4th International Ship Stability Workshop
St. John's, Newfoundland, Canada

October 28th and 29th, 1998

Summary of Discussion

Since its formation in 1995, the Ship Stability Workshop has presented a unique opportunity for experts in the field to gather together and present their latest research results. The Workshop provides an overview of the state of the art and the discussion developed from the presentations is an important part of the meeting. These notes are an attempt to summarize the discussion in each of the areas, but the very nature of the discussion leads in interesting directions, not necessarily tied in to the topic which initiated the thought. Therefore, there is some structure to these notes, but they certainly are not a verbatim record of the meetings, and they have been edited to make them more structured, since similar topics arose at different times during the meetings. The summaries are ordered in the same sequence as the presentation topics.

Numerical and Physical Modeling of Intact Stability

Discussion Leader, Prof. C. C. Hsiung, Dal-Tech University, Halifax, N. S.

The presentations made in this area highlighted several developments in the area of numerical modeling of intact and damaged stability. These are;

The development of hybrid models,
The use of numerical models,
The validation of numerical models,
The need for simple capsize criteria and
Data visualization.

The first area is the use of hybrid models, which are essentially linear, but with some non-linear capability. Professor Hamamoto presented a method for expanding strip theory type programs to include capsize due to loss of stability. Strip theory programs are well established for the prediction of seakeeping motions and loads, where the responses are essentially linearly dependent on wave height. The method works best for high frequency, low amplitude responses. The advantage of strip theory methods is the efficiency of computation. The method has been expanded into seemingly non-linear issues such as slamming and deck wetness. It has not been used for stability studies however.

Traditional strip theory programs do not consider the variation in ship stability with wave height, but use classical small angle stability in the linear regime. Professor Hamamoto's paper presented an alternative approach, which included change in GZ as a linear function roll angle. The revised equations of motion now result in unstable solutions, which allows for the prediction of capsize due to loss of stability. This method makes full advantages of the computational efficiency of strip theory, but enables it to be used for the study of ship capsizing.

Another attempt to deal with some of the problems of modeling ship motion behaviour in large waves was addressed by Dr. Umeda. In his paper, he points out that capsizing is a non-linear phenomenon. Traditional seakeeping programs deal with linear behaviour, as discussed by Prof. Hamamoto. Seakeeping predictions do not depend on initial conditions, because the motion is essentially stable. However, capsizing simulation does depend on the initial conditions, and starting a numerical experiment in the correct condition is critical. Different techniques for starting the simulation have been tired, such as the 'worst' condition of the ship relative to the wave, or by starting the simulation in a stable, periodic motion, and make a sudden change to the control system, such as the rudder. Dr. Umeda also discussed the use on non-linear system dynamics models and their use in conjunction with model experiments. Non-linear dynamics gives a much better assessment of the 'stability' of the situation than classical modeling approaches. In his paper he compares predictions made from numerical experiments with those made from non-linear analysis.

A very encouraging observation is that numerical models are being used for parametric studies. In this case, numerical experiments are carried out over a large parameter space and limiting conditions are established. The example given by Dr. McTaggart focused on ship stability, but other recent papers have also used this approach. It is encouraging to think that the output from relatively sophisticated numerical models is now at the point where it is accepted for the development of standards. The particular program used by Dr. McTaggart was FREDYN from MARIN. This approach has been used also in the area of damaged stability by Prof. Vassalos and others.

However, some of the computational methods can be very intensive. It is important to optimize the length of the numerical experiments, without compromising the accuracy. The approach taken by Dr. McTaggart was to fit probability distributions to observed data, and estimate extremes based on the fitted distributions, rather than on the measured results.

Validation of computer predictions against physical observations is an important part of their development. The experiments needed to validate computer codes require the measurement of different parameters from those which are used to predict overall system performance. The level of sophistication required in the measurement system is much higher, since the intention is to check hydrodynamic components, rather than the overall performance. Dr. de Kat presented a paper on some model experiments on a frigate hull, carried out in large waves. Extreme motions were observed in the form of surf riding, broaching and capsizing. The paper also compared the model experiments with numerical simulations.

