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Title:
Abstract *The present report (D1.2) outlines the work progress of the FP7 project GOALDS (Goal Based Damage Stability) from its starting date (1/9/2009) to and beyond its official end (31/10/2012).* *Chapter 1 gives a short overview of the project. Chapter 2 discusses the development of a new formulation for the calculation of the probability of survival in damaged condition. Chapter 3 describes the setup and the results of the tank testing that have been undertaken during the elaboration of the project. Chapter 0 presents the development of standard risk models for collision and grounding events of passenger ships, the definition and evaluation of Risk Control Options for a series of ROPAX and cruise ships and the derivation of the new damage stability requirement. Chapter 5 discusses the optimization and re-design of 4 ROPAX ships and 2 cruise ships based on the new damaged stability formulation. Chapter 6 provides a summary of the critical assessment of the obtained results and of the submission of a proposal to the IMO. Chapter 7 discusses the potential impact and wider societal implications of the project. Finally, in Chapter 8 and Chapter 9 the Dissemination Activities and Exploitation of Results are discussed respectively.*
Summary Report: **Introduction** The new probabilistic damage stability regulations for dry cargo and passenger ships (SOLAS 2009), which entered into force on January 1, 2009, represent a major step forward in achieving an improved safety standard through the rationalization and harmonization of damage stability requirements. There are, however, serious concerns regarding the adopted formulation for the calculation of the survival probability of ROPAX and mega cruise vessels; thus ultimately of the Attained and Required Subdivision Indices for passenger ships. Furthermore, present damage stability regulations account only for collision damages, despite the fact that accidents statistics, particularly of passenger ships, indicate the profound importance of grounding accidents. The proposed research project addressed the above issues by: Improving and extending the formulation introduced by MSC 216 (82) for the assessment of the probability of survival of ROPAX and mega cruise ships in damaged condition, based on extensive use of numerical simulations. Performing comprehensive model testing to investigate the process of ship stability deterioration in damaged condition and to provide the required basis for the validation of the numerical simulation results. Elaborating damage statistics and probability functions for the damage location, length, breadth and penetration in case of a collision / grounding accident, based on a thorough review of available information regarding these accidents over the past 30-60 years worldwide. Formulating a new probabilistic damage stability concept for ROPAX and cruise ships, incorporating collision and grounding damages, along with an improved method for calculation of the survival probability. Establishing new risk-based damage stability requirements of ROPAX and cruise vessels based on a cost/benefit analysis to establish the highest level for the required subdivision index. Investigating the impact of the new formulation for the probabilistic damage stability evaluation of passenger ships on the design and operational characteristics of a typical set of ROPAX and cruise vessel designs (case studies). Preparing and submitting a summary of results and recommendations to IMO for consideration.

State of the Art

The recently completed harmonisation process of existing damage stability regulations may be defined as the introduction of an unified assessment method for the damage stability of dry cargo and passenger ships on the basis of the probabilistic concept, without change of current safety standards set by IMO, which arguably nay be considered satisfactory on the basis that they reflect safely operating vessels. The main elements of the harmonisation process are the development of a unified probabilistic assessment concept, applicable to the relevant types of ships, and the definition of proper survivability levels for dry cargo and passenger ships that should be equivalent to those defined by currently in-force regulations for newbuildings. The previously in-force damage stability regulations (dry cargo ships: probabilistic SOLAS B-1, passenger ships: deterministic SOLAS 90/95 and probabilistic Resolution A.265) were assumed to reflect a satisfactory level of safety. It is noted that the equivalence remit of the IMO harmonisation process could only be met in an approximate, averaged way by the newly introduced harmonised regulations. Furthermore, the mandate of harmonisation was based on that fact that the new regulations should not lead to enhanced safety standards, except for some cases specifically approved by IMO-MSC.

However, a number of issues have emerged, requiring urgent consideration, as these affect the most safety-critical ships (large cruise ships and ROPAX ships in general), which are currently one of the fastest growing ship sectors and what is more important these ships constitute the core strength of the European shipbuilding industry. Such issues, listed in more detail in 1.2.5 of this deliverable, where the main initiative behind the GOALDS project.

Value added to GOALDS

This is the final report, summarizing the work carried out and the main achievements of this 3 years research project.

Achievements

1. Updating and developing all components of a probabilistic model of collision and grounding characteristics, respectively, and its ensuing impact on ship stability. Based on a thorough review of available information from all possible sources regarding collision and grounding accidents worldwide, appropriate formulae for the probability distributions of collision / grounding damage location, length, breadth and penetration were to be updated / developed.

2. Improving and extending the formulation introduced by MSC 216 (82) for the assessment of probability of survival (s-factors) for RoPax and cruise ships in damaged condition due to collision and grounding based on extensive use of state-of-the-art numerical simulation tools supported by a comprehensive model testing programme. To this end, a consortium was put together representing the whole spectrum of stakeholders in the maritime industry and at the same time possessing the required expertise and scientific know-how in the rule making process.

3. Performing model tests using two prototypes of RoPax vessels and two prototypes of large cruise liners, to provide experimental evidence on the process of ship stability deterioration after hull breach resulting from grounding or collision accidents and the required basis for the validation of the results obtained by numerical simulations.

4. Formulating a new probabilistic damage stability concept for large ROPAX and cruise ships, incorporating collision and grounding accidents, along with an improved method for calculation of the survival probability (improved A formulation).

5. Establishing new risk-based damage stability requirements of RoPax and cruise vessels by applying standard risk models for collision and grounding events as developed in SAFEDOR to a series of Cruise Liners and RoPax ships and using Cost-effectiveness analysis to establish the rightful level for the required index "R" which is consistent with the cost-effectiveness criteria

currently used at IMO.

6. Putting together design teams that comprise shipyards, owners, class and national administrations to investigate the impact of the new formulation for the probabilistic damage stability evaluation of passenger ships, to be developed in the context of the present proposal, on the design and operational characteristics of typical Cruise Liners and RoPax vessel designs.

7. Preparing and submitting to IMO a summary of results and recommendations for further consideration.

Not achieved ….

Input from other Deliverables

The final report summarizes the work carried out throughout the entire GOALDS project and therefore received input from all the Deliverables that have been elaborated and submitted from the beginning of the project.

Exploitation of results

A separate exploitation plan has been elaborated at the end of the project. A summary of exploitable results and exploitation activities is included at the end of this deliverable (Chapter 9).

This executive summary may be published outside the GOALDS consortium. *YES*

Work carried out by	Approved by
please declare the names of persons and their affiliations who contribute substantially to this document as applicable. G. Zaraphonitis, NTUA B.S. Lee, SaS O. Olufsen, DBV	please enter name of internal reviewer *A. Papanikolaou* *- signature on file -* *- signature of internal reviewer and date of acceptance -*
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1 Introduction

1.1 Executive Summary

Recent rapid changes in scientific and technological developments and an overall improved technical capability at a much larger scale are fuelling innovation in the shipping sector to meet the demand of larger, faster, more efficient and safer ships. This is taking place in an industry that is still fragmented and undermanned though intensively competitive and in a society that is more vigilant and more demanding on issues pertaining to life safety and the protection of marine environment. Safety is clearly in danger of being undermined and this necessitates change. This is particularly true for knowledge-intensive and safety-critical ships, like passenger ships and especially mega cruise ships, where the need for innovation creates unprecedented safety challenges that cannot be sustained by prescription. In this state of affairs, a new paradigm that treats safety as a design objective rather than through rule compliance as a constraint ('Design for Safety') and a formalized methodology capable of embracing innovation through routine utilization of first-principles tools, thus leading to cost-effective ways of dealing with safety ('Risk Based Design') were advocated by the EU maritime industry as the 'bridge' for the emerging gap.

Project GOALDS is targeting the enhancement of the damage stability and safety of passenger ships by use of risk-based assessment and design methodologies. The new probabilistic damage stability regulations for dry cargo and passenger ships (SOLAS 2009), which entered into force on January 1, 2009, represent a major step forward in achieving an improved safety standard through the rationalization and harmonization of currently in force damage stability requirements. There are, however, serious concerns regarding the adopted formulation for the calculation of the survival probability of RoPax and mega cruise vessels; thus ultimately of the Attained and Required Subdivision Indices for passenger ships. Furthermore, present damage stability regulations account only for collision damages, despite the fact that accidents statistics, particularly of passenger ships, indicate the profound importance of grounding accidents. Using state of the art methods and tools, project GOALDS is responding to the above concerns by a series of dedicated in depth research studies of a strong European project partnership.

The main objectives of the GOALDS project are the following:

(a) To enhance collision and grounding casualties database; to conduct statistical analysis of data regarding the location and extend of hull breach and check the validity of current SOLAS 2009 assumptions for passenger ships.

(b) To develop an improved formulation for the survival probability in case of flooding accounting for key design parameters of passenger ships and for the time evolution of flooding scenarios.

(c) To develop a new survivability model for flooding following grounding accidents and to integrate collision and grounding survivability formulations into a single framework.

(d) To validate the new formulations by experimental and numerical analyses.

(e) To develop a new damage survivability requirement for passenger ships in a risk-based context.

(f) To evaluate the practicability of the new formulations by a series of ship concept design studies, including formal multi-objective optimizations.

(g) Upon completion, to submit project results for consideration to IMO.

1.2 Project Context and Main Objectives

1.2.1 Overview of state-of-the-art

The safety of ships against sinking/capsize in case of loss of their watertight integrity is of prime interest to society, thus also to the international and national maritime regulatory bodies, the maritime industry and the scientific community. In the last decade, significant research has been carried out on the behaviour of damaged ships in waves and on the assessment of ship's damage survivability. Important aspects of the stability behaviour of a damaged ship have been thoroughly investigated on the way to more accurately approach the entire problem. The international scientific community kept developing and further improving numerical methods to closely match the findings of systematic physical model experiments.

In parallel to the development of scientific methods, significant progress was achieved in the international regulatory framework regarding the assessment of ship safety in damage condition. Marine safety regulations have been developed until now mainly in a reactive way, with accident experience providing the feedback to improved regulations. This approach might have been for some time satisfactory for large fleets of similar ships of certain design, for which past experience led to generally satisfactory standards of safety. However, it is less effective for unique and innovative designs, such as ships exceeding common size limits, currently under development, like the mega-ships of the cruise liner industry.

In response to these needs, the International Maritime Organization (IMO) and the shipping industry introduced improved methods to evaluate ship safety. Recently adopted harmonized regulations for damage stability of dry cargo and passenger ships on the basis of the probabilistic concept can be considered as a significant step forward in the assessment of ship safety against sinking /capsize in case of loss of watertight integrity.

1.2.2 Review of regulatory framework

Two main categories of regulatory concepts and methodologies for the assessment of ship damage stability have been thoroughly used, namely deterministic and probabilistic, leading to corresponding regulatory survivability standards (criteria). They both dispose inherent advantages and weaknesses that need to be kept in mind, when the survivability of a ship is assessed. Eventually, however, the survivability of a ship in a variety of operational and environmental conditions can be reliably assessed only by conducting physical or numerical model experiments (simulations) that might form the basis of future 'performance-based' survivability standards. A further development of the probabilistic assessment methods are 'risk-based' approaches which are more rational in the way that safety is assessed on the basis of the risk of an accident, namely loss of lives, pollution of marine environment and loss of property.

Deterministic approaches to ship damage stability are based on prescriptive, semi-empirical rules and criteria derived from statistical analysis of historical damage data and practical experience. Because of the semi-empirical way of deriving the applied criteria, these methods cannot ensure a reliable minimum level of required survivability in case of new ship designs deviating from the past, nor is the attained level of ship safety known.

The probabilistic approach to damage stability relies on a rational statistical assessment of historical accidental data and combines this statistical information with semi-empirical criteria to more rationally assess ship survivability for all statistically possible damage scenarios. In the last decade, several probabilistic models have been thoroughly investigated in order to improve the assessment of ship damage stability. The results of this research led to the new harmonized set of regulations of ship damage stability within a probabilistic framework that entered into force on January 1, 2009.

Inherent disadvantages of the deterministic damage stability assessment method, regarding the rational definition of minimum survivability standards for new ship designs and the determination of an acceptable to society, measurable level of safety, are also present in the new probabilistic procedures, however less arbitrary, noting that relative levels of ship survivability are identifiable in the probabilistic concept.

1.2.3 Probabilistic concept of ship damage stability

The probabilistic approach to ship damage stability is based on the assessment of the probability of a ship surviving after a collision incident and is expressed by the Attained Index, A. The calculation of this index requires the assessment of ship stability for a series of probable damage scenarios in predefined ship loading conditions. In the overall assessment, the survival performance of the ship in each examined damage scenario is taken into account by proper weight, accounting for the probability of occurrence of each damage scenario. The attained index, A, expressing the overall survivability of the ship, should be greater than a Required Subdivision Index, R, specified by the regulations (this constitutes in essence the standard).

1.2.4 Harmonisation process of existing & new regulations

The recently completed harmonisation process of existing damage stability regulations may be defined as the introduction of an unified assessment method for the damage stability of dry cargo and passenger ships on the basis of the probabilistic concept, without change of current safety standards set by IMO, which arguably nay be considered satisfactory on the basis that they reflect safely operating vessels. The main elements of the harmonisation process are the development of a unified probabilistic assessment concept, applicable to the relevant types of ships, and the definition of proper survivability levels for dry cargo and passenger ships that should be equivalent to those defined by currently in-force regulations for newbuildings. The previously in-force damage stability regulations (dry cargo ships: probabilistic SOLAS B-1, passenger ships: deterministic SOLAS 90/95 and probabilistic Resolution A.265) were assumed to reflect a satisfactory level of safety. It is noted that the equivalence remit of the IMO harmonisation process could only be met in an approximate, averaged way by the newly introduced harmonised regulations. Furthermore, the mandate of harmonisation was based on that fact that the new regulations should not lead to enhanced safety standards, except for some cases specifically approved by IMO-MSC.

1.2.5 Background and rationale

The new SOLAS 2009 harmonised probabilistic regulation for ship subdivision initiated a new era in rule-making in the maritime industry in line with contemporary developments, understanding and expectations. This is the culmination of more than 50 years of work, one of the longest gestation periods of any other safety regulation. One of the great achievements of this effort was thought to be the harmonization of standards for dry cargo and passenger vessels in a probabilistic framework which allows for a rational assessment of safety and design innovation. However, a number of issues have emerged, requiring urgent consideration, as these affect the most safety-critical ships (large cruise ships and ROPAX ships in general), which are currently one of the fastest growing ship sectors and what is more important these ships constitute the core strength of the European shipbuilding industry. These concerns, which form the kernel of the rationale for this project can be summarised as follows:

1. As the required subdivision index was derived by harmonisation (based on existing vessels, built in the 90ties), the new damage stability standard being statistical in nature (rather than performance-based) could not implicitly cater for the higher level of safety inherent (required) in these mega-ships; it rather maintains a safety level fit for the ships of a bygone era.
2. Lack of proper consideration (due to lack of availability) of large passenger ships in the sample studied in Project HARDER, raised concerns during the harmonisation process as to the suitability for the developed standards for damage stability among the IMO delegates, leading to a strong and explicit recommendation in IMO SLF47 to undertake pertinent research to address the damage stability standards for these ships (specifically to reformulate the probability of survival in a damage condition – s factor).

3. Water on deck issues greatly affecting the safety of ROPAX ships, were not included in SOLAS 2009, whereas in many countries, particularly the entire Europe, address this by regional agreements (Stockholm Agreement).
4. Finally, only survivability following collision events was addressed. A similar formulation for grounding accidents was not developed.
5. Within the EU-funded R&D project SAFEDOR (2005-2009), a series of high-level formal safety assessments (FSA studies) were performed for cargo and passenger vessels. The FSA studies on cruise and ROPAX vessels both concluded that the risk to human life could be reduced cost-effectively by increasing the required subdivision index.
6. The results of the FSA on cruise vessels performed within SAFEDOR show that a reduction of risk by 2.1 lives per ship per lifetime (30 years) may be achieved by increasing either GM or freeboard. Both design measures are shown to be cost-effective according to IMO criteria. However, due to the high-level approach within a FSA, only generic design measures were explored and found to be cost-effective. No complete new ship design concept was created to check the consequences of introducing higher subdivision requirements. Therefore, the FSA studies recommend undertaking research to investigate more thoroughly this issue.
7. Recent experience in the design of new large passenger ships according to the forthcoming probabilistic rules, tend to emphatically reinforce the foregoing. The rules appear to be inconsistent with design experience for high survivability for these ships and the level of vessel achieved in some of these designs is far higher than the level demanded by the rules, suggesting that there is "room" for higher standard of safety for large passenger ships without penalising other design considerations; this is in full support of the FSA findings.
8. Developments within SAFEDOR of holistic approaches in dealing with ship safety have revealed that the risk to human life from flooding (resulting from collision and grounding accidents) dominates the safety of passenger ships (almost 90% of the total risk), thus making it imperative to "get damage stability right".
9. Other developments within IMO concerning the safety of large passenger ships, led to concepts of progressively more holistic nature, namely "Safe Return to Port", again with flooding (and fire) accidents at the very centre of such developments; this necessitating a more thorough understanding of how damage stability ought to be catered for in ship design and operation.
10. Along similar lines, one of the top-agenda items at IMO, namely Goal-Based Standards is targeting in the longer term all ship types, with of course passenger ships being a main target, implicitly again pointing towards the need to sort out the damage stability standard for large passenger ships.

