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An American National Standard

# Standard Guide for Conducting a Stability Test (Lightweight Survey and Inclining Experiment) to Determine the Light Ship Displacement and Centers of Gravity of a Vessel[1]

This standard is issued under the fixed designation F1321; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

## INTRODUCTION

This guide provides the marine industry with a basic understanding of the various aspects of a stability test. It contains procedures for conducting a stability test to ensure that valid results are obtained with maximum precision at a minimal cost to owners, shipyards, and the government. This guide is not intended to instruct a person in the actual calculation of the light ship displacement and centers of gravity, but rather to be a guide to the necessary procedures to be followed to gather accurate data for use in the calculation of the light ship characteristics. A complete understanding of the correct procedures used to perform a stability test is imperative to ensure that the test is conducted properly and so that results can be examined for accuracy as the inclining experiment is conducted. It is recommended that these procedures be used on all vessels and marine craft.

## 1. Scope

1.1 This guide covers the determination of a vessel's light ship characteristics. In this standard, a vessel is a traditional hull-formed vessel. The stability test can be considered to be two separate tasks; the lightweight survey and the inclining experiment. The stability test is required for most vessels upon their completion and after major conversions. It is normally conducted inshore in calm weather conditions and usually requires the vessel be taken out of service to prepare for and conduct the stability test. The three light ship characteristics determined from the stability test for conventional (symmetrical) ships are displacement ("*displ*"), longitudinal center of gravity ("*LCG*"), and the vertical center of gravity ("*KG*"). The transverse center of gravity ("*TCG*") may also be determined for mobile offshore drilling units (MODUs) and other vessels which are asymmetrical about the centerline or whose internal arrangement or outfitting is such that an inherent list may develop from off-center weight. Because of their nature, other special considerations not specifically addressed in this guide may be necessary for some MODUs. This standard is not applicable to vessels such as a tension-leg platforms, semi-submersibles, rigid hull inflatable boats, and so on.

1.2 The limitations of 1 % trim or 4 % heel and so on apply if one is using the traditional pre-defined hydrostatic characteristics. This is due to the drastic change of waterplane area. If one is calculating hydrostatic characteristics at each move, such as utilizing a computer program, then the limitations are not applicable.

1.3 The values stated in inch-pound units are to be regarded as standard. No other units of measurement are included in this standard.

1.3.1 *Exceptions*—Other units may be used for the stability test, but the test results should be reported in the same units and coordinate system as the vessel's draft marks and Trim and Stability Book or similar stability information provided.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

[1] This guide is under the jurisdiction of ASTM Committee F25 on Ships and Marine Technology and is the direct responsibility of Subcommittee F25.01 on Structures.

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## 2. Referenced Documents

2.1 *ASTM Standards:*[2]
E100 Specification for ASTM Hydrometers

## 3. Terminology

3.1 *Definitions:*

3.1.1 *inclining experiment, n*—involves moving a series of weights, in the transverse direction, and then measuring the resulting change in the equilibrium heel angle of the vessel. By using this information and applying basic naval architecture principles, the vessel's vertical center of gravity *KG* is determined.

3.1.2 *Condition 1, n*—vessel in Condition 1 is a vessel complete in all respects, but without consumables, stores, cargo, crew and effects, and without any liquids on board except machinery fluids, such as lubricants and hydraulics, are at operating levels. Condition 1 is sometimes referred to as "operational light ship."

3.1.3 *Condition 0, n*—vessel in Condition 0 is a vessel as inclined.

3.1.4 *lightweight survey, n*—this task involves taking an audit of all items which must be added, deducted, or relocated on the vessel at the time of the stability test so that the observed condition of the vessel can be adjusted to the light ship condition. The weight, longitudinal, transverse, and vertical location of each item must be accurately determined and recorded. Using this information, the static waterline of the ship at the time of the stability test as determined from measuring the freeboard or verified draft marks of the vessel, the vessel's hydrostatic data, and the seawater density; the light ship displacement and longitudinal center of gravity can be obtained. The transverse center of gravity may also be calculated, if necessary.

3.1.5 *relative density, n*—(formerly known as *specific gravity*)—ratio of the mass of a given volume of material at a stated temperature to the mass of an equal volume gas free distilled water at the same or different temperatures. Both referenced temperatures shall be explicitly stated.

## 4. Significance and Use

4.1 From the light ship characteristics one is able to calculate the stability characteristics of the vessel for all conditions of loading and thereby determine whether the vessel satisfies the applicable stability criteria. Accurate results from a stability test may in some cases determine the future survival of the vessel and its crew, so the accuracy with which the test is conducted cannot be overemphasized. The condition of the vessel and the environment during the test is rarely ideal and consequently, the stability test is infrequently conducted exactly as planned. If the vessel is not 100 % complete and the weather is not perfect, there ends up being water or shipyard trash in a tank that was supposed to be clean and dry and so forth, then the person in charge must make immediate decisions as to the acceptability of variances from the plan. A complete understanding of the principles behind the stability test and a knowledge of the factors that affect the results is necessary.

