one wavemaking regime to one that is worse, while the persistence of some of the low frequency shallow water waves (or divergent wave groups) makes route selection difficult.

Speed restrictions to minimise wash have been used for fast ferry operation on the River Thames, in Hong Kong Harbour, and in the approaches to Harwich in the North Sea. For low speed leisure craft speed restrictions are also imposed on many recreational waterways for both safety reasons and environmental protection (Motor Boat and Yachting, 1997).

In many areas the problems associated with speeds near the critical Froude Depth or Length Numbers has been recognised and speeds are regulated accordingly. As already mentioned, Figure 5 shows the restricted speed/depth relationship suggested by the Danish Maritime Authority (1998) so that vessels avoid the critical speed range. In many cases high speed vessels are able to pass rapidly through this range because their operational speeds are past the critical speed or the main Froude Number hump. Service speeds which lie within the range are to be avoided.

Speed restrictions are also imposed on high speed vessels using fairways occupied by large displacement vessels constrained by their draught. This is to prevent unnecessary loss of underkeel clearance from roll and heave motion induced by the wash of the high speed vessel.

Although speed restrictions can in some cases be beneficial, there are understandably strong commercial pressures against their widespread adoption. Clearly their existence works directly against the whole purpose of high speed marine transport; too many or too severe speed restrictions tend to eliminate any advantages gained.

Hull Design

As it is the hull of the vessel which produces the waves, it is natural to assume that, by changing its design in some way, wave wash can be reduced at source.

For low speed pleasure boats, and stimulated by full scale measurements (May and Waters 1986), attempts were made to use various well-known devices to eliminate or reduce hull-generated waves. Firth (1991) and Ship and Boat (1997) described developments carried out at BMT using bulbous bows and wave shelves to cancel waves. This approach met with some success and was later extended by the work of Gadd (1997) in which the bulbous hull form was combined with a tunnel stern incorporating a large, slow-speed high-efficiency propeller. This environmentally-friendly design exhibited reduced wash characteristics by comparison with conventional cabin cruisers of similar displacement.

The benefits of cylindrical bows on canal or river narrow boats were demonstrated by McGregor and Ferguson (1993) when significant reductions in wash were produced compared to boats of conventional form.

For faster vessels Doctors (1997) and Doctors et al (1991) have considered ways of reducing the wave resistance and wash of river catamarans by hull shape changes. Although some of this work is purely theoretical, a low wash design was produced for use in Australia (Janes High Speed Marine Craft 1996). This exploited, among other things, the significant effect of displacement-length ratio on wash and resistance; the lower is this ratio, the lower the resistance and the lower the wash height.

This finding was confirmed in the SPAN study for high speed in shallow water. General design changes were made to the demi-hull of a high speed catamaran, but displacement-length ratio remained constant. The changes had small effects on wash and resistance at supercritical speeds; reducing the displacement-length ratio, on the other hand, had a noticeable effect.

Remedial Measures on Shore

While attempts are made to reduce ship-generated waves at source, other remedial measures to reduce their impact ashore have also been developed. An indication of high speed vessel wash on the safety of those on shore is given by the warning notices placed on vulnerable beaches. These warn people to beware of the wash of fast ferries either passing or slowing down nearby.

Protection of river banks vulnerable to wash erosion has been carried out by various means of which the reed bed has proved to be a useful wave damping device. Shoaling beaches usually cause the waves to break, but if solitons are created they may not be eliminated by this means and pass up, or even across, the beach. In some cases more permanent beach protection is being developed.

Summary

There is little doubt that the wash generated by high speed vessels causes a possible safety problem world-wide. This is now generally recognised and remedial measures are sought.

The role of ITTC members in providing understanding of the phenomenon and developing the means to minimise its effect by design and operation will be significant in the future, thereby ensuring that marine safety levels are not compromised.