Reduction of data into stability criteria continues to be an ongoing issue. The challenge is to take the complex problem of ship stability in waves, with all the associated aspects of non-linearity and random behaviour, and develop something which can be used as the basis for safety regulations or guidelines. Dr. Renilson presented a paper which outlines a single stability parameter, based on all wave slopes, speeds and wave headings. Whilst this method is attractive from a regulatory point of view, there was some concern that important information on the complex motions of ships would be lost.

An alternative approach to the presentation of motion data for ships is the use of video records for model experiments and animation for simulations. Several authors used video or animation during their presentation. Dr. de Kat, Dr. Umeda and Prof. Hamamoto showed videos of experiments on ship models. Whilst this can give a good overview of the results of a particular experiment, it can take many attempts to obtain a particular set of conditions that is required. Prof. Papanikolaou showed some animations of a damaged ferry capsizing. Animation certainly has some attractive potential for displaying the results of numerical simulations. However, whilst this method is very visual, it is difficult to use in the development of standards or regulations. The scientific approach to safety would be to analyze each ship in a representative range of wave conditions. A probabilistic approach to capsize would include the probability of capsize occurring on a given wave and the probability of that wave occurring.

Non-linear Dynamics and Ship Capsize

Discussion Leader; Prof. Don Bass, Memorial University of St. John's, NF.

The use of non-linear dynamics highlights the complexities involved in simulating a capsize. The advantage of this approach is that the numerical models are relatively simple and fully non-linear. The biggest disadvantage of this approach relates to the fact that the hydrodynamics are implicit rather than explicit. The strength of non-linear dynamics approach is in studying the 'big' picture of ship capsizing, in terms of wide ranges of ship and wave parameters. Work in this area continues to give new insights into the problems of ship capsizing.

Dr. Spyrou presented recent work on the dynamical systems approach to problems of ship stability in beam and following seas. He discussed the role of parametric excitation and roll damping at large roll amplitudes. The type of instability associated with parametric excitation epitomized by the Mathieu equation appeared to indicate capsize would take place in a number of cycles that was greater than the number observed by other researchers. Based on experiments, parametrically excited capsize took place in just 3 or 4 cycles of roll in following seas.

Dr. Spyrou pointed out that if it was necessary to take into account the non-linearities of the righting moment in evaluating large amplitude ship dynamics, it was equally important to model roll damping at large amplitudes given its significance in dynamic stability. He outlined a methodology for its evaluation. As was pointed out in discussions, large amplitude roll damping based on a simple (non-linear) roll equation is difficult to evaluate given other hydrodynamic factors associated with large heel angles, such as the effects of deck-edge immersion.

Bias is a significant factor in increasing the risk of capsize, as can be amply demonstrated using non-linear dynamics. It would seem however that it is not possible to demonstrate, at the present state of the art, that direction of bias is a significant factor in capsize vulnerability. Vessels biased to weather appear to have a greater risk of capsize.

In the wide ranging discussions following Spyrou's paper, auto-pilots were discussed . For example the question arose as to whether or not it was possible that a 'badly' designed auto-pilot could precipitate broaching (and possibly capsize). In severe stern seas, it was noted that the rudder and therefore the auto-pilot might be largely ineffective. Increasing the propeller race to increase the rudder effectiveness might have the adverse effect of instigating the dangerous regime of surf-riding. In severe seas, the rudder tended to shift from hard-over to port to hard-over to starboard. It was not clear whether a helmsman would do things much differently. A clearer understanding of the mechanism of broaching might make it feasible to design a 'more intelligent' auto-pilot, that was more able to avoid broaching situations.

Dr. Francescutto spoke on the identification of parameters in the non-linear equation of roll. Results based on a number of experiments with various vessels demonstrated the accuracy with which predictions agreed with tests in beam seas. Absolute roll versus relative roll equations were discussed. The roll damping derived from the relative roll equation differed from that derived in the absolute roll equation. Roll decay tests are to be carried out at some later date to determine which gave the better results.

Dr. Belenky presented work on a piece-wise linear approximation to non-linear roll dynamics. He demonstrated that the technique was able to produce results qualitatively very similar to those using the standard approach. He claimed the method was less tainted with numerical instabilities and uncertainties, since it provided an essentially analytical solution. However the main advantage of the method would appear to be its applicability to a probabilistic formulation of the notion of dynamic instability or capsize threshold.