## 5. Theory

5.1 *The Metacenter*—(See Fig. 1). The transverse metacenter ("*M*") is based on the hull form of a vessel and is the point around which the vessel's center of buoyancy ("*B*") swings for small angles of inclination (0° to 4° unless there are abrupt changes in the shape of the hull). The location of *B* is fixed for any draft, trim, and heel, but it shifts appreciably as heel increases. The location of *B* shifts off the centerline for small angles of inclination ("$\theta$"), but its height above the molded keel ("*K*") will stay essentially the same. The location of *M*, on the other hand, is essentially fixed over a range of heeling angles up to about 4°, as the ship is inclined at constant displacement and trim. The height of *M* above *K*, known as "*KM*", is often plotted versus draft as one of the vessel's curves of form. As a general "rule of thumb," if the difference from the design trim of the vessel is less than 1 % of its length, the *KM* can be taken directly from either the vessel's curves of form or hydrostatic tables. Because *KM* varies with trim, the *KM* must be computed using the trim of the ship at the time of the stability test when the difference from the design trim of the vessel is greater than 1 % of its length. Caution should be exercised when applying the "rule of thumb" to ensure that excessive error, as would result from a significant change in the waterplane area during heeling, is not introduced into the stability calculations.

5.2 *Metacentric Height*—The vertical distance between the center of gravity ("*G*") and *M* is called the metacentric height ("*GM*"). At small angles of heel, *GM* is equal to the initial slope of the righting arm ("*GZ*") curve and is calculated using the relationship, $GZ = GM \sin \theta$. *GM* is a measure of vessel stability that can be calculated during an inclining experiment. As shown in Fig. 1 and Fig. 2, moving a weight ("*W*") across the deck a distance ("*x*") will cause a shift in the overall center of gravity (*G–G'*) of the vessel equal to $(W)(x)/displ$ and parallel to the movement of *W*. The vessel will heel over to a new equilibrium heel angle where the new center of buoyancy, *B'*, will once again be directly under the new center of gravity (*G'*). Because the angle of inclination during the inclining experiment is small, the shift in *G* can be approximated by

