INTERNATIONAL SOCIETY OF ALLIED WEIGHT ENGINEERS, INC. *Serving the Aerospace - Shipbuilding, Land Vehicle and Allied Industries* SAWE Corporate Address P.O. Box 60024, Terminal Annex Los Angeles, CA 90060	**RECOMMENDED PRACTICE NUMBER 13** **Issued** **June 5, 1996** **Revised**

Standard Coordinate System for Reporting Mass Properties of Surface Ships and Submarines

Issue No. 1

Prepared by
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Change Record

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Foreword

The technical responsibility for the content and currency of this recommended practice resides with the incumbent chairperson(s) of the Marine Systems Government/Industry Workshop of the Society of Allied Weight Engineers. Any comments or questions regarding this recommended practice should be addressed to the SAWE Executive Secretary, whose address is shown with the Title Page logo with attention to the Marine Systems Government/Industry Workshop.

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1.0 Introduction

The purpose of this Recommended Practice is to establish a uniform three-coordinate system for surface ships and submarines (both submerged and surfaced). This coordinate system will be used in the determination of centers-of-gravity and weight moments of inertia as they relate to the three rotational degrees of freedom, roll, pitch and yaw. It further defines the preferred origin for centers-of-gravity. There are several origin conventions in use for surface ships and submarines and this Recommended Practice defines the preferred conventions with their applicability.

2.0 Definition of Terms

Center-of-Gravity - The center through which all weights which make up the ship and its contents may be assumed to act. This center has the conventional meaning used in mechanics when it applies to a ship (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).

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.

Longitudinal lever - 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.

Moment - The product of an item's weight times the perpendicular distance of the item's center-of-gravity about the referenced axis.

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

Referenced origin - The location of the intersection of the x. y and z axis referenced to the ship/submarine.

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

Transverse lever - The transverse lever is the perpendicular distance from the vertical centerline plane of the ship to the center-of-gravity of an item.

Vertical lever - 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.

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

3.0 Standard Coordinate System

The standard coordinate system for surface ships and submarines defines the axis orientation which is used to define the location of the center-of-gravity as well as the inertia characteristics.

3.1 Surface Ships

The standard axes for surface ships are shown in Figure 1. 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.

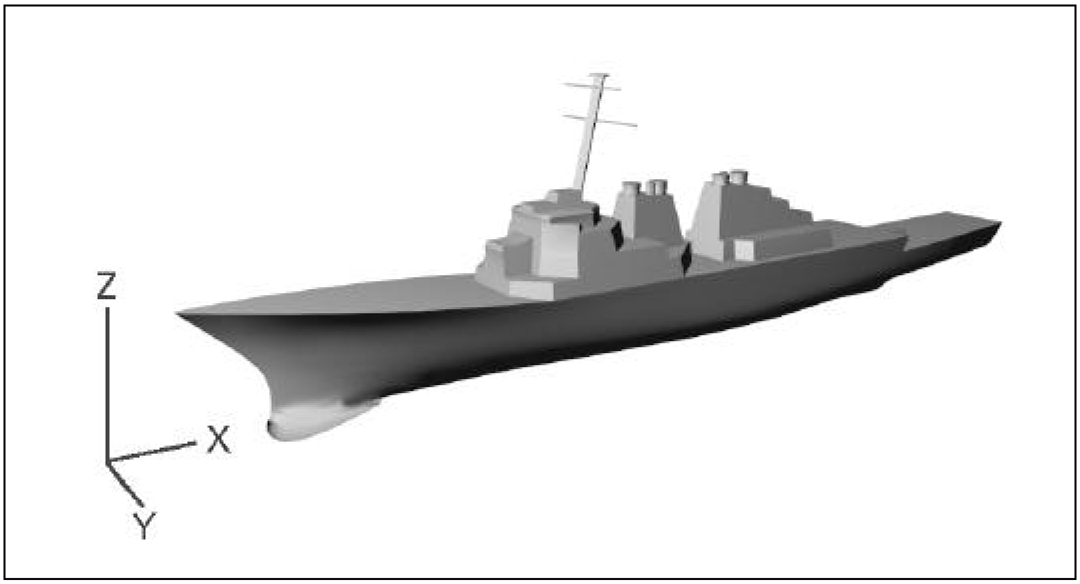

Figure 1 - Isometric view of surface ship with standard coordinate system

3.2 Submarines

The standard axes for submarines are shown in Figure 2. These axes are the same whether the submarine is submerged or on the surface. The coordinate system for submarines is identical to that for surface ships.

