The Safety of Small Boats (Including Fishing Boats) Against Capsize: A Review

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THE SAFETY OF SMALL BOATS (INCLUDING FISHING BOATS) AGAINST CAPSIZE: A REVIEW

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SUMMARY

There is a continuing desire from communities to ensure that small boats (and especially fishing boats) are safe to within acceptable limits, but there is not always consensus on the approaches taken to achieve this objective. The diversity of these boats makes it challenging to come up with a consistent evaluation method, and the shear numbers make it difficult to enforce the regulations that a law requires. This report attempts to review the different approaches that have been taken to ensure that small boats are stable. The author makes some recommendations regarding the research needed to improve the situation and defines a role for the Institute for Ocean Technology (IOT) in carrying out the necessary research.

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INTRODUCTION

Small boats are found in every region of the world where humans live close to water. These boats are used for fishing, hunting, transportation, working and recreation. For some types of boat, the shape and materials of construction have changed very little over the centuries. Many more types have taken traditional shapes and adapted them to new materials and technologies (in particular the internal combustion engine). Some have been specifically designed to take advantage of the latest building materials and technologies so that the resulting vessel has superior performance or exploits some constraints in the way the design is assessed.

Going to sea in small boats is risky. In exposed areas, the power of the wind and waves can overwhelm a small boat, no matter how good the design and how experienced the crew. But with good local knowledge and well-built craft that are correctly operated, small boats can be used with acceptable levels of risk.

There have been some notable disasters involving small boats and in particular two well-publicized instances involving sailboat races where boats were overwhelmed by extreme wind and waves. At one point during a storm in the Fastnet race (UK, 1979, BBC news) 150 boats were missing, and the final toll was fifteen lives lost and 136 people rescued from life rafts or damaged boats. In the Sydney-Hobart Race (Australia, 1998, Boat magazine) six lives were lost and 50 people rescued.

Long-distance ocean passage races are vulnerable to storms because of the large number of boats involved and the wide range of experience within the crews. The observation that modern boats (designed with wide beam, shallow draft and high aspect ratio keels) faired worse than the traditional designs (narrower hulls with a more integrated hull and keel) in each incident sparked much discussion on the suitability of the new designs, but it also raised important questions over what safety equipment should be carried on board. These incidents gained a lot of media attention because of the numbers of boats involved and the stress it put on marine search and rescue organizations.

The number of fatalities in the fishing industry far exceeds those incidents described above, with annual worldwide fatalities approximately 24,000 per year, and 24,000,000 non-fatal incidents (Gudmundsson, 2006). In Canada alone the number of fatalities has varied between 5 and 14 per year over the period from 1996 to 2005, giving an average risk of fatality of 32 per 100,000 fishers (BMT Fleet Ltd., 2006). However, these losses are within an industry perceived to be risky, and typically occur one incident at a time, so do not always get the same media attention.

There have been some notable losses of fishing boats off Newfoundland, with the Ryan's Commander (September 2004) receiving a lot of coverage in local and national media (CBC National News, February 13, 2005) and also being the subject of a Transportation Safety Board Enquiry (TSB 2006). The findings of the enquiry were that the vessel had a limited righting ability, relative to that required by the Transport Canada regulations, due to improper loading and inadequate permanent ballast. The West Coast of Canada has also had many losses of fishing boats due to poor stability. The one of the best-documented case in recent years was the 'Cap Rouge II', which sank in the mouth of the Fraser River in August 2002 (Allan and Neifer, 2004).

There is a continuing desire from communities to ensure that small boats (and especially fishing boats) are safe to within acceptable limits, but there is not always consensus on the approaches taken to achieve this objective. The diversity of these boats makes it challenging to come up with a consistent evaluation method, and the shear numbers make it difficult to enforce the regulations that a law requires. This report attempts to review the different approaches that have been taken to ensure that small boats are stable. The author makes some recommendations regarding the research needed to improve the situation and defines a role for the Institute for Ocean Technology (IOT) in carrying out the necessary research.

REGULATORY APPROACHES TO CAPSIZE SAFETY

International Maritime Organization (IMO)

The IMO is a United Nations specialized agency, which is responsible for the formulation of international treaties related to shipping, including safety (http://www.imo.org/). The safety of fishing vessels had been a matter of concern to IMO since the Organization came into existence in 1958, but the great differences in design and operation between fishing vessels and other types of ships had always proved a major obstacle to their inclusion in the Conventions on Safety of Life at Sea (SOLAS) and Load Lines. While other vessels load cargo in port, fishing vessels must sail empty and load their cargo at sea.

The Torremolinos Convention (IMO 1977 http://www.imo.org/Conventions/) contained safety requirements for the construction and equipment of new, decked, seagoing fishing vessels of 24 metres in length and over, including those vessels also processing their catch on board. Existing vessels were covered only in respect of radio requirements. Chapters in the convention covered stability, construction, watertight integrity and equipment; machinery, electrical installations and unattended machinery spaces; fire protection, detection, extinction, and fire fighting; protection of the crew; life saving appliances; emergency procedures, musters and drills; radiotelegraphy and radiotelephony; and onboard navigational equipment.

