Journal of Marine Science and Technology

Volume 23 | Issue 4 Article 1

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Rodrigo Pérez Fernández
PhD Naval Engineer. Escuela Técnica Superior de Ingenieros Navales (Universidad Politécnica de Madrid), Spain., rodriperfer@hotmail.com

Recommended Citation
Fernández, Rodrigo Pérez (2015) "STABILITY INVESTIGATION DAMAGED SHIPS," *Journal of Marine Science and Technology*: Vol. 23: Iss. 4, Article 1.
DOI: 10.6119/JMST-013-0719-1
Available at: https://jmstt.ntou.edu.tw/journal/vol23/iss4/1

Journal of Marine Science and Technology, Vol. 23, No. 4, pp. 399-406 (2015)
DOI: 10.6119/JMST-013-0719-1

STABILITY INVESTIGATION DAMAGED SHIPS

Rodrigo Pérez Fernández

Key words: damage and intact stability, merchant and warships, ship design, naval accidents.

ABSTRACT

There are many areas in which naval vessels could improve safety standards, although naval vessels are not necessarily regarded as less secure than the civil vessels. Although the navies never have considered water on deck a problem, it seems that this problem has a critical value in the ship damage stability analysis. As an example, this damage should be investigated if the ship has a low freeboard.

For this research various studies and calculations have been carried out on several designed test vessels. It is possible to decide which criteria to use in terms of damages for each type of vessel, for example a landing ship faces more risk having grounding or raking on its bottom. This technical paper concludes with a method that helps and supports the naval architect in the analysis of damage stability. In this way, the naval engineer is able to determine which of the existing criteria fits best with the requirements of the ships function by following these few principles.

I. INTRODUCTION

To avoid duplication, gaps and shortcomings in safety, it is important for the navies to work together with the Classification Societies in the development of effective and sustainable arrangements. Thus, development of rules for warships Naval Ships Rules by various Classification Societies is the most important contribution to work in this area. The idea of cooperation to make an International Convention for the Safety Of Life At Sea (SOLAS) goes back to the nineties of the last century. Remember that the philosophy of the SOLAS is applicable to merchant ships, and is not fully transferable to warships. In September 1998, Classification Societies of the Member States of the North Atlantic Treaty Organization (NATO) met to establish links within their own organization. This meeting established the Naval Ship Classification Association (NSCA), in May 2002, and the cooperation was defined according to the following terms of reference: promote safety standards at sea, promote measures to protect the marine environment, promote and develop common operating standards, undertake R&D to support the above and communicate the views of the partnership agreements and the NSCA.

II. A BIG DEBATE: DETERMINISTIC OR PROBABILISTIC CRITERIA

At this moment, the community of Naval Architects is debating between the probabilistic and the deterministic methods. It is therefore necessary to define in this technical paper what a deterministic or a probabilistic method is. To verify the validity of a model it is necessary to deduct from it a certain number of hypothesis and then to corroborate it with observations of predicted results.

Deterministic models correspond to mathematical models designed on the assumption that the result of an experiment is determined by the conditions under which it is performed; stochastic models (probabilistic) are those for which the data is obtained through a sampling of probability distributions. This sample allows that uncertainty (which can be reduced if more data is collected) and variability are propagated from the model and demonstrated in the results of the model.

Are probabilistic and deterministic approaches comparable?

- From a mathematical point of view: in general no.
- From a theoretical point of view: limited way.
- From a practical point of view (analysis of real ships…): yes.

In Table 1 and Table 2 it is possible to visualize the probabilistic and deterministic approaches, plus the damage criteria applicability.

Are different probabilistic approaches comparable?

- From a mathematical point of view: yes.
- From a theoretical point of view: yes.
- From a practical point of view (analysis of real ships…): yes.

Not all the civil ships must follow the probabilistic criteria. There are several groups of ships that do not follow the new criteria and still using deterministic criteria:

Paper submitted 08/14/12; revised 05/27/13; accepted 07/19/13. Author for correspondence: Rodrigo Pérez Fernández (e-mail: rodriperfer@hotmail.com).
PhD Naval Engineer. Escuela Técnica Superior de Ingenieros Navales (Universidad Politécnica de Madrid), Spain.