1.2.6 Main objectives and expected output

The GOALDS project was setup in order to address the above issues by:

1. Updating and developing all components of a probabilistic model of collision and grounding characteristics, respectively, and its ensuing impact on ship stability. Based on a thorough review of available information from all possible sources regarding collision and grounding accidents worldwide, appropriate formulae for the probability distributions of collision / grounding damage location, length, breadth and penetration were to be updated / developed.
2. Improving and extending the formulation introduced by MSC 216 (82) for the assessment of probability of survival (s-factors) for RoPax and cruise ships in damaged condition due to collision and grounding based on extensive use of state-of-the-art numerical simulation

tools supported by a comprehensive model testing programme. To this end, a consortium was put together representing the whole spectrum of stakeholders in the maritime industry and at the same time possessing the required expertise and scientific know-how in the rule making process.

3. Performing model tests using two prototypes of RoPax vessels and two prototypes of large cruise liners, to provide experimental evidence on the process of ship stability deterioration after hull breach resulting from grounding or collision accidents and the required basis for the validation of the results obtained by numerical simulations.
4. Formulating a new probabilistic damage stability concept for large ROPAX and cruise ships, incorporating collision and grounding accidents, along with an improved method for calculation of the survival probability (improved A formulation).
5. Establishing new risk-based damage stability requirements of RoPax and cruise vessels by applying standard risk models for collision and grounding events as developed in SAFEDOR to a series of Cruise Liners and RoPax ships and using Cost-effectiveness analysis to establish the rightful level for the required index "R" which is consistent with the cost-effectiveness criteria currently used at IMO.
6. Putting together design teams that comprise shipyards, owners, class and national administrations to investigate the impact of the new formulation for the probabilistic damage stability evaluation of passenger ships, to be developed in the context of the present proposal, on the design and operational characteristics of typical Cruise Liners and RoPax vessel designs.
7. Preparing and submitting to IMO a summary of results and recommendations for further consideration.

2 New formulation for the calculation of the probability of survival in damaged condition

One of the key objectives of the GOALDS project is to develop an integrated formulation for the assessment of the survivability of passenger ships in damaged condition, combining both collision and grounding accidents. To this end, the following tasks have been addressed:

a. to update/review and propose appropriate functions of probability distributions for collision / grounding damage characteristics, pertaining to location, length (effective length for grounding), breadth and penetration;

b. to develop methods for the assessment of ship survivability due to flooding after collision/grounding, including new s-factor formulations for passenger ships;

c. to take into account water on deck (WOD) issues for ROPAX vessels;

d. to propose methods for the integration of these functions with the view to be submitted to IMO for adoption within the general framework of SOLAS 2009.

2.1 Collision and Grounding Damage Characteristics

To obtain the probability distributions for collision and grounding damage characteristics, relevant accidents data have been collected and statistically analysed. The casualty data were mainly derived from classification societies damage files under the condition of water ingress as a consequence of the casualty. The HARDER database was rechecked and available additional data were implemented. New casualty data (after 2000) were identified by searching Lloyd's Register Fairplay casualty database (LRF). Cases which were identified as serious have been selected and sorted with respect to the corresponding IACS society. Cases identified/related to consortium members were submitted for consideration to the participating Class Societies. The casualty data collected in GOALDS allowed to increase the HARDER database by about 22% when considering only collision accidents, 51% when considering only groundings and by 29% when considering collisions, groundings and contacts. The resulting GOALDS accidents database consists of 1016 collisions, 472 groundings and 39 contacts. The synthesis of the GOALDS database is presented in Figure 1 and Table 1.

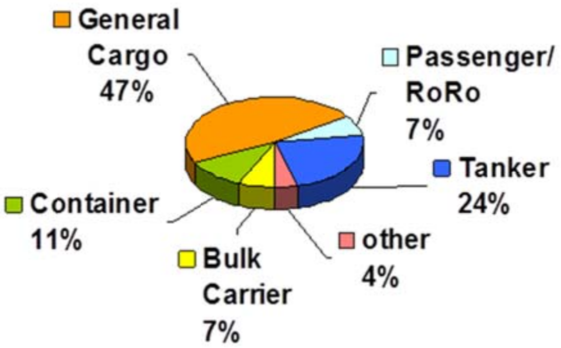

Figure 1: GOALDS Database – ship types

Table 1: Synthesis of the collisions and groundings database

	Collision	Grounding	Contact	Total
HARDER	832	312	35	**1179**
GOALDS	184	160	4	**348**
database	**1016**	**472**	**39**	**1527**

In general, the statistical analysis of collision accidents characteristics verified the HARDER data and the probabilistic formulae stipulated in the SOLAS 2009 (see Figure 2). The outcome from the new analysis does not provide strong justification for changing present SOLAS 2009 formulation for the calculation of the probability of location and extend of side damages due to collision accidents.

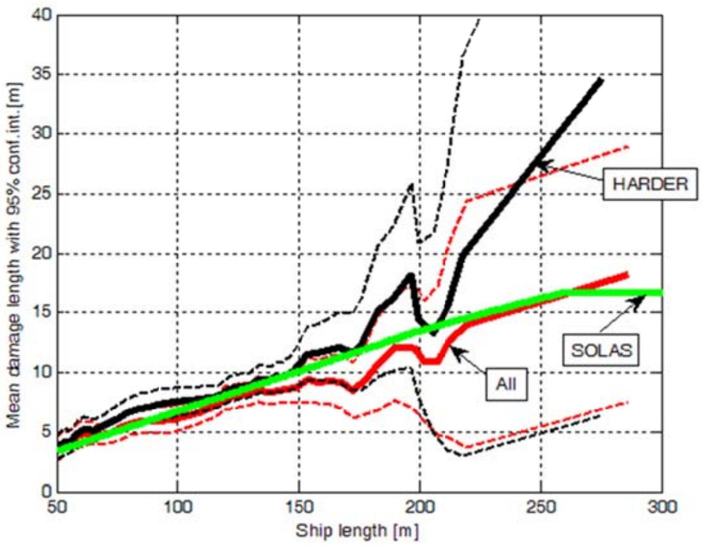

Figure 2: Mean value of damage length according to GOALDS, HARDER and SOLAS 2009

Grounding damage characteristics for those accidents resulting in hull penetration have been statistically analysed with the aim of:

a. describing grounding damage position and dimensions, and

b. evaluating present SOLAS minimum double bottom height requirements and deterministic bottom damage requirements.

In the analysis of grounding damage characteristics, full and not full hull forms have been dealt with separately in order to highlight possible different behaviours (Figure 3).

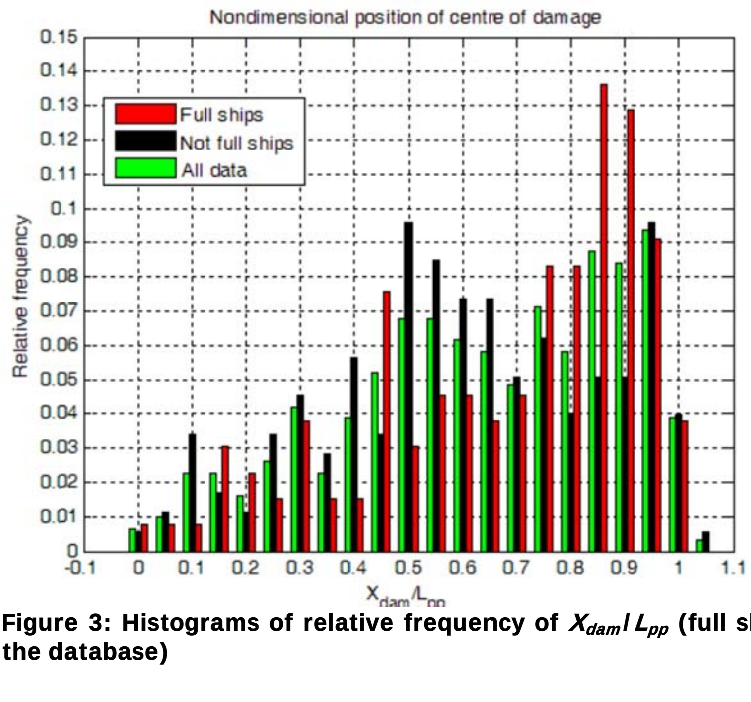

Figure 3: Histograms of relative frequency of X_{dam}/L_{pp} (full ships, not full ships and all ships in the database)

During the evaluation of the grounding casualties, some groundings had multiple damage penetrations recorded. Several cases were identified with up to 16 penetrations of the bottom shell plating. As many of those damages are small but widely spread over the ship's bottom it was decided to replace the multiple damages of each case by one *equivalent* damage. An *equivalent* damage covers the length of the damaged area, its area is equal to the sum of all individual damages and has a mean width (considering the mean width of all observed case damage widths). The SOLAS requirements have been assessed by estimating the probability of penetrating a double bottom constructed in marginal compliance of SOLAS standards and by calculating the probability of exceedance of bottom damage dimensions as specified by SOLAS. Figure 4 shows a scatter plot of measured damage penetration as a function of the ship breadth and the minimum double bottom height requirements as specified in SOLAS II-1/9 in general and for longer lower holds RoPax designs.

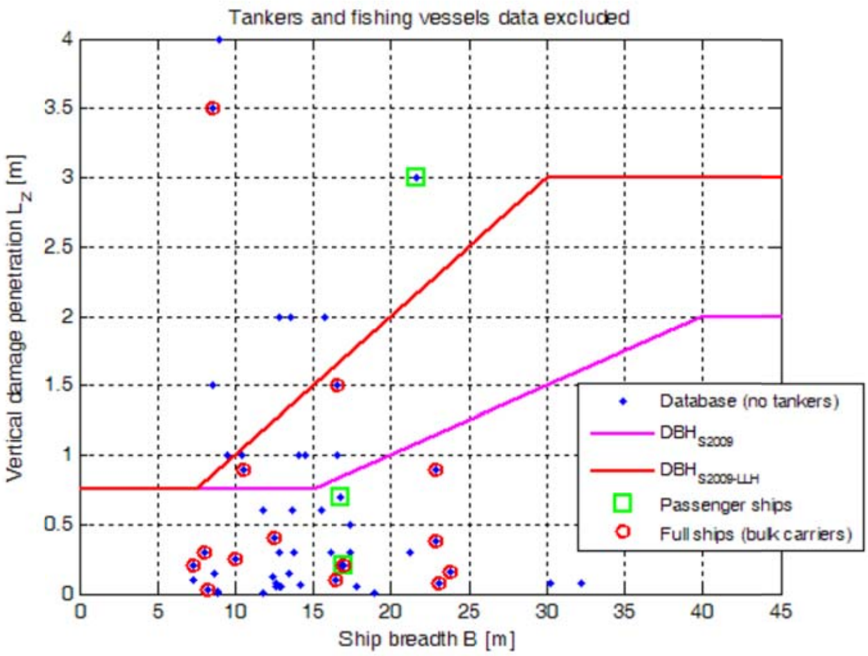

Figure 4: Vertical damage penetration vs. SOLAS requirements for double bottom height

The obtained probabilities of exceedance of bottom damage dimensions have been compared with known figures available from IMO documentation. In the course of the work, a statistical analysis has also been performed on the ship speed at the moment of grounding.

Table 2: Probability of penetration exceeding SOLAS minimum double bottom height.

$\Pr\{L_z > DBH_{S2009}\}$	27.3% [16.1%, 41.0%]$_{95\%CI}$	Samples: 55 Exceeding: 15
$\Pr\{L_z > DBH_{S2009\text{-}LLH}\}$	14.5% [6.5%, 26.7%]$_{95\%CI}$	Samples: 55 Exceeding: 8

2.2 Probability of surviving collision damages

The current formulation for assessing of a damaged ship survivability in waves is based on a concept developed within the EU-funded project HARDER. Although, the concept was conceptually robust its validation and implementation was based on a very limited sample and therefore it soon raised some concerns with respect to accuracy of the adopted regression model when applied to the designs deviating from the original sample. Specifically, it has been postulated that survivability of large ships or ships with stability-enhancing watertight architecture may be underestimating whereas the SOLAS s-factor may overestimate survivability of smaller RoPax vessels. Indeed, as some further works indicated the HARDER-based formulation proved to be unreliable when applied to the designs not rendered by the original sample. The simple regression formula, although very convenient in use, has been examined from point of view of completeness and flexibility. In particular its validity was often questioned for lack of reference to the freeboard (accumulation of water on deck) and size of the vessel. Furthermore, some concerns were expressed with respect to time-base of the formulation, i.e. the fact that the survival meant law probability of capsize in 30 minutes. As size of the modern passenger ships tend to increase it became apparent that 30 minutes will in many cases be insufficient to perform orderly evacuation and abandonment what subsequently might lead to catastrophic consequences.

In the knowledge that the existing SOLAS 2009 formulation for the harmonised survival factor for dry cargo and passenger ships does not account properly for the dynamic behaviour and design features of RoPax and cruise ships when damaged (it is explicitly stated in SLF 47 that a new formulation of survival factor for large passenger ships is expected to be submitted in the future) The GOALDS project aimed to develop a new s-factor formulation, suitable for RoPax and cruise ships as well as a generalised formulation for the Survival Time (Time to Capsize – TTC). Both objectives were pursued by using existing software tools, developed by the project partners during earlier EC projects (HARDER, NEREUS, SAFEDOR) in the form of numerical simulations, as well as the collective knowledge of all the participants concerning the use of analytical tools, experiential evidence and understanding of the physical phenomena involved. Numerical results were verified against purposely designed and controlled model experiments. The basic steps for the derivation of the GOALDS formulation for the calculation of the s-factor and Time to Capsize are summarized in the following:

2.2.1 Modes of loss

There are three distinct modes of ship loss following collision and/or grounding. These can be categorised as follows:

a. Capsize – gradual process of diminishing stability caused by progressive flooding (or continuing accumulation of floodwater within damaged spaces); it is a quasi-static phenomenon dependent on floodable volumes (floodwater) distribution and hydrostatic stability characteristics; the outcome is weakly dependent on opening geometry (which affects mainly time to loss).

b. Transient capsize – stability failure due to rapid floodwater ingress; it is a dynamic process dependent on opening size, floodwater distribution and hydrostatic stability characteristics.

c. Sinking – floatability failure; it is usually gradual, quasi-steady process with time depending strongly on rate of flow through the damage openings, internal openings and arrangements and floodable volume characteristics.

These three basic modes can be further categorised with respect to time to failure into rapid and gradual. Transient capsize falls into the former category whereas, capsize and sinking fall into the latter category. For the sake of simplicity and continuity, all the modes of loss mentioned here will be described by the word "capsize" henceforth.

2.2.2 Capsize transition band

Capsize band is a concept describing the transition of sea-states from those at which no capsize is observed (lower boundary) to those at which the probability of capsize approaches unity (upper boundary). In simpler terms, it is a band outside which capsize is either unlikely to happen or certain. In the light of the considerations presented in the previous section, the term "capsize" can be generalised to cater for both capsize and sinking. For a finite observation time, the probability of capsize can be approximated with a sigmoid function (Figure 5). It can be observed that, as the time of observation increases, the capsize band contracts towards its lower boundary, becoming a unit step function as time approaches infinity. This property is of major importance and had become one of the key findings made during the process of re-engineering of the s-factor. It is noteworthy that the concept of the critical sea state, Hscrit, as used for the s-factor in force, is associated with the sea state at which the probability of capsize (pf) is equal to 0.5, based on half hour tests.