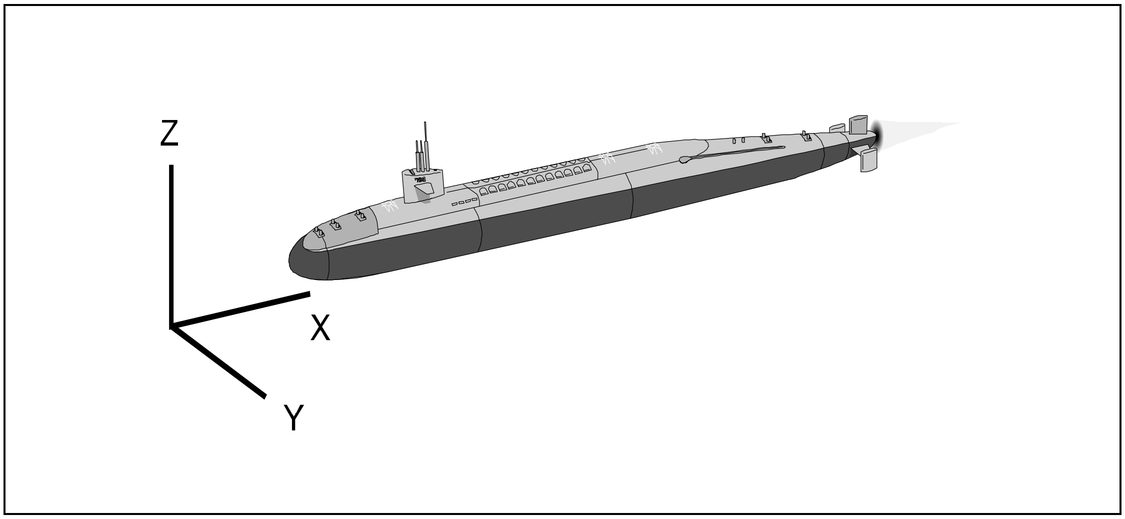

Figure 2 - Isometric view of submarine with standard coordinate system

3.3 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).

3.3.1 Referenced Origin

The location of the center-of-gravity of a surface ship or submarine is defined relative to the three axes shown in Figures 1 and 2. Distances are measured along the three axes from a referenced origin as shown in Figure 3. The recommended referenced origin for a surface ship or submarine is the intersection of the 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.

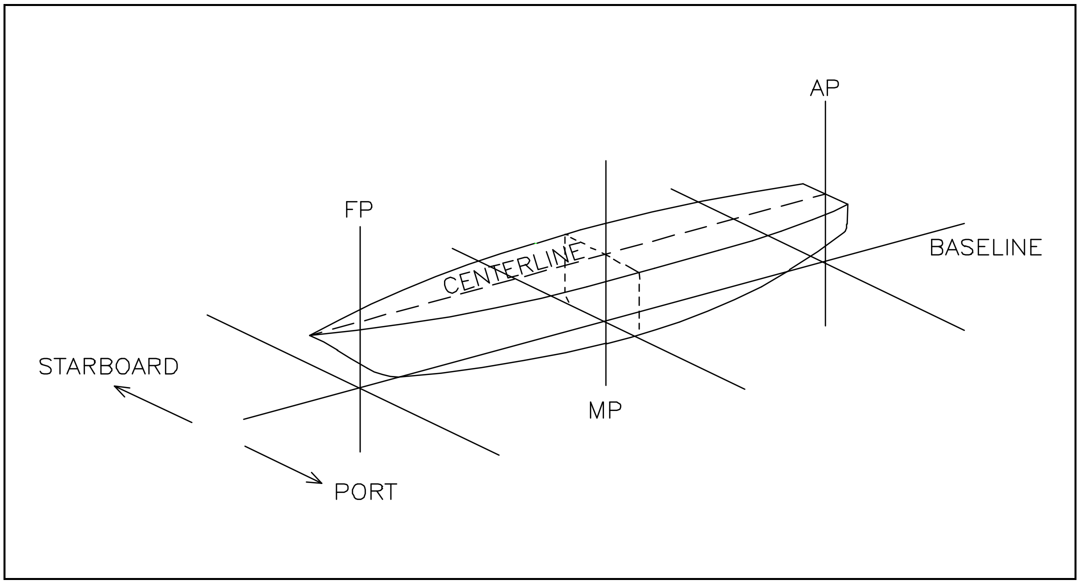

Figure 3 - Referenced origins

3.3.2 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 in each direction. 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.

