Incorporating Risk into Naval Ship Weight and Stability Control

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ABSTRACT

Currently the application of risk analysis and management in weight and stability control in the US Navy is haphazard, inconsistent, and seldom practiced. During design and build phases the risk management is handled by monitoring and managing weight and KG margins which are is based on stability limit studies that have no analysis of uncertainties or of progressive consequences for exceeding limits. For in-service ships, the current or predicted future conditions of the ships are compared to the same KG limit curves and the ships or ship classes are put into one of four stability statuses. This does not show how bad the ships are or what the consequences of going over the limits are, nor does it provide calculated values on which to base cost-benefit or other trade-off studies. Proper risk analysis and management can be brought into the process by quantifying uncertainties, identifying and calculating consequences, and by developing status metrics that are based on risk-based calculations. This will lead to the proper use of risk analysis and management tools and methods to better inform program managers and provide them with tools to help them make informed decisions.

KEYWORDS
Margin; metric; limits; risk; maturity; uncertainty

INTRODUCTION

Risk can be defined as a measure of the probability and severity of adverse effects (Haimes, 1998) or, more applicable to ship weight control and stability, uncertainties and consequences. Risk in these terms is not a highly visible concept in the day to day business of US Naval weight control and stability. In some cases this is because the uncertainties are not quantified, in some because the consequences are not defined, but in most because the metrics simply don't show the underlying risk calculations.

While it is unlikely that the US Navy will adopt probabilistic or risk-based criteria for weight control and stability any time soon, bringing risk analysis and management into the processes is being aggressively encouraged. This paper addresses some of the areas that are currently lacking in risk-based approaches and some areas where changes in metrics and reportage can provide better information upon which to make risk-based decisions.

RISK IN DESIGN PHASES

In the design and construction phases of a ship design, the US Navy is rigorous in identifying and tracking uncertainties for half of the equation: weight control. Information on these uncertainties are expressed qualitatively in the maturity of the weight estimate and quantitatively in the tracking of acquisition margin usage.

Maturity as uncertainty

Traditionally, the maturity of a weight estimate is derived by the amount of weight that is estimated, calculated, or weighed.[1] This has been presented in metrics such as shown in Figure 1 which provides only a rough indication of uncertainty at that time.

There is a concerted effort in several organizations to improve on the maturity index by subdividing the three categories further based on specific criteria. In some cases this results in five

[1] Other measures are also used such as the percent of drawings completed

categories: three estimated, one calculated, and one actual or weighed. In others there are nine or more subdivisions.

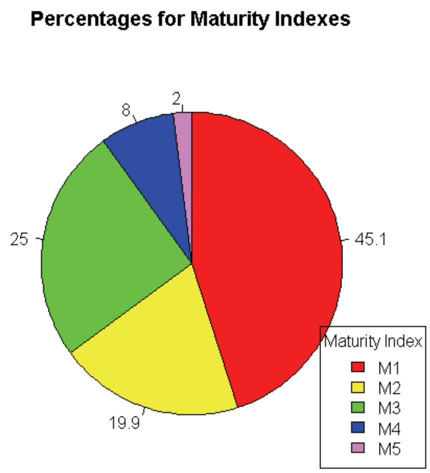

Fig. 1: Maturity plot. This is the traditional metric for maturity showing percentages for each of five maturity categories for one weight estimate.

There are mixed opinions as to the usefulness of increasing granularity of a measurement that can be subjective or, at best, based on a less than rigorous process. In other words, adding granularity is just a more precise way of showing a somewhat inaccurate measurement.

While the maturity of a weight estimate is not an accurate measurement, it is a valuable indicator of the total uncertainty of the weight estimate. One better use of this indicator is to improve the metric that displays it. The traditional pie chart provides only a snapshot of the condition and doesn't show the more important data: the change in maturity.

Figure 2 shows a metric that shows the maturity trend in both percentage of weight and average maturity based on a five category index. This shows the trend of uncertainty in the reports and provides average values that can be used in comparison or risk studies.