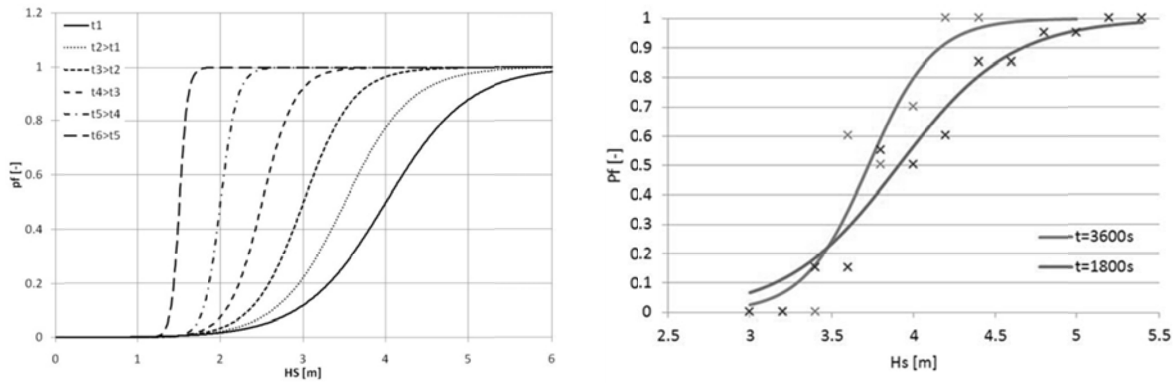

Figure 5: Assumed (left) and observed (right) behavior of capsize band as functions of the observation time.

2.2.3 Water on deck accumulation

The Water-on-Deck (WoD) is a term commonly used for accumulation of floodwater on the vehicle deck of a RoPax vessel. Its importance derives from observed correlation of the amount of accumulated water on deck and survivability of the vessel. In fact, it has also been argued that similar behaviour can be found for cruise vessels when the floodwater enters the service corridor, located above the bulkhead deck. The major difficulty while attempting to address the WoD problem is the stochastic and non-ergodic character of the flooding process, which generally makes the analysis very complex and time consuming. The necessity of analysing very long time histories casts, in many cases, proper analysis impossible even for numerical data (experimental data introduce additional difficulties related to the accuracy of the measurements and usual short time of observation). It is in this context that the capsize band properties can be used to reformulate or rather address this problem in a more convenient fashion. This can be done if the analysis of WoD accumulation is based on the surviving time realisations, with those just outside the lower boundary of the capsize band taken as a reference.

Although the technique adopted, i.e. time domain simulations and analysis based on a relatively small number of realisations, might be questionable, it should be noted here that the main purpose is to visualise and qualitatively compare flooding processes without any attempt to draw quantitative conclusions, such as critical amount of floodwater, etc. Indeed, the analysis, in spite of certain mathematical shortcomings, conveyed very important information. Firstly, it has been noticed that the 95th percentile in all the surviving cases reached an asymptote, whereas lack of it indicated progressive flooding that would eventually result in a loss. Secondly, although the limiting amount of floodwater would vary with Hs, such variability proved to be statistically insignificant. Furthermore, in most of the cases, should, in any particular time realisation, the limiting floodwater amount (the asymptotic value) exceed (by some statistically significant amount) the corresponding upper confidence limit, it would be a clear indication of subsequent loss.

The final outcome of the WoD analysis is that the flooding process of the surviving cases can be characterised by a statistically unique (for any given damage) limit, independent of sea-state and duration of observation. It is important to note that the limiting amount of floodwater coincides with the quantity obtained for the highest sea-state at which no losses were observed – lower boundary of the capsize band. Furthermore, as the analysis indicates, increasing the sea-state further does not have an impact on the limiting value but increases the probability of exceeding it. This probability is time-dependent – in the extreme case of infinite time observation all realisations in sea-states below the lower branch of capsize band would never exceed the limit whereas it can be expected that in sea states within the capsize band, the probability of exceeding the limit would approach unity. This is in essence equivalent to the unit-step representation of the capsize band. Finally, the analysis has proved that in spite of differences in the underlying physics, both modes of gradual loss (i.e. capsize and sinking) can be successfully approached with the same model. Furthermore, consistency of outcome of WoD investigation with observed properties of the capsize band allowed the definition of a critical significant sea-state to be reformulated:

The critical significant wave height, Hscrit, is a sea state at which no more than 5% of realisations, performed for at least 30 minutes, resulted in ship loss.

Given the asymptotic character and expected contraction of the capsize band it is postulated that 5% capsize rate should provide sufficient approximation of a "safe" sea-state irrespective of duration of observation, given it is longer than 30 minutes.

2.2.4 Critical significant wave height

The search for the critical sea-state of the ships at our disposal enhanced knowledge of the dynamics of capsize, water accumulation on car deck of RoPax vessels and the various mechanisms of capsize for the different types of ships. Most importantly, observations made with regards to time to capsize and the probability of capsize have led to better understanding of the critical sea-state boundary and uncertainty region. Due to the fact that the capsize band contracts towards the lower boundary, it was made clear that, ideally, the critical sea-state should be regarded as the sea-state at which the probability of capsize is 0, and where time of survival is infinite. That boundary appears to be related to the particular damage scenario and ship rather than testing time, which is in line with IMO's latest developments on performance-based requirements such as Safe Return to Port regulations (SRtP). Due to the uncertainty involved in the experiments, a probability of capsize of 0.05 should be used for the estimation of the critical sea-state, as postulated earlier.

2.2.5 The s-factor

The methodology followed in search of a representative formulation for the s-factor can be split in three stages. During the first stage, the parameters affecting the survivability had to be identified and their contribution measured. Further, given the scattering in the results, some quantity had to be found that would reduce it. Then, a comprehensive formula would be developed that would incorporate all the information and provide accurate results of survivability prediction. The limited sample size available within the GOALDS project prohibited extensive use of advanced techniques like Design of Experiments (DoE) for sensitivity analysis. That is why the study was mainly based on reasoning, experience and expertise and supported where possible by quantitative assessment. At the first stage, the SOLAS formulation was investigated from the point of view of choice of parameters in order to conclude whether the GZ_{max} and $Range$ are sufficient to predict accurately the critical significant sea-state. As a result it has been found that even the relatively complex expression derived from the DoE failed to significantly improve the accuracy of the SOLAS prediction. Nonetheless, the correlation coefficient increased from the initial value of 0.64 to 0.79.

The data available from previous projects were reasonably consistent due to the fact that it was practically one RoPax ship that was tested in various loading conditions. When more ships were added to the dataset, it became obvious that such a simplistic approach would not be possible, since many points were completely "misbehaving". Although such points might initially be qualified as outliers, their existence was proven by more experimental results. Thus, the search was on for a quantity that would bring all the data closer. The regression formula derives from the observation that both parameters, i.e. GZ_{max} and $Range$, present in the current s-factor formulation, might be suitable for accurate prediction of the critical significant wave height if only a scaling (size) parameter is present. The investigations led to the conclusion that the parameters to be included in the s-factor formulation should at least include GZ_{max}, $Range$, a measure of the residual volume (V_R) and additionally GM_f (metacentric height of flooded vessel). The data processing finally resulted in a suitable regression formula expressing H_{Scrit} as a function of the above values (GZ_{max}, $Range$, V_R and GM_f):

$$H_{Scrit} = \frac{A_{GZ}}{\frac{1}{2} \cdot GM_e \cdot Range} V_R^{\frac{1}{3}}$$

where GM_e is given as:

$$GM_e = \max\left(GM_f, \frac{CZ_{\max}}{\varphi_{\max} - \varphi_0} \right)$$

The angles φ_{max} and φ_0 correspond to the angles at maximum GZ and at static equilibrium, respectively.

The probability of surviving of a damaged ship is evaluated as the probability of encountering a sea state with a significant wave height not greater than the H_{Scrit} based on the IMO distribution of sea-states encountered during collision incidents:

$$s_{GOALDS} = \exp(-\exp(0.16 - 1.2 \cdot H_{Scrit}))$$

2.2.6 Time to capsize

In sea-states exceeding the critical significant wave height, the probability of survival and time to capsize decrease, the first following a sigmoid pattern, the latter according to a hyperbolic manner (Figure 6). Based on the available data, an appropriate formula has been obtained, expressing the TTC as a function of the actual significant wave height and H_{Scrit}:

$$TTC = \frac{\alpha}{(H_S - H_{Scrit})} \quad [\text{min}]$$

$$\alpha = 3 \cdot H_{Scrit}^{1.4}$$

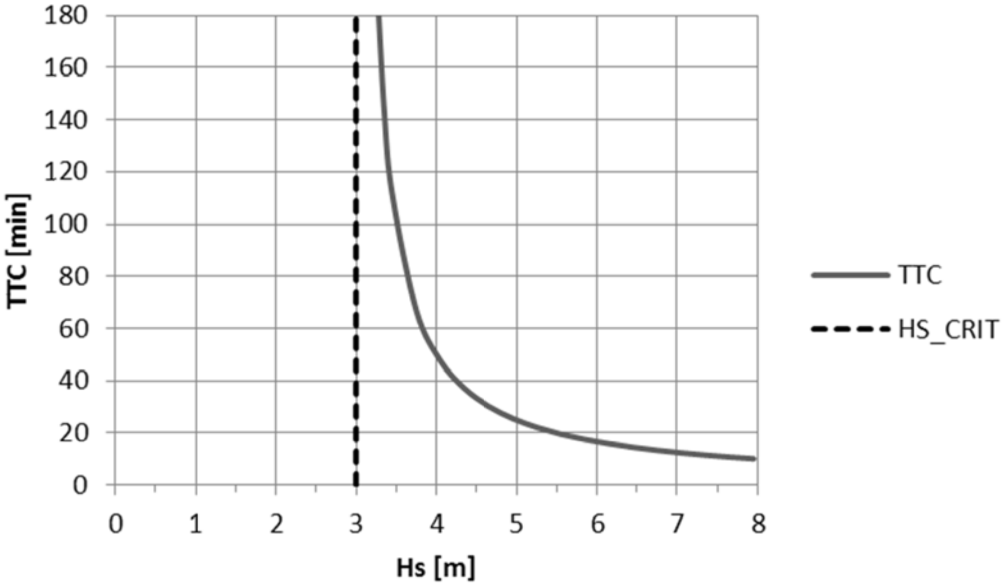

Figure 6: The concept of time to capsize

2.2.7 Comparison with SOLAS 2009 formulation

Although the comparison of average survivability ('A indices') shows that SOLAS prognosis (with WT structures above the main deck accounted for in the subdivision table) is comparable to GOALDS, any conclusion should be drawn with care. First of all, it should be remembered that the A-index is a weighted average with majority of damaged cases having sufficient stability to survive collision damages in sea-state of more than 4 m (s=1). Furthermore, if the attained index of subdivision is of order of 0.9, the proportion of marginal stability cases is biased towards higher sea states (> 2m); in this region the function mapping H_{Scrit} into s-factor is very insensitive to variations of the independent variable, H_{Scrit}. Therefore, the expected differences in A-index by SOLAS and GOALDS predictions have to be, on average, small. This has been already proved by extensive studies led by the SSRC within the EMSA project EMSA/OP/08/2009. In absolute terms, however, it can be seen that SOLAS is incapable of predicting the surviving sea-state accurately – confidence interval of the SOLAS prognosis, estimated on a basis of model tests, has width 4.5m – more than range of applicability of the formulation. In the case of GOALDS formulation the confidence band has width 2 m and zero mean.

A comparison of GOALDS prediction of H_{Scrit} and a regression based on response surface (DoE) with use of initial and final set of parameters is presented in Figure 7. As can be seen, DoE fails to increase significantly the correlation with experimental data in the case of initial (SOLAS) parameter set, but, applied to the final-formula parameters results in 99% correlation.

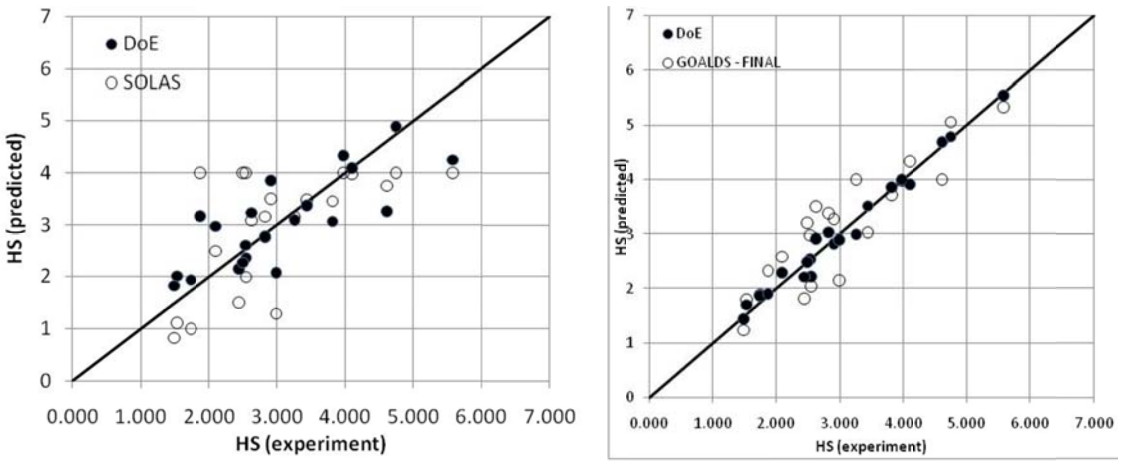

Figure 7: Comparison of GOALDS prediction of H_{Scrit} and a regression based on response surface (DoE) with use of initial and final set of parameters

As the actual sea state can be overestimated by SOLAS by as much as 2.5m the actual probability of survival may be significantly lower than predicted (e.g. 0.3 instead of predicted 0.94). In the case of GOALDS prediction overestimating of H_{Scrit} by 1m would cause the actual probability to be reduced from 0.7 to 0.3. At the other end of the scale, cases of high stability, underestimating the sea state by 2m (SOLAS) and 1m (GOALDS) would result in under-predicted probability of survival – from 0.99 (at H_{Scrit}=4m) to 0.82 (SOLAS) and 0.97 (GOALDS).

2.3 Probability of surviving grounding damages

The formulation of the probability of surviving grounding damages followed the line of developments of the collision damages, as it is important to have a consistent formulation for the survival factor irrespective of the accident in question, to be used in risk summation and estimation of the safety level of the ship. What is different in this case is that such formulations are attempted for the first time and hence there is added uncertainty as to the nature and importance of the governing parameters affecting the probability of survival post grounding and progressive flooding.

Therefore, more development work and more partners exploring different approaches were working in parallel for this case. Appropriate statistical, analytical, numerical and experimental studies have been undertaken to derive a model which could be representative of the phenomenon of stability deterioration in any grounding accident. The statistical studies addressed the available data on grounding accidents, whereby revision of actual ship status and its performance during the accident have been undertaken. Numerical studies comprised a broad range of simulation scenarios with available tools developed in previous EC-funded projects. The focus was on defining the parameters governing the process of ship stability loss. The experimental studies that have been undertaken in GOALDS were used to verify the results of numerical studies, but also to improve physical understanding of ship behaviour in a grounding event. The analytical studies entailed regression-type attempts in developing a generic formulation for probability of ship survival after grounding regarding: (a) a survival factor formulation for grounding damages and (b) a TTC probability distribution formulation for grounding damages.

The systematic studies on survivability of grounding damages have never been performed before. This provided unique opportunity to investigate the mechanism of flooding and subsequent ship loss resulting from bottom damages. Furthermore, the Monte Carlo simulations performed within the task gave good indication of risk level associated with grounding. Finally, the studies allowed formulating a formula for estimating the probability of surviving grounding damages and consequently delivered one of the key ingredients for developing a probabilistic damage stability framework in line with the framework for collision damages. This in turn is one of the basic requirements necessary to formulate an integrated damage stability standard.

According to the obtained results, in general, a grounding damage should not be a significant threat to the survivability of a well-designed and correctly operated passenger vessel in calm water and in waves. Unlike collision damages where a vessel is likely to lose a significant proportion of her restoring ability, a grounding damage will most likely result in no loss of restoring ability, thus of stability. This is because damaged/flooded compartments are located at lower decks, which leads to an increase in GM. This observation remains valid, provided that floodwater is contained in those compartments and does not spread through up-flooding routes into higher located compartments. Large heel angle could occur but, again, it should not pose a threat if unprotected openings do not submerge. In essence, the most significant threat related to grounding is progressive up-flooding. Analysis of the damages that resulted in loss during the Monte Carlo simulation showed that in most cases it was because of progressive up-flooding that the vessel was lost and if the damage had been contained in the damaged compartments the outcome would be different.

