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Weight Estimating and Margin Manual
For Marine Vehicles

Issue No. __-__

Prepared by
Marine Systems Government - Industry Workshop
Society of Allied Weight Engineers

in cooperation with the
Society of Naval Architect and Marine Engineers (SNAME), Ship Design – 1 Panel

Notwithstanding the above, if this recommended practice is incorporated into a contract, it shall be binding to the extent specified in the contract.

Change Record

Issue No.	Date	Title/Brief Description	Entered By

Forward

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1.0 INTRODUCTION

The purpose of this Bulletin is to document naval architectural practices and conventions used in the estimation and determination of the weight, centers of gravity and weight moments of inertia for surface ships, and to reference sources of weight estimating data for ships and their components for use at various stages of design. Conventions and practices for offshore drill rigs, high speed craft and submarines are mentioned in some instances to demonstrate alternative methodologies, but are documented only by references. Military practices and conventions are summarized and referenced but not fully documented.

Throughout this document the term weight is used to represent all the mass properties of a ship or object. These properties include the weight, center of gravity, weight moments and weight moment of inertia. Also, throughout this document the term weight as commonly understood in the maritime industry, is synonymous with mass. With that in mind, weight in U.S. customary units are measured in pounds and long tons (2,240 lbs.); and in SI units (metric), weight is measured in kilograms and metric tonnes (1000 kg). Refer to ASTM F 133293, *Standard Practice for Use of SI (Metric) Units in Maritime Applications [1]*[1] for conversion factors to convert inch pound quantities to SI (metric) quantities for units, moment, moments to trim, and so forth.

1.1 Weight Control Program

The U. S. Navy's weight control process was essentially formalized, as a program, in the middle 1960's. A SNAME paper, *Weight Control of U. S. Naval Ships,* presented at the Annual Meeting, in New York City, in November 1965, documented as well as highlighted key elements of the program. Additionally, this paper is viewed by most weight engineers as the formal introduction of the weight control program. Also, after the test of time (over 35 years), this manual [2] is still applicable and is particularly noteworthy when considering the many significant technological engineering advancements that have occurred over the last three decades. The following points paraphrase the essence of a weight control program, as it relates to U. S. Naval ships. It is a program that includes all actions necessary to ensure that a ship's weight and moments are consistent with approved naval architectural requirements for strength, stability and performance. It includes estimating, reporting, weighting, calculating, analyzing, and projecting. It involves making design decisions, analyses, and judgements, and recommending specific corrective action when necessary. It is a prime function of the administration and management of any ship design and construction project. Timeliness is considered one of the primary ingredients of a successful weight control program. Weight control must begin with the earliest phases/milestones of a ship design and keep pace with the ship's development through transitional design, detail design, construction, delivery and into the ship's service life. Weight reporting is a necessary part of weight control and provides the best representation of the displacement, KG, list and trim of the ship at periodic times during the various design and construction phases. Weight reporting, by itself, is not weight control. Too, often, the submission of weight reports (the act of weight reporting) has been mistaken for weight control. An essential component of an effective weight control program is the weight control plan which is developed by the shipbuilder to control the weight during the design and construction phases.

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1 Numbers in square brackets designate References, Section 9.0

The weight control plan is an essential part of the overall weight control program. It is usually required in the contract for the shipbuilder to develop and implement a weight control plan. It is general in nature, and outlines the type of weight control measures and procedures that are considered in order to meet the established weight control responsibilities. It may be structured to reflect general approaches to weight control, or outline more aggressive approaches in conjunction with incentives clauses. Examples of a weight control plan can found in References [3, 4, and 5]. However, the specific elements of the plan are developed around the contractual requirements and the commitment to the overall mass properties goals and objectives.

2.0 DEFINITION OF TERMS

Accepted Weight Estimate (AWE): The AWE defines the weight and center of gravity of a ship that was awarded under a specification type contract using the information that was available at the time of contract award. It establishes contractual values for weight and KG and is the baseline for detail design and construction.

Acquisition Margins: Acquisition margins are weight and KG allowances included in weight estimates to account for the inherent limits of precision and the undefined variations of component weight and center of gravity that take place during design development and the construction of ships.

Aft Perpendicular (AP): A vertical line intended to denote the after end of a ship's immersed body. The AP is often placed at the centerline of the rudder stock, the after extremity of the design waterline or the after extremity of the sternpost.

Agreed Weight and Center of Gravity Estimate: An estimate of light ship weight and centers of gravity data, mutually agreed upon between the owner and the shipbuilder shortly after award of the shipbuilding contract, based on the ship design information (i.e., specifications, drawings, and so forth) available at the time of award.

Allocated Baseline Weight Estimate (ABWE): The ABWE is the contractor's definition of the weight and center of gravity of a ship that was awarded under a performance type contract at the time of hull and propulsion configuration approval. It is the baseline for detail design and construction.

As Built Weight and Center of Gravity Estimate: A detailed final estimate of light ship weight and centers of gravity data, adjusted for inclining experiment results, reflecting the as built ship including the net effect of contract modifications.

Center of Gravity (CG): The center through which all weights which make up the ship and its contents may be assumed to act. This center as it applies to a ship has the conventional meaning used in mechanics, i.e., it is the point at which the sum of the moments of all the weights in the ship with reference to any axis through this point is equal to zero. Its three coordinates (VCG, LCG and TCG) are calculated by dividing the sum of each of three moments by the sum of weights.

Concept (Basic, Feasibility) Design: The translation of the owner's requirements, or mission requirements, into a broad definition of an item of hardware that can be produced and operated in a manner that will satisfy the stated mission.

Contract Design: Consist of the preparation and formalization of the drawings, specifications, and other technical data required to establish the contractual base for negotiation of a construction contract with a shipbuilder(s).

Contract Modification Margin: A weight and KG allowance included in the weight estimate to account for increases associated with contract modifications issued during the Detail Design and Building [Engineering and Manufacturing Development] Phase.

Detail Design: This work is usually accomplished by the shipbuilder or his agent and primarily involves the preparation of detail working drawings for ship construction, procurement specifications for the purchase of materials and planning for the ship construction, testing and trials.

Detail Design and Building (or Engineering and Manufacturing Development [6]) Margin: A weight and KG allowance included in the weight estimate to account for contractor responsible design changes to the current weight due to ship construction drawing development, growth of contractor furnished material, omissions and errors in the accepted weight estimate, as well as differing shipbuilding practices, omissions and errors in the ship construction drawings, unknown mill tolerances, outfitting details, variations between the actual ship and its curves of form, and similar differences.

Forward Perpendicular (FP): A vertical line drawn through the point of intersection of the design waterline and the forward extremity of the ship.

Government-Furnished Material Margin: A weight and KG allowance included in the weight estimate to account for increases caused by the growth in Government furnished material during the Detail Design and Building [Engineering and Manufacturing Development] Phase.

Gyradius: The radius of gyration for roll, pitch, or yaw is the square root of the quotient of the ship's weight moment of inertia about the roll, pitch, and yaw axes, respectively, divided by the ship's displacement.

KG: The height of the ship's vertical center of gravity as measured from the bottom of the keel (includes keel thickness).

Longitudinal lever (LCG): The longitudinal lever is the perpendicular distance from a transverse plane through the longitudinal reference of the ship to the center of gravity of an item or group of items.

MarAd: The United States Maritime Administration whose overall mission is to promote the development and maintenance of an adequate, well-balanced, United States merchant marine, sufficient to carry the Nation's domestic waterborne commerce and a substantial portion of its waterborne foreign commerce, and capable of serving as a naval and military auxiliary in time of war or national emergency.

Mass properties: Mass properties are those physical characteristics which define the magnitude, location, and distribution of weight in the ship. They include weight, center of gravity location, weight moments, and moments of inertia. The term "mass" is more definitive than the somewhat ambiguous term "weight"; however, historical use and common practice will lead to the retention of the word "weight" for many years as applied to the control of mass properties aboard ships.

Mid Perpendicular (MP): The halfway reference point between the FP and the AP.

Molded Baseline: The top surface of the keel plate at its lowest point.

Moment: The product of an item's weight multiplied by the item's lever arm.

NAVSEA: The Naval Sea Systems Command whose overall mission is to transform military requirements into naval capabilities through research, development, engineering, design, acquisition, modernization, maintenance and logistics support of effective ships, systems and weapons which enables sailors and marines to conduct timely and sustained worldwide maritime operations.

Pitch inertia: The moment of inertia about the transverse axis (*y*) through the ship's center of gravity.

Preliminary Design: Development of the final ship proportions, arrangements, power plant type, and structural layout that will satisfy the mission requirements. Several arrangements are often developed for comparison.

Preliminary/Contract Design (or Program Definition and Risk Reduction [6]) Margins: A weight and KG allowance included in the weight estimate to account for increases associated with design development during the Preliminary/Contract [Program Definition and Risk Reduction] Phase.

Referenced origin: The location of the intersection of the *x*, *y* and *z* axes referenced to the ship, see Figure 1.

Roll inertia: The moment of inertia about the longitudinal axis (*x*) through the ship's center of gravity.

Service Life Allowances (SLAs): Weight and KG allowances included in design to accommodate changes due to both authorized (e.g. ship alterations), and unplanned growth (e.g. accumulation of paint and deck covering, personal belongings, unauthorized changes, etc.) during the ship's operational lifetime which increase displacement and impact stability. The purpose of the SLA is to assure that the ship will not exceed its draft and stability limitations, despite growth throughout its service life.

Transverse lever (TCG): The transverse lever is the perpendicular distance from the vertical centerline plane of the ship to the center of gravity of an item or group of items.

Vertical lever (VCG): The vertical lever is the perpendicular distance from a horizontal plane through the molded baseline of the ship to the center of gravity of an item or group of items.

Weight estimate: A weight estimate is a prediction of the weight and location of the center of gravity of the ship at the time of delivery based on the definition of the design at the time the estimate is computed.

Yaw inertia: The moment of inertia about the vertical axis (*z)* through the ship's center of gravity.

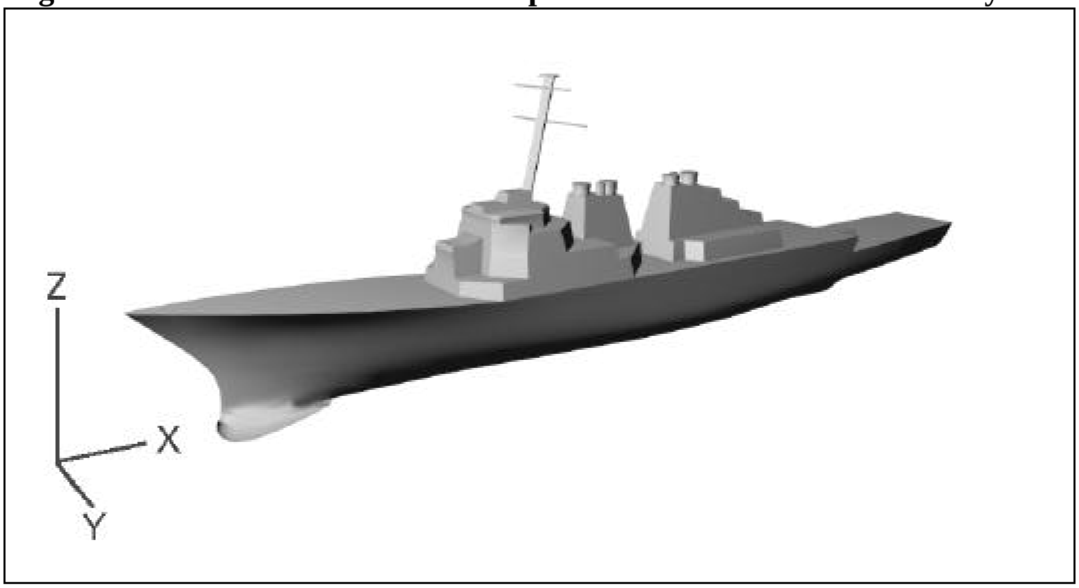
3.0. STANDARD REFERENCE SYSTEMS

3.1 U.S. Customary – Station 0 at FP

3.1.1 Standard Axes

The U.S. standard axes for surface ships are shown in Figure 1 [7]. The roll axis for surface ships is the *x-axis*. It is oriented along the centerline of the ship, running forward and aft. Longitudinal dimensions are measured along or parallel to this axis. The pitch axis is the *y-axis*. It runs transversely port and starboard. Besides being the axis for pitch, transverse dimensions are measured along or parallel to this axis. The yaw axis is the *z* axis. It runs vertically and dimensions are measured along or parallel to this axis.

Figure 1 Isometric view of surface ship with standard U.S. coordinate system



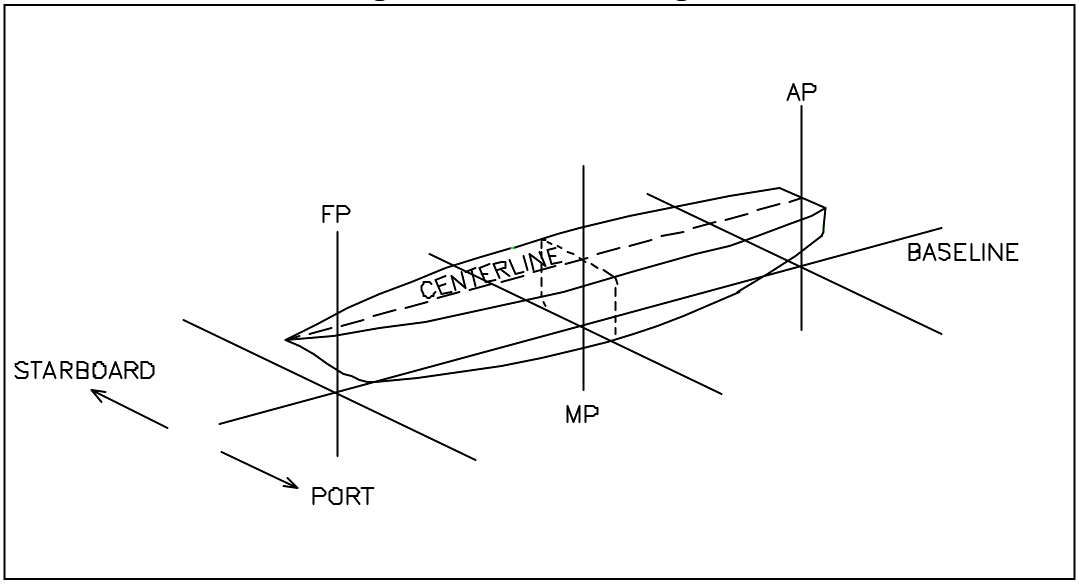
3.1.2 Center of Gravity

The distance measured vertically along the *z* axis from the referenced origin to the ship center of gravity is referred to as the Vertical center of gravity (VCG). The distance measured longitudinally along the *x-axis* from the referenced origin to the ship center of gravity is referred to as the Longitudinal center of gravity (LCG). The distance measured transversely along the *y-axis* from the referenced origin to the ship center of gravity is referred to as the Transverse center of gravity (TCG).

