Ship Stability & Safety in Damage Condition through Operational Measures

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ABSTRACT

Guaranteeing a sufficient level of safety from the point of view of stability is typically considered to be a matter of design. However, it is impossible to ensure safety only by design measures, and operational measures can then represent a complementary tool for efficiently and cost-effectively increasing the overall safety of the vessel. Time could therefore be coming for systematically considering operational measures as a recognised and normed integral part of a holistic approach to ship safety from the point of view of stability. In this respect, the scope of this paper is to identify open challenges and to provide, in general, food for thought for stimulating a discussion on the topic of operational measures, with specific attention to the damaged ship condition. The aim of the discussion should be to provide ground for further proceeding towards the goal of implementing a virtuous integrated approach to ship stability safety which gives due credit to effective and robust operational risk control options.

Keywords: *ship stability; ship dynamics; ship safety; operational measures; damaged condition.*

1. INTRODUCTION

Required levels of safety with respect to damage ship stability are typically guaranteed by the consideration and evaluation of the effectiveness of proper passive measures at the design stage against applicable regulatory provisions. These measures are in the form of potential design alternatives (hull shape, subdivision, systems redundancy and availability, etc.) and for acceptable loading conditions.

Concerted research and development efforts in the period of the last 20 or so years have mobilised the international maritime community to research on the theoretical understanding of the flooding process and to focus and act on the development of new probabilistic rules for damage stability for all ship types, new ship designs extending and challenging known design limitations, and the Safe Return to Port (SRtP) regulations. Risk-based approaches and cost-effectiveness considerations have been extensively used in this process. A major finding is that the overall level of safety of a ship can only be guaranteed when considering passive design measures in conjunction with active operational measures, in a holistic, balanced and cost-effective manner.

The concepts of time to flood and time to evacuate and how they interrelate are fundamental notions in determining safety thresholds with respect to ship stability and flooding. In principle, vulnerability to flooding relates to the cumulative probability for time to capsize within a given time in the operational environment of the vessel, accounting either for all statistical damages or for a given damage scenario. This also provides the key input for

vulnerability monitoring, which in turn offers all the essential information for damage control and emergency response.

There are therefore many further opportunities for research and development associated with the idea of giving a more systematic and quantifiable importance to operational measures. At the same time, however, there are also numerous challenges. Some ideas regarding opportunities and challenges have been collected in the following, where the discussion is split in three sections, namely: operational guidance and procedures; systems availability post-damage; active measures for damage containment. In this paper, we provide elaborations on open challenges and food for thought for stimulating a discussion on the topic of operational measures, with specific attention to the damaged ship condition.

2. OPERATIONAL GUIDANCE AND PROCEDURES

Technological advances in computing hardware over the last decades have facilitated solution of many problems in ever decreasing amount of time. However, the progress in technical calculus, involving modelling based on the fundamental physical laws, has been just as significant, and despite the availability of ever grater processing power, many cases of numerical approximations to reality remain impractical to compute. It is for this reason that advanced prognosis have only had limited success in proliferating the field of instantaneous decision support.

Although highly advanced computerised safety management systems (SMS), have found accelerated support, their advisory functionality are mostly limited to detection only, with more sophisticated prognosis and advisory capabilities remaining at prototyping and development stages.

Such prototype simulation approaches available for use in prognosis comprise a range of phenomena such as (a) ship response to flooding progression, modelled through various but direct solution to conservation of momentum laws, or through quasi-static iterative approximations, (b) structural stress evolution under flooding, (c) the mustering process, (d) fire and smoke spread, and possibly many other.

Some of the reasons inhibiting their more wide use for decision support arise due to a series of practical problems in addition to sheer computational effort, such as the following:

• Each of these processes may vary at any instant of time due to changing conditions.

• The input is subject to considerable uncertainty.

• For any set of input information the outcome is random due to computational and modelling uncertainties as well as due to random nature of environmental or process conditions themselves.

• Each may be seriously influenced by decision choices.

The nature as well as inseparable combination of these engineering challenges imply that the projection functionality would need to be iterated for a range of uncertain conditions of either of the scenarios occurring as well as for a range of decision options, so that the best choice can be identified with controllable degree of confidence. This, in turn, implies that the computational task of scenario projection in real time in support of decision making will likely remain a serious challenge, as most of these analyses require substantial amount of processing time, at present accounted in hours.