2.4 Integrated Damage Stability Standard

Rules are typically derived for each hazard separately, with little effort spent on defining denominating contributions to risk for setting them at appropriately balanced levels or without scope for designer's freedom to attain such balance with more holistic goals. The SOLAS2009 regulation has been adopted to address the hazard of collision based on the probabilistic framework but ignores grounding damages. A new framework has been developed in this Task of the GOALDS project, то formally integrate the risk contribution of both hazards aiming to support the development and adoption of an integrated standard. The development of this framework is based on the following principles: (a) The risk may be quantified by means of loss statistics, such as cumulative annual frequency of exceeding specific number of fatalities per ship, or the expected annual number of fatalities per ship, often referred to as "potential loss of life" or PLL for short. (b) Risk may be modelled by assuming several mutually exclusive sets of events.

For the development of a an integrated standard for ship's stability in flooded state in this project, it is assumed that the risk may be considered from the top view as the expected number of fatalities, and that it results from two key mutually exclusive chains of events, involving collision or grounding, respectively. The resulting risk may then be considered as the sum of the individual risks associated to collision and grounding accident.

Both collision and grounding accidents have been formulated in the form of chains of events enabling the calculation of the associated risk to human life, based on the assigned probabilities of occurrence or the annual frequencies of the various events. The concept of integration is proposed to be derived from the most fundamental reasoning on risk tolerability. Namely, from the regulatory point of view it is a fairly routine assumption that a design must not give rise to risk to life (or other pertinent loss) greater than some level considered tolerable. The development of the standard for ship's stability in flooded conditions is of an integrated format, whereby a single criterion is to determine the amount of risk that is considered ALARP and which results from flooding due to either collision and/or grounding.

The analysis resulted in an integrated Attained Subdivision Index A that may be expressed as follows:

$$A = 0.71 \cdot A_c + 0.29 \cdot A_{gr} \geq R(N_{\max})$$

In the above formula, A_c and A_{gr} stand for the Attained Subdivision Indices calculated for collision and grounding damages respectively. The Integrated Attained Subdivision Index should be not less than a Required Index R, which depends only on the number of Persons on Board (POB).

2.5 Development of software for damage stability calculations based on the new formulation

Following the development of the new survival factor, NAPA macros were developed in order to enable the testing among end-users. The new formulation has been programmed and then tested by end users. All parameters and criteria have been thoroughly discussed among the consortium members, aiming for precise definitions on the practical use of the formulation.

During the development phases, different approaches were tested. At an earlier stage, the macros that calculate the GOALDS attained index were independent on the SOLAS 2009 calculation, which would increase flexibility of its use. However, this approach proved to be time consuming as all damage cases are calculated twice, once for obtaining the SOLAS 2009 attained index and a second run for the GOALDS results. Having in mind that the damage cases and subdivision draughts are the same for SOLAS and GOALDS, the final approach is to base GOALDS calculations on already stored results from the SOLAS run. This reduces flexibility as the SOLAS 2009 calculation must be run beforehand, but at the same time the time required for obtaining results is decreased which is beneficial when keeping in mind the amount of risk control options being evaluated by other work packages.

3 Verification of Numerical Results by Physical Model Tests

Within the GOALDS project, an extensive set of model testing has been carried out. The objective of this work was to derive experimental evidence on the process of ship stability deterioration after hull breach typical for collision and grounding accidents. The evidence corresponds to the relation between specific set of damage and environmental conditions and corresponding time it takes for the limit state condition to evolve (vessel losing its functional equilibrium attitude).

For the experiments four sample ships were selected to represent the typical passenger vessels which can often be encountered today but for which there is a dearth of experimental or full scale data available. These are two Ro-Pax ferries and two cruise ships as follows:

- Large Ro-Pax (LBP 176m, 1400 passengers) ***R1***
- Small Ro-Pax (LBP 97.9m, 622 passengers) ***R2***
- Post-Panamax cruise ship (LBP 274.73m, 3840 passengers) ***C1***
- Panamax cruise ship (LBP 260.6m, 2500 passengers) ***C2***

The Ro-Pax ferry models were tested by the Hamburg Ship Model Basin (HSVA), while the cruise ship models were tested by the Vienna Model Basin (VMB). The models were subjected to a collision damage and a grounding damage.

3.1 Selection of Damage Scenarios

The grounding damage to inflict on the models was essentially a 2-compartment asymmetrical type, but there was a practical requirement of ensuring that the flooding due to grounding damage takes place within the extent of the detailed internal arrangement installed in the ship models, since internal modelling was highly resource-intensive and only limited part of the ship could be modelled accurately. This meant that the grounding damage and collision damage induced flooding in the broadly similar regions of the ship. The challenge, therefore, was to select a number of severe 2-compartment damages and correlate them with the grounding statistics in order to select the collision damage extent which would also correspond to the extent of the inner bottom penetration due to grounding. This process was aided by static damage stability calculations and time-domain simulation of dynamic ship behaviour after damage for a large number of 2-compartment damage cases.

In light of these conceptual and technical challenges a set of criteria for modelling grounding has been established as follows:

a. Wherever applicable, the inner bottom penetration for post-grounding up-flooding should affect the compartments lying within the longitudinal extent limiting the representative collision scenario.

b. Bottom shell breach should extend to double bottom compartments adjacent to the watertight compartments affected by inner bottom penetration in order to investigate the effect of trim on survivability.

c. Grounding damage location does not need to be towards the foremost part of the ship.

Additionally in the case of cruise vessels it has been decided to use three-, instead of two-, compartment damages in collision tests. This has been preceded by the extensive numerical test carried out by SSRC to verify the damage selection by means of expected capsize rate and time-to-capsize.

3.2 Test setup and procedure

The hulls were manufactured from GRP and the internal compartments were constructed with plywood. The internal compartments were modelled with either plywood (for R1 and R2) or plexiglass (for C1 and C2), paying special attention to the modelling of the correct shape and volume permeability of the compartments.

The model set up (damage opening) and all test series were carried out in accordance with the provisions in the Annexes I and II of the EU Directive 2005/12/EC.

The model was dynamically trimmed in order to meet the specified GM value as well as the radius of gyration. Prior to the tests, roll decay tests were performed to determine the roll damping coefficient for each load and damage condition.

The motions of the model were measured using an optical tracking system. The heave, roll and pitch motions of the model were recorded. The model drifting in the seaway was followed by the towing carriage. The mean drifting velocity of the model during each run was determined by averaging the speed of the towing carriage.

Tests were carried out for a number of initial GM values. Additionally for R1 a second damage scenario was tested involving damage beyond B/5 which resulted in flooding of lower hold. The model had to be modified for this scenario by installing watertight side casings to counter the excessive buoyancy loss caused by flooded lower hold. The central casing was removed for the duration of this damage scenario testing.

Figure 8: Vehicle deck modeling of RoPaX R2

Figure 9: Cruise Vessel C1, Side Damage from #183 to #229

Figure 10: Cruise Vessel C1, Bottom Damage from #183 to #243

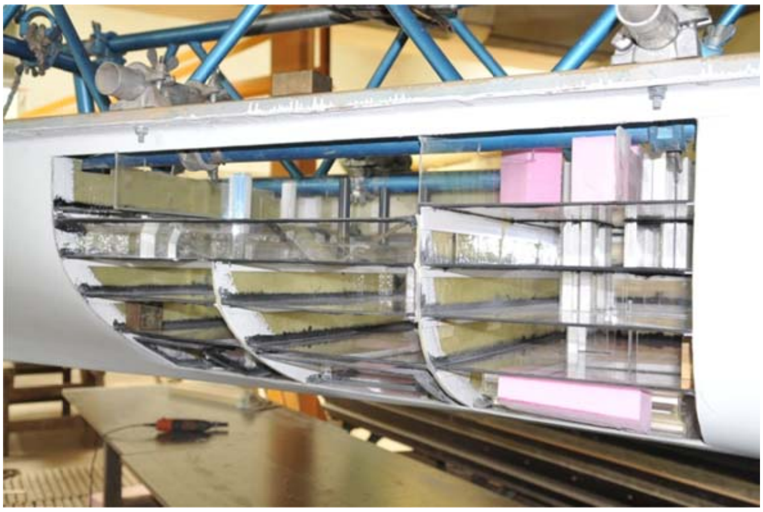

Figure 11: Cruise Vessel C2, Side Damage from #226 to #286

Figure 12: Cruise Vessel C2, Bottom Damage from #228 to #305

3.3 Summary of test results

3.3.1 Large Ro-Pax Ferry (R1)

a. Collision damage with centre casing. In total 68 runs were made spanning over 3 different KG values:

   i. Loading condition with GM_0 = 2.391m: 100% of survivability Hs up to 4.50m. In Hs of 4.75m the survivability was decreased to 80 % while in Hs 5.00m waves the survivability was only 20%.

   ii. Loading condition with GM_0 = 2.191m: Full survivability was found only in waves of 2.75m Hs. In 3.00m waves the survivability decreased to 60%.

   iii. Loading condition with GM_0 = 2.291m: With this GM value, which is only 0.1m below the minimal required value, full survivability was found in 3.75m high waves. In waves of 4m Hs the survivability reduced to 50%.

b. Collision damage with side casings (LLW damaged): 16 runs were made.No capsize was found in 6.50m Hs waves, due to the increased buoyancy from the side casings.

c. Grounding damage: Within 41 test runs no capsize occurred up to Hs of 6.50m, even with reduced GM values and cut ventilation pipes.

3.3.2 Small Ro-Pax Ferry (R2)

a. Collision damage. In total69 valid test runs were made for two different values of KG (and hence GM values).

   i. Loading condition with GM_0=2.488m: 100% survivability in Hs of 3.00m. In Hs of 3.75m the survivability was reduced to 20%.

   ii. Loading condition with GM_0=2.103m: 100% survivability in Hs of only 1.75m. In Hs of 2.25m the survivability was reduced to 17%.

b. Grounding damage. 56 runs were made in total. No capsize event was observed in Hs up to 5.00m for both intact GM values. Ventilation pipes from the lower compartments were cut at the height of the car deck. From these air pipes water up-flooded the car deck. But again no capsize occurred in waves of 5m, because at a certain heeling angle the amount of water coming in through the air pipes decreased and an equilibrium was reached. Increased survivability could be attributed to the lowered centre of gravity due to the presence of flood water in the lower compartments.

3.3.3 Post-Panamax Cruise Ship (C1)

None of the 'static equilibrium' runs with the doors closed resulted in capsize in waves up to Hs = 4.0m. The initial GM value for all the runs was 2.563m. The second phase of collision damage experiments was carried out with the semi-watertight doors in open position. The testing suggested that the survival boundary at this condition is somewhere between Hs = 2.25m and Hs = 2.5m, but conservatively put at 2.25m. The last phase of collision damage experiments was carried out in the 'transient mode'. A trial run with open semi-watertight doors (SWDs) was carried out in the 'transient mode' in still water which resulted in a rapid capsize of the vessel (60s in full scale). This experiment illustrates how important it is that the connecting (typically semi water-tight collapsible) doors on bulkhead deck which are located near the ship's sides should always be kept closed while the ship is at sea. The runs with SWDs closed did not produce any capsize, and accordingly GM had to be reduced to induce capsize events. A degree of randomness was observed and this was attributed to the presence of multiple free surfaces during transient flooding. No capsize was observed in the grounding damage cases.

3.3.4 Panamax Cruise Ship (C2)

Through some exploratory runs and an extensive numerical investigation, a configuration which was likely to produce a critical condition was identified. The tests then were focussed on identifying the wave height at which capsize starts occurring for this condition. The model GM of 2.010m survived in 2.0m waves. This was confirmed by further 10 runs with the test duration doubled (to 60 minutes). The higher intact KG value of 15.855m (GM of 1.798m) was chosen for the grounding damage test condition. Furthermore, the tests were conducted in transient mode only with Hs of 4.0m for the duration of 1800s full scale. Even then, the vessel did neither capsize nor show any sign of capsizing in all 10 runs, although a maximum roll angle of up to 15° was observed on a few occasions.

3.4 Review of results

3.4.1 Collision Damages

The experimental results can be used for the derivation of the probability of capsize in a given sea-state within the finite time duration. The model with a specified loading condition and damage was subjected to a given sea-state for a number of times (typically 10 runs), and the number of runs ending with capsize is counted. This is divided by the total number of runs in that sea-state to produce the capsize rate or probability of capsize. This procedure is repeated for all sea-states to produce the so-called 'capsize transition band'. Valuable information can be drawn from this band such as critical significant wave height. The latter can then be linked to geometrical features of the ship(s) being studied in order to establish the relationship between stability characteristics and critical sea-state and, potentially, time to capsize.

The capsize band is usually characterised by a sigmoid function. The function is derived based on the fact that the graph representing probability of loss (capsize rate) is very similar to the cumulative probability of Gaussian distribution function. However, the quantitative information contained in these graphs should be treated with some caution because of the limited number of experimental results available. It is worth noting that this curve will move to the left with increasing KG (or decreasing GM) values. The curve for a higher KG value is also noticeably steeper than the ones for lower KG values.

Another important entity associated with the loss transition band is a critical significant wave height. A rough estimate of the critical wave height can be made from the graphs. However, a greater number of data points would be required to render the data with higher statistical significance.

Time to capsize (TTC) is another parameter which is of great import. However, the apparent high survivability characteristics of all the sample ships made it difficult to produce meaningful graphs of this important parameter.

3.4.2 Grounding Damages

In all the tests performed with the models inflicted with a grounding damage on the bottom, the models survived the test period without showing the least sign of progressing to capsize or sinking. Indeed the damage hydrostatics show that in most cases the stability improves when damaged. It was not possible to obtain the range of positive stability in some cases and consequently they have been left out from this table, but where available, the range in damaged state was either comparable or better than the intact state.

3.4.3 Transient Flooding

Results of experiments carried in 'transient mode' for sample ship C1 show that a large passenger vessel can experience excessive heel or roll motion in the intermediate stages of flooding soon after (typically within 10 minutes of) the breach of the hull. This is probably caused by simultaneous flooding of multiple decks exposed to sea and the consequent multiple free surfaces. The abrupt ingress of water would also act as an extra source of motion excitation.

Despite the initial large angle heel, the model recovered and achieved 'steady' damage equilibrium when the SWDs were kept closed. However, when the SWDs were left open, both C1 and C2 models promptly capsized in the 'transient mode' tests in calm water. This clearly demonstrates the importance of keeping the SWDs closed in securing the damage survivability of passenger ships.

3.5 Conclusions

Through the experimental study described in this report the following conclusions have been reached:

a. The sigmoid distribution of capsize rate for R1, R2 and C2 suffering collision damage has been obtained. It is expected that C1 would have shown similar characteristics, if more tests with the model could have been run.

b. Time to capsize has shown a very wide distribution for all models suffering collision damage.

c. The most important parameter which determines the survivability of a damaged vessel is the intact stability characteristics, the most obvious of which is GM.

d. In order to obtain experimental data of statistical significance many more tests have to be run for the same models.

e. Tests carried out in 'transient mode' for sample ships C1 and C2 show that a large passenger vessel can experience excessive heel or roll motion in the intermediate stages of flooding soon after the breach of the hull. This aspect will require further investigative attention in the future.

f. The importance of keeping SWDs closed even in harbour has been clearly demonstrated, as the large cruise ship models which refused to capsize in most arduous conditions readily succumbed when the SWDs were left open. Both cruise models showed very good damage survivability, when the SWDs were kept closed.

4 Risk-based damage stability requirement

Objectives: To establish new risk-based damage stability requirements of ROPAX and cruise vessels that are consistent with the IMO safety requirement as formulated in the IMO FSA Guidelines.