In the 1980s, it became clear that the 1977 Torremolinos Convention was unlikely to enter into force, largely for technical reasons, and IMO decided to prepare a replacement in the form of a Protocol (IMO 1993). The Torremolinos Protocol updates, amends and absorbs the parent Convention, taking into account technological evolution in the intervening years and the need to take a pragmatic approach to encourage ratification of the instrument.

The Torremolinos Protocol applies to vessels over 24 metres in length (80 ft), but certain Chapters are only applicable to vessels of 45 metres in length and over. The Protocol, however, allows for Administrations to determine which particular regulations of these Chapters should apply to vessels of between 24 metres and 45 metres in length.

To ensure uniform standards, the Protocol encourages National Administrations to establish uniform regional standards to apply to fishing vessels operating in the same region, taking into account mode of operation, sheltered nature and climatic conditions in that region. Regional agreements in operation include:

> Guidelines for the safety of fishing vessels of 24 m and over but less than 45 m in length operating in the **East and South-East Asia region**, adopted at a Conference in Tokyo in February 1997
>
> **European regional agreement** applicable from 1 January 1999. The European legislation introducing a harmonised safety regime for fishing vessels of 24 metres in length and over was adopted in December 1997 and is entirely based upon the 1993 Torremolinos Protocol.

These documents are comprehensive and cover all aspects relating to the safety of the fishing vessel and its crew. The stability criteria given in these documents are very prescriptive in terms of the minimum functional relationship between the righting moment arm (GZ) and the angle of heel. In cases where there is insufficient stability data, a formula is given for the minimum transverse metacentric height (GM) based on length, beam, depth and freeboard. The protocol also discusses the need to evaluate stability with applied wind forces, water on deck, flooding of the fish holds, ice accretion and changes in loading condition. An important part of the IMO standard is the need for an inclining test, in the light ship condition, as soon as possible after the vessel is built to check the location of the centre of gravity.

IMO has also developed, in collaboration with the Food and Agriculture Organization (FAO) and the International Labour Organization (ILO), a number of non-mandatory instruments. These include the FAO/ILO/IMO Voluntary Guidelines for the Design, Construction and Equipment of Small Fishing Vessels, (IMO 2005), which apply to vessels between 12 m and 24 m. The Voluntary Guidelines (a revised version of those approved in the 1970s) have been developed for use primarily by competent authorities, training institutions, fishing vessel owners, fishermen's representative organizations and non-governmental organizations having a recognized role in fishermen's safety and health and training.

International Organization for Standardization (ISO)

ISO Standard 12217 (1999) applies to boats between 6m and 24 m in length. Vessels in this category can be assessed experimentally using crew or ballast weights equivalent to the crew, or by calculation. Factors considered are the downflooding height and downflooding angle, resistance to waves and wind, buoyancy and stability in a swamped condition, and stability under power. Additional tests are applied to sailboats to represent the ability to recover from a knockdown. Vessels do not pass or fail within this system, but instead are assigned a design category based on limiting wind speed and significant wave height combinations, which depends on the results of the evaluation of the design. The categories are summarized below in Table 1. Boats are expected to fully operate in the design category and survive in more severe conditions.

Table 1: Summary of ISO 12217 Design Category Definitions

Design Category	**A**	**B**	**C**	**D**
Significant wave height, up to m	7.0	4.0	2.0	0.3
Typical Beaufort wind force	Up to 10	Up to 8	Up to 6	Up to 4
Calculation wind speed, m/s	28	21	17	13

The standard includes definitions of the degree of water tightness for openings in the hull or superstructure. These are given in Table 2.

Table 2: Summary of ISO 12217 Degree of Water Tightness

Degree	**Degree of tightness providing protection against**
1	Continuous immersion in water
2	Temporary immersion in water
3	Splashing water
4	Water drops falling at an angles of up to 15 degrees from the vertical

Small boats under 6m long are assessed in design category C or D by a series of physical tests to demonstrate the ability of the boat to survive. These include downflooding height tests with maximum load and offset load (where the weight is significantly off the centreline of the boat). In each case people (or ballast weights to simulate the crew) are positioned in the boat and physical measurements are made of the height of the freeboard above the waterline. An additional test includes simulating the manual start of an outboard motor. The process can be particularly effective for mass produced boats to the same design, since the assessment need only be done once.

Transport Canada (TC)

The Marine Safety Branch of Transport Canada is responsible for the Acts and Regulations applied to ships and boats in Canadian waters. Under the current regulations fishing vessels are assessed using TP-7301: Stability, Subdivision and Load Line Standards (Transport Canada 1975). The stability of fishing vessels is covered in Chapter STAB 4. These regulations apply to Large Fishing Vessels (with a length over 24.4 m or displacement over 150 gross tons). An inclining test must be carried out, and this information is developed to give information, in the form of a booklet on the stability of the vessel in specified loading conditions. This booklet must be carried on board the vessel. The requirements for STAB 4 match those of the Torremolinos Protocol. .

