A Potential Framework for a Performace Based Damage Stability Standard for Naval Vessels

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ABSTRACT

This paper investigates the possibility of moving from the current prescriptive damage stability criteria used by the UKMoD, to performance based criteria by using a 'goal based' approach. The current stability criteria and damage extents that U.K naval vessels have to be able to survive is defined in DEFSTAN 02-109 [2] (The defence standard). This document presents the damage lengths that different size vessels are to be able to survive anywhere along their length. This document also states the minimum acceptable intact and damaged stability standards for the vessels for which the UKMoD is responsible.

This paper describes how the goal based approach could be applied to the damage stability assessment of naval vessels. The following sections describe a framework that could be used for defining a performance based damage stability standard. This includes a description of what should be considered at each stage and some of the aspects that the authors believe should be defined in the standard.

1. INTRODUCTION

This paper investigates and presents a possible framework for moving from the current prescriptive damage stability standard, used by the UKMoD, to a performance based standard, by using a 'goal based' approach.

The current stability criteria and damage extents that U.K naval vessels have to be able to survive are defined in DEFSTAN 02-109 [2] (The defence standard). This document presents the damage lengths that the different size vessels are to be able to survive anywhere along their length.

This document also states the minimum acceptable intact and damaged stability standards for the vessels for which the UKMoD is responsible. The current damage lengths are defined as follows:

- Vessels of waterline length less than 30m; any single main compartment.
- Vessels of waterline length between 30m and 92m; any two adjacent main compartments. A "main compartment" is to have a minimum length of 6m.
- Vessels of waterline length greater than 92m; damage anywhere along its length, extending 15% of the waterline length, or 21m whichever is greater.

Significant subdivision is common practice in naval ship design. These internal arrangements introduce the potential for both symmetric and asymmetric flooding when damaged. The current stability criteria are based largely upon the criteria originally suggested by Sarchin and Goldberg [1] in 1962. The work by Sarchin and Goldberg was based on data gathered from WWII hull forms. This traditional damage stability analysis using quasi-static approximations cannot account for the behaviour in a seaway or for example, the head of water on a bulkhead, bounding a damaged region. For this V-line example for the Royal Navy, a dynamic allowance over and above the static damage waterline is included in order to account for

vessel motions in a seaway. It has until recently not been possible to asses the suitability of these criteria.

In 1990 the Cooperative Research Navies (CRNAV) Dynamic Stability group was established with the aim of deriving dynamic stability guidance for naval vessels. To help achieve their objectives the numerical simulation program FREDYN was developed, and continues to be applied extensively – both to intact and damaged vessels. This time-domain program is able to take account of non-linearities associated with drag forces, wave excitation forces, large-angle rigid-body dynamics and motion control devices. The latest version of FREDYN permits investigations into the dynamics of damaged vessels operating in realistic environments.

Tools like FREDYN permit investigations into the dynamics of damaged vessels in realistic environments, rather than simple pseudo-static analysis, which is the current practice. This allows all aspects of the stability performance to be evaluated for a particular vessel. This step forward in evaluation has the potential to allow stability standards to move towards a specified level of performance that is expected after damage rather that the current prescriptive criteria.

In recent times there has been a trend in many areas of the engineering industry to move away from traditional prescriptive based regulation and apply a ‘goal based’ approach to regulation instead [3][4][5][6][7]. The advantage of the ‘goal based’ approach is that there are no prescriptive ways of how to meet the goals, just the goals and requirements that must be met. This gives a greater level of flexibility to a designer, particularly for novel design where a conventional prescriptive standard may be unsuitable.

The objective of this paper is to discuss the work that is currently being conducted to assess the possibility of a performance based stability standard for Royal Navy vessels.

2. CURRENT PRESCRIPTIVE STANDARDS

Current stability standards used in many navies, including the UK, almost exclusively follow a prescriptive format, in which the stability code or standard specifies a detailed means to achieve an un-quantified level of intact and damage stability performance which is largely generic for all types of vessels.