4.1 Development of standard risk models for collision and grounding events of passenger vessels

The fleet at risk pertaining to the SOLAS damage stability provisions for passenger ships (conventional ROPAX and cruise ships with length over 80m) has been determined based on clearly defined selection criteria. High level event sequences and detailed event trees covering collision and grounding scenarios have been developed. Data have been collected from a variety of relevant sources, including HIS-Fairplay and LMIU, but also class societies and other sources, to calculate the best possible estimates of the collision and grounding frequencies and probabilities. The same sources have further been used to establish probabilities for struck or striking ship, the operational state when the collision took place i.e. en route, limited waters or at terminal. Probability for sinking is set equal to (1-A) where A is the probability for surviving the collision, calculated according to the GOALDS formulation. Fatality rates in case of sinking were initially assumed to be equal to 100 % as the ship would be assumed to sink rapidly and the potential survivors following the sinking of a ship after a collision could not be seen as resulting from orderly evacuation. Likewise, event trees have been developed for grounding scenarios, considering a variety of aspects and parameters that could be taken from the accident statistics. Branches on the event trees have been populated with probabilities taken from the accident statistic such as: powered or drifting grounding, grounding on a soft or hard seabed and whether the ship floats free after the grounding or not. Corresponding to the collision risk model the probability of sinking is set again equal to (1-A) where A is the probability for surviving the grounding. The risk models have been developed separately for RoPax and Cruise/Passenger ships.

4.2 Benchmarking against existing results

A thorough comparison of the GOALDS risk model and accident statistics with previous work e.g. the SAFEDOR FSA studies on Cruise and RoPax ships has been performed as well as a review of statistical material of historical data available from collision and grounding accidents. As already mentioned, in the developed risk model a fatality rate of 100% was initially assumed in those cases where the ship capsize/sinks. This approach along with some additional simplifications regarding operational status and sea state was identified as Risk Model A. As the work escalated it became apparent that the majority of the task members found this assumption difficult to defend based on observations from real accidents which even included rapid capsize under harsh condition. An alternative assumption, reflecting that the rate of fatalities would depend on whether the ship capsized/sinks fast or slow, was then developed and used in a similar way as in previous studies. This approach has been identified as Risk Model B and includes operational branches in the event trees representing operational status and sea state. It was however noted and agreed that the survivors from a rapid capsize/sinking accident are not normally a result of an orderly evacuation.

In terms of concluding and validating the difference between risk models A and B, the PLL (Potential Loss of life) was used as parameter, and corresponding values have been compared under various assumptions of persons on-board (e.g. capacity of vessel) and attained index A both for RoPax and Cruise ships. As expected, it was observed that the Risk Model A gave substantial higher values of PLL than Risk Model B. Both models were used further in subsequent calculations.

The risk model for grounding has also been subject to benchmarking and validation. At the time of preparing the report there was no method developed for calculating an attained index A for grounding accidents. Therefore two simplified formulations have been proposed for consideration, where the attained index A for grounding is a function of the attained index A for collision.

4.3 Derivation of a new damage stability requirement for collision and grounding based on cost-benefit analysis

The participating shipyards provided the sample ships that were used for the cost benefit assessments. There were two Ropax ships; medium and large and two cruise ships; medium and large. For each sample ship, a design team has been established for the purpose of proposing and evaluating possible changes in the design that could improve the survivability following a collision or grounding in terms of the attained index A, and hence reduce the risk. Each design change was considered to be a Risk Control Option (RCO). Each design team has proposed between 6 and up to 12 RCOs for each sample ship that have been calculated and assessed. The costs relevant for each RCO have been established from the experience of shipyards and operators. Costs have been categorized as additional building costs, e.g. additional steel material and steel work; operational costs such as harbor fees, hotel power load and added fuel costs. All costs and benefits were taken into account as net present value for the assumed life time of 30 years. For each sample ship and each RCO the attained index A has been calculated using both the current SOLAS formulation and the new GOALDS formulation. The GOALDS formulation, based on a new approach for the calculation of the s-factor in the final stage of damage was supplemented by the current SOLAS 2009 criteria for the calculation of the survival probability during the intermediate stages of flooding and for the effect of the external moments. The grounding index A was estimated using an approximation formula relating it directly to the collision index. Using the developed risk models, the benefit from each RCO in terms of reduction in Potential Loss of Lives (PLL) is assessed, and subsequently, the effectiveness of the corresponding RCO is evaluating using the IMO CAF (Cost of Averting a Fatality) criterion. The RCOs that have been found to be within the IMO CAF criterion formed the basis for proposing the level of the required index R. As an additional result, a proposal for updating the CAF criterion was formulated, considering changes in living standard, inflation etc. from year 1996 until today.

4.4 Conclusions

The work that have been carried out for the derivation of a risk-based damage stability requirement provides a substantial amount of exploitable results from which it can be concluded that:

a. The deviations between Attained index A calculated in accordance with current SOLAS and the GOALDS proposal are rather small

b. The GOALDS s-factor used in combination with selected SOLAS criteria to account for the probability of survival during the intermediate stages of flooding and for the effect of external moments was shown to be robust.

c. The level of the required index R for passenger ships can be significantly raised based on the results from the CBA. As expected, additional RCOs are found to meet the CAF criterion when Risk Model A, assuming 100 % fatalities when the ship capsizes/sinks, is used. However regardless of which risk model is used, higher levels of R can be suggested based on the cost benefit assessment.

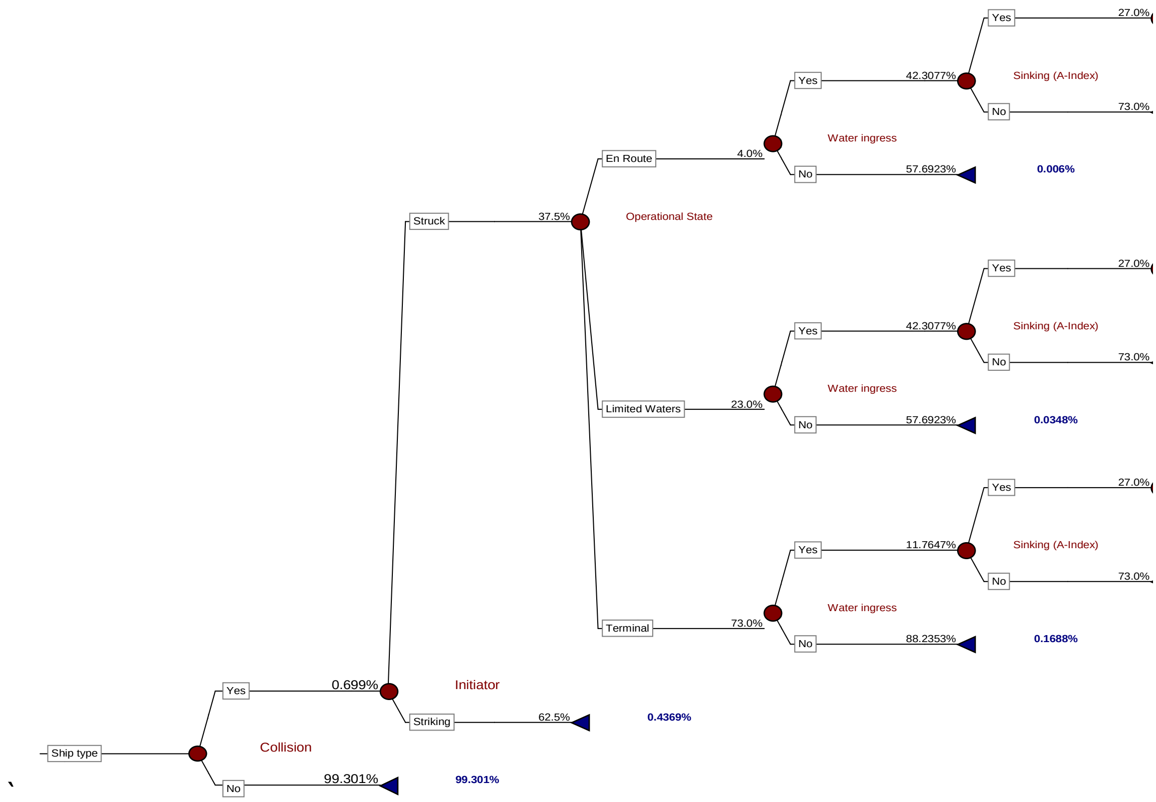

Figure 13: Graph of collision risk model B for Cruise vessels

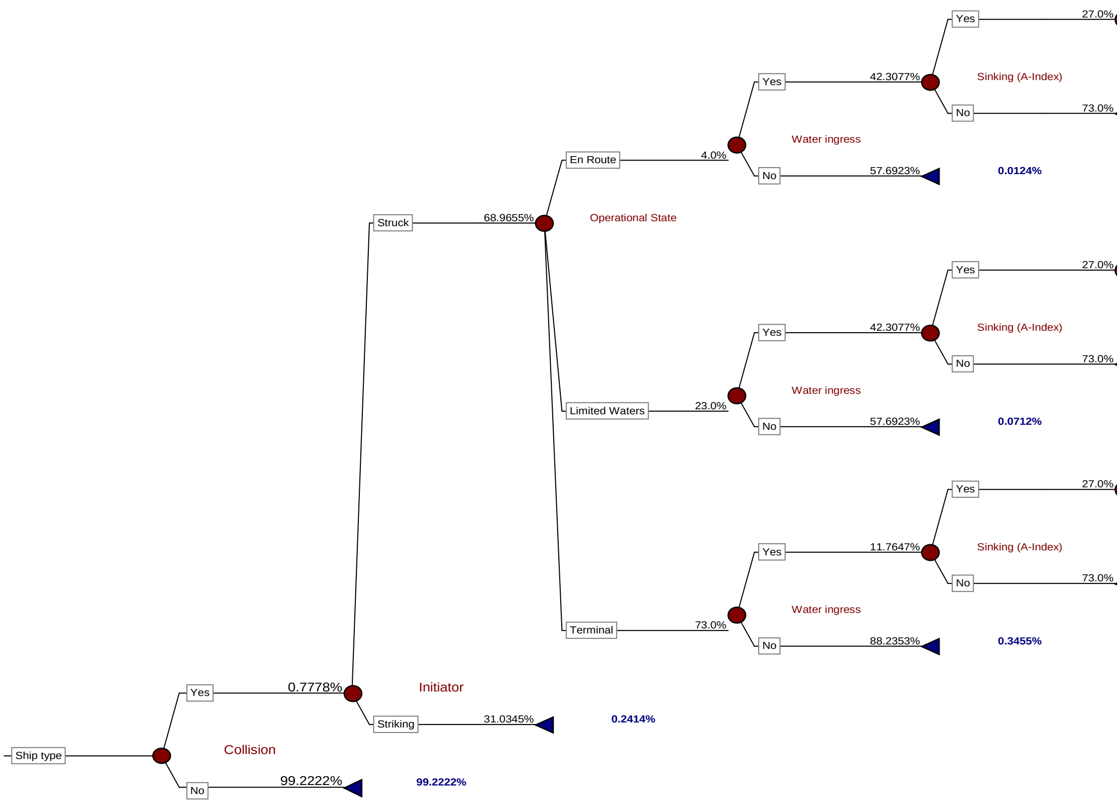

Figure 14: Graph of collision risk model B for ROPAX vessels

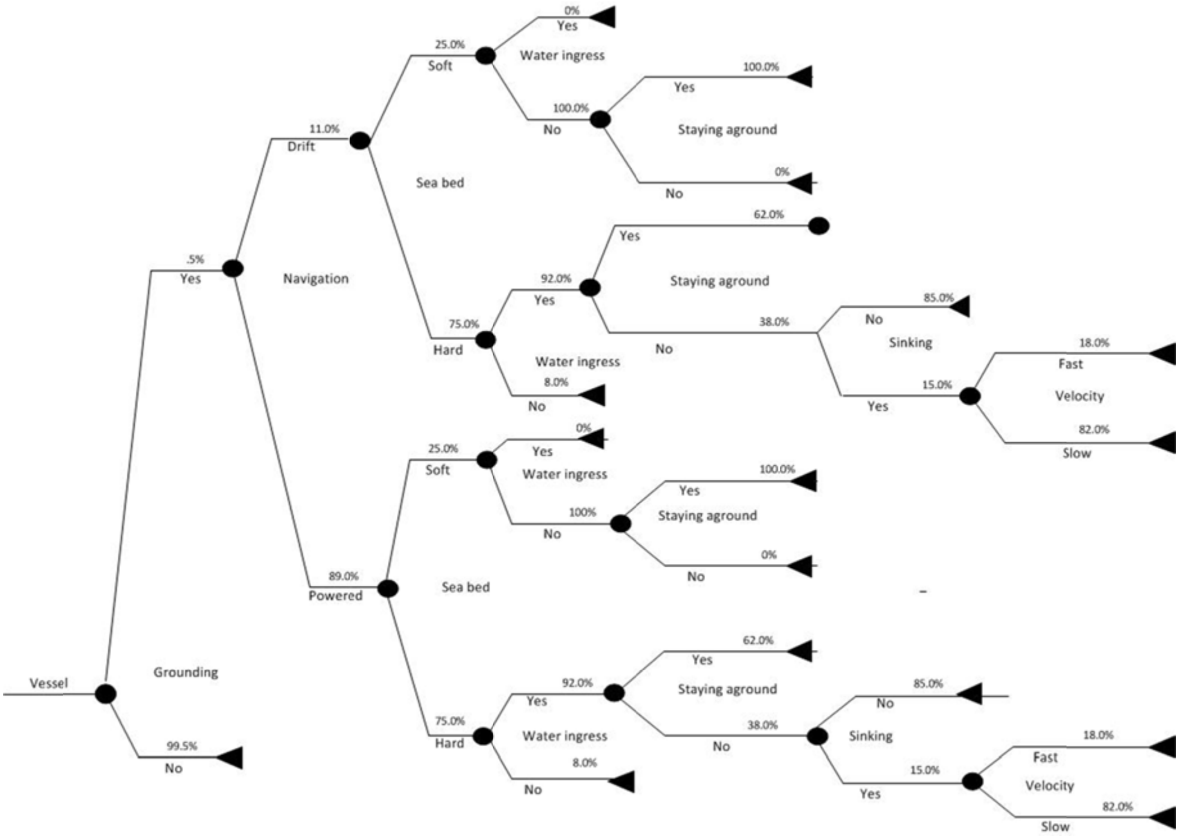

Figure 15: Graph of grounding risk model B for Cruise vessels

5 Innovative ship concept designs based on the new damage stability requirement

Among the objective of GOALDS was to undertake conceptual design and optimization studies of a series of sample passenger ships meeting the newly developed damage stability requirements, considering building cost and efficiency in operation. This enables the systematic investigation of the impact of the new formulation for the probabilistic damage stability of passenger ships on the design and operational characteristics of ROPAX and cruise vessels. An additional objective of this part of the GOALDS work was to rationally define the required subdivision index for passenger ships, based on systematic optimization studies of passenger ships of different type and size, while applying risk and cost effectiveness analysis. The feasibility of enhancing the required subdivision index compared to the current SOLAS 2009 levels, which proved non-satisfactory in a variety of cases, is thus investigated. A first proposal in this respect has been presented in the previous section, considering the cost effectiveness of a limited number of Risk Control Options.

The exploration of the impact of the new formulation is formalized and automated by the introduction of parametric models along with formal, multi-objective optimization procedures. Using specifically developed parametric models, which were tuned to the design of employed sample ships, it is possible to elaborate numerous design alternatives by simply altering the values of the selected design parameters, while linking the parametric models with multi-objective optimization software tools; this enables the rational exploration of the vast design space and the identification of 'optimum' designs, combining enhanced survivability in damaged condition with acceptable (or even improved) economic characteristics in comparison to the original designs.

Six sample ships (four ROPAX and two cruise ships) were selected to be explored/optimized/redesigned. A large number of alternative designs were generated using the developed parametric models and then assessed for the adopted constraints and objective functions. 'Best' feasible designs were selected from the Pareto fronts thus formed. The obtained results were presented in a dedicated workshop organized by GOALDS in Hamburg (May 29, 2012) seeking to receive concluding feedback from the shipyards, operators and other stake holders of passenger ship maritime safety.

5.1 Optimization procedures

Two different design optimization procedures, developed independently by the Ship Design Laboratory of the National Technical University of Athens (NTUA-SDL), and the Ship Safety Research Centre of the University of Strathclyde (SSRC), encompassing the parametric design and optimization of ROPAX and cruise ships were adapted to the new survival factor formulation and applied in collaboration and with the support of the corresponding shipyards providing expertise and empirical data, as and when necessary, for the optimization of selected sample vessels.

The optimization studies were based on the development of a detailed parametric geometry model of each ship in the CASD software NAPA, resembling as accurately as possible the original design. The parametric models were linked to multi-objective optimization software to carry out the formal optimization. Three studies (a small ROPAX, a medium ROPAX and a Panamax cruise ship) were performed by NTUA-SDL using the commercial optimization software modeFRONTIER. The remaining three studies (a small ROPAX, a large ROPAX and a post-Panamax cruise ship) were performed by SSRC employing the in house optimization software .SPIRALTM.

