Weight Design Margins in Naval Ship Design— A Rational Approach

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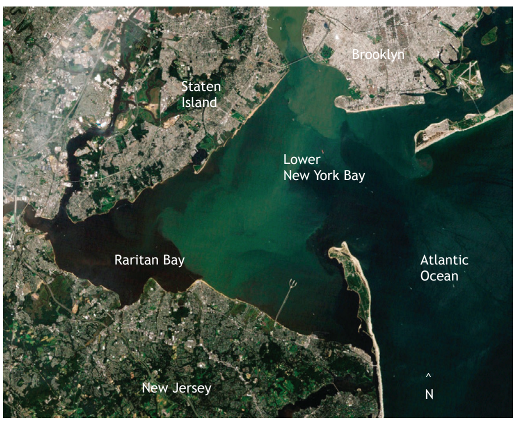

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This article examines the benefits of having the government serve as an engineer and integrator of software-intensive tactical systems, and the capabilities the government—along with industry partners—brings to such an enterprise. This article also focuses on how U.S. Navy laboratories can bring together the multi-discipline approach and diverse team needed to leverage advancements in data science, brain cognition, augmented reality, emerging distributed software architectures and agile software development methods to support improved U.S. Navy command and control solutions. Further, this article will discuss how such an approach can support emerging dynamic operational constructs like distributed lethality.

Captain Kurt J. Rothenhaus USN, Mr. Bill Bonwit, Captain George Galdorisi (USN, retired), Ms. Anna Stang, Space and Naval Warfare Systems Center Pacific

ON THE COVER

MEDITERRANEAN SEA (July 31, 2016) The amphibious assault ship USS Wasp (LHD 1) transits the Mediterranean Sea. Wasp is deployed with the Wasp Amphibious Ready Group to support maritime security operations and theater security cooperation efforts in the U.S. 6th Fleet area of operations.

U.S. Navy photo by Mass Communication Specialist 1st Class Eric S. Garst/Released

CDR Omri Pedatzur
Israeli Navy

Weight Design Margins in Naval Ship Design—A Rational Approach

ABSTRACT

Optimal design of a ship requires a fine balance between all the classic key parameters of naval architecture: weight, stability, speed, range, etc. The methodology of the design spiral is well established, but many recent projects present examples of poor implementation of the methodology, proving that anything that can go wrong—and as Murphy promised, actually will.

This paper reviews a few failures and design flaws from the last decade, associated with insufficient weight design margins and poor weight control. The paper suggests an easy way to implement weight design margins into naval ship design according to the complexity and risk level of the vessel and its sub-systems.

KEY WORDS

- Weight Design Margin
- Bonen Scale
- Key Weight Estimate

INTRODUCTION

PROPER SYSTEM ENGINEERING of a naval vessel leads to optimal and safe design parameters; the vessel fulfils all customer requirements, abides by all design standards and mandatory regulations, and includes acceptable margins for future growth over the life expectancy of the vessel.

On the other hand, poorly executed system engineering leads to unbalanced, overweight vessels that don't meet the customer requirements, don't follow the applicable standards, have almost zero margins for future growth, and (worst of all) may present severe safety problems.

Increase in the vessel's weight is the biggest enemy of the optimal design spot, because it immediately leads to degradation in stability, speed, range, and structural integrity. Needless to say, every weight increase during the design phase or during the construction phase results in smaller margins for future growth, leaving the new vessel limited for decades to come, sometimes with severe initial problems that will get even worse as years go by.

It seems that a significant portion of new vessels suffer from this problem, regardless of size, type of vessel, or designer. Numerous naval projects have made headlines in the last few years because of their weight problems, reminding us that there is always room for improvement in the art of design margins and weight control.

New Zealand Royal Navy Protector Class Offshore Patrol Vessels

In July 2004, the New Zealand Ministry of Defence ordered two offshore patrol vessels (OPVs) from Tenix Defense (later BAE Systems) as part of the $500 million defense acquisition project named Protector. The first of them, HMNZS Otago (Figure 1) was launched in 2006 with 100 tons of weight above the maximum design displacement of about 1,800 tons (Grevat, 2008), which affected its operational capability, including its ability to sail in Antarctic waters (in order to minimize the ship's weight its ice strengthening was reduced, leaving the ship's plates vulnerable to pounding by blocks of ice).

