

**Development of a Standard Method for
Measuring the Buoyancy-to-Weight Ratio for
Oil Spill Containment Boom**

Prepared for:

**Minerals Management Service
Herndon, VA**

Prepared by:

**S.L. Ross Environmental Research Limited
Ottawa, Ontario**

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Disclaimer

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1. Introduction

In a study funded by the Minerals Management Service, a total of 31 containment boom tests were reviewed dating from 1975 and 1999 (Schulze and Lane 2001). Much of the testing was performed at Ohmsett, but some tests were done at other simulation facilities and others were performed in offshore conditions. The study suggested that better boom performance was achieved with increased buoyancy-to-weight, and that the oil loss rate was directly related to boom draft. Results of a recent study performed at Ohmsett (Potter 2003) indicate that better boom performance is indeed found with increasing buoyancy. The buoyancy to weight ratio is also of interest in classifying a boom for different service environments; for example, ASTM standard F1523 specifies a minimum buoyancy-to-weight of 3:1 for calm water conditions, 4:1 for protected waters, and 8:1 for offshore use. However, at present, there is no standard methodology for calculating or measuring the buoyancy-to-weight ratio of a boom.

The American Society for Testing and Materials (ASTM) F20 subcommittee on booms has recognized this shortcoming and members have long suggested that a standard be developed to measure this important boom characteristic. Their need for such a standard has been based on two elements: the obvious need for a standardized methodology, but also to establish an agreement on the elements that should and should not be included in a buoyancy measurement or calculation.

As part of the 2003 work at Ohmsett cited above, the buoyancy-to-weight ratio was measured for several booms. The results indicate that it can be measured fairly accurately using simple equipment available at the Ohmsett facility, and that the results show a good correlation with calculation methods (i.e., estimating weights and displacements of individual boom components).

However, there are limitations to the techniques used in the 2003 study. First, the techniques and equipment used for measuring buoyancy, while suitable for the relatively small booms studied, would not be applicable to larger booms such as those that would be used in offshore response. Second, some of the equipment used for the measurements was ad-hoc and should be refined to

lessen any inherent errors and provide confidence that the technique could be used as a standardized methodology.

2. Objective and Goals

The objective of the proposed work was to develop a standard method for measuring the buoyancy-to-weight ratio of oil spill containment boom.

The following tasks were performed to meet the study objective:

- Existing methods for estimating a boom's buoyancy to weight were reviewed.
- A direct measurement methodology, applicable to a range of boom types and sizes, was developed for use at the Ohmsett facility.
- The methodology was validated through testing at Ohmsett.
- A draft standard was prepared based on this methodology, and submitted to the ASTM subcommittee on booms to initiate the process for consensus approval.

3. Existing Standards And Calculation Methods

A number of boom manufacturers and suppliers were contacted to determine what methods were currently used to measure or calculate a boom's buoyancy to weight ratio. The results of this are summarized as follows.

- No manufacturers use a direct measurement technique to determine the displacement of a constructed boom or boom segment.
- The most common method of estimating buoyancy is to measure the dimensions of the various boom components, and then calculate their displacement (and hence, their buoyancy) based on this.

- Some manufacturers have used a direct measurement technique to determine the displacement of boom components, for example, for irregularly-shaped floats whose dimensions can not be easily or accurately measured.
- Unit values for displacement of skirt materials are very difficult to measure accurately, but are thought to be insignificant to the total displacement of a boom, and are often ignored as a result.
- Weights are typically estimated during the design process, using unit weights provided by component suppliers (e.g., ounces per square yard of skirt material).
- The assembled boom is typically weighed prior to delivery to the customer, as it is of interest for shipping purposes.
- Although most booms have a “standard section length” (which varies from model to model), manufacturers will generally produce a boom in any length that the customer requests. As a result, it is common to quote weights and displacements as a unit value of pounds per linear foot. This number generally ignores the weight of the connector assembly, which can be significant in some cases.
- There is some confusion on the use of the terms “gross buoyancy” and “reserve buoyancy”, which of the two should be specified, and which elements of buoyancy should be included in each of the two.
- Manufacturers generally supported the idea of a standardized methodology, particularly from the perspective of establishing which components of a boom should be included in the calculation or measurement, and which components need not be considered.

