integrated flooding control and standard for stability and crises management

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1 Scientific relevance to the call topics

The size of new passenger ships has increased tremendously during the past decades, see Figure 1. This trend is expected to continue, as bigger size means new opportunities and economics of scale. However, with larger number of passengers onboard the same vehicle the risk to life increases, and hence new insights and methods to deal with it need to be explored.

Since it is known\(^1\) that the major risk to persons onboard is posed by the hazard of flooding, the proposed project FLOODSTAND sets to respond to this need by two differently focused approaches\(^2\):

a) deriving new detailed, more reliable information and modelling principles on the process of ship flooding and developing new methods for analysing the flooding extent onboard

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\(^1\) See e.g. EU SAFEDOR, FP6

\(^2\) These two approaches originate from the approaches presented in the FP7-SST-2007-RTD-1 Collaborative Small or Medium Scale Focused Research project proposals a) FLOODCONTROL and b) I STAND, which are here merged together as the proposed project FLOODSTAND.
b) developing a standard for a more comprehensive measure of damaged ship stability than standards in use today.

SLF committee of IMO has also established “Time dependent survivability of passenger ships in damaged condition” as an important agenda item. Furthermore, there is a need for a reliable assessment of the available time for evacuation onboard the damaged ship as the time-to-sink can vary within a large frame (e.g. Royal Pacific sunk in less than 15 minutes in 1992 and Sea Diamond in about 15 hours in April 2007).

Several flooding simulation tools have been developed in Europe during the past decade. So far the main emphasis has been on the RoRo vessels with a flooded vehicle deck, but recently also the progressive flooding of large passenger ship has been studied with time-domain simulations. The recent ITTC benchmark studies have proved that flooding simulation tools provide reasonable results when all the affecting parameters are modelled properly in the numerical method. Therefore, it is of utmost importance that reliable values for these parameters are established through systematic experiments and dedicated computations. This work is essential in order to utilize sophisticated flooding simulation tools for improving ship safety.

Flooding simulation should always be considered in its entirety: the applied numerical method has to be verified and validated but also all (semi) experimental coefficients must be valid for the studied flooding case. Otherwise, the results cannot be considered as reliable. An example of the effects of the applied critical pressure head for collapsing of cabin doors is presented in Figure 2. The effect on the time-to-flood can be very remarkable.

- In this project, the necessary parameters for the openings and structures will be assessed on the basis of dedicated experiments and systematic computations with sophisticated state-of-the-art tools.
- In addition, guidelines for modelling and using flooding simulations, both as a design tool and as part of the decision support system onboard a damaged ship, will be developed.

![Figure 2](image)

Figure 2  Example of the time history for the volume of flooded water with different values for collapsing of cabin doors (H_{col}). A small difference (0.5 m) in the input data can cause a remarkable difference in the flooding process and in the time to reach a critical condition.

Unlike any regulations developed to date, the planned research will also propose a standard that will reflect the stochastic (random and time dependent) nature of ship stability loss when damaged in waves. The standard will be based on first-principles modelling, building on precision of modelling of floodwater progressions through the ship not available today, and thus it will reflect the nature of the foundering as a process comprising loss of
either (or both), floatability and stability, but also and more importantly ultimate loss of human life. Since risk-based, the standard will form a rational basis for decision making during emergency (abandon or stay onboard and return to port or wait for assistance as the least risky option). It is expected that by explicit disclosure of risks associated with ship flooding and thus addressed from the very first design stages to every day of ship operation, the safety and security levels can be raised substantially, possibly by as much as an order of magnitude from levels provided for by today’s regulations.

Therefore, FLOODSTAND addresses one of the ultimate goals of the Theme 7th of the FP7, namely that of contribution towards developing “safer” and thus globally competitive transport systems for the benefit of all citizens and society.

This FP7 goal is made more specific in the text of the Activity 7.2.4 which calls for improving safety and security of surface transport by (a) developing technologies and intelligent systems to protect vulnerable persons such as passengers or crew, and (b) developing advanced engineering systems and risk analysis methodologies for the design and operation of vessels with emphasis on passive and active safety, i.e. including monitoring systems, rescue and crisis management. This Activity considers safety as an inherent component of the total transport system embracing infrastructures, freight (goods and containers), transport users and operators, vehicles and vessels and measures at policy and legislative levels, including decision support and validation tools.