Special Problems in Ship Stability

Discussion Leaders, Dr. Kevin McTaggart, DREA, Dartmouth, N.S. & Prof. C. C. Hsiung, Dal-Tech University, Halifax, N. S.

Papers in this session covered a wide range of topics. Most of them dealt with small vessels, including planing hulls. Small ships have special problems with regard to stability. For planing craft, stability comes from hydrodynamic forces, rather than hydrostatic ones. The hydrodynamics can induce some system instabilities, since the location of the centre of pressure can change. Porpoising (longitudinal instability) and chine walking (lateral instability) have both been frequently observed in planing hulls at some speed and loading conditions. Understanding these phenomena is critical to designing safe and effective ships. There were two papers on the stability of planing hulls. Full scale measurements on small ships are also challenging, and two papers presented were related to this topic. Finally, one paper was presented on the influence of dynamics on the stability of a flooded ship.

Professor Rutgersson's paper described a proposed series of full scale trials examining maneuvering properties of small naval craft in a seaway. The trials will assess the capability of ships to stay on course and avoid broaching in waves. The researchers propose that maneuvering performance in moderate seas will be a useful indicator of performance in more severe seas.

There was discussion on the feasibility of developing a broaching index. Among other factors, broaching is dependent among the amplitude of overshoot angles. There was considerable interest regarding the type instrumentation that will be used for the trials. An onboard GPS unit connected to a laptop computer will provide a record of ship course. Wave conditions will be measured using a wave buoy, which could be supplemented by relative motion measurements at the bow. Video observations from a helicopter could also be available. Ship motions would be measured in 6 degrees of freedom.

It was only planned to study one ship loading condition for the Finnish ship, but it was possible that several loading conditions could be studied for a Swedish vessel, 20 m LOA.

Professor Hamamoto gave a brief description of some model scale zig-zag maneuvering tests being planned in Japan.

Dr. Dand's presentation on damage stability experiments provided interesting physical insights and generated much discussion. Dr. Dand defined dynamic stability as the ability of a floating body to return to its original position after being disturbed. The behaviour of a damaged ship was shown to be sensitive to the shape of the damage opening and to heel bias. The validity of the IMO damage opening was challenged, since real damage is much more ragged. Also, whether the damage is trapezoidal or rectangular has an effect on the flooding process. Bias was found to have a large influence on experimental results. Values as small as 0.1 degrees were found to significantly increase the wave height survived by the model.

The occurrence of capsize can be quite dependent on the vessel drift motions after damage occurs. In the case of the European Gateway, it had a residual drift speed of 4-6 knots after separation from its colliding vessel. This effect could be particularly important for high speed craft. Considering that high speed ferries are becoming common, more attention should be given to damage stability after high speed collisions.

The session on Tuesday morning began with a short presentation from Dal-Tech on work they had done on the influence of water trapped on deck , and its influence on ship motions. The numerical model includes water shipping onto the deck and water draining off, over the bulwarks. Results of some simulations were presented.

Professor Ikeda presented a paper on experiments to determine hydrodynamic forces and moments (six components) on a planing hull. The model was towed at different yaw angles, heel angles and trim angles. These data will be used to develop an understanding of the forces acting on a planing hull during a turn.

Professor Kijima also presented the results of an experimental study on planing hulls. The objective of this paper was to determine ways of improving the transverse stability of planing hulls. Stability was improved by the use of spray strips. The strips had little effect on the resistance. The model heels, as forward speed increases, due to asymmetry in the pressure distribution, rather than a dynamic reduction in static stability.

Dr. Birmingham presented a paper on the challenging aspects of determining the stability of small boats, for which there was no technical information. The paper presented a method which in theory, would give the necessary information, by moving weights horizontally and vertically on the ship and comparing the roll periods for each condition. However, it was found that the accuracy required to measure roll period is beyond the practical limits of resolution in a working environment. Discussion stimulated by this paper focused on alternative methods, such as developing the hull lines from stereo photography. There was also some concern about the size of the weights that needed to be moved. The practical movement of weight means that the technique is only applicable to small boats, but this is the area where the most data is missing. Also, in practice it is difficult to induce pure roll, without inducing heave and trim.

Numerical and Physical Modeling of Damaged Stability

Discussion Leader, Prof. Sander Calisal, UBC, Vancouver, B. C.