Small fishing vessels (over 15 gross tons but less than 150 gross tons and less than 24.4m long) are required to carry stability information only if they are fishing for herring or caplin and the ship was built after 1977, or underwent substantial modification after that date. If the vessel is engaged in these fisheries, then it must meet the requirements of STAB4. Vessels under 15 gross tons are not required to have any stability information.

There are other sections of TP-7301 that apply to small boats other than fishing boats. Many small boats will fit into one of two chapters, although they are not specifically included. STAB 5 applies to passenger vessels carrying more than 12 passengers, and STAB 6 applies to non-passenger vessels and vessels carrying less than 12 passengers. Both of these chapters offer prescriptive criteria for assessing the stability of the ship.

Transport Canada has recently proposed a revision to the fishing vessel regulations, which have been discussed with fishing boat owners and operators through its consultative process (Transport Canada, 2006), but these proposals have not been made into law. This proposal attempts to ensure a more unified approach to safety for fishing boats from 9 metres (30 ft) up to 24 metres (80 ft), and eliminate some of the obvious gaps in the current rules. In this proposal, extensive use is made of international rules and codes where they represent ‘best industry practice’. The proposal covers ‘open’, ‘partially closed’ and ‘fully closed’ construction techniques. For vessels over 15.2 m (50 ft), the rules are based on ship like parameters, similar to those within the IMO regulations. For vessels under this limit, the proposed rules are more appropriate to smaller craft, and are in line with the ISO requirements.

SOCIAL AND ECONOMIC FACTORS: THE BENEFITS AND THE COSTS BASED ON ANALYSIS OF THE NEWFOUNDLAND FLEET

Cod caught with long lines was the mainstay of the fishery in Newfoundland until the two-year moratorium imposed by the Department of Fisheries and Oceans in 1992. After that point the fishery became more diverse. Crab (caught in traps) and shrimp (caught in trawls) became much more significant to the economy. In order for a vessel to be competitive, it required multiple licences and multiple types of fishing gear for one boat. The use of licenses for multiple species makes the vessel a more viable business but requires the skipper and crew to learn new techniques and fish in different locations, some of which were much further offshore than those used in the past (Memorial University, 2006). As a result small boats were operating much further from their home port. All of these changes put more emphasis on the safe design and operation of the vessel.

The government department responsible for issuing fishing licences is the Department of Fisheries and Oceans. The relationship between a vessel size and the amount of fish harvested is complex, but the general assumption has been that larger vessels have higher capacity for catching and storing fish than smaller vessels, and since they are more expensive to operate, will need to catch more fish per trip. Other factors, such as the latent capacity of the fleet (the capacity that is unused in the current situation) and the use of competitive or individual quota stock management strategies also factor into this relationship. When competitive management methods are used, the large boats should have an advantage since there is no limit on the amount of fish caught within a fixed time frame. With individual quotas, size should be less of an advantage since there is a limited theoretical maximum catch available to each operator.

In Eastern Canada, a fishing licence is issued to a vessel less than 65 ft long, overall. As fishers have requested and been granted more capacity for their boats, the only option has been to build wider and deeper hulls, within the restricted overall length. Many of these shapes are now outside the range of previous experience and their handling characteristics in waves are not well understood. Also, these vessels have very high fuel consumption because the resistance of these shapes is relatively high. This length restriction is a continuing concern for safety regulators, since the boats are being built with very high decks and very wide beams.

The effect of regulations on the health and safety of fishers in Newfoundland was studied by *SafetyNet* (Memorial University, 2006). In this study the researchers noted that for fishers in Newfoundland, the three most important regulations perceived to be having the most affect on safety were length restrictions limiting boats to 65 ft, set season length, where gear must be set and retrieved within fixed dates, and regulations that require mandatory safety equipment and training. The *SafteyNet* study found that fishers often equate safety with high quality communication and navigation equipment, and acceptance of this technology may actually increase the level of risk, since it gives the perception that it will be easier to save the boat and crew in the event of an incident.

On the west coast, the vessel length restriction is different. Here a vessel cannot be replaced with a larger one, but there is no restriction based on a maximum overall length. This region has experienced 157 capsizes of fishing boats in the period from 1975 to 2005, with 77 fatalities between 1991 and 2005. The Worker’s Compensation Board of B. C. has implemented training programs in stability safety, through its *FishSafe* program (Howe and Johansen, 2006), for fishers on the west coast.