Vulnerability Log, or VLog for short, has been proposed to be the functionality to inform the crew at all times on the instantaneous

vulnerability to flooding of the vessel, considering its actual loading conditions, the environmental conditions and the actual watertight integrity architecture (Jasionwoski, A, 2011). The vulnerability is proposed to be measured in terms of the probability that a vessel might capsize within given time when subject to any feasible flooding scenario. Figure 1 demonstrates the distribution of vulnerability logged on a demonstration ship.
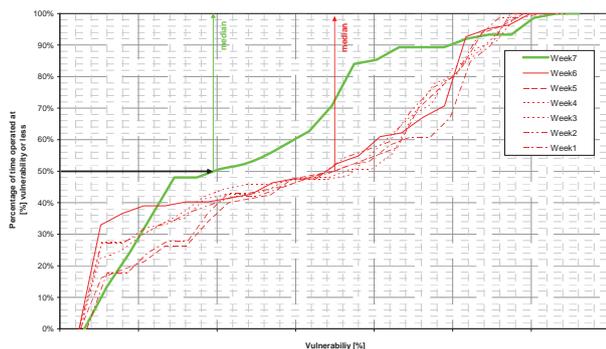

Figure 1: Distribution of vulnerability logged on a demonstration ship. The actual vulnerability values are undisclosed. The impact of the awareness of the crew on the day-to-day management of watertight integrity, and hence crew and ship preparedness, can be seen in Week 7, when explanation and training on use of VLog had been given

Since until a casualty occurs it is impossible to anticipate any specifics of a flooding case a ship might suffer and therefore let the crew prepare for it, it seems plausible that instead the crew is made aware of the range of such flooding specifics together with projected impact these can have on the ship state. The crew would be able to infer the criticality of the situation evolving immediately, based on their own awareness, and hence decide instinctively of the best possible actions to follow. Ship vulnerability to flooding will naturally vary significantly from a flooding case to a flooding case, and subject to what condition the vessel operates at, at which environment and what is the watertight integrity status. All these must, therefore, be considered.

The framework for vulnerability assessment given in the source (Jasionwoski, A, Vassalos,

D, 2006) can serve as a very informative model for use in the context of decision making. It reflects fundamentals of physical processes governing ship stability in waves and explicitly acknowledges uncertainty of such predictions by exploiting probability theory.

Therefore, further research efforts should be expanded to establish and verify practicalities of the principles of the proposed functionality, as well as to assess impact of all engineering approximations that are used in application of the proposed model. Many such aspects should be considered, with key focus on uncertainty in the widest sense, pertaining to its both aleatory as well as epistemic types. Example impact of treatment of actual tank loads in assessing stability, effects of damage character, relative importance of transient flooding stages, accuracy of physical experimentation used as basis data, or simple elements such as effect of computational speed on functionality of the whole proposition, or ergonomics of the conveying techniques used. The prime objective is to find solution acceptable for wider industrial application.

3. SYSTEMS AVAILABILITY POST-ACCIDENT

Formally, the safe return to port regulations adopted at 82nd session of MSC and subsequent amendments to SOLAS are not linked to damage stability and although it makes little sense to speculate about the reasons behind the separation, the formal disengagement by IMO seem to be utterly intentional. Nevertheless, the separation does not undermine the strong and authentic interrelation between the damage stability framework and SRtP, at least in part of the latter referring to flooding casualties (in short: all SRtP-compliant vessels need to demonstrate that their safety-critical systems remain operational outside the casualty area following single-compartment flooding). That is, SRtP capability is to be demonstrated for specific subset of all possible flooding scenarios.

As a matter of fact, it is the way the subset of flooding scenarios is being defined that prevents harmonisation of SRtP with damage stability framework. The SRtP subset is deterministic while the damage stability calculations draw from probabilistic domain (Cichowicz, J, Vassalos, D, Logan, J, 2009, Dodman, J., 2010). Notwithstanding the lack of harmonisation the SRtP is an important concept that transposes concept of survivability from that of the hull to that of the ship. In essence, the SRtP require the assessment to be performed on system models embedded within the vessel arrangement including both WT subdivision and A-class boundaries. Such modelling and evaluation philosophy was adopted during the development of iSys – an FMEA and SRtP-compliance assessment tool.
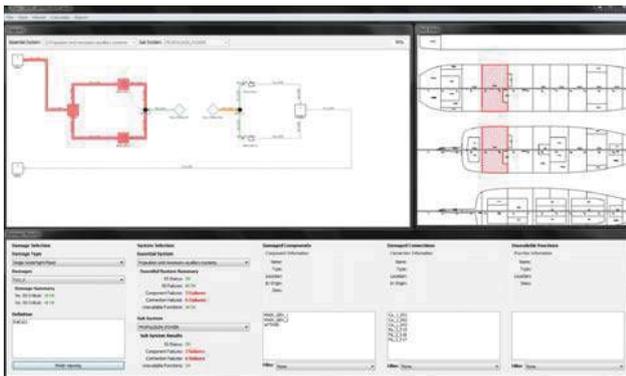

