SOLAS 2009 – Raising the Alarm

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ABSTRACT

In anticipation of the new harmonised probabilistic rules for damage stability being adopted in January 2009, a number of ship owners are opting to follow these rules in advance, somewhat hesitantly and reluctantly considering the general lack of experience and understanding but also the confusion that prevails. In this climate, the authors have found a fertile ground for introducing a methodology to deal optimally with this problem, deriving from the arsenal of tools and knowledge available at SSRC and SaS. As a result, the authors are involved in some way or other with many ships currently being designed in accordance with the new probabilistic rules for ship subdivision. This involvement has revealed a somewhat more serious problem with probabilistic damaged ship stability calculations, which is hidden in the detail of the rules, but one that matters most. This paper highlights this problem and recommends a way forward.

KEYWORDS

SOLAS 2009, damage survivability, probabilistic rules-based design

INTRODUCTORY INFORMATION FOR AUTHORS

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Dracos Vassalos is Professor and Head of Department of Naval Architecture and Marine Engineering of the Universities of Glasgow and Strathclyde and the Director of SSRC, a world-leading centre of excellence on ship stability and safety. His life-long vocation has been to promote the use of scientific approaches in dealing with maritime safety and to create a critical mass in the research community by nurturing safety enhancement through innovation. He has lectured widely, published some 400 technical publications, won a string of prizes and awards, including some 100+ major research contracts totalling over £15M. Currently, Professor Vassalos is Chairman of the International Standing Committee of the "Design for Safety" Conference, a theme instigated and promulgated by SSRC and serves as member of the UK delegation to IMO for ship stability.

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Andrzej Jasionowski graduated from the Technical University of Gdansk (MEng, 1997), and the University of Strathclyde (PhD, 2002). His current role involves being the Technical Manager of SSRC and a Director of Safety at Sea Ltd., an engineering consulting company offering specialist services to the maritime industry on ship stability and safety and on the design of knowledge-intensive, safety-critical ships. His main interests comprise ship hydrodynamics, damaged ship dynamics, stability, modern risk assessment, inductive inference, modelling uncertainty, numerical algorithms development and the philosophy of safety. Andrzej Jasionowski is credited with a number of research awards and prizes and the publication of some 30 journals and conference papers.

INTRODUCTION

In January 2009, the new harmonised probabilistic rules for ship subdivision will become mandatory, initiating a new era in rule-making in the maritime industry in line with contemporary developments, understanding and expectations. This will be the culmination of more than 50 years of work, one of the longest gestation periods of any other safety regulation. Considering that this is indeed a step change in the way safety is being addressed and regulated, "taking our time" is well justified. However, the intention to provide a qualitative assessment of safety (a safety index) might have been enough at the time the probabilistic framework for damage stability was conceived (indeed for as recent as a few years ago) but this is not the case today. With the advent of Design for Safety and of Risk-Based Design, quantification of safety, consistently and accurately, is a prerequisite to treating safety as a design objective. This, in turn, entails that the level of detail in the method used to quantify safety carries a much bigger weight. With this in mind and in the knowledge that the Attained Index of Subdivision in the probabilistic rules is a weighted summation of survival factors, calculating survival factors consistently and accurately is paramount. Unfortunately, a close scrutiny of the work that led to the current formulation of the s-factor revealed that it is simply the result of a series of unjustified compromises, which inadvertently crept in during the rule-making process. In this formulation, due to be adopted in 17 months time, the s-factor derives from a regression analysis of only a filtered set of old cargo ships and as such it will be unsuitable even for this category of ships, considering the evolutionary changes in most cargo ship types. More importantly, recent research results indicate that, on the average, the formulation which is soon to be adopted seriously underestimates the inherent survivability of cruise ships whilst it drastically underestimates the survivability of Ro-Ro passenger ships. What is of crucial significance is that there is little consistency between the actual survivability of both these vessel types (the most safety-critical of ships) and that postulated by the currently proposed formulation. The problem does not end here: since this formulation was used to calculate the Index-A for a representative sample of various vessel types so as to evaluate the Required Index of Subdivision R (in principle, the safety level to be adopted), these results will also be in disarray. In short the proposed amendments SOLAS 2009 are in need of major re-evaluation!