THE NEED FOR A MULTI-DIMENSIONAL SOLUTION
Education

Assessing the stability of a ship is one of the fundamental aspects of naval architecture. Hydrostatic stability and the factors affecting it are generally well understood within the naval architecture profession. Fishing is unusual compared to most aspects of ship operation because the cargo is loaded at sea. This puts extra burdens on the safety of the ship, since the designer and operator must ensure that the stability is sufficient to allow for exposure to wind and waves, and that the ship does not flood during loading. A further complication is that a very stable boat will typically have a shorter roll period than an unstable boat, which can make the boat very uncomfortable (and even dangerous) for the crew during fishing or onboard processing operations.

Calculating the hydrostatic stability of a ship needs very detailed information on the shape of the hull, and the weights and location of centres of gravity for all components of the ship structure, cargo, fuel, stores, etc. The righting moment for a given heel angle is a function that varies significantly with different loading conditions for the same ship and can be quite different for ships of different construction material and different hull shapes. Stability can be significantly reduced if there is a free surface within the internal fuel tanks, or when water is trapped on the deck. In some cases, fish can also behave like a liquid, with a similar effect on reducing stability. The calculation of stability is relatively straight forward for a case where the offsets of the hull are known, and when the ship has had an inclining test to establish the location of the centre of gravity for at least one loading condition. However, very many small fishing boats do not have all the data needed to make this calculation, and it can be costly to obtain once the vessel has been built.

The technical nature of calculating the stability of a ship can make it daunting subject to understand. As it stands, naval architects prepare the information in a stability book for the required loading conditions, which can be many different conditions. This information is reviewed by Transport Canada, and checked against the legal requirements for the vessel, based on its size and fishing operations. The shear volume and number of conditions can make it difficult for non-technical people to interpret the results. One of the comments made at the recent CMAC meetings was that the information on the stability of a particular fishing vessel must be made into a ‘living document’ so that the skipper can understand it and use it in the detailed planning of fishing operations. Despite these challenges, there are some examples of ways of trying to make this information understandable by the fishing vessel master (Johnson & Womak, 2001, Womak, 2002 Howe & Johansen, 2006,).

Educating naval architects to the actual practices during fishing operations is another area where work needs to be done. Most practicing naval architects have little experience with actual fishing operations and so are unfamiliar with what actually goes on aboard the boat at sea. In his presentation at the CMAC meetings in November 2006, Robert Allan suggested that there was a need for a document describing actual fishing boat practice for naval architects, so that all dangerous conditions experienced in normal operations can be understood and evaluated.

Technology

There are some technologies that can have a very big impact on the ability of a fishing vessel crew to survive an incident. Radio and navigation equipment let the crew communicate their position and the nature of the incident with other vessels in the area, and inform shore-based stations of their problems. The speed of response of the rescue team is a key factor in the crew of a damaged vessel surviving the incident.

Other technologies that must be carried on board are personal flotation devices, immersion suits, life rafts and electronic positioning emergency radio beacons (EPERB), which are activated manually or automatically in the event of an incident. Close to major centres of population, cell phones can also be a cheap and effective communication method, but have the disadvantage of being point-to-point communication devices, rather than providing a broadcast. These technologies can be expanded to include a man-overboard notification, using a tag worn by crewmembers when on deck. These technologies will likely continue to be improved, made more affordable and become more accepted by crewmembers.

There are examples of the boats themselves having technology added to try and improve their behaviour in a seaway. Paravanes are damping devices for roll, which consist of a weighted plate and a cable fixed to symmetrical booms on either side of the boat. When the boat rolls, one plate is dragged upwards on a tight cable while the paravane on the slack side sinks. As the boat rolls the other way, the process is reflected. An alternative to paravanes is the anti-rolling tank. Here a volume of water is carried in a tank, and the damping force results from the phasing of the ship's roll with the movement of water in the tank. A large bulbous bow can also damp out pitch motion, while providing some fuel savings and increased tank capacity. All of these devices can be shown to work in some circumstances, but there are concerns about the potential negative effects of these devices. In the case of paravanes, they can become dangerous if one cable breaks, allowing the vessel to roll heavily on one side. The anti-roll tanks can actually reduce stability at some wave encounter frequencies, and in these conditions the tank should be dumped. Bulbous bows can have a negative effect on trim, and as a result affect the stability.

At the CMAC meetings in November 2006, the *FishSafe* program described its evaluation of commercial ship hydrostatics software and the intention of modifying it so that the skipper can calculate the stability condition for his ship in real time. Technology can also be used to monitor the motions of a ship in waves. Ship Motion Control of Sweden (http://www.shipmotion.se/) offers a sensor and software package targeted for fishing vessels. Informal discussions at the recent CMAC meeting revealed a reluctance among the regulators to accept either of these types of technology because of liability issues around predictions that might indicate the vessel is safe, when in fact it was not, due to faulty sensors or data input. The use of software for education and planning, without any enforced legal requirement should be encouraged, since it can make the crew more aware of the condition of their boat.