3.1.3 Referenced Origin

The location of the center of gravity of a surface ship is defined relative to the three axes shown in Figures 1. Distances are measured along the three axes from a referenced origin as shown in Figure 2. The recommended referenced origin for a surface ship is the intersection of the ship's forward perpendicular (FP), the ship's centerline plane and the ship's baseline. It is recognized, however, that the origin can also be referenced to the ship's mid perpendicular (MP) or the aft perpendicular (AP). The VCG should have a sign convention of positive for items above the referenced origin and negative for those below. For LCG the sign convention should be positive for all items aft of the referenced origin and negative for those forward. For TCG the sign convention should be positive for all items on the port side and negative for those on the starboard side. However, these LCG and TCG sign conventions are not an adopted standard in the marine industry at this time.

Figure 2 Referenced origins



3.1.4 Calculation

The weight estimate for a ship at any stage in the design is composed of a finite number of items. The weight of each of these items is included in the estimate along with the location of the item's center of gravity (CG). This is given as the vertical (z), longitudinal (x) and transverse (y) distance of the center of gravity from the defined referenced origin. This data is sufficient to calculate the total weight and center of gravity of the ship by simply adding the weights and moments of the item's center of gravity about the referenced origin.

3.2 European Customary – Station 0 at AP

3.2.1 Standard Axes

The standard axes for surface ships using European practice are basically the same as the U.S., except for the longitudinal reference origin and transverse sign convention.

3.2.2 Referenced Origin

The location of the center of gravity of a surface ship is defined relative to the three axes shown in Figure 2. The recommended referenced origin for a European surface ship is the intersection of the ship's aft perpendicular (AP), the ship's centerline plane and the ship's baseline. It is recognized, however, that the origin can also be referenced to the ship's mid perpendicular (MP) or the forward perpendicular (FP). Although the AP is normally used, the referenced origin can be changed as needed depending on the design or the shipyard. The VCG should have a sign convention of positive for items above the referenced origin and negative for those below. For LCG the sign convention should be positive for all items forward of the referenced origin and negative for those aft. For TCG the sign convention should be positive for all items on the starboard side and negative for those on the port side..

3.3 Weight Classification Systems

The weight classification system is a method by which all weight estimates are functionally organized. The weight classification system provides the naval architect or weight engineer with a format for organizing weight data that will be in a consistent format. The system allows for the grouping of materials, equipment and components of the ship in a structured order to facilitate weight estimating, comparison to previous designs, and to assure completeness. Additionally, the weight classification system provides guidance and definition at a system and subsystem level and aids in the preparation of a complete and accurate estimate.

A common term used in weight engineering is "weight group." Group is a fundamental unit of ship classification, identified by one numeric digit or an alphabetic designator. For weight estimates and reports, a group is the first character or digit of the multi digit system. The summation of weights and moments for all of the three digit elements that begin with the number 1 is the total for Group 1, and similarly for the other groups.

The basic weight group definition of a ship design is represented by the ship's structure, machinery and equipment, auxiliary systems, outfit and furnishing, mission equipment, acquisition margins and loads. The system and subsystem components of a ship design are generally classified in a one and three digit hierarchical numeric system. The weight estimate for the ship design will be summarized by an estimate of lightship, margins and loads.

Weight estimates will generally be categorized by one of several type of Work Breakdown Structures (WBS) or weight classification systems. The following classification systems are those most commonly used in today's weight engineering environment for the design of naval and commercial ship design programs.

3.3.1 ESWBS (U. S. Navy)

The Expanded Ship Work Breakdown Structure (ESWBS) [8] is a five digit functional classification system. For weight reporting purposes, only the first three digits of this system apply. The fourth and fifth single digit classification levels are used to incorporate the functions that support maintenance and repair needs.

There are nine one-digit groups in the ESWBS weight classification system that comprises the weight estimate . They are as follows:

ESWBS	Description
1	Hull Structure
2	Propulsion Plant
3	Electric Plant
4	Command and Surveillance
5	Auxiliary Systems
6	Outfit and Furnishings
7	Armament
M	Margins, Acquisition
F	Loads, Departure Full

The ESWBS groups (1-7, and M) represents the projected ship design in Condition A (Lightship w/ Margins). The ESWBS group F (loads) added to the projected lightship results in Condition D (departure full load). Other unique loading conditions may added and defined by other lettrs.

As previously mentioned, the weight classification is a hierarchical numeric system. The ESWBS 1-digit groups represent the system level and the subsystem level is defined by the ESWBS 3-digit elements.

Appendix A provides a complete listing of the ESWBS 1-digit groups and 3-digit elements.

3.3.2 MarAd (U. S. Commercial)

Weight estimates and reports prepared for U.S. commercial ship designs are classified in accordance with the MarAd weight classification system [9].

The MarAd weight classification system is comprised of the three major groupings below:

Hull Structure	Weight Codes 0-0 to 9-9
Outfit	Weight Codes 10-0 to 19-9
Machinery	Weight Codes 20-0 to 29-9

Appendix B provides a complete listing of the MarAd weight classification system.

3.3.3 Other Systems

Weight estimates and reports prepared for U.S. Navy small craft designs are classified in accordance with the weight classification system for U.S. Navy small craft [10]. This system is similar in content to that of the ESWBS system.

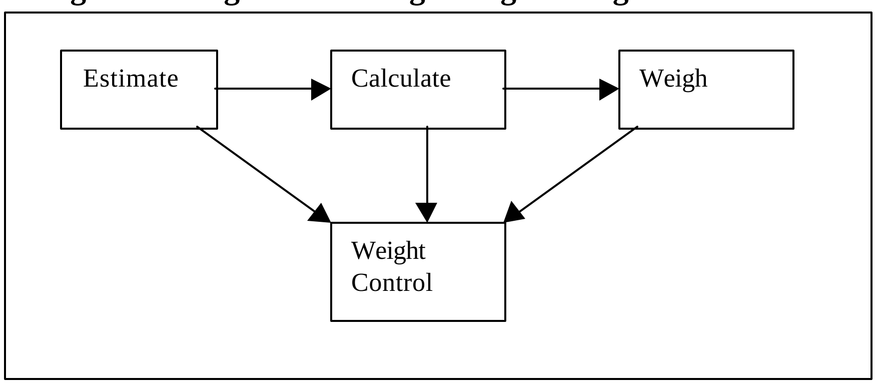
A similar classification system to the ESWBS is commonly developed for non-naval ships, where mission related lightship equipment and outfit is substituted for armament in Group.

4.0 WEIGHT AND CG ESTIMATING METHODS AND PROCEDURES

4.0.1 The Process

The weight estimate is the first step in a process to predict the final weight of the ship design in a weight control process. The purpose of the weight control process is to insure that the ship will be delivered within the naval architecture limits of the hull design. The final weight of the ship is predicted using estimating methods presented in this chapter. As the detailed design is developed, the final detailed weight estimate is refined to include new information. The weight is confirmed by weighing individual components, assemblies and eventually the whole ship. The final weight of the ship is monitored through a weight control process during all the different stages of design and construction.

Figure 3 – High Level Weight Engineering Process



Weight Estimating is usually associated with the initial prediction of the final ship weight; however it is used in all phases of the process. During detail design, the weight of paint on the ship may be estimated using factors because it may not be cost effective to do surface area calculations. Estimating methods may be used as a check of the reasonableness of detailed weight calculations. During the ship weighing or inclining experiment, a surveyor may estimate the weight of stores in a storeroom based on the available volume and a stowage factor. All of these examples employ the same principals of weight estimating.

4.0.2 Elements of Weight Estimating

All weight estimating methods are done in the context of an organization and there must be certain elements in place to insure that the weight estimating effort will be successful.

4.1 Basic Weight Estimating

4.1.1 Weight Control

The weight estimate must be done in the context of the ship design process as governed by a sound weight control program. A weight control program describes how the weight will be controlled to be within the naval architectural limits of the ship and the implied accuracy of estimate at each design stage. It is very easy to either spend too much effort or too little effort in preparing a weight estimate at any point in the ship design process. During early stage ship design, the design manager may be interested in a weight that is accurate within +/5 % of the final weight. During detail design and construction, the weight of an assembly or module may need to be more accurately estimated for the safety of the personnel lifting it with a crane. Conversely, methods that are appropriate for early stage design may not be appropriate for the detail design phase.

4.1.2 Calibrated Methods

A weight estimate should not be given to an internal or external customer without validating its accuracy by some independent means. Staton [11] describes this as reasonability checking and states that "Some method of checking results should be part of any analyses." While he provides several methods to quickly check weight, center of gravity, and mass inertia, he suggests that for major proposals an alternate method should be used to estimate each component or group. This can be done by using complimentary methods such as the top down method and the bottom up methods described below for the same design, or by a line item adjudication of the differences between the current ship weight estimate to a similar design. However, both methods should be calibrated against a known ship or component.

4.1.3 Database

A database of ship designs, components and materials is invaluable when creating a weight estimate. The database can be as simple as an organized set of files on various subjects, or a complete software storage, retrieval and analysis program. The information in the database may be used as parents for a new ship, or as similar components for a ship. The basic characteristics are listed below in the table below.

Table 1 – Weight Estimating Database

Type	Contents	Examples
Ships	Naval Architecture Characteristics Weight Reports System diagrams Specifications Photographs Test Reports	Magazine articles Sister ships Pervious designs studies Technical papers
Component	ASTM or Mil Standards Vendor Catalogs Vendor Drawings Equipment Specifications Test records Records of weighing	Machinery Outfitting
Materials	Specifications Catalogs Tables of Unit Weights or densities Records of weights	Steel plate Piping Insulation Paint SAWE's *Weight Engineers Handbook* [12]

4.1.4 System Knowledge

The weight estimator should have a working knowledge of the function, and arrangement of the subject of the estimate. In many design offices weight engineers are senior personnel who have spent time building, designing, or operating ships. The weight estimator must be familiar with the entire design and building process, and the operations of the ship. In fact some shipyards use training programs as described by Shamburger [13] and Staton [11], to establish a common basis of understanding of the weight engineering process. The weight estimator must be able to interpret specifications, drawings, and system specifications. This knowledge is invaluable when an expert opinion is required for checking a weight estimate for reasonableness. Of course diversity in the make-up of a weight estimating group is a great benefit.

4.1.5 Design History

The weight estimate must be documented so that someone can check the estimate for reasonableness and so that it can be used as a basis of estimates for future projects. The design history should include the reference for the baseline, and parent information, and how the data was manipulated into an estimate. Each design office will have its own format and method to document the basis of the estimate, such as engineering calculation or department procedures, or validation test reports of estimating software.

4.2 Factoring Methods

4.2.1 Basic Weight Estimating Equation

The weight estimating equation is simply a unit weight multiplied by the number of units plus an uncertainty. The trick to weight estimating is determining the unit weight and the number of units in the final ship design before the system engineers have completed the design. There are several basic methods to define the unit weight of which three are described below. The number of units is dependent on what is used for a unit weight. The uncertainty of the weight estimate is based on the estimating method, and the accuracy of the system definition at the time of the estimate.

4.2.2 Unit Weights

The unit weight methods use a constant weight for a single item or portion of an item. Typically one thinks of a unit weight of an outfitting item such as a chair and then just counts the number of chairs to determine their weight. An alternative might be to determine unit weights for all the furniture, joiner bulkheads, and auxiliary machinery required for each passenger onboard a passenger ship.

4.2.3 Fractions

The fraction methods use a ratio between a proposed and known system.

4.2.4 Algorithm

The algorithm methods use equations based on one or more variables to describe the weight of the ship, system, or component.

4.2.5 Baseline

The Baseline method is the most commonly used method for estimating the weight of a new ship design. Typically, a lead ship of a class or a sister ship built for another owner is used as a bench mark on which changes are added. For example, the parent weight estimate may have been made for a sister ship which was an offshore supply vessel while the new design maybe an anchor handling supply vessel that is exactly the same except it has bigger engines and is outfitted with anchor handling gear. This method is also known as the Plus and Minus method as described by Hogg [14].

The weight engineer will use the latest information available for the parent ship as a baseline. Ideally, the inclining experiment or a lightship survey of the parent ship should be used. These tests are not required for many marine craft, so the original weight estimate may need to be used. The parent ship design history will be compared to the specifications and arrangements of the new design to determine the impact of any weight changes. The time applied to the estimate for each change must be determined so that small changes do not use as much effort per pound of change as a large change or one that has a significant effect on ship stability. The new ship weight estimate is the parent ship weight plus all the changes.

4.2.6 Ratiocination (scaling)

This is the second most common method used to estimate the weight of ship. It assumes that the same principles of distortion used to define the ship's lines in the naval architecture used to create the new ship from a parent ship, can be applied to weight estimating. The method multiplies a parent ship system weight by a scaling factor to create the current ship system weight estimate. The scaling fraction is usually based on a parameter such as ship length, beam, engine rating, etc.

Several authors have documented various algorithms used by this method. Straubinger [15] of NAVSEA presented a detailed description of the method in a paper, which has been repeated in the SAWE *Weight Engineers Handbook* [12]. Both sources give scaling fractions for the Ship Work Breakdown Structure commonly used on naval surface ships. This method is easy to automate with common tools such as a spreadsheet, and it has been automated in more complex programs such as those described by Aasen [16], Ray [17], Redmond [18], and Robbins [19]. Foreign navies also use the method as described by Orton [20].

Although the method is a useful starting point in a ship design process, it does have its limitations. Specifically, new technologies or special features that are not common to both the parent and current ship designs are not accurately scaled. The ratiocination-based weight estimate should be corrected for these attributes.

4.2.7 Statistical

This method develops an algorithm to describe the weight of a system or weight group based on a regression analysis of multiple parent ship design designs. The regression analysis can be linear, logarithmic, polynomial, or exponential. While spreadsheets are commonly used today to complete the regression analysis, graphical methods can also be used as described by Scott

[21]and in Chapter 18 of SAWE *Weight Engineers Handbook* [12]. This method is very common and is described by Hogg [14], Johnson [22], Lamb [23], Penny [24], Watson, [25] Schneekluth [26] and others. The equations derived from this method can be used in automated weight estimating software, such as spreadsheets.

By using several parents as a baseline, this method allows the estimator to see trends that may not be apparent in the ratiocination method. For example a regression equation for hull steel weight might be developed based on the cubic number of set of parent ships. The uncertainty of the polynomial equation to exactly predict the hull steel weight for a specific cubic number can be calculated as described by Staton [11] and Aasen [16]. The Root-Mean-Square sum of these uncertainties is an estimate of the uncertainty of the entire weight estimate as described by Kern [27]. In practical terms, weight groups with the highest uncertainty need a closer look.

The method is extremely labor intensive because the weight estimates of the parent ship must all be normalized to same indexing system, and a regression equation is required for each mass property considered.

