NAME – SSRC

Maritime and Coastguard Agency Lectureship

FINAL REPORT

By

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1. EXECUTIVE SUMMARY

The scope of the grant-in-aid in support of a Research Lectureship post at the Ship Stability Research Centre, Department of Naval Architecture and Marine Engineering of the Universities of Glasgow and Strathclyde was to disseminate knowledge to the Maritime and Coastguard Agency (MCA) of research and development activities in the area of risk-based ship design, operation and regulation to ensure that the UK remains at the forefront of strategic changes in ship safety during the period April 2003 to March 2006.

The agreement between the Maritime and Coastguard Agency and the Ship Stability Research Centre contains a number of technical objectives which detail the specific information and knowledge deemed necessary under the remit of this grant-in-aid, as follows:

- Reporting of developments in pro-active rule compliance and "rule-tool mapping".
- Reporting of developments in risk-based design frameworks/methodologies and life-cycle risk/cost models.
- Monitoring and reporting developments on safety performance analysis tools and on safety "equivalence" between risk-based rules and performance-based criteria using first principles tools and approaches.
- Monitoring and reporting on all developments concerning human and organisational factors as well as modelling aspects concerning quantitative assessment of their effect on maritime safety.
- Updating MCA staff on EU and international developments on safety research, concerning specific projects, Thematic Networks and future developments (e.g., Integrated Projects and Networks of Excellence).
- Involve MCA staff in EU research programmes on a need basis and as advised by MCA.
- Assist MCA staff, as required, in preparing IMO submission papers pertinent to SSRC research.
- Assisting MCA staff on all the above and on any safety-related matters as required.
- Research gap analyses and recommendation on research priorities in consultation with MCA staff.
- Research the survivability of small passenger vessels

The principal means used to address this scope were the following:

- Quarterly reports comprising:
  - Updates on EC-funded research projects under execution, based on information made public by the respective project consortia (deriving mainly from papers and articles published in journals and conferences, open workshops, newsletters)
  - Information on new research initiatives (on the development of research proposals)
  - Announcement of future conferences and related dissemination activities
  - Information on research work presented in conferences and scientific journals

  - Full papers and other publications of particular interest published by SSRC staff during the said period

- Direct (informal) communication with MCA staff

The main conclusions that can be drawn on the current status of risk-based ship design, operation and regulation are the following:

- A consistent measure of safety must be employed and a formalised procedure of its quantification adopted (risk analysis). For this to be workable, considering the complexity of what constitutes safety, a clear focus on key safety "drivers" is necessary (major accident categories). A number of formalised procedures for risk quantification, risk assessment and risk management exist in various contexts, for instance *Formal Safety Assessment* (FSA) for rule-making, *Safety Case* addressing for specific design/operational concepts, among others. The current thinking on a safety assessment framework for design has been described.

- Such procedure must be integrated in the design process to allow for trade-offs between safety and other design factors by utilising overlaps between performance, life-cycle cost considerations, functionality and safety at parameter level. Consequently, additional information on *safety performance* and *risk* will be available for design decision-making and design optimisation.

- Considering the level of computations that might be necessary to address all pertinent safety concerns and the effect of safety-related design changes on functionality and other performance factors, a different handling is required; namely, the use of parametric models to facilitate trade-offs and access to fast and accurate first-principles tools. The design optimisation process becomes thus a typical case of multi-objective, multi-criteria optimisation problem. A common ship design model managed within an integrated design environment (software platform) will also be required for this process to be conducted efficiently.

It is noted, that the concepts presented reflect the current level of understanding and experience with risk-based ship design. It is anticipated that during the developments to be undertaken as part of SAFEDOR activities in the near future, the ideas presented here will be further elucidated, nurtured, refined and evolved.

The report also described the current state-of-the-art on first principles tools. Advanced first-principles tools are needed to enable routinely prediction of safety performance of a vessel in critical design scenarios. The main conclusions that can be derived are the following:

- First-principles tools and methods to predict safety performance for most initiating events, design scenarios and their consequences are available today. In general, the technology of these tools is considered to be mature, i.e. partial application of risk-based design is possible today in any area the designer feels that such an approach would benefit them.

- There are certain elements that require further research and development. These mainly relate to the issue of provision of fast and accurate predictions for almost all the areas current tools address. It can be very safely claimed that the short- and middle-term needs will be addressed within the relevant sub-projects of SAFEDOR.

- The major challenge is communication among these tools and their integration in designers' / shipyards' design environments. Most of these tools are stand-alone applications, and even though the input / output formats in some of them (for example, the stability and survivability tools) do not introduce any significant integration problem, there are certain software packages (for example, all the risk modelling tools) that have been developed as stand-alone applications, complete with graphical user-interfaces. The drawback in this case is that most tools do not offer internationally accepted standard interfaces. It is also expected in this case, that the relevant SAFEDOR sub-project will achieve some desired results in this respect.

An element that will also receive much attention in the near future relates to training of practitioners at various positions within the maritime industry (regulators, shipbuilders, operators, designers). As described here and in other publications, significant developments in the area of risk-based ship design, operation and regulation have taken place over the last decade or so, mainly at a research level. We are currently experiencing the first attempts for application in design, operation and regulation, which, in order for the potential benefits offered to be realised, would require efforts towards effective training.

The Research Lecturer would like to gratefully acknowledge the support provided by the Maritime and Coastguard Agency in the form of this grant-in-aid, as well as the MCA staff for the input and discussions on the subject at all stages. Colleagues at SSRC as well as from the various research projects are also acknowledged for their continuous efforts and discussions on the subject of risk-based ship design, operation and regulation.

2. SCOPE, OBJECTIVES AND MEANS

The scope of the grant-in-aid in support of a Research Lectureship post at the Ship Stability Research Centre, Department of Naval Architecture and Marine Engineering of the Universities of Glasgow and Strathclyde was to disseminate knowledge to the Maritime and Coastguard Agency of research and development activities in the area of risk-based ship design, operation and regulation to ensure that the UK remains at the forefront of strategic changes in ship safety during the period April 2003 to March 2006.

The principal means used to address this scope were the following:

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The agreement between the Maritime and Coastguard Agency and the Ship Stability Research Centre contains a number of technical objectives which detail the specific information and knowledge deemed necessary under the remit of this grant-in-aid.

These technical objectives, together with statements of actions taken to fulfil them, are given below:

<u>Objective 1</u>: *Reporting of developments in pro-active rule compliance and "rule-tool mapping"*

Developments taken place in the areas of probabilistic damage stability, fire and smoke propagation, evacuation and use of risk analysis in the rule-making process have been reported through the means described above. Rule-tool mapping may mean use of first-principles tools for rule development (as in the case of probabilistic damage stability) or direct use of first-principles tools to demonstrate compliance (as in the case of use of advanced evacuation techniques). It is certain that rule development will increasingly follow this path in the years to come. Section 6 of this report provides the current state-of-affairs in relation to first-principles tools.

Objective 2: *Reporting of developments in risk-based design frameworks/ methodologies and life-cycle risk/cost models*

During the period of this grant-in-aid significant developments in this area have taken place by a number of organisations in Europe. SSRC has been in the forefront of these developments, and all quarterly progress reports submitted contained an update on this issue. A final update is provided as section 5 of this report, reflecting the current state-of-affairs on this subject.

Objective 3: *Monitoring and reporting developments on safety performance analysis tools and on safety "equivalence" between risk-based rules and performance-based criteria using first principles tools and approaches*

First-principles tools for safety performance prediction are currently considered to be mature from a development and validation point of view. Developments in this area have been disseminated to the MCA. The principal future challenge is designers to make use of these tools in implementing risk-based ship design and, as in Objective 1 above, regulators making use of this knowledge for rule development. Section 6 of this report provides a brief summary of the current state-of-knowledge.

Objective 4: *Monitoring and reporting on all developments concerning human and organisational factors as well as modelling aspects concerning quantitative assessment of their effect on maritime safety*

Objective consideration of human and organisational factors is a very challenging undertaking. Current practice in risk analysis is consideration of human and organisational factors on a qualitative basis and on the basis of expert judgement. During the reporting period limited advances on a scientific evaluation of these factors has taken place. This research area is expected to receive significant focus in the years to come. Substantial activities of the FLAGSHIP Integrated Project (Safe Operation of Ships, 2005 – 2009) and to some extent within the SAFEDOR Integrated Project are expected to contribute significantly on this technical objective.

Objective 5: *Updating MCA staff on EU and international developments on safety research, concerning specific research projects, thematic networks and future developments (e.g., Integrated Projects and Networks of Excellence)*

This objective has been met by the dissemination to the MCA of knowledge developed and activities of a large number of research initiatives, through the quarterly progress reports or by inviting MCA staff to participate in seminars, workshops and a training course. Section 3 of this report outlines the updates provided, in the form of summaries of research developments and brief details of the said dissemination activities.

<u>Objective 6</u>: *Involve MCA staff in EU research programmes on a need basis and as advised by MCA*

MCA has participated in the HARDER project (development of the new probabilistic framework for damage stability). The MCA was also invited to participate in SAFEDOR, a major research initiative on risk-based design, operation and regulation (2005 – 2009). MCA was a partner in a research proposal on the development of Goal-Based Standards, submitted on August 2005, which however was not retained by the EC. Finally,MCA staff were invited and attended a number of workshops and seminars and a training course run within the activities of the Thematic Network SAFER EURORO, details of which are given in Section 3 of this report.

<u>Objective 7</u>: *Assist MCA staff, as required, in preparing IMO submission papers pertinent to SSRC research*

SSRC has assisted MCA in the International Maritime Organization Sub-Committee on Stability Loadlines and Fishing Vessels (SLF SDS) correspondence group on the development of the new framework for probabilistic damage stability. SSRC staff have also assisted the MCA in preparing papers for IMO submission on two occasions, as requested, namely, on evacuation tests and procedures and on the principles of development of advanced evacuation tools.

<u>Objective 8</u>: *Assist MCA staff on all the above and on any safety-related matters as required*

At a limited number of occasions advice was sought by MCA staff on specific issues arisen. This assistance was provided in all cases requested. A one-day presentation on risk-based ship design, followed by discussions with MCA staff was also held during September 2005.

<u>Objective 9</u>: *Research gap analyses and recommendation on research priorities in consultation with MCA staff*

Research initiatives and priorities that SSRC was embarking upon were communicated to the MCA well in advance through informal communication and/or the quarterly progress reports. The SSRC research strategy document, attached to the agreement for this grant-in-aid, details SSRC's research priorities, also the Annex of this report provides an overview of SSRC's research activities.

<u>Objective 10</u>: *Research the survivability of small passenger vessels*

SSRC has undertaken the upgrading to the Stockholm Agreement standards (model tests) of the whole Caledonian MacBrayne fleet, which is considered to be of particular importance and relevance, since these were among the first Stockholm Agreement model tests the MCA has administered. A separate risk analysis study on the carriage of dangerous goods by the small Caledonian MacBrayne vessels was also undertaken by SSRC. Similarly, this study was of the very first risk analysis studies administered by the MCA in demonstrating an "equivalent" level of safety, hence of particular importance.

As a general conclusion, SSRC believe that the objectives mentioned above have been met to an extent that can be considered as acceptable for the grant-in-aid provided by the Maritime and Coastguard Agency.

3. KNOWLEDGE DISSEMINATED

A brief account of the knowledge disseminated to the MCA during the period of this grant-in-aid is provided in this section. EC research projects, activities of which have been reported, are described in brief in the first subsection, followed by brief accounts of the conferences, publications and workshops MCA has been updated upon.

It is noted that the updates referred to above were based on information made public by the respective project consortia (deriving mainly from papers and articles published in journals and conferences, open workshops and/or newsletters).

3.1 Research Projects

NEREUS: Design for Damage Survivability

The NEREUS project aimed at developing and validating by demonstration, an innovative design methodology based on a risk assessment approach employing first principles models representative of the physics involved in the flooding process. It is anticipated that first-principles methods would allow practising naval architects to realistically predict, measure and improve the level of safety of a given RoRo design and therefore the approach fosters total integration of survivability in the design process as a regular design parameter. Specific achievements of this project include the following:

1. Achievement of a higher understanding of the dynamics of the damaged ship behaviour and refinement of tools to predict it with sufficient accuracy;
2. Adaptation of widely accepted methods to assure safety in design to the particular needs of the design of RoRo vessels, using the above tools;
3. Demonstration of the efficiency of the methodology above and disseminate it amongst RoRo vessel designers and regulatory bodies.

ROROPROB: Probabilistic-Based Optimal Design

The ROROPROB project aimed at improving safety by developing and implementing a new formalised design methodology for optimal Ro-Ro passenger ship subdivision. The procedure is based on the probalistic concept-based damage stability regulations. Proper optimisation tools has been used to reduce the required computational and design effort. Specific achievements of this project include the following:

1. Development of a formalised design methodology for optimal compartmentation and internal arrangements of passenger ro-ro ships adopting the probabilistic concept of damage stability;
2. Evaluation of the robustness of a probabilistic rules-based design procedure in a range of scenarios and its sensitivity to the main design parameters involved in the assessment process and hence define suitable constraints as appropriate;

3. Development of local and global optimisation techniques for enhanced damage stability characteristics and integrate these within the design methodology;
4. Demonstration of the developed probabilistic rules-based methodology on ro-ro concept designs to meet specific user-defined criteria and requirements.

HARDER: Probabilistic Rules for Damage Stability

The objectives of the project HARDER were to systematically investigate the validity, robustness, consistency and impact of harmonised probabilistic damage stability regulations on the safety of existing ships and on the design evolution of new ship concepts for various types of cargo and passenger ships. Furthermore, to propose and demonstrate appropriate measures for improvements through the development of typical demonstrator designs.

Deliverables of the project included the following:

- Updated damage statistics for the collision and grounding in the struck ship, and analysis and results for the probability distributions for the collision energy to be absorbed in the struck ship;
- Probability distributions for the damage location and size (p, r and v factors) for typical ship types;
- Generalised expression of the probability of survival for any vessel type and configuration following side collision damage;
- Report containing an overall recommendation as regards the validity, robustness and consistency of the suggested methodology;
- Report on regression analysis results and on alternative formulations of Required Subdivision Index;
- General assessment of the impact of harmonised probabilistic damage stability regulations on future ship design;
- Report on recommended new harmonized probabilistic damage stability regulations.

SAFER EURORO: Design for Safety (Thematic Network)

The strategic aim of SAFER EURORO II TN was to facilitate the development of a formalised design methodology for safer ships by promoting an integrated approach that links ***behaviour prediction*** through the utilisation of appropriate ***technical "tools"***, ***risk assessment*** deriving from risk-based methodologies for assessing ship safety and disparate ***design activities*** and issues.

Specific objectives included the following:

- To continue developing and strengthening links and synergy within each Thematic Area (TA) and to ensure effective integration among the areas, facilitating concurrent engineering practices whilst accounting for the requirements dictated by the evolution of ship design and operation.

- To pursue systematic monitoring, review, analysis and transfer of technological developments within each TA in support of risk-based methodologies and design integrative processes.

- To synchronise research effort through scheduling of the pertinent but diverse research activities involved in the monitored RTD projects (Table 1), through purposely organised meetings and workshops and through appropriate dissemination and knowledge transfer, to take full advantage of the overlaps and synergies among projects to target and exploit deliverables maximally. With some projects, in particular, for example the HARDER project, there is considerable involvement from Japan, China, Korea, USA and Canada with progressively more countries wishing to participate in this project through the Subdivision and Damage Stability Working Group at the International Maritime Organisation, which monitors closely all developments in HARDER. This internationalisation of the project instead entails considerable co-ordination activities well beyond that of simply "running" a network.)