The biggest gap in assessing the stability of small boats is the lack of documentation of the many of the boats. In cases where the boat has been designed by a naval architect, there are typically some hull lines and an inclining test can be carried out. When the boat has been built without a lines plan, obtaining the offsets can be costly, since the hull must be measured. The cost of obtaining the stability information can vary between $5,000 and $15,000, depending on how much information is available on the boat. A presentation at the recent CMAC meeting described the use of a laser scanner for measuring hull offsets. This device is potentially very accurate, but the cost of the laser unit is very high (several hundred thousand dollars), and unlikely to be amortized by only doing vessel measurements. The company that made the presentation (Summit Metrology Inc, www.summitmetrology.com) uses the same system for scanning any three-dimensional object. Alternative technologies to the laser should be investigated, since a cheap system to obtain hull measurements would be an extremely important tool to improve fishing vessel stability.

IOT organized a workshop on fishing technology R&D (Molyneux, 2002) where many of these technologies were discussed.

Regulation

Safety related regulations are usually enforced to protect workers on board a vessel, or to protect the environment from damage as a result of an accident. In an ideal world, an industry would be self-regulated, since it should be clear that the benefits of preventing an incident far exceed the costs of the safety precaution. Unfortunately, this ideal is not often reached, due to lack of foresight (or education) and a reluctance to spend money on items that do not contribute directly to making profit. As a result, governments attempt to enforce laws that will keep the associated risks to a level that 'society' considers reasonable. The challenge for governments is designing a law that is effective and clearly enforceable. This becomes challenging when there are complex technical interactions involved, as in the case of ship stability.

The typical format for ship safety regulations is a series of prescriptive rules, which result in a numerical measurement of some parameter considered to be important in preventing an accident. In the case of ship stability, these tend to be factors such as a minimum transverse metacentric height, minimum peak righting moment arms, or minimum freeboard. This approach has the advantage that once an acceptable procedure has been established, the vessel can be analyzed (using the plans or the actual vessel) and the resulting numerical value compared to the values used in the regulations. In the case of the IMO type analysis, this will be a pass or fail, and in the ISO type analysis, it will be the determination of the limiting Design Category. This approach works well if the parameter assessed is directly related to the safety condition being considered, and if all the boats that are being assessed have similar design characteristics so that any empiricism in the method is evenly applied to all ships.

In cases where the safety of the vessel depends on the complex interaction of several parameters, or a vessel is a long way from the conventional 'norm' the prescriptive method may be less successful and alternatives must be found. There are two alternatives to prescriptive rules, both of which have had some influence on the form of IMO regulations.

Guidelines for Formal Safety Assessment have been published (IMO, 2002). Formal safety assessment is a rational and systematic approach for assessing the risks relating to marine safety and for evaluating the costs and benefits of alternative solutions for reducing the risks. Another method that can be used is Goal Based Standards (Hoppe, 2005). Under this approach, the regulation is written around the objective to be achieved, and the proponent must demonstrate to the satisfaction of the regulator that their proposed design will meet this goal. The trend in regulation is away from prescriptive rules and towards rules that allow more freedom for designers, builders and operators to propose innovative solutions. The challenge for regulators is ensuring that the new approaches provide at least the same level of safety as the established prescriptive rules.

IOT has been involved in some preliminary attempts to evaluate Formal Safety Assessment applied to small boat stability problems (Hermanski & Daley, 2006). The formal safety assessment process is based on an understanding of first principles, combined with a large accident database that can be used to estimate probabilities of an event. The method should work best when 'experts' from different fields with experience of the problem discuss the issues in detail to identify potential hazards and the ways that they can be dealt with. As a result, it may be time consuming to apply this process to every vessel individually, but it may be applicable to types of vessel with similar design characteristics. IOT hosted a workshop, with participants from government and academia, on the application of formal safety assessment to small boat stability (Winsor, 2006).

CURRENT AREAS OF RESEARCH INTO SHIP STABILITY IN WAVES

International Towing Tank Conference

Research into ship capsizing, using model experiments and numerical simulation has been a topic carried out by marine research institutes around the world and has been reviewed by the ITTC Specialist Committees listed in Table 3 (ITTC, 1999, 2002, 2005). Proceedings for the conferences containing the committee reports are available off the ITTC website (ittc.sname.org/proceedings).

Table 3: ITTC Specialist Committees, 1996 to 2008

ITTC Specialist Committee Reports	**Date Formed**	**Date Reported**
Stability	1996	1999
Prediction of Extreme Motion & Capsizing	1999	2002
Stability in Waves (I)	2002	2005
Stability in Waves (II)	2005	(2008)

The terms of reference for the committees have become more specific as time has progressed. The initial committee had a very broad mandate, but the work of the committees became more specific as the committees reported back to the Conference. Since 1996, the Committees have developed procedures for model experiments on intact and damaged ships, carried out benchmark studies comparing numerical predictions against model experiment data and reviewed the state of the art in areas of research related to ship stability in extreme waves.