4. Development of a Test Methodology

4.1 *Alternative Approaches*

Two general methods were considered for measuring boom buoyancy. The first method would involve immersing a section of boom in a tank and measuring the volume of water displaced by the boom. This is the method that was used in the study in 2003, albeit with much smaller boom than was envisioned for this series of tests. The second possible method that was considered was to measure the force required to submerge a section of boom in the main tank at Ohmsett. The main considerations for these two methods are discussed below.

Using the displacement method, with several inshore booms, required a small portable tank of approximately 500 gallons. For larger offshore booms, a much larger tank would be required. A number of candidate booms that could be made available for testing were examined for their dimensions and estimated weights and buoyancies. It was determined that a 30 cubic yard, open-top trash container (aka dumpster) could accommodate at least a 50-foot length of a typical offshore boom, which is a standard section length for many booms. The 20-foot length of the container would accommodate at least a full segment length of most booms, and one or more segments could be fit into the tank if they were doubled back along each other. It was estimated that a section length of offshore boom would have a total buoyant force in the range of 5,000 to 15,000 lbs. A restraining device would have to be built to fit within the dumpster to resist this force and hold the boom under water.

Consideration was also given to performing the test in the main tank at Ohmsett, and measuring the force to submerge the boom. This would have necessitated designing a netting or cabling system to effectively capture the boom such that it could be pulled under water by a small number (preferably two) of cables rigged with load cells. Based on the estimated buoyancies, the required resisting force would be in the range of 2,000 to 8,000 lbs per cable, which would have been feasible using one or more of the concrete blocks available from a previous study at Ohmsett on breaking waves. There were two major areas of concern with this approach. One was that the depth of the tank (8 feet) might not be sufficient to fully submerge an offshore boom in this manner: although the total boom height would be in the range of 5 feet, and additional depth

of 3 feet or perhaps more would be required for the rigging and load cells. There was also concern that it would be extremely difficult to ensure that the rigging would be vertical leading into the load cells, or alternatively, that the angle of the rigging could be accurately measured. In either case, it would be impossible to resolve the submerging force into vertical and horizontal components as would be required.

It was also felt that this method offered no advantages in what was perceived to be the major potential measurement error, the trapping of air within the boom segments. In fact, because the boom segments would be gathered together as the boom was submerged, it was thought that there might be a greater likelihood of inadvertently trapping of air between boom segments, and less opportunity to attempt to release the air during the measuring process.

For these reasons it was decided to proceed with the displacement method for the test methodology.

4.2 Equipment Considerations for Displacement Measurement

Dumpsters are generally not completely water-tight, so two layers of plastic sheeting were prepared to line the inside of the container (Figure 1). A steel frame was also designed by Ohmsett staff to fit within the dumpster and hold the boom under water. The frame is shown in Figures 2 and 3. Figure 2 shows the basic structure of the frame as it is being lowered into the tank. In Figure 3, a series of 2x8 planks have been inserted into the C-channel that forms the bottom of the frame. Also in Figure 3, the six vertical members of the frame are shown bolted to angle iron that spanned the dumpster and secured the frame to the sides of the dumpster. The frame could be bolted at several different heights depending on the size of the boom to be tested.

A flow totalizer (Figure 4) was fitted to the water supply; it provided a digital readout of total volume delivered per test. Ohmsett staff confirmed its accuracy to be within $\pm 0.1\%$ in a calibration test prior to the test series (MAR 2004).



Figure 1: Installation of liner inside tank



Figure 2: Restraining grid being lowered into tank



Figure 3: Restraining grid in position within tank



Figure 4: Flow totalizer fitted to water supply line

4.3 Test Procedure

A total of four booms were tested in the apparatus described above, with one additional boom tested in a smaller tank using a similar procedure.