As the figure shows, increased average maturity, or increased percentages of higher maturity, relates to lower overall risk. In this case, risk is based on the overall uncertainty of the weight estimate and not to direct consequences to the ship except for the risk of failing to meet required margins. In short, the greater percentage of the weight estimate that is estimated or weighed, the better the weight estimate will match the real ship and the lower the risk of not meeting weight and stability requirements.

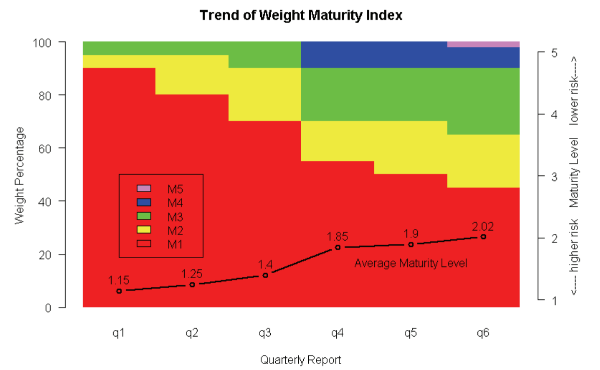

Fig. 2: Maturity trend plot. This clearly shows the change in maturity over a period of multiple quarterly weight reports. Maturity is shown as a percentage of weight and as an average maturity based on a five category maturity index.

Margins

Acquisition margins are risk mitigation measures. The weight control process in the design and build stages is based, in part, on the monitoring of weight and KG margins. [1] These margins are established at the start of each stage of design and are contractual obligations at the start of the design and build stage. The accepted weight estimate (AWE) sets these margins and the usage trends are carefully watched until delivery.

These margin amounts are based on historical data with modifications based on the complexity or innovative nature of the design. This provides some risk mitigation since the initial amount of margin is based on previous lessons learned.

The constant monitoring of margins is, in actuality, risk management. The goal is to deliver the ship with the proper amount of service life allowance that will provide sufficient margin to carry through to the end of the ship's life. By constant margin monitoring during design and construction, the risk of not meeting the service life allowance is constantly being evaluated.

[1] Margin ballast for submarines.