These prescribed means include the specification of set damage lengths, list and heel angles and a list of GZ parameters.

Some existing requirements have performance elements, such as the V-lines criteria that include static levels of heave and roll allowance to account for dynamic motion behaviour after damage. Although these V-lines are used mainly for structural calculations, these standards still do not indicate clearly how they work with the other damage criteria to achieve a desired stability goal.

Most prescriptive standards both in the navies and in the commercial world, only establish minimum damage requirements.

These standards do not provide a means to quantify an actual level of performance or safety in the vessel design. This could lead to vessel designs with costly features that do not actually improve the performance or safety.

Additionally, vessel designs can incorporate features not explicitly covered by the current standards, the consequences of these novel features may be unknown.

By providing a performance-based standard, or by adding a performance-based option to the existing DEFSTAN 02-109 [2] standard, a formal measure to prove the performance is acceptable to all of the customers (i.e. the equipment capability customer and fleet) may be developed.

3. THE 'GOAL BASED' APPROACH

The 'goal based' approach can be demonstrated by using a multi-layer pyramid similar to that shown in Figure 1. In simple terms, this shows the systematic refinement into greater detail at each level of what is required to meet the overall performance goals and objectives defined at the top level.

Tier 0 details the aims of the standard in general terms.

Tier 1 details the overall goals i.e. what is to be achieved by application of the standard.

Tier 2 breaks down these goals into functional areas which detail the functions performed by application of that section of the standard.

Tier 3 is the requirements level. Requirements are presented for each functional area. In some generic diagrams showing the 'goal based' approach, the 'requirements levels' are subsumed into the verification level. For the application to naval damage stability, it is desirable to split this into two separate distinct requirements levels commensurate with the UKMoD acquisition methodology. The two levels allow for a definition of what is required in the form of User Requirements and the level of performance deemed acceptable in the form of Systems Requirements.

Tier 4, the verification layer, then becomes the processes by which the performance against the requirements is demonstrated. The Verification level is used to measure the performance of the vessel and to identify whether the vessel meets all the requirements detailed in tier 3 and hence whether it meets the overall goals.

Tier 5 is the Justification level. This is the final layer that provides the feedback to check and justify that the standard provides the necessary performance against the original goals.

4. CATEGORISING VESSELS

Currently in DEFSTAN 02-109 [2] damage criteria, vessels are categorised by ship length, which then prescriptively defines the damage length that the vessel must survive, and the static criteria values that they must meet. A new way of categorising Naval vessels has been proposed by QinetiQ [8], which introduces a way of categorising front line fighting vessels by their role, rather than just on ship length. Included in the definition of the vessels role are the characteristic weapon threats from a variety of weapon types that the vessel is expected to survive, operating in that role. The UKMoD is also in the process of defining appropriate accidental damage (collision, grounding and raking) extents to be included in future standards.

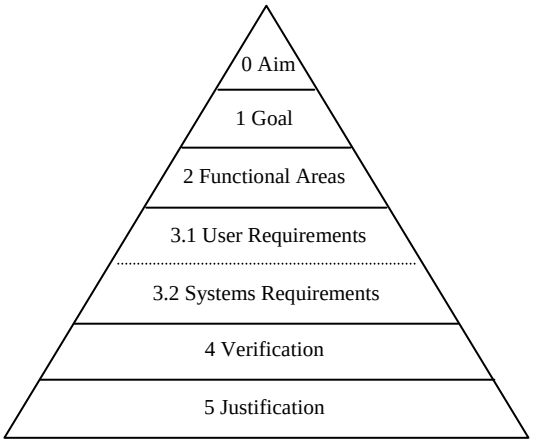

Figure 1 Goal Based Pyramid

5. THREATS TO WATERTIGHT INTEGRITY

There are many potential threats to Royal Naval vessels these may be categorised as described in the NATO Naval Ship Code [9] into Foreseeable Damage and Extreme Threat Damage. In simple terms Foreseeable Damage (in terms of damage stability assessment) is that resulting from accidental damage such as collision, grounding or raking and Extreme Threat Damage is damage caused by a hostile act.