4.0 Weight Moment of Inertia/Gyradius

The weight moment of inertia of a ship or submarine 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 4. 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 (1) documents the methodology used in calculating and projecting weight moment of inertia/gyradius values for naval surface ships. It also contains a comparative analysis of calculated weight moment of inertia values among the ships, as well as the results of a sensitivity analysis on their relationship.

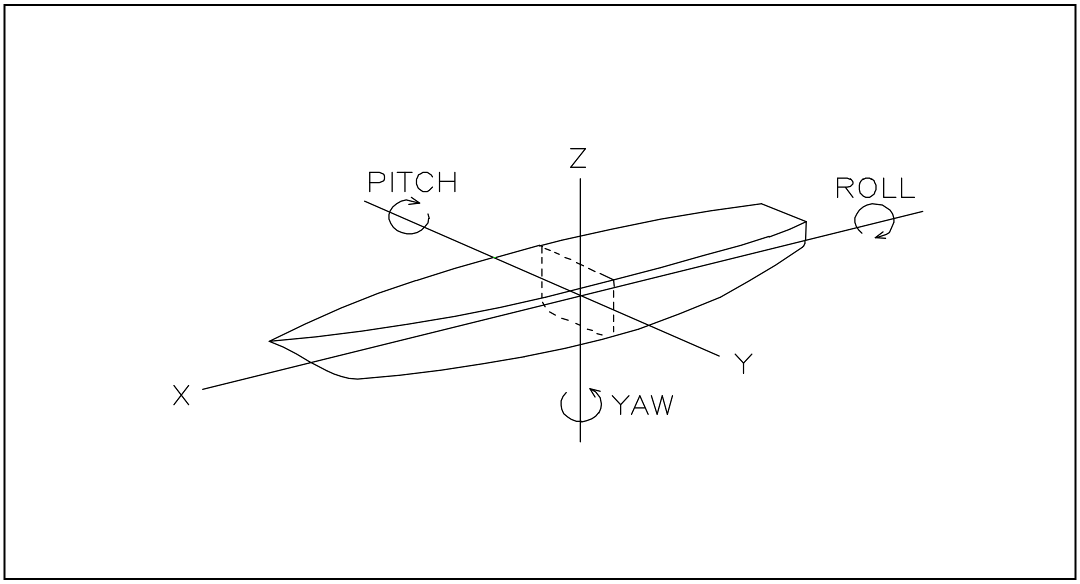

Figure 4 - Three Rotational Motions of a Ship

The total weight moment of inertia (I) for a ship or submarine is the sum of the totals of the item weight moment of inertia and the transference weight moment 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 or submarine'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.

4.1 Weight Moment of Inertia

The weight moment of inertia consists of the summation of the transference inertia (I_t) and item inertia (I_o). The weight moment of inertia about the three rotational axes are expressed as:

roll inertia:

$$I_{xx} = \sum_n \left[w_n \left(y_n^2 + z_n^2 \right) \right] + \sum_n i_{ox_n}$$

or

$$I_{xx} = I_{tx} + I_{ox}$$

pitch inertia:

$$I_{yy} = \sum_n \left[w_n \left(x_n^2 + z_n^2 \right) \right] + \sum_n i_{oy_n}$$

or

$$I_{yy} = I_{ty} + I_{oy}$$

yaw inertia:

$$I_{zz} = \sum_n \left[w_n \left(x_n^2 + y_n^2 \right) \right] + \sum_n i_{oz_n}$$

or

$$I_{zz} = I_{tz} + I_{oz}$$

where;

w_n = weight of the n_{th} element

x_n = longitudinal distance of the n_{th} element from the ship's or submarine's overall CG to the item's CG along the x-axis

y_n = transverse distance of the n_{th} element from the ship's or submarine's overall CG to the item's CG along the y-axis

z_n = vertical distance of the n_{th} element from the ship's or submarine's overall CG to the item's centroid CG along the z-axis

i_{ox_n} = weight moment of inertia of the n_{th} element about an axis parallel to the x-axis and passing through the CG of the n_{th} element.

i_{oy_n} = weight moment of inertia of the n_{th} element about an axis parallel to the y-axis and passing through the CG of the n_{th} element.

i_{oz_n} = weight moment of inertia of the n_{th} element about an axis parallel to the z-axis and passing through the CG of the n_{th} element.