Table 1. Probabilistic *vs.* deterministic approaches.

Approach	Probabilistic	Deterministic
Damage Size	Variable	Fixed
Number of damaged spaces	No pre determinate	Fixed
Damage Cases	Several/Free	Few/Fixed

Table 2. Damage criteria applicability.

Ships	Carriers	Passenger
Before 2009	Probabilistic (Old SOLAS)	Deterministic (SOLAS 90) Probabilistic (A.265)
After 2009	Probabilistic (new rules)	Probabilistic (new rules)
Size	L ≥ 80 (m)	All

- Tankers, chemical ships.
- Ships with a reduced freeboard.
- Special craft and offshore ships.
- High speed crafts.

In summary, it could be said that a deterministic model assumes that the actual result is determined by the conditions under which the experiment takes place, however when a stochastic model is used, the experimental conditions determine only probabilistic behavior (the probability distribution) of the observable results. The criteria of US Navy and British Royal Navy are based on deterministic models, so it is necessary to remember the importance of these models. Given the relevancy of probabilistic methods, they have been evaluated; in particular we have studied the philosophy and new tools for its calculation.

It is equally important to point out the pros and cons of using probabilistic criteria. These probabilistic criteria are aiming to provide estimates of uncertainty and variability associated with each of the predicted levels of risk. This is one of the positive aspects (stochastic) of such configuration models, but also leads to confusion in the interpretation of the data. Furthermore, those same estimations are uncertain and depend on the methods and assumptions used to make these calculations. This fact is frequently overvalued due to the limited data set available, and perhaps overestimating risk associated with a particular fault.

An assessment procedure would be considered a more effective method for implementing the proposal of survival of an optimized schema of design of vessels. The assessment procedure is an approach that bases the probability of survival on the basis of survival in quasi static criteria such as that of the US Navy and British Royal Navy. Philosophy for the transformation of these deterministic in a set of rational criteria with a stochastic approach or probabilistic criteria is based on the Resolution A.265 (VIII) of the Design Data Sheet (DDS) for passenger ships. Passenger ships, longer than the military ships, still rely on deterministic criteria.

From the first of February of 1992 the probabilistic method was inserted into SOLAS as Part B-1 of the Chapter II-1,

Table 3. Use cases about required subdivision index.

Case	Carriers (new *vs.* old rules)	Passenger (new rules *vs.* A.265)
Length	> in new ones	> in new ones except very high L
Number of people	N/A	> in new ones except very high N

annex Regulation for subdivision and damage stability of cargo ship over one hundred meters in length, that applies to dry cargo ships constructed on or after the first of February of 1992. Later on, ships with length between eighty and one hundred meters were also included.

The 8th Assembly of International Maritime Organization (IMO), in the Resolution A.265 (VIII), adopted a set of probabilistic regulations of subdivisions, which increased the requirements for damage stability passenger ships according to the Part B of Chapter II of the SOLAS 1960 for passenger ships.

Finally in the 80$^{\text{th}}$ session of IMO, Maritime Safety Committee (MSC) the working group finalized a substantial revision of SOLAS CHII pt 1 A, B and B1 aiming at harmonized damage stability requirements for all ship types except tankers, performed by means of a common probabilistic methods. The draft was adopted at the MSC 80 without further modification. The revised Ch II-1 will apply to all new passengers vessel, ro-ro (roll on-roll off) and cargo ships built on or after the first of January of 2009 (Pérez and Riola, 2011a).

Probabilistic concepts address the probability of damage occurring at any location throughout a ship and adopt a more rational criterion of subdivision by considering the likelihood of damage resulting in the flooding of only one compartment, or any number of adjacent compartments, either longitudinally, transversely or vertically. The residual buoyancy and stability of a ship is calculated for each such case of damage, and either a positive or a zero contribution is associated to each case, depending on, whether or not, the residual buoyancy and stability are considered sufficient.