There have been numerous studies into

accidental damage in the commercial world, such as the HARDER project [10], that have analysed the statistics from past ship collisions. This has allowed algorithms to be developed, which allow expected damage caused by collisions to be calculated. This collision damage is often based on length and displacement of vessels and relates to the statistical information gathered from previous collision incidents.

From survivability studies completed for the UKMoD, it is possible to list the weapon threats to the vessels in each of the roles.

From the list of weapon threats that a particular vessel is likely to be subject to in its specified role and expected to survive and remain operational means that realistic damage lengths can be calculated. Existing detailed information regarding the damage effect from a wide selection of weapons is contained in the UKMoD survivability library. The damage caused to the structure in the surrounding area is also detailed. These documents present the damage extent data for various weapons.

In general a range of damage extents may be applied with different criteria based on the damage extent to ensure that the effect of damage is not disproportionate to the initial damage event.

6. DEFINING THE 'GOAL'

The goals of a performance based standard should provide a broad, qualitative expression of the overall, primary concern of the document. Goals should be stated in terms that are potentially quantifiable, even if the precise measurement scale is not specified. Goals therefore, may be stated in terms of impact on the vessel, the crew, the mission operability, the environment or any combination of these.

The goal or set of goals should encompass the overall aim for the performance and safety of the vessel. They should be generic in nature and not specific to a particular vessel role. Achieving these goals should ensure that the vessel is sufficiently stable so that the safety of the crew and the vessel itself is commensurate with the expectations of the customers for a Royal Navy warship. These should also be grouped into overall goals, goals in hostile situations (extreme threat damage) and those caused by accidental damage (foreseeable damage), as the accepted level of risk and hence safety can vary significantly between hostile and accidental damage scenarios.

The high level goals should be clearly defined in the stability standard as a requirement for any front line naval vessel.

7. OVERALL GOALS AND OBJECTIVES

For a front line naval vessel the hostile and accidental damage overall Goal could be defined as follows:
'The vessel should provide adequate buoyancy, freeboard, stability and subdivision to survive damage from any of the perceived hostile or accidental damage threats to the watertight integrity for a vessel in its role'

Additional Hostile Overall Goal - Mandatory
To provide safe evacuation of crew following unforeseeable damage (i.e. that in excess of design extreme threat damage).

The set of goals can be then presented in a number of broad categories, which also divide into separate accidental and hostile damage goals such as:

(a) **Life Safety**; Accidental and Hostile Goals
(b) **Vessel Protection**; Accidental and Hostile Goals
(c) **Mission Continuity**; Hostile Goals

The stability standard would define these categories for the goals as they are suitable for all roles of vessel. The standard would require mandatory goals under these headings that must be included for all vessels. This may not be an extensive list and will also encourage the project team to add other goals for their vessel based on

the vessels individual survivability requirements:

7.1 Life Safety – Accidental and Hostile Goals

Goals relating to life safety are the most common and clearly the most important in damage emergency situations. The crew places trust in the vessel to maintain a level of safety and protection from adverse conditions.

The following are examples of the goals that may be defined in the Life Safety Category:
The vessel is to be able to provide a safe environment for the crew on board after an accidental or hostile damage incident.
The vessel is to remain habitable and safe for the crew either until a place of safety can be reached or the threat has receded.
The vessel should allow damage control parties to undertake damage control in a safe manner.

An additional Hostile damage Goal might be:
The vessel should allow safe evacuation of the crew following unforeseeable hostile damage (i.e. that in excess of design extreme threat damage).