The New Zealand Ministry of Defense claimed that the two OPVs are unseaworthy and refused to accept the vessels, leaving them in limbo at the Williamstown docks. The initial crew of 70 stationed in Melbourne for the sea trials and commissioning of the vessel returned home until the problems with the

Figure 1: HMNZS Otago (P148) Protector-class Offshore Patrol Vessel IMAGE CREDIT: ROYAL NEW ZEALAND NAVY

Figure 2: S-80 Isaac Peral-class submarine under construction IMAGE CREDIT: NAVANTIA

vessels weight could be solved, resulting in a huge crisis and unflattering headlines in the media (Gordon, 2009).

This kind of problem doesn't stay static but rather deteriorates with time. New Zealand Defense Minister Dr. Wayne Mapp expressed his disappointment in 2008, "Normally, they can just add whatever they like to these ships, but with these ones, loads will have to be managed very carefully. There are usually [weight] margins to play with, but with these ships that margin is less" (Porteous, 2008).

After long and problematic contract negotiations between the shipyard and the Ministry of Defence, both ships were commissioned in 2010, nearly two years after the original target date (De Silva, 2010). The OPVs have already served on several lengthy patrols of the Antarctic, though they lack the capability of operating in heavier levels of ice coverage. In 2013, New Zealand Foreign Affairs Minister Murray McCully said a planned patrol of the Antarctic fishery was canceled due to concerns about the ability of the vessel to operate in the Southern Ocean. He claimed that he was advised that the mission was not possible because it was "not within the capabilities of the vessel" (Manins, 2013).

Spanish Navy Isaac Peral-class AIP Submarines

Submarine design projects suffer from the same problem, however, for these types of projects it is not just a matter of meeting customer requirements or following the design standards, but rather having (or not having) enough buoyancy to balance their own weight.

The new project of the Spanish Navy, the S-80 Isaac Peral-class submarine (Figure 2), consists of designing and building four state-of-the-art AIP submarines with a total price tag of $3 billion.

The first of the four submarines is 70 to 100 tons overweight, out of 2,430 tons maximum design displacement. According to Navantia, the Spanish shipbuilding company responsible for its design, that excess bulk is enough to prevent the Isaac Peral submarine from successfully resurfacing once submerged. (Davis, 2013).

Construction on the S-80 class submarines began in early 2005, but the weight problems emerged just as the hull of the first submarine was nearly completed in 2013. Spain will now pay the U.S. Navy contractor Electric Boat millions of dollars over three years to assess the issue and carry out the work required to correct it. The problems can be fixed by extending the length of the submarine's hull, perhaps by a few meters, in order to increase buoyancy. However, this kind of major redesign at this advanced stage of the project has an enormous price tag. According to a former director of Spain's Office of Strategic Assessment, "The buoyancy problem alone could cost up to half a billion euros to cover redesign and extra construction, without considering the propulsion problem." (Kington, 2013).

The final price tag will be reflected not only in terms of money, but also in a significant delay in the delivery date, and a potential threat to Navantia sales as well as to the Spanish Navy's budget. The Isaac Peral-class submarine might float again in the future, but nothing will compensate for the poorly executed system engineering and inadequate general arrangement of the vessel.

In both cases, New Zealand and Spain, neither the government authorities nor industry supplied explanations regarding the root causes of the problems. Several broad explanations as to the lack of design margins and loss of weight control in naval ship design are discussed later on.

The Need for Weight Margins

Good management of design and construction margins requires allocating virtual extra weight onboard the vessel and making sure that the ship design maintains its key performance parameters even with the added weight. As the design and construction progresses, the virtual weight may turn out to be the actual weight. Thus, the "big question" is how much weight should be added as a design and construction margin?