- To identify and integrate relevant trans-network research activities, particularly in the TN CEPS where design is at the core (one CEPS project, namely CRASH COASTER is important in the pursuit of SAFER EURORO targets and one Technology Platform, namely VRSHIPS-ROPAX 2000, represents a joint effort between SAFER EURORO and CEPS). The same applies to activities from other EU programmes and key actions (e.g., TN THEMES) to ensure optimal utilisation and management of existing and emerging resources and capabilities.

- In this respect, to maintain and support a research direction that is clear enough and well suited to the targeted objectives of the industry and the priorities and contents of Maritime Industry RDCG Master Plan and to offer recommendations for updating the latter, as required.

- To retain emphasis on the generic nature of the formalism to ascertain capability of application to all safety-critical vessels (e.g. LNG/LPG, fishing vessels, tankers, bulk carriers, high speed craft, containerships, new concepts) whilst accounting for wider aspects of ship safety (e.g., life-cycle issues, environment, operation, management, production, human factors engineering, legislation) and to facilitate the formation of a European Research Area on the basic underlying philosophy of "Design for Safety".

<u>SAFEDOR: Design, Operation & Regulation for Safety</u>

SAFEDOR is newly funded Integrated Project (2005 – 2009) responding to the need of the EU maritime industry for evermore innovative solutions for better quality, cleaner and safer transport. It undertakes to deliver the foundation for Europe to sustain world-leadership on safety-critical and knowledge-intensive ships, services, products, equipment and related software and to instil systematic innovation in ship design and operation by modernising the maritime regulatory system.

SAFEDOR constitutes the culmination of EU-wide concerted effort expended by a large number of maritime organisations over the last decade to foster radical shift from the current maritime safety regime, through the activities of the thematic network SAFER EURORO ("Design for Safety"). To this end, SAFEDOR has pooled together an accolade of leading expertise from across the whole maritime spectrum to pursue its vision of strengthening the competitiveness of the EU maritime industry by enhancing safety through innovation.

This entails development of a holistic approach that links risk prevention / reduction to ship performance and cost, with safety treated as a life-cycle issue and a design objective, implying focus on risk-based operation and need for risk-based regulations within an integrated risk-based design framework, utilising routinely first-principles tools. This all-embracing system is the key to attaining optimum design solutions and it will act as catalyst to pan-European cooperation with strong structuring and integration effects. SAFEDOR will produce a series of prototype ship designs to validate and implement this novel approach and ascertain its practicability. To accelerate transition from conventional to risk-based design, the wider maritime community will be inculcated through a rigorous knowledge management, training and dissemination system of all technological, methodological and regulatory developments whilst continuing to nurture, enthuse and fuel a maritime safety culture.

SAFECRAFTS: Safe Evacuation

This project is emphasising on the rescue process by both quantifying the performance of the Life Saving Appliances (LSA) and improving the concept of reaching the rescue vessel in a safe and reliable manner. The challenge is to exploit a first principles approach (regarding hydromechanics, mechanics, human behaviour, quantitative risk assessment and emergency management) in the design of rescue systems for passengers and crew, addressing both hardware and procedures/management. Aim must be to prove attained safety levels acceptable to the EU community. Stated safety levels must be supported by sound scientific evidence. In this respect physical model tests and full scale tests will play a decisive role.

The expected benefits include safety improvement and acceptance of rescue systems by the International Maritime Organization. A more efficient use of investments with respect to rescue systems, as well as a reduction of required investments and space on board for LSA. This project is scheduled to conclude its activities on October 2007.

LOGBASED: Logistics-Based Ship Design

The LOGBASED project aims at developing more efficient ro-ro vessels as an integral part of developing and operating more effective intermodal transport value chains. Currently, vessel performance evaluations are normally limited to the isolated vessels' performance. Seldom, is the overall performance of the logistics value chain assessed and benchmarked with the vessels' performance included. The aim of this project is, therefore, to develop a specific logistics-based design process with an opportunity to assess the performance of transport value chains with the vessel performance as an integral part of this assessment. Thus, more efficient vessels' solutions can be developed in the future so that these may be used for the displacement of long-haul road freight and for opening up new intermodal corridors.

The new advised design and assessment approach should particularly be capable of guiding a consistent and streamlined design process of the maritime solutions of a transport value chains. In this way, can the overall 'theoretical', logistic solution's performance be assessed and benchmarked at the design stage, including but not limiting to the vessels performance. It is a separate goal of this project when applying this new logistics-based design approach to improve efficiency of the vessel's performance with up to 30 % (fuel economy, building costs, environmental impact, stability, payload, weight/volume, manoeuvrability and turn around time in port). This project is scheduled to conclude its activities on April 2007.

<u>POP&C: Pollution Prevention & Control</u>

The consequences of tanker accidents are often catastrophic, as can be vividly attested by the recent disasters of the *Erika* and *Prestig*e, raising the issue of oil spills to the highest priority for the EU community. The POP&C project aims to address this issue head on by focusing on prevention and mitigation in ship design and operation for existing and new vessels. Specific objectives include:

- To develop a risk-based methodology to measure the oil spill potential of tankers
- To develop a risk-based passive pollution prevention methodology (design and operational lines of defence)
- To develop a risk-based active post-accident pollution mitigation and control framework.

The objectives will be achieved by identifying and ranking critical hazards such as collision and grounding, fire and explosion and structural failure, leading to estimates of probability of capsizing/sinking from loss of stability or structural failure, which combined with estimates of consequences within a risk-based framework will provide pollution risk. Risk reduction through preventative measures and post-accident mitigation and control measures such as decision support tools, human-machine interface, safe refuge will also be developed.

Deliverables include pollution risk methodology and assessment tools, decision support tools for pollution prevention and crisis management, and design and operational guidelines for containment of pollution risk. This project is scheduled to conclude its activities on January 2007.

<u>EU-MOP: Elimination Units for Marine Oil Pollution</u>

A completely new and multidisciplinary concept for handling oil spillage should be developed and implemented for European waters. This will give, aside from obvious environmental protection benefits, a certain impulse to the respective European industry/community and it will finally result to an exportable product as far as marine oil spill confrontation is concerned. What we have in mind can be contemplated as a revolutionary system for an advanced method of the in-situ confrontation of spotted and verified oil pollution.

More specifically, the establishment of a research activity focusing on the development of a range of autonomous Elimination Units for Marine Oil Pollution

(EU-MOP) is proposed, capable of mitigating, and eventually eliminating, the threat arising from the occurrence of an oil spill. Effectively, the end-result of this line of activity will be the mass-production of autonomous, low cost, possibly recyclable, vessels/drones that will be released in the oil spill area, will automatically (through suitable sensors) track the oil concentration specifics of the spill and will apply either mechanical or energy/catalysis-based chemical countermeasures in a local sense, that will however control the oil spill globally due to the large number of the units. A range of such units would be designed, so as to cope with the wide variety of spills that are likely to occur (large, high-seas spills are very different from small, coastal spills, and it would not be realistic to develop a 'one size fits all' concept).

This project would also develop a total integrated system for this kind of concept, including communications, logistical support, and response management. We aim to establish a strong, multidisciplinary and competitive consortium of world experts that will finally conclude the effort and produce both scientific and operational products and conclusions. The innovations included will promote the corresponding European know-how and will render the proposed system as a competitive factor to other non-European similar efforts. This project is scheduled to conclude its activities early 2008.

<u>VIRTUE: Virtual Towing Tank Utility in Europe</u>

VIRTUE constitutes an EU-wide initiative of leading marine CFD players to create a “Virtual Basin” by integrating advanced numerical fluid analysis tools to tackle multi-criteria hydrodynamic performance optimisation of ships in a comprehensive and holistic approach, aiming to complement model testing in real basins and hence substantially enhance the provision of current services to the marime industry and to nurture development of innovative design techniques and concepts. This newly-funded Integrated Project is scheduled for the period 2005 – 2009. This coherent and all-embracing hydrodynamic analysis system will help increase the competitiveness of the EU shipbuilding and shipping industries, promote a truly European co-operation with strong structuring and integration effects, strengthen SMEs through involvement in leading edge developments as a means to gaining and sustaining competitive advantage and leadership and enhance quality and safety in waterborne transportation. VIRTUE’s scientific and technological objectives to achieve these ambitious goals include to:

- Improve hydrodynamic testing through improved reliability of CFD tools
- Enhance existing CFD tools in terms of performance and accuracy and further validation
- Formally integrate numerical tools, using proven approaches, into an environment for complete modelling and simulation of ship behaviour at sea
- Provide smooth and versatile communication and data exchange link between marine CFD service providers, such as model basins, and the end user
- Provide the means – CFD tools, integration platform and optimisation techniques – to cover the whole range of hydrodynamic problems and to facilitate and support multi-disciplinary design optimisation of new ships.

3.2 Conferences and Technical Papers

Summaries of the activities of 20 relevant international conferences held during the period 2003 to date have been provided to the MCA, in the form of abstracts of the papers presented and of full technical papers presented by SSRC staff. The following papers have been supplied to the MCA:

- **Framework for Risk-Based Ship Design**

Various updates on the work carried out at SSRC have been provided to the MCA throughout the duration of this research lectureship. The following are the references to these publications.

Vassalos, D, Konovessis, D and Vassalos G: "A Risk-Based Framework on Design for Safety", IMDC 2003, May 2003, Athens, Greece, 15pp.

Konovessis, D and Vassalos, D: "Total Ship Safety: A Life-Cycle Risk Based Design Methodology", European Safety and Reliability Conference, ESREL 2003, Maastricht, June 2003, 16pp.

Vassalos, D: "A Life-Cycle Risk-Based DOR (Design-Operation-Regulation) for Safety", Key Note Address IMAM 2002, Crete, May 2002, 15pp.

Vassalos, D: "Risk-Based Design – From Philosophy to Implementation", Keynote Address, 2nd International Conference on Design for Safety, Osaka, Japan, October 2004, 11pp.

Vassalos, D. and Konovessis, D.: "Design for Safety: R&D Developments and Future Prospects", Proceedings of the International Conference on Marine Research and Transportation (ICMRT 2005), 19-21 September 2005, Ischia, Italy, 12 pages.

Vassalos, D., Konovessis, D. and Guarin, L.: "Fundamental Concepts of Risk-Based Ship Design", Proceedings of the 11th International Congress of the International Maritime Association of the Mediterranean (IMAM 2005), 26-30 September 2005, Lisbon, Portugal, 7 pages.

- **Weather Criterion – Questions and Answers**

By Dracos Vassalos, Andrzej Jasionowski and Jakub Cichowicz, paper presented at the STAB 2003 Conference, Madrid, September 2003

Following the reopening of the Intact Stability Code by the International Maritime Organisation (IMO), a number of questions are being raised concerning the practical applicability of Resolution A.562 known as the Weather Criterion on modern passenger ships and answers sought on a way forward by way of either re-examining and suitably tuning the criterion to reflect current (and emerging) ship particulars or adopting merging approaches/philosophies to assessing ship safety, using first-principles performance assessment tools. This paper attempts to provide pertinent answers to these questions.

- **Risk/Cost Model for Large-Scale Flooding of High Speed Monohulls**

By Dimitris Konovessis, Dracos Vassalos and Daria Cabaj, paper presented at the FAST 2003 Conference, Ischia, October 2003

Following a brief introduction on risk-based design, the paper elaborates on the development of a probabilistic risk/cost model for the estimation of consequences of large-scale flooding with reference to the probability of a high speed monohull craft to remain afloat, slowly capsize or rapidly sink when damaged at a given sea state. The probabilistic nature of the model refers both to data required as input as well as to the state-of-the-art first-principles tools to be deployed for the determination of the probability of survival. The paper concludes with results from initial implementation of the adopted model in a number of case studies.

- **A Risk-Based Design Methodology for Pollution Prevention and Control**

By Seref Aksu, Dracos Vassalos, Cantekin Tuzcu, Nikos Mikelis and Peter Swift, paper presented at the International Conference on Design & Operation of Double Hull Tankers, London, February 2004

Stricter international regulation enacted in the early 1990s and advances made in design and safe operation of tankers saw a significant improvement in the tanker industry safety record. According to The International Tanker Owners Pollution Federation, oil pollution from tankers for the period 1997-03 was only 25% of the pollution for the period 1990-1996. The total number of reported tanker incidents with pollution for the period 1997-03 was only 37% of the figure for the period 1990-1996, while at the same time the total oil trade has increased by 15%. Two particular accidents have detracted from the tanker industry's good record. The cause and effect of the Erika (1999) and Prestige (2002) incidents, with their heavy oil cargoes causing extensive pollution on European shores, have had major political, social and economic implications. Single hull tankers have been gradually being phased out according to the International Maritime Organization's global regime for more than ten years, but last year Europe went beyond international regulations and implemented a unilateral accelerated phase-out, which has since led to the international phase-out being accelerated too. The control system for tankers has also been tightened up at the same time as the industry itself has taken initiatives to ensure that the structural integrity of tankers is maintained to good standards throughout the life of the ships. Despite the political and economic importance of these issues, some of the relevant new regulation still tends to be made before incidents have been properly investigated. Political pressure rather than proper risk analysis may determine which types of oil tanker pose the highest pollution risk, the relative safety of new tanker designs, or the most appropriate response to an evolving oil pollution incident. To address this issue rationally, the European Commission provided funding to the tune of €2.2 million for a 3-year project entitled "Pollution Prevention and Control – Safe Transportation of Hazardous Goods by Tankers" (POP&C) under Framework Programme 6 (FP6), which started earlier this year. The

POP&C project proposes to deliver a framework and suitable tools for a methodological assessment of risk to be undertaken to provide a rational basis for making decisions pertaining the design, operation and regulation of oil tankers. Such support can be used to make more informed decisions, which will in turn contribute to reducing the likelihood and severity of future oil spills. The project brings together prime protagonists from the area of maritime safety in Europe. Deriving from the foregoing exciting developments, it is the purpose of this paper to present the main philosophy behind the POP&C project and to detail and explain the basics of the methodology to be adopted aiming to achieve the specific objectives outlined above.

- **A Risk-Based Approach to Probabilistic Damage Stability**

By Dracos Vassalos, paper presented at the 7th International Ship Stability Workshop, Shanghai, November 2004

With the harmonisation process of probabilistic damage stability regulations just finished (SLF47, September 2004) and the expectation that the proposed regulatory framework will be adopted by SOLAS in autumn 2005 and enforced in 2006, this paper argues that with current and expected developments in the short term on risk analysis and risk-based concepts, the new rules run the danger of becoming obsolete before they are enforced as any direct relation to rigorous risk analysis is not obvious and any further attempts to keep alive "compromised" concepts of risk will lead to more confusion and delays in achieving real progress.