The Report of the Specialist Committee on Ship Stability in Waves (ITTC, 2005) included a discussion on basic frameworks for stability assessment. The committee considered three types of design assessment. The first method considered was ‘prescriptive’ assessments based on semi-empirical rules and regulations derived from statistical data and practical experience such as the IMO and ISO assessment methods. This is the format for most current regulations related to ship stability.

The committee (ITTC, 2005) considered an alternative assessment, which was ‘Risk Based’. This approach aims to define an assessment of risk (defined as probability of an event multiplied by the consequence of it happening) that is relatively even for all hazards that can occur to the ship. Thus a design must be equally tolerant to a frequent event of small consequence and a rare event with catastrophic consequences. The evaluation of the probabilities however, is often based on statistical data for casualties, evaluation of experts and historical practice rather than an understanding of first principles.

The third alternative considered by the committee (ITTC, 2005) was ‘Performance’ based assessment. In this approach simulations or model experiments can be used to evaluate the inherent characteristics of the vessel being assessed. The safety level of the ship should account for the specific operational conditions and can be evaluated by a series of specified numerical or experimental tests in given scenarios and environmental conditions. The committee considers that this method will be the future as far as intact stability assessment is concerned. The committee recognized that producing regulations with this approach needs the availability of numerical and experimental procedures for stability assessment that are validated and verified, and that the resulting designs must be at least as safe as designs produced to the existing standards. One of the key roles of this Committee is to recommend the best practice in the area of model experiments and simulations to regulatory organizations considering the application of performance based assessments.

A lot of research work related to ship stability in waves has been published in the nine proceedings of the STAB series of conferences, related to the Stability of Ships and Offshore Structures in Waves.

Research Within St. John's Related Small Boat Safety
Ship Stability and Capsize

Fishing vessel stability in waves was an important element within the research program when the Institute for Ocean Technology (formerly Institute for Marine Dynamics) opened in 1985 and continued to be so after the program was re-defined in the mid 1990's. The connection between researchers and users was initiated through workshops where the fishing community was invited to discuss their problems (Cumming, 1985, 1989, Molyneux, 2002, Winsor, 2006). Research related to small boat safety has continued up to the present day, but the emphasis has shifted from the ultimate stability of the vessel to the vessel as a workplace, and the hazards created by high levels of acceleration to people working on the ship.

One computer code developed was MOTSIM, a non-linear time domain seakeeping code that simulates motion in six degrees of freedom, with forward speed in any wave conditions (Pawlowski & Bass, 1991). The ship's geometry is defined in terms of a sequence of sections, each of which is described by a set of panels. At each time step, the code determines the intersection of these panels with the waterline and redefines the paneling describing the ship's wetted surface. The pressure forces associated with the incident waves are then numerically integrated over this surface, using second order Gaussian Quadrature. The waves are taken as second order Stokes waves. The normal velocity distribution associated with the velocity of the vessel and the incident wave particle velocity is averaged over each panel and then a least squares fitting of this distribution based on the wetted panels belonging to a particular section is made such that a unique decomposition of the modal velocities (surge, sway, heave and roll) is obtained that most closely satisfies the body boundary condition on the section. The use of the wetted surface to determine modal velocities serves as an approximation to a non-linear body boundary condition.

The code allows for more general decompositions of the velocity distribution to be made using a higher number of non-standard modes. From this decomposition, the scattering forces and moments are determined for each section based on pre-calculated memory functions. The memory functions for each section are derived from added mass and damping coefficients from zero speed linear theory over a truncated semi-infinite frequency range. Their use allows for arbitrary frequency content in the scattering forces and moments. The added mass and damping coefficients can be either 2 or 3 dimensional. Corrections are made for forward speed.

Viscous effects associated with roll damping and manoeuvring are determined using semi-empirical formulae or experimentally determined coefficients. The total forces are then used in the non-linear equations of motion to determine the motions of the vessel.

The code has been successfully validated for the case of a fishing vessel with water trapped on the deck (Bass & Cumming, 2000). Dr. Bass took part in the Prediction of Extreme Motions and Capsize Committee (ITTC, 2002) benchmarking exercise, using MOTSIM.

Since it opened in 1985, IOT has had an almost continuous interest in using model experiments to evaluate small boat safety or validate numerical models. Early work focused on the development of an understanding of the physics of capsizing using a unique combination of free running, partially captive and fully captive model experiments (Grochowalski, et al., 1986, Grochowalski, 1989, Grochowalski, 1990, Grochowalski & Archibald, 1994). These experiments were carried out in Sweden and in St. John's. Numerical predictions were developed and refined based on these experiments (Grochowalski & Hsiung, 1998, Qiu et al. 1999).