There are multiple codes of practice and rules of thumb to cope with this question, but it seems that some of the recommended practices fail to differentiate between the various types of projects, resulting in excessive margins for simple and almost risk-free designs, and insufficient margins for complex ship designs that are subject to higher risk.

Managing the design margins according to the risk level of the vessel requires a standard scale to evaluate the risk and complexity of the project.

The Project's Risk and Complexity Level According to the "Bonen Scale"

Long time Rafael Advanced Defense Systems director-general, Dr. Zeev Bonen, defined a standard scale, commonly known as the "Bonen Scale," to quantify the complexity and risk associated with R&D projects in the defense industry (Bonen, 1969). The "Bonen Scale" has become a national standard in system engineering all across the Israeli defense industry, including air, land, naval, and space systems. According to Bonen, every system or subsystem can be ranked on a 1 to 4 scale, which will eventually determine the number of design cycles.

LEVEL 1—*Duplicating an Existing System*

The design phase presents common engineering problems that have successfully been dealt with before. The tools and methods are well known and practiced and the exact performance key parameters are guaranteed. Usually, the design phase of the project demands 1-2 design cycles.

An example of this phase is the design of a new regular size container ship by Hyundai Heavy Industries. It is unusual to find a new naval ship design (not commercial off-the-shelf) that qualifies for "Level 1," and this example is taken from the Merchant Marine market to emphasize this point.

Figure 3: Swedish Navy Visby-class corvette

IMAGE CREDIT: KOCKUMS

LEVEL 2—*Upgrading an Existing System*

There is sometimes a need to change, upgrade, or add new features to a previously designed system. The performance key parameters can be predicted with a decent level of certainty. Usually, 2 to 3 design cycles are needed before the design phase ends. For instance: adding a helicopter landing pad and a light aluminium hangar to the existing Israel Navy SAAR 4 missile ship design without changing the propulsion, electrical, and auxiliary systems to receive the SAAR 4.5 Hohit-class, a new variant of the missile ship that can carry a small helicopter, (a project that was accomplished by Israel Shipyards, LTD for the Israel Navy).

LEVEL 3—*Development of a New System*

A brand new design with no previous versions, but other similar projects have demonstrated that the project is feasible. However, more investment is needed to enter a new design arena to deal with unfamiliar subjects. An example of this is the development of the Arleigh Burke-class destroyer by the U.S. Navy and Bath Iron Works.

According to Bonen, in this type project the design teams do not always choose the right solution in the beginning and might complete multiple design cycles before they reach the proper system architecture. Once the right solution is chosen, three design cycles are usually needed in order to complete the design phase.

LEVEL 4—*Technological Breakthrough*

Nothing like this has ever been done before. Total pioneering that requires learning new disciplines, developing new theories, designing tools, etc. For instance, the development of the Visby-class corvette (Figure 3) by the Swedish Navy and Kockums Naval Solutions. The Visby-class hull

Figure 4: U.S. Navy's Sea Jet IMAGE CREDIT: U.S. NAVY

Complexity and risk level according to the "Bonen Scale"	Stage of the project			
	Feasibility study	Contract design	Detailed design	Construction
Level 1	5%	4%	2%	1%
Level 2	10%	8%	5%	2%
Level 3	15%	12%	8%	4%
Level 4	25%	15%	10%	5%

Table 1. Managing the weight design margins according to the ship's features.

and superstructure design is considered to be a technological breakthrough mainly because the 72.7 m vessel is made of composite materials, and the ship design heavily emphasizes low signatures and stealth technology.

In this type of project, Bonen recommends conducting a pre-project R&D effort, and even building a small scale prototype before starting full scale development in order to test and demonstrate the feasibility of the solution.

One example of this risk reduction process is the 133-ft. Sea Jet (Figure 4) that was built as a technology test bed in order to test and demonstrate some of the breakthrough technologies that were later integrated into the U.S. Navy's 600-ft. Zumwalt-class destroyer (Palmer, 2005).

