DISCUSSION

A COMPREHENSIVE APPROACH TO SURVIVABILITY ASSESSMENT IN NAVAL SHIP CONCEPT DESIGN

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COMMENT

Professor Hans Hopman, Deflt University of Technology

I first want to congratulate the authors with their result in an attempt to address survivability assessment in the concept design phase of a naval ship. Especially the developed method for assessing "recoverability" as an integrated part of "survivability" is very original as well as a very practical and transparent approach. This method fits very well with the level of design information that can be made available during concept phase and the need for design decisions on this matter. Existing, more accurate methods for assessing these aspects often require much more design information, often only available much later in the design process when the freedom to further improve the design, based on these results of the assessment, has been reduced dramatically.

However, some remarks on the method that has been developed:

1. From the paper it is not clear how the vulnerability assessment of systems on board is done. It seems that only the number and location of components have been used to "calculate" the vulnerability of the system. The actual routing of cabling and piping systems connecting these components to be able to perform as a system, is also important for the design of these systems when vulnerability is taken into account. Options for routing are also very dependent on the arrangement and number of decks, bulkheads, passageways etc. It is not clear how the impact of routing of connections has been taken into account in the assessment. See Ref 55 for an example how this aspect can be assessed during concept design.

2. The performance measures used for the assessment of the recoverability seem to include some kind of already chosen "starting point" for the NBC-organization on board as the preferred principle solution, (i.e. one FRP station forward and one FRP station aft) has already been decided upon. The decision how to organize and manage this process on board, however, is a major design decision that also "drives" the required layout and size of the vessel as well as the size of the crew. Also the level of automation and the impact of using alternative technologies (like water mist systems) will have an effect on the required NBC-organization on board and, therefore, the vulnerability and recoverability of the design. However, I think that this approach is very valuable and could be a very could starting point for further development in order to also include the design issues as mentioned, in the method.

Andrew Martin, BEng (Hons) MSc CEng MRINA

The authors are to be congratulated on a valuable reminder that naval ships should be expected to go in harm's way and should be designed to do so. They have recognised that features that drive survivability are often fixed early in the design process, so that analysis must be conducted at the concept stage in a design if a highly survivable warship is to be achieved.

This paper contends that an integrated approach to survivability is necessary, allowing the balancing of susceptibility, vulnerability and recoverability. In broad terms this is a sensible approach and should allow an informed debate when a large-scale reduction in the capability of any individual component is proposed during design in the expectation that the other components will pick up the shortfall. I would argue that there is less space to trade one aspect of survivability off against another than might always be appreciated. It all depends on the scenario that is examined and a few examples will serve to demonstrate that there needs to be a minimum baseline performance for each aspect of survivability.

- A warship in harbour with limited crew on board, attacked by missile or IED: An integrated approach would recognise that security, vulnerability reduction features (e.g. duplication and separation, armour etc.) and any automatic damage control measures are all key contributors.
- A warship at sea attacked by a medium weight anti-ship missile: Hard and soft kill defences, above-water signature control, vulnerability reduction features and damage control capability all contribute to the ship survivability.
- A warship at sea, attacked by a heavy-weight torpedo: Only by preventing the weapon reaching its optimum detonation position will the ship survive. Signature control, mobility and soft kill defences provide the survivability.
- A warship transiting a choke-point, struck by multiple small arms/ATGW: Recoverability actions are crucial with multiple simultaneous incidents contained by both automatic and manual damage control activities.

With this in mind, the use of a single, anti-ship missile scenario is understandable and can be used to explore all three aspects. It cannot however be used to trade one aspect of survivability below the minimum that a different scenario would require.

The use of *Spectre* and *SURVIVE Lite** is welcomed as they are respected and internationally recognised tools. As an experienced *SURVIVE* user, I have found it perfectly appropriate for concept level design and I have used it for this purpose for many years. The key advantage of *SURVIVE Lite* lies in the ability to rapidly model a ship-like object, with the user guided through the build and assessment process. The *SURVIVE* code itself can readily operate at the same level of detail as *SURVIVE Lite* for concept analysis, but it has the potential to develop the model further to perform more complex analyses if necessary.