In probabilistic terms, a ship does not need to survive in every possible case of damage. The probabilistic criterion provides that there are a number of survival cases which allow obtaining a total value A (Attained Subdivision Index) equal or greater than a reference R (Required Subdivision Index). In the new SOLAS revision, in addition, the partial index A_s, A_p and A_l are not less than $0.9 \bullet R$ for passenger ships and $0.5 \bullet R$ for cargo ships. For an easy understanding about the implication of the new R index, please see Table 3.

The A index attained by a ship considered to be measure its level of safety against both sinking and capsizing. In this way, two ships that have different main dimensions but whose A indexes are equal, may be considered as having the same level of safety. Three loading conditions need consideration:

$$A = 0.4 \bullet A_s + 0.4 \bullet A_p + 0.2 \bullet A_l \tag{1}$$

where the index s, p and l represents the three loading conditions, and the factor that multiplies to the index indicates the degree of the index A according with each loading condition.

It is worth mentioning the debate between deterministic or probabilistic methods continues. In addition it must be emphasized that no *Navy* used stochastic methods or probabilistic as exhibited during the development of Naval Ship Code (NSC) when the President of the International Association of Classification Societies said that it would thus remain. Therefore, since the focus of this paper was on warships, mainly due to the appearance on the scene of the new *NSC* which will be mandatory for all military naval constructions this year and leveraging the use of a Computer Aided Design (CAD) system, the objective was the comparison of the various deterministic criteria and whether the new *NSC* was really more or less restrictive than the previous version and in which cases (Pérez and Riola, 2011b).

Some of the factors that can improve the probabilistic criteria:

- Combination of water on deck with the probabilistic concept.
- To optimize compartment and ship design from the point of its damage stability. *KG* (permissible height of the center of gravity) calculation using a data base of real cases.
- Analysis by ship type.

III. NAVY CRITERIA

1. US Navy Criteria

The criteria used to evaluate adequate damage stability performance according the Design Data Sheet (DDS) is based on a reduction of the righting arm equal to $0.05 \bullet \cos\theta$, and it is included in the righting arm curve to account for unknown unsymmetrical flooding or transverse shift of loose material. Beam wind heeling arm curve is calculated with the same method as used for intact stability calculations, but considering a beam wind velocity of around 33 (knots) as defined in DDS. The damage stability is considered satisfactory if the static equilibrium angle of heel θ_c, point C without wind rolling effects does not exceed 15°. The limit angle θ_1 of the damage righting arm curve is 45° or the angle at which unrestricted flooding into the ship would occur, whichever is less (Sarchin and Goldberg, 1962) and (Surko, 1994).

In Table 4 there is a comparison between the most important naval damage criteria, UK Naval criteria (called NES 109) and US Naval criteria (named DDS-079).

The criterion is considered fulfilled if the reserve of dynamic stability A_1 is not less than $1.4 \bullet A_2$, where A_2 extends θ_r to windward. The tendency during recent decades in surface naval ship design was to assess and minimize susceptibility through detailed signature management. For the naval architect it is usually enough to assess the adequacy of its design with respect to vulnerability through the use of the damaged stability requirements introduced by the various navies, such as those used by the US Navy and the UK Ministry of Defense (MoD).

Table 4. UK *vs.* US Navy damage stability criteria.

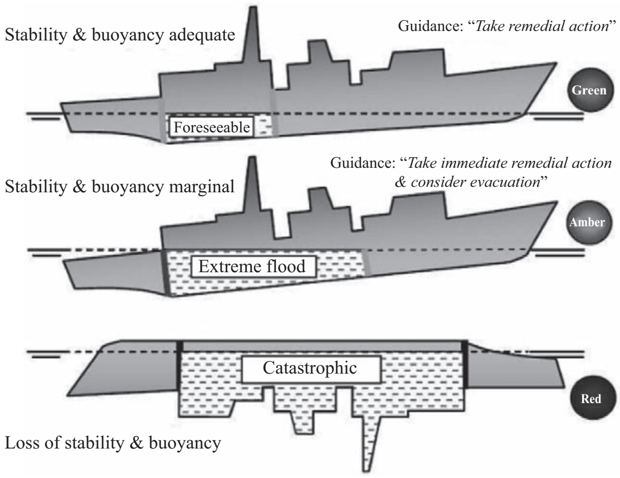
Criteria	NES 109	DDS-079
Damage length	$L_{WL} < 30$ m	1 compartment
	30 m $< L_{WL} <$ 92 m	2 comp of 6 m
	92 m $< L_{WL}$	15% L_{WL}
Permeability	Watertight Void	95%
	Accommodation	95%
	Machinery	85%-95%
	Stores	60%-95%
Area A_1	> 1.4 Area A_2	