This paper attempts to present these issues and in so doing to raise the alarm, hoping that in the time remaining no effort will be spared in ensuring that the best ever regulatory achievement in our industry will not fail to achieve it's aims before it gets started.

THE PROBABILISTIC CONCEPT OF SHIP SUBDIVISION

The first probabilistic rules for provision of stability after damage on passenger vessels, deriving from the work of Kurt Wendel on "Subdivision of Ships", [Wendel] were introduced in the late sixties as an alternative to the deterministic requirements of SOLAS '60. Subsequently and at about the same time as the 1974 SOLAS Convention was held, the International Maritime Organisation (IMO), published Assembly Resolution A.265 (VIII). The next major step in the development of damaged ship stability standards came in 1992 with the introduction of SOLAS part B-1 (Chapter II-1), containing a probabilistic standard for cargo vessels, using the same principles embodied in the 1974 regulations. This, in turn, necessitated launching at IMO the regulatory development of "Harmonisation of Damage Stability Provisions in SOLAS, based on the Probabilistic Concept of Survival" in the belief that this represented a more rational approach to addressing stability after damage.

In this state of affairs, the compelling need to understand the impact of the introduction of probabilistic damaged ship stability regulations in the design of cargo and passenger ships and the growing appreciation of deeply embedded problems in both the rules and the harmonisation process itself, provided the motivation for the adoption of an in-depth evaluation and re-engineering of the whole probabilistic framework through the EC-funded €4.5M, 3-year project HARDER [HARDER 2003]. The overriding goal of this project was to develop a rational procedure for probabilistic damaged ship stability assessment, <u>addressing from first principles all relevant aspects and underlying physical phenomena for all types of ships and damage scenarios.</u> In this respect, HARDER became an IMO vehicle carrying the major load of the rule-development process and fostering international collaboration at its best – a major factor contributing to the eventual success in achieving harmonisation and in proposing a workable framework for damaged ship stability calculations at the IMO SLF 47.

A stage has now been reached where the draft text of the major revision to the subdivision and damaged ship stability sections of SOLAS Chapter II-1 based on a probabilistic approach has been completed, following final amendments in January 2005 to Regulation 7-1 involving calculation of the "p" factor. The revised regulations were adopted in May 2005 by the IMO Maritime Safety Committee (MSC) and will be entering into force for new vessels with keels laid on or after 1 January 2009.

One of the fundamental assumptions of the probabilistic concept of the ship subdivision in the proposed regulations is that the ship under consideration is damaged, that is the hull is assumed breached and there is (large scale) flooding. This implies that the cause of the breach, the collision event with all the circumstances leading to its occurrence, are disregarded, and hence the interest focuses on the *conditional* probability of the loss of stability.

In other words, risk to life is assumed to be irrelevant on the likelihood of occurrence of a collision event that ends in hull breaching and flooding. For this reason, the regulations imply the same level of "safety" irrespective of the mode of operation that can e.g. take place in area of varying density of shipping (congestion of traffic), or indeed can be so different depending on ship type, or can involve vastly different consequences, etc, all of which might imply considerably different levels of <u>actual</u> risk. This said, all risk-related factors (e.g. size of ship, number of persons on board, life saving appliances arrangement, and so on) are meant to indirectly be accounted for by the Required Index of Subdivision, R. Summarizing, the probability of ship surviving collision damage is given by the Attained Index of Subdivision, A, and is required not to be lesser than the Required Index of Subdivision, R, as given by expression (1):

$$A = \sum_{j=1}^{J}\sum_{i=1}^{I} w_j \cdot p_i s_{ji} \quad ; \quad \mathrm{A} > \mathrm{R} \qquad (1)$$

Where:

- A/R Attained/Required Index of Subdivision
- j loading condition (draught) under consideration
- J number of loading conditions considered in the calculation of A (normally 3 draughts)
- i represents each compartment or group of compartments under consideration
- I set of all feasible flooding scenarios comprising single compartments or groups of adjacent compartments
- w_j probability mass function of the loading conditions (draught)
- p_i probability mass function of the extent of flooding (that the compartments under consideration are flooded)
- s_{ij} probability of surviving the flooding of the group of compartment(s) "i", given loading (draft) conditions j occurred

The index A can thus be considered as the expected value of the "s-factor", with "p- and w-factors" being the respective likelihoods, reflected in worldwide ship collision statistics:

$$A = E(s) \tag{2}$$

Consequently, (1-A) can be considered as the marginal probability of (sinking/capsize) in these scenarios, and as such it can be used for deriving the collision-related risk contribution, [Vassalos 2004].

The Required Index of Subdivision, R (derived principally from a regression on A-values of representative samples of existing ships) represents the "level of safety" associated with collision and flooding events that is deemed to be acceptable by society, in the sense that it is derived using ships that society considers fit for purpose, since they are in daily operation.

The new regulations represent a step change away from the current deterministic methods of assessing subdivision and damaged ship stability. Old concepts such as floodable length, criterion numeral, margin line, 1 and 2 compartment standards and the B/5 line will be disappearing.

With this in mind, there appears to be a gap in that, whilst development of the probabilistic regulations included extensive calculations on existing ships which had been designed to meet the current SOLAS regulations, little or no effort has been expended into designing new ships from scratch using the proposed regulations. However, attempting to fill this gap through research and though participation in a number of new building projects has revealed a more serious problem that affects the consistency and validity of the derived results and hence of the whole concept. These findings constitute the kernel of this paper and are described next, following a brief reminder on the derivation in project HARDER and the eventual adoption at IMO of the survival factor "s".

PROBABILITY OF SURVIVAL – "s-factor"

It has to be pointed out that despite the wide-raging investigation undertaken in HARDER, the survival factor "s" adopted in the new harmonised probabilistic rules designates simply the probability of a damaged vessel surviving the dynamic effects of waves once the vessel has reached final equilibrium, post-damage. All other pertinent factors and modes/stages of flooding are not accounted for. Moreover, whilst considering 7 ship models in the test programme [HARDER 2001], representing a range of different types, sizes and forms, namely: 3 Passenger ships (2 Ro-Ro's and one cruise liner) and 3 dry cargo ships (a Ro-Ro Cargo Ship, a Containership, and a Bulk Carrier - a Panamax Bulk Carrier was added later), the formulation for the s-factor focused on Ro-Ros and non-Ro-Ros. This categorisation derives primarily from the capsize mechanisms pertinent to these two categories.

Therefore, and without labouring the detail of the formulation (for which SSRC was responsible), the following two approaches were followed:

s-Factor for Low Freeboard Ro-Ro Ships

It was always the intention to base the survival factor for Ro-Ro ships on the SEM methodology, [Vassalos 1996]. In brief, the method statically develops the volume of water that will reduce the damage GZ curve to exactly zero and at the ensuing critical heel angle, θ, two parameters: h – the dynamic water head and f – the freeboard are calculated as shown in Figure 1.

The statistical relationship between parameters (h) and (f) and the significant wave height of the critical survivable sea state (H_S) is then established.