In some optimization studies the outer hull was kept constant, emphasising on the optimization of the internal arrangement, while in other cases the main dimensions of the ship were also varied. In one case (the large ROPAX), a radical modification of the shape of the hull was introduced, enabling the designer to create watertight compartments above the waterline far from the ship's centre line, providing protection to the large garage areas, while at the same time keeps the intact GM values and the roll periods within acceptable limits.

5.2 Optimization studies

5.2.1 First small ROPAX

The first of the small ROPAX designs (Ship 1a) is a small ferry that can carry lorries and cars on the vehicle deck. Vehicles can also be loaded on the hoistable car deck, which can be used when no lorry is carried on the main car deck. Bellow the vehicle deck the ship is subdivided only by transverse bulkheads (no lower hold). The original design has a length between perpendiculars of 120.0m, a beam of 22.0m and a design draught of 5.2m with a Gross Tonnage of 14600GRT. The ship's transport capacity is up to 240 private cars, or alternatively 30 lorries and 91 cars. The ferry can be used for overnight trips, with up to 800 passengers onboard and around 50 members of the crew. Passengers are accommodated either in cabins or lounge seats. The subdivision length corresponds to 129.96 m with required index of subdivision R=0.716 (SOLAS 2009 Ch II-1 Regulation 6).

The objectives of the study were to maximise safety, expressed in terms of probabilistic subdivision index "A", to maximise economic viability and to minimise environmental impact, expressed in terms of EEOI. A series of optimization scenarios were studied, aiming to optimize a) the damaged survivability and the economic performance, b) the economic performance only, c) the economic performance under specific constraints on the transport capacity and d) the economic performance, eco-friendliness and safety. From the Pareto designs, obtained during the first optimization scenario, the "most safe" and the "most economic" design have been selected. The first one has a Subdivision Index according to SOLAS equal to 0.983 and according to GOALDS equal to 0.99, while its Net Present Value is equal to 2.93m$. The corresponding values for the second design are: A_SOLAS=0.965, A_GOALDS=0.98, NPV=5.85m$. A comparison of the Attained Subdivision Index calculated according to SOLAS 2009 and GOALDS formulation for the designs obtained during this optimization study is presented in Figure 16.

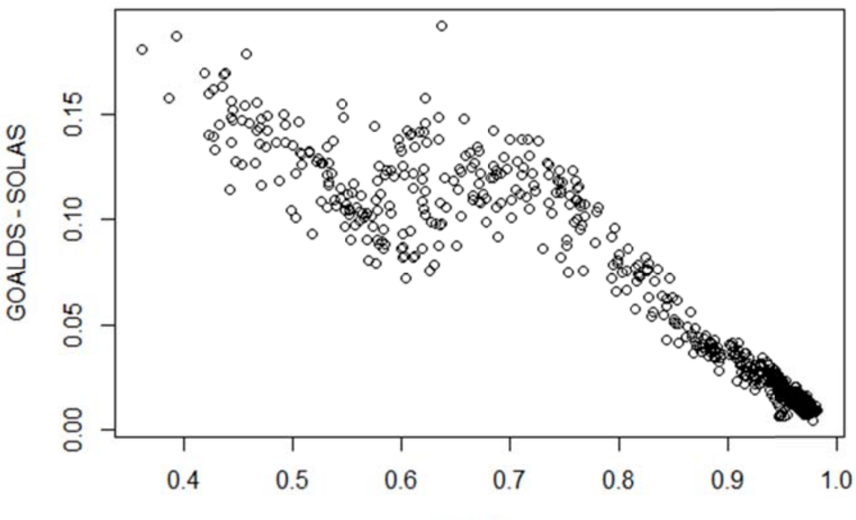

Figure 16: A_{GOALDS} vs A_{SOLAS} for Ship 1a (1st small ROPAX)

5.2.2 Second small ROPAX

This a typical, small size ROPAX ship, with transverse subdivision and no lower hold. The ship is fitted with one trailer deck (deck 3), while a hoistable car deck is arranged above it, with its aft panel being used as a ramp. Deck 3 is designated as the freeboard deck and it is considered to be watertight. The original vessel was designed in compliance with the requirements of the SOLAS 90 and Stockholm Agreement, while also complying with the International Load Line Convention 1966 and the subsequent amendments. It was divided into 13 watertight zones by 12 main transverse bulkheads. The original design has a length between perpendiculars of 89.0m, a beam of 16.4m and a design draught of 4.0m with a Gross Tonnage of 4418GRT. The ship's transport capacity is up to 622 passengers in winter (lounge seats in closed decks for 588 passengers plus 9 cabins for 34 passengers) and 800 passengers during the summer season, 28 crew members, 153 private cars, or alternatively 19 trucks and 3 cars. According to the SOLAS 2009 regulation, the required index of subdivision of the original design is equal to 0.743 (SOLAS 2009 Ch II-1 Regulation 6).

The objectives of the study were the maximization of safety, expressed in terms of the difference between the attained and required subdivision index (A_SOLAS-R_SOLAS), the maximization of the Net Present Value Index calculated over a life time of 30 years, the maximization of the roll period, in order to ensure acceptable roll responses and the minimization of the number of transverse bulkheads to reduce construction cost and to improve everyday operation. In total 694 alternative designs have been obtained, 511 of which complied with the applied constraints (feasible designs). Four designs from the Pareto front have been identified for further consideration, from which the final "optimum" has been selected. This design has been obtained by increasing the main dimensions of the original ship as follows: length between perpendiculars has been increased by 4.0m (4.5%), the beam has been increased by 0.5m (3.0%) and depth to main deck has been increased by 0.2m (2.4%). The maximum draught has been marginally reduced by 0.05m (1.25%). Its GM values are considerably increased (by 0.57m at the lightest draught and 0.47m at subdivision draught) in comparison to the original design. Even with a reduction of the number of transverse bulkheads from 12 to 10, it exhibits an enhanced survivability level, expressed by increased subdivision indices (A_SOLAS=0.918 and A_GOALDS=0.923). The increased length of the ship results in an increase of the lanes length by 4.9% and a reduction of the required propulsion power by 1.3%. The combined effect of these changes results in an increased NPV of 6.42m$. A comparison of the Attained Subdivision Index calculated according to SOLAS 2009 and GOALDS formulation for the designs obtained during this optimization study is presented in Figure 17.

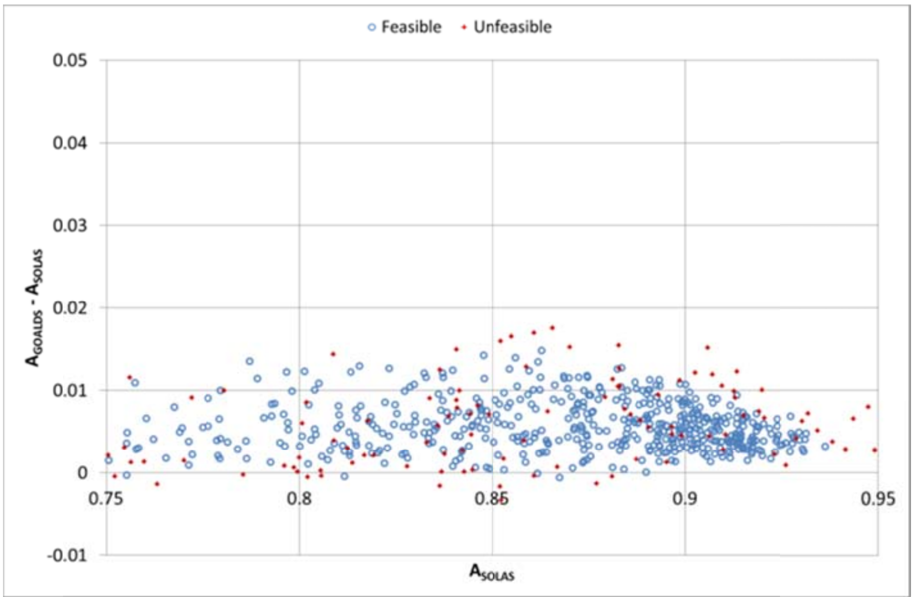

Figure 17: A_{GOALDS} - A_{SOLAS} vs A_{SOLAS} for Ship 1b (2nd small ROPAX)

5.2.3 Large ROPAX

This is a large modern cruise ferry with a roro deck for trucks and trailers, a large lower hold for cars and an additional car deck within the super structure. The cargo handling is based on a drive-through concept with large stern ramps and a bow door and ramp on the bulkhead deck. Access to the other cargo areas is provided via internal ramps. A hoistable car deck is provided to allow for sufficient car capacity. The ship is designed as an overnight ferry with a large number of cabins and suitable public rooms, like restaurants, shopping areas, conference center, lounges and a spa area. The propulsion concept is based on a twin screw plant with CPP and 4 geared main engines. Auxiliary power is provided by 4 diesel generators.

The vessel is designed to comply with SOLAS2009 and the Stockholm Agreement, as well as the latest safe return to port requirements according MSC 216(82). The LSA capacity is based on short-international voyage with limited space in lifeboats and the remaining capacity in state-of-the-art marine evacuation systems (MES).

The original design has a length between perpendiculars of 214.32m, a beam of 32m and a subdivision draught of 6.7m with a Gross Tonnage of 70000GRT. The ship's transport capacity is up to 3300 passengers, with a crew of 200 persons, 1500m trailer lanes and in addition 960m private cars lanes. According to the SOLAS 2009 regulation, the required index of subdivision of the original design is equal to 0.83296 and the attained index is equal to 0.84164.

The original design has a large non-subdivided long lower hold (LLH) providing extra cargo capacity for the ship. However, there have been concerns about the safety level of ships equipped with LLH; for some designs approximately 10% of damage cases are not survivable merely because of LLH. Therefore, the abandonment of the LLH idea has been thought to be a good alternative, provided the needed cargo capacity is maintained. Another design feature is the car deck, which is also not subdivided into watertight compartments to ensure high cargo capacity and ease of cargo handling.

As far as the further increase in ship's damage survivability is concerned, the widening of the ship has been one of the conventional and sometimes convenient solutions. Specifically, if the increase of the ship breadth does not result in an excessive GM, and there is an acceptable surplus in the cargo capacity, this design solution can be often economically justified. The above considerations formed the basis for the design optimization study for ship 2. Specifically, the parametric ship model included options to have LLH-free and car deck subdivided, which were then compared with other design options such as those equipped with LLH and with present/absent subdivision of the car deck. Additionally, an alternative shape for the hull form has been proposed, of increased width between deck 3 and deck 5 by 3 meters. The extra space is made watertight using longitudinal and transvers bulkheads, increasing the floatability and stability of the ship in case of an accident. A vast number of alternative designs have been derived during the optimization. Among them, the most safe design has an index of 0.98/0.99 SOLAS/GOALDS, although the net revenue was compromised by some 89m$ over the life cycle. Therefore, overall, this design can be a good alternative to the baseline, provided the reduced revenues can be sacrificed for significantly improved damage survivability. The most economically efficient design has also a high index (A = 0.94/0.95 SOLAS/GOALDS), while at the same time, due to its extra cargo capacity, has a potential extra life cycle earning capacity of greater than 8m$. A comparison of the Attained Subdivision Index calculated according to SOLAS 2009 and GOALDS formulation for the designs obtained during this optimization study is presented in Figure 18.

5.2.4 Medium ROPAX

This is a typical ROPAX ship, for short international voyages. It is fitted with three trailer decks: a main and an upper trailer deck and a lower garage below the main deck. A hoistable car deck is arranged on the upper car deck. The vessel is fitted with side hinged bow doors and bow ramp and with two combined stern ramps. Access to the upper deck is arranged from the main deck via a tiltable ramp and to the lower garage deck via a fixed ramp with ramp cover. Deck 3 (main deck) is designated as the freeboard deck and it is considered to be watertight. The vessel is fitted with four diesel engines. Each set of two engines is coupled to one gear, connected to shaft line and propeller.

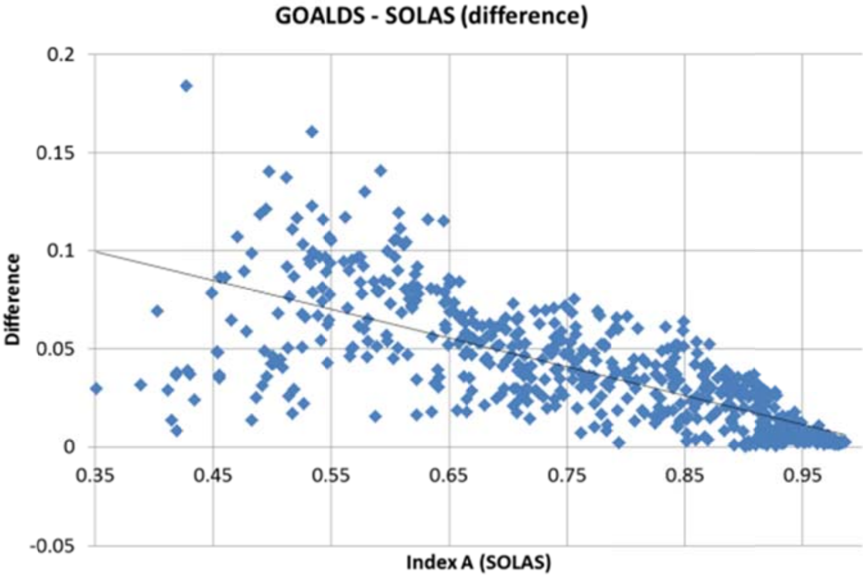

Figure 18: A_{GOALDS} - A_{SOLAS} vs A_{SOLAS} for Ship 2 (Large ROPAX)

The vessel complies with the requirements of SOLAS 2009 (all rules in force for keel laying at 31/12/2009), as well as with MARPOL 73/78 as amended (including addition to regulation 12A) and with the International Load Line Convention 1966 and following amendments.

The original design has a length between perpendiculars of 162.85m, a beam of 27.6m and a subdivision draught of 7.1m with a Gross Tonnage of 36000GRT. The ship's transport capacity is up to 2080 passengers, with a crew of 120 persons, and 1950m trailer lanes. According to the SOLAS 2009 regulation, the required index of subdivision of the original design is equal to 0.79804 and the attained index is equal to 0.80305.

During the optimization study 547 alternative designs have been obtained in total, 423 of which complied with the applied constraints (feasible designs). The design maximizing both the SOLAS and the GOALDS attained index was selected as the optimum design for further evaluation. The obtained subdivision indices for the optimum design are equal to 0.884 according to the GOALDS formulation and 0.8824 according to SOLAS. Even higher subdivision indices were also obtained but would require an even higher GM value, violating corresponding constraints specified by the shipyard to ensure acceptable roll motions and accelerations. This increase in safety can be achieved with an increased building cost of 2.18m$ in comparison with the original design. The total cost that has to be paid over a lifetime of 30 years for the increased level of safety (the gross economic impact of the design modification) is calculated equal to 5.90m$. The gross economic impact is calculated considering the differences from the original design in building cost, fuel expenses and other operational costs. The differences in annual revenues are considered only in case of reduced trailers capacity, while in the case of the increased capacity no extra revenue is credited, assuming that there is no additional cargo available to be transported. The optimum design has an increased trailers capacity in comparison with the original one. If only a small portion of the additional transport capacity could be exploited annually, the additional income would easily overcome the increased building and operating costs, creating additional profit for the operator.

The optimum design was subsequently recalculated with the addition of two transverse watertight bulkheads on the main car deck. In this case the subdivision index increased further to 0.91285 according to SOLAS and 0.91661 according to the GOALDS formulation. A comparison of the Attained Subdivision Index calculated according to SOLAS 2009 and GOALDS formulation for the designs obtained during this optimization study is presented in Figure 19.