4.2.8 Volumetric Density

This method multiplies a density fraction by the volume of a space to predict the weight of the contents. The center of gravity of the estimated weight is normally assumed to be at the volumetric center of the space. The mass gyradius of the contents is usually estimated at 33% of the span of the space along each principal axis. A more common example is the prediction of the ballast water capacity of a tank. Typically, the molded volume of the tank is calculated first, and then it is multiplied by a series of density fractions to cover structural deductions and the density of seawater. This same method can be applied to a storeroom, a berthing space, or an engine room. The density fractions can be either derived from previous ship designs, or from a simple calculation, or from government and industry guidelines.

4.2.9 Deck Area Fraction

This method multiplies a weight fraction by the deck area of a space to predict the weight of the contents. The vertical center of gravity is assumed to be either at the center of the space above the deck, 3 feet above the molded deck height for contents that are accessed by personnel who are standing or at the molded deck height for deck coverings. The longitudinal and transverse centers of gravity are assumed to be located at the center of the deck area in the plan form. The mass gyradius is usually 33% of the span of the space along each principal axis. Along the vertical axis the span may be either the full height of the space, 6 feet or zero feet, depending on the method used to estimate the vertical center of gravity.

4.2.10 Regulatory Bodies Rules and Industry Design Standards

This method uses the hull structure and equipment specification standards found in government and industry standards to estimate the size from which a weight and center of gravity can be developed. Classification society guidelines contain equations for determining the minimum scantling sizes for structure and components. These equations and assumptions of standard practices are used as a basis of parametric equations.

For example the plate thickness is sized as a function of the hydrostatic head and the unsupported span of the plate. The global and local structural dimensions that are usually available at any stage of the design process define the hydrostatic head of a tank or shell plating. Shipyard standard practices define preferred stiffener spacing which defines the unsupported span of the shell plating. The minimum thickness of the shell plating can therefore be determined, and the weight estimated based on the surface area using the deck area fraction method described above.

Additionally, the classification rules and industry standards often define the minimum size and number of components required on board. For example, the classification society rules define the minimum size and length of anchor chain onboard. These values can be used to estimate the weight of these components based on standard purchasing practices at the shipyard.

Care should be taken to insure that the algorithms developed by this method are applicable to the ship under consideration. Application of classification society standards may prove to be erroneous. However, the classification society rules for a commercial ship may be interchangeable, since these standards are based on similar risk and load assumptions. Johnsen presents a fine an example of this method applied to tanker design weight estimates. Ferreiro describes a detailed comparison of design standards on the concept design weight of estimate in detail.

4.2.11 Top Down

This method begins with the total ship weight or design displacement developed from lines plan or from a limiting displacement study. The total weight and centers of gravity are allocated to various weight groups according to estimating fractions. The fractions are developed from statistical studies of similar ships. The weight is allocated down the hierarchical tree of the work breakdown system by starting with hull, machinery and outfitting first (as in the MARAD system [9]). Next the weight is allocated down to next tier in each weight group. In the case of hull structure it would be allocated down to the shell, decks, bulkheads, foundation, deck house etc. Finally, when the weight is allocated to the lowest practical the individual weights are checked by using other methods for specific components. Once the lowest level of weights has been checked and corrected for reasonableness and insertion of specific components, the whole ship weight is added up.

The advantage of a Top Down approach is that it is system focused. Since it is based on previous ship designs, it will capture a value for all weight groups based on past practices. This method can give a very quick estimate of a whole ship, without spending time on details that may not be known to the responsible design engineer at this early design stage.

It is very difficult to estimate the weight of specific components specified by the owner into the estimate in a reliable manner. For example, to do this successfully the lowest level of a propulsion system weight estimate must be subdivided between the components specified by the owner (i.e. propulsion diesel) and the remaining system (i.e. shafting, gears, and auxiliaries). The parent weight estimates used for developing the weight fraction must all be subdivided, and redeveloped.

4.2.12 Bottom Up

This method develops an estimate of the weight at the lowest level of work breakdown system. These individual values are summed up the hierarchical tree to develop the total ship weight. Different estimating methods are used for each line item at the lowest level of the work breakdown system, based on the information available at the time. This method is complimentary to the top down method, in that its weakness tends to be the top down's strengths and vice versa. The bottom up method is a useful for checking the reasonableness of the top down method and vice versa.

4.2.13 Midship Extrapolation Method

This is a fraction method that uses the unit weight of the midship section to estimate the steel weight of the weight of the entire hull. An algorithm that describes the bow, midship, and stern sections of the hulls as fractions of the midship section are multiplied by the respective lengths. The method is similar to multiplying the sectional area curve by a weight per foot over the entire length. Hogg [14] describes this method as fundamental method to estimate hull structural weight. The method can be applied to any structural or machinery item that has a varying by similar prismatic shape.

4.2.14 Percent Complete

This method is used to develop a launch weight estimate or an estimate of the weight to complete at the time of lightship survey. The weight engineer estimates the amount of the system or change installed on the ship at a point in time. This fraction is applied to the complete system to develop the current weight. The method describes the fraction of the whole weight estimate that has been installed or removed.

4.2.15 Synthesis Programs

Synthesis programs are used to produce Random-Order-Magnitude, concept, and feasibility studies for most new designs. These are very sophisticated computer programs that integrate all engineering disciplines to predict ship physical and performance characteristics based on mission requirements. Typically these are proprietary programs that rely on existing databanks (which include weight) for each ship type to produce the initial concept. A detail description of these programs is beyond the scope and intent of this document but they work basically on the synthesis concept. The synthesis is made up of several modules that develop the initial concept design: hull geometry, hull subdivision, hull structure, appendages, resistance, propeller, machinery, weights, area and volume, etc. Specifically, with the input of a few primary design requirements, and manning and payloads, a preliminary inboard profile can be created and an initial size defined. The software gets convergence on the hull geometry via several methods then in proceeds to the hull subdivision module, structure and down the line with each design module until convergence has been obtaining for the design. The weight module produces an initial weight based on a specific weight classification along with VCG and LCG estimations.

5.0 WEIGHT AND CENTER OF GRAVITY MARGINS

5.1 General

Weight and KG margin values are needed for all ship designs in order to ensure that the estimated displacement and KG values as originally projected during the initial conceptual phase of the ship design are met at delivery. Regardless of whether the ships are for commercial or military applications, weight and KG margins are an important element of the displacement and KG projections for a ship design.

5.2 Commercial

For commercial applications the margin values vary depending upon the ship, design and construction process. For U.S. Maritime Administration (MarAd), a value of 3% for weight and 3% for KG is usually recommended, as a Detail Design and Building Margin.

5.3 Military

For Military applications (i.e., U. S. Navy Surface Ships) the margin values vary depending upon a variety of circumstances and are discussed below.

5.3.1 Acquisition Margins

U. S. Naval ship design practice utilizes the concept of a predicted baseline weight estimate that reflects the displacement, KG, list, and trim of the ship at delivery. To achieve this, acquisition weight and KG margins are essential elements of the design practice. Margin values for the specified margin accounts should be developed using a structured and systematic method which assigns design risk (based on previous design experience) to the state of the design based on a set of standard design characterization factors. These factors are subjective and unique within each organization. They should be developed after careful consideration of the weight control process, building methods and practices, corporate approach to weight control, and other considerations that can affect the weight control program. Cimino [28] describes a methodology for margin selection that utilizes a set of typical design characterization factors used to select margins. These factors tie in statistically with historical margin growth to produce margin values that are unique to the design and typically fall within the mean and mean plus one standard deviation range. However, margin allocations should always be developed in line with the following considerations:

- Historical patterns of refinement and growth as reflected in weight estimates during the progress of a design and during shipbuilding.
- Consideration of each ship design requires individual consideration of its unique features, unknowns, indeterminates and complexities.
- Avoiding injudicious application of margins, whether excessive or insufficient which can result in unrealistic projections of ship displacement and KG at delivery and can either increase shipbuilding costs related to ship size or result in expensive corrective measures.

- Acquisition strategy and policies which can deviate substantially from previous practices and design requirements and as a result can significantly impact margins.

While feasibility studies only require a single overall margin allocation for weight and one for KG, as acquisition programs develop they require more definitive weight and KG margins allocations for each phase of the design to account for increases associated with design development and building during those phases.

5.32 Service Life Allowances

Service life Allowances are also required for weight and KG since experience has shown that the displacement and KG of a naval ship tends to increase during commissioned service. These allowances are intended to provide for reasonable growth during the ship's service life without unacceptable compromise of the principal naval architectural characteristics, notably those characteristics relating to the specific performance of hull strength, reserve buoyancy, and stability. Performance characteristics, which must be satisfied at the end of a new ship's service life, will be identified by dialogue with the appropriate Sponsor. Other performance characteristics, normally including speed and endurance, will be satisfied at delivery and are permitted to degrade as service life growth occurs. However, predictions for these characteristics, both at delivery and at the end of the predicted service life, will be prepared and reported in the Preliminary and Contract Design (or Program Definition and Risk Reduction [6]) Reports. For any deviation from these values, the concurrence for the selected values shall be obtained via the Sponsor.

5.4 Policy

Acquisition Margins and Service Life Allowances shall be selected and applied as follows:

5.4.1 Acquisition Margins

Acquisition margins shall be applied to all ship designs such as: new, modified repeats, conversions or modernizations, or on a case basis as indicated by the Navy where major impact on mass properties of the ship is indicated. These acquisition margins are provided for each ship design phase to account for increases associated with design development and the building process. They should be tailored to the specifics of the design and shall reflect aspects such as the uniqueness of the design, the degree of definition of developmental systems incorporated, and the assumption of risk. The amount of margin to be provided must be determined and included in feasibility (or Concept Exploration [6]) studies, or the feasibility study that defines the weight and moment impacts of conversions or modernizations. Acquisition weight and KG margins should be selected within the ranges of Table 2 for feasibility stage design, and later, for the individual margin accounts. However, the selection range is used as a guide in determining the appropriate margin selection. In special cases, rational deviations from the values shown may be considered. For example, design studies reflecting radical hull forms, exotic hull materials, or major subsystems which are in the early developmental stages may require larger margin allocations. Conversely, incorporating items identical to previous designs may require smaller margin allocations.

Table 2 – Acquisition Margin Value Ranges by Ship Design and Construction Phases

Percentage of Displacement of the Light Ship Condition

	Mean	**Mean +1 Standard Deviation**
Total Acquisition Margin	6.0	17.5
Specific Margin accounts:		
Preliminary and Contract Design	0.8	4.4
Detail Design and Building	4.5	9.8
Contract Modification	0.4	2.1
GovernmentFurnished Material	0.2	0.7

Percentage of KG of the Light Ship Condition

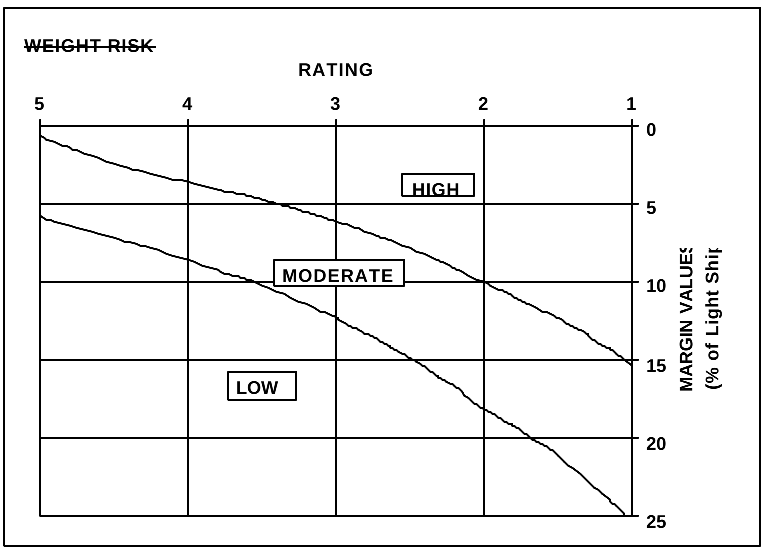
	Mean	**Mean +1 Standard Deviation**
Total Acquisition Margins	4.8	14.5
Specific Margin accounts:		
Preliminary and Contract Design	2.7	6.1
Detail Design and Building	1.7	5.1
Contract Modification	0.3	1.9
Government Furnished Material	0.1	0.4

a. The value ranges shown for Total Acquisition Margin are not developed using the statistical or arithmetic combination of the individual margin accounts. The total acquisition margin values are developed by characterizing the design and applying the individual margin accounts as they would be applied during a design . The cumulative effects, using the mean and mean plus one standard deviation are the ranges that are shown for total acquisition margin.

b. Preliminary/Contract design margins are applied to the lightship baseline weight estimate, excluding ballast. For subsequent design phases, margin values are based on the previous values of lightship plus the margins allocated to the previous design phase. Procurement margins (i.e. Detail Design and Building, Contract Modifications and GFM) are applied simultaneously to the resulting Preliminary/Contract Design weight estimate.

c. Risk is defined as the probability that the margin used will exceed the margin selected. A risk assessment method may provide a general guidance of the adequacy of already selected margin values. The aforementioned design characterizations are related statistically to historical margin growths to produce margin values that are unique to the design and consistent with past results. The method also provides a means of assessing the risk of variation from the selected margin values. Characterization of design uncertainty is never precise, and so for any characterization a range of margin values corresponding to the mean and the mean plus one standard deviation in the distribution of the statistical data, is considered to have an associated risk that can be mitigated with various weight control programs. This design uncertainty corresponds approximately to a risk of at most 50% chance of the estimated value being exceeded (i.e., margin exceeded) and a 16% chance of the estimated value being underestimated (i.e., margin not fully used). Weight and KG risk assessment curves for these values have been developed based on the statistical analysis and design characterizations as mentioned above, and shown in Figure 4. The curves display the values of characterization ratings between 1 and 5 and the associated margin risk lines at the lower bound (16% chance of the margin being exceeded) and at the higher bound (50% chance of the margin being exceeded). The margin values are expressed as a percentage of Light Ship weight and KG. Table 3 defines the values for the characterization ratings. Once the appropriate total margin values have been selected a level-of- confidence (or risk) may be associated by using Figure 4. Table 4 relates the three general levels of risk (i.e., low, moderate and high) to the programmatic risk mitigation necessary. The selection of margin values with high risk must be fully justified and appropriate risk mitigation instituted.