7.2 Vessel Protection – Accidental and Hostile time Goals

Vessel protection considers the impact of damage on the equipment and contents in the vessel. This goal is primarily for the purpose of protecting the asset that is the vessel and ensure its availability. There is no account for this within current damage stability standards. Instead, there are ways to predict areas and volumes affected by damage (e.g., flooding). Thus, the goal of reducing the impact of flooding (maintaining watertight integrity) within the vessel would fall into the general category of vessel protection; e.g., limiting the spread of progressive flooding for example. This is commensurate with the current UKMoD damage stability guidance presented in SSP24 [3] which state that the consequences of the damage should not be disproportionate to the initial event.

The following is an example of what could be defined in the standard as a mandatory goal for all front line naval vessels and are directly linked to requirements defined in the UKMoD subdivision standard which is till under development:
The subdivision of the vessel is to minimise the spread of floodwater and allow the ships crew to limit the extent of flooding due to damage.

7.3 Mission Continuity – Hostile Damage Goals

The goal of ‘mission continuity’ is similar to that of vessel protection. However, instead of considering the physical damage to the vessel, mission continuity is more concerned with the ability of vessel and crew to both defend herself and perform its required mission. Mission interruption is one example of a mission continuity loss and can be described as “indirect loss,” as contrasted with “direct loss” from damage to ship systems due to structural and flooding damage. Obviously, the vessel must remain afloat and stable for a required period of time for this to happen, so there is a link between vessel protection and mission continuity. However, mission continuity is intended to allow the Navy to protect themselves and continue their mission. This category of goals would not have any specified mandatory goals in the standard. The goals in this category would depend on the specific vessels survivability requirements as required by the customers.

The following is an example of what could be defined by the project team.
‘The vessel should remain operational with the ability to defend herself against further damage following all perceivable hostile damage incidents’.

The standard will state that Mission Continuity goals for hostile time goals must be defined for the vessel, but will not mandate explicitly what this would be for the vessel.

8. THE FUNCTIONAL AREAS

The functional areas of performance-based standards are intended to be more specific than goals. In the context of performance based standards, functional areas provide a greater level of detail than goals. Functional areas are stated in more specific terms than goals. Functional areas are the link between goals and requirements and therefore the required performance criteria. In general, functional areas describe a series of actions necessary to achieve the goals. They are a further expansion of the goals related to the expected performance. This breakdown is expanded until the requirements can be derived in the next level of the process.

A number of techniques can be performed to do this for the specific vessel role. For Naval vessels, the goals defined above are specified further with these functional areas and can be split into two, for both accidental and hostile damage scenarios.

The stability standard would describe the accidental and hostile damage functional requirements under the following functional areas:

Functional Area 1 – Life Safety
Functional Area 2 – Vessel Protection
Functional Area 3 – Mission Continuity

Under each of these functional areas the functional requirements will be defined. Some of which will be considered mandatory as they are safety related, others will be dependant on the survivability requirements of the platform. These additional requirements should be reasonably detailed and vessel specific. For example, the requirement should include the definition of the sea conditions in which the vessel should be able to meet the required goals.

This section of the standard will define the damage threats that the vessel in each of the roles is required to meet along with a qualitative level of acceptable performance based on the severity of the threats. The level of qualitative performance, i.e. the vessel performance against the severity of damage would be defined in the standard as a minimum level that is acceptable. These should provide a clear link to the goals for that vessel. This level of acceptable performance will be ultimately used with the measures of performance to demonstrate satisfactory compliance with the goals during the Verification process.

The ability to realistically state the possible accidental and hostile damage threats allows the resulting damage from accidental and hostile threats to be calculated. This results in a number of damage cases that can be ranked in order of severity, often rated by how many compartments have lost watertight integrity.

8.1 Examples of Functional Requirements for the Life Safety Functional Area

An example of a functional requirement which would fall under the Life Safety functional area is:

Following significant damage from one of the accidental or hostile damage threats defined for the vessel in this role, anywhere along her length, the vessel shall:

Remain sufficiently afloat and upright so that the crew can remain safe onboard in a sea state up to that agreed with the Naval Authority (the UKMOD certifying body for stability).

For example the agreed sea state could be the maximum operational sea state when considering hostile damage.