Prior to the start of each test, the tank was emptied of water and the liners were visually inspected for tears. When a previous test had indicated a leak, an attempt was made to patch the liner. Thick rubber mats were laid out on the bottom of the tank to protect the liner from damage. As the boom was put into the tank, these mats would be moved to the areas of greatest concern such as the boom's end connectors (Figure 5).



Figure 5: Rubber mats positioned near boom end connectors to protect liner

The boom was then put into the tank (Figure 6), doubling it back on itself to fit within the tank (Figure 7). For inflatable booms, the boom was then inflated to its design pressure, and the pressure checked with a dial gauge.

The restraining grid was then positioned within the tank and lowered to the appropriate height above the boom. The position of the grid was such that the boom could float freely with its skirt in a vertical position. This allowed the test crew to inspect the boom while water was being added to the tank, and to jostle the boom membrane to ensure that air was not trapped between boom segments or between folds in the skirt.

Water was then added to the tank until the boom was completely submerged. As the planks restraining the boom tended to bow upwards from the buoyant force of the boom, this meant that the planks had to be submerged as well. A mark was established on the grid to which the tank was filled for each test, and the vertical location of the mark verified with a combination square that was placed on the grid frame at its southeast corner. The tank was filled to the mark with the boom in position beneath the grid. When all tests had been completed, the tank was refilled to the mark with the boom out of the tank but with all other equipment (i.e., the grid, liner, mats) in their operating position. The difference between these two volumes was taken to be the displacement of the boom.

For two of the booms, it was not possible to fit the entire section length within the tank. For these booms, several boom segments were put into the tank, inflated, and measured as described above. The results were then scaled up appropriately for the full section length.

Booms were weighed using a 4,000-lb load cell (stated accuracy, $\pm 0.15\%$, or ± 6 lbs, MAR 2004) rigged to the forks of a lift truck. The boom to be weighed was set on a wooden pallet, which, along with the lift rigging, was weighed separately as the tare weight. Both measurements were repeated to produce at least three measurements, which were then averaged to produce a result.



Figure 6: Boom being placed within tank



Figure 7: Boom doubled back on itself within tank

4.4 Description of Booms Tested

A goal of this study was to develop a test that would be applicable to a range of boom sizes and types. In particular, this meant testing relatively large booms suitable for offshore conditions. This category of boom has a height of 3 to 5 feet (or more). Most booms in this category use air-filled floatation chambers as opposed to the solid foam floatation often used for inshore booms. Three such booms were selected for testing. Of these three, two were complete standard-length versions of the boom, while the third was a short piece of boom, two floatation segments long, made for training and demonstration purposes. In addition, one boom that uses solid-foam floatation, and that was tested in the 2003 study, was also used. Finally, a small, inshore boom with solid plastic floatation was selected. The boom characteristics are summarized below. Note that, as the objective of the study was to evaluate test methodology rather than evaluate booms, the products used in the study are identified only as boom ‘A’, ‘B’, and so on.

Table 1: Booms selected for use in study

Boom	A	B	C	D	E
Applicable Environment	offshore	offshore	offshore	Calm / protected	Calm / protected
Floatation Type	Air-inflatable	Air-inflatable	Air-inflatable	Rolled-foam	Foam-filled plastic floats
Boom height, inches	67	50	59	24	24
Estimated B:W Ratio	15:1	13:1	10:1	13:1	3:1

5. Test Results

5.1 Measured Buoyancy-to-Weight Ratios

Table 2 summarizes the measured weights and buoyancies, and compares them with the values estimated by the manufacturer. The weights were calculated from manufacturer supplied unit weights (pounds per foot) plus estimated connector weights. Buoyancies were similarly calculated from manufacturer supplied unit buoyancies (pounds per foot).

Table 2: Summary of estimated and measured weights and buoyancies

Boom	A	B	C	D	E
Estimated Weight, lbs	935	855	188	291	266
Measured Weight, lbs	967 (+3.4%)	932 (+8.9%)	201 (+7.0%)	289 (-0.6%)	281 (+5.6%)
Estimated Buoyancy, lbs.	14,355	11,495	1,172	3,770	847
Measured Buoyancy, lbs	12,943 (-9.8%)	9,934 (-14%)	1,005 (-14%)	2,807 (-26%)	802 (-5.3%)
Estimated B:W Ratio	15	13	6.2	13	3.2
Measured B:W Ratio	13 (-13%)	11 (-21%)	5.0 (-20%)	9.7 (-25%)	2.9 (-10%)
All booms full-length sections except 'C', which was two segments in length.					