A damage incident for the purposes of this chapter is defined as a breach of watertight or watertight integrity. When the watertight or watertight integrity of a ship is breached by any mechanism the ship is at risk of loss due to flooding. The extent of the breach and the ship's initial loading condition and material state will dictate the likelihood of the ship being lost. Irrespective of whether the damage is caused by an accidental or hostile event all damage can be categorized. The level of safety and performance following damage will depend on the severity of the damage incident.

2. Naval Ship Code

In addition to navies, Classification Societies through the NSCA have a standing invitation to attend the meetings of the specialist team as active participants. The specialist team is tasked with the development of a NSC that will provide a cost-effective framework for a naval surface ship safety management system based on and benchmarked against IMO conventions and resolutions. The Specialist Team has established a Goal Based Approach to the development of the NSC and is now developing each chapter in turn. This folder in the *NAS* (Naval Authority System) library contains the latest documents including NSC chapters, related guidance and records of meetings. The NSC adopts a goal based approach. The basic principle of a goal based approach is that the goals should represent the top tiers of the framework, against which ship is verified both at design and construction stages, and during ship operation. This enables the NSC to become prescriptive if appropriate for the subject, or remain at a high level with reference to other standards and their assurance processes. The goal based approach also permits innovation by allowing alternative arrangements to be justified as complying with the higher level requirements. The increasing width of the triangle as the NSC descends through the tiers implies an increasing level of detail (Riola and Pérez, 2009).

A catastrophic event, Fig. 1, caused by damage that the ship and persons on board would not be expected to survive, will result in rapid loss of the ship. Following an extreme event, resulting from damage more severe than foreseeable but not



Source: Guide to the Naval Ship Code.

Fig. 1. Severity of damage event for stability.

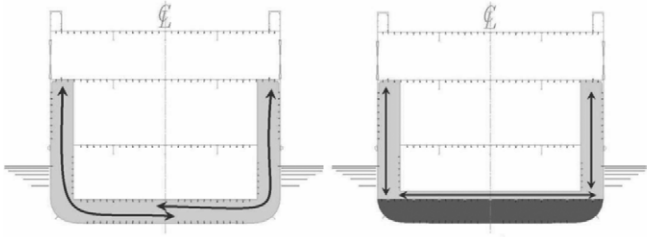


Fig. 2. Solutions for the communication between tanks.

catastrophic, the ship would be expected to remain afloat in a condition that will allow personnel to evacuate if required. In the event of damage below the extreme level, foreseeable damage, the ship would be expected to survive although the level of real operational capability will depend on a particular navy's concept of operations. Chapter III is primarily concerned with foreseeable operating conditions up to extreme damage, with exception of the Regulation 6 preservation of life.

IV. WARSHIP CASE STUDY

1. Application

Nowadays, in both practical navigation and shipyard technical offices, stability tests in load and sea conditions, as in working or damaged conditions, are performed with software packages that starting from the ship design are able to quickly compute the required data. This research focuses on evaluating the configuration of ships. The CAD used allows visualization of the detailed requirements generated from the stability requirement chosen, and also enables data entry to compute minimum GM's. Inside the modules, it is possible to check the most common standard stability criteria and a user can define criteria, obtaining if necessary, the limiting KG values.

The two chosen ships, called first and second project, for this analysis have a double bottom with a height upper to a tenth of the beam. First project is similar to a warship and second project is similar to a merchant ship.

Different configurations, as shown in the Fig. 2, have been applied to both of them. To find the dimensions, a database with merchants and warships of similar characteristics has been used.