*The minimum level of performance required is **"Crew Safe"** and this is required for damage up to the following lengths, Table 8-1-1, for the different roles of vessel:*

Table 8-1-1 – Crew Safe Level

Vessel Role	Compartments flooded (up to)
2	2
3	3
4	3
5	4

The definition of **Crew safe** is – The vessel is not operational and the weapon systems are not on line. The vessel is unable to defend herself from further attack. Through extensive damage control the flooding can be contained and the vessel will remain afloat with sufficient stability.

The vessel no longer has self-propulsion. The vessel is unlikely to sink/capsize in the next 3hrs.

Following damage from any unforeseeable hostile damage (i.e. that in excess of design extreme threat damage) for a vessel in this role, anywhere along her length, the vessel shall: -

Survive long enough to allow safe evacuation all of the crew onboard in up to a sea state defined by the Naval Authority, if the vessel cannot be prevented from sinking.

The minimum level of performance required is defined as "Sinking" and this is required for damage over the following lengths, Table 8-1-2, for the different roles of vessel:

Table 8-1-2 – Sinking Level

Vessel Role	Compartments flooded (up to)
2	3+
3	4+
4	4+
5	5+

The definition of **Sinking** is – The vessel has been damaged significantly. There is no operational capability and most systems are off line. It is unlikely the flooding can be contained and the vessel is likely to sink/capsize in the next 3 hours. Evacuation of the crew is the priority and should be achieved before the vessel sinks/capsizes. Table 8-1-2 provides the extent of damage that would be considered by the Naval Authority to allow the sinking performance level.

8.2 Examples of Functional Requirements for the Vessel Protection Functional Area

The Vessel Protection goals could be refined into the following functional areas.

Following moderate damage from one of the accidental or hostile damage threats defined for the vessel in this role, anywhere along her length, the vessel shall:

Remain sufficiently afloat and upright so that she can continue to provide the level of defence required with at least one weapon system and the ability to manoeuvre in a sea state up to that agreed with the customers.

*The minimum level of performance required is **"Defence"** and this is required for damage up to the following length, Table 8-2, for the different roles of vessel:*

Table 8-2 – Defence level

Vessel Role	Compartments flooded (up to)
2	1
3	2
4	2
5	3

The definition of **Defence** is – The vessel is not fully operational, but has some communications and has some weapon systems on line to continue to defend herself and move. Damage control is more difficult but the flooding can be contained. Moving under her own propulsion is limited or not possible. The vessel will be lower in the water with list and trim.

The stability standard would provide the functional requirements defined from the overall goals along with a minimum mandatory level of performance for each role of vessel. For example, for a small 1 compartment damage, a role 2 vessel i.e. MCM, should pass performance level 'defence' or better. The expect level of damage for this performance level is given in Table 8-2.

8.3 Examples of Functional Requirements for the Mission Continuity Functional Area

The Mission Continuity Goals could be refined into the following functional areas.

Following minor damage from one of the accidental or hostile damage threats given for the vessel in this role, anywhere along her length, the vessel shall:

Remain sufficiently afloat and upright so that she can continue to provide the level of "Operation" required with at least one weapon systems in a sea state up to that agreed by the customers.

The minimum level of performance required is to be ***"Operational"*** *and this is required for damage up to the following lengths, Table 8-3, for the different roles of vessel:*

Table 8-3 – Operational Level

Vessel Role	Compartments flooded (up to)
2	Minor slow fill to 1 compartment
3	1
4	1
5	2

The definition of **Operational** is – The vessel is still close to fully operational. The vessel has most systems still on-line including most weapon systems, communications and radar. The vessel may have reduced propulsion capability, but could move at least slowly to a safe port under her own power and control. Damage control parties can work effectively and the flooding extent will be quickly limited and controlled. The vessel maintains a substantial reserve of buoyancy without significant list or trim.

The stability standard would provide the functional requirements defined from the overall goals along with a minimum mandatory level of performance for each role of vessel. For example for a frigate, with small weapon damage causing flooding to a single compartment, should be fully operational and meet all of the performance goals. The expected level of damage for this performance level is shown in Table 8.3.