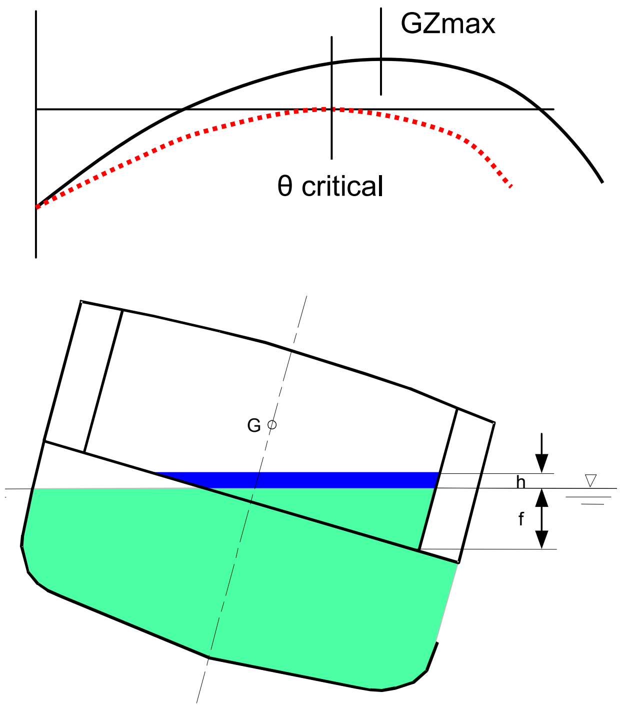

Figure 1: The SEM Methodology

Accounting finally for the likelihood of occurrence of this sea state at the time of casualty led to the following relationship (Figure 2):

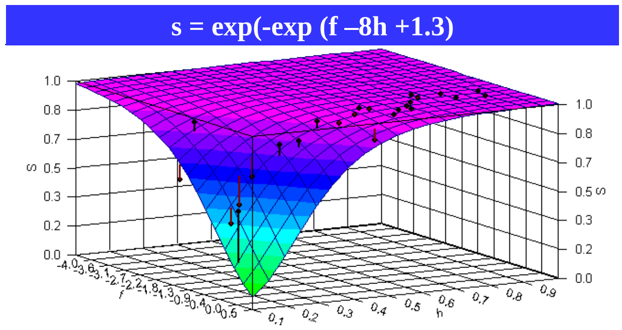

Figure 2: SEM-Based s-Factor for Ro-Ro Ships (25 Cases – 4 Ship Models)

s-Factor for non-Ro-Ro Ships

Having applied the SEM methodology to non-Ro-Ro ships and achieved what was considered unsatisfactory results, the focus shifted towards the more traditional damage stability criteria employing the use of properties of the GZ curve, such as GZ max, GZ Range, and GZ Area. In simple terms, the correlation of these three traditional parameters with the observed survival sea states from the non-Ro-Ro model tests was first established, shown here in Figures 3 to 5.

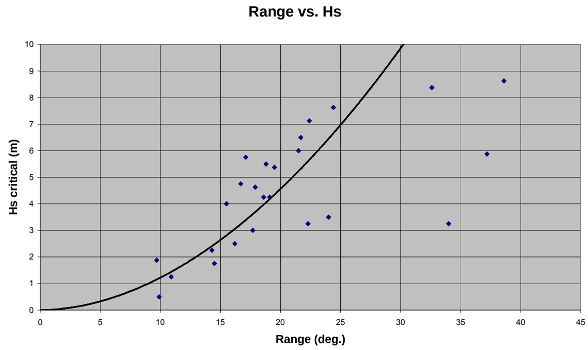

Figure 3: Regression of GZ range

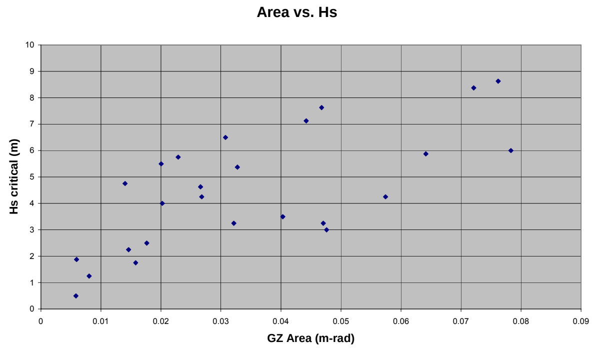

Figure 4: Regression of GZ area

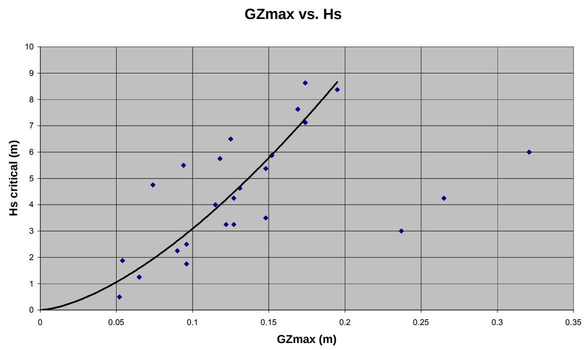

Figure 5: Regression of GZ max

A review of these results led to discarding the GZ area parameter due to apparent lack of correlation, with most points not falling naturally on the observed trends. Adopting finally an existing SLF format and with Hs limited to 4m, similar to Ro-Ro vessels, yielded the following final formulation (Figure 6):