3.7 Safety Criteria

In this section a number of "Rules of Thumb" are gathered together which should allow ITTC members to assess whether a particular design will be dynamically stable and safe. They have been collected from the open literature and are grouped into two main areas:

- design guidelines
- model test criteria.

It is hoped that they will help to answer some of the questions relating to the appropriate magnitude of a given dynamic quantity rather than just its presence or absence. In other words, it is hoped that these will indicate how much dynamic stability (say) is needed, rather than simply stating that "the craft should be dynamically stable".

Design Guidelines

Monohulls: The region of broaching of a fast planing vessel decreases as the vessel's metacentric height is increased (Renilson and Tuite, 1996).

For a fast planing craft, although the period of rolling induced by pitch is almost constant, roll becomes unstable when the pitch period is a multiple of half the roll period (Katayama and Ideka, 1995, 1996c).

To avoid dynamic roll instability in planing hulls (Petersen and Werenskiold, 1997):

- Increase L/B ratio
- Avoid trim at rest and keep running trim above 3^o at Froude number $Fn > 1.5$
- Keep warp abaft amidships below 15^o
- Use entrance angles less than 30^o and
- Raise the vertical position of the rudders.

For frigate-like vessels operating in severe sea conditions, the following design guidelines are suggested (De Kat et al, 1994):

- The righting lever in calm water should remain positive up to a heeling angle of at least 90°
- The minimum area under the righting lever curve for unlimited operation in the design condition must be between 1.00 m-rad (for a vertical prismatic coefficient C_{VP} = 0.55) and 0.67 m-rad (for C_{VP} = 0.70). Linear interpolation should be used for intermediate C_{VP} values
- The minimum dynamic stability between 30° and 40° for unlimited operation in the design condition must be between 0.13 m-rad (for C_{VP} = 0.55) and 0.10 m-rad (for C_{VP} = 0.70). Linear interpolation should be used for intermediate C_{VP} values.

Trim flaps should be sealed where they join the transom to prevent directional instability and broaching (Sububier, 1995).

Yaw/heel coupling can be reduced by means of spray rails, if metacentric height cannot be increased, to reduce directional instability in planing or semi-displacement craft (Sububier, 1978).

Suitable positioning of the lcg and centre of lateral resistance can provide good handling qualities (Dand and Cripps, 1995). For a high speed rescue boat a range of from +3% to -5% was recommended where a positive quantity refers to the point of application of the linear motion sway force being ahead of the lcg.

The most likely conditions for broaching in a following sea are (Sagara, 1981):

- $\lambda/L=2.0$
- encounter heading α=20° to 30°
- $V\cos\alpha \approx V_w$ where V is craft speed and V_w wave speed.

With fast monohulls in high seas, capsizing occurs at wave heights causing relative motion to exceed the freeboard amidships, even if the metacentric height is sufficient (Lungren, 1993).

For operability estimates of high speed monohulls at pre-planing speeds in waves, the following approximations may be used (Grigoropoulos and Loukakis, 1998):

- RMS pitch (°)≈0.22 H_s (m)
- RMS acceleration at cg(g)≈0.03 H_s (m)
- added resistance ≈15%.

SES: An increase in the height-to-length ratio of the flexible stern sealing bag/skirt reduces vertical accelerations in low sea states (Ulstein, 1995).

WIG Vehicles: Due to the proximity of the ground plane, a WIG can be inherently unstable if the aerodynamic centres are mismatched (see Section 3.3 for references)

Multihulls: In calm shallow water at high speeds, the directional stability of a model catamaran was found to be improved at supercritical speeds and degraded in the trans-critical region (SPAN study 1999).

Model Test Criteria

Calm Water Directional Stability (see 21st ITTC HSMV committee report).

Tow or self-propel model, free in roll, pitch and heave at various speeds and an initial heel. The following criteria apply:

- performance of towed model with rudder force to compensate yaw moment.