2. Results

Safety at sea has improved considerably in recent decades thanks to the incorporation of new technologies to the ships and the legislative effort made by the IMO, without forgetting the work of ship inspections and Classification Societies ensuring that vessels are constructed and operated according to existing regulations. The major maritime disasters have traditionally been coupled with the pressure of public opinion, alarmed at the loss of life at sea. It has prompted the governments of the major maritime nations in a legislative effort to improve the safety of ships. This is the first case of SOLAS, held in London in 1914, two years after the sinking of the RMS Titanic, though it was not actually due to the outbreak of the World War I. It is not necessary to go back to early last century to find new examples, the collapse and subsequent overturning of the MV Estonia in 1994, in waters of the Baltic Sea, was the driver, as discussed in chapter two of this article of the Stockholm Agreement and a series of resolutions IMO related to the stability of such vessels.

The IMO, as a United Nations agency, was founded in Geneva in 1948, but did not start its activity until 1952, to develop and maintain the regulatory framework for governing the shipping, including aspects such as security or pollution, taking into account the international conventions as SOLAS or MARPOL, among others. It is organized into specialized committees and subcommittees, consisting of experts from member countries to study various aspects of maritime safety and the updating of regulatory legislation. This is the case of the MSC, which means all aspects that directly affect the sea, such as construction and equipment or the training of crews.

In the naval field, there are no organizations equivalent to the IMO to understand the international level of the safety of such vessels. Traditionally, the warships are taking the existing rules of IMO that do not interfere with naval objectives and adapting them as far as possible. The intact stability calculations are made for checking if the warship complies with the intact stability criteria and that if not fulfilled, the values were obtained at the end of the study would be worthless.

Back to the study, depending on ship compartment and flood conditions will get damage stability results. In Fig. 3 there is one of the damage conditions applied in the first test ship. The flood damage can be considered by an opening in the side, at the bottom or the failure of the deck to allow the entry of water and lead to flooding of the ship. In this paper, the damage occurs on one side, bottom up. The ships have been damaged, compartment by compartment. When one compartment is flooded, there is a loss of buoyancy, a change

Table 5. Intact stability criteria.

CRITERIA NUMBER	DESCRIPTION
1	GZ of 0.2 (m) between 30° and 90°
2	DN of 55.0 (mm•rd) between 0° and 30°
3	DN of 90.0 (mm•rd) between 0° and 40°
4	DN of 30.0 (mm•rd) between 30° and 40°
5	GM > 0.150 (m)
6	Angle for which a maximum GZ is obtained > 25°
7	IMO weather criterion

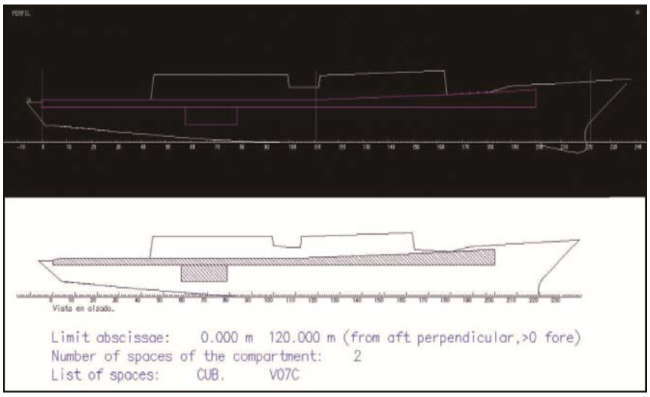


Fig. 3. Longitudinal section/first flood for first project.

of trim, a variation of a transverse metacentric height and longitudinal metacentric height variation. Now the intention is to study the GM's minimum, or KG's maximum for the three criteria that we want to compare. To explore the stability problems, it needs the help of software to carry out the calculations. In the case of this research to study the SOLAS, the US Navy and the British Royal Navy criteria, the calculations were made using a CAD, choosing a damage condition and a load condition of the vessel intact, and are getting results that are developed below. The worst damage is one where *KG's* maximum is the minimum among all possible failures, or put another way, which has the stronger GM's minimum for each draft.