The five papers presented in this session all dealt with different aspects of the problem of water accumulation on the deck of a flooded RO-RO Ferry. This topic has received a great deal of discussion since the sinking of the Estonia and the introduction of the Stockholm Convention. A major step forward has been to specifically include water on the deck of a damaged RO-RO ship when assessing its stability. However, there are competing models for the amount of water, and their merits are the subject of academic discussion.

Professor Vassalos presented a paper studying the effect of degrees of freedom on flooding the deck of a RO-RO ferry model. After the presentation there was discussion concerning the location of the damage and the resulting worst case scenario. All experiments had been carried out with midships damage and level trim. Forward damage and bow down trim was suggested as being a case for further study. There was also discussion over the type of wave used. All experiments were carried out with long-crested waves. For long crested waves, the motion of the model is in phase with the waves, whereas for short crested waves, the model moves less, and may be considered to be more static (and more likely to flood). Also wind will influence the results, assuming that the waves are wind generated and the directions coincide. This will result in an increase in the drift velocity and a subsequent reduction in encounter frequency. This was studied by the author and it was found to have little effect on the results.

Mr. Molyneux presented some work done for Transport Canada, reanalyzing model test data to compare it with the Static Equivalent Method, proposed by Dr. Vassalos. There was some discussion over the use of the term 'Static Equivalency' and it was noted that the Stockholm Agreement had taken a different approach. Based on experiment results, it was found to be difficult to determine a critical volume of water on the deck.

There was also discussion over the form of the equation for the SEM, where

$$h_{crit} = A * Hs^B$$

The author's original intention had been to expand this relationship to include the effect of freeing ports, but the IMD data was too scattered to develop a meaningful relationship. There was some discussion on the benefits of freeing ports (open and flapped) and no consensus was reached on the benefits of fitting them.

Mr. Koniecki presented some more work done for Transport Canada, also related to predicting the amount of water on the deck of a flooded RO-RO ship. The SEM takes no account of how water gets onto the RO-RO Deck. His paper attempted to develop a method for predicting the amount of water on deck, based on the height of the free surface above sea level and the relative motion of the ship. This can now be expanded to include freeing ports, irregular shaped openings etc. Discussion focused on the use of a weir model for flow onto the deck, ability of the model to drift and the availability of experiment data in the public domain.

Mr. Ishida presented a paper which looked at the influence of wave period, initial heel angle and the relationship between critical height of water on deck and critical wave height to cause a capsize. The findings of the research showed that it is possible for ships to survive the values of Hs in excess of those given by the SEM, provided that the modal period was increased to values associated with deep water rather than coastal spectra. The discussion prompted by this presentation focused on the influence of wave period and the assessment of the volume of water on deck.

Ms. Jost presented the results of a study to better define the critical height of water on the deck, as defined by the Stockholm Agreement. Model data for three different ferries were discussed, with different residual freeboards. Each design was built to different stability standards, due to the year of construction. Design modifications of bulkheads and side casings were studied for each ship. Most of the discussion focused on the experiment techniques used. Also, there was some discussion on the most cost effective ways to improve survivability of existing ships. Residual freeboard was found to be a very important factor influencing survivability, but subdivision below the main deck is prohibitively expensive after construction. The alternatives are side casings and bulkheads on the main deck.

Application to Ship Design and Operation

Discussion Leader, Mr. David Murdey, Institute for Marine Dynamics, St. John's, NF.

This session covered some specialized areas of ship design in relation to stability. It was more general in nature than the previous sessions. Three papers were presented, by Professor Calisal, on a viscous flow model for water discharge, Professor Papanikolaou on design for survivability of warships and merchant ships and Professor Vassalos on the concept of a secure RO-RO ship. Mr. Alan also presented a wrap up of the Workshop, from the perspective of a regulator. His notes have been included.

Professor Calisal attempted to take our understanding of water discharge through freeing ports to the next level. Models given in other presentations at the workshop simplified the problem of water discharge to a weir flow model, which did not include a rigorous treatment of viscous flow. Professor Calisal presented a two dimensional viscous flow model which simulated the water profile as a function of space and time. The results from the simulation were compared with data measured during experiments. The discussion questioned the importance of surface tension in the model. The model experiments were conducted with a sprung freeing port, which was 12 inches long by 4 inches high. This was typical of ports used on fishing vessels. However, the nature of the trap door was criticized, since it did not bear much relationship to flapped freeing ports.