Test should be performed with 3° initial heel and maximum heel at maximum speed should be less than 8°

- performance of towed model without rudder to compensate yaw moment

Tests should be performed with both 3° and 6° initial heel and the maximum increase of heel at maximum speed should be less than 1.5° and 3° respectively

- performance with self-propelled model with steering force applied to compensate yaw moment

Tests should be performed with 3° initial heel and maximum heel at maximum speed should be less than 10° degrees.

Bow Diving

Model must be able to retain a margin of 20% wave height of green water on deck.

Porpoising

See 21st ITTC HSMV Committee report for details. Quasi-stationary pitch motion to have a period not less than 5 seconds (full scale). If there is no correlation between pitch and heave motions then porpoising will be unlikely.

Acceleration and Motion Limits

See IMO HSC Code for prescribed limits (IMO 1996).

3.8 Symbols and Terminology

The following symbols and terminology have been used in this report:

Analytic Hierarchy Process

A method for formalising decision making where there are a limited number of choices but each has a number of attributes and it is difficult to formalise some of those attributes. In applying the AHP, the decision maker must specify an overall goal, and select criteria that support the achievement of that goal. The method is based on determining weights of the selected criteria in one level of the problem hierarchy to the level above by pairwise comparisons of attributes.

Blocking Coefficient

An index for evaluating a marine traffic environment (Nagasawa, Hara, Nakamura and Onda, 1993).

Bridge Resource Management

The ability of a bridge crew to use the available technical equipment and deploy human resources in an optimal manner (Huth and Firnhaber, 1997).

FMEA Failure Mode and Effects Analysis
FSA Formal Safety Assessment
SAR Search and Rescue

Shore-Based Pilotage

An act of pilotage carried out in a designated area by a pilot licensed for that area from a position other than on board the vessel concerned, in order to conduct the safe navigation of that vessel (definition according to the International Maritime Pilots Association).

Vessel Traffic Services (VTS)

Any service implemented by a competent authority designed to improve the safety and efficiency of marine traffic and the protection of the environment. It may range from the provision of simple information messages to extensive management within a port or waterway (definition according to the IMO).

Virtual Prototyping (VP)

The designing and modelling of the process of building, testing and operating a prototype system by means of virtual simulation techniques.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions of the Committee

The assessment of the safety of high speed craft, especially those carrying passengers, requires a multi-disciplinary approach. A hint of some of the key areas for study has been given in this report and it is clear that there is an important role for the expertise resident within the ITTC.

It is obvious however that to cover the subject adequately, those working in hydrodynamics and dynamics would have to broaden the scope of their work to encompass a working knowledge of such disciplines as risk analysis and human factors. The interface between such topics and the more usual areas of study for hydrodynamic specialists has been explored by a number of hydrodynamics laboratories and the fruits of their efforts may be seen in documents such as the IMO Code of Safety for High Speed Craft (IMO 1996).

Consideration of safety embraces not only human life, but also the environment and this report has shown the problems that remain to be solved in understanding and mitigating the effects of wash from high speed craft.

There is much to be done and this Committee, carrying on the work of the HSMV Committee of the 21st ITTC, believes that a Committee specialising in the safety of high speed craft should continue for at least another term. It is hoped that the work of the present Committee will both help and inspire others to carry out research in this important and growing area of the marine world.

General Technical Conclusions

At present there is a lack of research specifically directed at the safety of HSMVs.

- More research or data are needed on:
  - The theory of HSMV wash in deep and shallow water and in the near and far fields,
  - Full scale wash measurements,
  - The theory of HSMV dynamic stability,
  - Human factors and HSMV operation,

(This topic includes not only training - which will require special simulation facilities- but also team work and appropriate bridge manning levels to minimise the adverse effect on safety of human error),

- Communication between HSMVs,
- High speed navigation techniques including automatic control devices,
- Full scale tests to satisfy the IMO HSC Code,
- Analytical models of HSMV behaviour in extreme motions,
- Wash problems can be reduced by suitable choice of route and speed, but trade-offs are necessary,
- Vessel Traffic Systems (VTS) in close quarters situations are essential,
- There is a lack of safety criteria to link performance measured in a hydrodynamic laboratory to acceptable levels of safety. As an example, there are apparently no criteria for hysteresis loop width and height for the controllability of HSMVs,
- Casualty data for HSMVs is sparse; the main cause of the accident is seldom given.