9. DEFINING THE REQUIREMENTS

The next level down from the functional areas is the requirements level. This is where the level of performance to achieve the functional requirements and hence the overall goals is defined. This layer has been again split into a URD (user requirements document) and SRD (system requirements document) levels. The URD will describe a set of requirements relevant to the functional areas. These will then be used to define actual levels of performance required in the SRD. This set level of performance will be compared against the actual vessel performance in the verification level.

The standard would explicitly provide some of the URD requirements but will not define the SRD requirements, as these may be vessel specific and must be agreed with the customers based on the required performance. The measure of the performance level is to be stated in the standard by the Naval Authority responsible for the standard. The stability assessment will require both the URD and SRD requirements to be clearly defined in the submission report for a certificate of safety stability. It must also provide existing standards, statute requirements or policies that must be met in order to achieve any of the goals.

9.1 URD Requirements

In this level the performance requirements (limiting factors) to meet all of the functional requirements are specified. The performance requirements would be related to the physics of the flooding vessel, the onboard systems and the human factors effects relating to the crew.

9.2 SRD Requirements

In the system requirement level, the actual performance level that is deemed acceptable to meet the functional areas and overall goals is defined. This level will draw out the actual measurable terms that can be evaluated during the verification level.

Possible examples of the limiting measurable factors are:

(a) Limiting a heel or trim angles;
(b) Limiting vertical and lateral accelerations;
(c) Limiting flooding levels
(d) Limiting flooding rates
(e) Limiting submergence

As an example of how the requirements can be drawn down following are examples of the 'Life Safety' functional area defined above:

In order to achieve the functional requirements for 'Life Safety" the URD should state:-

Minimum performance of Crew Safe requires:-

- Reserve of buoyancy – deck above water
- Reserve of stability
- Low motions and accelerations
- Watertight integrity
- Minimum performance of Sinking requires:-
- Time to sink > Time to evacuate
- Further refining the **SRD requirement** to achieve the Life Safety functional requirements requires: **(Note: numbers are for example purposes only)**
- Deck edge above the water
- Mean roll angle < 25 degs
- Mean pitch angle < 5 degs
- Peak roll motions < ±12 degs (4 degs RMS for 1% exceedence)
- Peak Pitch motion < ±6 degs (1 degs RMS for 1% exceedence)
- >20 degrees range of positive stability from mean list angle
- Time to sink > time to evacuate
- The **Crew Safe** performance level would require the following or the equivalence proved:–
- All motion criteria are met more than 95% of the time i.e. a probability of exceedence of motion criteria of less than 5%.
- The deck edge is not continually submerged at any point.
- The probability of sinking in the three hours is less than 4% (1/25) in any sea state up to and including the required design sea state at the worst heading.
- The **Sinking** performance level would require the following or the equivalence proved:
- The deck edge is regularly submerging.
- When the probability of sinking in the three hours is equal or greater than 4% in any sea state up to and including the design sea state at the worst heading.
- Time to sink must be 1.5 (or agreed by Naval Authority and the customers) times the time to evacuate the remaining crew.

10. THE VERIFICATION PROCESS

Since a performance-based design will involve performance requirements that do not necessarily comply with simple prescriptive requirements, it is necessary to verify that the design will produce a warship that meets the damage stability goals and objectives. A procedure to do this is defined as a "verification methodology," and the Naval Authority will need to provide guidelines on the selection and use of such methods.

In this context "verification" is to establish the accuracy of the claim that a proposed solution meets the established damage stability goals and objectives for a vessel in its role. The stability standard would state that the verification process must confirm that the vessel's ability to achieve the level of performance set in the requirements has been demonstrated by qualified people, appropriately using sound methods applied to appropriate and accurate data.