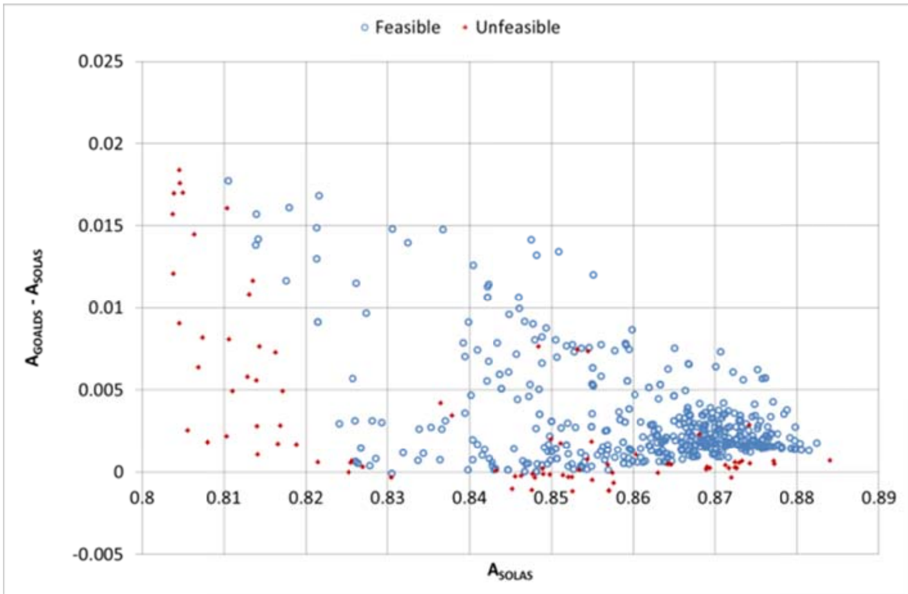

Figure 19: A_{GOALDS} - A_{SOLAS} vs A_{SOLAS} for Ship 3 (Medium ROPAX)

5.2.5 Post Panamax Cruise Ship

The next design to be optimized was a Post Panama sized modern cruise ship, designed for world-wide cruises with capacity of total 5600 persons on board. The design of the vessel fulfils all relevant international rules and regulations. Lifesaving appliances are provided for 5600 persons on board in long international traffic. The vessel has seven main fire zones, while it is divided into 22 watertight compartments below the bulkhead deck (deck 4). Above the bulkhead deck the spaces have been divided into partial watertight compartments. The vessel has a diesel-electric type propulsion plant installed in two watertight compartments. Two electric propulsion motors are located in separate watertight compartments, protected with compartments on each side.

The design complies with all relevant IMO rules and regulations applicable to ships with keel laying after 1 July 2010, including MSC216(82), probabilistic damage stability, Intact Stability Code (IS Code 2008), Load line Convention, MARPOL, including fuel oil tank protection and Safe Return to Port MSC216(82).

The original design has a length between perpendiculars of 300.7m, a beam of 37.4m and a subdivision draught of 8.8m with a Gross Tonnage of 125000GRT. The ship's transport capacity is up to 4200 passengers, with a crew of 1400 persons. According to the SOLAS 2009 regulation, the required index of subdivision of the original design is equal to 0.84867 and the attained index is equal to 0.87079.

The derived optimized design was a result of two-step optimization process. The purpose of the first step was to determine the optimum number of bulkheads and WT doors on the bulkhead deck, and the distribution of tanks (by altering the tank purpose). The second step was related to sizing optimization, with the purpose of determining optimum locations for WT bulkheads and tank sizes for a given topology. The final design is based on the same hull as the baseline design. The design achieved is similar to the baseline design in many aspects. There are some changes which differentiate optimized ship form the baseline design. The changes were applied to the position of bulkheads between main fire zone bulkheads, whereas the number of bulkheads is 21, which is equivalent to the baseline design. The obtained subdivision indices for the optimum are equal to 0.952 according to the GOALDS formulation and 0.93 according to SOLAS. The optimized design exhibits significantly higher damage survivability and this is mainly due to the presence of wt. doors on the bulkhead deck, for the position of bulkheads (the number is the same!) has not changed significantly. A comparison of the Attained Subdivision Index calculated according to

SOLAS 2009 and GOALDS formulation for the designs obtained during this optimization study is presented in Figure 20.

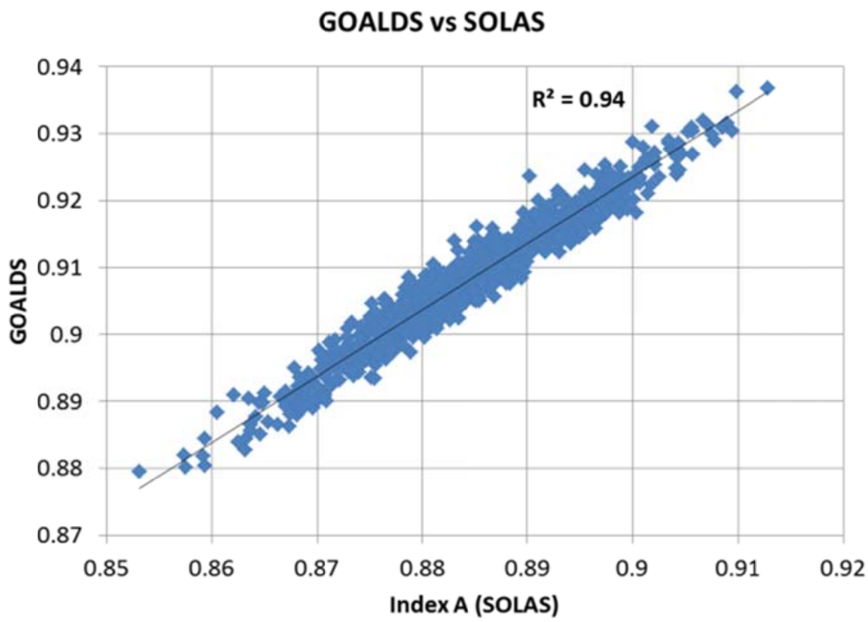

Figure 20: A_{GOALDS} vs A_{SOLAS} for Ship 3 (Post Panamax Cruise Ship)

5.2.6 Panamax Cruise Ship

The original ship is a conventional PANAMAX cruiser carrying up to 3000 passengers and 1000 crew members. The design of the vessel fulfils all relevant international rules and regulations. The vessel has seven main fire zones, while it is divided in 19 watertight compartments below the bulkhead deck (deck 4). Above the bulkhead deck the spaces have been divided into partial watertight compartments. The vessel has a diesel-electric type propulsion plant. Two electric propulsion motors are located in separate watertight compartments, protected with compartments on each side.

The design complies with all relevant IMO rules and regulations including MSC216(82), probabilistic damage stability, Intact Stability Code (IS Code 2008), Load line Convention, MARPOL 12A, and Safe Return to Port MSC216(82).

The original design has a length between perpendiculars of 269.134m, a beam of 32.2m and a subdivision draught of 7.85m with a Gross Tonnage of 92000. The ship's transport capacity is up to 3000 passengers, with a crew of 1000 persons. According to the SOLAS 2009 regulation, the required index of subdivision of the original design is equal to 0. 82152 and the attained index is equal to 0. 84622.

During the optimization study 681 alternative designs have been obtained in total, 508 of which complied with the applied constraints (feasible designs). Two ships on the Pareto Front were selected for the final assessment; the selection was based on the value of the GOALDS attained index versus total economy or additional cost. The first alternative, with an increase in breadth of only 0.7m in comparison to the original design, was selected for its combination of a very good economic performance along with a significantly increased subdivision index in comparison with the original design. Its building cost is increased by 2,66m$ in comparison with the original design, while over a lifetime of 30 years the gross economic impact of the design modifications is equal to -0.11m$. The negative impact is mainly a result of the reduced fuel costs, which over the lifetime of the ship counterbalances the increased building cost. The subdivision indices of this design alternative are equal to 0.89224 (SOLAS) and 0.92884 (GOALDS).

The second alternative, with an increase in breadth by 1.2m and in length by 2.8m in comparison to the original design has subdivision indices (both according to GOALDS and SOLAS 2009 formulations) very close to the maximum obtained, while at the same time exhibits a satisfactory economic performance. Its building cost is increased by 6.63m$ in comparison with the original design, while over a lifetime of 30 years the gross economic impact of the design modifications is equal to 14.6m$. The subdivision indices of this design alternative are equal to 0.92884 (SOLAS) and 0.95399 (GOALDS). A comparison of the Attained Subdivision Index calculated according to SOLAS 2009 and GOALDS formulation for the designs obtained during this optimization study is presented in Figure 21.

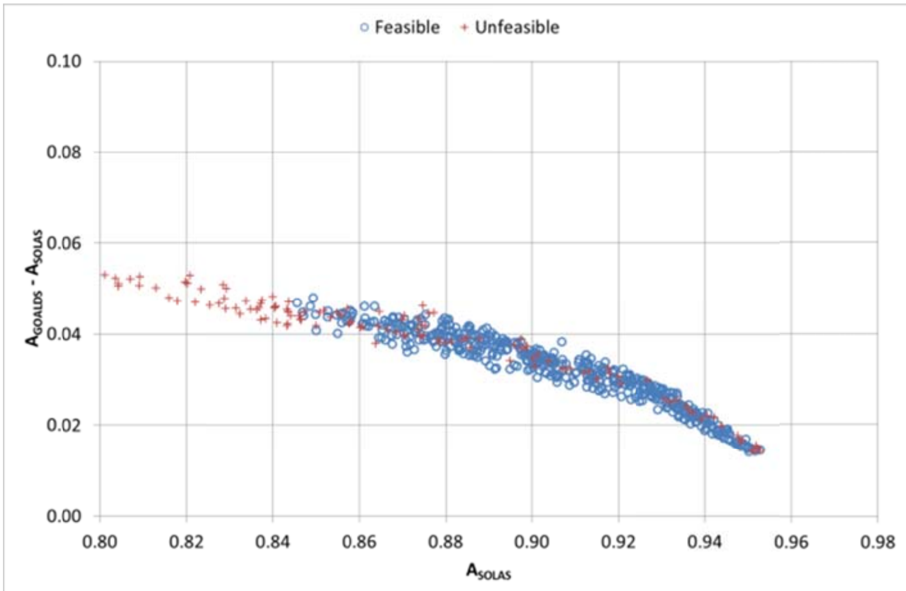

Figure 21: A_{GOALDS} - A_{SOLAS} vs A_{SOLAS} for Ship 5 (Panamax Cruise Ship)

5.3 Conclusions

The obtained results indicate a close relationship between the Attained Indices calculated according to the SOLAS 2009 regulation and the GOALDS formulation, with the latter being always slightly larger. The differences between the two indices are quite small (usually less than 0.05) and are getting smaller as they both increase towards 1.0. Larger differences (even up to 0.15) where observed only in the cases of ship 1a and ship 2 and only for designs with reduced safety in damaged condition.

The calculation of the new subdivision index according to the GOALDS formulation is based on a new formula for the survival s-factor. Validation studies demonstrated improved correlation of the proposed GOALDS s-factor with numerical simulation results as well as with an enhanced sample of experimental data, in comparison with the SOLAS 2009 regulation. It is therefore argued that the attained index calculated according to the GOALDS formulation represents an improved measure of the safety of the ship in a damaged condition.

An important conclusion from the conducted studies is that it proves cost effective, when considering the reduction of risk of PLL, to generate designs with attained indices over 0.90 for the entire range of passenger ship sizes considered. This practically suggests that the risk for the loss of life may be greatly reduced, compared to the SOLAS 2009 provisions and becomes quite uniform, independently of ship size.

It should be kept in mind that ship design is a complex process, and, therefore, it is difficult to capture all design details within a parametric model. The parametric models are based on several simplifications, regarding for example the calculation of weights and VCG, powering and building costs. Therefore, the obtained results in terms of stability and economic impact must be treated with some caution. Nevertheless, the applied optimization methodology, which presumes the development/existence of a parametric model with all main design features of the ship's layout, can be a valuable tool, assisting the designer in the exploration of the huge design space within reasonable computing time. The developed methods and software tools may also assist administrators/regulators in setting-up/defining reasonable levels of ship's survivability after flooding that can be achieved cost effectively by a variety of Design Risk Control Options.

6 Critical assessment of results and submission to IMO

Among the main objectives of GOALDS in the final stage of the project were the following tasks

- to perform a critical evaluation of the new formulation for the survivability of damaged passenger ships
- to perform a critical evaluation of the new requirement for the survivability of damaged passenger ships
- to seek consensus regarding the new formulations among the partnership and flag state administrations participating the advisory committee and
- to prepare a proposal for possible amendments of currently in force regulations through a submission to IMO

6.1 Critical evaluation of the new formulation for the survivability of damaged passenger ships

Based on the systematic calculations carried for a series of sample ships, the conclusion can be drawn that the new s-factor proposal, as implemented, has been shown to be robust. It delivers results that are in general close to the calculations carried out with the current SOLAS. However, this could possibly also be an effect of the investigated sample ships, which were designed according to current SOLAS.

It is noted that there were more model test data utilised for the development of the formulation for ROPAX ships than for the cruise vessels. For the cruise vessels only one of the sample ships has been utilized for the new s-factor formulation, and the number of points describing the probability for capsizes and corresponding critical wave heights are relatively few. It is therefore a source for some uncertainty whether the new s-formulation adequately covers the special cruise ship arrangement on the bulkhead deck, where there are normally partial watertight bulkheads leading an open corridor.

As shown for the conducted validation studies, the s_{goalds} can give high probability of survival even for GZ-curves considered to be weak. It is therefore considered important that the complete formulation for s is applied in practice. Furthermore, it is recommended that more research work is carried out on the intermediate stages of flooding.

There is also a need to develop a clear interpretation of the residual volume VR prior to a submission of results for considerations to IMO. The GOALDS s-factor should not be proposed to replace the current SOLAS s-factor as the parameters reflecting evacuation of the ship are not included.

The calculation of the A based on the GOALDS formulation should be seen as reflecting a passenger ship’s capability to be its own lifeboat. The calculation of A and corresponding required level of R to be developed should therefore be proposed as additional requirements to passenger ships covered by current SOLAS.

6.2 Critical evaluation of the new requirement for the survivability of damaged passenger ships

The work conducted in WP 5 and WP6 of GOALDS leads to a proposal for the required damage stability index R of passenger ships using the Cost-Benefit Assessment (CBA). For the CBA risk models for collision and grounding accidents were developed based on comprehensive investigation of casualty reports and under consideration of the expertise provided by the project partners. The developed risk models allow a calculation of risk in terms of fatalities and loss of ship related to the damage stability of the ship. For representative sample ships design variations focusing on increased damage stability were developed, so-called Risk Control Options. These design variations were developed by yards and application of numerical optimisation methods. For

CBA the additional costs of these RCOs were determined and evaluated as specified in the FSA guidelines. Cost beneficial RCOs were used to develop a proposal for R-Index related to people onboard.

An important conclusion from the conducted studies is that it proves cost effective, when considering the reduction of risk of Potential Loss of Lives (PLLs) of People On Board (POB), to generate designs with attained indices over 0.90 for the entire range of passenger ship sizes considered. This practically suggests that the risk for the loss of life may be greatly reduced, compared to the SOLAS 2009 provisions and becomes quite uniform, independently of ship size.

It should be kept in mind that ship design is a complex process, and, therefore, it is difficult to capture all design details within the parametric models used in project's optimization studies. The parametric models are based on several simplifications, regarding for example the calculation of weights and VCG, powering and building costs. Therefore, the obtained results in terms of stability and economic impact must be treated with some caution. Nevertheless, the applied optimization methodology, which presumes the development/existence of a parametric model with all main design features of the ship's layout, can be a valuable tool, assisting the designer in the exploration of the huge design space within reasonable computing time. The developed methods and software tools may also assist administrators/regulators in setting-up/defining reasonable levels of ship's survivability after flooding that can be achieved cost effectively by a variety of Design Risk Control Options.

6.3 Proposal of new formulation and requirement for the survivability of damaged passenger ships

The final task of the project focused on the preparation of a submission to IMO summarising the key results and presenting the new formulation and requirement for the survivability of damaged passenger ships. The submission is a joint submission of both participating flag states (DMA and MCA), in close collaboration with relevant EC DG MOVE services (EMSA). The submission has been planned for IMO-SLF55 (deadline for electronic submission December 14, 2012).

For adequately preparing the submission text and reaching a consensus among project's partners about the proposal of GOALDS to IMO-SLF, a preparatory task meeting was held in October 2012 in Hamburg, in which representatives of the end users (yards and operators) were participating. The meeting participants agreed to support the DMA-MCA submission paper by three INF papers as following:

1. Summary of work on collision and grounding statistics, D7.3.1 (GL), with two ANNEXES (D.3.1 and D3.2)
2. Summary of work new survival factor for passenger ships, D7.3.2 (SSRC)
3. Summary of work on new risk based damage stability requirement, D.7.3.3 (DNV)

The IMO-SLF55 submission paper refers specifically to the following highlights of GOALDS:

1. Extending the formulation introduced by IMO-MSC 216 (82) for the assessment of the probability of survival of passenger ships in damaged condition, based on extensive use of numerical simulations.
2. Performing comprehensive model testing to investigate the process of ship stability deterioration in damaged condition and to provide a basis for the validation of the numerical simulation results.
3. Compiling damage statistics and probability functions for the damage location, length, breadth and penetration in case of a collision / grounding accident, based on a thorough review of available information regarding these accidents over the past 60 years worldwide.