Where DN means dynamic stability and it is measured in (mm•rd) and GZ is the righting arm in (m).

In order to realize a complete study, it is necessary to study the intact stability. Some of the results are shown in Table 5, Table 6 and Table 7. In these tables DP is displacement in tons, GM is minimum permissible metacentric height in meters and KG is permissible height of the center of gravity in meters.

3. IMO Applicability

SOLAS implies safety, but is by no means applicable to all types of vessel. Mainly because many of its rules are unworkable or unrealistic for the warships.

Due to the need to unify criteria for the countries of the NATO and the lack of a security policy that ensures minimal compliance, a group of specialists was formed with the task of

Table 6. Intact stability limit values for first project.

Draft (m)	DP (T)	Criteria	GZ (m)	GM (m)
3.65	4069.5	7	12.43	3.64
4.43	4801.9	7	13.03	2.23
5.37	6364.5	7	13.30	1.19
6.21	7488.1	7	13.40	0.68

Table 7. Intact stability limit values for second project.

Draft (m)	DP (T)	Criteria	GZ (m)	GM (m)
9.03	42511.5	7	11.352	2.518
10.75	50138.3	7	12.104	1.576
12.50	66453.2	7	12.442	0.854
14.22	78184.4	7	12.623	0.339

developing the NSC, a naval military code based on national standards, international standards such as High Speed Craft, high-speed vessels, and primarily, the applicable rules of the SOLAS, to promote improvements in the design construction and in specific areas such as navigation in international waters, communications or environmental protection. SOLAS begins by defining criteria on the extent of damage to consider. These dimensions, based on statistics of failure, are defined as a fault length equal to 3% of the length plus three meters, a penetration of damage equal to B/5 and a height of damage that goes from bottom to top without limit. The worst damage in SOLAS, considering water on deck, is composed of two compartments, as it is shown in Tables 8 and 9.

There are certainly some obvious weaknesses in the requirements of the Agreement and this must be borne in mind when assessing *ro-ro* safety. The Stockholm Agreement was created on the presumption that a vessel designed, or modified, to SOLAS'90 standards ensures survival at sea states with Hs of only 1.5 (m). This was suggested in the face of uncertainty and lack of understanding of the phenomena involved. The evidence amassed so far and presented in the following suggests that this was a considerable underestimate. The maximum penalty of 0.5 (m) height of water on deck is ill based. It is to be noted that the forty-nine tests used to measure water accumulation on the car deck comprised only four open decked ships, the others having car decks with: three transverse bulkheads, five central casing, nineteen central casing with transverse bulkheads, eight side casings and ten side casings with transverse bulkheads. It is straightforward to prove that the height of water accumulated on a subdivided deck is considerably larger than the height of water accumulated on open decks.

More importantly, requirements based on subdivided decks are likely to promote designs with similar arrangements, which is contrary to the ro-ro concept itself. Finally, the effect of water on deck is taken into account by a calculation method that does not preserve the physics of the problem, and being based on static and deterministic approaches, it tends to negate

Table 8. Worst damage along with IMO for first project.

MAXIMUM KG AND MINIMUM GM CALCULATION			
Draft (m)	Displacement (T)	KG_{MAX} (m)	GM_{MIN} (m)
3.65	4069.5	14.761	1.301
4.43	4801.9	13.959	1.048
5.37	6364.5	13.335	0.889
6.21	7488.1	12.996	0.791

Table 9. Worst damage along with IMO for second project.

MAXIMUM KG AND MINIMUM GM CALCULATION			
Draft (m)	Displacement (T)	KG_{MAX} (m)	GM_{MIN} (m)
9.03	42511.5	13.345	2.435
10.75	50138.3	12.776	2.002
12.50	66453.2	12.322	1.567
14.22	78184.4	11.986	1.231

Table 10. Worst damage along with DDS for first project.

MAXIMUM KG AND MINIMUM GM CALCULATION			
Draft (m)	Displacement (T)	KG_{MAX} (m)	GM_{MIN} (m)
3.65	4069.5	15.147	0.919
4.43	4801.9	14.232	0.787
5.37	6364.5	13.641	0.673
6.21	7488.1	13.412	0.620

Table 11. Worst damage along with DDS for second project.