The verification method is the point where one demonstrates whether the vessel designed to the required design specifications and assumptions, and confronted with the challenges of the hostile and accidental damage scenarios, will perform in accordance with the goals and functional areas, as measured by the performance criteria. The design specifications define the role and function of the vessel, along with the characteristics, assumptions, and scenario data, are required inputs to the verification method. The outputs of verification methods are compared to the required performance from the SRD criteria in order to determine the acceptability of proposed, alternate solutions.

10.1 Methodology and Tool Selection

There are various types of tools available to use in the verification process, ranging from basic hand calculations to full computer models.

Each of the many types can be used to provide results for various, necessary pieces of information that are required to verify a design's performance. It is important to be thorough when selecting a verification method. One must carefully consider what information the verification method needs in order to show that the criteria are satisfied, and ensure that this information is included among the available input. Methodologies can range from quasi-static analysis to dynamic analysis using a tool such as FREDYN or even model tests.

10.2 Level of Acceptable Performance

Unlike many engineering scenarios that use the goal based approach, the measure of the performance against the criteria derived from the requirements and hence overall goals can be difficult to clearly evaluate.

The level of acceptable performance is expressed primarily in the criteria brought out of the SRD requirements. The criteria are quantifiable measures of the goals and objectives. In performance-based design it will be the Naval Authority in discussion with the main customers who will determine the level of acceptable performance subject to overall limits set in the performance-based standard. The standard quantifies the Navies expectations with goals for the design to meet, and the Naval Authority determine whether the criteria provide the performance and safety required by the UKMoD. The Naval Authority would have mandatory safety goals and requirements defined in the stability standard, which would have to be proved as a minimum regardless of vessel role.

Statements of goals, objectives and criteria in the submission document, will together with the qualitative level of performance, specify the naval requirement for acceptable performance. The choice of high-challenge scenarios (significant asymmetric damage for example) required by the standard, is another area where the Naval Authority could drive the acceptable performance. When selecting scenarios, it is important to note that damage scenarios in excess of the threats assessed are effectively deemed to be acceptable losses. Considerable thought should go into drawing the line between damage scenarios which are deemed severe enough and likely enough to use in assessing a design and more severe damage case which are deemed too unlikely to use in the assessment.

The threats that were assigned to the vessel roles should ensure that most of the damage threats result in only moderate or minor damage that result in performance levels of defence or operational. However, the more significant threats are still accounted for in the crew safe and sinking performance levels.

After defining the problem, selecting appropriate scenarios, documenting the assumptions on environment and vessel conditions, and selecting an appropriate verification method, it is necessary to verify the proposed design. Whichever methods are chosen the output must be carefully analysed and compared to the criteria from the requirements levels. While the Naval Authority generally will not specify that an exact type of verification method be used, they may place restrictions on certain model or calculation types. Either way, the project team must verify that the method can reasonably predict or produce the appropriate results. The project team will have to select a verification method that generates output data that can be directly compared to the performance criteria or they will have to prove performance equivalence with an alternative method.

11. JUSTIFICATION

The approval of the Naval Authority would be the final activity in the process, and it is his/her decision to either give approval or request further verification of the proposed solution. It is not the role of the Naval Authority to judge whether or not a prescriptive method could have been done in place of the performance-based submission; only to evaluate the design he/she receives.

The justification layer is a feedback layer where the performance is traced back up the goal based pyramid layers to identify if the overall goals have been achieved. The Naval Authority will examine the verification methods in detail and the results produced to identify whether they believe that the verification method and the requirements actually complete the goals.

12. CONCLUSIONS

It has been shown that:

- Current prescriptive standard are used for damage stability in many navies including the UK. The Goal Based approach could allow a greater level of flexibility to a designer, particularly for novel design where a conventional prescriptive standard may be unsuitable.
- The 'goal based' approach could be applied to the damage stability for naval vessels and cover both accidental and hostile threats.
- A framework as described in this paper could be used for defining a performance based damage stability standard as an addition to the current prescriptive standard.

13. ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the permission granted by QinetiQ and the UKMoD for publishing some of the findings from the investigation.

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