In all but one case, the weight of the boom was underestimated (by 3 to 10%) and the buoyancy of the boom was overestimated (by 5 to 26%). The net effect was that the buoyancy-to-weight ratio was overestimated in every case, by 10 to 25%.

The buoyancy measurement was repeated twice for one boom (Boom D) to observe the repeatability of the test procedure. The results are shown in Table 3. Tests #1 and #3 had virtually identical results, varying by 0.3%, while as a whole the results are within $\pm 5\%$ of the average.

Table 3: Tests to confirm repeatability

	Volume of Water Added to Tank, gallons	Volume of Boom, gallons	Boom Displacement, pounds	Variance
Test #1	2273	327	2732	-2.7%
Test #2	2247	353	2949	+5.1%
Test #3	2272	328	2740	-2.4%
Average	--	--	2807	

Volume of water added without boom = 2601 gallons.
Variance measured against average.

5.2 Discussion

It was somewhat surprising that the measured weights varied as much as they did when compared with manufacturer-estimated weights (average variance of 5%) in view of the fact that this measurement is easily made and subject to little inherent error. There is no simple explanation for this: the booms were all in essentially new condition, dry, clean of any marine growth, and free of any ancillary equipment.

Buoyancies were all lower than estimated by the respective manufacturers. There are several areas of the test procedure that could have allowed errors in the measurement. The volumetric measurement of water delivered to the tank is probably not a major source of error: the totalizer was calibrated prior to and during the test and showed no variability. Further, the duplicate tests with one of the booms indicate little inherent error in fluid measurement.

A major concern with the test method is the potential for trapping air between floatation chambers or within folded-over portions of the skirt or sail. (Note that trapped air would lead to an increase in apparent buoyancy.) It was not felt that this was a problem in this set of tests based on periodic observation of the boom as the tank was filled, and manual agitation of the boom to ensure that trapped air was freed from the boom.

The fact that all but one weight estimate was low, and all buoyancy estimates were high may indicate that there is an inherent bias on the part of manufacturers in estimating the buoyancy-to-

weight ratio of a boom. However, in no case was the “error” significant enough to change the classification of a boom from offshore to protected-water designation, or protected to calm-water.

5.3 *Issues Encountered During Testing*

Despite the use of two liners within the tank, protective mats at critical areas to protect the liners from damage, and taking great care when placing the boom within the tank, the liner was damaged on several occasions during the tests. In no case was the damage enough to cause significant leaks, and the leaks were captured with a number of drip trays so that the leaked water could be added back to the tank and not affect the measured values. In future, it would probably be easier and more effective to dispense with the liners and instead seal the tank door with flexible caulking or other like material.

As noted above, the boom was periodically inspected during the filling process to ensure that air was not trapped within the boom. In only one case was any significant amount of air released during this inspection, which speaks well for the care taken in setting the boom in place initially and avoiding any folds in the boom membrane. Nonetheless, to have confidence in this technique, it is important that such an inspection be performed. This means that the filling process should be done over a period of no less than one or two hours to allow ample time for inspection and agitation of the boom.

5.4 *Preparation of Draft ASTM Test Standard*

Based on the results of this study, a draft test standard was prepared and submitted to the ASTM subcommittee at the February 2004 meeting. The draft is attached, as Appendix A. Further work on the standard will include soliciting comments on the draft standard from users and manufacturers in the time period leading up to the next ASTM meeting in October 2004. Based on this review, the standard will be revised accordingly, reviewed again by the subcommittee, and prepared for balloting and approval.