MAXIMUM KG AND MINIMUM GM CALCULATION			
Draft (m)	Displacement (T)	KG_{MAX} (m)	GM_{MIN} (m)
9.03	42511.5	15.034	1.045
10.75	50138.3	14.089	0.902
12.50	66453.2	13.501	0.771
14.22	78184.4	13.248	0.663

Fig. 4. USS Nevada trapped in Pearl Harbor.

the potential for adopting rational approaches to safety through the introduction of operational sea states and performance-based standards.

4. US Navy Applicability

The US Navy stability criteria are documented in the DDS, which is divided into criteria for damage stability for both sides′ protected and non-protected vessels. The non-protected criteria relate to the 82.3 (m) cutter that is the class used in this investigation. The DDS states that an angle of less than fifteen degrees is required after damage for operational requirements. There is no mention of cross-flood systems except for in the side-protected vessels, which states that the maximum list shall not exceed twenty degrees and that arrangements exist for rapidly reducing the list to less than five degrees (US Navy, 1975). The current stability criteria used by the US Navy were developed during and shortly after World War II. See the USS Nevada in the Fig. 4.

These criteria are based on static righting arm curve, are largely empirical, and do not explicitly consider many variables which can have a major impact on dynamic intact stability (US Navy criteria outputs in Table 10 and Table 11). However, they are accepted by the experts, and within conventional hull forms, have proven to be a reliable, generally conservative, ordinal measure of intact stability. Current international efforts for improving naval ships stability criteria are focused on time domain analysis including the capability to model a steered ship. Merchant ship intact stability is addressed in a number of IMO regulations.

The IMO weather criteria considers wind with gusts and a roll-back angle which is dependent on the ship's static righting arm and other ship roll characteristics. The US Navy and other navies have not kept pace with IMO developments. They continue to rely on the empirical World War II criteria until the more sophisticated methods are developed and validated. Validation and acceptance of these new methods may take some time. Current naval ship can be greatly improved with a few small changes which maintain the integrity of their basic approach, and increase their commonality with the IMO criteria. These changes are worth making now, to support the design of new ships until more sophisticated methods are in place. The worst damage is that which includes three compartments.

5. New Approach

The damage categories, in the NSC, are based on defined shapes:

- Sphere. To be used for explosions. For explosions detonating against the outside of the hull, half the sphere to be used.
- Cube. To be used to define the volume directly affected by fire and which may change in shape to fit the compartment.
- Raking/grounding. To be used in the appropriate horizontal orientation to describe the extent of raking or grounding

Table 12. Worst damage along with *NSC* for first project.

MAXIMUM KG AND MINIMUM GM CALCULATION			
Draft (m)	Displacement (T)	KG_{MAX} (m)	GM_{MIN} (m)
3.65	4069.5	15.034	1.045
4.43	4801.9	14.089	0.902
5.37	6364.5	13.501	0.771
6.21	7488.1	13.248	0.663

Table 13. Worst damage along with NSC for second project.

MAXIMUM KG AND MINIMUM GM CALCULATION			
Draft (m)	Displacement (T)	KG_{MAX} (m)	GM_{MIN} (m)
9.03	42511.5	13.966	1.756
10.75	50138.3	13.338	1.444
12.50	66453.2	12.782	1.212
14.22	78184.4	12.342	0.996

damage, the apex representing the maximum penetration.

- Collision. To be used in the correct vertical orientation to describe the extent of collision damage from the bow of another ship, the apex representing the maximum penetration.

The extent of the worst damage category is defined as damage category C, significant: sphere with 10 (m) of radius, cube with 20 (m) of sides, raking/grounding with 40 (m) of length and 5 (m) of equal sides and collision damage with 40 (m) of height and 5 (m) of equal sides. The temperature is heat caused by initiating event assuming no other combustion. Time to rise to peak of 20 (min), peak temperature 400° (C), duration of peak temperature 400 (min) and time for temperature to revert to normal 200 (min).