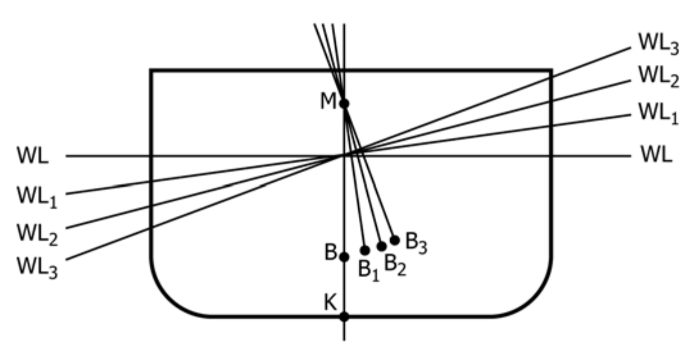

FIG. 1 Movement of the Center of Buoyancy

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

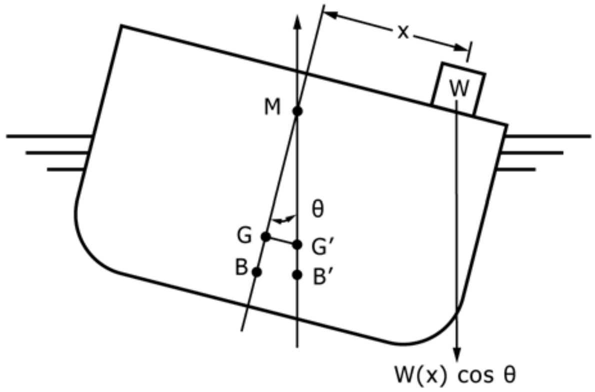


FIG. 2 Metacentric Height

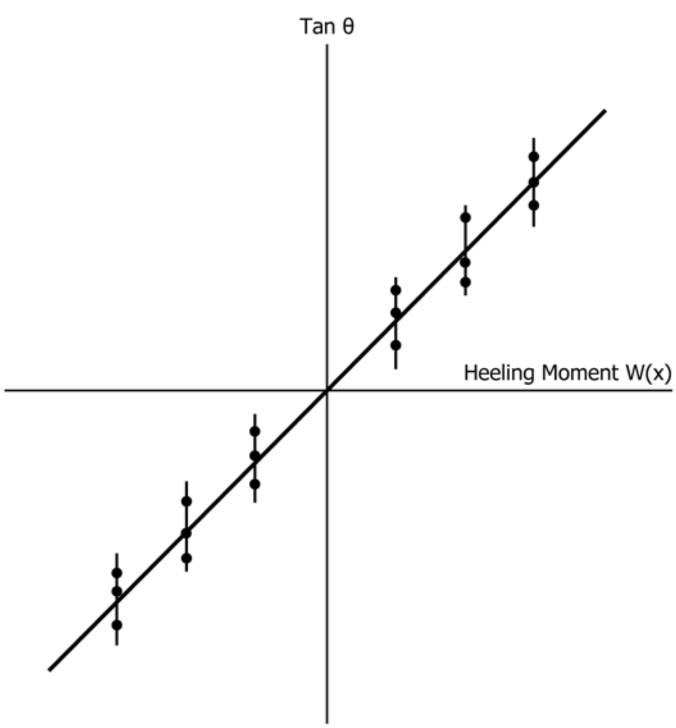


FIG. 3 A Typical Incline Plot

*GMtan θ* and then equated to (*W*)(*x*)/*displ*. Rearranging this equation slightly results in the following equation:

$$GM = \frac{(W)(x)}{(displ)(\tan\theta)} \quad (1)$$

Since *GM* and *displ* remain constant throughout the inclining experiment the ratio (*W*)(*x*)/*tan θ* will be a constant. By carefully planning a series of weight movements, a plot of tangents is made at the corresponding moments. The ratio is measured as the slope of the best represented straight line drawn through the plotted points as shown in Fig. 3, where three angle indicating devices have been used. This line does not necessarily pass through the origin or any other particular point, for no single point is more significant than any other point. A linear regression analysis is often used to fit the straight line.

5.3 *Calculating the Height of the Center of Gravity Above the Keel—KM* is known for the draft and trim of the vessel during the stability test. The metacentric height, *GM*, as calculated above, is determined from the inclining experiment. The difference between the height *KM* and the distance *GM* is the height of the center of gravity above the keel, *KG*. See Fig. 4.

5.4 *Measuring the Angle of Inclination*—(See Fig. 5.) Each time an inclining weight, *W*, is shifted a distance, *x*, the vessel will settle to some equilibrium heel angle, *θ*. To measure this angle, *θ*, accurately, pendulums or other precise instruments are used on the vessel. When pendulums are used, the two sides of the triangle defined by the pendulum are measured. ("*Y*") is the length of the pendulum wire from the pivot point to the batten and ("*Z*") is the distance the wire deflects from the reference position at the point along the pendulum length where transverse deflections are measured. *Tangent θ* is then calculated:

$$\tan\theta = Z/Y \quad (2)$$

After each weight movement, plotting all of the readings for each of the pendulums during the inclining experiment aids in the discovery of bad readings. Since (*W*)(*x*)/*tan θ* should be constant, the plotted line should be straight. Deviations from a straight line are an indication that there were other moments acting on the vessel during the inclining. These other moments must be identified, the cause corrected, and the weight movements repeated until a straight line is achieved. Figs. 6-9 illustrate examples of how to detect some of these other moments during the inclining and a recommended solution for each case. For simplicity, only the average of the readings is shown on the inclining plots.

5.5 *Free Surface*—During the stability test, the inclining of the vessel should result solely from the moving of the inclining weights. It should not be inhibited or exaggerated by unknown moments or the shifting of liquids on board. However, some liquids will be aboard the vessel in slack tanks so a discussion of "free surface" is appropriate.

5.5.1 *Standing Water on Deck*—Decks should be free of water. Water trapped on deck may shift and pocket in a fashion similar to liquids in a tank.

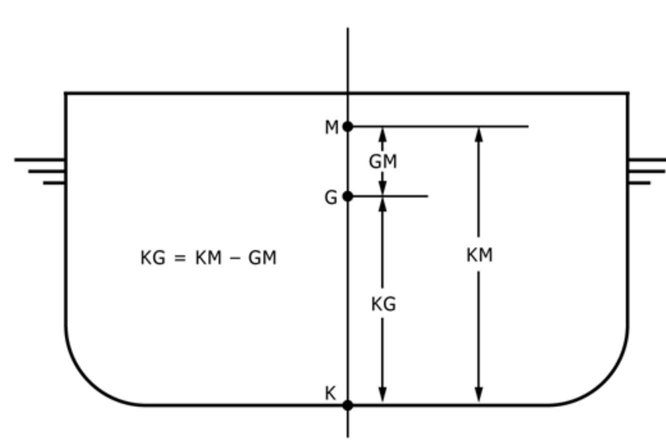


FIG. 4 Relationship between *GM*, *KM*, and *KG*