In the ongoing review process, comments will be sought on the following items in particular:

- Agreement on which components should be included in a buoyancy measurement or calculation. One contentious item is whether or not to include components that may lose buoyancy through ordinary use, and thus should not be included in buoyancy measurements or calculations.
- Use of direct measurement techniques for irregularly-shaped components whose dimensions cannot be accurately measured and whose volume cannot be accurately calculated.
- Inherent errors due to air trapped by flotation, skirt, or sail elements.
- Other concerns that may affect accuracy, precision, and repeatability.

6. Conclusions

Tests were performed on five different booms to determine their buoyancy-to-weight ratio through a direct measurement technique. The goal was to develop a simple technique that could be used to determine this fundamental characteristic of an oil spill containment boom.

The technique that was used is based on measuring the volume of water displaced by the boom when totally submerged. This was done in a portable trash container with a purpose-built grid used to hold the boom under water as the tank was filled. Two measurements were taken, one with the boom submerged in the tank, and the second with the boom out of the tank but all other test apparatus in the position they were for the first measurement. The calculated difference was taken as the boom displacement, and this was converted to pounds of buoyant force using the density of fresh water. The boom was weighed prior to the test to determine its “dry weight”. The buoyancy-to-weight ratio is the ratio of the two values.

The measurements indicate that manufacturers generally underestimated boom weights by a small amount, and overestimated boom buoyancies by a slightly larger amount, with the result that measured b:w ratios were underestimated by 10 to 25%, as compared with values measured with this test methodology.

The methodology was repeated with one boom to produce three separate measurements, producing values within $\pm 5\%$, which is judged to be a reasonable accuracy for this type of test procedure.

Based on the results, a draft standard was prepared based on the methodology used here, and submitted to the ASTM subcommittee on booms to initiate the process for consensus approval. Work on the draft standard will continue under ASTM, possibly leading to its approval as a test standard.

7. References

MAR Incorporated. 2004 Buoyancy to weight measurement by displacement study (TO-424) – test documentation. Minerals Management Service. Herndon, Va.

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**Appendix A: Draft ASTM Standard
on Determining the Buoyancy-to-Weight
Ratio of Spill Response Booms**

Standard Guide for Determining the Buoyancy to Weight Ratio of Spill Response Booms

*Author: Steve Potter
Draft #2, April 2004*

1. Scope

1.1 This guide describes a practical method for determining the buoyancy to weight (B/W) ratio of oil spill containment booms.

1.2 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 and health practices and to determine the applicability of regulatory limitations prior to use.

2. Referenced Documents

2.1 ASTM Standards

F818 Standard Terminology Relating to Spill Response Barriers

F1523 Standard Guide for Selection of Booms in Accordance With Water Body Classifications

3. Terminology (from F818)

3.1 Gross Buoyancy - weight of fresh water displaced by a boom totally submerged.

3.2 Reserve Buoyancy - gross buoyancy minus boom weight.

3.3 Buoyancy to Weight Ratio - gross buoyancy divided by boom weight.

4. Significance and Use

This guide describes a method of determining the buoyancy to weight ratio of spill response booms. The principle is based on Archimedes Law, which states that a body either wholly or partially immersed in a fluid will experience an upward force equal and opposite to the weight of the fluid displaced by it.

Unless otherwise specified, when used in this document, the term buoyancy to weight ratio, refers to the gross buoyancy to weight ratio. Buoyancy is an indicator of a spill response boom's ability to follow the water surface when exposed to current forces, fouling due to microbial growth (which adds weight), and wave conditions. Surface conditions varying from quiescent for different water body classifications will have an adverse effect on collection or containment performance. When waves are present, conformance to the surface is essential to prevent losses. Minimum buoyancy to weight ratios for oil spill containment booms are specified in F1523 for various environmental conditions.

This guide provides the methodology necessary to determine the buoyancy to weight ratio using a fluid displacement method. This method is typically applied to booms having relatively low B/W ratios (in the range of 2:1 to 10:1). Booms with greater buoyancies may also be tested in this manner, but it may also be acceptable to use calculation methods where the potential error in doing so would have a less significant effect on performance.