More recently, work at IOT has been carried out within the SafetyNet project (Memorial University, 2006) focussing on Motion Induced Interrupts (MIIs), (Bass et. al, 2004, Akinturk et al. 2005, Bass et al. 2005). Emphasis has shifted from ultimate stability of the boat to the links between vessel responses to waves (in particular accelerations) on the safety of crewmembers at different locations within the ship. The project activity has focused on the combination of numerical simulation, model experiments and full-scale measurements to refine numerical models to give accurate predictions of MIIs for fishing boats between 35 and 65 ft.

Escape, Evacuation and Rescue (EER)

A related area of research that has been a very successful contribution to IOT's program has been Escape, Evacuation and Rescue. This research has focused on the comparison of different evacuation systems from offshore oil and gas production systems, in a range of environments. It has included simulations, model experiments and full-scale trials. Results for different cases are presented in the literature (Simoes Re et al. 2003, Simoes Re & Veitch, 2004, Simoes Re et al. 2006). The rescue craft themselves are small boats, but they function as part of an integrated approach to escape and evacuation.

Discussion

Womak (2002) discusses the development of the parameters within the IMO Stability regulations. The data used for this analysis dates back to 1939, and included very little information on fishing boats. The IMO regulations have clearly stood the test of time, but the initial selection of the ranges of the variable was somewhat subjective. The original work recognized the difficulty in applying a single regulation to a class of vessels with a very wide range of dimensions and operating practice.

There is no doubt that ship capsizing in waves is an intellectually rewarding area to study, since the behaviour of a ship in large waves is very complex. A capsize can occur for many different reasons. The Stability Committee (ITTC, 1999) identified the following modes of capsize for an intact ship.

Static stability loss

Change in water plane and buoyancy distribution in waves

Dynamic stability loss

Dynamic rolling
Parametric excitation
Resonant excitation
Impact excitation
Bifurcation (two stable states, with different roll amplitudes)
Broaching (overtaking waves, single wave or large amplitude yaw angle)

Other factors

Water on deck
Wind induced heel
Cargo shift

Since it can be assumed that for a real sea state the waves are randomly distributed, and capsizes can occur in one or two wavelengths the difficulty of predicting ship capsize in realistic ocean environments becomes obvious. Time domain analysis is essential and the complexity of the computer codes means that they are relatively slow to run. A few minutes of motions can take several days to simulate. As a result, running simulations that can be used for statistical analysis in realistic sea states is not always practical, due to the amount of computing time required. The most practical assessment method is to compare the motions of a ship in regular waves over a range of ship speeds, wave heights and periods.

Similar problems are encountered in the experimental field, where model basins have finite dimensions and practical run times are only a few wave encounters. In these circumstances, developing statistically significant run lengths becomes costly.

All this analysis has given a detailed understanding of the physics behind potentially dangerous situations, but it has not had much impact on stability regulations, due to the limitations of the current analysis techniques. On a positive note, this research has been used to give guidance to vessel operators to identify loading conditions and sailing instructions (ship speeds and headings relative to the wave direction that are most likely to be dangerous). These are typically displayed as charts and polar plots that can be carried on the bridge of the ship.

As the trend in regulation moves to allow more creative solutions that provide a specified minimum safety standard, it is important that the analysis tools are capable of supporting this type of decision-making.

RECOMMENDED ROLES FOR INSTITUTE FOR OCEAN TECHNOLOGY

Based on the skills and experience available at IOT and an assessment of the required research for small boat capsize safety. Table 4 below gives a summary of potential research areas where IOT can lead, and the areas where IOT can provide important support to organizations more qualified than IOT to lead the work. The cases where IOT can lead are then reviewed in detail.

Table 4: Matrix of Research Requirements and IOT Capabilities

Area	IOT Lead	IOT Support
Education of fishers		IOT to work with other organizations to improve knowledge of stability within fishing communities.
Technology development		IOT to encourage and assist SMEs to develop relevant technology for equipment and training related to small boat safety.
Regulations	IOT to develop mathematical and experimental tools appropriate for development of performance based regulations	IOT to support Transport Canada in the development of suitable regulations for small boat safety.
	IOT to assess the capsize safety of small boat designs using mathematical and experimental tools.	IOT to support naval architects, boat builders and operators in assessing current and proposed designs.
	IOT to develop and maintain a database of safety related incidents for small boats that can be used in performance based design and regulation.	
	IOT to assess escape, evacuation and rescue procedures and equipment suitable for small boats.	

Development of Mathematical Models of Ship Stability and Capsizing

Numerical models will continue to be an important area of research within the field of ship capsizing in waves. The complex interactions between the vessel motion and the water (including water flow on and off the boat) are a long way from being solved on a routine basis and code development and refinement is likely to continue for some time.

An accurate model of the behaviour of a vessel in waves can have a variety of applications. It can be used in research to give an understanding of the physics of the situation, it can be run to assess the effects of parametric variations on the safety and comfort of a vessel and it can be used as a simulator for training purposes.

IOT experience is that the most productive approach for code development is to share it with other institutes, in particular universities, which can provide faculty and graduate students to work on the challenging areas of research.