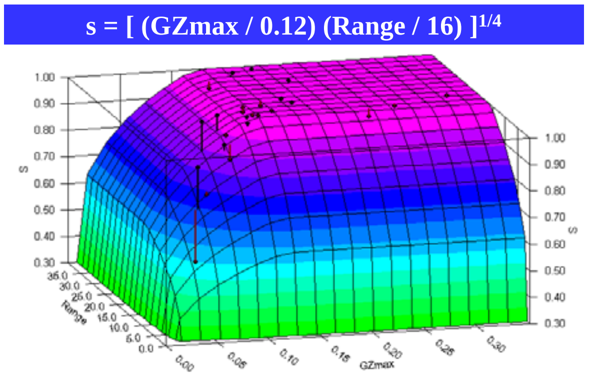

Figure 6: GZ-Based "s"-Factor for Conventional Ships (25 Cases – 3 Ship Models)

It may be noticed that 25 damage cases were used in the formulations described in the Figure 5 and another 25 damage cases in Figure 6. Thus, the whole data set used in project HARDER, and shown here in Figure 7, comprises 51 data points (the one point not accounted for relates to the cruise ship).

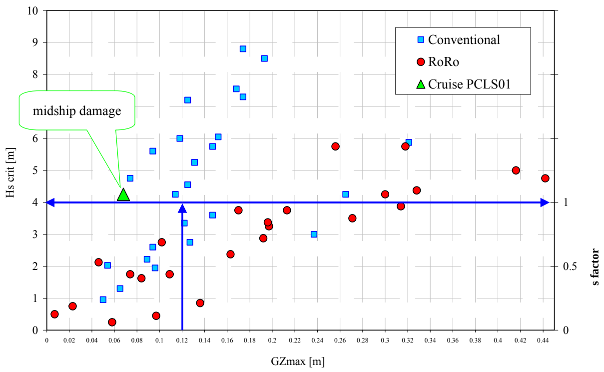

Figure 7: Data set of 51 measured points of survivability in the HARDER project

Based on the aforementioned developments the following points are noteworthy:

- The formulation for the survival factor in the new harmonised probabilistic regulations for damaged ship stability, due to be adopted in January 2009, is based solely on conventional cargo ships, Figure 6.
- The SEM methodology was never adopted; hence there is no formulation for the survival factor in SOLAS 2009 that could be applied to anything other than non-Ro-Ro ships.
- Examining also Figure 7, leads to some additional and even more disturbing observations:

  →The single result on the cruise ship, which was never used, shows that even with marginal static stability characteristics the vessel survives in sea states with Hs in excess of 4m. Several tests since then clearly demonstrate that the current formulation underestimates the survivability for cruise ships; as a general trend the bigger the vessel the larger the error!

  → On the other end of the spectrum, the formulation due to be adopted overestimates the survivability of Ro-Ro ships. In other words, survivability of Ro-Ro ships is lower than what the formulation implies.

Having made these sobering observations, there is yet another issue to consider: the development of the Required Index, R, for passenger ships. The original results, shown in Figure 8, represent the A-values calculated on the basis of the new formulation for a representative sample of ships.

Considering the arguments made above, it may justifiably be proposed that the observed trends simply reflect the oversight of the fact that the s-factors considered in the new harmonised rules had nothing to do with passenger ships.