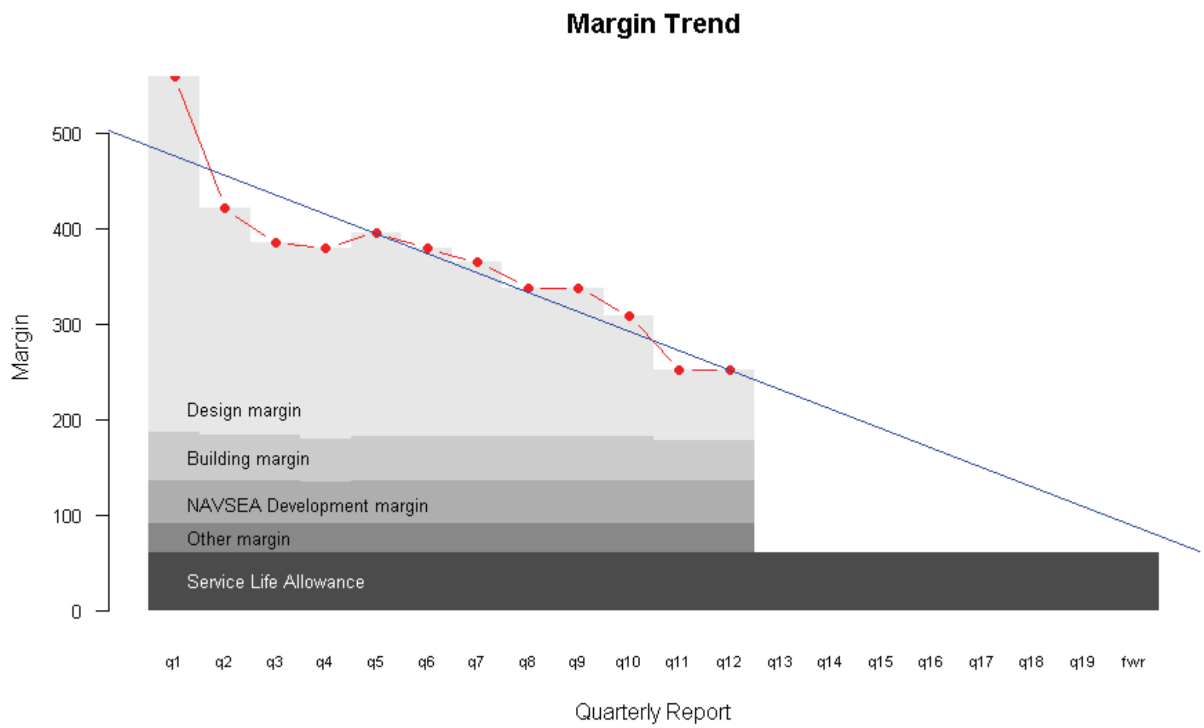

Fig. 3:. Margin trend plot. Typical stacked plot showing six margin "pots" and the trend of margin usage over twelve quarterly weight reports

The expenditure of margin during these phases is from decisions that are risk-based, even if that word is not used. The trade-off of, say, producibility changes to cost in margin is calculated in terms of margin usage and the risk of not meeting service life allowances..

The metrics of margin usage trends provide a method of monitoring the risk of not meeting delivery requirements by constant extrapolation of data to that endpoint. However, the methods and assumptions going into making those extrapolations, or even into the interpretation of the data, are not codified or based on objective mathematics. Without codified ways of looking at the margin usage trend data and extrapolations there will always be a subjective aspect to choosing margins and interpreting margin usage trend data. This may not be a bad thing, but it is a source of uncertainty and an area that can be ddifficult to defend. See figure 3 for a typical metric used to show margin usage by quarterly weight report.

The greater uncertainty lies in the other half of the equation: the stability limits upon which the margins are based. The stability studies and the hydrostatic calculations are significant factors that can, and have, completely disrupted the orderly weight control process. Changes to hydrostatics or limit curves established by stability studies can induce huge margin hits unexpectedly. These changes are absorbed by depleted margin and are never folded back into the process to produce hydrostatics and limit curves that show uncertainties.

While limit curves may have some padding - normally for inclining experiment margin the process is not iterative and does not attempt to quantify uncertainties within the calculations.

The uncertainties in the stability studies are not quantified and the consequences of exceeding the limits are not well defined and thus risk cannot be analyzed or managed. So for these design and construction phases we are monitoring weight uncertainty (margin) without the full understanding of the uncertainties and consequences (or risk) contained in the limits.

With a set goal for margin at delivery, service life allowance, adverse consequences due to exceeding limits may never present themselves, or if they do, it is at the end of the ship's life. However, two circumstances warrant the better definition of consequences in the stability studies: ships that deliver without the full service life allowance, and corrections to limits that can remove SLA from ships in service. In both these situations, the consequences and risks have to be determined when the situation is encountered.

Determining both the uncertainties within the stability studies and the consequences of exceeding the resultant limits early and continuously throughout the design and construction of the ship will provide the information for understanding the risks of expending margin. Feeding this information back into the margin calculation, will help to optimize margin amount selection thereby saving money and effort.

IN-SERVICE PHASE

The stability status used for in-service Naval ships is based on four conditions (Cimino and Tellet 2007):

Status 1: An increase in weight and a rise of the ship's center of gravity are acceptable. Added weight and moment resulting from changes will not require any compensation unless the magnitude of the additions is so large as to make the ship approach stability limits.

Status 2: Neither an increase in weight nor a rise of a ship's center of gravity can be accepted.

Status 3: An increase in the ship's weight is acceptable, but a rise of the ship's center of gravity must be avoided.

Status 4: A rise of the ship's center of gravity is acceptable, but increase in weight must be avoided. Compensation for added weight may be obtained by removal of and equal or greater weight at any level.