Figure 4 – Weight and KG Risk Assessment



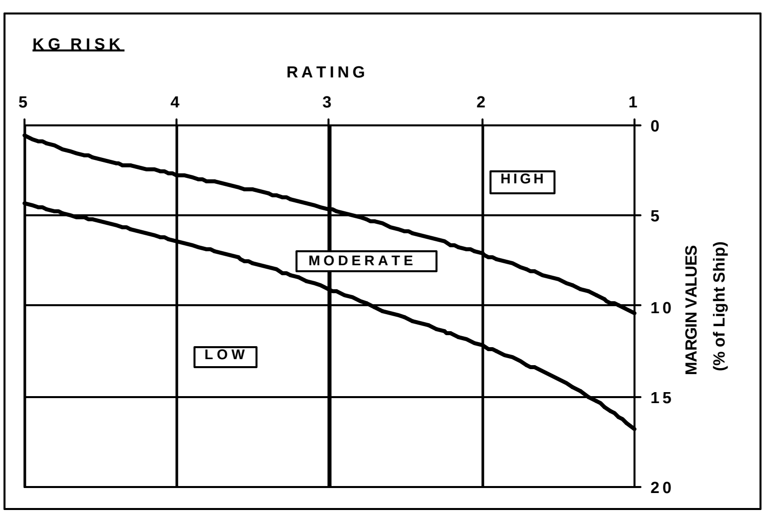


Table 3- Design Characterization Ratings

RATING	DESIGN CHARACTERIZATION
1	Developmental design/High level of uncertainty
2	New concept design/Some significant level of uncertainty
3	Similar design with major changes/Some level of uncertainty
4	Similar design with minor changes/Little level of uncertainty
5	Follow design with minor changes/Almost no uncertainty

Table 4 – Risk Consequences

RISK ASSESSMENT	RISK CONSEQUENCES
HIGH	Design might not meet safety limits (subdivision, strength, service life allowances), might involve redesigns and schedule impacts. Extreme weight control measures will be required.
MODERATE	Risk can be controlled by an effective weight control program that would involve incentives, Not-to-Exceed values, and other risk mitigation measures.
LOW	Safe design with very little uncertainty and applying standard weight control and reporting procedures.

5.4.2 Service Life Allowances

SLAs shall be included in all new and modified repeat designs such that, when delivered, each U. S. Navy surface ship shall be capable of accommodating the anticipated growth of weight and KG during its service life without compromise of the hull strength, reserve buoyancy, and stability characteristics established for the class. SLAs are allocated according to the ship type and the values shown on Table 5.

The weight and KG values in Table 5 are based on historical growth data for the ship types noted. These are the minimum values that must be provided in new construction ships. As the values in Table 5 are based on a service life of 20 years (30 years for carriers and large deck amphibious warfare ships), an increased SLA may be required for ships with longer projected service lives. The increase in SLAs should be evaluated on a case basis until there is data to update Table 5.

Table 5 – Service Life Allowance Values

Ship Type:	Weight [a] (Percent (%))	KG [b] Meters (Feet)
1. Combatants	10.0	0.30 (1.0)
2. Carriers	7.5	0.76 (2.5)
3. Amphibious warfare ship types		
a. Large deck	7.5	0.76 (2.5)
b. Other	5.0	0.30 (1.0)
4. Auxiliary ship types	5.0	0.15 (0.5)
5. Special ships and craft	5.0	0.15 (0.5)

Notes: [a] Weight percentage based on the predicted full load departure displacement at delivery
[b] KG values based on the predicted full load departure KG at delivery

SLAs are generally depleted during the service life of a ship. Depletion of the SLA and the status of each ship with respect to its naval architectural limits shall be monitored throughout the ship's active service. Weight and/or moment compensation requirements for any alteration which unacceptably degrades the remaining stability or reserve buoyancy allowances shall be identified.

For ships designed to carry dry cargo (i.e., auxiliary and amphibious ships), the full load departure condition will include the notional dry cargo load out. For ships designed to carry liquid cargo the cargo tanks shall be considered filled to 95% of the total net volume of each tank designed to carry petroleum products and 100% of the total net volume of each tank designed to carry cargo potable water or cargo reserve feed water.

For SWATH or other unique hull form designs, the minimum SLAs for weight and KG shall also be based on Table 4 for the applicable ship type. In addition, an analysis shall be conducted to determine the center of anticipated SLA growth for KG. The results of this analysis shall be highlighted to the appropriate sponsor, along with rationale for values used.

SLA requirements for major modernization’s and conversions shall be assessed on a case basis. A study taking into account the age of the ship, the remaining service life, the available weight and KG growth potential, etc., shall be performed to determine a specific recommendation for the modernization/conversion. These values, with supporting rationale, shall be highlighted in appropriate Sponsor presentations.

5.5 Contracting Practices

When a design agent or builder accepts a contract for the design and construction of a ship, he assumes a contractual responsibility for delivering a ship that meets the mass properties related performance. For a surface ship these values are usually a combination of displacement (deadweight), center of gravity, list, trim, speed, payload, and other mission critical performance parameters.

5.5.1 Commercial ship acquisition practices

Commercial contracting practices are dependent on the Owner's and the shipbuilder's contractual agreement. However, a general outline and approach is discussed in Reference [5], Section 6.

5.5.2 Military ship acquisition practices

Military (i.e., U. S. Navy Surface Ships) contracting practices are dependent on the acquisition strategy. Four types of basic acquisition approaches are discussed below:

a. Navy controlled design. Ship acquisitions are controlled by the Navy when the Navy releases a design data package as part of the bidding process. This package contains Not-to-Exceed (NTE) weight and KG values developed by the U. S. Navy and are included as part of the contract. In addition, liquidated damages may be included in the contract clause to establish the level of compensation due to the Navy should the NTE values be surpassed. The goal of this type of procurement is to have the bidder demonstrate that a ship can be delivered at or below the NTE values before award of the contract. If the above values cannot be met based on the definition of the contract design package, the bidder than should define the actions and associated costs needed to achieve the NTE values. The mechanism that demonstrates the bidder's ability to achieve the NTE values is the requirement to submit an independent weight estimate with the bid response. The independent weight estimate should represent the bidder's detail design and construction methods and practices. This weight estimate is prepared by utilizing the design data package which represents the contract design, since it includes contractual along with guidance drawings, ship specifications, and certain lists and schedules of Government Furnished Equipment, and loading factors. Contract drawings define the geometry, arrangement, and major structure of the design. They are engineering drawings from which ship construction drawings are developed. Guidance drawings, while not providing weight data directly, are useful in preparing such data. Piping and wiring diagrams are such drawings. Also, additional information may be used from standard drawings, design data sheets, technical manuals, manufacturer's catalogs, component lists, and vendor catalogs to prepare the independent weight estimate.

The other goal of this policy is to have an Accepted Weight Estimate (AWE) soon after contract award. The establishment of the AWE is the contractual basis which is used to determine margin depletion responsibility and essentially measures the contractor's weight control performance; therefore it excludes any Government-initiated changes.

Below is an example of a Standard Contract Clause for Weight Control which may be tailored to suit the specific acquisition strategy of the contract:

> "In accordance with the procedures set forth in section **xxx** of the Specifications, the Contractor shall enter into agreement with the Government as to the Accepted Weight Estimate (AWE) for the ship(s) under this contract, and such an agreement shall be set forth in a Supplemental Agreement. The AWE values for full load displacement and vertical center of gravity above bottom of keel (KG) are the baseline of measuring Contractor responsibility within the meaning of this clause. The aforementioned AWE values shall be equal or less than the NTE values:

Contractor responsible Full Load Displacement	**xxxxxxx**	long tons
Contractor responsible KG	**xx.xx**	feet

In the event an agreement on the AWE cannot be reached within four months after contract award of this contract, the NTE values become the AWE values.

The parties also recognize and agree that it is virtually impossible and completely impracticable to establish actual damages which would be suffered by the Government for the failure of the Contractor to deliver the ship(s) within the NTE values. Therefore in recognition of the above, the parties hereto have specifically agreed to and established the following schedule of liquidated damages as a reasonable forecast of the potential damages which would arise in the event that the Contractor responsible does not meet the full load displacement and/or KG, as determined above exceed the NTE values:

Weight – For each whole **xx** ton increment in excess of the NTE displacement set forth in paragraph (a) of this clause, the Contractor shall pay to the Government **xxxxxxx** dollars up to a maximum of **xxxxxxx** dollars.

KG – For each whole **xx.xx** foot increment in excess of the NTE vertical center value set forth in paragraph (a) of this clause, the Contractor shall pay to the Government xxxxx dollars up to a maximum of **xxxxxxx** dollars."

Also, list and trim requirements are set forth in the Specifications.

In addition the Government may offer monetary incentives for measures that the Contractor has undertaken that are considered above the performance of the contract to develop some performance area specified by the government. In such cases a Board is established that defines the evaluation period, expected performance level, and available monetary award for that period.

b. <u>Acquisition based on performance-type specifications</u>

For ships acquired using performance-type specifications (e.g., speed endurance, payload, etc.) the required Service Life Allowances will also be specified. In lieu of the AWE an Allocated Baseline Weight Estimate will be generated by the appropriate shipbuilders and will be submitted with the hull and propulsion configurations for approval by the NAVY. The Allocated Baseline Weight Estimate must satisfactorily show that the ship as proposed will meet the specified performance and be delivered within specified service life allowances. Weight estimating and control requirements will be included in the procurement specification. Submittal and approval dates for the Allocated Baseline Weight Estimate will be specified in the pertinent Contract Data Requirement List (CDRL) to coincide with the submittal of the hull and propulsion configurations.

c. <u>DoD Regulation 5000.2 –R Procurement</u> This is the newest procurement approach established under Acquisition Reform. In this approach the Government describes the system (ship) objectives and the minimum acceptable requirements (thresholds) for operational performance of the system. A preferred concept is selected for program initiation and moves forward through the design development and production process. The effect of this approach to weight control and service life allowances is currently under evaluation.

d. Other types of acquisition

For those acquisitions where neither of the above pertains, i.e., where a design exists which has been built, a shipbuilder's weight estimate will be required at the time of contract award. Examples of this type include standard barges and certain standard commercial ships and craft.

6.0 REPORTING REQUIREMENTS

As the design progress progresses, the weight estimates for all of the ship's components must be integrated into a weight report. The weight report is used to track the total lightship weight and centers of the ship and aids in the design process to determine if the ships hull form and size correlates to the lightship weight. As the design spiral converges, the weight report is continuously updated to ensure that the final estimate is as close as possible to the actual weight and maintained within the vessel's naval architectural limits.

In addition to the final weight report, separate weight reports can also be produced for a proposed alteration to structure or equipment. The U S. Navy categorizes weight reports into three categories:

a. Standard reports, which include weight and moment data for a completed ship. These reports may be specified by the contract and may be required to be submitted at various stages in the design.

b. Supplementary reports, which are weight and moment reports of government furnished materials. They may also be required by the contract.

c. Special reports, which are prepared by the contractor for their own use or at the request of NAVSEA. They may be required by the contract.

These reports are described, in detail, in Reference [4].

6.1 Detail Corresponding to Level of Design

When a design commences, a method is established for weight reporting. The method should be able to accommodate changes in weights as well as the addition of new weights. A good tool in the development of a weight report is a computer spreadsheet program. If the spreadsheet is properly prepared, weights can be modified, added or subtracted very easily. Structural components and distributed materials should always be calculated on a weight per standard unit basis (e.g., lb/sq. ft, lb/lineal ft.) to allow automatic recalculation of the weight and center when either the size or type of member is changed. This procedure will save time as the design is refined and hull size and scantlings are finalized.

The level of detail in the weight report will follow the level of detail in the design. In the early stages of design, the weight report will most likely contain weight estimates at the ESWBS one digit level. These weight values will be approximate and can be based on several sources including similar ship designs and weight per area of steel structure. At this level, the weights will provide a ball park figure which will be used to approximate propulsion, cargo capacity, manning requirements, approximate cost, etc.

As the design continues and more details are added, the weight report will be refined. At the preliminary design level, the weight report is often at the ESWBS three digit element level. At this level, the weight estimate will be used to determine the stability of the ship, the hull stresses, and to select the optimum propulsion plant.

When the design reaches the contract or detail design level there is enough information to produce a final weight report. In this estimate, every piece of equipment and structure is accounted for, including allowances for coatings, furniture etc. The goal for this is an estimate of the actual lightship weight of the vessel within a few percent.

6.2 Margins, Loading Conditions

The weight report is an estimate of all the weights included in the lightship weight of the ship. It will contain assumptions, approximations, omissions and errors. Many weight groups such as piping, wiring, auxiliary machinery etc. are very difficult to estimate and it is likely that only approximate values will be available. It is impossible to account for every piece of material added to the ship or to precisely estimate the weight of all weight groups. Therefore, the weight report should include certain margins to account for these inaccuracies and to act as safety factors. The proper margins to be used should be determined based on experience, evaluation of the accuracy of the weight estimate, and the impact the particular margin will have on the design. For example, on a particular tanker design in which stability is not an issue, the margin added to VCG would not be as critical as on a RORO ship design which barely meets the stability criteria. The RORO ship should have a larger VCG margin to ensure that the vessel will meet stability requirements when completed.

The Final Weight Report must include loading conditions which are calculated to correspond to each condition in the Trim and Stability Manual. The loading conditions are calculated by starting with the lightship weight estimate and adding all other deadweights present for the particular condition. The loading condition calculations will be used to determine the stability of the ship and the hull stresses as well as the draft and trim at each condition. They will also be sent to the Coast Guard and classification societies as proof that the vessel meets the applicable stability requirements.

7.0 WEIGHT MEASUREMENT

7.1 Weighing of Material and Equipment.

A comprehensive weight control program is made up of many facets, one of the essential elements in the program is the actual weighing of material and equipment. The credibility and confidence of the weight estimates and reports depend on accuracy, and actual scale weights of equipment, material and components provide the most accurate weight data.

The amount of actual weighing on a given contract depends on the degree in which shipbuilders implement their weight control program. Some of the major factors that influence full implementation of weight control are: the shipbuilders' confidence in the Accepted Weight Estimate or the Allocated Baseline Weight Estimate, the available Weight and KG Design and Build Margin, liquidated damages and/or incentives assigned to the contract, and the type of vessel being constructed. For example, most ships constructed for the U.S. Navy require a weight control program that ensures that the ship's weight and moments be consistent with its naval architectural limits for displacement, strength, stability, list, trim, and performance (such as speed, endurance, and seakeeping) [4]. Historically, those contracts that contain Not-To-Exceed limits for weight and KG, and impose liquidated damages and incentives for weight and KG promote shipbuilders to initiate and maintain a strong weight control program.