In parallel with the development of computer codes is the validation of the results. It is essential to compare the results of the simulations with measurements of the physical situation. The complex nature of ship behaviour in waves is likely to require increasingly sophisticated model experiments to provide data for validation.

If performance based evaluation becomes more acceptable to regulatory agencies, then it is likely that numerical simulation and model testing will become the accepted methods of evaluation. The ITTC will probably continue to work in this area to recommend the best practice. Validation model experiments would be a valuable contribution to the work of the ITTC and other technical organizations in the field.

Alternative Approaches to Regulation: Performance Based Assessment

All of the tools necessary for a performance-based assessment of the stability of the Canadian fishing fleet are available in St. John’s. The fleet can be analyzed to find typical and extreme versions of different types of vessel. In particular, any type of vessel with an accident rate higher than the average should be investigated in detail. The designs can be analyzed for motions in waves using a computer code, and the limits of safe operation can be compared for different designs. The safety of the designs can also be compared against the IMO and ISO safety assessment methods for ultimate stability as well as MIIs affecting the vessel as a workplace. The effect of limiting vessel length to 65ft can be investigated on both factors.

This research can be expanded to include other environmental factors affecting stability such as wind heeling moment and icing. For non-fishing boats it can also include passenger movement, the ability of the crew to evacuate and their ability operate safety related equipment.

Databases of Incidents

A database of incidents involving fishing vessel losses, based on reports of the Transportation Safety Board would be an important resource, since it can be used to validate any of the assessment methods. In the end the objective is to understand what is causing accidents and what factors might be taken to reduce the risk. Ideally this database should be expanded to include data from other countries and near misses to give a full picture of the risks.

SafetyNet has prepared a database of on-board incidents related to workplace injuries. This too will be a valuable resource when comparing MIIs between different types of boat. The database should be maintained and expanded to provide data for validation of all regulatory assessment methods.

Technology Assessment

IOT has been carrying out research projects focusing on Escape, Evacuation and Rescue in a marine environment. Most of this research has been focused on offshore oil and gas developments, where a relatively small number of companies have large research budgets. The fishing industry is the complete opposite, with a very large number of small independent operators. The evaluation and certification of escape, evacuation and rescue equipment for fishing boats would be a logical extension of the work done so far.

Other areas that IOT could be involved in are the development and technical assessment of items such as roll damping devices (model or full scale), life saving equipment, stability assessment technology and training and measurement of hull shape for stability calculations. This would likely be in conjunction with SMEs with some connection to the fishing industry.

MOVING FORWARD

1. Agreement in principle from IOT management that the area of small boat safety, with a particular emphasis on the prevention of capsizes and survivability in the event of capsizes is a worthwhile research area.

2. Consultations with local individuals and organizations to develop detailed project proposals based on suggested research areas. Preliminary local contacts are listed in Appendix 1.

3. Refinement of regional project plans based on national interests and priorities. Preliminary national contacts are listed in Appendix 1.

4. Identify areas of international collaboration that will be beneficial to the area of small boat safety.

CONCLUSIONS

Based on a review of the literature related to ship safety, there appears to be a strong role that IOT can play in the development of effective safety standards for small vessels, and especially fishing vessels. The strengths of the researchers in St. John's make us uniquely placed within Canada to specialize in the development and validation of computer codes for predicting the behaviour of small vessels, up to and including capsize. These modeling methods can be used to develop modern, performance based regulations, that will allow designers and regulators to accept innovative solutions to safety related problems.

The second major area of research that can be carried out at IOT is the development and evaluation of appropriate escape, evacuation and rescue systems for small boats. IOT has a proven track record in this field for the offshore oil and gas production sector, and it would be a small step to apply this to small boats.

There appear to be some promising areas of research and development of safety related products focused on the small vessel sector. These can be related to safety equipment, navigation and communications equipment and simulators for training. IOT can work with SMEs to bring these products to market through the Ocean Technology Enterprise Centre.

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APPENDIX 1

POTENTIAL CONTACTS FOR CONSULTATION

St. John's Region

Terry Hounsell	TC/Marine Safety
Merv Wiseman	CCG/Search & Rescue Coordinator
Gary Savage	IRAP/ITA
Dag Friis	MUN/NAOE
Don Bass	MUN/NAOE (retired)
Wei Qiu	MUN/NAOE
Gareth Igloliorte	BMT Fleet Technology
Randy Billard	Virtual Marine Technology
Piotr Waclawek	Navsim Technology
Carl Harris	CMS/MI
Stephen Bornstein	Safetynet/MUN
Barb Neiss	Safetynet/MUN

Expand to include fisheries organizations (including DFO) after preliminary contacts with marine safety agencies, IRAP and academics.

National

Victor Santos Pedro	TC/Marine Safety
Andrew Kendrick	BMT Fleet Technology
Robert Allan	Robert Allan Ltd.
Marcel Ayeko	Transportation Safety Board
Guy Bussieres	Transportation Safety Board