Professor Papanikolaou discussed various design aspects of survivability for surface warships and merchant ships, using a common probabilistic approach. Warships have unique problems associated with survivability, due in part to the lack of regulations. Generally there is a lack of data for naval vessels. Existing survivability prediction programs require considerable detail and so the design has to be well developed before they are appropriate. Also there is a lack of statistics for probability based methods. Also included in the presentation was an animation of a passenger vessel capsizing, which visualized the results of a numerical simulation.

Professor Vassalos presented a paper on the concept of a 'capsize proof' RO-RO ferry. The study included alternative methods of draining water off the deck, such as combinations of freeing ports, positive and negative sheer, and positive and negative camber. These systems have the advantage that they do not obstruct the car deck with side casings or bulkheads. There was some concern about the ability of this system to handle deck washing systems. There was also some discussion over the use of the term 'safe haven'. It is used within the Offshore Industry, as the safest place within an offshore structure. The term is not strictly applicable to a ship, since the ship can sink, but the concept of 'design-for-safety' was very much appreciated, and studies like this help to clarify the boundaries established by 'conventional' thinking.

Wrap-Up Session

Tom Allan made the final presentation. His notes are given below.

Speaking at the close of a workshop such as this is not easy, particularly after listening to words of some of the most accomplished academic naval architects in the world. I have to admit to, at times, being slightly lost when listening to some of the more theoretical postulations. It is because of this that I have a few simple requests and it goes beyond the question asked by Dr. Spyrou; "What is the motivation in what you are trying to do?" I would make the question a little simpler; "What is the end result of what you are trying to achieve - will it assist the design naval architect to improve or make safer the design of a particular type of ship or even ship design in general?"

Will your work provide additional information to assist the master - to help him to operate his ship in a safer manner? I would ask that each of you have these few basic principles in mind at all times as you carry out or develop research projects such as those you have discussed over the past two days.

So "Have we got it right?" is my main question - have we addressed everything that needs to be addressed? In this instance I am thinking particularly of the future designs of high density passenger ships. Currently we have designs for 3500-4000 persons - can we afford a disaster where in excess of 3000 persons may be lost? How do we evacuate this number of persons from the ship in the event of fire or, in your specific area of expertise, after a collision?

A few other questions I would ask you to ponder again under the theme " Have we got it right?"; collisions of high speed craft at speed; and to address a subject which has been debated extensively at this workshop - when carrying out damage model tests, are we using the correct or most appropriate damage opening.

It is my belief that the current opening used in the damage model tests for acceptance under the Stockholm Agreement is <u>not</u> the most appropriate. For these tests we use the SOLAS defined damage opening. For the deterministic method of calculation I would agree that this opening is appropriate in that it ensures an adequate spacing of transverse watertight bulkheads. However for physical model tests, as I said, it is not appropriate - it does not reflect the type of damage openings caused by collision and during the model tests themselves the SOLAS opening probably allows more water to exit the hull than would normally be expected.

What is the most appropriate shape of damage opening that we should be using for physical model tests? From a safety point of view it should be the most onerous shape of opening for the ship - but I have to ask you; "What should that shape be?"

On the same subject I have been fascinated by the amount and diversity of work you are all carrying out on the aspect of "water on the car deck" of ro-ro passenger ships. I don't think that Hartmut Hormann (Germany), Iwao Watanabe (Japan) nor I realized what we were releasing into the world of Naval Architecture after our initial meeting in Tokyo in January 1995 as part of re-assessment of ro-ro passenger ships with the IMO Panel of Experts. I just trust that we are not entering a phase of "academic nit picking" on the subject and that some useful criteria will eventually be developed.

There were two papers that I would ask each of you to consider seriously for a solution which would assist industry. First the paper by Richard Birmingham on "The Stability Assessment of Small Working Craft without Reference to Hydrostatic Data" which is looking for a simple formula to assess the stability of small workboats when no basic hydrostatic information is available. The second paper was that presented by Martin Renilson proposing a standard presentation method with a limiting KG envelope curve. Both of these papers, if solutions can be found, would be of great benefit to the industry.

In closing I would like, on behalf of myself and IMO, to thank each of you for the efforts made to improve the science of Naval Architecture and from that base the improved safety of ships of all types.