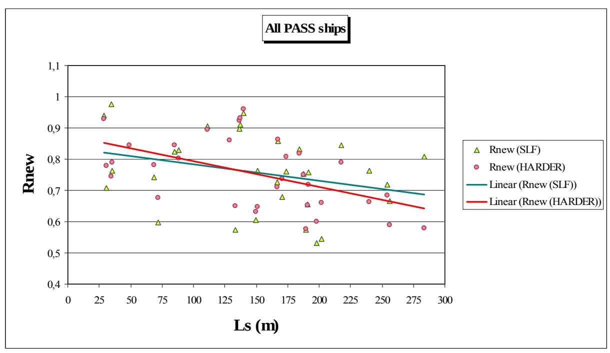

Figure 8: R_{new} for all passenger ships

Not realising this fact, rather than questioning the method of calculation, it was attempted instead to make sense of the results at hand, using an approach questionable at best, which was surprisingly adopted by Member States at IMO; the tidal wave of the new probabilistic rules managed to push an excellent framework through the door but it seems that a series of questionable assumptions went though with it.

EMERGING EVIDENCE FOR RAISING THE ALARM ON SOLAS 2009

SAFENVSHIP Project

In the proposed formulation for the s-factor, described above, the still water GZ curve characteristics are calculated by assuming that the lowest-most spaces, within the damaged zone, flood instantly and that static balance between vessel mass, displaced water and floodwater describe fully the vessel stability.

To gain better understanding of the meaning of the above approximation and, in general, of the stability of modern passenger ships, a study was undertaken, [Jasionowski 2005], including probabilistic damaged ship stability calculations, numerical time-domain simulations and scaled-model tank testing of three cruise ship designs, considered representative of modern passenger ships. Figure 9 shows a sample result of the study. Altogether 33 different damage cases of the three vessels were investigated, chosen to provide a range of *s*-factors and distribution of damages along the whole length of the vessel; damage openings were chosen with a level of "high severity" in mind. Deriving from this study the following points are noteworthy:

- Of the 33 cases considered, 16 were found to lead to the vessel capsizing within two hours, sometimes rapidly. Of the 16 "capsizing" cases, 10 had an s-factor between 0 and 1, with some having s=1.0. Of the remaining 17 "surviving" cases, 7 had an s-factor equal to zero!
- The study demonstrates that traditional GZ-curve characteristics cannot adequately describe the behaviour (and hence the destiny) of a damaged ship with the complexity in watertight subdivision of internal spaces found on a typical cruise vessel, and consequently, that the formulation for the s-factor in its present form cannot meaningfully represent the <u>average</u> resistance of such ships to capsize when subjected to flooding, following collision damage. Another reason for this deficiency derives from explicitly neglecting the presence of multiple free surfaces (MFS effect), a phenomenon specific to ships with complex watertight subdivision, which substantially weakens or indeed leads to complete erosion of stability <u>at any</u> of the stages of flooding (this is a finding post-HARDER).

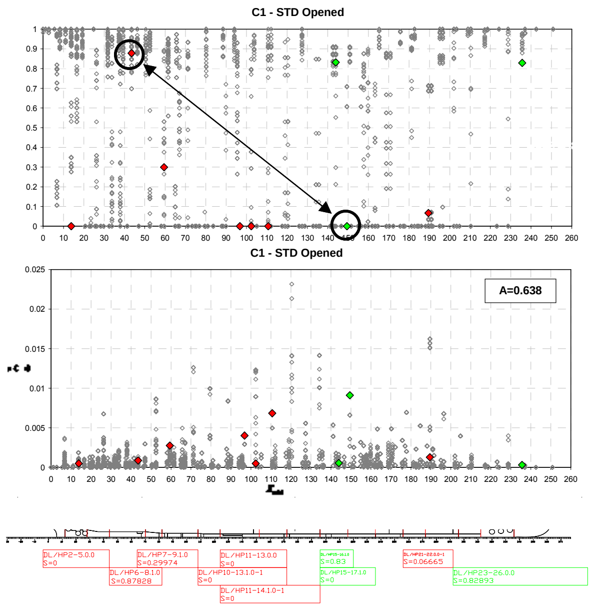

Figure 9: A map of "s" factors (upper plot) and the expression $p\cdot(1-s)$, for all damage cases considered as a function of the damage locations. The red boxes in the lowest-most plot indicate cases where the ship capsized within 2 hours simulation time, whereas green boxes indicate survival cases