As explained in the foregoing, FLOODSTAND sets to address these specific aims by focusing on two topics of the call, namely:

- **Topic 7.2.4.1.1 – Safety and security by design**
  - Subject 1 – Advanced modelling, simulation, engineering and testing tools aimed at the improvement of safety and security performance of ships. In particular developments including methodologies and design environments for risk based design and approval, virtual testing methods, pre-normative research towards standards and regulations, and explanatory measures to assess their impact.

- **Topic 7.2.4.1.3 – Crises Management and Rescue Operations**
  - Subject 1 – Systems and tools (e.g. decisions support systems) to assist and support control centres, masters, crew, drivers and emergency services handle emergency situations (e.g. evacuation of capsizing vessels involving large numbers of passengers).
  - Subject 3 – Operational procedures for incidence identification, notification, rescue and rapid resumption of normal operations including the support to new standards.

As mentioned above, the expected impact of FLOODSTAND is contribution towards measurable reduction of risk to human life associated with maritime transport, and thus increases of both safety- and security-levels.

The details of the FLOODSTAND concept and objectives are described next.
1.1 The concept

1.1.1 Flooding simulation

In passenger ships, the non-watertight subdivision in the watertight compartments is usually rather dense. Consequently, these structures will have a large effect on the progress of the floodwater in the event of damage. Currently, there is no reliable data for the behaviour and strength of widely used structures (such as fire doors) under the pressure of floodwater. In flooding simulation, it is necessary to include also the leaking through closed doors since the simulated time-to-flood depends heavily on the applied model for the leaking. Consequently, the whole failure process needs to be assessed with a reasonably simplified approach. The critical collapsing pressure heads currently available are not sufficient for time-accurate simulations. The results from the experiments and FE (finite element) analyses will provide the necessary information for several typical door and panel constructions.

Since the flooding simulations require a large amount of computer time, simplified approach is used for calculating the flows inside the damaged ship. The applied methods have been validated with experiments (e.g. van’t Veer and de Kat\(^3\)). This approach is used in all flooding simulation tools. However, this technique involves experimental discharge coefficients that take into account the pressure losses in the openings. At the moment, proper values for discharge coefficients are not known for various typical openings and structures in a modern passenger ship. These values will be determined on the basis of large scale experiments and full scale RANSE (Reynolds averaged Navier-Stokes equations) computations. Also the scale effects will be studied. Furthermore, the effects of restricted ventilation level and the counter air pressure will be assessed and formulae for pressure losses in air pipes will be derived on the basis of systematic computations. As a result, the time-domain simulation of cross-flooding is expected to become much more accurate, while the parameters are applicable for all flooding simulations.

Little knowledge is available with respect to the survivability of damaged cruise ships at calm water and in waves. Some initial simulation work has been done during the recent years at MARIN and at TKK, pointing out that the progress of the floodwater and the survivability of the damaged ship can be simulated, but that at the same time many uncertainties exist with respect to modelling principles for the internal arrangement of cruise ships, and the cabin areas in particular. In practice, it is not possible to model the whole ship with every detail.

The majority of passenger cruise ships are being built in Europe. Recent accidents (like the sinking of the Sea Diamond in Greece in April 2007 and the sinking of M/S Explorer in antarctic waters in November 2007) have again\(^4\) raised the question of adequate level of damage control and the technical tools for that on board the ships. The topicality of this issue is becoming even more important since the number of large passenger ships on European waters is continuously increasing. Evacuation of a cruise liner always has its own risks, especially in bad weather conditions. Therefore, in the event of damage and subsequent flooding, the master of the ship (and/or the emergency response centre) has a remarkable responsibility for the decision about the evacuation. A


\(^4\) Some concerns about “what could have happened?” can always be presented, although in these cases the evacuation and rescue operations of the persons onboard were successful, performed in favourable conditions, including good weather, sufficient time available etc.
reliable application, using real time level sensor information and a state-of-the-art time-domain flooding simulation tool will provide the necessary estimation of the ship’s behaviour in the case of damage. The calculation results of such a tool would form a solid basis for the decision support system since it could indicate the need for evacuation and abandonment along with the available time for this.