Figure 2: The iSys package allows for rapid modelling of complex systems embedded in ship's arrangement. The tool allows for assessing post-casualty availability of the systems and is capable of generating recommendations for restoring functionality

The most difficult aspect of post-casualty availability assessment derives from complexity of interconnected system models with time needed for evaluation by traditional calculators linked exponentially to the model size. Furthermore, as experience shows identification of design flaws in typical onboard plant requires high-resolution models able to capture fine details of the functionality. The design principles of ship systems are robust and backed by long experience hence in principle the onboard system are equally robust

and have acceptable level of built-in redundancy. Yet, the complex system often suffer from well-hidden deficiencies resulting in serious vulnerabilities to even minor flooding or fire accidents (as observed during some quite-recent incidents on cruise ships). The problem of such concealed vulnerabilities is particularly important for passenger ships (ever-growing in capacity and sailing to the most remote corners of the oceans) and the off-shore production plants (where again the isolation and accessibility of remote assistance becomes a serious issue).

Finally, the concept of post-casualty availability has an additional flavour in the context of active means of reducing a risk of rapid capsize. In particular, although the project GOALDS demonstrated clearly that accuracy of survivability assessment can be greatly improved by adopting the rational and design-friendly s-factor formulation. This allows for safer designs and cheaper designs but still the "mythical" requirements for the required index R to be equal to 1 remains commercially unattainable without use of active stability-enhancing devices. These, in turn would have to comply with "enhanced" (probabilistic) SRtP requirements. This highlights how strong the link between damage stability and systems' availability is.

4. ACTIVE MEASURES FOR DAMAGE CONTAINMENT

Traditionally, in order to reduce the severity of the consequences of a flooding event, we have been relying on passive risk control measures, for example, enhanced internal watertight subdivision arrangements. This has received considerable focus and research over the last 30 years, and it seems that we may have reached a stage that no further vulnerability enhancements may be expected from passive design measures.

In this respect, there are measures that may reduce the severity of consequences of a

flooding event, measures of operational nature and/or active measures and as such less amenable to statutory verification unless an alternative method is applied.

Therefore, new measures for risk reduction (operational and in emergencies) should be considered in addition to design (passive) measures. What needs to be demonstrated and justified is the level of risk reduction and a way to account for it, the latter by adopting a formal process and taking requisite steps to institutionalise it. IMO Circular 1455 on Alternatives and Equivalents offers the means but we still have to overcome the philosophical and practical problems of "summing up" risk reduction from design and operational means.

For risk control measure in damage stability the rules are focusing on design solutions, normally referred to as passive measures (category 1 measures) shown in Figure 3 (Vassalos, D, 2013). Operational/active measures (category 2 measures) whilst abundant in SOLAS Ch. II-2 (e.g. damage control), have not been validated to the same level of rigour as category 1 measures. Finally, measures/systems focusing on emergency response (category 3 measures), such as Decision Support Systems for Crisis Management, Evacuation, LSA, Escape and Rescue, whilst fuelling debates on being effective risk control measures or not, the cost-effectiveness of their risk reduction potential has never been measured nor verified.
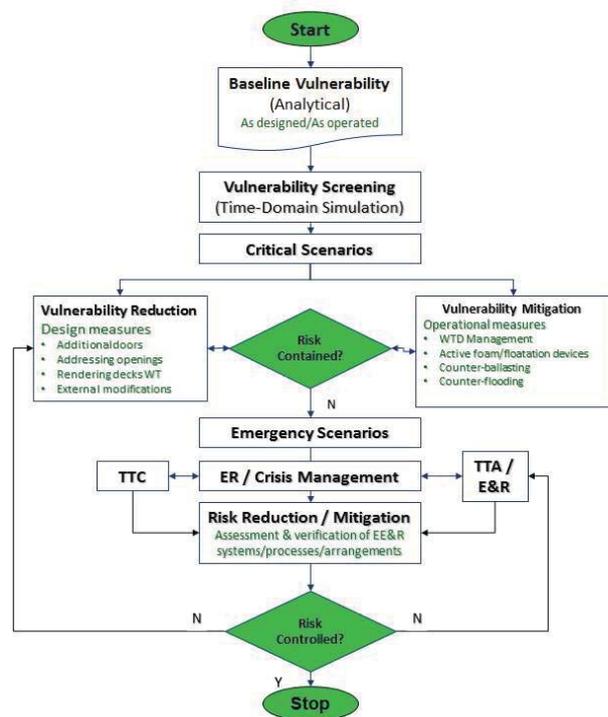