The following identifies the requirement for actual weighing of material and equipment in support of a comprehensive weight control program for all surface ships:

7.1.1. The actual weight of all components and equipment greater than 500 pounds (unless otherwise specified), both Contractor and Government furnished, shall be determined through accurate scale weighing along with the estimation or calculation of centers of gravity. The actual weights for materials, components, and equipment, less than 500 pounds, shall be determined on a selective or sampling basis, as determined by the contractor, to provide unit weight data. Potential candidates for actual weight determination on a selective basis include such items as insulation, structural plates and shapes, sheathing, piping, electrical cable and the components and equipment less than 500 pounds. Where factors or percentages are utilized, such as for estimating and calculating paint, mill tolerance, and welding, the contractor shall substantiate these values by supplying background information (current and historical). Historical background information on paint, mill tolerance, and welding factors shall be forwarded with the Bidders Independent Weight Estimate or Preliminary Allocated Baseline Weight Estimate. The final values for paint, mill tolerance, and welding factors, based on current ship information, will be forwarded with the Final Weight Report. In addition, to minimize the amount of actual weight determination at the shipbuilding site, the contractor shall require, through acquisition documents, subcontractors or vendors to submit information on the current weight and center of gravity of all major assemblies, equipment, fittings or components to be installed on the ship. It is suggested that information be submitted by subcontractors or vendors in the following sequence:

a. An estimate of weight and center of gravity in the proposal.

b. The calculated weight and center of gravity when the design is completed.

c. The actual weight and calculated center of gravity when the fabrication or assembly is completed. [4]

7.1.2. The weighing equipment (load cells) shall be accurate to 0.25 percent of the applied load and shall be sized at seventy-five percent of the item being weighed. The estimated center of gravity shall be determined for all major equipment and submitted with the estimated weight. The location of the equipment center of gravity shall be defined relative to the standard three axis coordinate system *x*, *y*, and *z*. The *z* axis is generally measured from a reference point on the bottom of the equipment and referred to as the Vertical Center of Gravity (VCG). The *x-axis* is generally measured from a reference point on the rear of the equipment and is referred to as the Longitudinal Center of Gravity (LCG). The y-axis is generally measured from a reference point on the centerline of the equipment and is referred to as the Transverse Center of Gravity (TCG). The estimated Center of gravity shall be obtained by the summation of moments about each axis including a minimum of eighty percent of the weight of the subcomponents for the equipment. Equipment that is symmetrical requires no calculations for the axis of symmetry. The calculated center of gravity will be based on 100 percent of components.

7.1.3. Additionally, a procedure employed by some shipbuilders in their arsenal of weight control techniques is a steel plate weighing inspection process. This process actually requires the steel maker to replace over-gauge plates at the steel mill, resulting in significant weight savings. This weight control process imposes reduced plate thickness tolerances and verifies through plate weighing and measuring that each plate is produced within a specified mill tolerance. Shipbuilders have experienced negative mill tolerance through this technique which also includes a system of plate sorting that actually enhances the KG of the ship under construction. As plates are weighed, they are marked “heavy” or “light” and during actual ship construction the “heavy” plates are placed lower in ship construction.

7.2 Deadweight Survey/Lightship Determination.

These commonly used terms refer to determining only displacement, and the longitudinal and transverse coordinates of the center of gravity. The procedures for a deadweight survey are the same as for an inclining experiment except that inclining weights are not used and no observations and calculations are made for vertical locations of inventory items, KG, GM, and free surface. NAVSEA or USCG may authorize a deadweight survey in lieu of an inclining experiment on sister ships where a satisfactory inclining experiment has been performed and approved for the lead ship, [29].

7.3 Inclining Experiment.

The inclining experiment represents a key aspect of weight control and weight measurement. It is the means of actually weighing a vessel and measuring its center of gravity. An inclining experiment consists of moving one or more known large weights across the ship, measuring the angle of list produced, reading drafts and surveying the compartments and tanks onboard the ship. The inclining experiment is used to determine compliance with the requirements of the Weight Control Program and to provide a baseline for data concerning weight and center of gravity for use in all considerations of stability, [29]. Conducting an accurate inclining experiment requires much coordination, cooperation and teamwork. The inclining coordinator, usually a Naval Architect, must be attentive to the details of the experiment. He must be willing to follow up with such things as checking that cross connect valves are closed, venting air out of full tanks, checking for discontinuities in free surface and waterplane characteristics, weighing and covering the inclining blocks prior to the test, ensuring the bilge has been pumped clean and dry, verifying inclining station communications, and reviewing the curves of form, tank tables and other reference documents for consistency of reference systems. Along with all the preplanning inclining meetings, the inclining coordinator invariably will be reminded that "we need to expedite this," "let's get this over with," "this is costing money and holding up ship production." So there will be a need to overcome the resistance of people who inadvertently may compromise the accuracy of the experiment.

All ships should be inclined to a standard of accuracy that not only verifies the contractual requirements of the Weight Control Program but is an experiment that can be validated, and validation normally comes in the form of another repeated experiment. The accuracy of an inclining experiment and the many thoughts about how to validate the experiment to compare, prove or disprove the weight estimate has been the basis for many hours of discussion; it is generally accepted by most shipbuilders that the accuracy of an inclining experiment is 0.25 feet (+/-) for KG and within 0.50(+/-) percent of displacement.

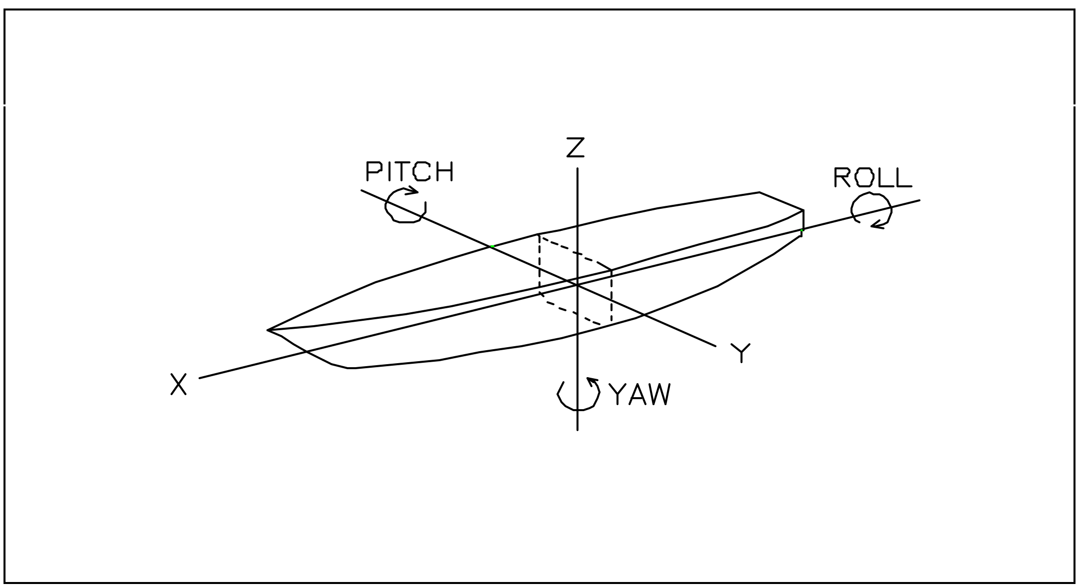
It should also be noted that the International Convention on *Safety of Life at Sea* requires that "every passenger or cargo vessel shall be inclined on completion" [3] while other vessels are to be inclined as defined and directed by the ship specification. Each regulatory agency has it's own detailed requirements for conducting an inclining experiment. Also, ASTM F 132192, *Standard Guide for Conducting a Stability Test (Lightship Survey and Inclining Experiment) to Determine the Light Ship Displacement and Center of Gravity of a Vessel* [29] describes the general procedures for conducting a Stability Test.

8.0 OTHER

8.1 Weight Moment of Inertia/Gyradius

The weight moment of inertia of a ship is calculated about the longitudinal *x-axis* for roll, transverse *y-axis* for pitch, and vertical *z* axis for yaw. The three rotational axes for motions are shown in Figure 5. While the inertia used in these calculations is referred to as the weight moment of inertia (expressed in units of weight times foot squared), it is normally expressed in terms of mass moment of inertia. However, since the weight estimate contains the weight of the item rather than the mass, the use of weight moment of inertia is appropriate in lieu of mass moment of inertia. Ultimately, the value being determined in the analysis is the gyradius which does not have units containing mass or weight. If the calculation is done consistently using weight, then the proper gyradius will result. Reference [30] documents the methodology used in calculating and projecting weight moment of inertia/gyradius values. It also contains a comparative analysis of calculated weight moment of inertia values among the U. S. Naval ships, as well as the results of a sensitivity analysis on their relationship.

Figure 5: Three Rotational Motions of a Ship



The total weight moment of inertia (I) for a ship is the sum of the item weight moments of inertia and the transference weight moments of inertia. The inertias of each item must first be calculated and then summed to give the total ship inertia. The item weight moment of inertia (I_o), is calculated relative to the center of gravity of the item about its own axes, oriented in the same direction as the ship's axes. The transference weight moment of inertia (I_t), is defined as the weight of the item times the square of the distance from the item's center of gravity to the ship's center of gravity. The weight moment of inertia for a surface ship is determined relative to its own center of gravity in a specified loading condition, normally full load. For submarines, the weight moment of inertia is calculated relative to the submarine's center of gravity in either a specified submerged or surfaced loading condition.

8.1.1 Weight Moment of Inertia

The weight moment of inertia consists of the summation of the transference inertia (I_t) and item inertia (I_o). For further details with regard to estimating weight moment of inertia/gyradius values about the three rotational axes, see Reference [7].

8.1.2 Gyradius

The gyradius (K) is calculated about the three rotational axes: roll, pitch and yaw. Mathematically, $K = \sqrt{I/\Delta}$ by definition. Where I is the weight moment of inertia about a particular axis and Δ is the total displacement (weight) of the ship.

8.1.3 Gyradius Estimated Values

In early stages of a ship design the weight estimates lacks sufficient detail to estimate or project gyradii values. Therefore, estimating the gyradii values using the "rules of thumb" method is an acceptable approach. Reference [30] documents the methodology used in estimating and projecting gyradii values. Table 6, below, is provided as guidance in the selection of the appropriate gyradii values for surface ships and submarines. These values correlate with the "rules of thumb" method, but reflect the ship types and type of hull form. Also, the values are expressed in terms of a tolerance (+/-) based on a one standard deviation of the ship data studied.

Table 6. Estimated Gyradius Values for Surface Ships and Submarines

• **SURFACE SHIPS**	**ROLL (%B)**	**PITCH (%L)**	**YAW (%L)**
DDG 51	38.9%	25.2%	25.1%
ARS 52	36.5%	25.1%	24.9%
FFG 60	36.2%	24.4%	24.3%
CG 62	40.4%	25.3%	25.2%
MCM 1	38.1%	24.3%	24.4%
LHD 2	42.0%	25.6%	25.6%
CVN 73	40.9%	23.2%	23.4%
LPD 17	40.5%	23.8%	23.8%

MEAN, CONVENTIONAL HULLS FORMS	**38.9%**	**24.7%**	**24.7%**
TOLERANCES (+/-)	**2.1%**	**0.8%**	**0.7%**
TAGOS 19	43.3%	30.5%	32.8%
TAGOS 23	43.6%	27.7%	29.4%
LCAC 24	29.1%	23.9%	27.5%
MEAN, UNCONVENTIONAL HULLS FORMS	**39.9%**	**28.3%**	**30.7%**
TOLERANCES (+/-)	**7.2%**	**3.3%**	**2.7%**
MEAN, SURFACE SHIPS	**39.2%**	**25.8%**	**26.5%**
TOLERANCES (+/-)	**4.0%**	**2.5%**	**3.3%**

• **SUBMARINES**	**ROLL (%B)**	**PITCH (%L)**	**YAW (%L)**
LSV NSURFACE	37.4%	22.9%	22.9%
SSN 756 NSURFACE	36.4%	24.0%	23.9%
SSBN 737 NSURFACE	36.7%	24.3%	24.2%
SSN 756 NSUBMERGES	34.7%	25.7%	25.7%
SSBN 737 NSUBMERGES	34.9%	26.3%	26.3%
MEAN, SUBMARINES	**36.0%**	**24.6%**	**24.6%**
TOLERANCES (+/-)	**1.2%**	**1.4%**	**1.4%**

"RULE OF THUMB"	**40.0%**	**25.0%**	**25.0%**

8.2 Longitudinal Weight Distribution

One of the byproducts of the weight estimate is a longitudinal weight distribution. A weight distribution is normally developed for both the ships' lightship and full load conditions. Each element of weight and its longitudinal center of gravity (LCG) is summed to produce the ship's longitudinal weight distribution. The longitudinal distribution is usually based on the 20 station spacing between the ships' FP and AP or between main transverse bulkheads. The weight and LCG of each element is calculated in the form of a series of trapezoids or rectangles and summarized as a weight curve for lightship and full load condition. The weight distribution curve is a graphic representation of the weight of the ship plotted as ton per foot (or any other desired units) on a vertical scale versus the length of the ship on a horizontal scale. Figures 6 and 7 represent a recent study of longitudinal weight distribution of ships of varying classes and types. The vertical scale represented in Figures 6 and 7 indicate the percentage of weight at each station for lightship and full load condition, respectively. At various stations there are some wide variances between the ship types based on configuration; however, it is believed that the data represented in these plots can be of some value to the naval architect or weight engineer in developing an early stage design weight distribution for the purpose of structural hogging and sagging calculations.

The weight of lightship and full load condition of the ships used in this study are as follows:

Table 7: Lightship and Full Load Conditions

Ship	Lightship (LTons)	Full Load Cond. (LTons)
MHC 51	827.0	874.6
DDG 65	6855.6	8797.2
LSD 50	11502.6	16317.0
LPD 17	17219.4	25073.8
LHD 2	28026.6	40420.1
TAO DH 204	15916.9	40461.1