1.1.2 Integrated standard

The design process is the instant when a ship is equipped with the physical basis of its floatability and stability to prevent catastrophic loss in case of a hull breach.

The “amount” of floatability and stability a ship must be equipped with is prescribed by a set of SOLAS Ch II regulations. These regulations have been constantly being developed and periodically implemented, in principle, since the loss of RMS Titanic. The latest development, the so referred to probabilistic damaged ship stability regulations, will be in force as of 2009. However, all these advancements have focused on devising and proposing stability measures without explicitly disclose-able meaning.

For instance, when it is required that an area under the GZ curve is to attain at least a set value of $X \, \text{rad} \cdot \text{m}$, it does not imply that a ship with a damage with this $X \, \text{rad} \cdot \text{m}$ area is survivable in all environmental conditions in which a ship can suffer a damage. In fact, it does not imply at all which conditions are survivable. Even if these conditions could be inferred indirectly for specific damage case (e.g. new SOLAS 2009\textsuperscript{6}), it is impossible to determine the exact decision-important information, such as the criticality of the ship condition for ordering abandoning, or the effect of crew actions such as engaging of the propulsion for a manoeuvre on stability in waves. Furthermore, no information on the severity of casualty is possible to be derived if the actual damage casualty is out with damage scenarios considered for stability approval, which indeed is most often the case. Also, these regulations do not provide any basis for accommodating for any error margins in judgement on what the damage character actually is.

In short, current damaged ship stability standards represent some consensual degree of ability for a ship to attain a state of functional equilibrium if disturbed from it; however, this ability has never been resolved into practical information, such as:

(a) Should the ship return to port after a collision incident when it is half a nautical mile from the port or should it be abandoned immediately? Or

(b) Should the ship return to port after a collision in a “bad” weather when it is 200 miles from the nearest port, possibly in Alaska, or should the potentially 8,500 persons onboard be asked to abandon the vessel?

Weighing of information for a decision in both these cases will be different. And today such weighing for a decision is left to the discretion of ship’s crew with similarly discretionary advice from far-away onshore supporting teams.

\textsuperscript{5} The Europe-regional Stockholm Agreement is the only standard which implies explicitly that a ship is to “survive” impact of specific sea conditions on stability in case of a “worst” 2-compartment flooding extent. However, only heuristic criteria for choice of the “worst” case have been proposed, and hence it could not be guaranteed that every damage case, other than the specifically tested, is survivable. The standard is based on only a specific damage opening characteristics. Also, nothing is implied on damages beyond the 2-compartment extent used in the standard.

\textsuperscript{6} Jasionowski, A, \textit{et al}, SAFEDOR D2.1.3, 30th November 2006, \url{www.safedor.org}. The inference refers to “average” flooding extent, that is similarly to Stockholm Agreement, the survivable sea states only refer to SOLAS damage opening.

\textsuperscript{6}
The FLOODSTAND project sets to devise basis, a standard, for such decisions, so that either the crew or the on-shore team advises accordingly to rigorous criteria accommodating for all information that is relevant to such decision making at every instant of time, as well as for all the uncertainties associated with eventually committing to this decision. The decision making process will thus be limited to providing with accurate assessment of all the relevant input information, rather than judgement if these or the other ship states are better for this or the other decision. The judgement element will be replaced with reading of the standard’s recommendation. The crew’s responsibility would thus be limited to provision of as representative information of the casualty as is possible and then timely execution of the recommendation.

It is proposed that the judgement standard is based on the concept of conditional risk. The decision to be executed will always be that which results in the least risk at given instant of time. From the point of view of development within the proposed project, the risk will be considered as a mathematical expectation of the loss conditional on a specific decision option available and relevant to a specific casualty case (damage characteristics, ships systems availability, evacuation systems, rescue proximity, ship state e.g. watertight doors closed, etc), as is shown schematically in concept equation (1) and Figure 3.

\[
E(\text{loss}|\text{decision}_i) = \sum_j \text{loss}(j) \cdot p_{ij}(j|\text{decision}_i)
\]

For \( j = 1 \ldots N_{\text{max}} \) and where \( N_{\text{max}} \) is total number of persons onboard.