After the study of the outputs, it is possible to declare that the worst damage is the grounding, as it is shown in Tables 12 and 13. Proof that ships meets all known criteria, will not tolerate a failure of forty meters in length in the double bottom. Therefore, for comparison between criteria, it will not be used the failure of raking/grounding, defined in the NSC. Of the other three types of damage, and if comparable with the SOLAS, the worst of all is the one defined by a cube of twenty meters on the side. Such as the title of the work submitted for this article it is important to note that a detailed study of the navies criteria to use for the calculations, made by a CAD, the criterion of NES-109. It is necessary in this case study the damage defined as the NSC with a cube.

V. CONCLUSION

In this paper, we have proposed a comparative analysis of the different criteria of stability after damage. For this research the various studies and calculations have been carried out on a designed test vessel. We have created a vessel to comply with different conditions, like having an empty deck, without pillars, one propeller shaft and whose forms are as close as possible to a warship. See Fig. 5.

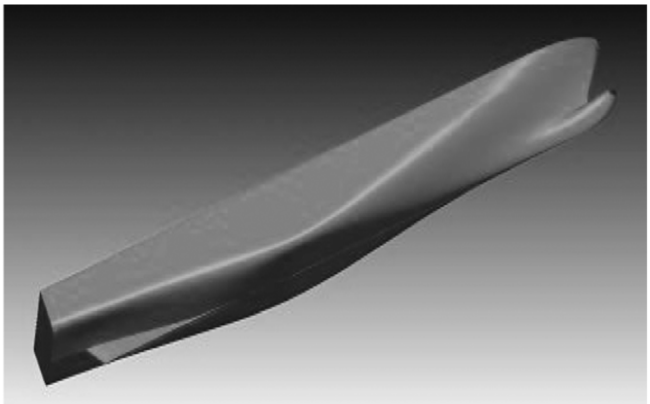


Fig. 5. Second project studied in a 3D visualization.

A most important conclusion to emphasize, that while the approach of the British Royal Navy is more restrictive than the US Navy, if we are considering the Stockholm Agreement to SOLAS, is that this convention is the most restrictive of all. If water is seen on deck, no military approach is more restrictive than the IMO. It means that the navies never have considered in their calculations water on deck. It is true that due to civil ro-ro accidents, during the nineties, the IMO started considering the water on deck as dangerous and it was incorporated an annex to the SOLAS, to take account this problem. Although the navies never have considered this kind of flood, it seems that this problem has a critical value in the ship damage stability analysis. In concrete, this damage should be investigated, if the ship has a low freeboard.

There are many areas where military vessels could improve safety standards, although not necessarily to be regarded as less secure than the civil vessels. However, there are major difficulties in implementing all the rules of the Classification Societies in the naval field; especially to establish a priority mission and capacity combat against security. It is important to distinguish the importance of the new rules NSC. The NSC has become the criterion of stability in damage than more is acclimating to the navies' standards in the XXI century, as it has been reflected throughout the paper. For each type of vessel could be a priority for study in terms of damages of the NSC. As the NSC is to provide a level of safety appropriate to the role of the ship and benchmarked against statute while taking into account naval operations, it is necessary to define the degree of survivability in a form that can be taken into account in the development and application of all NSC chapters. By way of example, the fundamental difference between the approach to fire safety for naval and civilian shipping is that SOLAS considers the risk of fire based on the function of each compartment whereas for naval ships, hostile acts may result in fire anywhere on the ship, both externally and internally. The consequence is that the solutions that are adopted for accidents may differ from those that are required to prevent and counteract hostile damage events. Thus, for the effective application of the NSC, it is necessary to clearly define the extent of damage that reflects both accidental damage and potential damage caused by hostile acts, the damage location, the degree of vulnerability (protection, redundancy of systems, materials used), the required post-damage ship capability and the philosophy for recovery from the damaged state. Each navy will have its own unique approach to this issue, and it is not possible to be prescriptive in the NSC. However, it is possible to provide a basic framework that can then be adapted by each Naval Administration. It is then essential that the owner and naval administration agree the required level of survivability in these terms for each class of ship.

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