Figure 6: Lightship 22-Station Weight Distribution

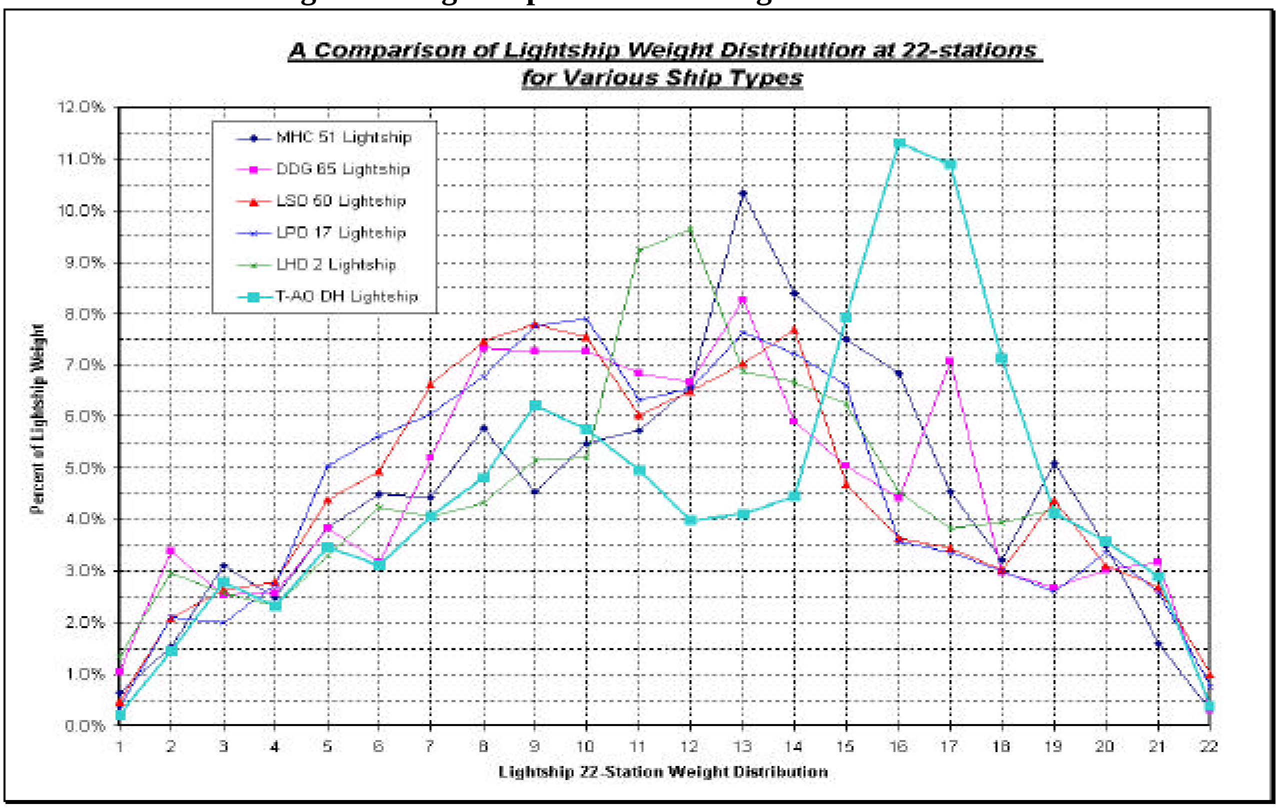
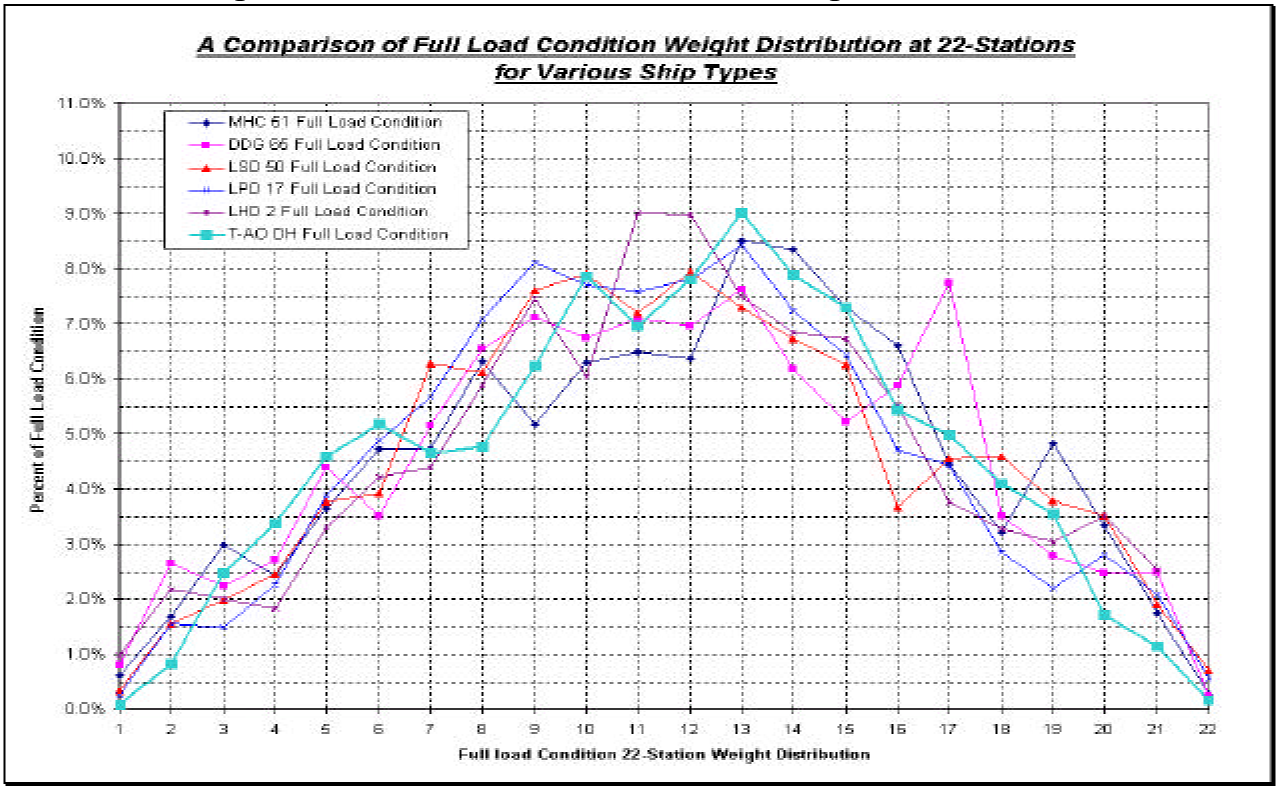


Figure 7 Full Load Condition 22-Station Weight Distribution



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APPENDIX A

ESWBS 1-DIGIT AND 3-DIGIT LISTING

EXPANDED SHIP WORK BREAKDOWN STRUCTURE (ESWBS) THREE DIGIT SUMMARIES

ESWBS	TITLE
1	**GROUP 1 HULL STRUCTURE**
100	HULL STRUCTURE, GENERAL
110	SHELL AND SUPPORTING STRUCTURE
111	SHELL PLATING, SURFACE SHIP AND SUBMARINE PRESSURE HULL
112	SHELL PLATING, SUBMARINE NONPRESSURE HULL
113	INNER BOTTOM
114	SHELL APPENDAGES
115	STANCHIONS
116	LONGIT. FRAMING, SURF SHIP AND SUBMARINE PRESSURE HULL
117	TRANSV. FRAMING, SURFACE SHIP AND SUBMARINE PRESSURE HULL
118	LONGITUDINAL AND TRANSVERSE SUBMARINE NONPRESSURE HULL
119	LIFT SYSTEM FLEXIBLE SKIRTS AND SEALS
120	HULL STRUCTURAL BULKHEADS
121	LONGITUDINAL STRUCTURAL BULKHEADS
122	TRANSVERSE STRUCTURAL BULKHEADS
123	TRUNKS AND ENCLOSURES
124	BULKHEADS IN TORPEDO PROTECTION SYSTEM
125	SUBMARINE HARD TANKS
126	SUBMARINE SOFT TANKS
130	HULL DECKS
131	MAIN DECK
132	2ND DECK
133	3RD DECK
134	4TH DECK
135	5TH DECK AND DECKS BELOW
136	01 HULL DECK (FORECASTLE AND POOP DECKS)
137	02 HULL DECK
138	03 HULL DECK
139	04 HULL DECK AND HULL DECKS ABOVE
140	HULL PLATFORMS AND FLATS
141	1ST PLATFORM
142	2ND PLATFORM
143	3RD PLATFORM
144	4TH PLATFORM
145	5TH PLATFORM
149	FLATS
150	DECK HOUSE STRUCTURE
151	DECKHOUSE STRUCTURE TO FIRST LEVEL
152	1ST DECKHOUSE LEVEL
153	2ND DECKHOUSE LEVEL
154	3RD DECKHOUSE LEVEL
155	4TH DECKHOUSE LEVEL
156	5TH DECKHOUSE LEVEL
157	6TH DECKHOUSE LEVEL
158	7TH DECKHOUSE LEVEL
159	8TH DECKHOUSE LEVEL AND ABOVE
160	SPECIAL STRUCTURES
161	STRUCTURAL CASTINGS, FORGINGS, AND EQUIV. WELDMENTS
163	SEA CHESTS
164	BALLISTIC PLATING

ESWBS	TITLE
165	SONAR DOMES
166	SPONSONS
167	HULL STRUCTURAL CLOSURES
168	DECKHOUSE STRUCTURAL CLOSURES
169	SPECIAL PURPOSE CLOSURES AND STRUCTURES
170	MASTS, KINGPOSTS, AND SERVICE PLATFORMS
171	MASTS, TOWERS, TETRAPODS
172	KINGPOSTS AND SUPPORT FRAMES
179	SERVICE PLATFORMS
180	FOUNDATIONS
181	HULL STRUCTURE FOUNDATIONS
182	PROPULSION PLANT FOUNDATIONS
183	ELECTRIC PLANT FOUNDATIONS
184	COMMAND AND SURVEILLANCE FOUNDATIONS
185	AUXILIARY SYSTEMS FOUNDATIONS
186	OUTFIT AND FURNISHINGS FOUNDATIONS
187	ARMAMENT FOUNDATIONS
190	SPECIAL PURPOSE SYSTEMS
191	BALLAST, FIXED OR FLUID, AND BUOYANCY UNITS
192	COMPARTMENT TESTING
195	ERECTION OF SUB SECTIONS (PROGRESS REPORT ONLY)
198	FREE FLOODING LIQUIDS
199	HULL REPAIR PARTS AND SPECIAL TOOLS
2	**GROUP 2 PROPULSION PLANT**
200	PROPULSION PLANT, GENERAL
210	ENERGY GENERATING SYSTEMS (NUCLEAR)
211	(RESERVED)
212	NUCLEAR STEAM GENERATOR
213	REACTORS
214	REACTOR COOLANT SYSTEM
215	REACTOR COOLANT SERVICE SYSTEMS
216	REACTOR PLANT AUXILIARY SYSTEMS
217	NUCLEAR POWER CONTROL AND INSTRUMENTATION
218	RADIATION SHIELDING (PRIMARY)
219	RADIATION SHIELDING (SECONDARY)
220	ENERGY GENERATING SYSTEMS (NONNUCLEAR)
221	PROPULSION BOILERS
222	GAS GENERATORS
223	MAIN PROPULSION BATTERIES
224	MAIN PROPULSION FUEL CELLS
230	PROPULSION UNITS
231	PROPULSION STEAM TURBINES
232	PROPULSION STEAM ENGINES
233	PROPULSION INTERNAL COMBUSTION ENGINES
234	PROPULSION GAS TURBINES
235	ELECTRIC PROPULSION
236	SELFCONTAINED PROPULSION SYSTEMS
237	AUXILIARY PROPULSION DEVICES
238	SECONDARY PROPULSION
239	EMERGENCY PROPULSION
240	TRANSMISSION AND PROPULSOR SYSTEMS
241	PROPULSION REDUCTION GEARS
242	PROPULSION CLUTCHES AND COUPLINGS

ESWBS	TITLE
243	PROPULSION SHAFTING
244	PROPULSION SHAFT BEARINGS
245	PROPULSORS
246	PROPULSOR SHROUDS AND DUCTS
247	WATER JET PROPULSORS
248	LIFT SYSTEM FANS AND DUCTING
250	PROPULSION SUPPORT SYSTEMS (EXCEPT FUEL/LUBE)
251	COMBUSTION AIR SYSTEM
252	PROPULSION CONTROL SYSTEM
253	MAIN STEAM PIPING SYSTEM
254	CONDENSERS AND AIR EJECTORS
255	FEED AND CONDENSATE SYSTEM
256	CIRCULATING AND COOLING SEA WATER SYSTEM
257	RESERVE FEED AND TRANSFER SYSTEM
258	HP STEAM DRAIN SYSTEM
259	UPTAKES (INNER CASING)
260	PROPULSION SUPPORT SYSTEMS (FUEL AND LUBE OIL)
261	FUEL SERVICE SYSTEM
262	MAIN PROPULSION LUBE OIL SYSTEM
263	SHAFT LUBE OIL SYSTEM (SUBMARINES)
264	LUBE OIL FILL, TRANSFER, AND PURIFICATION
290	SPECIAL PURPOSE SYSTEMS
298	PROPULSION PLANT OPERATING FLUIDS
299	PROPULSION PLANT REPAIR PARTS AND SPECIAL TOOLS
3	**GROUP 3 ELECTRIC PLANT**
300	ELECTRIC PLANT, GENERAL
310	ELECTRIC POWER GENERATION
311	SHIP SERVICE POWER GENERATION
312	EMERGENCY GENERATORS
313	BATTERIES AND SERVICE FACILITIES
314	POWER CONVERSION EQUIPMENT
320	POWER DISTRIBUTION SYSTEMS
321	SHIP SERVICE POWER CABLE
322	EMERGENCY POWER CABLE SYSTEM
323	CASUALTY POWER CABLE SYSTEM
324	SWITCHGEAR AND PANELS
325	ARC FAULT DETECTOR (AFD) SYSTEMS
330	LIGHTING SYSTEM
331	LIGHTING DISTRIBUTION
332	LIGHTING FIXTURES
340	POWER GENERATION SUPPORT SYSTEMS
341	SSTG LUBE OIL
342	DIESEL SUPPORT SYSTEMS
343	TURBINE SUPPORT SYSTEMS
390	SPECIAL PURPOSE SYSTEMS
398	ELECTRIC PLANT OPERATING FLUIDS
399	ELECTRIC PLANT REPAIR PARTS AND SPECIAL TOOLS
4	**GROUP 4 COMMAND & SURVEILLANCE**
400	COMMAND AND SURVEILLANCE, GENERAL
410	COMMAND AND CONTROL SYSTEMS
411	DATA DISPLAY GROUP
412	DATA PROCESSING GROUP
413	DIGITAL DATA SWITCHBOARDS

ESWBS	TITLE
414	INTERFACE EQUIPMENT
415	DIGITAL DATA COMMUNICATIONS
417	COMMAND AND CONTROL ANALOG SWITCHBOARDS
420	NAVIGATION SYSTEMS
421	NONELECTRICAL/NONELECTRONIC NAVIGATION AIDS
422	ELECTRICAL NAVIGATION AIDS (INCL NAVIG. LIGHTS)
423	ELECTRONIC NAVIGATION SYSTEMS
424	ELECTRONIC NAVIGATION SYSTEMS, ACOUSTICAL
425	PERISCOPES
426	ELECTRICAL NAVIGATION SYSTEMS
427	INERTIAL NAVIGATION SYSTEMS
428	NAVIGATION CONTROL MONITORING
430	INTERIOR COMMUNICATIONS
431	SWITCHBOARDS FOR INTERIOR COMMUNICATION SYSTEMS
432	TELEPHONE SYSTEMS
433	ANNOUNCING SYSTEMS
434	ENTERTAINMENT AND TRAINING SYSTEMS
435	VOICE TUBES AND MESSAGE PASSING SYSTEMS
436	ALARM, SAFETY, AND WARNING SYSTEMS
437	INDICATING, ORDER, AND METERING SYSTEMS
438	CONSOLIDATED CONTROL AND DISPLAY SYSTEMS
439	RECORDING AND TELEVISION SYSTEMS
440	EXTERIOR COMMUNICATIONS
441	RADIO SYSTEMS
442	UNDERWATER SYSTEMS
443	VISUAL AND AUDIBLE COMMUNICATION SYSTEMS
444	TELEMETRY SYSTEMS
445	TELETYPE AND FACSIMILE SYSTEMS
446	SECURITY EQUIPMENT SYSTEMS
450	SURVEILLANCE SYSTEMS, SURFACE AND AIR
451	SURFACE SURVEILLANCE RADAR SYSTEMS
452	2D AIR RADAR SYSTEMS
453	3D AIR RADAR SYSTEMS
454	AIRCRAFT CONTROL RADAR SYSTEMS
455	IDENTIFICATION SYSTEMS
456	MULTIFUNCTION RADAR SYSTEMS
457	INFRARED SURVEILLANCE AND TRACKING SYSTEMS
458	AUTOMATIC DETECTION AND TRACKING SYSTEMS
459	SPACE VEHICLE ELECTRONIC TRACKING
460	SURVEILLANCE SYSTEMS (UNDERWATER)
461	ACTIVE SURVEILLANCE SONAR
462	PASSIVE SURVEILLANCE SONAR
463	MULTIPLE MODE SURVEILLANCE SONAR
464	ACOUSTIC ANALYSIS SYSTEMS
465	BATHYTHERMOGRAPH
466	AIRBORNE MULTIPURPOSE SHIP EQUIPMENT SYSTEMS
468	SURFACE SHIP COMBAT SYSTEMS
469	SUBMARINE COMBAT SYSTEMS
470	COUNTERMEASURE SYSTEMS
471	ACTIVE EW (INCL COMBINATION ACTIVE/PASSIVE)
472	PASSIVE ECM
473	UNDERWATER COUNTERMEASURES
474	DECOY SYSTEMS