4. Formulating a new probabilistic damage stability concept for passenger ships, incorporating collision and grounding damages, along with an alternative method for the calculation of ship survival probability.
5. Establishing new risk-based damage stability requirements of passenger vessels based on a cost/benefit analysis to establish the highest level for the required subdivision index.
6. Demonstrating that a potentially commercially viable passenger ships (RoPax and cruise ships) could be built to a significantly higher Attained Index
7. Investigating the impact of the new formulation for the probabilistic damage stability evaluation of passenger ships on the design and operational characteristics of a typical set of ROPAX and cruise vessel designs (case studies).

IMO member states are asked to consider the outcome of the GOALDS project and take action, as appropriate.

7 Potential Impact and Wider Societal Implications of the Project

The final objective of the GOALDS project is to develop and submit to IMO a proposal with an enhanced formulation for the assessment of solvability of passenger ships in damaged condition, resulting from a collision or grounding accident. It is hoped that this proposal will be subject to consideration in IMO and that it will provide the basis for the improvement of current damaged stability regulations, leading to an enhanced level of safety for the persons onboard. This has been herein linked in a rational way to societally satisfactory acceptance levels for the potential loss of lives of people onboard passenger ships.

The submission of results of EU funded projects to IMO (continuing the successful tradition introduced by the FP4 project HARDER and later continued by the FP6 project SAFEDOR and FP7 FLOODSTAND) enhances the visibility and importance of the European Union in international maritime rules-making bodies, like the International Maritime Organisation.

In addition to the above, the EU community added value is through the further enhancement of the competitiveness of the European passenger shipping and shipbuilding industry, of naval architects, researchers and marine technology providers with respect to the introduction of innovations and optimization of passenger ship design.

The European shipbuilding industry is the undisputed market leader in the sector of cruise ships due to its specialisation to high-quality and high-technology vessels. Practically all large cruise ships of today and most of the larger ROPAX vessels are built in Europe, while the shipyards building these vessels have a major influence on the welfare of the surrounding society, the national and European economies. However, it is not an easy task to maintain the leading position in this limited branch. Tough competition from outside Europe must be faced recurrently. The only way to make it possible is a continuous process of development, search for new possibilities in design by considerable efforts in R&D. New innovative solutions that may break old limits can be found, but this process must be carried out in a controlled way, otherwise it may not be possible to guarantee safety.

In addition to its importance for the European shipbuilding industry, cruising is a major source of inbound tourism for European countries, according to the European Cruise Council. Between 1995 and 2005, demand for cruising worldwide more than doubled from 5.7 million to 14.4 million passengers. Over the same period the number of Europeans taking cruise holidays around the world more than trebled from 1 million to 3.3 million. The rapid growth is expected to continue in the coming years. Within Europe, 2.6 million cruise passengers embarked on cruises from European ports in 2005, and 99% of these were European national, and their holidays generated 13 million passenger visits to European ports. It can be concluded that passenger ship sector is, in short, a major industry in and for Europe.

By the obtained results of this project, new knowledge is publicly available to support pre-normative research towards standards and regulations, and explanatory measures to assess their impact. The proposed new goal-based damage stability standard supports both the ship designers to explore novel design options and the administrations in their rational approval procedure. In this way the project helps both the designers and safety authorities to better protect the vulnerable persons onboard. The improvement of the reliability of the assessment of the safety onboard is a very demanding task for all stakeholders of marine safety faced by the rare, but hazardous event of flooding after ship damage.

8 Dissemination Activities

Dissemination of the project's output has been at a number of levels. During the course of the project, regular progress reports, technical papers etc. documenting the developed foreground information have been produced to meet specific milestones and for presentation at the GOALDS workshops, the proceedings of which are published, and made available through the set-up project's web site (www.GOALDS.org). The research is thus reaching a wide audience of technical experts in ship design and ship safety.

8.1 Project Workshops

During the elaboration of the project, a series of Workshops has been organized:

8.1.1 First Project Workshop

The first project workshop was held on September 8-9 2010 at the premises of University of Strathclyde, Glasgow, UK. It was organized by the GOALDS beneficiary Ship Stability Research Centre (SSRC,) in collaboration with the project coordinator (NTUA-SDL). The workshop has been attended by a large number of researchers, professionals and experts in the field of ship safety. Presentations have been given by participants of the GOALDS consortium as well as by invited speakers from the European Commission, the Advisory Committee, IMO, U.S. Coast Guard the Swedish Maritime Authority, the National Maritime Research Institute of Japan and from the Industry. The workshop addressed first analysis results and developments in the framework of 1st year research activities of GOALDS on passenger ship safety and in particular in relation to passenger ships damage stability. During the first session, invited speakers from IMO, the European Commission, Flag Administrations and Research Institutes discussed key issues of ship safety with emphasis on damaged stability. During the second and third session, project partners addressed the GOALDS objectives and rationale, while results and developments obtained during the first year of the project were presented and discussed. The workshop offered the opportunity for a thorough and constructive discussion on the GOALDS objectives, the adopted scientific approach and early project results, as well as on other important subjects related to current damage stability rules and possible amendments of the regulatory framework. Presentations, valuable comments and concerns were expressed by the Advisory Committee, Flag Administrations and Shipyards. Finally, related research developments in Japan were presented and discussed.

8.1.2 Second Project Workshop

The second project workshop was held on October 31 to November 1, 2011 at the premises of DNV Headquarters in Høvik-Oslo, Norway. It was jointly organized by two GOALDS beneficiaries, namely the Maritime and Coastguard Agency (MCA, UK) and Det Norske Veritas (DNV, Oslo) in collaboration with the project coordinator (NTUA-SDL). The workshop has been attended by a large number of researchers, professionals and experts in the field of ship safety. Presentations have been given by participants of the GOALDS consortium as well as by invited speakers from the European Maritime Safety Agency (EMSA), IMO (SLF), the National Maritime Research Institute of Japan and from the related EU FP7 project FLOODSTAND. The workshop addressed progress results and developments in the framework of the 2nd year research activities of GOALDS on passenger ship safety and in particular in relation to passenger ships damage stability. During the first session, invited speakers from European Maritime Safety Agency, IMO, Flag Administrations and Research Institutes discussed key issues of ship safety with emphasis on damaged stability. During the second and third session, project partners addressed the GOALDS objectives and rationale, while results and developments obtained during the second year of the project were presented and discussed. The workshop offered the opportunity for a thorough and constructive discussion on the GOALDS objectives, the adopted scientific approach and current project results, as well as on other important subjects related to current damage stability rules and possible amendments of the regulatory framework. Presentations, valuable comments and concerns were expressed by the Advisory Committee, Flag Administrations, Shipyards and from the EU project FLOODSTAND. Finally, related research developments in Japan were presented and discussed.

8.1.3 Third Project Workshop

The third project workshop was held on May 29, 2012 at the premises of Germanischer Lloyd SE in Hamburg, Germany. It was organized by GL in collaboration with the project coordinator (NTUA-SDL). The workshop has been attended by invited representatives of the GOALDS consortium, GOALDS Advisory Committee members, the European Maritime Safety Agency and European Commission – DG MOVE. The workshop addressed intermediate and final results of the optimisation of a series of sample passenger ships and developments of innovative designs in relation to passenger ships' damage stability. It offered the opportunity to evaluate the impact of the new GOALDS damaged stability approach on the design and on the operational characteristics and performance of a sample of RoPax and Cruise vessels and to assess the survivability and efficiency of the designs obtained by formal optimizations in comparison to the original vessels. During the workshop, passenger ship designs of enhanced survivability and efficiency were presented. The enhanced designs are the result of employed parametric, multi-objective optimisation procedures applied to the original vessel design concept. The survivability properties of the generated designs, expressed by the attained subdivision indices, may be used as a yardstick for the definition of the risk-based damage stability requirement. It is considered very important that the workshop enabled to receive valuable feedback on the design work of WP6 from all stakeholders of maritime safety, namely the shipyards, operators, class societies, flag states, administrators and research institutes.

8.1.4 Fourth Project Workshop

The fourth project workshop was held on May 30, 2012 at the premises of Germanischer Lloyd SE in Hamburg, Germany. It was organized by Germanischer Lloyd in collaboration with the Danish Maritime Authority. The workshop has been attended by invited representatives of the GOALDS consortium, GOALDS Advisory Committee members, the European Maritime Safety Agency and the European Commission – DG MOVE. The workshop focused on a critical evaluation of the new formulation of probability of survival (GOALDS task 7.1) and the new risk-based requirement for the survivability of damaged passenger ships (GOALDS task 7.2), following the development activities in WP3 and WP5. This workshop aimed at providing an independent evaluation of the newly derived formulations for the survivability of damaged passenger vessels. The focus was on a review performed by the work package leader (GL) with the objective to identify possible weak elements in the new formulations. The effect of the new damage stability requirement with respect to societal acceptance was assessed through this workshop.

8.2 Other Dissemination Activities

Presentations and publications regarding the GOALDS objectives and outcome of results have been presented by the project coordinator, the PMC and project members in the following Conferences, Workshops, and scientific journals:

- 11th Int. Ship Stability Workshop (MARIN-Wageningen, June 2010)
- Year 1 GOALDS Public Workshop (SSRC-Glasgow, September 2010)
- 3rd International Symposium on "Ship Operations, Management and Economics", SNAME local branch, Athens (October 2010)
- 4th Int. Design for Safety Conference (Trieste , October 2010)
- Int. Correspondence Group IMO-SLF progress report (London, January 2011)
- Lloyd's Register, Strategic Research Initiatives in Greece, HORIZONS (Greek Poseidonia Edition), June 2010, pp.24 – 25

- RINA, Invited presentation at London Branch, January 13, 2011
- 12th Int. Stability Workshop (DTMB-Washington, June 2011)
- Year 2 GOALDS Public Workshop (DNV-Oslo, October 2011)
- Invited EC DG MOVE & Res. (Brussels, March 2012
- Invited EC EMSA (Lisbon, March 2012)
- EU Transport Research Arena, TRA12 (Athens, April 2012)
- Invited press Conference, Transport Research Arena, TRA12 (Athens, April 2012)
- Invited EC Passenger Ship Safety Conference (Brussels, April 2012)
- Journal Marine Science and Technology (Springer Publ., Tokyo, 2012)
- Journal Procedia - Social and Behavioral Sciences (Elsevier Publ., 2012)
- 3rd and 4th GOALDS workshops (GL-Hamburg, May 2012)
- 11th International Marine Design Conference IMDC2012 (Glasgow, May 2012)
- Invited EC DG MOVE (Brussels, July 2012)
- 12th International Conference on Stability of Ships and Ocean Vehicles STAB 2012 (Athens, September 2012)
- IMO-SLF final report (submission by DMA-MCA, Dec. 2012)

A project web site (http://www.goalds.org) was set-up by the coordinator, to facilitate the communication and dissemination of project information among the project partners, the members of the Advisory Committee and the public; access to the project's site and internal project pages is controlled by a password system, which considers various levels of authorization according to the user's origin.

9 Exploitation of Results

The main outcome of GOALDS is its contribution towards the enhanced safety of the passenger maritime transport and the facilitation of the application of rational, risk-based procedures to the design of RoPax and cruise ships, a clear domain of the European shipbuilding industry. This is achieved by delivering a rational, fully validated, robust and consistent method for assessing the safety of passenger ships in case of a collision or grounding. On the way to this goal, the project is delivering a whole array of useful applications and products. In this way, the project aims at further developing and complementing past work of several research projects, which have contributed to the development and the adoption of the new harmonized damage stability regulations.

By the available results of the project, new knowledge is becoming publicly available to support pre-normative research towards standards and regulations, and explanatory measures to assess their impact. The proposed new goal-based damage stability standard will support both the ship designers to explore novel design options and the administrations in their rational approval procedure. In this way the project helps both the designers and safety authorities to better protect the persons onboard. The improvement of the reliability of the assessment of the safety onboard is a very demanding task for all stakeholders of marine safety faced by the rare, but hazardous event of flooding after ship damage. The outcome of this project is being sought by the entire international maritime community, working in recent years on the further improvement of passenger ship's safety, especially in view of ultra large cruise ship design and operation.

Essential results of the proposed research pertaining to the improvement of current international passenger ship regulations are submitted for consideration to the International Maritime Organization (IMO), with the help of the participating flag authorities and the formed Advisory Committee. Proper actions have already been taken to timely inform IMO relevant committees (mainly SLF) about the progress of project's work and to coordinate the timely submission to IMO in view of ongoing discussions at the International Correspondence Group of SLF about the revision of SOLAS 2009.

A close collaboration of GOALDS with the Intersessional Correspondence Group (ICG) of IMO-SLF on 'Damage Stability Regulations for Passenger Ships' was envisaged and has been established, as well as an ongoing co-operation with other organizations such as EMSA, MCA, EUROYARDS and expert groups of the industry such as the CLIA Cruise Ship Safety Forum.

Formal participation of the coordinator to the IMO ICG was provided, depending on the agreed terms of reference for such group on each intersessional year. The participation was achieved either via a flag state delegation, the EC or another NGO (e.g. CLIA or CESA). An alternative was also to submit formal information papers to the IMO via the GOALDS Flag State Partners (DMA and MCA).

Additional activities and measures for the exploitation of the research output are coordinated by an Exploitation Committee, consisting of the Project Coordinator, two appointed additional Exploitation Managers from the industry and one University. A draft exploitation plan was included in the First Interim Report. A revised exploitation plan was elaborated and submitted during the execution of the project (month h20). The exploitation plan was updated and resubmitted at the end of the project.

The project is aimed at providing a quantum leap in understanding the complex physics behind the behaviour of a damaged passenger ship. Considering the fundamental differences in RoPax and cruise ship design, and the unique concept of simplified generic models should enable designers and regulators with far better tools than before for making rational designs and regulations. New and updated accidents databases have being established, and unique tools for quantifying the probability of damage and calculating expected extent of damage following a grounding and probability of survival are made exploitable by all parties.

Therefore the results are mainly targeted to assist regulators in their work with new and improved regulations for passenger ships covered by SOLAS, with an expected time for exploitation of maximum three years. The timing is very appropriate in light of the need for new passenger ships to comply with the challenges of the water-borne transportation in Europe and the international cruise business. By introduction of new and rational, risk-based criteria now, new passenger ships may be designed with greater flexibility without compromising safety.

The main product of GOALDS – a rational probabilistic approach to assessing collision and grounding of passenger ships and the rational criteria deriving there from - as well as the consequence analysis tools leading to these may of course be exploited by the maritime community on a worldwide basis, but the detailed knowledge and understanding of the method remains within Europe, and thus providing the European maritime community with a significant technological edge.

This is especially valid for the shipbuilding industry, which needs to gain significant knowledge on how to apply the new approach on the design of passenger ships following an improved probabilistic concept, better accounting for the special design features of RoPax and cruise ships. It is underlined that, although the end result has to be exploited and disseminated to the whole world's maritime industry, the in-depth expertise, experimental data, numerical models etc. shall remain within the European Community for exploitation according to separate agreements. Agreements on the exploitation of the results and intellectual property are regulated by the Consortium and the signed Consortium Agreement. The exploitation of the project's outcome will be governed by the following principles:

1. It is the agreed policy of the Partners to allow foreground information on all aspects of the research to be seen and reviewed by members of the project members, as it is developed, and applied as appropriate.
2. It is the agreed policy of the Partners to allow the individual organisations involved to develop further the computer modelling techniques established by the research for sole commercial exploitation in whatever capacity is deemed appropriate.
3. The leading principle concerning Intellectual Property Rights is that all partners will retain IPR over their own work and innovations, unless otherwise explicitly agreed.
4. The experimental data derived, whilst available for sharing during the course of the work, will as soon as the project is completed, revert to the sole ownership of the organisation responsible, to be exploited as appropriate.

The strategy for application of GOALDS results should not involve complex commercial agreements amongst the partners; for instance, the exploitation of new designs by shipyards or the exploitation of new design philosophies and acceptance procedures by the Classification Societies, Flag Authorities and the Ship Designers.