In section 3.2e it is suggested that a probability distribution is applied to the likelihood of each hit. This is a recurrent question in vulnerability analysis and the traditional UK approach, used when assessing the performance of a ship, rather than a weapon, is to assume that all hits are equally likely. Have the authors considered non-uniform probability distributions for hits and are they aware of advantages and disadvantages of doing so?

The development of recoverability simulation has been a long process and reliable predictions demand a huge amount of data for modelling purposes, making a model used in a SURVIVE recoverability assessment at least an order of magnitude more complex than a concept SURVIVE or SURVIVE Lite model. A new approach is welcome, particularly the development of performance measures suitable for concept stage design. The performance measures that have been suggested appear to be a reasonable first step with a combination of accessibility and repair-ability considered. While more sophisticated metrics are possible, (e.g. mean time to extinguish a standard fire) these tend to require the level of detail that is only available in later design stages and implemented in the full SURVIVE code. The authors also recognise in the final section on 'Future work' that the weighting given to each performance measure is only the 'opening salvo' in what promises to be a fascinating debate.

* The terms *SURVIVE* and *SURVIVE Lite* are registered trademarks of QinetiQ Plc

Paul Horstmann, Technical Director SCL

The paper presents a useful method for looking at many aspects of survivability at the concept stage. I fully support the philosophy that survivability aspects should be given greater importance at the earliest stages of warship design and that they should not be viewed as easy candidates for sacrifice in the design trade-off.

I don't necessarily agree that the various components of survivability are difficult to quantify, although recoverability is the most immature, as is mentioned in the paper. I do agree that there has previously been limited success in assessing all of the components together.

The analysis of the recoverability metrics method would appear to suggest that many of the metrics chosen are not discriminatory in the final results and that other metrics should be explored. It would be informative to hear more on this and whether the authors agree with this assessment.

The paper does not note that recent projects such as Type 26 have gone further in reviewing the various survivability aspects and attempting to cost them as part of cost capability trade-offs. Admittedly the features were assessed individually, in Type 26, rather than together – but it is worthy of note that current RN projects are making progress in assessing survivability at an early stage.

Minor Issues for the authors consideration:

- The ASM is one of the many threats faced, it is arguable whether or not it is the principal threat
- Not sure that Spectre is operated by Dstl – I thought it was a QinetiQ tool, please check
- Full SURVIVE runs can be carried out at the concept stage

AUTHORS' RESPONSE

Professor Hopman's contribution is welcomed as that from an eminent naval ship designer now in academia. We agree that the routing of major ship systems is a vital design choice that ought to be made in the Concept Phase. However, current concept definitions are generally insufficient and certainly largely numerically based approaches suffer particularly from implied choices built into the assumptions for the weight estimates for distributed ship systems. This clearly means that later investigations of differing standards or design styles (such as zoning or more extensive duplication of routes and cross connections to improve Survivability) will be cost constrained and unlikely to be incorporated after the Concept Phase. This strongly argues for a Design Building Block type approach in concept as illustrated in the design studies reported in our paper and discussed more fully in Reference 10.

Professor Hopman also mentions the choice of numbers of FRP and the level of automation. Similarly, if significantly different styles of manning and automation are to be investigated and the whole ship design consequences are to be considered, this can only be sensibly done in the Concept Phase as beyond that the project will be committed to the design solution (and importantly therefore the cost). Thus the Concept Phase for major warships needs to be much more of an

exploratory exercise, where new configurational solutions, new technologies, new ship organisational options all need to be fully investigated – which can only be adequately undertaken using a DBB type approach to ship concept definition [21].

Mr Martin's comments are the first of two by experienced ship survivability experts. As such they are greatly appreciated, in that this is a small cohort whose voice is insufficiently heard in decision making in naval acquisition. Mr Martin's support to our investigation at an appropriate level of concept design is most welcome and we support his assertion that there needs to be a "minimum baseline performance" for the Survivability of naval vessels. His four cases have some good examples which we would not disagree with except to say there are sufficient examples to suggest that, while prevention of "optimum detonation" is highly desirable, the last ditch recourse to an ALARP level of watertight integrity is still appropriate.