ESWBS	TITLE
475	DEGAUSSING SYSTEMS
476	MINE COUNTERMEASURE SYSTEMS
480	FIRE CONTROL SYSTEMS
481	GUN FIRE CONTROL SYSTEMS
482	MISSILE FIRE CONTROL SYSTEMS
483	UNDERWATER FIRE CONTROL SYSTEMS
484	INTEGRATED FIRE CONTROL SYSTEMS
489	WEAPON SYSTEMS SWITCHBOARDS
490	SPECIAL PURPOSE SYSTEMS
491	ELECTRONIC TEST, CHECKOUT, AND MONITORING EQUIPMENT
492	FLIGHT CONTROL AND INSTRUMENT LANDING SYSTEMS
493	AUTOMATED DATA PROCESSING SYSTEMS (NONCOMBAT)
494	METEOROLOGICAL SYSTEMS
495	SPECIAL PURPOSE INTELLIGENCE SYSTEMS
498	COMMAND AND SURVEILLANCE OPERATING FLUIDS
499	COMMAND AND SURV. REPAIR PARTS AND SPECIAL TOOLS
5	**GROUP 5 AUXILIARY SYSTEMS**
500	AUXILIARY SYSTEMS, GENERAL
510	CLIMATE CONTROL
511	COMPARTMENT HEATING SYSTEM
512	VENTILATION SYSTEM
513	MACHINERY SPACE VENTILATION SYSTEM
514	AIR CONDITIONING SYSTEM
515	AIR REVITALIZATION SYSTEMS (SUBMARINES)
516	REFRIGERATION SYSTEM
517	AUXILIARY BOILERS AND OTHER HEAT SOURCES
520	SEA WATER SYSTEMS
521	FIREMAIN AND FLUSHING (SEA WATER) SYSTEM
522	SPRINKLER SYSTEM
523	WASHDOWN SYSTEM
524	AUXILIARY SEA WATER SYSTEM
526	SCUPPERS AND DECK DRAINS
527	FIREMAIN ACTUATED SERVICES OTHER
528	PLUMBING DRAINAGE
529	DRAINAGE AND BALLASTING SYSTEM
530	FRESH WATER SYSTEMS
531	DISTILLING PLANT
532	COOLING WATER
533	POTABLE WATER
534	AUXILIARY STEAM AND DRAINS WITHIN MACHINERY BOX
535	AUXILIARY STEAM AND DRAINS OUTSIDE MACHINERY BOX
536	AUXILIARY FRESH WATER COOLING
540	FUELS AND LUBRICANTS, HANDLING AND STORAGE
541	SHIP FUEL AND FUEL COMPENSATING SYSTEM
542	AVIATION AND GENERAL PURPOSE FUELS
543	AVIATION AND GENERAL PURPOSE LUBRICATING OIL
544	LIQUID CARGO
545	TANK HEATING
546	AUXILIARY LUBRICATION SYSTEMS
549	SPECIAL FUEL AND LUBRICANTS, HANDLING AND STOWAGE
550	AIR, GAS, AND MISCELLANEOUS FLUID SYSTEMS
551	COMPRESSED AIR SYSTEMS
552	COMPRESSED GASES

ESWBS	TITLE
553	O2 N2 SYSTEM
554	MAIN BALLAST TANK BLOW AND LIST CONTROL SYSTEM
555	FIRE EXTINGUISHING SYSTEMS
556	HYDRAULIC FLUID SYSTEM
557	LIQUID GASES, CARGO
558	SPECIAL PIPING SYSTEMS
560	SHIP CONTROL SYSTEMS
561	STEERING AND DIVING CONTROL SYSTEMS
562	RUDDER
563	HOVERING AND DEPTH CONTROL (SUBMARINE)
564	TRIM AND DRAIN SYSTEMS (SUBMARINES)
565	TRIM AND HEEL SYSTEMS (SURFACE SHIPS)
566	DIVING PLANES AND STABILIZING FINS (SUBMARINES)
567	STRUT AND FOIL SYSTEMS
568	MANEUVERING SYSTEMS
570	REPLENISHMENT SYSTEMS
571	REPLENISHMENTATSEA SYSTEMS
572	SHIP STORES AND EQUIPMENT HANDLING SYSTEMS
573	CARGO HANDLING SYSTEMS
574	VERTICAL REPLENISHMENT SYSTEMS
575	VEHICLE HANDLING AND STOWAGE SYSTEMS
580	MECHANICAL HANDLING SYSTEMS
581	ANCHOR HANDLING AND STOWAGE SYSTEMS
582	MOORING AND TOWING SYSTEMS
583	BOATS, BOAT HANDLING AND STOWAGE SYSTEMS
584	LANDING CRAFT HANDLING AND STOWAGE SYSTEMS
585	ELEVATING AND RETRACTING GEAR
586	AIRCRAFT RECOVERY SUPPORT SYSTEMS
587	AIRCRAFT LAUNCH SUPPORT SYSTEMS
588	AIRCRAFT HANDLING, SERVICING AND STOWAGE
589	MISCELLANEOUS MECHANICAL HANDLING SYSTEMS
590	SPECIAL PURPOSE SYSTEMS
591	SCIENTIFIC AND OCEAN ENGINEERING SYSTEMS
592	SWIMMER AND DIVER SUPPORT AND PROTECTION SYSTEMS
593	ENVIRONMENTAL POLLUTION CONTROL SYSTEMS
594	SUBMARINE RESCUE, SALVAGE, AND SURVIVAL SYSTEMS
595	TOWING, LAUNCHING AND HANDLING FOR UNDERWATER SYS.
596	HANDLING SYS. FOR DIVER AND SUBMERSIBLE VEHICLES
597	SALVAGE SUPPORT SYSTEMS
598	AUXILIARY SYSTEMS OPERATING FLUIDS
599	AUXILIARY SYSTEMS REPAIR PARTS AND TOOLS
6	**GROUP 6 OUTFIT & FURNISHINGS**
600	OUTFIT AND FURNISHINGS, GENERAL
610	SHIP FITTINGS
611	HULL FITTINGS
612	RAILS, STANCHIONS, AND LIFELINES
613	RIGGING AND CANVAS
620	HULL COMPARTMENTATION
621	NONSTRUCTURAL BULKHEADS
622	FLOOR PLATES AND GRATINGS
623	LADDERS
624	NONSTRUCTURAL CLOSURES
625	AIRPORTS, FIXED PORTLIGHTS, AND WINDOWS

ESWBS	TITLE
630	PRESERVATIVES AND COVERINGS
631	PAINTING
632	ZINC AND METALLIC COATINGS
633	CATHODIC PROTECTION
634	DECK COVERING
635	HULL INSULATION
636	HULL DAMPING
637	SHEATHING
638	REFRIGERATED SPACES
639	RADIATION SHIELDING
640	LIVING SPACES
641	OFFICER BERTHING AND MESSING SPACES
642	NONCOMMISSIONED OFFICER BERTHING AND MESSING SPACES
643	ENLISTED PERSONNEL BERTHING AND MESSING SPACES
644	SANITARY SPACES AND FIXTURES
645	LEISURE AND COMMUNITY SPACES
650	SERVICE SPACES
651	COMMISSARY SPACES
652	MEDICAL SPACES
653	DENTAL SPACES
654	UTILITY SPACES
655	LAUNDRY SPACES
656	TRASH DISPOSAL SPACES
660	WORKING SPACES
661	OFFICES
662	MACHINERY CONTROL CENTERS FURNISHINGS
663	ELECTRONICS CONTROL CENTERS FURNISHINGS
664	DAMAGE CONTROL STATIONS
665	WORKSHOPS, LABS, TEST AREAS (INCL PORTABLE TOOLS, EQUIP)
670	STOWAGE SPACES
671	LOCKERS AND SPECIAL STOWAGE
672	STOREROOMS AND ISSUE ROOMS
673	CARGO STOWAGE
690	SPECIAL PURPOSE SYSTEMS
691	TRANSMISSION LOSS TREATMENT
698	OUTFIT AND FURNISHINGS OPERATING FLUIDS
699	OUTFIT AND FURNISH. REPAIR PARTS AND SPECIAL TOOLS
7	**GROUP 7 ARMAMENT**
700	ARMAMENT, GENERAL
710	GUNS AND AMMUNITION
711	GUNS
712	AMMUNITION HANDLING
713	AMMUNITION STOWAGE
720	MISSILES AND ROCKETS
721	LAUNCHING DEVICES (MISSILES AND ROCKETS)
722	MISSILE, ROCKET, AND GUIDANCE CAPSULE HANDLING SYS.
723	MISSILE AND ROCKET STOWAGE
724	MISSILE HYDRAULICS
725	MISSILE GAS
726	MISSILE COMPENSATING
727	MISSILE LAUNCHER CONTROL
728	MISSILE HEATING, COOLING, TEMPERATURE CONTROL
729	MISSILE MONITORING, TEST AND ALIGNMENT

ESWBS	TITLE
730	MINES
731	MINE LAUNCHING DEVICES
732	MINE HANDLING
733	MINE STOWAGE
740	DEPTH CHARGES
741	DEPTH CHARGE LAUNCHING DEVICES
742	DEPTH CHARGE HANDLING
743	DEPTH CHARGE STOWAGE
750	TORPEDOES
751	TORPEDO TUBES
752	TORPEDO HANDLING
753	TORPEDO STOWAGE
754	SUBMARINE TORPEDO EJECTION
755	TORPEDO SUPPORT, TEST AND ALIGNMENT
760	SMALL ARMS AND PYROTECHNICS
761	SMALL ARMS AND PYROTECHNIC LAUNCHING DEVICES
762	SMALL ARMS AND PYROTECHNIC HANDLING
763	SMALL ARMS AND PYROTECHNIC STOWAGE
770	CARGO MUNITIONS
772	CARGO MUNITIONS HANDLING
773	CARGO MUNITIONS STOWAGE
780	AIRCRAFT RELATED WEAPONS
782	AIRCRAFT RELATED WEAPONS HANDLING
783	AIRCRAFT RELATED WEAPONS STOWAGE
784	AIRCRAFT RELATED WEAPONS ELEVATORS, UPPER STAGES
785	AIRCRAFT RELATED WEAPONS ELEVATORS, LOWER STAGES
786	AIRCRAFT RELATED WEAPONS, HYDRAULICS
790	SPECIAL PURPOSE SYSTEMS
792	SPECIAL WEAPONS HANDLING
793	SPECIAL WEAPONS STOWAGE
797	MISCELLANEOUS ORDNANCE SPACES
798	ARMAMENT OPERATING FLUIDS
799	ARMAMENT REPAIR PARTS AND SPECIAL TOOLS
F	**GROUP F FULL LOAD, LOADS**
F00	LOADS (FULL LOAD CONDITION)
F10	SHIPS FORCE, AMPHIB. FORCE, TROOPS AND PASSENGERS
F11	SHIPS OFFICERS
F12	SHIPS NONCOMMISSIONED OFFICERS
F13	SHIPS ENLISTED MEN
F14	MARINES
F15	TROOPS
F16	AIR WING PERSONNEL
F19	OTHER PERSONNEL
F20	MISSION RELATED EXPENDABLES AND SYSTEMS
F21	SHIP AMMUNITION (FOR USE BY SHIP ON WHICH STOWED)
F22	ORDNANCE DELIVERY SYSTEMS AMMUNITION
F23	ORDNANCE DELIVERY SYSTEMS
F24	ORDNANCE REPAIR PARTS (SHIP AMMO)
F25	ORDNANCE REPAIR PARTS (ORDNANCE DELIVERY SYS. AMMO)
F26	ORDNANCE DELIVERY SYSTEMS SUPPORT EQUIPMENT
F29	SPECIAL MISSION RELATED SYSTEMS AND EXPENDABLES

ESWBS	TITLE
F30	STORES
F31	PROVISIONS AND PERSONNEL STORES
F32	GENERAL STORES
F33	MARINES STORES (FOR SHIP'S COMPLEMENT)
F39	SPECIAL STORES
F40	FUELS AND LUBRICANTS
F41	DIESEL FUEL
F42	JP5
F43	GASOLINE
F44	DISTILLATE FUEL
F45	NAVY STANDARD FUEL OIL (NSFO)
F46	LUBRICATING OIL
F49	SPECIAL FUELS AND LUBRICANTS
F50	LIQUIDS AND GASES (NON FUEL TYPE)
F51	SEA WATER
F52	FRESH WATER
F53	RESERVE FEED WATER
F54	HYDRAULIC FLUID
F55	SANITARY TANK LIQUID
F56	GAS (NON FUEL TYPE)
F59	MISCELLANEOUS LIQUIDS (NON FUEL TYPE)
F60	CARGO
F61	CARGO, ORDNANCE AND ORDNANCE DELIVERY SYSTEMS
F62	CARGO, STORES
F63	CARGO, FUELS AND LUBRICANTS
F64	CARGO, LIQUIDS (NON FUEL TYPE)
F65	CARGO, CRYOGENIC AND LIQUIFIED GAS
F66	CARGO, AMPHIBIOUS ASSAULT SYSTEMS
F67	CARGO, GASES
F69	CARGO, MISCELLANEOUS
F70	SEA WATER BALLAST (SUBMARINES)
F71	MAIN BALLAST WATER (SUBMARINES)
F72	VARIABLE BALLAST WATER (SUBMARINES)
F73	RESIDUAL WATER (SUBMARINES)
M	**GROUP M ACQUISITION MARGINS**
M00	MARGINS
M10	CONTRACTOR CONTROLLED MARGINS
M11	DESIGN AND BUILDING MARGIN
M12	BUILDING MARGIN (RESERVED)
M20	GOVERNMENT CONTROLLED MARGIN (SURFACE SHIP)
M21	PRELIMINARY DESIGN MARGIN (SURFACE SHIP)
M22	CONTRACT DESIGN MARGIN (SURFACE SHIP)
M23	CONTRACT MODIFICATION MARGIN (SURFACE SHIP)
M24	GEM MARGIN (SURFACE SHIP)
M25	FUTURE GROWTH MARGIN (SURFACE SHIP)
M26	SERVICE LIFE MARGIN (SURFACE SHIP)
M27	NUCLEAR MACHINERY MARGIN (SURFACE SHIP)
M30	GOVERNMENT CONTROLLED MARGIN STATUS (SUBMARINES)
M31	PRELIMINARY DESIGN MARGIN (SUBMARINE)
M32	CONTRACT DESIGN MARGIN (SUBMARINE)
M33	NAVSHIPS DEVELOPMENT MARGIN (SUBMARINE)
M34	NUCLEAR MACHINERY MARGIN (SUBMARINE)