- **Passenger Ship Safety** – Science Paving the Way

By Dracos Vassalos, Andrzej Jasionowski and Luis Guarin, paper presented at the 8th International Ship Stability Workshop, Istanbul, October 2005

The prevailing regulatory framework addressing ship safety originates in some distant past and carries a heavy "baggage" of experiential determinism and rules of thumb; all throwing a smoke screen onto science and quenching most attempts to dealing with safety in a scientific, all embracing and systematic approach. Goal-Based Standards are meant to provide a new impetus to achieve this but experience so far suggests if anything even more determinism and even less science in the strife to face uncertainty and complexity with only "crumbs" of understanding of the real issues at hand. There is only one real exception, giving science the opportunity and all of us hope that scientific approaches to addressing safety will at long last be called upon to pave and lead the way: [Large] Passenger Ship Safety. Nothing is meant to be preconceived here; safety can have a field day before it is cut down to face reality and cost. Goal-Based Approaches, *Casualty Threshold, Safe Haven, Safe Area, "Zero" Tolerance in human life loss, De-risked Ships*; all goes and is being seriously discussed at IMO. This paper presents a critique of recent developments at IMO, in particular the new probabilistic rules of damage stability calculations, in an attempt to demonstrate the need to use knowledge in all its forms to make a difference in safety improvement before proceeding to suggesting a workable approach to address one exciting development in the regulatory front: Casualty Threshold. Emphasis is placed on explaining the framework that could embrace and support such development and on the pre-requisite scientific knowledge to realise it

- **Risk Characterisation of the Required Index R in the New Probabilistic Rules for Damage Stability**

By Maciej Pawlowski and Dracos Vassalos, paper presented at the 8th International Ship Stability Workshop, Istanbul, October 2005

The required index of subdivision R, is meant to represent relative safety against collision damage and is understood by most to be a safety standard. Using first principles analysis based on the concept of risk this paper shows that the formulation of R in the recently adopted probabilistic rules for damage stability demonstrates lack of real understanding of what the probabilistic framework was meant to provide as well as lack of real knowledge of how it all started and what it really R represents.

3.3 Seminars / Workshops / Training Course

MCA has been informed on various dissemination activities of EC projects (mostly of the SAFER EURORO Thematic Network). Proceedings and presentations of the following activities have been supplied to the MCA:

- **Large Passenger Ship Safety Workshop, Trieste, January 2004**

SAFENVSHIP Project – Project Results and Future Plans	Dr Giovanni Scarpa – Fincantieri
SAFENVSHIP Project – Fire Safety Related Activities	Mr Andrea Salvo – Fincantieri
SAFENVSHIP Project – Weather Criterion	Mr Andrea Serra – Fincantieri
SAFENVSHIP Project – Weather Criterion	Mr Gabriele Bulian – DINMA, University of Trieste
Numerical simulations: Time to flood	Dr Riaan Van't Veer – MARIN
Survival Time of Damaged Passenger Vessels	Dr Andrzej Jasionowski – Safety at Sea Ltd.
Time Dependent Survival Probability of a Damaged Passenger Ship	Dr Petri Valanto – HSVA
Structural Survivability of a Modern Passenger Ship	Mr Rob Tagg – Herbert Engineering Corporation Inc.

- **Risk-Based Ship Design Seminar, Nantes, July 2004**

Equivalent Level of Safety: Passenger and Dry Cargo Ships, Presentation of IMO – ISCG, SLF 47 Work	Professor Apostolos Papanikolaou NTUA-SDL
Risk Concept of Damage Survivability	Professor Dracos Vassalos SSRC
Towards an Integrated First-Principles Approach for Passenger Cruise Vessel Risk-Based Design	Dr Giovanni Scarpa Fincantieri
Experience with Risk-Based Decision Making in the Maritime Industry	Dr Rolf Skjong DNV
Risk-Based Approval at GL – Experience and Expectations	Dr Pierre C. Sames GL
Risk-Based Design and Verification – Experience and Challenges	Mr Renato Robino RINA
Design for Safety	Mr Pierre Besse BV
Risk-Based Design @ CAT – Experience, Challenges and Potential Applications	Mr Philippe Neri Alstom CAT

- **Goal-Based Standards Workshop, Hamburg, January 2005**

Goal-Based Standards – In Need of a Framework	Professor Dracos Vassalos SSRC
Outline of a Risk-Based Approval Framework	Mr Jeppe Skovbakke Juhl Danish Maritime Authority
Goal-Based Standards: Performance-Based Design Approach for Qualifying the New Generation of Passenger Cruise Vessels	Mr Giovanni Scarpa Fincantieri
Goal-Based Standards for Design and Construction of Ships	Mr Panos Zachariadis Atlantic Bulk Carriers Ltd., Greece
Goal-Based New Ship Construction Standards	Mr Dragos Rauta INTERTANKO
Goal-Based Standards: A Cruise Operator View	Mr Tom Strang Carnival Corporation Plc., UK
Elements of a Goal-Based Regulatory Framework	Dr Rolf Skjong DNV
SAFEDOR Contribution to the Development of Goal-Based Standards	Dr Pierre C. Sames GL

➢ Training Course on Risk-Based Ship Design, Glasgow, June 2005

Risk-Based Design Concept, Methodology and Framework	Professor Dracos Vassalos SSRC
Safety Assessment and Risk Acceptance Criteria	Dr Rolf Skjong DNV
Outlook of Future Approval for Risk-Based Design Ships	Dr Pierre C. Sames GL
Collision and Grounding	Professor Peter Friis Hansen Technical University of Denmark
Crashworthiness	Mr Alex Vredeveldt TNO
Damage Stability and Survivability	Dr Andrzej Jasionowski SSRC
Fire / Smoke and Evacuation	Dr Fernando Caldeira-Saraiva British Maritime Technology

➢ Goal-Based Standards Workshop, Crete, October 2005

OPENING ADDRESSES

Manolis Kefalogiannis, Minister of Mercantile Marine, Hellenic Republic
Tom Allan, Chairman of Maritime Safety Committee of IMO, United Kingdom
"IMO's Work On Goal-Based New Ship Construction Standards"

SESSION 1
Chairman: **Tom Allan** (Chairman of IMO Maritime Safety Committee, United Kingdom)
Jeff Lantz, US Coast Guard, Chairman, IMO Working Group on Goal-Based Standards
"Current Results & Future Issues For IMO's
Goal Based Standards For New Ship Construction"
George Gratsos, Standard Bulk Transport Corp., Greece
President, Hellenic Chamber of Shipping

SESSION 2
Chairman: **Pierre Sames** (Germanischer Lloyd, Germany)
Roberto Cazzulo, RINA S.p.A., Italy, Chairman of IACS EG/GBS
"Classification Society's View about the Scope,
Verification Process and Acceptance Criteria"
Koichi Yoshida, National Maritime Research Institute, Japan
"Risk-Based Approach on GBS"

SESSION 3
Chairman: **Rolf Skjong** (Det Norske Veritas, Norway)
Anneliese Jost, Federal Ministry of Transport, Germany
"Safety Level Approach for Goal Based Standards"
Dragos Rauta, Technical Director, INTERTANKO
Ralf Sören Marquardt ,CESA's IMO representative, Community of European Shipyards' Associations (CESA)
"Designing, Building and Maintaining High-Quality Ships:
Shipbuilder's Views on Goal-Based New Ship Construction Standards"

MCA staff have participated to the two workshops on Goal-Based Standards and the training course on Risk-Based Design.

4. ACTIVITIES

In this section of the report a brief account of the activities of the MCA Lecturer is provided.

Teaching

- Undergraduate & postgraduate modules at the Department of Naval Architecture and Marine Engineering (Ship Design, Waterborne Transport, Risk Safety & Reliability, Modelling & Optimisation in Design, Marine Regulatory Framework, Marine Transmission Systems, Marine Environmental Safety).

- Postgraduate short training courses with the MTEC consortium (Maritime Economics, Risk Safety & Reliability).

Student Supervision

- Three to four undergraduate final year student projects per year (subjects include: analysis of tanker operations in icing environment, development of a maritime security scheme, FPSO security, estimation of docking loads, shipyard safety during repairs of LNG vessels, semi-submersible safety, etc.).

- One to two postgraduate MSc student projects per year (subjects include: reliability of ship operating systems; fire safety and evacuation; active fire safety; risk-based ship design implementation, etc.).

- Three MPhil students in total (subjects include: propulsion systems reliability and virtual reality models for ship damage control).

- Second supervisor to three PhD students on the subjects of development of tools and implementation of risk-based ship design.

Research

- Project Manager SAFER EURORO Thematic Network

- Academic Responsible for a KTP Project on Fire Modelling

- Work Package Leader in LOGBASED and Safety at Speed Projects

- Deputy WP Leader and SP Leader in SAFEDOR

- Member of the research team on NEREUS, VRSHIPS and ROROPROB Projects

Publications

- Four to five conference papers per year
- A number of Journal Papers under preparation

5. RISK-BASED SHIP DESIGN

This section of the report, provides a full account of current considerations on risk-based ship design. This is based on current work SSRC is carrying out within the activities of the SAFEDOR project, and will be presented at the Ninth International Marine Design Conference to be held at Michigan, USA in May 2006.

5.1 Background

Traditionally ship safety has been dealt with by adherence to rules and regulations, thus treated as a constraint in the design process. With technology and users requirements developing faster than knowledge can be assimilated and best practice produced, this approach to safety assurance is expected to be largely ineffective. More specifically, the lack of a systematic and all-embracing approach to ship safety, offering a framework that allows for a strategic overview of safety and the derivation of effective solutions, meant that the wealth of information amassed over many years of research and development on stand-alone safety-critical areas remains under-utilised, whilst ship safety continues to being unnecessarily undermined.

However, recent well-publicised marine disasters (Herald of Free Enterprise 1987, Exxon Valdez 1989, Scandinavian Star 1990, Estonia 1994, Erika 1999, Express Samina 2000, Prestige 2002), linked to intolerable consequences with respect to human life, property and the environment, triggered a chain of events that raised safety awareness among the whole maritime community and the wider public. Concerted efforts internationally forced the subject of safety to the forefront of developments, overcoming the inertia of the marine industry and giving way to scientific approaches to assessing safety at the expense of the traditionally governing empiricism. A new stronger resurgence of safety as a key issue that cannot be considered in isolation any longer nor fixed by add-ons is prevailing, bringing home the long overdue realisation that lack of safety or ineffective approaches to dealing with it can drive shippers out of business. This progressively acquired appreciation that the marine industry is a “risk industry” is catching up with the maritime profession, necessitating changes in people’s attitude and the adoption of holistic risk-based approaches to maritime safety, capable of striking a balance between all the many facets affecting safety cost-effectively and throughout the life cycle of the vessel. Added to the above, recent civil catastrophes of cosmic proportion (the September 11 2001 events in the USA) have brought all safety-driving forces (socio-political, techno-economic and ethical) in alignment, pushing safety issues to the fore-front of societal problems. As a result, a clear tendency to move from prescriptive to performance-based approaches to safety is emerging internationally and this, in turn, is paving the way to drastic evolutionary changes in design, where safety is dealt with as a central issue with serious economic implications rather than a simplistic compliance.

Concerted efforts to respond to these developments in the marine industry led to the establishment of the first significant EU Thematic Network (TN) SAFER EURORO (SAFER EURORO 1997; 2001), (Vassalos et al. 2005), aimed to promote a new design philosophy under the theme “Design for Safety” - an initial partnership of 33 that grew to more than 90 organisations from across the whole spectrum of the marine industry in Europe. The strategic objective of SAFER EURORO was to integrate safety cost-effectively within the design process in a way that safety "drives" ship design and operation. This in turn entailed the development of a formal state-of-the-art design methodology to support and nurture a safety culture paradigm in the ship design process by treating safety as a design objective rather than a constraint. The internationalisation of the TN output through contribution to IMO activities and through other dissemination activities, the significant contribution to the regulatory process (for example, HARDER and SAFETY FIRST were instrumental to the development of the probabilistic damage stability and fire safety regulations, respectively) and the increasing realisation by all concerned that scientific approaches to dealing with ship safety offer unique opportunities to the maritime industry to strengthen competitiveness, have helped create a momentum that is now providing the "fuel", the inspiration and the foundation for SAFEDOR (SAFEDOR 2005), (Christensen et al. 2005). This is a newly-funded EU FP6 Integrated Project, aimed at integrating safety research in Europe and beyond and to drive risk-based design to full implementation ranging from concept development to approval.

5.2 Motivation for Risk-Based Ship Design

It is interesting to note that the first principle in "Design for Production" as recommended by (Storch 1995) is to "use common sense" and by analogy nothing stirringly new is presently advocated in suggesting "Design for Safety" as the way forward to improving ship safety. However, even though good designs should always take into account safety matters, this has invariably been governed by minimum compliance with the rules and hence not addressed optimally. Many may argue that competent designers have always strived to produce safe designs but history demonstrably shows that intention is not substitute for methodological treatment when it concerns a complex and multi-disciplinary subject such as ship safety. To this end, a formalised methodology for designing safe ships must be adopted aiming to promote safety to the heart of the design process rather than being seen to be in conflict with ship production and operation and be treated in isolation from other ship design factors.

A historical exploration into the development of Safety of Life at Sea and an examination of the safety-related drivers reveals trends which ought to be considered with care in facing a future full of new challenges. These include:

- Enhancement of safety is sought through legislation.
- Regulations address mainly the ship itself, more specifically areas perceived to be safety critical (e.g., subdivision).
- Clear goals and objectives are missing (prescriptive regulations).
- Safety rules and regulations have been driven by disaster and public outrage (reactive approach).
- Raising of safety standards has always been preceded by casualties including considerable loss of life (or property).
- The pace of rule development until recently has been slow.
- Safety has been treated as a separate, conflicting engineering discipline without any consideration of cost-effectiveness analyses or attempt in understanding how it interacts with other design factors.
- Vested interests always delayed and often defeated the imposition of new regulations or forced a compromise that was unwise or unworkable. As a

result, maritime law has constantly shown a large time interval between accidents and prevention of their repetition.

- There are underlying trends of decreasing loss in ships and fatalities but those have to be considered in conjunction with the decreasing human tolerance to risk which becomes unacceptable, however remote the possibility of a tragedy involving large loss of life. Today, human life is much more precious than ever before. An emerging trend concerns also the importance attached by humans to the protection of the marine environment, which must not be taken lightly.
- Developments in shipping happen faster than experience is gained, thus the traditional reliance on experience and codes of best practice is "running thin".
- Over-capacity of transportation, over-supply of services and painfully low margins, drive some of the best companies and the core of the seagoing skill-base out of shipping. The resulting combination of an ageing fleet, sub-standard ships and multi-national crews presents safety problems.
- Global media coverage brings the accident at the door of the public and is capable of stirring strong emotions.
- Shift of safety focus from hardware to software follows wide awareness and growing appreciation of the role of human factors on safety matters.
- Phenomenal progress in science and technology over the recent past presents the shipping industry with opportunities to meet emerging challenges cost-effectively and safely.

Considering the above, adopting a risk-based design approach that embraces innovation and promotes routine utilisation of first-principles tools will lead to cost-effective ways of dealing with safety and to building and sustaining competitive advantage, particularly so for knowledge-intensive and safety-critical ships; knowledge intensive as such ship concepts are fuelled by innovation and safety critical as with such ship design safety is indeed a design "driver". This section specifically targets these issues, by detailing current advances on the establishment of a risk-based design framework with the view to maximizing safety through treating safety as a design objective with the support of advanced safety performance prediction tools, in a systematic and all-embracing approach to ship safety integrating all factors concerning safety at sea for the entire vessel life-cycle.

5.3 Safety in Ship Design

The aim in ship design is to deliver a vessel design that <u>performs</u> in accordance with the expectations defined by the owner's operational or functional requirements while complying with the statutory rules and regulations as well as ensuring that the construction process keeps to budget and schedule. A possible generic and high-level representation of the ship design process is illustrated in Figure 1. This representation is by no means unique or exhaustive but it will be used subsequently as a basis for underlining the expected contribution and implications of risk-based design.

