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.

The main objectives of the GOALDS project were 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.

Project Context and Objectives:

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.

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.

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).

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 may 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 new buildings. 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.

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.

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.
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.
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.
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.

Project Results:
1) New formulation for the calculation of the probability of survival in damaged condition

One of the key objectives of the GOALDS project was 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:

1.1 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.

In general, the statistical analysis of collision accidents characteristics verified the HARDER data and the probabilistic formulae stipulated in the SOLAS 2009. 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. 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. 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 exceeding bottom damage dimensions as specified by SOLAS. The obtained probabilities of exceeding 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.

1.2 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:

1.2.1 Modes of loss

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

a) Capsize;
b) Transient capsize; and
c) Sinking - floatability failure.

These three basic modes can be further categorised with respect to time to failure into rapid and gradual.

1.2.2 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). 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.

1.2.3 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. 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.

1.2.4 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.

1.2.5 The s-factor

The investigations led to the conclusion that the parameters to be included in the s-factor formulation should at least include GZmax, Range, a measure of the residual volume (VR) and additionally GMf (metacentric height of flooded vessel). The data processing finally resulted in a suitable regression formula expressing Hscrit as a function of the above values (GZmax, Range, VR and GMf). 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 Hscrit based on the IMO distribution of sea-states encountered during collision incidents.

1.2.6 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. Based on the available data, an appropriate formula has been obtained, expressing the TTC as a function of the actual significant wave height and Hscrit.

1.3 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. 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.

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. 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.

1.4 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, to 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 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.

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

$$A = 0.71A_c + 0.29A_{gr}$$

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).

1.5 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.

2) 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 (two Ro-Pax ferries and two cruise ships) which can often be encountered today but for which there is a dearth of experimental or full scale data available.

2.1 Selection of Damage Scenarios

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.

2.4 Review of results - Conclusions

Through the experimental study, 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.

3) 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.

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

The work that has 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.

4) 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.

4.1 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 mode FRONTIER. 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 SPIRAL™.

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) 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

5.1 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 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.

5.2 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.

5.3 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:

a) Summary of work on collision and grounding statistics, D7.3.1 (GL), with two ANNEXES (D.3.1 and D3.2)
b) Summary of work new survival factor for passenger ships, D7.3.2 (SSRC)
c) 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:

a) 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.
b) 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.
c) 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.
d) 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.
e) 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.
f) Demonstrating that a potentially commercially viable passenger ships (RoPax and cruise ships) could be built to a significantly higher Attained Index.
g) 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.

Potential Impact:

Expected impact of the GOALDS 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 socially 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.

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 (see http://www.goalds.org online). The research is thus reaching a wide audience of technical experts in ship design and ship safety.

During the elaboration of the project, a series of Workshops has been organized:
1) First Project Workshop: held on September 8-9 2010 at the premises of University of Strathclyde, Glasgow, UK.
2) Second Project Workshop: held on October 31 to November 1, 2011 at the premises of DNV Headquarters in Hovik-Oslo, Norway.
3) Third Project Workshop: held on May 29, 2012 at the premises of Germanischer Lloyd SE in Hamburg, Germany.
4) Fourth Project Workshop: held on May 30, 2012 at the premises of Germanischer Lloyd SE in Hamburg, Germany.

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 PropediaXXX(Elsevier Publ.)
- 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
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.

Project website: http://www.goalds.org/

Related documents

140802371-8_en.zip

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