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Advanced damage stability assessment for surface combatants

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ABSTRACT

One of the major contributors to the survivability of a surface combatant is her reduced vulnerability to weapon effects and as such the ship's damage stability characteristics determine a ship's ability to resist the consequences of possible flooding, namely to not capsize and/or sink. There are serious concerns about the limitations of the current semi-empirical deterministic criteria in which a combatant's damage stability is assessed upon. This paper details a comparison between the current approach and a newly presented probabilistic approach with the aim of determining which will result in a more accurate way of estimating the level of survivability of a particular design. A study is also presented in which the maximum damage length used in the naval ship assessment is increased to merchant ship standards of $0.24L_{bp}$.

1. Introduction

Surface warships differ from other categories of ships in that they are designed to operate in a man-made hostile environment. In addition to being able to withstand damage from collision and grounding, a surface combatant must be able to avoid and withstand the effects of modern anti-ship weapons. As warships are designed and built to support high-end combat operations, survivability and the ability to 'fight hurt' is a vital design objective.

One of the main contributors to a surface combatant's survivability is her invulnerability to weapon effects and as such the damage stability and floatation characteristics of the vessel determine its vulnerability. Therefore, it is critical for the designer to minimise the vulnerability of the vessel from the early design stages in order to maximise its survivability. This can be achieved through the use of optimal subdivision, adequate reserved buoyancy and by considering a large number of damage scenarios and combinations of operational and environmental conditions.

For the past half of century the majority of warship stability criteria was based on a set of empirically defined stability criteria proposed by Sarchin and Goldberg (1960) based largely on WWII battle damage experience. The criteria used by major navies such as the U.S. Navy (USN) and Royal Navy (RN) have been reviewed over the years however, there have been no significant changes yet. Although the criteria have served their purpose for many years, they now appear to be outdated, given the advances in our capability to simulate the behaviour of a ship after damage (Harmsen, 2000; Mc Taggart and De Kat, 2000), and there are serious concerns about their limitations and applicability to modern naval ship designs. Some of the shortfalls of the criteria include (Surko, 1994)

- capability of modern warships to survive damage from current threats, in demanding environmental conditions, is not known,
- modern hull forms and construction techniques differ greatly from the ships used to determine the criteria, and
- assumption of moderate wind and sea conditions at the time of damage.

This suggests that even though a vessel may comply with the standards outlined, the designer and operator may not have a clear understanding of the survivability performance and operational limits of their vessel.

In view of these shortcomings a number of naval organisations established the Co-operative Research Navies (CRNav) Dynamic Stability group back in 1989 with the aim to provide better understanding to the physical phenomena and characteristics of dynamic stability (Perrault et al., 2010). This led to the formation in 1999 of the Naval Stability Standards Working Group (NSSWG) tasked to develop "*a shared view on the future of naval stability assessment and develop a Naval Stability Standards Guidelines document which can be utilised by the participating navies at their discretion*" (Perrault et al., 2010).

In contrast to the slow progress of naval standards, the International Maritime Organisation (IMO) have made significant advances in terms of upgrading safety standards of merchant vessels. The acceptance of the new harmonised probabilistic

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damage stability framework of SOLAS 2009 for the damage stability assessment of passenger and dry cargo vessels shows that the maritime industry and regulatory bodies are convinced that this is the right way forward. Boulougouris and Papanikolaou (2004) previously presented a methodology for the probabilistic damaged stability assessment of naval combatants and its application to their design optimisation. The methodology allows the risk that the vessel will be lost, as a result of damage, to be quantified. Thus, minimal risk can become a design optimisation objective and the surface naval ship can be optimised for minimum risk while still being efficient and economical.

This paper details a comparative study of the currently used semi-empirical deterministic approach and the proposed quasi-static probabilistic approach to assessing the damage stability of a surface combatant. Each approach is applied to a generic frigate and the merits and shortcomings of each method along with the results are presented. In addition, a study was carried out on a frigate which meets the current deterministic criteria in order to observe the effects of increasing the survivable damage length.