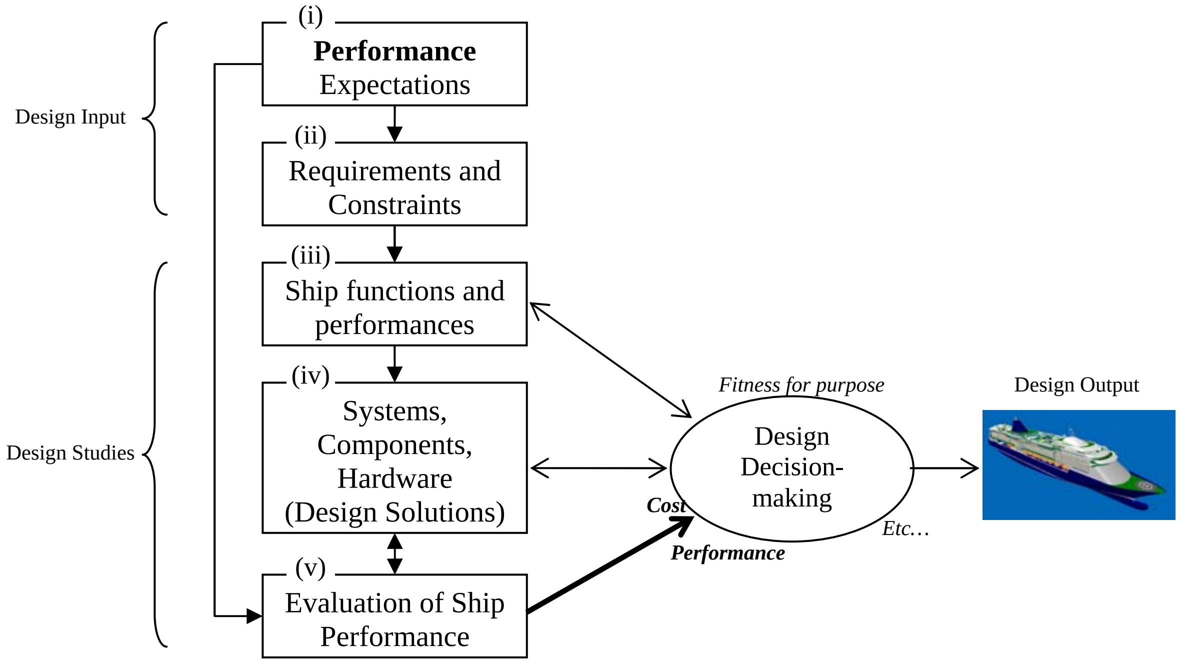


Figure 1: High-Level *Conventional* Design Process

Design Input

As illustrated in Figure 1, the input for design is divided in two phases dealing with general "performance" expectations and requirements mainly deriving from the shipowner's own market, business, and logistic analysis, as well as from other expectations from relevant stakeholders: shareholders, general public opinion, charterers, customers, etc. The shipyard is also an important stakeholder when it comes to defining requirements and constrains as building cost and time are the two major factors determining competitiveness in shipbuilding. Such requirements, referred to hereafter as **"performance"** expectations, can be of any nature; examples are listed below, among others (for both passenger/cargo ships, see also Figure **2**):

- Logistics: cargo capacity (determines general dimensions of the ship), number of passengers, cost per transported cargo unit, service speed, no assistance from tugs whilst entering busy ports, lifespan (influences structural reliability considerations), port and canal restrictions (suezmax, panamax), cargoes parcel size, services on board (restaurants, casinos, etc.)
- Business/market: capital cost, operating costs: choice of propulsion, energy production, etc.
- Construction: material for the structure, choice of propulsion system, etc.
- Safety (of passengers, crew, environment, cargo and the vessel itself): conventionally focused on rule compliance e.g. SOLAS, MARPOL, ICLL, etc. May also include choice between different technologies (e.g. high-foam vs. CO_2 fire fighting systems, type of LSA, etc.)
- Others: unrestricted worldwide navigation, high percentage of external cabins, etc.

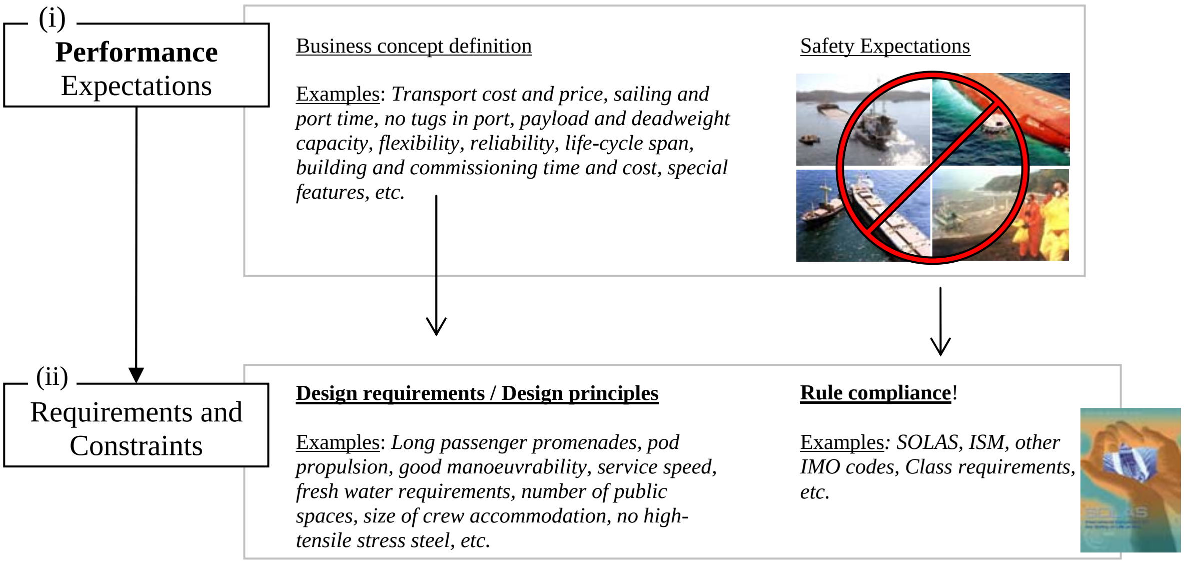


Figure 2: Elements that Drive Design Input

Design Studies

Design optimisation is a juggling act of many factors including safe operation, technical performance, preferences, cost logistics, feasibility, aesthetics, etc (see Figure 3). In this list, <u>safety</u> is not considered later than everything else, it is however limited to <u>rule compliance</u> and hence it is treated as a design constraint – not as a design variable.

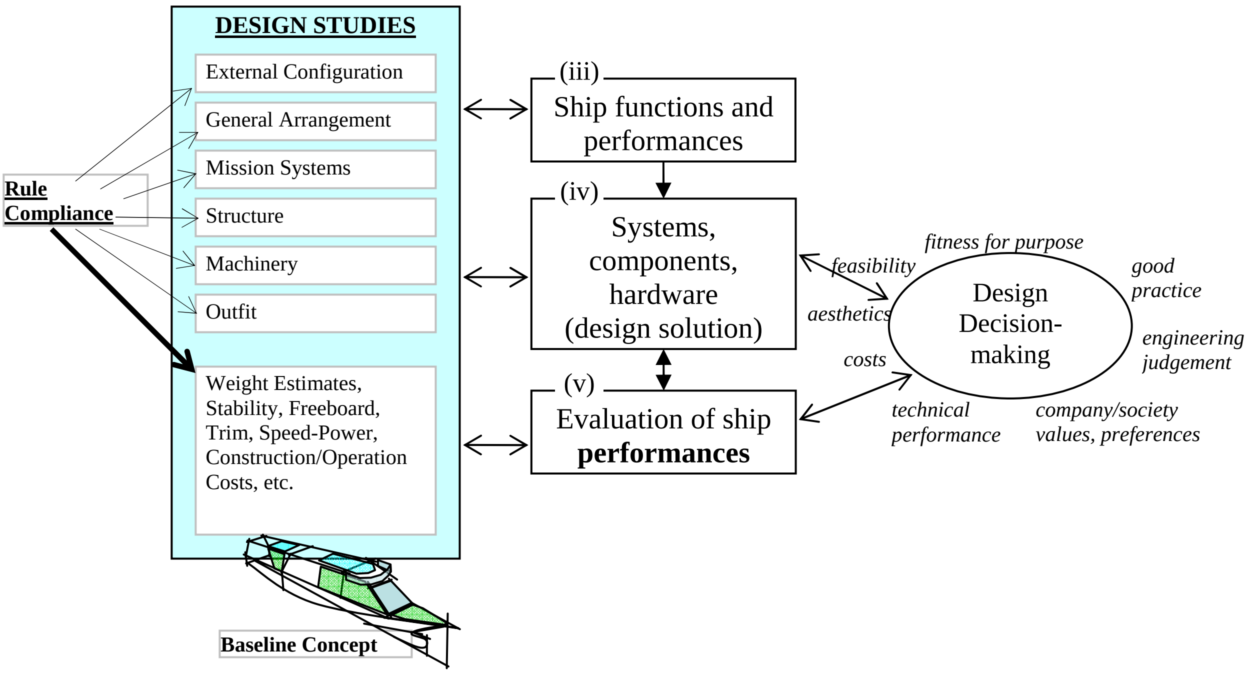


Figure 3: Safety Considerations in "Conventional" Design (Rule-Compliance Approach)

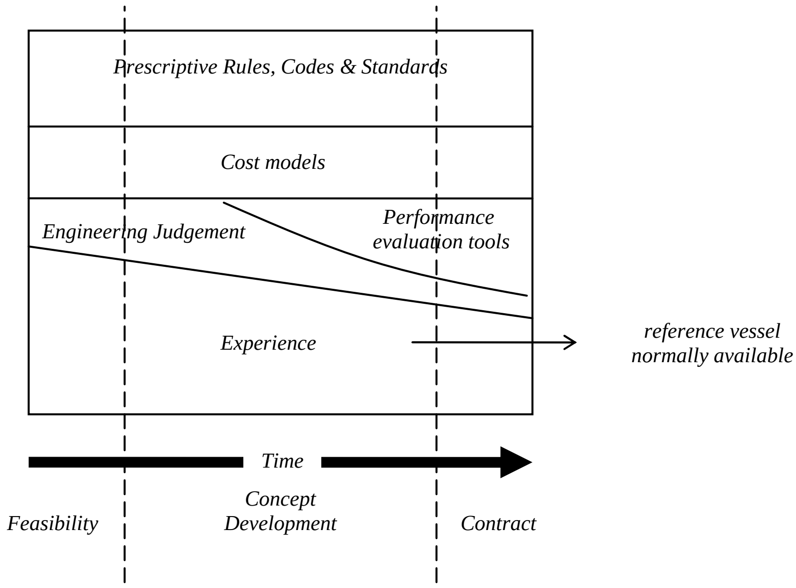


Figure 4: Significance of Key Decision Factors to Design Decision-Making

At early design stages, where major design decisions are made and cost items assigned, design decision making bases mainly on the designer's experience, engineering judgment and the level of creativity possible within the prescriptive rule envelope (see Figure 4). This approach implies that development of "competitive" designs is based on the designer's competence rather than on rational and more informed basis. That undertaking has resulted in the ill-based concept that investment in safety compromises returns. Moreover, compliance with prescriptive regulations implies absolute trust that the minimum safety level implicit in them is deemed to be appropriate for the type of vessel and operation intended. In the rule compliance approach, safety performance is prescribed by the rules, i.e. rules define what the safety performance parameters are and what values should be attained (design criteria). Examples, among others, are listed below:

- To avoid structural failure: Minimum scantlings, corrosion margins, design loads, etc.
- To avoid loss of stability: GZ curve requirements, etc.
- To mitigate the consequences of a collision: B/5 penetration, A index, etc.
- To mitigate the consequences of grounding: Double bottom extent and height, etc.
- To mitigate the consequences of a fire: Fire rating → 1 hour fire protection (ΔT_{max}=180 °C, etc.), maximum length and area of a MVZ (48m, 1600 m^2, respectively), etc.

Prescriptive rules and regulations drive key aspects of the design. From the early stages of the process, rule compliance is implicit in the development of the general arrangement, on the choice of ship mission systems (including safety systems), in structural design (minimum scantlings, design loads, strength criteria, etc.), in the outfit (materials fire grade, etc), in stability evaluation (SOLAS Chapter II-1), etc. (see Figure 3). There are negative and positive sides of the "*rule compliance*" approach and the arguments can be summarised as follows:

- Rules are minimum requirements that reflect average safety, hence may not be appropriate, consistent, and/or optimal in all cases (e.g., SOLAS A.167, SOLAS 90, even SOLAS Chapter II-1).
- Most rules are developed in the wake of major accidents; as such, they are targeting to reduce consequences to appease public outrage; in some cases, emphasis or even relevance to design is all but lost.
- If the evaluated design is not encompassed or does not correspond to data set used to derive the rules, then the design may be unnecessarily penalised or its safety-performance might not be optimal or it might even be unsafe. For instance would the probabilistic rules be applicable to multi-hull vessels?
- In a rule-based regime "there is no chance to beat the competitors", as advances in technology are conveyed to others by the (prescriptive) rules. On the other hand, with safety imposed as a constraint to the design process, the transfer of knowledge between the design, production and operational phases is hindered (rule evolution is too slow).
- By specifying minimum requirement, a design that fulfils the requirement by far is considered as of the same safety level as a design that just "passes" the requirement – this is the major point where designers do not usually achieve a balance ("best compromise") and the reason for the conclusion that "safety costs".
- Rules are however easier to fulfill and facilitate class/flag changes (desirable). They are easy to apply and easy to check for the unskilled (which is rather undesirable).

Over the years, most rules have proved to "serve well" the design objectives and most changes and improvements have been the result of individual high-profile accidents or significant changes in other casualty statistics (e.g. bulk carriers' losses in the early 1990s and development of SOLAS Chapter XII). However, rather than waiting for an accident to happen and then act in haste to set up new rules that may even end up undermining rather than improving safety, all pertinent knowledge deriving from such accidents is analysed and stored in a structured way and used as early as possible in the design process (as shown in Figure 5), then a drastic shift of emphasis on prevention must surely be witnessed. Further more, doing so would allow for trade-offs between safety and other design factors and would lead to safe and more competitive designs.