ESWBS	TITLE
M35	FUTURE GROWTH MARGIN (SUBMARINE)
M36	STABILITY LEAD STATUS (SUBMARINE)
M37	TRIMMING LEAD STATUS (SUBMARINE)
M40	BALLAST STATUS (SUBMARINE)
M41	LEAD, INTERNAL (SUBMARINE)
M42	LEAD, EXTERNAL (SUBMARINE)
M43	LEAD, MET (SUBMARINE)
M44	STEEL, INTERNAL (SUBMARINE)
M45	STEEL, EXTERNAL (SUBMARINE)
M46	STEEL, MBT (SUBMARINE)
M47	LEAD CORRECTION, MET (SUBMARINE)
M48	LEAD CORRECTION, OTHER THEN MET (SUBMARINE)

APPENDIX B

MARAD WEIGHT CLASSIFICATION LISTING

HULL STRUCTURE (Group 0-9)

CODE	ITEM	CODE	ITEM
0-0	Stem casting	5-0	Pillars and Girders
1	Stern frame casting	1	
2	Boss casting	2	
3	Shaft struts	3	
4	Misc. Hull Castings	4	
5		5	
6		6	
7		7	
8		8	
9		9	
	Forgings and Castings		**Pillars and Girders**
1-0	Flat Plate keel	6-0	Inner Bottom Plating
1	Shell plating	1	Platform Deck
2	Bulwarks	2	Sponsons
3	Bilge keels	3	Cantilevers
4	Boss plating	4	Cofferdam Flats & Floors
5	Rubbing strips and fenders	5	Helicopter Platform
6	Sea Chests / Skin coolers	6	Miscellaneous Flats and Floors
7	Skegs	7	Stability Column Support Legs
8	Thruster Tunnels / Wells	8	Protective Covers / Barriers
9		9	
	Shell Plating		**Hull Miscellaneous**
2-0	Center vertical keel	7-0	Main Engine Foundations
1	Trans. framing in 1.B.	1	Boiler Foundations
2	Long. framing in 1.B.	2	Auxiliary Machine Foundations
3	Trans. framing outside 1.B.	3	Shaft Stools Foundations
4	Framing in peaks	4	Miscellaneous Foundations
5	Transom and cants	5	Cryogenic / Chemical Foundations
6	Web frames	6	
7	Long'l Girder Ring	7	
8	Long'l Stringer Ring	8	
9		9	
	Framing		**Foundations**
3-0		8-0	
1		1	
2		2	
3		3	
4		4	
5		5	
6		6	
7		7	
8		8	Miscellaneous Houses
9		9	Stack Enclosure
	Deck Plating and Beams		**Superstructures**
4-0	Main trans. W.T. bhds.		**SUB TOTAL GROUPS 0 THROUGH 8**
1	Trans. W.T. and O.T. bhds	9-0	Riveting and Welding
2	Long. W.T. and O.T. bhds	1	Welding
3	Structural N.W.T. bhds	2	Mill Tolerance
4	Nonstructural bhds	3	
5	Trunks structural	4	
6	Trunks nonstructural	5	
7	Stair enclosures	6	
8	Hatch coamings	7	
9	Drill Wells / Leg Wells		
	Bulkheads and Trunks		**Riveting and Welding**

OUTFIT (Group 10 – 19)

CODE	ITEM	CODE	ITEM
10-0	Steel Masts, Kingposts, etc.	15-0	Anchors, Chains, Lines
1	Steel Booms	1	Boats and Boat Handling
2	Steel Hatch Covers and Beams	2	Rigging and Blocks
3	Steel Stairways	3	Canvas Work
4	Steel Sheet Metal Work	4	Miscellaneous Deck Outfit
5	Drill Derricks	5	Underwater Support Equipment
6	Self-Unloading Booms	6	Exterior Paint
7		7	Interior Paint
8		8	Tank Paint
9		9	Special Coatings
	Structure Steel in Outfit		Deck Outfit
11-0	Deck Castings, Mooring Fittings	16-0	Galley and Pantry Equipment
1	Mast and Spar Forgings	1	Utility Space Equipment
2	Rails and Stanchions	2	Steward's Outfit
3	Ladders	3	
4	Miscellaneous Hull Fittings	4	
5	Ratproofing	5	
6	Guide Struc. / Lashings	6	
7	Prim. Cryogenic Contain.	7	National Defense
8	Sec. Cryogenic Contain.	8	
9	Tug / Barge Connections	9	
	Hull Attachments		Steward's Outfit / Defense
12-0	Sliding W.T. Doors	17-0	Fire Det. and Ext. System
1	Hinged W.T. Doors	1	Heating System
2	Manholes and Scuttles	2	Ventilation Natural
3	Airports, Windows and Lights	3	Ventilation Mechanical
4	Hatches and Ports O.T. or W.T.	4	Refrigerating Systems
5	N.W.T. Steel Doors	5	Plumbing Fixtures and Drains
6	Skylights and Companions	6	
7	Movable Ramps	7	
	Lights, Doors Hatches, Ramps		Hull Engineering
13-0	Wooden Masts and Spars	18-0	Bilge and Ballast System
1	Wood Hatch Covers	1	Cargo Oil System
2	Hold Ceiling and Sparring	2	Deck Steam and Ex. System
3	Miscellaneous Carpenter Work	3	Fire Mains
4	Wood Decks	4	San. and Fresh Water System
5	Wood Houses	5	Fuel Oil Transfer System
6	Composition Deck Covering	6	Vents, Sounding and Overflows
7	Sheet / Block Deck Tile	7	Cryogenic / Chem. Cargo Sys.
8	Ceramic / Misc. Deck Tile	8	Inert/ Nitrogen System
9	Cement and Misc. Coverings	9	Hydraulic System
	Carpenter Work and Decking		Piping
14-0	Interior Joiner Work	19-0	Deck Machinery
1	Furniture	1	Steer. Gear and Rudder
2		2	Communicating System
3	Joiner Decks	3	Electric Plant
4	Decorative Joiner Work	4	Dumb Waiters and Elevators
5	Accommodation Ladder	5	Auxiliary Boiler
6		6	Distiller. Plant (ship use)
7	Special Insulation	7	Stabilizers
8	Insulation in Quarters	8	Thrusters
9	Fire Insulation	9	Bulk Unloading
	Joiner Work		Miscellaneous Machinery

MACHINERY (Group 20-29)

CODE	ITEM
20-0	Main Propulsion
1	Turbine Drain and LeakOff System
2	Main Reduction Gears
3	Main Condenser
4	Main Air Ejector
5	Main Circulating System
6	
7	
	Main Propulsion Units
21-0	Feed Heaters
1	Feed and Condensate System
2	
3	
	Feed and Condensate Equip.
22-0	Makeup Feed System
1	Contaminated System
2	Salt Water Eva p. System
3	
4	
	Evaporator System
23-0	Shafting
1	Bearings and Stern Tube
2	Propellers
3	Miscellaneous Shafting Parts
4	Shafting and Propeller Spares
5	
6	
	Shafting and Propellers
24-0	Lube. Oil System
1	Miscellaneous Engine Oil Tanks
2	
3	
	Lubricating Oil System
25-0	Service Compressed Air Serv. Sys.
1	Starting Air System
2	Scavenger Air System
3	
4	
	Air System

CODE	ITEM
26-0	Boilers
1	Fuel Oil Burners
2	Soot Blowers
3	Boiler Draft System
4	Automatic Combustion Control
5	Stacks and Uptakes
6	F.O. Service System
7	LNG Boil Off System
8	
	Boilers and F.O. System
27-0	Main Steam Piping
1	Auxiliary Steam Piping
2	Exhaust and Escape Piping
3	Steam Drain System
4	Whistles
5	
6	
	Steam Piping
28-0	Access
1	Work Shop
2	Lifting and Handling Gear
3	Machinery Space Ventilation
4	Machinery Space Fixtures
5	Spare Parts
6	Miscellaneous Instruments and Gages
7	
8	
	Miscellaneous
29-0	Liquids in Machinery (Gr. 1219)
1	Water (Gr. 2028)
2	Oil (Gr. 2028)
3	
4	
	Liquids in Machinery

APPENDIX C

INCLINING EXPERIMENT GENERAL GUIDANCE

Inclining Experiment General Guidance

The following represents general guidance when planning as well as conducting an inclining experiment:

- An inclining experiment is the only satisfactory method of accurately determining the location of the center of gravity of a ship.[6, 7] The following paragraphs relate to actions that should be addressed in planning for the experiment:

1.. The accuracy of the inclining experiment is improved when the ship is as nearly complete as practicable, and therefore the inclining experiment should be conducted toward the end of the construction period, and in some cases where ship stability is in question, a deadweight survey or an inclining experiment is performed prior to any sea trials. Simply stated, the ship should be as near complete as practicable for the test. In most cases there is a requirement for the technical office (U.S. Navy, U.S. Coast Guard, American Bureau of Shipping, DNV, Owner, etc.) to officially witness the experiment, therefore the inclining procedure and schedule of events should be submitted for their review at least thirty days prior to the event.

2. A thorough cleaning of the ship should be conducted prior to the experiment. Weight surveys including estimates of weight and the longitudinal, transverse and vertical center of gravity locations must be conducted. The survey of (weights to deduct) is to determine the amount of foreign material such as scaffolding, or other construction material that is not part of lightship but may be onboard ship at the time of the inclining experiment. Another survey of (weights to add) is performed to determine all items which are part of the lightship but have not been put onboard. Additionally, a survey for items of lightship (weights to relocate) that are onboard but not in their final position must be identified, the moments that will result from the relocation of these items must be recorded. The information from the surveys will be used in the development of the inclining report. The surveys take advantage of the most accurate weight information available and in some cases require actual weighing of individual components.

3. The ship's trim and list should be as near to zero as practicable for the test to avoid having to make adjustments to the tank capacity and curves of form data. It is common practice to use concrete leveling blocks for this purpose. In addition, care must be exercised in the determination of the liquids in tanks and their associated free surface effect on the test. Ideally, tanks should be either completely full or completely empty for the experiment. An empty tank literally means that the tank is empty. The liquid below the suction has been removed through whatever means, this may include actually moping of tanks. Whereas a full tank means that the sounding is above the top of the tank. To prevent air pockets in tanks, air escapes are required at the highest point of the tank and heeling of the ship is necessary to assist in the removal of air while filling the tanks. In general, tanks that must contain liquid should be between 20 and 80 percent full, provided that calculations for free-surface effect can be calculated accurately. Additionally, a careful review of the piping systems must be performed to determine cross-connect piping, all valves must be closed to prevent any transfer of liquids.

4. Efforts should be made to reduce the number of people aboard during the test, and those onboard should stay in an assigned location during the experiment. In addition, doors, crane booms and boats should be secured to prevent swinging during the experiment.

5. All mooring lines should be well slacked while inclining measurements are being taken, and the gangways, fenders, and construction lines should be clear of the ship. Wind forces effect the accuracy of the test and it is recommended that should wind forces exceed 10 knots, the test should be delayed until the winds subside.

6. The displacement of the vessel is determined by reading the draft marks, therefore, it is important that the installation of the draft marks on the vessel be certified prior to the inclining experiment. When reading drafts, they should be taken simultaneously from boats located on the port and starboard sides. Readings are to be taken from the forward, amidships, and after draft marks at the time of the inclining. Some shipbuilders have developed a draft reading device made up of a clear tube with a hole in the bottom and a scale inside to help dampen out wave action. The U. S. Navy Technical Manual on weights and stability addresses the accuracy of reading drafts as "Draft readings should be taken to the nearest one-quarter of an inch."[6] The importance of weight measurement accuracy can be further emphasized by comparing a typical Navy destroyer's tons per inch of draft (TPI); whereas, one quarter of an inch equates to over 13 tons displacement. A larger ship such as the LHD Wasp Class, the reading to the nearest one-quarter of an inch will equate to over 38 tons displacement.

7. The most common device for measuring the angle of list is a pendulum constructed of a fine wire such as piano wire, of sufficient length, with a heavy plumb bob damped in a trough filled with heavy weight oil. A horizontal batten is attached to each trough for recording pendulum deflections. Another device, a u-tube made of clear vinyl or plastic and filled with water affixed to vertical battens is installed transversely port to starboard. When reading measurements, it is important to note that the ship should be allowed sufficient time to settle-out after each block movement.

- The following reflects a condensed version of the events of an inclining experiment:

1. The inclining experiment for some shipyards begins around midnight in an attempt to take advantage of typically calmer wind and sea conditions. A survey of weights to add, weights to deduct and weights to relocate is needed because it is the nature of ship construction to have unexpected changes in the day to day condition of the ship. All spaces should be included in the survey, including voids and spaces reported as empty. All doors and hatches are secured in their normally open or closed position. All tanks and voids should be sounded just prior to starting the experiment and also after the experiment. Specific gravity of the liquids in the tanks should be taken and recorded. The lengths of the pendulums or u-tubes should be measured and recorded, the position of the pendulum wire installation should be verified to ensure that the wire hangs from a knife edge to ensure a free swing of the wire. At this point the ship should be breasted out and basically free floating (all lines slack).

2. After the ship is determined ready for the test, all personnel onboard are instructed to remain in their assigned inclining experiment locations. Three draft readings are taken, individually at each of the three draft mark locations, the port and starboard readings should be taken simultaneously. Water samples should also be taken at this time from various locations and depths along the side of the ship to determine slip water density.

3. The next step of the experiment is to measure the inclination, First, all six battens are marked simultaneously to a zero point before any block movement takes place. A minimum of two movements to starboard and two to port are required. The distance each block is moved is measured from its initial position and recorded. After each block movement, and after the ship has stabilized from the block movement, the signal to read the measurement of the inclination is given. If the ship maintains some level of residual motion, the reading should be taken at the midpoint of the motion. Readings from all stations are taken simultaneously and marked on the battens. To maintain accuracy of the experiment, a novice should not be placed in a position to read and record the markings of the battens, since this task normally requires experience and practice to become proficient.

4. After each block movement, measurements are recorded and the tangents of the angles of inclination are plotted against the moments of the inclining weights. A straight line plot is desired, whereas variations in the straight line plot may indicate that conditions (wind, incorrect block weight, incorrect pendulum or utube measurement, etc.) may have adversely influenced the experiment. A plot other than a straight line should be investigated, and after checking in some cases some of the points of the plot may be discarded. If the plot is satisfactory, all battens are to be collected for verification of markings, plot sheets and other data needed to complete the inclining report.

5. The last step of the experiment is to take one final set of tank soundings. The inclining coordinator at this point shall announce the inclining experiment is complete.