This status system provides no information on how okay or how bad the ships are. Ship classes (or sometimes sub-classes) are moved from one status to another based on subjective decisions. There is no risk-based analysis or criteria for status change and no metric that shows current risk or risk trends or even any measures of uncertainties.

There is also no clear procedure or actions to be taken when a ship or ship class exceeds current limits. Risk is not calculated but rather the ship is just shown outside the limits.

As a legacy from design, uncertainties are not identified or quantified save for the usual inclining delta built into the KG limit curves. This delta is a value (typically 0.25 ft (0.076 m)) (Wood, 1977) that is applied to the limit curve of all ships in the class and is based on the estimated error band of an average inclining experiment instead of on the calculated error band of that particular inclining experiment. That is why it is applied to the KG limit curve rather than applying the error to the results of the inclining experiment. While great efforts are taken to ensure the inclining experiments are performed well, there is no effort to understand the major possible sources of error or to quantify and report these errors bands.

Without the understanding and quantification of uncertainties in both the stability studies and the stability verification rfforts (inclining experiments), risk analysis and management turns into a PowerPoint exercise with guesses as to the uncertainties involved and the overall risk. And since the consequences are not well understood, even these guesses cannot be properly assessed or managed.

INCLUDING RISK

The question is: How to include risk into the overall weight and stability control process?

As mentioned before, the US Navy is not ready to accept probabilistic stability criteria, but that does not mean that risk-based control and monitoring can¬not be established using the current quasi-static stability criteria.

For the design and build phases, the first step is to quantify the uncertainties mentioned above and combine weight control and stability studies into one iterative process:

- Determine error ranges for hydrostatics calculations.
- Develop families of stability limit curves based on calculated consequences of exceeding those limits.
- Develop margin policy based on those families of stability limit curves.

- Make stability studies iterative during the design and construction phases with feedback to margin selection.
- Manage margin based on error ranges and calculated consequences of exceeding available margin.

With the error ranges and consequences established throughout design and build, in-service risk management can be accomplished by determining error ranges for each inclining experiment and subsequent availability weight and moment changes, and then by weight and moment monitoring and reporting using metrics that incorporate the risk equation. The metric serves the traditional purpose of showing the location of the ship in relation to the limits, but also overlays information on the uncertainty of the point and the consequences of exceeding the limits. In essence, the KG limit plot becomes a risk metric.

This is illustrated in Fgure 4. The traditional curve shows a point for each ship and one limit curve with truncating displacement limit lines.

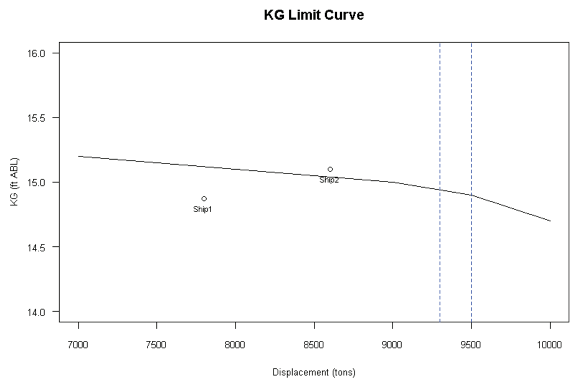

Fig. 4 Typical KG limit curve showing the postion of two ships.

Figure 5 shows an improved metric with the error range of the ship reflected by the height and width of the ellipse (in this case 1%) and multiple limit curves color coded to known consequences (e.g., increase heel angles, margin line immersion, etc.).