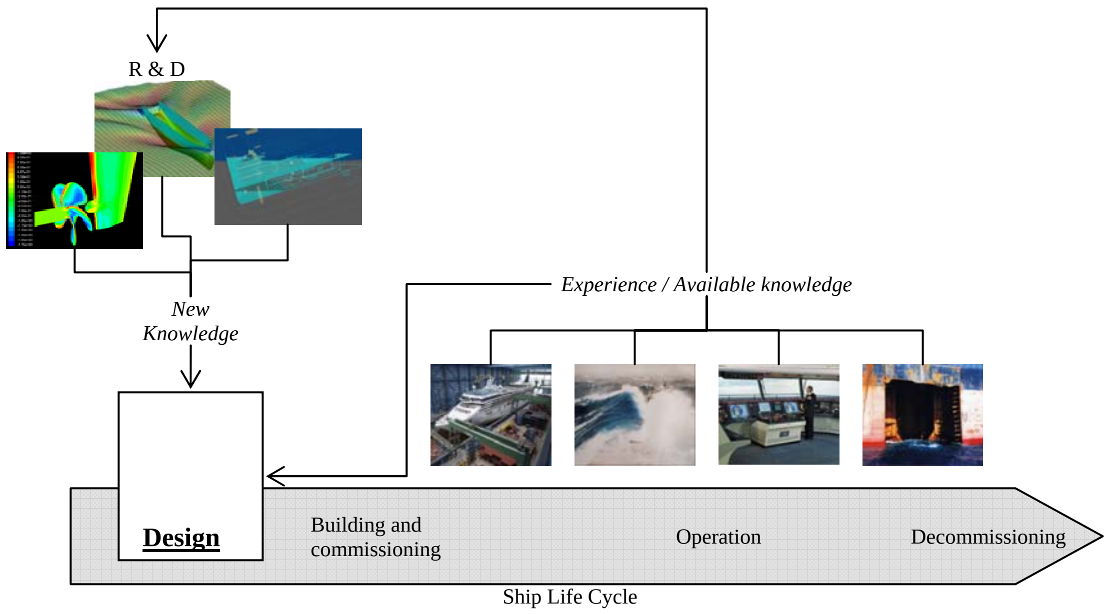


Figure 5: The "Common Sense" Approach to Ship Design

This common sense approach provides the foundation for the adoption of "risk-based" approaches for design and operation and the concepts associated with it are progressively being used in ship design: notably, the principle of safety *equivalency*. In this respect, if the reference to alternative design and arrangements implicit in Reg. 17 of SOLAS II-2 (fire safety) is accepted, risk-based design can be seen as a generalisation of the corresponding fire safety (risk) assessment procedure (implicit in IMO's MSC Circ.1002) to **ALL** safety aspects of the ship and without the need for a "statutory" design to demonstrate safety equivalence. There is of course an added complication and a fundamental difference: the simultaneous consideration of multiple risks (major deviation from prescriptive rules and SOLAS in general) that will be addressed in the next section.

5.4 Risk-Based Ship Design Framework

In addressing risk-based ship design, it is important to first make the following considerations:

- The notion of "*Risk*" is usually associated with events, the outcome of which we don't like. Hazards in ship operations have led in the past to well-publicised collisions, groundings, sinkings, founderings, etc., in many cases resulting in significant loss of life, and damage to the environment. There is no doubt that ***shipping operations are risky*** and ships should be also designed with this in mind**.**

- In order to address safety explicitly, we need to measure it ("*what gets measured gets done*"): In this respect, ***risk*** is considered the currency of *safety*. Hence explicit consideration of safety is equivalent to evaluating risk during the design (risk-based design).

- From a practical viewpoint, the application of risk-based design will be biased towards design concepts with high levels of innovation. In risk-based design, the target is to increase the influence of good practice, engineering judgment, state-of-the-art tools and knowledge, all of which are part of Quantitative Risk Analysis (QRA).

Within the context above, and taking into account the notions presented in the previous section, it can be stated that the essential *advance* that risk-based design represents in relation to ship design as is practiced today, is the explicit, rational and cost-effective treatment of safety. To achieve this, the following have to be considered:

a) A consistent <u>measure of safety</u> must be employed and a <u>formalised procedure of its quantification</u> adopted (risk analysis). For this to be workable, considering the complexity of what constitutes safety, a clear focus on key safety "drivers" is necessary (major accident categories). Numerous formal procedures for risk quantification, risk assessment and risk management exist in various contexts (for instance FSA for making rules, safety case for specific design/operational solutions, among others). The right-hand-side of Figure 6 illustrates the elements of a typical "safety assessment process".

b) Such procedure must be integrated in the design process to allow for <u>trade-offs</u> between safety and other design factors by utilising overlaps between performance, life-cycle cost considerations, functionality and safety at parameter level. The interfaces between the ship design process and the safety assessment procedure are illustrated in Figure 6. Consequently, additional information on *safety performance* and *risk* will be available for design decision-making and design optimisation, which in principle, should not change.

c) Considering the level of computations that might be necessary to address all pertinent safety concerns and the effect of safety-related design changes on functionality and other performances, a different handling is required; namely, the use of <u>parametric models</u> to allow for trade-offs through overlaps at parameter level and access to fast and accurate <u>first-principles tools</u>. The design optimisation process becomes thus a typical case of multi-objective, multi-criteria optimisation problem. A common ship design model managed within an integrated design environment (software) will also be required for that process to be conducted efficiently.

With the above in mind, risk-based design can be defined as follows:

> *Risk-based design is a formalised methodology that integrates systematically risk assessment in the design process with prevention/reduction of risk (to life, property and the environment) embedded as a design objective, alongside "conventional" design objectives (such as speed, capacity, etc)*.

It is noted that Figure 6 depicts a possible high-level *<u>framework of risk-based design</u>*. The elements of such framework and its implications for ship design are described next.

Safety Assessment Procedure

In principle, the safety assessment procedure referred to above is a systematic and formalised ***risk*** assessment process, which can be carried out in a variety of ways. The selection of the right approach has to be viewed in the context of the following drivers (HSE 2001):

- Design stage: will determine the level of flexibility to possible design changes as well as the level of design knowledge. At concept design stages (pre-contract) there is flexibility for major design trade-offs; on the other hand, there is lesser knowledge about the ship, hence the risk assessment approach must be limited to coarser methods. The risk assessment can - of course - be refined during advanced design stages (as more design details are available) and up to construction and commissioning process.
- Major hazard potential: the greater the potential exposure to total loss or multiple fatality, the less desirable it is to use only conventional rules-based approaches for decision-making. Hence the focus on major ship accident categories.
- Risk decision context: with higher elements of novelty, uncertainty or stakeholder concern will also push towards more thorough risk assessment, hence the bias of risk-based design towards high innovation, high-value vessels.

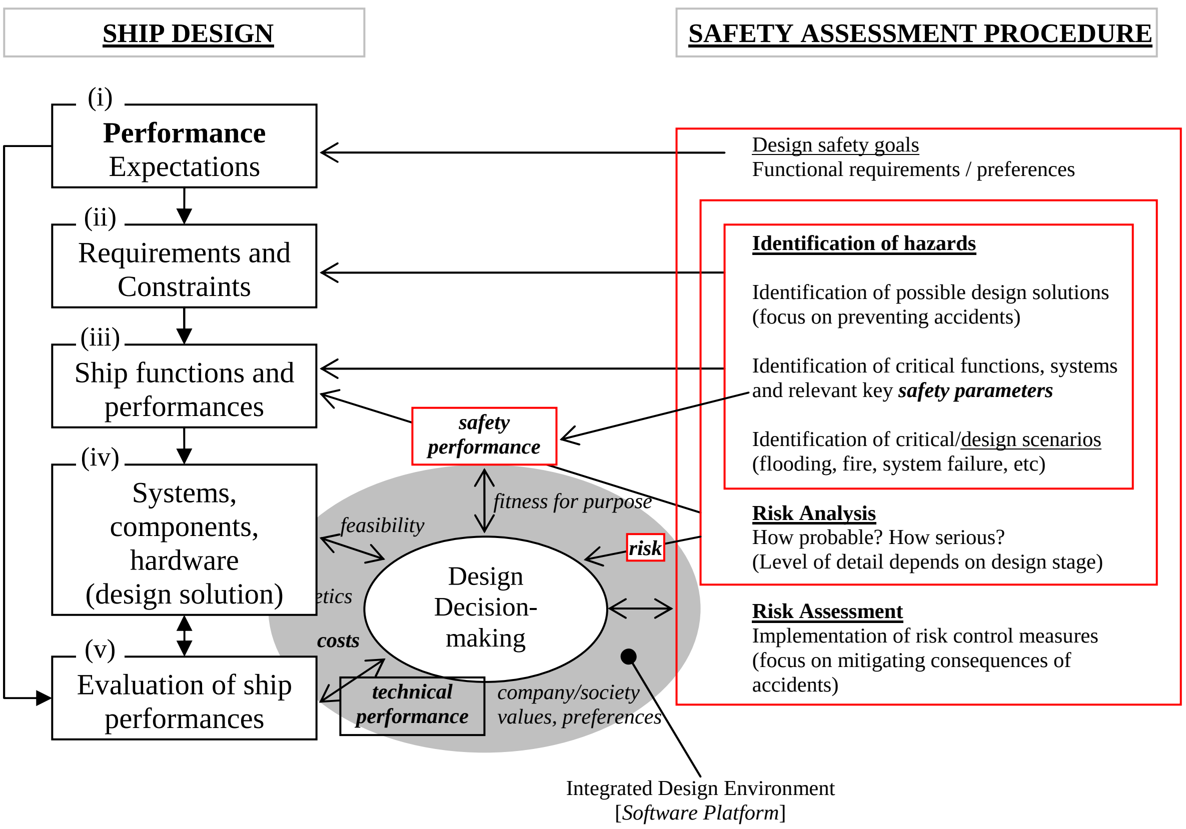


Figure 6: A High-Level Framework for Risk-Based Design Implementation

Definition of Safety Goals

Safety goals – as other design goals, are related to the ship's mission and ship's purpose. Explicit safety ***goals*** are already part and parcel of the design input. Examples of design goals driven by safety considerations (mainly associated with company values and policies) can be listed as follows:

Top-Level Goals

- No accidents leading to total ship loss (collisions, groundings, stranding, fires, etc)
- No loss of human life due to ship related accidents
- Low impact to the environment (no air emissions, low noise, low wash)
- Minimise impact to the environment in case of a ship accident

Specific Technical Goals

- Vessel to remain upright and afloat in all feasible operational loading and environmental conditions
- Vessel to remain upright and afloat in case of water ingress and flooding
- Ship structure to withstand all foreseeable loads during its lifetime (e.g., no extreme load structural failure or fatigue failure of key structural members)
- Sufficient residual structural strength in damage conditions
- High passenger comfort (no sea sickness, low vibrations levels, low noise levels)
- Etc.

Similar safety goals may be implicit in statutory or class requirements for risk acceptability – if such are available for approval purposes. Other design goals can be summarised in the following expression:

- Fit for purpose! (Turnaround time, service speed, capacity, services, etc.)

Identification of Hazards

In order to achieve *generic* safety goals as those stated above, more *specific* functional requirements must be defined so that compliance with such requirements would ensure achievement of the safety goals. In line with risk-based approaches, the identification of such requirements must be based on a systematic and rational assessment of what can impede the achievement of the safety goals; thus the "what-can-go-wrong" question must be explored systematically. This can be accomplished using hazard identification techniques. Hazard identification is usually a qualitative exercise based primarily on expert judgment. Various techniques and formats for reporting are available depending on the case, the purpose and the level of the design knowledge available (HAZID, FMEA, SWIFT, HAZOP, etc.).

To this end, it is always useful to have a clear definition of the ship's mission and its operational profile, the latter may include (but not be limited to) the following:

- Departure: bunkering, loading/unloading, manoeuvring out of port, etc.

- Passage: services on board, other functions, navigation in restricted waters, in open waters, etc.
- Arrival: manoeuvring into port, berthing, unloading/loading, etc
- Others: dry-docking, maintenance and repairs, etc.

Within the above operational profile, significant hazards, which could lead to catastrophic loss of the vessel, significant loss of human life/injuries, and/or significant damage to the environment, must be identified and their design implications understood so that appropriate design measures can be taken to prevent the ensuing accidents and to mitigate the severity of their consequences. In principle, and depending on the ship type, hazards that may lead to all or some of the accident categories need to be included in the subsequent steps of the safety assessment procedure. The outcome of such exercise at initial design stages may be illustrated as indicated in Table 1.

TABLE 1: EXAMPLE OF RESULTS FROM HAZARD IDENTIFICATION

Ship type: RoPax; Capacity: 1000 pax, 200 cars, 20 lorries, 50 trailers, etc.		
Operational mode	Hazard	Accident category
…	…	…
Loading of vehicles	Vehicles carrying dangerous goods, Electrical faults within vehicles, Drivers (human) errors	(1) Fire / explosions on car deck, contact damage to car deck structural members
…	…	…
Embarkation of passengers	Relative motion between span-link and ship	(2) Span-link failure when pax embarkation/disembarkation
…	…	…
Transit and navigation in coastal areas	Proximity to grounding hazards, wind, currents, loss of power, loss of steering, other vessels activity	(3) Collision (4) drifting grounding, (5) power grounding
…	…	…

Identification of Critical Design Scenarios

What makes risk-based design feasible and manageable, hence practicable, derives from the fact that ship safety, as a top-down process, is governed only by a handful of factors which, when considered individually or in combination, define a limited set of design scenarios with calculable probabilities of occurrence and consequences that could collectively quantify the life-cycle risk of a ship at sea. These relate to accident categories with major hazard potential, thus can be derived from hazard identification. When generic design scenarios are available, these must be adapted and customised to the specific design features and expected performances of the vessel in question.

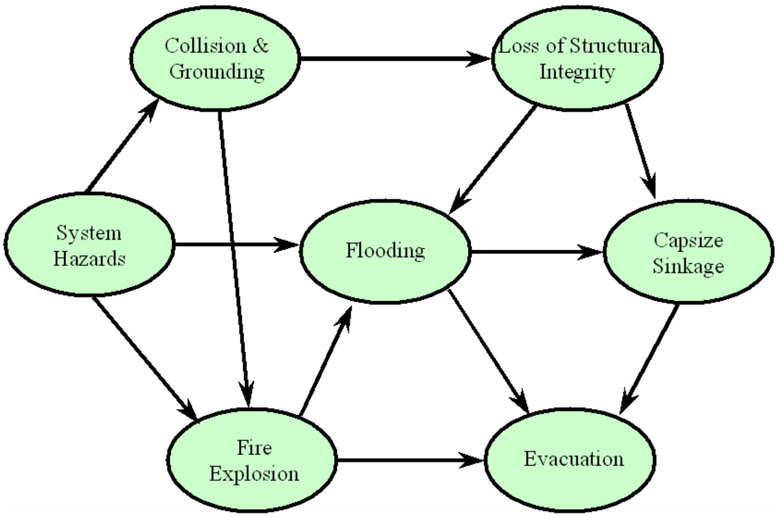


Figure 7: Typical Structural Links of Design Scenarios

Definition of (Safety-Related) Functional Requirements

Once a list of prioritised hazards is available (based on qualitative ranking of risk) along with relevant design scenarios, specific functional requirements and evaluation parameters need to be formulated. These can be seen as an additional set (in relation to the normal set of performances) of safety performance requirements, an example of which is shown in Table 2. These, of necessity, must be based on engineering judgment and available ***safety knowledge***. With a consolidated list of safety-related functional requirements, the design process can proceed as normally. Such requirements will, alongside other conventional design requirements, be used by a designer to put together the first base line design and to identify design disciplines for evaluation.