2. Survivability

The survivability of a naval combatant can be defined as *"the capability of a (naval) ship and its shipboard systems to avoid and withstand a weapons effects environment without sustaining impairment of their ability to accomplish designated missions"* (Said, 1995). Survivability consists of two main aspects

- Susceptibility – inability of the ship to avoid being damaged in operation and is also referred to as the probability of being hit (P_H).
- Vulnerability – inability of the ship to withstand the effects of a threat weapon and is also referred to as the probability of serious damage or loss when hit ($P_{K/H}$).

Survivability is the opposite of killability which is the probability that the ship will be lost due to enemy action. Killability can be described mathematically as the product of susceptibility and vulnerability. A ship kill can be expressed in many different ways, in this case the definition given by Ball and Calvano (1994) is referred to

- System kill – damage of one or more compartments which leads to the failure of a ship system.
- Mission area kill – damage which leads to the loss of a mission critical area such as Anti -Air Warfare (AAW).
- Mobility kill – damage which leads to the ship being immobilised through the loss of propulsion or steering.
- Total ship kill – damage which leads to the loss of the ship through insufficient buoyancy, loss of transverse stability or abandonment due to fire.

The mathematical relationship between survivability (P_s), susceptibility and vulnerability is as follows (Ball and Calvano, 1994):

$$P_s = 1 - (P_H \times P_{K/H}) \tag{1}$$

The relationship infers that both susceptibility and vulnerability are of equal importance to the survivability of the vessel. Some naval design philosophies have included to 'design for peace' as the probability of being damaged in operation is very low. They will therefore accept that in the event of a hit that the vessel will be out of action or have limited participation in the operation. Thus their focus has been to minimise the susceptibility of the vessel. Most of the scenario simulations ran would assume a single hit has a kill probability equal to one for smaller vessels and two hits would be assumed sufficient to sink a larger vessel. Although modern surface ships are powerful military assets on the open ocean, they lose their advantage near shore. Even the stealthiest vessel is susceptible to asymmetrical threats. Thus, by treating the vulnerability as a property with a deterministic outcome, pass or fail, it is not possible to truly quantify the survivability of the vessel.

3. Deterministic assessment

Currently, both the USN and RN use deterministic criteria to assess the stability of naval ships after damage. The stability standards previously used by the UK MOD, NES 109, was recently reissued in DEFSTAN 02-900 part 1: Ship safety & Environmental Protection (UK MOD, 2013). However, the criteria used in the assessment of stability and reserve buoyancy after damage remain unchanged. Table 1 shows the semi-empirical damage stability criteria currently used by the USN and RN for surface combatants. Both use a damage length of 15%L_{wl} for larger vessels however the UK also implements a minimum damage length of 21 m. Although the survivability requirements between naval ships and merchant vessels differ significantly it is of interest to note that the current IMO probabilistic damage approach considers damage extents up to 24%.

Although both criteria are very similar, the UK criteria are slightly more demanding, namely the use of a 15° roll back angle requires that UK warships have a greater righting energy to achieve the same reserve dynamic stability criteria. In addition, the use of a minimum length of damage shows progress towards a threat based standard for damage length.

4. Probabilistic assessment

Boulougouris and Papanikolaou (2013, 2004) previously presented a methodology for the probabilistic damaged stability assessment and its application to design optimisation. It is based on the fundamentals of the probabilistic damage stability concept

Table 1
Current UK and US damage stability criteria for surface combatants.

Criteria	UK Defstan 02-900		U.S.N DDS 079-1	
Damage length	$L_{WL} < 30$ m	1 Compartment	LWL < 100 ft	1 Compartment
	30 m $< L_{WL} <$ 92 m	2 Comp or at least 6 m	100 ft $< L_{WL} <$ 300 ft	2 Comp or at least 6 m
	$L_{WL} > 92$ m	Max{15%L_{WL} or 21 m}	300 ft $< L_{WL}$	15% L_{WL}
Permeability	Watertight void	97%	Watertight void	95%
	Accommodation	95%	Accommodation	95%
	Machinery	85%	Machinery	85%–95%
	Stores etc.	80%–95%	Stores etc.	60%–95%
Angle of list or loll	< 20°		List < 15°	
GZ at C	60% of GZmax		–	
Area A1	> 1.4 A2		> 1.4 A2	
Longitudinal GM	> 0		–	
Buoyancy	Longitudinal trim less than required to cause down-flooding		3 in. margin line	