Management of Design Margins According to the Complexity and Risk Level of the Project

Originally, the "Bonen Scale" was used to define various system characteristics, such as the number of design cycles before the final design freeze can be reached, or the number of testing prototypes before serial production can begin.

This paper suggests using the same scale to quantify the recommended weight design margins according to the stage of the project and the level of complexity and risk.

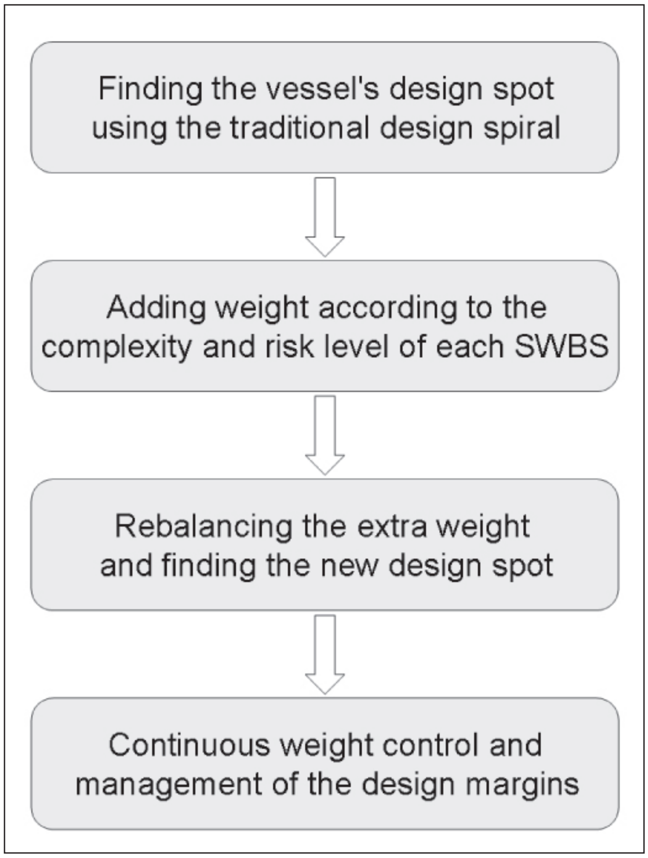

Figure 5: Management of weight margins in a naval vessel.

The design margin values listed in Table 1 are the author's recommendations and may vary depending on the effectiveness of the other activities in the vessel's weight control plan.

The ship's service life weight margins have to comply with the naval authority requirements that are set in advance, regardless of the risk level or the current phase of the project. Therefore, the service life weight margins should be added on top of the values listed above.

The values listed in Table 1 should not be added to the vessel's initial weight estimate as a whole, but rather to the different SWBS groups according to each group risk and complexity level.

For instance, a vessel design that incorporates breakthrough hull design with existing propulsion system will add, during the feasibility study phase, 25% extra weight in SWBS group 1, but only 5% in SWBS group 2. The final weight design margin of the whole vessel will rarely reach the highest values associated with "level 4" risk, because even if both the hull and the propulsion system are innovative, other components like auxiliary systems, outfit and furnishing are usually associated with lower levels of risk.

The U.S. Navy utilized a more refined methodology, although conceptually similar to the one presented above. U.S. Navy margin policy has a total acquisition weight margin range from 6% to 17.5% of lightship and a total acquisition KG margin range from 4.8% to 14.5% of lightship with associated confidence intervals of 50% and 82%, respectively (International Society of Allied Weight Engineers, 2001). These figures quite match the values listed in Table 1, as most of the U.S. Navy new vessels projects can be considered as a "Level 3" since only in rare cases is the ship design a total pioneering effort that requires learning new disciplines and developing new theories.

Using the predetermined values listed in Table 1, followed by the process presented in Figure 5, is an easy way to implement design margins into naval ship design, and it is crucial that the extra weight will be followed by extra KG to present degradation in the stability of the vessel. The values of the KG margins in each SWBS group can be obtained by the same method to reflect the uncertainty of the design.

Both the weight of the vessel and ship's center of gravity above keel (KG) must be monitored carefully from the very beginning, and it is both the designer's and the customer's responsibility to make sure the weight margin is not expended too quickly.