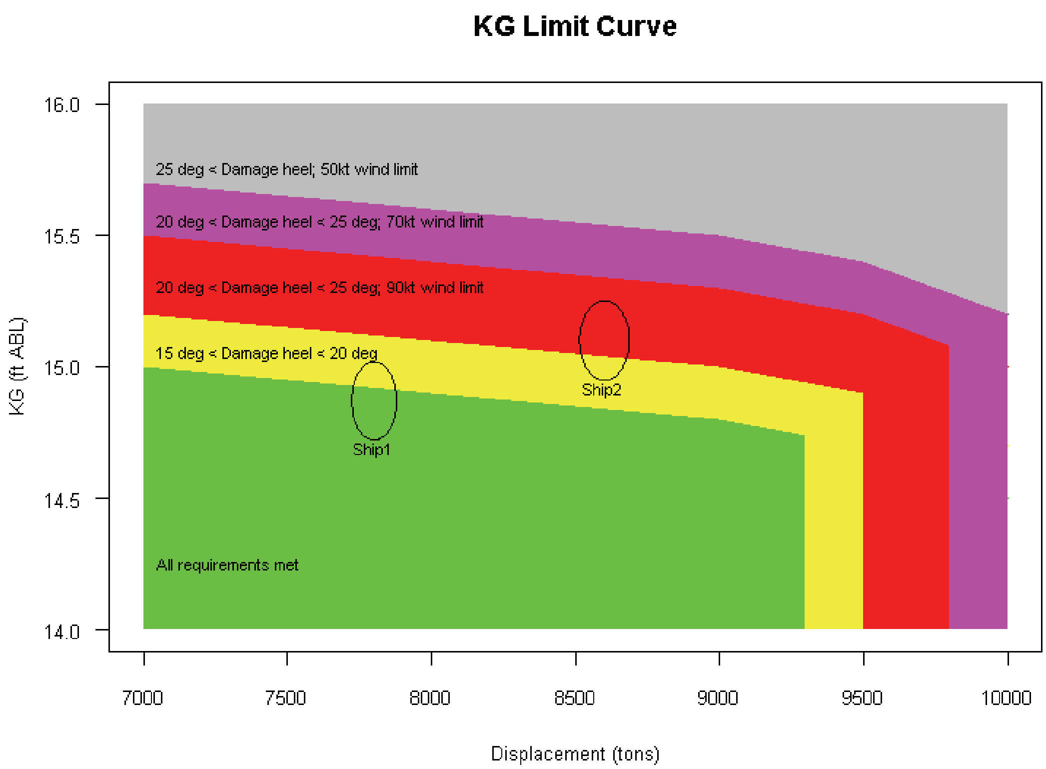

Fig. 5: Improved KG limit metric showing uncertainties and consequences

The interpretation and use of these kinds of metrics can now be based on overall ship class risk profile and a set risk tolerance policy. For instance, a conservative program manager may want restrictions on the ships if,. say, more than one half of the ellipse area is in the yellow area, the rest being green. The information behind such a metric allows for more structured triggers for action instead of the current system where a ship or class may flip from Status 1 to Status 2 with little forewarning.

Besides the simple use of better metrics, having quantified error bands and consequences allows us to apply standard risk analysis and management tools to decisions that have impacts to margins or ship stability.

For instance, the impact of installing a ship alteration package is now seen as a shift of the ship on the KG limit curve. If the point moves above the curve the ship can be moved into Status 2, or ballast may be added to reduce the KG, or the alteration package may be reduced or canceled (unlikely). The decision here is necessarily somewhat arbitrary since the consequences are undefined and thus often the more expedient or less costly path is taken at the expense of ship stability.

With known risk values, each of these options can be analyzed with a standard risk tool such as a decision tree and an informed decision can be made.

CONCLUSIONS

To analyze, manage, or simply understand risk one must understand both the uncertainties and consequences within the process. For US Naval weight control and stability, parts of the risk equation are known and managed well, even if it is done so without using recognized risk terminology. Other parts are not done well and should be examined to see where the rigor and useful tools of risk analysis and management could be used to advantage.

One improvement is the quantification of error bands in hydrostatic calculations, another is the clear understanding of adverse consequences from exceeding limits. Once these things are understood, new metrics can be designed to directly show the risks.

Finally, understanding the full risk equation will allow the use of a wide variety of tools to aid in decision making. This has the potential to reduce acquisition margin requirements, reduce cost of future margin recovery measures, and quantify the costs and benefits of design changes.

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