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Damage survivability of cruise ships – Evidence and conjecture

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ABSTRACT

This paper delves into damage stability legislation as it applies to passenger ships. The Concordia accident, like many others before it, has shaken the maritime profession once again with many questions being asked without being able to provide credible answers. Old ships have been designed to lower standards (it is common knowledge that new ships are safer than old ships, with the latter comprising the majority of the population), new standards are holistic and goal-based offering knowledge of the standard these ships are designed to, which is not true for old ships, emergency response is an altogether different science in modern ships and many others. Notwithstanding this state of affairs, there is another more fundamental weakness in the regulations for damage stability, perhaps at the heart of most problems with cruise ships safety, old and new. A critical review into damage stability legislation, as it applies to passenger ships, offers compelling evidence that cruise ship characteristics and behaviour have not been accounted for in the derivation of relevant damage stability rules. As a result, the regulatory instruments for damage stability currently in place do not provide the right measure of damage stability for cruise ships and, even more worryingly, the right guidance for design improvement. This leads to a precarious situation where cruise ships are underrated when it comes to assigning a damage stability standard whilst depriving designers of appropriate legislative instruments to nurture continuous improvement. Documented evidence is being presented and the ensuing results and impact discussed. Recommendations are given for a way forward.

1. Introduction

SOLAS regulations is the Bible of safety and like the latter, it is considered “holy” by many and it will take endless debates to change a line, even though the former has been written, in the best of circumstances, by naval architects not yet canonised. A passenger ship is a vessel carrying 12 or more passengers (… and is involved in international trade), irrespective of size, shape, age, construction and condition. This state of affairs has served the maritime industry well for over a century, as it has taken half as long for all concerned to realise that current rules are becoming progressively less relevant and amendments have run their course. The Secretary General of the International Maritime Organization (IMO) Koji Sekimizu, realising fully this state of affairs has set 2029 (the 100th anniversary of SOLAS) as the date by which a new, more relevant, SOLAS will be introduced. Sadly, he is leaving in less than a year's time and the chance that another Naval Architect will be filling his shoes is slim. In the interim, we have reached the embarrassing situation of having to conceal knowledge on the fact that treating all IMO-defined passengers ships the same, is alienating the profession when it comes to developing and setting standards for damage stability. It is certain there are many other “anomalies” in SOLAS concerning all sort of different issues but damage stability is big enough a subject when it comes to passenger ships to consider it in isolation. More specifically, there is documented evidence to demonstrate that passenger ship damage stability rule development to date is based almost 100% on cargo ships and, more recently, on RoRo passenger vessels (Project HARDER, 2003). Whilst the difference between cargo ships and RoRo passenger vessels in terms of damage stability and survivability might be obvious, concerning in particular water on car deck (a characteristic vulnerability of RoPax), any such differences between cruise ships and RoPax are not so obvious to non-specialists. A few points worth mentioning here include:

- Whilst the difference between cargo ships and RoRo passenger vessels in terms of damage stability and survivability might be obvious, concerning in particular water on car deck (a characteristic vulnerability of RoPax), any such differences between cruise ships and RoPax are not so obvious to non-specialists. A few points worth mentioning here include:
- Old cruise ships (generally with small metacentric height) may capsize during the transient phase of flooding as a result of multiple free surfaces (Vassalos et al., 2006) whilst RoPax may capsize as a result of progressive flooding and water accumulation on the

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car deck. Having said this, legislation is focusing on new ships, which is also the focus in this paper.