Figure 3: Vulnerability Management

It is also evident that survivability following a serious incident such as hull breach due to collision or grounding, resulting in water ingress, is still relatively low. Deriving from the foregoing, the following arguments may be put forward:

- Design (passive) measures are saturated. Hence, any such measures to improve damage stability severely erode the ship earning potential and are being resisted by industry.
- Traditionally, the industry is averse to operational (active) measures and it takes perseverance and nurturing to change this norm.
- Up until recently, there was no legislative instrument to assign credit for safety improvement by active means. It is IMO Circular 1455 that opened the door to such innovation.
- Key industry stakeholders are keen to explore this route.

Inspired by these considerations, a system that can be fitted to new or retrofitted to existing RoPax in order to reduce the

likelihood of capsize/sinking and further water ingress following a major incident / accident (Vassalos, D, 2015). The proposed system utilises standard units comprising containers of polyurethane foaming agents, pumps and piping, distributed to safety-critical ship compartments and delivered through dedicated nozzles either directly into the compartment or in a flexible membrane, which is pre-inflated in an emergency and then filled under pressure. The system is able to withstand the ingress water pressure and provides a void filling mechanism to reduce flooding and thus enhance the buoyancy and stability of the vessel. The use of the system is under the full control of the crew, with a decision support system available to help the ship officers decide where and when the system will act as well as inform them of the ensuing effect. The system complies with identified requirements for the timely delivery of the foam in the damaged compartments to prevent progressive flooding and stability loss.

The foam itself meets all the environmental and health criteria, it is not toxic to humans and its release does not pose any danger to the people onboard or the environment. The system is illustrated in Figure 4.

Key characteristics of the system include:

Modular/Standardised design:

• System of (standard) parts
• Raw foam stored in sealed containers
• Dedicated pump per container
• Piping system running along the centre of the vessel
• Nozzles located in each of the primary spaces.

Non-intrusive:

• Optimum location in vessel – "void", "out of the way" spaces.
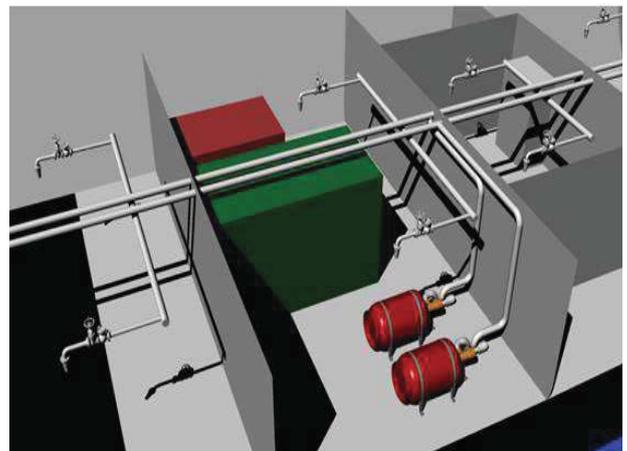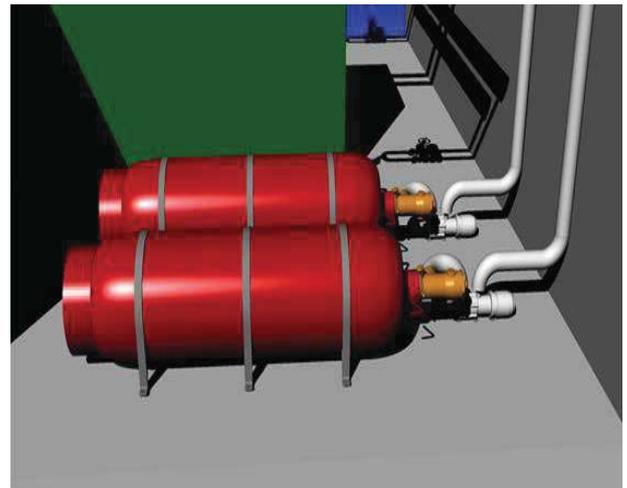

Figure 4: Damage Stability Recovery System (DSRS)

5. FINAL REMARKS

In this paper, we provided some elaborations on the current state-of-affairs with regards to operational measures relating to damage stability and safety. The aim is to stimulate discussion and provide ground for further proceeding towards the goal of implementing a virtuous integrated approach to ship stability safety which gives due credit to effective and robust operational risk control options.

6. ACKNOWLEDGEMENTS

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