TABLE 2: EXAMPLE OF POSSIBLE SHIP FUNCTIONS, PERFORMANCES AND PERFORMANCE EVALUATION PARAMETERS

Required safety "Function"	Ship safety performance	Safety performance evaluation parameters / functional requirements (to be identified following risk analysis)
Collision and Grounding Safety	Vessel to remain upright and afloat in all feasible water ingress scenarios	Prevention: ▪ Effectiveness of navigational equipment; bridge layout design (alarms, visibility, controls, etc) Mitigation: ▪ Loss of structural integrity of the hull, damage extend, time to flood, flooding extent, instantaneous heeling, time to capsize, damage control arrangements, etc. Power, propulsion and steering redundancy after damage.
Fire safety	Safety objectives implicit in SOLAS II-2	Prevention: ▪ Limit the amount of ignition sources and combustible materials on the car decks, etc Mitigation: ▪ Alarm and detection effectiveness, fire protection, time to reach untenable conditions, effectiveness of fire fighting arrangements, etc.
Others …		Prevention: ▪ Car deck layout designed for easy of loading/unloading (visibility, space, ramp arrangements, ventilation, lighting, crew communication arrangements, etc.)
…	…	…

5.5 Design Decision-Making

Use of risk analysis or alternatively of risk-knowledge models in ship design would provide additional information on safety performance and risk levels to the design decision-making process. The use of risk-knowledge models would allow such information to be easily re-calculated if design changes are made. If similar parametric models existed for other ship performances (weight, efficiency, capacity, etc.) and economic implications (relative initial and running costs, earning potential, etc.) then if would be possible to make major design decisions and trade-offs optimally and cost-effectively in a practical time-scale.

In relation to design decision-making, in the same way as there are explicit ship performance evaluation criteria (design criteria), and economic "targets" (within owners requirements) there is a need to define safety performance evaluation criteria and risk acceptance criteria. The latter could be related to safety performance criteria, so that safety performance could be used in the design iterations, alongside or even instead of explicit risk acceptance criteria. As a result, key design aspects of the initial baseline designs (watertight subdivision, structural design, internal layout, main vertical zones, bridge layout, materials, major ship systems, etc.) can be optimised from the point of view of ship performance, cost implications, potential earnings whilst ensuring that the safety performance level (as quantified) is appropriate and commensurate with acceptable and quantified risk levels (provided that such do exist).

It is obvious that some design decisions determine the construction costs, other determine the operating cost and potential earnings. Whilst ship designers are, to a large extent, able to manage the construction costs, it is also unlikely that they would be able to do the same with the operational economic profile of the vessel. For the former, shipyards possess detailed knowledge and empirical models (indeed such relationships do exist within shipyards) to estimate construction costs. For the latter, it is the shipyards' clients (the shipowners) who possess detailed knowledge and working models of their operational costs and earnings profile.

Notwithstanding the above, the ultimate decision about the design parameters and variables lies of course with the designers themselves and other involved stakeholders (shipowner, shipyard, etc.). The quantified ship *performances* (technical performance, safety performance, costs, earning potential, and risk) would be weighted alongside other factors that are outside the design studies themselves (preferences, company policies, etc). In this context, ship design decision-making could be illustrated as indicated in Figure 8. The key aspect of the proposed approach is that any ship design decision will be <u>well-informed</u> and will lead to design concepts that are technically sound (at least to a level commensurate with the current available state-of-the-art), fit for purpose, and last but not least, with a known level of safety that is more likely (than by following rules) to meet modern safety expectations.

At early design stages, Performance-, Earnings-, Costs-, and Risk-knowledge models ("PERC") would provide the designer with means to rapidly and reasonably accurately obtain quantitative information for rational and transparent design decision-making (see Figure 9). It is obvious that not all necessary Performance- and Risk-Knowledge models would be available in all cases; however, the implied availability of a *global* parametric description of the baseline design solution would facilitate the use of explicit performance and safety-performance (first-principles) evaluation tools and would allow formal (numerical) optimisation techniques in ship design to be used effectively. Indeed, the possibility of optimising ship performance without regulatory constrains is what would make a significant difference in ship design decision-making as the best design solution (from all relevant perspectives) may lie outside the regulatory envelope. Established optimisation tools and techniques can help the designer to explore a much wider design solution envelope (see Figure 10) within the time scale available during early design concept development and beyond.

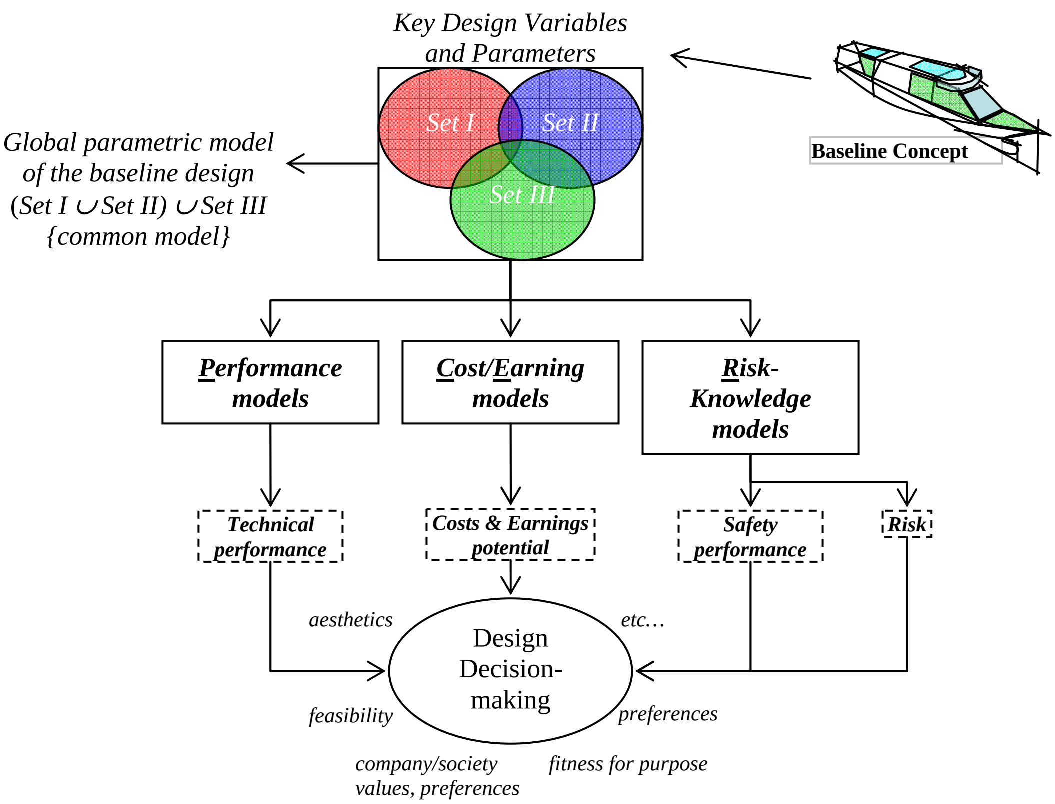


Figure 8: Decision-Making in Risk-Based Design
Sets I, II and III – Performance, Cost/Earnings and Risk Parameter Models

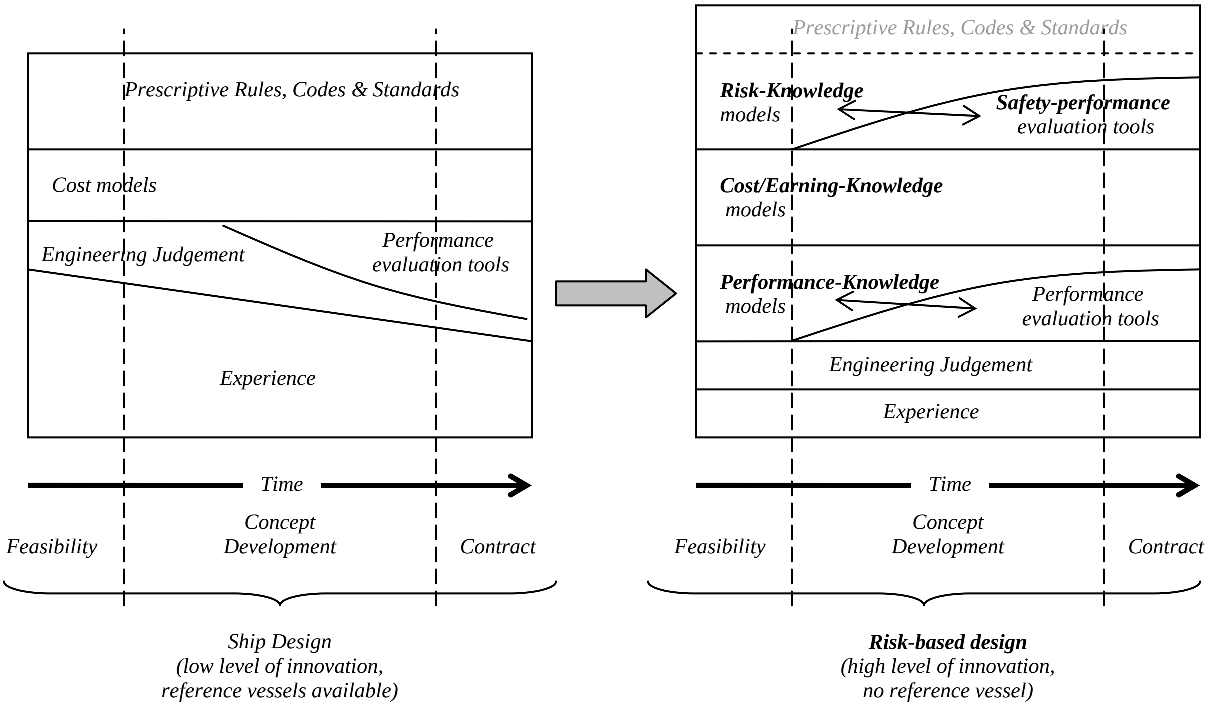


Figure 9: Significance of Key Factors to Decision-Making in Ship Design

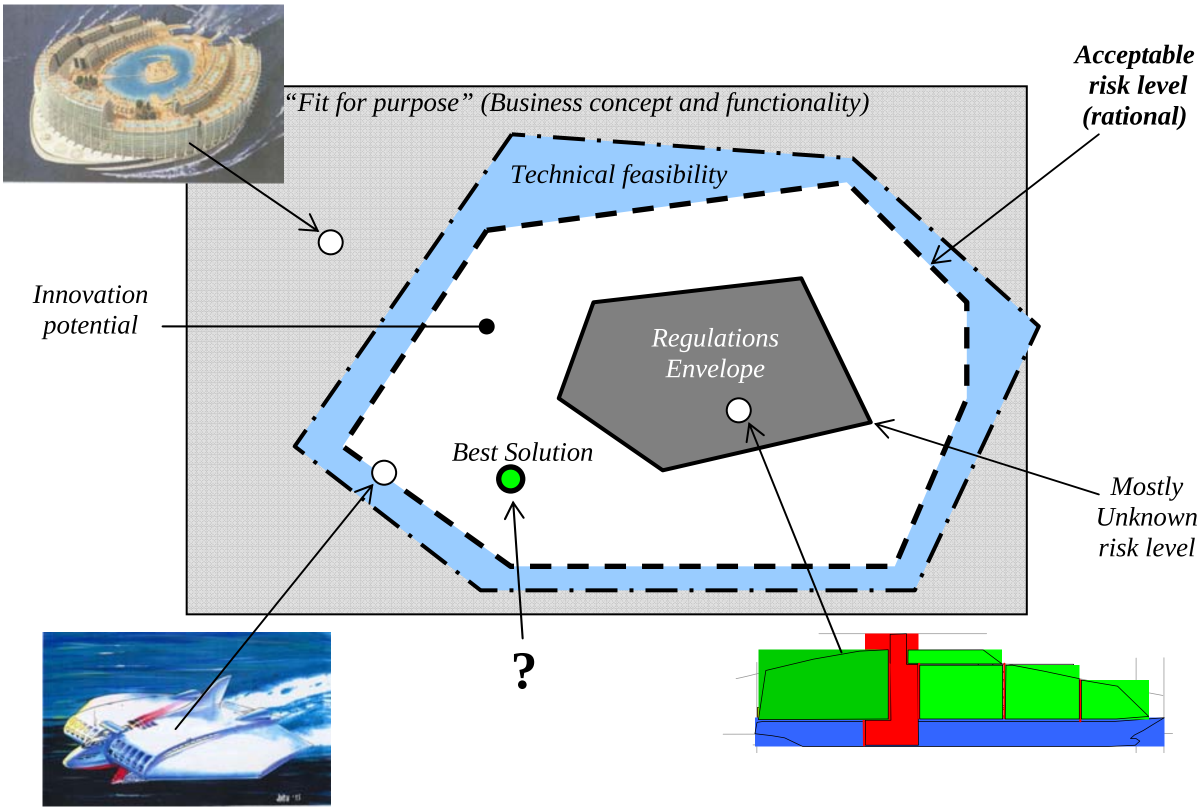


Figure 10: Possible Design Solution Envelopes

6. FIRST-PRINCIPLES TOOLS

6.1 Collision and Grounding

Advanced software is available to predict collision and grounding probability as well as related damages. This software, called GRACAT (http://www.mt.mek.dtu.dk/gracat/), was developed during the ISESO project from 1998 to 2001 at the Technical University of Denmark. The basic modelling principles and the capabilities of the software are described by Hansen and Simonsen (2002). The program is free of charge for research purposes but a fee will be charged for commercial use.

The software consists of three basic analysis modules and one risk mitigation module: frequency, damage, and consequence. These modules can be used individually or in series and the analyses can be performed in deterministic or probabilistic mode. Finally, in the mitigation module risk profiles for the calculated consequences can be calculated and compared to alternative solutions by assignment of a cost function to the consequences. Thus, the possible analyses range from a deterministic crash analysis to a comparative risk analysis of two vessels operating on a specified route where the result is the probability density functions for the cost of oil outflow in a given area per year for the two vessels.

The software package is integrated in itself and no standard interfaces are available. The package only links to the I-Ship- software used at the Technical University of Denmark. I-Ship in turn can be linked to NAPA.

To start the analysis, main data has to be entered. This includes main data (bow definition and hydrodynamic coefficients) ship hull and compartments (via I-Ship), loading conditions and causation factors. If structural damages are to be predicted, the structure of the vessel has to be modelled using dedicated macro elements. Usually, a library of structural elements is created first and then used to define the ship structure. The structural data can be exported but the format is not described. It is anticipated that no common interface to import structural data exists. The second step is the scenario definition which starts with a description of the geographical scenario (route, turning points, traffic data, and specification of the bathymetry for grounding predictions). Again, no standard interface seems to exist.

Various analysis formats are possible. This relates to deterministic and probabilistic analyses. It seems that no interfaces are available to export intermediate steps and results from the software package. However, each module is in principle a stand-alone module that could be linked to a risk-based design environment if appropriate interfacing is done with support form the developers

6.2 Flooding, Capsize / Sinking

Collision, grounding and/or stranding are the largest contributors to the risk of sinkage/capsize for any type of vessels. The probability of survival and eventually the time to sink and/or capsize following damage are crucial factors in determining the actual level of safety of a ship design, especially in the case of passenger-carrying vessels. Whilst the former can be reasonably estimated using empirical methods, the latter (time to sink/capsize) strongly depends on the geometry, topology and status of the internal compartmentation and openings (including doors, ducts, valves, etc) in addition to the random sea environment.

Containment of collision damage safety has recently been advanced to a stage at least comparable to that of fire, particularly so with the development of harmonised regulations for damage stability calculations (SLF 47). The relevant design iteration is shown in Figure 11. All assumptions accepted, p_i x $(1\text{-}s_i)$, provides a direct frequency estimation (Vassalos, 2004) for the scenario in question whilst the consequences can be estimated through the use of first principles tools, as illustrated in Figures 12 and 13.