Mr Martin notes we have used just one attack scenario, that of the ASM with a standard hit probability distribution. This was done to derive and demonstrate the proposed integrated survivability approach, while recognising for a complete analysis it needs to be extended across the full range of attack senarios. In addition to the four cases he lists we would add the underwater mine threat and vulnerability, when the ship is tied up alongside, to asymmetric attack.

The issue as to whether the full SURVIVE code can be usefully employed in the Concept Phase we take to mean its employment would only be possible at the very latest stage of that phase. In early stage design most of the design effort is to support Requirement Elucidation [21] and largely focused on cost drivers such as speed, combat system capability and the extent of sustainability. This means ship size, ship style and even ship type (say, mono versus multihull) are all fluid that it is only sensible to have a very broad investigation of Survivability, when it is unlikely the ship definition will be sufficient or coherent enough to resort to full a SURVIVE level of modelling. There are always exceptions and it may well be that, say, a SLEP of an existing ship might be an attractive option and then a definition of sufficient granularity should be readily available and if the SLEP option appears to be degrading the Survivability this could justify even in the Concept phase in detailed analysis the investment to avoid subsequently regrettable decisions.

We note Mr Martin's support for the recoverability performance measures we proposed. The UCL team were fortunate in being able to draw on earlier work on the approach produce in our collaborative work on personnel movement metrics with the University of Greenwich [56] and adapted the Performance Metrics to this Survivability study. We finally agree with Mr Martin's recognition that an integrated approach has been produced but much more work needs to be done to fully work up the necessary insights for naval ship concept designers. Noting the massive investment routinely provided for combat systems development (which of course can enhance the Susceptibility leg of the Survivability triumvirate), if just a small portion was to be diverted to a systematic investigation of the sensitivities that should be explored using our integrated approach then this would probably be highly cost effective.

Dr Horstmann is the second survivability expert whose pertinent comments we are pleased to receive supporting our emphasis on the importance of addressing Survivability early in the naval ship design process. He queries our assertion that the components of Survivability are difficult to quantify. Any such performance measure can be nominally quantified, the issue is just how meaningful is such quantification? Thus Susceptability is largely assessed by running Operational Analysis models, all of which have a degree of questionable rigour vis a vis the "real world" of naval combat [57], while vulnerability at the level of capsize and foundering prediction is essentially a comparative assessment. When all three aspects of survivability are combined this is very much combining "chalk and cheese" numbers (to adopt Rydill's critique of systems engineering applicability to naval ship design [58]). On the Recoverability approach presented, it has to be said the analysis is indicative rather than comprehensive and definitive. As in our final comment to **Mr Martin**, we consider much further work both to widen the scope and the range of sensitivity analysis now needs to be conducted for the approach to properly assist future naval ship designs.

Dr Horstmann also suggests more work has been done recently on the UK Type 26 Frigate in particular. Aside from little of this (for obvious reasons) having been published in open literature, most has taken place beyond the Concept Phase and, as Dr Horstmann notes, this has been separately undertaken on the three elements of Survivability. The essence of our proposal is to combine the three elements (not least because they are interdependent) while also, most importantly, to do so as early as possible in the Concept phase, when the range of options (as with the three frigate configurations) is still diverse and assessment of overall Survivability can influence both the configuration and style of the emergent design. Most importantly early assessment of Survivability should be brought into the debate in the Requirement Elucidation process, so that it influences the evolution of an affordable set of requirements and this can only be properly done by considering material options (in an open and extended dialogue with the requirements owner/naval staff) [21].

Two of the supplementary points raised by Dr Horstmann have already been addressed in our response to Mr Martin. In regard to his third point, on SPECTRE, we can confirm that this was operated by Dstl for the Susceptability assessments on all seven ship design

studies summarised in this paper, as part of Dstl's sponsorship of the first author's research at UCL.

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