When evaluating the B/W ratio of a spill response boom, consideration should be given to the inherent properties of the boom that may affect the net B/W ratio while in use. These considerations include but are not limited to absorption of water into floatation materials, membranes that are abraded during normal use, and entry of water into components of the boom.

The entry of water into boom components is of particular concern with booms that contain their floatation element within an additional membrane (this is the case for many booms that use rolled-foam floatation, and relatively lightweight material for the boom membrane), and for pockets that enclose cable or chain tension members or ballast. When new, the membrane enclosure may contain air that would result in increased buoyancy. In normal use, the membrane material may be easily abraded such that it would no longer contain air, and water would be allowed in at abrasion locations. For such booms, the membrane enclosure should not be considered as part of the floatation of the boom, and

the membrane should be intentionally punctured to allow water to enter during the test procedure.

5. Summary of Test Method

5.1 Displacement Method –The Buoyancy to Weight Ratio is estimated using two key values, the dry weight of the boom and the gross buoyancy of the boom. The gross buoyancy is equal to the weight of the water that the boom displaces when submerged. Therefore, by submerging the boom, a volume/weight of water that is displaced by the boom can be measured and used to calculate the second key value.

6. Equipment Requirements

6.1 This method requires a scale to measure the dry weight of the boom, an open-top tank sufficient in volume and footprint area to physically hold the boom section or segment, a means of submerging the test section, a fresh water supply, and a method of accurately measuring the water in the tank or the volume that is delivered to the tank. A recommended method of submerging the boom is to use a fabricated grid of dimensional lumber or steel that fits inside the tank surface area.

6.2 The preferred method of determining the displacement of the boom would be to use a complete boom section including end connectors, tension members and ballast, etc. Depending on the size of the boom, it may be more practical to measure only a portion of the boom (several segments, for example) and to scale the results. It is helpful, but not essential, that the tank have a consistent cross-sectional area. Prior to use, the tank should be leveled and a datum established from which to obtain relative measurements from.

6.3 For accurate results, the area of the tank should not greatly exceed the area that the boom occupies within the tank. A recommended rule-of-thumb for this would be that the surface area of the tank be no greater than one-half the area occupied by the boom or boom segments being tested.

7. Test Method

7.1 Obtain the dry weight of the boom to be tested (section, segments, and/or components) and record the weight.

7.2 Inspect the boom for areas that may trap air during the test (e.g., ballast chain pocket, layers of fabric sewn together, or voids at hinges, connectors, and flotation chambers). A means of allowing water to fill these air pockets must be provided for accurate results

7.3 Place the boom within the tank, orientating it as it would be deployed for use, and taking care to not introduce folds in the boom skirt that could trap air.

7.4 Place the submerging grid (or other device to restrain the boom below water) in position. There should be enough space for the boom to float freely as the tank is filled.

7.5 Fill the tank with water and allow sufficient time for trapped air to escape. Filling the tank to submerge the boom should take no less than one hour, during which time the flotation element and the skirt should be moved around to facilitate the release of trapped air. (Note that this must be done periodically, and will be difficult or impossible once the boom is submerged and its buoyant force is holding the boom against the restraining grid.)

7.6 Once the boom and the restraining grid have been submerged, record the volume of water that has been delivered and mark the water level from the datum.

7.7 Remove the boom from the tank and empty the tank. Repeat the filling of the tank with the boom removed, filling to the same water level. Record the volume of water that is delivered to achieve this. The difference between this and the measurement in 7.6 will be the displacement of the boom.

8. Calculation Methods

Calculation methods are acceptable for booms with buoyancies greater than xxx:1. (*Need to specify a value here: suggest something in the range of 10 or 15:1.*) Booms of this buoyancy are typically relatively large booms that would be difficult to measure by the above displacement method. As well, the potential error in a calculation method vs. a direct measurement would have a less significant effect on boom performance.

Calculating boom displacement

An alternative to the direct measurement of displacement would be to measure the dimensions of all components of the boom, estimate their displacement by volume, and then convert this to buoyant force using the density of fresh water.

9. Precision and Bias

11. Report

12. Keywords