4.2 Recommendations to the Conference

None.

4.3 Recommendations for Future Work

- Full scale and model tests of HSMVs should be made in various sea states, (especially in quartering seas) to find the effect of CG position and GM on course-stability and capsize,
- Deduce dynamic stability criteria from the above data,
- From measurements of wash in the far field at model and full scale produce an accurate decay law. The effects of shoaling water on wash should also be investigated.
- The ITTC trial codes should be up-graded to take account of the special requirements of HSMVs, with special regard to the HSC Safety Code,
- The casualty database for HSMVs developed by this Committee should be maintained,
- Safety criteria (and rules-of-thumb) should be collected and developed for HSMVs.

Examples are:

- acceptable hysteresis loop height and width for course-keeping,
- parameters of design/operation to avoid broaching,
- acceptable wash height.

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The Specialist Committee on Safety of HSMV

Committee Chair: Dr. Ian W. Dand (BMT SeaTech Ltd.)
Session Chair: Mr. Brian Bowden (Secretary of AC)

I Discussions

Contribution to the Discussion of the Report of the 22nd ITTC Specialist Committee on Safety of HSMV

by Martin Renilson, Australian Maritime College

First, I would like to congratulate the committee on an interesting and valuable report which touches on a wide range of important safety issues related to high speed marine craft. As the trend for an increasing number of these craft continues I believe this will become an ever important topic for member organizations in the future.

I would like to comment on three different aspects covered by the committee and to point to what I believe is an important omission.

Vessel Wash

As identified in the report this is becoming a very important issue to the designers and operators of high speed marine craft. I know of a couple of cases where the introduction of stringent regulations based on wash height have caused major changes in vessel operation which have resulted in previously profitable routes becoming unprofitable.

In addition, there are now a number of local authorities introducing wash height limitations with penalties as strict as non acceptance of the vessel if they are not met. This puts extreme pressure on the designer and builder who rush to testing organizations such as our own to give them confidence that their vessel will indeed meet the requirements. I am therefore a bit surprised at the apparent low key approach to this amongst many member organizations.

An additional complicating factor is that most authorities do not fully understand the problem, and adopt differing criteria - many unrelated to the problems caused by vessel wash, open to different interpretations and difficult to measure full scale. There is a crying need to develop a standard approach to this, which I'm sure will utilize the decay law which the committee has identified as being an important aspect of their future work. I concur with this and offer our proposed method given in the reference [Macfarlane, 1999] for their consideration.

My final point on this topic is that there is also a need for confidence of the prediction from model to full scale. One of the problems we have identified is that wave heights a distance from the model are influenced by the walls of the tank - even quite some distance from the wall - making full scale prediction of wave height more than a very short distance from the vessel centreline very difficult.

Four degree of freedom manoeuvring models

The committee has correctly pointed out that in many cases it is important to adopt 4DoF manoeuvring models for high speed marine vehicles. This point was also addressed briefly by the manoeuvring committee.

My point is that although 4DoF manoeuvring models are available, I believe the important deficiency at present is a lack of information on the actual coupling coefficients - particularly for high speed marine vehicles. Does the committee have any information on what work has been done on this? If not, I believe this should form a recommendation for the future work of the committee.

Bow diving

Again this is an important issue. As with many such issues it is often swept under the carpet as being an operational issue. When bow diving has occurred it is usually identified that the vessel is travelling too fast and the operators are blamed, but the designers rarely give them operating guidelines!

The conduct of experiments to check for the possibility of bow diving is very complex and we need standard guidelines on how to conduct these. Issues such as the self propulsion method, restraints on the model and the types of waves should be addressed.