In case of deviation, there is an urgent need to make a correction in the design and not to skip to the next design phase with insufficient margins, risking or limiting the vessel both in the short term (right after launching) and in the long term (during its service).

The suggested method should not replace the project's official weight control plan, the periodical detailed weight reports, and all other weight control activities. In addition, having sufficient margins in the current design phase does not mean that weight control issues should be disregarded.

Unlike a merchant vessel that carries the same number of containers or the same amount of oil on its first and last journey, the margins left for future growth are extremely crucial for naval ships.

Naval vessels are expected to be in active service for 25 to 35 years and in rare cases even longer, while the weapons systems are often changed and replaced. Naval ships need to undergo significant overhauls and upgrades during their service life, and the future growth margins enable the ship to successfully cope with these demands as well as carry various as yet unknown payloads in the years to come, all while continuing to maintain the initial requirements and design standards.

Figure 6: USS Freedom IMAGE CREDIT: U.S. NAVY

Insufficient service life allowance may result in a ship being removed from service well before the end of the projected service life due to inability to accept modifications needed to preserve its mission effectiveness.

Critical Design Limits and Performance Traps

Each ton of overweight causes a small degradation in the vessel's performance. However, it is definitely not a linear function; in some cases, a small amount of overweight can be a game changer, reducing the overall performance of the vessel by an order of magnitude. One example is the weight of submarines, as previously mentioned, that can tolerate overweight only up to the point in which it can no longer float.

In the case of high speed planing craft, one extra ton can make the difference between successful hydrodynamic lift, resulting in a top speed of 35+ knots, to hydrostatic lift that ends up with barely half of the declared top speed. In other cases, a few extra tons can make the difference between meeting the design standards and failing to comply with regulations.

Other critical design limits might be draft or weight limitations with the purpose of compatibility with specific facilities or infrastructure (cranes, docking yards, etc.).

Special attention should be given to carefully identifying those critical design limits in advance and making an extra effort to steer clear of performance traps.

Case Study: The U.S. Navy Littoral Combat Ship (LCS) Program

The U.S. Navy Littoral Combat Ship (LCS) program includes ships from two different variants: the Freedom vari-


Figure 7: USS Independence
IMAGE CREDIT: AUSTAL USA/GENERAL DYNAMICS

ant—a classic monohull designed and built by Lockheed Martin (Figure 6)—and the Independence variant—a unique trimaran designed and built by Austal USA and General Dynamics (Figure 7). Although the two variants differ widely from each other, they both suffer from the same problem of overweight, resulting in lower-than-designed speed in the Independence variant, shorter than designed range at 14 knots in the Freedom variant, and smaller than designed margins for future growth in both variants.

In July 2014, the United States Government Accountability Office (GAO) submitted a report titled Littoral Combat Ship—Additional Testing and Improved Weight Management Needed Prior to Further Investment that discussed the overweight of LCS. By the time the report was submitted, four out of the first six LCS had 19 to 67 tons overweight and didn't meet the life allowance requirement of 50 tons.

USS Freedom (LCS 1) can meet its sprint speed of 40 knots but it hasn't been able to reach the distance and speed requirement of 3,500 nautical mile range at 14 knots (Phelps, 2014).

USS Independence (LCS 2) can only sprint at 39.5 knots, under the required 40 knots, since the vessel is at a weight in which it "exceeds its naval architectural limit," according to the GAO report.

The GAO report states that LCS 2 weight "provides no service life allowance for weight and restricts the ship's ability to execute its required missions... Operating a ship in excess of its naval architectural limit can make it prone to failure in certain weather or damage conditions, and the ship can also see a decreased service life due to structural fatigue."

U.S. Navy officials have also stated "they will limit fuel loads on LCS 2, as necessary, to ensure the naval architectural limit is not exceeded." (GAO, 2014).

The weight problems in the LCS project are far smaller than the other examples listed above, but they are presented here as a case study in order to examine the weight problems of the two LCS variants with respect to the risk and complexity level of each variant.