- As such, new Cruise ships, having very large metacentric height and increased internal layout complexity when upper decks are involved in the flooding process, face slow sinking/capsize (Papanikolaou et al., 2013). RoPax are vulnerable to rapid capsize (NWEP, Svensen and Vassalos, 1998).
- Moreover, in many cases, cruise ships capsize or sink following up-flooding. As a result, the time to capsize with cruise ships is becoming even longer; hours (with cruise ships) rather than minutes (with RoPax).
- Accounting for all the above, damage stability/survivability, post-SOLAS 2009, focusses on the whole-ship concept rather than the ship hull (below the subdivision deck, as it is the case with cargo ships). As such and because of the above, geometric modelling for damage stability calculations differs. With RoPax the car deck is considered as part of the survivability studies whilst in cruise ships at least two additional decks are accounted for.
- This being the case, progressive flooding in cruise ships (the cause for eventual sinking and capsize) is very much different due to the complexity of the internal architecture as compared to RoPax, for example. The whole emphasis on damage stability and survivability changes.
- Cruise ship survivability is more affected by details in local geometry as these impact on progressive flooding whilst RoPax are affected by global parameter changes (e.g., beam, freeboard) as the design vulnerability to flooding refers to the car deck.
- As a result of the above, flooding of cruise-ships (ships with complex internal subdivision) is inherently uncertain; there are multiple paths to same end state/different end state from similar initial conditions during periods of time that are similarly uncertain.
- In all research on damage stability ad survivability to date, leading to new legislation, very little effort has been expended on cruise ships (one experimental point in Project HARDER and one in Project GOALDS), Figs. 3 and 5, respectively.
- There is, of course, one additional issue; perhaps the most important of all. Cruise ships are knowledge intensive with innovation a primary ingredient for success. As such, they are safety critical, considering the thousands of people onboard some of the modern megaships. Therefore, from a societal risk perspective, cruise ships warrant much more attention than any other ship type when it comes to damage stability and survivability following collision/grounding; a contribution of some 90% to total risk of passenger ships.

Because of all the above and, in particular, lack of understanding and hence attention on the damage stability of cruise ships, an unfathomable situation has arisen where cruise ship damage stability is underrated by the rules whilst rendering any attempts to improve damage stability of cruise ships futile, using current IMO cost-effectiveness criteria for decision making. This was the overriding conclusion of a recently completed project on the damage stability of passenger ships, where cruise ships and RoPax have been considered (EMSA III Project, 2016).

This is a precarious position for the cruise ship industry to be in for both the safety-cultured and the rule-evading owners; the former because the current regulatory framework does not justify improving cruise ship safety, which we know cannot be right, and the latter because newbuildings cruise ships can easily meet the common "passenger ships pool" regulations and are relaxed in this futility. This situation must change. We must change it. As Naval Architects, we owe it to the travelling public, who board these ships by the thousands at a time.

2. Probabilistic concept of ship subdivision

2.1. Conceptual formulation

A direct link between the probabilistic concept of ship subdivision and modern concepts of risk estimation may simplistically be expressed as follows:

$$R_c = P_c \text{ x } P_{w/c} \text{ x } P_{f/w/c} \text{ x } P_{l/f/w/c} \quad (1)$$

where:

- R_c Collision risk;
- P_c Probability of a collision event, dependent on loading condition, area of operation, geography, topology, bathymetry, route, traffic density, ship type, human factors, etc.;
- $P_{w/c}$ Probability of water ingress, conditional on collision event occurring (accounting for all the above);
- $P_{f/w/c}$ Probability of failure (capsize/sinking/collapse), conditional on collision and water ingress events occurring – expressed as a function of e.g., sea state, structural strength and time;
- $P_{l/f/w/c}$ Consequences (Probability of Loss) deriving from the collision event, conditional on all the foregoing; this accounts for loss of (or injury to) life, property damage / loss and impact to the environment. The former will depend on time to capsize and time to abandon ship (as determined from evacuation analysis – passenger ships) and the latter of e.g., probabilistic oil outflow using relevant models of oil spill damages and results from known accidents or through analysis using first-principles tools.

Considering the above and on the basis of work by Lützen (2001), the relevant probabilities can be calculated from first-principles (with appropriate empirical adjustments). Hence, if a more specific analysis is warranted for a novel ship design concept, the probability of collision damage that leads to hull breaching and flooding could be calculated. Moreover, based on work reported in Jasionowski and Vassalos (2006) and Dogliani et al. (2004), the various terms in Eq. (1) could also be addressed for each pertinent scenario from first principles. This allows for complete risk analysis of any damage case.

2.2. Basic formulation (SOLAS 2009)

One of the fundamental assumptions of the probabilistic concept of ship subdivision in SOLAS 2009 is that the ship under consideration is damaged, i.e. the hull is assumed to be breached and there is (large scale) flooding. This implies that the cause of the breach, the collision event and the circumstances leading to its occurrence are disregarded; hence the interest focuses on the conditional probability of survival. Other pertinent factors, such as size of ship, number of persons on board, life-saving appliances arrangement, and so on, are directly or indirectly accounted for by the Required Index of Subdivision R. Therefore, the probability of ship surviving collision damage is given by the Attained Index of Subdivision, A, using the following expressions:

$$A = \sum_{j=1}^{J} \sum_{i=1}^{I} w_j . p_i . s_i \quad (2)$$

where,

- j represents the loading conditions (draught) under consideration;