Newbuilding Design Experience

With the introduction of the new probabilistic rules, the dilemma of prescriptive SOLAS-minded designers must be overcome. Using an approach, known as **platform optimisation**, SSRC/SaS developed a fully automated optimisation process leading to ship designs with an acceptable level of flooding-related "risk" (i.e., compliance with statutory requirements) that can be optimised along with cost-effectiveness, functionality and performance objectives. Alternatively, high survivability internal ship layouts can be developed, without deviating much from the current SOLAS practice, thus making it easier for ship designers to relate to the proposed procedure.

This procedure has been extended to address in full the damage survivability of a new building cruise and a RoPax vessels from first principles in a systematic and all embracing way, as explained in [Vassalos 2007].

Moreover, a direct link between Index-A and flooding-related risk contribution has been established, thus facilitating a better understanding of the meaning of all the factors involved and of their significance in affecting safety. This has also led to new evidence concerning the inconsistency and inaccuracy in the details of the new probabilistic rules, as summarised in Figure 10.

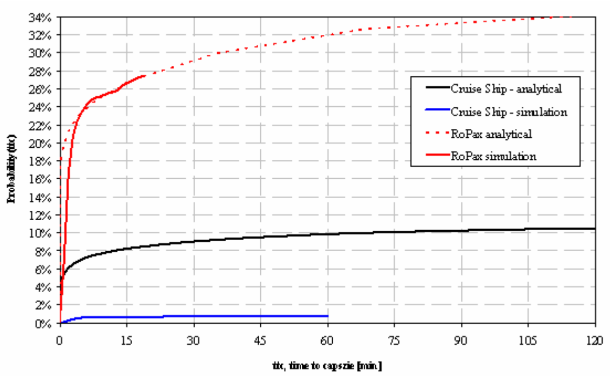

Figure 10: Cumulative probability distributions for time to capsize for a traditional Ro-Ro vessel and a large new building cruise ship. Deepest draft loading conditions.

The cumulative probability distributions for time to capsize, for the ships shown in Figure 10, are derived using two approaches: (a) an analytical expression based on the formulation of the new probabilistic rules, [Jasionowski 2006], and (b) a Monte Carlo time-domain simulation using 500 damage cases that represent the statistics of damage characteristics used in these rules. Both ships comply with the new rules. Moreover, as explained in [Vassalos 2007], the values of these distributions tend to 1-A within reasonable time period of several hours. Therefore, based on these results which seem to be typical for these groups of vessels, the following observations can be made:

- For the Ro-Ro vessel, [Jasionowski 2007], approximately one in three collision and flooding events would lead to capsize within an hour as inferred from either, analytical solution or numerical simulation (this is not a good standard!)
- Application of the new rules indicates that the cruise ship will follow a similar fate in approximately one every 10 events whilst using first-principles time-domain simulation tools the rate becomes approximately 1:100. This is a big difference!

This and other similar results have alerted the industry to the extent that a new investigation is being launched in an attempt to sort out the details in the new rules before they are adopted in January 2009, in the belief that the probabilistic rules constitute one of the most significant developments in the rule-making history of the maritime profession.

CONCLUSIONS

Based on the results and arguments presented in this paper the following conclusions can be drawn:

- The index A of new probabilistic rules on ship subdivision can be interpreted as a value that reflects the average survivability of a vessel following collision damage and flooding in a seaway. As such, an accurate calculation of the survival probability in these rules is of paramount importance.
- This being the case, there is new evidence emerging that indicates gross errors in the derivation of survival factors, demanding swift action by the profession to avert "embarrassment" on global scale.
- Such action is already being planned but it needs a wider participation to ensure that

results will be available on time to re-engineer a correct formulation before the new rules are enforced.

- More importantly, in the knowledge that the probabilistic rules are inconsistent and inaccurate, due care is needed in designing new (passenger) ships; in particular, the use of time-domain simulation tools or physical model tests must be fully exploited.

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