![Figure 3](image)

Figure 3: The FLOODSTAND concept of the “least risk” to be used as the decision merit function.

Furthermore, it is proposed that this casualty mitigation standard be directly used for revision or, indeed, setting of design standards. For instance it could be required that a ship is designed so, that the expected loss for every one of a set of specific damage cases (e.g. every damage leading to 3-compartment flooding) and given specific mitigation action (e.g. stay onboard) is not more than a given acceptable level. Indeed, the proposed method could be implemented directly in the risk-based frameworks under development in other currently running projects, notably such as SAFEDOR, thus complementing these developments for the ship operation and crises management factors, neither of which is addressed in objectives of these projects today. It is for this reason that FLOODSTAND is proposed to be regarded as an integrated standard for stability and casualty mitigation. The developments required to be undertaken could be categorised according to the following questions:
(a) How to measure the loss, e.g. should it be a number of fatalities for given casualty scenario \( \text{loss}(N) = N \), or its power \( p \) expressing weight distribution accordingly to severity of the loss, i.e. \( \text{loss}(N) = N^p \), or some other function, such as e.g. \( \text{loss}(N) = a \cdot N + b \cdot N^p \), or should it be function also accommodating for effects such as discomfort, or possibly long-term distress mental impact or other harm? This measure must ensure that the expected loss does reflect the lesser tolerability of bigger loss regardless of its likelihood.

(b) How to consistently calculate the loss likelihood for a given casualty case, instantaneously updating for new information on the ship/flooding state? Specifically, which type of computational methods and data should be used to accurately assess the likelihood \( p_{\text{decision}}(N) \) for the key loss variable \( N \) for each of the decision options and accommodating for the foundering and rescue process in each damage case, in other words how to consistently integrate the following elements:

- the process of flooding into the ship with subsequent loss of stability or/and floatability,
- the impact of environment change over time as well as impact of manoeuvres in waves on stability in a damaged state, and
- the process of persons mustering, abandoning and ultimately rescuing to safety.

This problem is addressed in a consistently integrated manner today. The prime reason for this state of affairs is lack of (a) consensus on the methodology to be applied for assessing the process of stability deterioration, evacuation and rescue of persons, and (b) their consistent verification procedures and acceptance criteria.

Therefore, it is proposed that a set of benchmark data are established, against which state-of-the-art available methods, coefficients and other assumptions are tested and relevant uncertainty bounds pertaining to each of them are developed. The standard would thus comprise (a) detailed casualty severity model (2), (b) benchmark data and (c) uncertainty bounds for specific approaches applied to assess ships stability and rescue-ability.

### 1.2 Objectives

The FLOODSTAND is a result of the merger of two separate project proposals with some differences in approaches and objectives. Therefore, this project can also present two main objectives with further eight sub-objectives:

a) Increase the reliability of flooding simulation tools in design and onboard use by establishing modelling principles and uncertainty bounds, in particular:

1. *Establishing guidelines* for modelling leaking through closed doors and the critical pressure head for collapsing under the pressure of floodwater
2. *Simplified modelling of pressure losses* (discharge coefficients) in flows through typical openings.
3. *Feasible and realistic modelling of compartments with complex layout*, such as cabin areas, for flooding simulation tools.
4. *Use of flooding monitoring systems* and time domain simulation for assessing the damage and flooding extent onboard the damaged ship
b) Establish a method for instantaneous classification of the severity of ship flooding casualty, with the following key objectives:

5. *Stochastic ship response modelling:* establish requirements and uncertainty bounds for methods for prediction of the time it takes a ship to capsize or sink after damage.


7. *Standard for decision making in crises:* establish a loss function $\text{loss}(N)$ and $p_{N|\text{decision}_i}$ for the integrated standard. The loss function must reflect in a balanced manner the societal concerns pertinent to a “large” loss. The $p_{N|\text{decision}_i}$ will reflect the above requirements on the methods to be used for generating basis information on stability, evacuation and rescue process as well as the associated uncertainty.

8. *Demonstration:* develop implementation system and test effectiveness of the standard in rating different decisions for various casualty cases as well as test the approach in design environment.