I would like to ask the committee where their proposed criteria of '…a margin of 20% wave height of green water on deck' came from.

Damage Stability of High Speed Marine Craft

High speed marine craft are often lightweight and by their nature travel at high speed - often in restricted waterways. As a consequence, if involved in a collision or grounding they can sustain considerable damage - much more than a conventional ship.

Existing damage stability regulations are based on conventional ships, however there are currently proposals to develop different, much stronger regulations for high speed marine craft. If this happens we can be sure that member organizations will be required to assist in predicting the motions and possible capsize of such vessels in a range of very severe damage stability conditions in waves and I would have thought this an important safety issue which should have been considered by this committee.

References in the report

Finally, I would like to note that there are a number of errors in the references in the report. As this is an important aspect of the committee report I believe it would strengthen this if an errata could be issued.

By Bruno Della Loggia, CETENA

The Committee Chairman and members are to be congratulated for the fine and interesting work they have done. However, one topic we think could usefully be added to the recommendations to the Conference.

The topic is related to the need to encourage the ITTC member of organizations to collect experimental data through the use of monitoring systems for full scale operating vessels.

Only in this way, in my opinion, would be possible to create a database regarding both motion and acceleration amplitudes in different continuous as well as dynamic sea loads, including stresses and pressure values, given, for example, by slamming phenomena.

An appropriate exploitation of this database would offer the scientific community and ship designers a deep knowledge of HSMV behaviour in a seaway.

This approach would lead to more accurate structural load evaluation and, as a consequence, would increase safety levels by reducing the risk of structural failures. To this end we think it interesting to report that CETENA was charged by an Italian research group to develop and conduct a project regarding the monitoring of the behaviour in a seaway of one of the longest fast ferries built up to the present.

This monitoring and data analysis project lasted one whole year and ended last June.

A preliminary presentation of the monitoring/recording device and data collected has been given in [Grossi, 1999]

by Gerhard Strasser, S.V. in Wien

The tasks for the committee included the development of two procedures. You explained why the procedure about dynamic instability was not prepared. Can you explain why the procedure on full-scale tests was not dealt with?

by Jan o. de Kat, MARIN

I would like to thank the committee for the most interesting report. Although it is a seemingly comforting thought that there are only a few cases of reported incidents related to dynamic stability, there have certainly been more than a few incidents associated with broaching (loss of directional stability in following seas) and nose diving(bow plunging resulting in sudden deceleration).

While such extreme (and dangerous) motion events could be considered as potential operational problems, it may become a real design issue in the near future. As pointed out in the committee's report, the HSC code is under revision at IMO. One of the newly proposed sections states that safety against dynamic instability (e.g. nose diving) has to be demonstrated; they could use full scale testing, numerical simulation or tank testing. Once accepted at IMO, this would result in a demand for established model testing procedures which do not exist yet. It would seem logical that the ITTC establish relevant procedures. I would like to ask the committee's views on this issue.

II REPLIES

The Committee is grateful to all those who discussed their Report; their contributions have added significantly to its value.

Dr. Renilson makes some relevant and important points. He raises the question of wash and points out that a rationally-based set of wash criteria are needed. The Committee whole-heartedly agrees and believes that Dr. Renilson's additional reference provides a useful starting point. It must be emphasised however that the problem is complex; the formation of dangerously large waves depends on many factors such as:

- the seabed topography between the vessel and the position of interest,
- vessel speed and water depth,
- the behaviour of the vessel, especially if it is turning and therefore "focussing" waves on the inside of the turn.

Dr. Renilson raises the problems of extrapolating, to the far field, measurements inevitably made in the near field in the towing tank. We offer an additional reference [GADD, 1999] on this problem which describes a mathematical extrapolation method using tank test data. This gives plausible results once the initial near field tank measurements have been obtained.

Dr Renilson asks for information on 4DOF simulation models for high-speed craft. Our work was hampered by the lack of such information in the open literature. While

4DOF models for container ships have been published [EDA, 1980] few have been presented for what are conventionally thought of as high-speed craft. Those that have are often restricted to 3DOF [Kallstrom, 1996].