The Freedom variant could be considered as "Level 3" in SWBS Level 1 group mainly because it's based on a monohull, the most common hull shape for both merchant and naval ships. As presented in Table 2, the overweight of USS Freedom was considerably smaller than that of the other variant, and the recovery after the first prototype was quick and quite remarkable.

The Independence variant could be considered as "Level 3.5" in the same SWBS group level and on the same scale, mainly because it's based on a trimaran, a unique multihull and quite uncommon form for naval application that incorporates many risks and a higher level of complexity, primarily in ship structural strength and general arrangement issues.

We would therefore expect, based on this rough technological risk analysis, that the higher Bonen scale variant would experience larger weight excess in its various design and manufacturing stages. And indeed, according to the data presented in Table 2, the Independence variant not only gained more weight, but also had a slower recovery rate, and even after the first three ships there is still more to be done in order to meet the U.S. Navy service life allowance requirements.

Discussion

Weight control programs are not new concepts. The U.S. Navy weight control program was formulated in 1961 and established formal weight margins in 1963.

It took 15 years to accumulate a database large enough to be considered reasonable for a statistical study of weight margins, and in 1978 this database was used to update the Weight Margin Policy for Surface Ships and expand it to include a KG margin policy (Cimino & Filiopoulos, 1997).

Processes and procedures, acquisition margins, and service life allowances, as practiced today, have been in place and successfully executed since the late 1970s.

It has been within the last decade or so that almost every design has been plagued with serious weight control problems, and the lack of weight control appears to be endemic to most navies. This paper offers several broad potential explanations for this phenomenon.

Flexible Gate Reviews

Acquisition reform in the U.S. Navy placed the feasibility study, and in some cases even the preliminary design, exclusively in the hands of industry vs. government.

This approach has proved to be detrimental to weight control because the ship design spiral was well understood and practiced within the U.S. Navy; designs were conducted until every functional area was satisfied before exiting to the next design phase.

This practice has been substituted with other less effective methods and pseudo-design gate reviews geared only to meeting schedule.

The U.S. Navy 1978 Acquisition Margin Policy defined an upper value for the Detail Design and Build (D&B) phase as 5.3% of lightship at contact award. The 1992 update of the policy increased this value to 9.8%.

Nowadays, many ship designs proceed to the D&B phase with insufficient weight margins, without design closure and before proper design maturity is accomplished. Insufficient weight margins in the design phase almost automatically lead to overweight and the results are inevitable.

The Lost Art of Weight Estimation

The key weight estimate is the initial development of the baseline. During this time, ship systems are not fully detailed out and this is the time when credible weight estimators earn their keep.

It seems that this art of weight estimation and engineering has been lost or substituted by CAD systems. CAD systems do not account for weight estimating relationships, distinction of normal growth patterns versus abnormal growth, and inputs from historical databases. CAD systems can provide only accurate estimates as final weight reports.

A fully modeled compartment will provide the weight of every nut and bolt, however, by the time compartments reach their 75-90% modeling completion, the design trade space has closed out and only minimal changes can be induced (such as weight reduction).

Variant	Ship	Currently meets service life allowance requirements?[a]
Freedom Variant	LCS 1	No—24 tons less than requirement
	LCS 3	Yes—exceeds requirement by 106 tons
	LCS 5[b]	Yes—exceeds requirement by 17 tons
Independence Variant	LCS 2	No—67 tons less than requirement
	LCS 4	No—34 tons less than requirement
	LCS 6[b]	No—19 tons less than requirement

[a]LCS has a service life allowance requirement of 50 metric tons. Numbers are rounded.
[b]LCS 1-4 have been delivered, and therefore builder's remaining margin has become part of the service file allowance.

Table 2. Status of recent Littoral Combat Ship (LCS) service life allowances. (UNITED STATES GAO, 2014)

Contractual Issues

Successful weight control programs must include Not-to-Exceed displacement and KG values in the contract, and most importantly, liquidated damages for exceeding these values. The value of liquidated damages does not constitute arbitrary penalties, but rather an attempt by the customer to recover the partial costs of corrective measures or loss of performance.