I_{ox} = sum of the item weight moments of inertia for all elements about an axis parallel to the x-axis

I_{oy} = sum of the item weight moments of inertia for all elements about an axis parallel to the y-axis

I_{oz} = sum of the item weight moments of inertia for all elements about an axis parallel to the z-axis

I_{tx} = sum of the transference weight moments of inertia for all elements about an axis parallel to the x-axis

I_{ty} = sum of the transference weight moments of inertia for all elements about an axis parallel to the y-axis

I_{tz} = sum of the transference weight moments of inertia for all elements about an axis parallel to the z-axis

4.2 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.

Gyradius for roll is: $K_{xx} = \sqrt{\dfrac{I_{xx}}{\Delta}}$

Gyradius for pitch is: $K_{yy} = \sqrt{\dfrac{I_{yy}}{\Delta}}$

Gyradius for yaw is: $K_{zz} = \sqrt{\dfrac{I_{zz}}{\Delta}}$

A simplified representation of the methodology used to determine the roll gyradius of an item is shown in Figure 5. The gyradius calculation for pitch and yaw are similar to that for roll, except that the axes orientation for pitch and yaw are different.

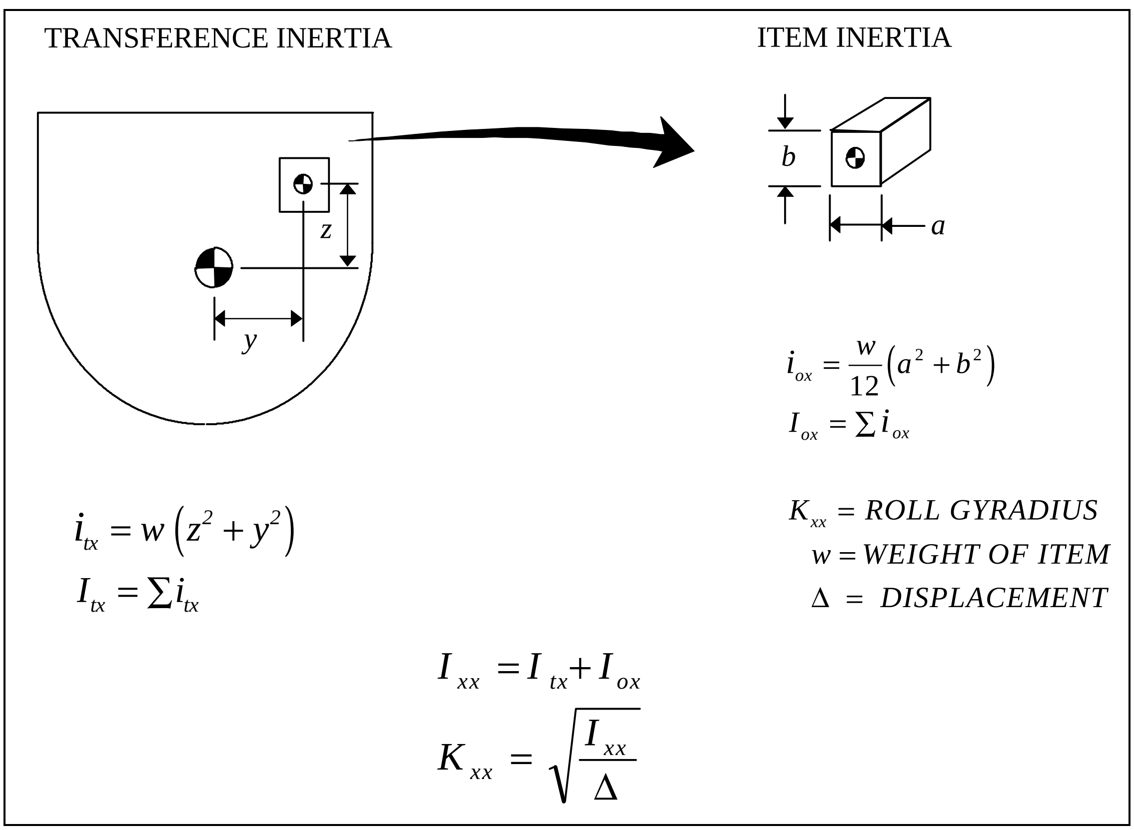

Figure 5 - Roll Gyradius Calculation

5.0 References

Reference | Title

1 "Naval Ships' Weight Moment of Inertia - A Comparative Analysis", Dominick Cimino and Mark Redmond, Society of Allied Weight Engineers, Paper No. 2013, May 1991