The phenomenon of bow diving is mentioned by both Dr Renilson and Dr de Kat. We agree that standard test techniques are urgently required and refer both discussers to the report to the 21st ITTC of the High Speed Marine Vehicles Committee for some further thoughts. The water-on-deck criterion queried by Dr Renilson came from that Committee report and was suggested by MARINTEK at Trondheim.

The question of damage stability is, of course, of vital importance for high-speed craft. We did not cover this aspect in our report because we were not entirely convinced that it lay within our remit, but rather within that of the Specialist Committee on Stability. Unfortunately at present the regulatory authorities seem uncertain as to how damage to high-speed craft should be defined, a problem already solved for conventional low speed ocean-going vessels. Until this is resolved, it is difficult to provide guidelines on model tests for its exploration. However, as a Committee, we feel that the dynamics of a fast craft immediately after the damage has occurred must addressed. This contrasts with the assumption for damage stability model tests required by regulatory authorities for ro-ro vessels and described in detail in the Report of the Specialist Committee on Stability. For such tests, it is assumed that the vessel has passed through the immediate post-damage phase and has settled to a steady down-weather drift. A fast vessel suffering damage at high speed may never reach the drifting phase before it capsizes or founders.

The Committee thanks Dr Renilson for pointing out errata in the references at the end of its report. We append a list of corrections at the end of this reply.

Dr Della Loggia raises the question of full scale monitoring. We agree with him as to its importance and thank him for adding to our reference list. We would suggest that there is an urgent need not only for motion and acceleration monitoring, but also for the monitoring of hull stresses while in service. In addition to monitoring the ship responses we could also monitor the behaviour of the crew and the passenger in order to derive more realistic seakeeping criteria. Some steps in this direction are being made by a number of organisations.

Dr Strasser notes that we have not fulfilled our requirement to provide a procedure for full scale testing of high-speed craft. While we apologise for what can be construed as an omission, we would mention in our defence that we found it quite impossible to carry out such a task. The design and operation of high speed passenger-carrying vessels is proceeding and developing at a rapid rate; a stable situation has not, in our opinion, been reached for the required model tests, quite apart from full scale testing. The actual full-scale trials, which are actually undertaken for such vessels, are far less comprehensive than those given in the various ITTC Codes and not all builders and owners carry out the same trials. Add to this the additional requirement of IMO that compliance with safety standards be demonstrated at full-scale, and a rapidly-changing picture emerges. Faced with this, the Committee decided to submit information on some full-scale trials for consideration and to indicate to members present IMO requirements which go beyond conventional full-scale trial codes. We do not feel that the time is right to develop procedures in such a changing climate.

This dilemma is highlighted in Dr de Kat's timely contribution to the discussion. He rightly points out the fact that the IMO Code of Safety for High Speed Craft is under revision and will require yet further demonstrations of compliance at model and full scale. Model test and full-scale procedures are needed in practice for an area – dynamic stability – which is still a topic of research. We agree with Dr de Kat that the ITTC is the organisation to establish such procedures and would urge member organisations to do so. But first the fundamental issues must be clearly understood. Such understanding requires proper and focussed research.

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ERRATA:

The following errata have been noted in the Committee's report:

Page 638, Section 3.7: Under "Design Guidelines", second paragraph, the authors should be "Katayama and Ikeda".

Page 639, Section 3.7: Under "Design Guidelines" after the second bullet list, the author should be Suhrbier.

Page 642, References: References to "The Environmental Impact of High Speed Ferries" and "The Impact of High Speed Ferries on the External Environment" are repeated.

Page 643. Insert the following reference:

Chislett, M.S. & Mlgaard, A., (1998), Waterjet Steering and Stopping Forces", Conference on Waterjet Propulsion – Latest Developments, Royal Institution of Naval Architects, Amsterdam.