This policy is not uniformly applied to naval ship designs, or when applied the liquidated damages amount is farcical and can be easily absorbed as a cost to do business.

Reduction Of Acquisition Margins To Meet The Cost Budget

The U.S. Navy 1984 Weight Task Force concluded "pressures to underestimate weights during early stage design in response to concern that the ship would be cancelled if it could not be acquired within the allocated budget" is as relevant today, which dictates reduced acquisition margins as the least resistant approach to meet the cost budget.

Management Awareness

Project managers acknowledge weight control but are less sensitive to adverse weight trends unless they exceed the applicable naval architecture rules and standards.

Tendency to Consume the Service Life Allowances before Launching the Vessel

Service life allowance is one of the few areas in a design that can be reduced or eliminated without compromising the ship's present mission. Unfortunately, both the industries and the navies trend to compromise future growth capacity for immediate project-based acquisition concerns (Peer, 2012).

Summary

This paper focuses mainly on the issue of weight, which may be the most harmful effect on the vessel's performance and safety. Good management of design margins requires implementing the same methodology to other key parameters such as speed, drag, range, electric power load, etc.

Poor management of design and construction weight margins reduces the margins remaining for future growth. This can leave the vessel limited for decades and in the worst case, as presented in this paper, poor practice can lead a project to a total catastrophe resulting in unacceptable performance and not meeting the mandatory design standards even before the vessel enters active service. The vessel can be fixed only at a few points in time, mainly during the early design phase, when the change is cheap yet effective, and can be implemented easily while still maintaining proper systems engineering. During the construction phase and after launching there is often almost nothing to be done, forcing designers and customers to accept poor performance and limitations, though they were set in motion during the design phase.

This paper proposes a methodical design weight margin system based on project complexity and in turn has the potential to ensure future ship designs have appropriate expected lifetime weight and KG margins at delivery. NEJ

REFERENCES

Bonen Z., On the Planning of Development Projects, Proceeding of the 3rd Annual Conference on Operation Research, Tel Aviv, Israel, July 1969.

Cimino D. & Filiopoulos C., Weight and KG Margin Analysis of Naval Surface Ships, 56th Annual Society of Allied Weight Engineers Conference, Bellevue, Washington, 19/5/1997.

Davis C., Spain's S-81 Isaac Peral Submarine Cost $680 Million to Build... And Can't Float," *The World Post*, 24/5/2013.

De Silva R., "Boon or Curse? Royal New Zealand Navy Struggles to Make 'Otago' Operational," *Defence IQ*, 9/6/2010.

Gordon J., "Biggest losers: New Zealand Rejects Our 'Fat' Frigates," *The Age National*, 3/5/2009.

Grevat J., "Safety and weight worries delay Project Protector Deliveries," *Jane's Navy International*, 24/12/2008.

International Society of Allied Weight Engineers, Weight Estimating and Margin Manual for Marine Vehicles, SAWE Recommended Practice Number 14, 22/5/2001.

Kington T., "Navantia Gets U.S. Help To Fix Overweight Sub," *Defense News*, 5/6/2013.

Manins R., "Captain Defends Otago's Capabilities in Ice," *Otago Daily Times*, 1/3/2013.

Palmer W., "Advanced Electric Ship Demonstrator—Sea Jet Serves as a Technology Testbed," *SeaFrame*, Vol 1, Issue 2, Fall 2005.

Peer D., "Future Growth Margin is The Real Issue," *Canadian Naval Review*, 26/3/2012.

Phelps N., "Report: Littoral Combat Ships Too Heavy," *Navy Times*, 4/8/2014.

Porteous D., "Problem Ships Not For Sale," *Otago Daily Times*, 20/12/2008.

United States Government Accountability Office (GAO), Littoral Combat Ship - Additional Testing and Improved Weight Management Needed Prior to Further Investments, GAO Report 14-749 to Congressional Committees, 30/7/2014.

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