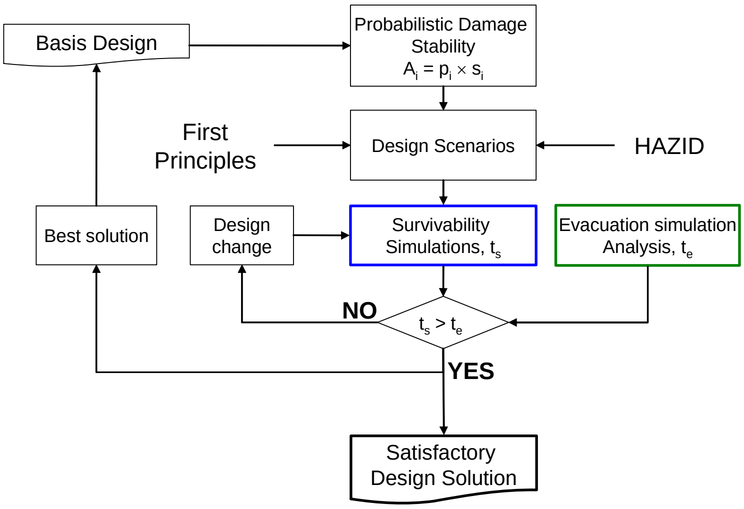


Figure 11: RBD iteration for collision damage safety

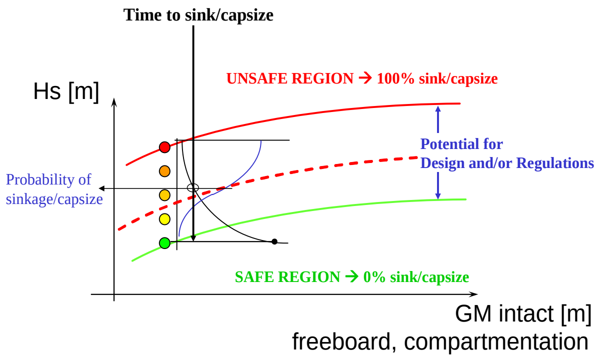


Figure 12: Evaluation of time to sink/capsize through first principles time domain simulation tools (Typical probability curves showing probability of capsize and time to capsize)

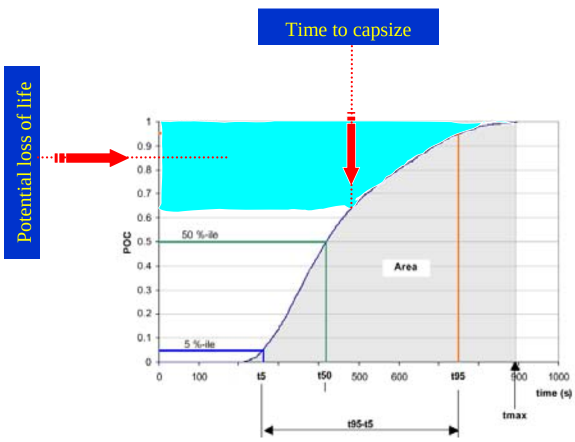


Figure 13: Evaluation of potential loss of life through passenger evacuation advanced simulation tools (Typical passenger objective completion curve)

The dynamic response of a damaged vessel, and the progression of floodwater through it in a random seaway form a highly non-linear dynamic system, the behaviour of which can only be assessed through time domain simulation. Building on this view, the University of Strathclyde began to develop the first-ever numerical model of this kind already 15 years ago. Since then, this model has been amply validated and calibrated through its application in both research and consulting work, before arriving at its current version, PROTEUS-3.1. This software suite is capable of simulating the vessel's behaviour (6-dof motions at zero or forward speed of intact or damaged ships, the latter of single or multiple compartment configuration) as well as the evolution of transient and progressive flooding through any damage compartment configuration and any shape and position of the openings through which flooding can occur. In addition, a number of non-linear effects can be incorporated, such as wave generated drift, wind loading, instantaneous hydrodynamic forces and moments, dynamic effects of cargo shifting, impulsive ramming excitation and mooring forces, among others.

All the effects listed above, would affect the time needed for orderly assembly and eventually, the time needed for safe evacuation of all people on board. Because of these characteristics, in particular modelling of the transient and progressive phases of flooding under the effects listed above, PROTEUS is the first flooding simulation program to be linked to evacuation software (Evi), providing an integrated simulation environment. This allows for the evaluation of the safety objectives of the scenario under consideration through an iterative procedure.

Other software programs for prediction of large-scale flooding following damage include CAPSIM (National Technical University of Athens), FREDYN (MARIN), SIMBEL (GL) and RollS (FSG). All tools apply direct pressure integration for the calculation of the hydrostatic forces, taking into account memory effects. Flooding (ingress / egress of water to / from spaces open to the sea) is modeled through simple hydraulic models based on the Bernoulli equation. Major characteristics of these tools are summarised in the following table:

TABLE 3: DAMAGE SURVIVABILITY SIMULATION TOOLS

Name of Tool	Organisation	Potential Theory Approach	Damping Forces Modelling	Floodwater Free Surface Modelling
RollS	FSG	Strip theory, 6 DOF	Non-linear roll damping according to P. Blume	Plane and free movable (when period away from natural); Glimm's equations (when period close to natural)
CAPSIM	NTUA	3D source panel theory, 6 DOF	Equivalent linear roll damping estimated from the available intact ship roll decay measurements	Plane and free movable
PROTEUS	SSRC	Strip theory, 6 DOF	Adaptive linear roll damping acc. to Ikeda	Plane and free movable
FREDYN	MARIN	Strip theory, 6 DOF	Nonlinear (Equivalent linear & quadratic) roll damping based on a modified Ikeda's approach	Plane and horizontal
SIMBEL	GL	Nonlinear strip	Nonlinear (equivalent	Plane and free

		theory, 6 DOF, space state model	linear & quadratic) roll damping according to P. Blume	movable (when period away from natural); Glimm's equations (when period close to natural)

Most of the software programs referred to above have undergone extensive validation to reach their present maturity. Within the remit of the Stability Specialist Sub-Committee of ITTC, most of the organisations listed above have participated in benchmarking their software over the last 5 years. The major conclusion from the benchmarking activities is that the tools can readily predict within reasonable engineering accuracy the survival boundary of any given damage case. Currently, research is focusing on two specific aspects: in providing accurate predictions of the time to sink / capsize and in developing methods for fast and accurate predictions of flooding.

6.3 Loss of Intact Stability

Intact ship stability is customarily assessed with a set of prescriptive requirements addressing, in an empirical way, the characteristics of the GZ curve (the so-called "general criteria"); and also through a simplified account of ship roll dynamic response under the effect of wind and waves acting from abeam ("the weather criterion") (IMO, 1993). These criteria tell little to the designer about the stability margin corresponding to certain environmental conditions; in other words they do not provide a quantitative link between operational risk and the ship environment. Moreover, they are not suitable for integration within a design methodology where safety is treated as an objective rather than as a constraint.

The industry is currently favouring a transition from prescriptive ship safety rules and regulations towards an approach based on a detailed analysis of the risk of ship operation. By its very nature, this approach combines an account of the probability of occurrence of undesirable events, such as ship capsize, with an appraisal of the potential consequences, and thus it appears as the rational way forward for intact ship stability assessment. However, to reach from concept level to practical implementation, several basic scientific gaps require attention; and before all, how a rational treatment of the dynamics of extreme ship motions could be embedded meaningfully upon the probabilistic framework of a risk assessment methodology.

In rough seas ships may capsize in a variety of ways depending on ship-wave encounter, extremity of excitations, occurrence of resonant phenomena and complex behaviour arising from coupling mechanisms as well as from the existence of strong nonlinearities. A sound probabilistic approach of ship stability assessment requires that some analytical or numerical tools are available that can predict all targeted modes of capsizing: pure loss of stability as a result of sharply reduced restoring capability on the wave crest, parametric rolling in following or in head seas, broaching, breaking waves' effect, shipping of green water on deck, etc. From one scenario to another, the probabilistic character of wave excitation is likely to entail different treatment (e.g. attention on a single breaking wave for beam sea capsize; or the encounter of a wave group with certain characteristics for parametric rolling or cumulative broaching).

Tools for first-principles assessment of loss of intact stability under the different modes briefly described above, as well as attempts to foster a probabilistic assessment of intact stability can be found in the literature; yet the issue, due to its width and depth, is still regarded as unsolved. Specific tasks to realise a rational treatment of loss of stability in the intact condition, which form part of on-going research, include the following:

- Identification of critical modes, mechanisms and scenarios that may result in instabilities and/or capsize (HAZID on intact stability), including the identification of suitable risk control options (RCOs).

- Development of suitable probabilistic wind and wave profiles for unrestricted and restricted service which could be interfaced with a risk-based ship stability assessment.

- Development of probabilistic procedures, methods and tools for understanding and predicting the various modes of ship capsize under regular and irregular excitations.

- Integration of the above within a probabilistic framework of ship stability assessment which should be capable of producing quantitative predictions of risk for a given wind-wave environment.

- Evaluation of the developed methodology for the selected critical scenarios and to demonstrate its potential through application to ships within a risk-based design process.

6.4 Fire / Explosion and Smoke Propagation

Two kinds of models are currently used for predicting fire and smoke propagation: zone and field models. Zone models use macro-elements with prescribed properties to discretise the volume geometry under consideration. Field models use fine discretisation of the volume in order to solve for mass and momentum equations. Zonal models are much faster than field models but limited to certain geometries. An overview of available software is available in appendix 6 of the guidance notes on alternative design and arrangements for fire safety (ABS 2004). The following two sections are based on these guidelines.

Smoke has a large effect on passengers that evacuate in an emergency. Therefore, the close linkage of fire / smoke prediction tools with mustering and evacuation prediction tools is a prerequisite for accurate analyses. The running R&D-project FIRE EXIT aims to link SMARTFIRE with maritimeEXODUS and will provide the first coupled software suite of this kind (http://www.bmtproject.net/fire-exit/). SSRC is also currently developing a similar capability by linking LESSFIRE (a suite of fire simulation zone and field models, which is under development) with Evi through various research projects (Guarin, 2004).

Zone models

The zone modelling concept divides the hypothetical burning enclosure into two spatially homogeneous volumes, i.e., a hot upper layer and a cool lower layer. This two-layer approach has evolved from the observation of such layering in real-scale fire experiments. Hot gases collect at the ceiling and fill the compartment from the top. While these experiments show some variation in conditions within the layer, these are small compared to the differences between the layers. Thus, zone models can provide a fairly realistic simulation under most conditions. Mass and energy balances are enforced for each layer, with additional models describing other physical processes appended as differential or algebraic equations, as appropriate. Examples of such phenomena include fire plume, flows through windows, ceilings and vents, radiative and convective heat transfer and solid fuel pyrolysis rate, etc.

The basic assumption of all zone fire models is that each room can be divided into a small number of control volumes, each of which is internally uniform in temperature and compositions. The major limitations of zone models are directly related to the modeling assumptions. The uncertainty of the modeling results can be significant if the temperature profiles are sensitive to the height of fire origin below the ceiling in a real fire scenario.
Another shortcoming of the zone model is the assumption of instantaneous plume spread upon impingement of the plume with the ceiling. If the compartment is sufficiently large (e.g., a warehouse) or long (e.g., a corridor), the assumption of instantaneous volume filling may be violated.

A large number of zone models exist and the reader is referred to the guidelines mentioned above.

Field models

Field (or CFD) models represent the other alternatives of deterministic analysis. This approach is based on basic local conservative laws for physical quantities such as mass, momentum, energy and species concentrations. These equations are solved with spatial and temporary resolutions to yield the distributions of the variables of interest. Due the turbulent characteristics of thermally driven flows, the biggest challenge that arose in using CFD methodology is how to properly handle turbulence.

A handful of CFD codes can be used for problems involving fires. These use a number of different approaches to the subprocesses that need to be modeled. Some of the most important of these subprocesses include turbulence modeling, radiation and soot modeling and combustion modeling, etc.

In order to fully specify a problem, a set of boundary and initial conditions must be provided. Boundary conditions place limits on the physical environment. Boundary conditions generally can be in two categories: thermal boundary conditions and velocity boundary conditions. There are four types of thermal boundary conditions: adiabatic, constant temperature, thermally thick and thermally thin. If the surface material is assumed to ignite and burn at certain temperature, the relationship between the pyrolyzing fuel and the rate of energy released should be taken into account.

Again, a large number of tools are available. Among the more widely known special fire codes are FDS and SMARTFIRE. Multi-purpose CFD codes are usually also capable to predict smoke propagation.

Comparison between zone and field models

As the problems grow more complex, zone models will be inadequate to fully address them. Zone models provide very limited detail, with bulk average values being predicted in a few select locations within the enclosure. Zone models utilize equations employing empirical relationships and constants obtained from experiments. Such empirical expressions used to describe physical behavior in zone models could break down as the geometry becomes more complex. Therefore, the use of zone models for problems that lie outside the range of experiments is very limited.

Field models avoid the simplifications inherent in zone models. In some fire cases, the geometry of the room and its outfitting can have significant effects on the nature of recirculation patterns, thus, the higher spatial resolution of field models can be important. In many cases, the detailed knowledge of the temperature and/or flow fields near sprinklers or smoke detectors is required to ac*curately predict the activation.*

Fluid dynamics considerations are automatically built into field models, rather than being forced into oversimplified approximations. Thus, field models follow the movement of the plume, rather than assuming that deposition of mass and energy from combustion/plume zone into the upper layers is instantaneous. Similarly, they describe the spread of the ceiling jet into the entire upper layer, rather than assuming the instantaneous mixing within it.

Explosions

Software used for the prediction of explosions is commonly used by engineers working for the navies. Software packages known are SAVIUS in Italy, RESIST in the Netherlands and MINERVE in France. The packages require the full description of the structure. If the pressure pulse from an explosion is known, commercial software like, e.g, LS-DYNA can be used to predict the structural response.

6.5 Mustering and Evacuation

Flooding and fire constitute the principal hazards that may lead to passenger evacuation. If these hazards develop into an uncontrollable situation, it must be ascertained a priory that ALL people on board can be evacuated safely. Mustering and evacuation analysis should therefore be aimed at developing a system (a minimum standard of evacuability) that guarantees this assertion to an acceptable level by utilising advanced consequence analysis tools for flooding, fire and evacuation within a risk-based framework. Evacuability in this respect represents a risk measure of passenger evacuation at sea expressed as an index, for a given pertinent scenario, environment, passenger distribution and demographics and initial response time. Developing such a system will ensure focus on passenger safety in a systematic and all embracing way that safeguards against the consequences from given (design) flooding and/or fire scenarios that may lead to abandoning a ship or mustering to a safe refuge onboard, by providing an active link between the two; in particular the likelihood of these scenarios occurring and the ensuing consequences in a way that allows for systematic risk prevention/reduction through passive (design) and active (operation) means. In this respect, one can deal cost-effectively with design, operation, regulation and training issues.

The process of evacuating a (large) passenger ship is a very complex one, not least because it involves the management of a large number of people on a complex moving platform, of which they normally have very little knowledge. These characteristics make ship evacuation quite different to evacuation from airplanes and buildings. To address the risk associated with passenger evacuation at sea, the term *Evacuability* (passenger evacuation performance capability) has been devised (Vassalos, et al, 2002) entailing a wide range of capabilities that encompass evacuation time, identification of potential bottlenecks, assessment of layout, life saving appliances, passenger familiarisation with a ship's environment, crew training, effective evacuation procedures/strategies, intelligent decision support systems for crisis management and design/modification for ease of evacuation. From a technical point of view, the mass evacuation of thousands of people from an extremely complex environment with unknown inaccessibility problems exacerbated by (potentially co-existing) incidents such as progressive flooding, fire/smoke and the inherent uncertainty deriving from unpredictability of human behaviour, is a problem with severe modelling difficulties at system, procedural and behavioural levels.

Evacuation has been a high priority in the International Maritime Organisation's (IMO) agenda since 1999 when SOLAS imposed evacuation analysis to be carried out early in the design stage of new Ro-Ro passenger ships. Following this, the Fire Protection Sub-Committee, after three years of work, issued in February 2002 a set of revised Interim Guidelines for new Ro-Ro passenger ships – new cruise ships and existing ships on a voluntary basis – to be carried out either by simplified analysis or computer-based advanced analysis. Such analysis allows for assessment at the design stage of passive safety (in-built) of the ship evacuation system only, while operational safety (active), pertaining to any measures to enhance emergency preparedness and to better manage crisis in case of an emergency, is only dealt with by means of a safety factor. In this respect, the IMO evacuation scenarios address issues relating to layout and availability of primary evacuation routes as well as passenger distribution and response times but does not address any real emergencies and hence the need to prepare for these trough better planning, training and decision support, all related to the functionality of the crew onboard, which is as crucial to passenger mustering as a good layout of the escape routes.

Stemming from these developments, evacuation analysis through numerical simulations can now be undertaken meaningfully. The term *Evacuability* reflects ability to evacuate a <u>ship environment</u> within <u>a given time</u> and for <u>given initial conditions</u> and is defined as follows:

$$E = f\{env, d, r(t), s(n_i); t\}$$

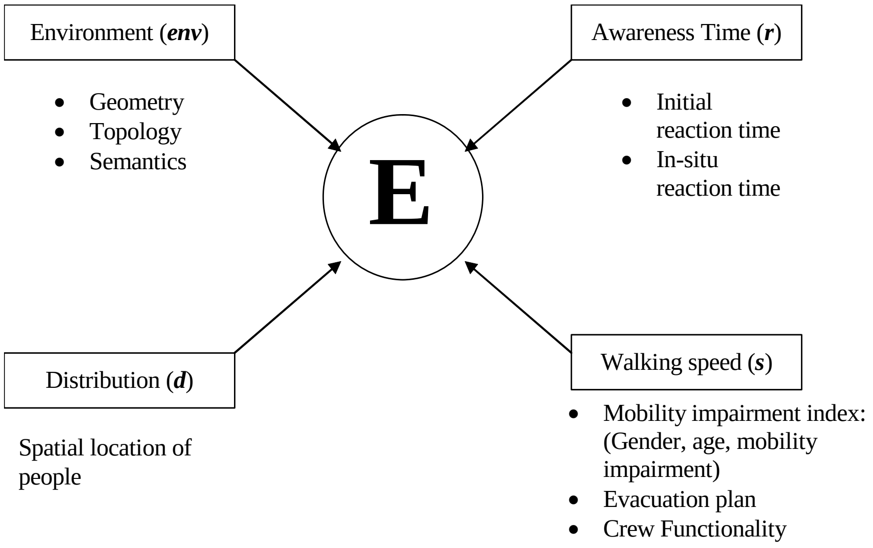


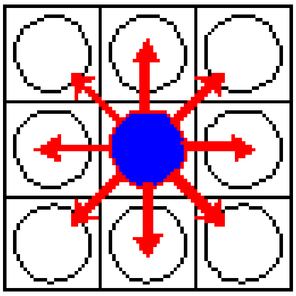
Figure 14: The concept of *Evacuability* (E)

Thus, *Evacuability* is a function of a set of initial conditions, ***env***, ***d*** and ***r(t)***, and evacuation dynamics, $s(n_i)$ and provides a direct risk measure of passenger evacuation in a ship-sea environment.

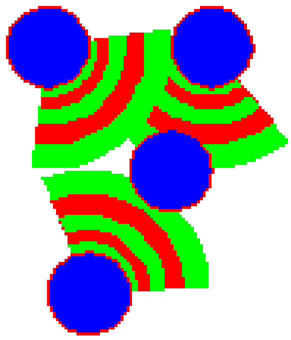
On the basis of the above, it may be stated that *Evacuability* is a well-defined problem that can be formulated and solved (simulated) for given initial conditions and passenger flow parameters. In fact, there exist several advanced passenger evacuation simulation tools, some of which are able to deal with design and operational issues as well as be coupled with other advanced prediction tools for flooding, fire, and be utilised to prevent /reduce risk to human life safety, as postulated in the foregoing. The most well-known evacuation programs are:

AENEAS
(http://www.gl-group.com/maritime/newbuilding/shipsafety/aeneas/3615.htm);
EVI (www.shipevacuation.co.uk); and
maritimeEXODUS (http://fseg.gre.ac.uk/exodus).

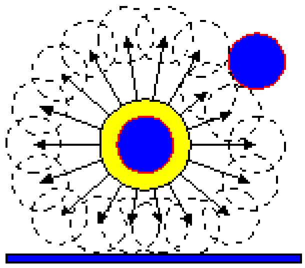
The agent model considers human behaviour in an evacuation to depend on a set of crucial characteristics as described in the foregoing. A hazard within the evacuation environment will affect these characteristics changing the performance of the agents. All these three advanced evacuation simulation programs apply microscopic modelling to model the agents within the simulation environment. Identification of a technique which will allow enough information to be retrieved from the surrounding locality to enable a decision to be made on a course of action is thus of paramount importance. Consequently, the choice of solution depends on matching the efficiency of the technique for obtaining information from the locality to the desired range of decisions (capability) of the agent. There are mainly three solutions to this problem:



Grid based techniques: Grid based techniques simplify the problem of obtaining information from the surrounding locality by dividing the space up into a grid. Consequently, it is then very easy for an agent to search neighbouring squares. This approach makes for a very rapid simulation tool. However, due to relationship between the size of the square and the size of agents there is only a relatively low number of decisions that can be taken. Furthermore, discrete grid bases approaches are severely limited on variety of geometries that can be represented. This technique is basically employed within AENEAS and maritimeEXODUS.



Social Force Methods: Social force methods can be see as the exact opposite to the grid based approach. These methods aim to model the interaction between agents and obstacles in great detail. A force based system is used, controlled by the distances between, to obtain a technique can provide continuous decisions. In accordance with the force based approach, agents operate in a continuous space which allows for a maximum range of flexibility in the geometric environment. However, the continuous space approach is very expensive when it comes to determining information around the locality of an agent. Consequently, this approach is not particularly effective for tools operating in a practical engineering environment.



Hybrid approaches: Evi uses a hybrid approach which aims to take the advantages from the other two techniques. It represents an approach which aims to utilise the effectiveness of grid based technique with the flexibility of social force methods. In order to simplify calculation, a range of discrete decisions are established around the agent with the objective of identifying the one which will allow the agent to travel the greatest distance toward the local target. In addition, a continuous local (social/personal) space is established around each agent which other agent will aim to avoid. This space is use to prevent deadlock situation when the number of agents in an area become dense. The agent makes a decision of the best use of its personal space to resolve any conflicts that may arise. As a result, this approach allows the evacuation process to be modelled in sufficient detail and still run in real time.

7. CONCLUSIONS

This report has provided a summary of the activities undertaken by the Research Lecturer at the Ship Stability Research Centre, Department of Naval Architecture and Marine Engineering of the Universities of Glasgow and Strathclyde during the period April 2003 to March 2006, a post supported by a Grant-in-Aid provided by the Maritime and Coastguard Agency.

The main conclusions that can be drawn on the current status of risk-based ship design, operation and regulation are the following:

- A consistent measure of safety must be employed and a formalised procedure of its quantification adopted (risk analysis). For this to be workable, considering the complexity of what constitutes safety, a clear focus on key safety "drivers" is necessary (major accident categories). A number of formalised procedures for risk quantification, risk assessment and risk management exist in various contexts, for instance *Formal Safety Assessment* (FSA) for rule-making, *Safety Case* addressing for specific design/operational concepts, among others. The current thinking on a safety assessment framework for design has been described.

- Such procedure must be integrated in the design process to allow for trade-offs between safety and other design factors by utilising overlaps between performance, life-cycle cost considerations, functionality and safety at parameter level. Consequently, additional information on *safety performance* and *risk* will be available for design decision-making and design optimisation.

- Considering the level of computations that might be necessary to address all pertinent safety concerns and the effect of safety-related design changes on functionality and other performance factors, a different handling is required; namely, the use of parametric models to facilitate trade-offs and access to fast and accurate first-principles tools. The design optimisation process becomes thus a typical case of multi-objective, multi-criteria optimisation problem. A common ship design model managed within an integrated design environment (software platform) will also be required for this process to be conducted efficiently.

It is noted, that the concepts presented reflect the current level of understanding and experience with risk-based ship design. It is anticipated that during the developments to be undertaken as part of SAFEDOR activities in the near future, the ideas presented here will be further elucidated, nurtured, refined and evolved.

The report also described the current state-of-the-art on first principles tools. Advanced first-principles tools are needed to enable routinely prediction of safety performance of a vessel in critical design scenarios. The main conclusions that can be derived are the following:

- First-principles tools and methods to predict safety performance for most initiating events, design scenarios and their consequences are available today. In general, the technology of these tools is considered to be mature, i.e. partial application of risk-based design is possible today in any area the designer feels that such an approach would benefit them.

- There are certain elements that require further research and development. These mainly relate to the issue of provision of fast and accurate predictions for almost all the areas current tools address. It can be very safely claimed that the short- and middle-term needs will be addressed within the relevant sub-projects of SAFEDOR.

- The major challenge is communication among these tools and their integration in designers' / shipyards' design environments. Most of these tools are stand-alone applications, and even though the input / output formats in some of them (for example, the stability and survivability tools) do not introduce any significant integration problem, there are certain software packages (for example, all the risk modelling tools) that have been developed as stand-alone applications, complete with graphical user-interfaces. The drawback in this case is that most tools do not offer internationally accepted standard interfaces. It is also expected in this case, that the relevant SAFEFOR sub-project will achieve some desired results in this respect.

An element that will also receive much attention in the near future relates to training of practitioners at various positions within the maritime industry (regulators, shipbuilders, operators, designers). As described here and in other publications, significant developments in the area of risk-based ship design, operation and regulation have taken place over the last decade or so, mainly at a research level. We are currently experiencing the first attempts for application in design, operation and regulation, which, in order for the potential benefits offered to be realised, would require efforts towards effective training.

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8. REFERENCES

ABS (2004) "Guidance notes on alternative design and arrangements for fire safety".

CHRISTENSEN, H., HENSEL, W., DE LUCAS, A. P., SAMES, P. C., SKJONG, R., STRANG, T. AND VASSALOS, D. (2005) "SAFEDOR- Risk-Based Ship Design, Operation and Regulation", Proceedings of the International Maritime Association of the Mediterranean (IMAM) 2005 Congress, 26 – 30 September, Lisbon, Portugal.

HANSEN, P. FRIIS AND SIMONSEN, B. CERUP (2002) "GRACAT: Software for grounding and collision analysis", Journal of Marine Structures, Special issue on Ship Collision and Grounding. Vol. 15, No. 4-5 July-October 2002. pp. 383-402.

HSE (2001) "Marine Risk Assessment", Offshore Technology Report, No. 2001/063, prepared by Det Norske Veritas for the Health and Safety Executive, UK.

GUARIN, L., MAJUMDER, J., SHIGUNOV, V., VASSALOS, G. AND VASSALOS, D. (2004) "Fire and Flooding Risk Assessment in Ship Design for Ease of Evacuation", 2nd International Conference on Design for Safety, Osaka, Japan, October 2004, 7pp.

IMO (1993) Code on Intact Stability for All Types of Ships Covered by IMO Instruments. Resolution A.749(18), London.

SAFEDOR (2005) "Risk-Based Design, Operation and Regulation for Ships", EC FP6 IP 516278, www.safedor.org.

SAFER EURORO (1997, 2001) "Design for Safety – An Integrated Approach to Safe European Ro-Ro Ferry Design", ERB-BRRT-CT97-5015 and G3RT-CT-2001-05050, www.safereuroro.org.

STORCH, R. L. (1995) "Ship Production", Second Edition, SNAME.

VASSALOS, D., KIM, H. S., CHRISTIANSEN, G. AND MAJUMDER, J. (2002) "A Mesoscopic Model for Passenger Evacuation Simulation in a Virtual Ship-Sea Environment and Performance-Based Evaluation", 'Pedestrian and Evacuation Dynamics', Springer-Verlag, Berlin; Heidelberg; New York, 2002, pp 369-391.

VASSALOS, D. (2004) "A Risk-Based Approach to Probabilistic Damage Stability", 7th International Ship Stability Workshop, Shanghai, China, 1-3 November 2004, 12 pp.

VASSALOS, D., KONOVESSIS, D. AND GUARIN, L. (2005) "Fundamental Concepts of Risk-Based Ship Design", Proceedings of the International Maritime Association of the Mediterranean (IMAM) 2005 Congress, 26 – 30 September, Lisbon, Portugal.

VASSALOS, D., GUARIN, L. AND KONOVESSIS, D. (2006) "Risk-Based Ship Design Implementation – Riding the Learning Curve", Proceedings of the 9th International Marine Design Conference, May 2006, Ann Arbor, MI, 14 pages.

ANNEX A

The Ship Stability Research Centre

The Ship Stability Research Centre (**SSRC**) is the world leading centre on Ship Safety. Established on 22 January 1997 in response to demand from the international maritime industry to adopt scientific approaches in dealing with ship safety. SSRC staff deal with wide-ranging aspects of motion dynamics and control, stability, safety and design of ships and advanced marine vehicles. It consists of two research units addressing basic research (concept development) and strategic/applied research (tool development) as well as one commercial unit offering wide-ranging specialist services to the marine industry by targeting the technological gap between front-end research and industry best practice (www.safety-at-sea.co.uk). The annual turnover of SSRC amounts to £1.5M from EPSRC, UK Government, EU, Industry and International Collaborative Research Programmes. During its years in existence, SSRC has had a profound influence on the maritime industry, establishing itself as the acknowledged pace setter on ship safety in all its various forms ranging from philosophical to research, regulatory, design and operational aspects.

Major achievements in these areas include the following:

- Promulgating the theme "Design for Safety" which has gained wide acceptance through the establishment and co-ordination of the largest EU Thematic Network with 92 organisations from 16 countries and a research portfolio amounting to €100M, thus promoting the adoption of a safety culture in the maritime industry
- Establishing a scientific basis for damage stability research
- Major breakthrough in non-linear ship dynamics and scientific explanation of complex ship behaviour in extreme environments
- Setting internationally adopted safety standards for Ro-Ro vessels and subsequently undertaking the upgrading of 80% of the north EU ferry fleet
- Instigating a major revision of international regulations on the safety of bulk carriers in the process of helping DETR as a principal witness in the RFI of MV Derbyshire
- Providing the industry an arsenal of innovative tools for addressing safety cost-effectively during the whole life-cycle of ships
- Becoming a focal point of active international collaboration.

The SSRC is a member of the ITTC Specialist Committee on Ship Stability (Chair 1996-2202), the Chair of the International Standing Committee on Ship Stability Conferences and Workshops and supports actively the UK delegation at IMO for Ship Stability and Safety of Fishing Vessels, High Speed Craft, Bulk Carriers and Large Passenger Ships.