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Standard Guide for Collecting Containment Boom Performance Data in Controlled Environments[1]

This standard is issued under the fixed designation F2084/F2084M; 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.

ε^1 NOTE—Editorial changes were made in Sections 4, 7, 11, and Table 2 in June 2012.

1. Scope

1.1 This guide covers the evaluation of the effectiveness of full-scale oil spill containment booms in a controlled test facility.

1.2 This guide involves the use of specific test oils that may be considered hazardous materials. It is the responsibility of the user of this guide to procure and abide by the necessary permits for disposal of the used test oil.

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

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 and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D97 Test Method for Pour Point of Petroleum Products
D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)
D971 Test Method for Interfacial Tension of Oil Against Water by the Ring Method
D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method
D1796 Test Method for Water and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)
D2983 Test Method for Low-Temperature Viscosity of Lubricants Measured by Brookfield Viscometer
D4007 Test Method for Water and Sediment in Crude Oil by the Centrifuge Method (Laboratory Procedure)
D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter
F631 Guide for Collecting Skimmer Performance Data in Controlled Environments
F818 Terminology Relating to Spill Response Barriers

3. Terminology

3.1 *Boom Performance Data Terminology*—Terms associated with boom performance tests conducted in controlled environments:

3.1.1 *boom submergence (aka submarining)*—containment failure due to loss of freeboard.

3.1.2 *first-loss tow/current velocity*—minimum tow/current velocity normal to the membrane at which oil continually escapes past a boom This applies to the boom in the catenary position.

3.1.3 *gross loss tow/current velocity*—the minimum speed at which massive continual oil loss is observed escaping past the boom.

3.1.4 *harbor chop*—a condition of the water surface produced by an irregular pattern of waves.

3.1.5 *preload*—during testing, the quantity of test fluid distributed in front of and contained by the boom prior to the onset of a test.

3.1.6 *tow speed*—the relative speed difference between a boom and the water in which the boom is floating. In this standard guide relative current speed is equivalent.

3.1.7 *wave height*—(significant wave height) the average height, measured crest to trough, of the one-third highest waves, considering only short-period waves (i.e., period less than 10 s).

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[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.

3.1.8 *wave period*—(significant wave period) the average period of the one-third highest waves, measured as the elapsed time between crests of succeeding waves.

4. Significance and Use

4.1 This guide defines a series of test methods to determine the oil containment effectiveness of containment booms when they are subjected to a variety of towing and wave conditions. The test methods measure the tow speed at which the boom first loses oil (both in calm water and in various wave conditions), the tow speed at which the boom reaches a gross oil loss condition (both in calm water and in various wave conditions), boom conformance to the surface wave conditions for various wave heights, wavelengths and frequencies, (qualitatively), resulting tow forces when encountering various speeds and wave conditions, identifies towing ability at high speeds in calm water and waves, boom sea-worthiness relative to its hardware (i.e., connectors, ballast members), and general durability.

4.2 Users of this guide are cautioned that the ratio of boom draft to tank depth can affect test results, in particular the tow loads (see Appendix X1 discussion).

4.3 Other variables such as ease of repair and deployment, required operator training, operator fatigue, and transportability also affect performance in an actual spill but are not measured in this guide. These variables should be considered along with the test data when making comparisons or evaluations of containment booms.

5. Summary of Guide

5.1 This guide provides standardized procedures for evaluating any boom system and provides an evaluation of a particular boom's attributes in different environmental conditions and the ability to compare test results of a particular boom type with others having undergone these standard tests.

5.2 The maximum wave and tow speeds at which any boom can effectively gather and contain oil are known as boundary conditions. Booms that cannot maintain their design draft, freeboard, profile, and buoyancy at these conditions may be less effective. The boundary conditions depend on the characteristics of oil viscosity, oil/water interfacial tension and oil/water density gradient.

6. Test Facilities

6.1 Several types of test facilities can be used to conduct the tests outlined in this guide:

6.1.1 *Wave/Tow Tank*—A wave/tow tank has a movable bridge or other mechanism for towing the test device through water for the length of the facility. A wave generator may be installed on one end, or on the side of the facility, or both.

6.1.2 *Current Tank*—A current tank is a water-filled tank equipped with a pump or other propulsion system for moving the water through a test section where the test device is mounted. A wave generator may be installed on this type of test facility.

6.1.3 Other facilities, such as private ponds or flumes, may also be used, provided the test parameters can be suitably controlled.

6.2 Ancillary systems for facilities include, but are not limited to a distribution system for accurately delivering test fluids to the water surface, skimming systems to assist in cleaning the facility between tests, and adequate tankage for storing the test fluids.

7. Test Configuration and Instrumentation

7.1 The boom should be rigged in a catenary configuration, with the gap equal to 33 % of the length; or boom gap-to-length ratio of 1:3. Towing bridles are generally supplied by the manufacturer for both ends of the boom which provide attachment points for towing (Fig. 1). At each end of the boom, the towing apparatus shall be joined to the tow bridle or tow lead by a single point only. Boom towing force should be measured with in-line load cells positioned between the boom towing bridles and tow points.

7.2 Preload oil should be pumped directly into the boom apex.

7.3 Data obtained during each test should include electronically collected data and manually collected data. Oil and water property data should be based on fluid samples obtained during the test period. Recommended data to be collected during testing, along with the method of collection, is listed in Table 1.

8. Test Fluids

8.1 Test fluids may be crude, refined, or simulated, but should be stable and have properties that do not vary during a

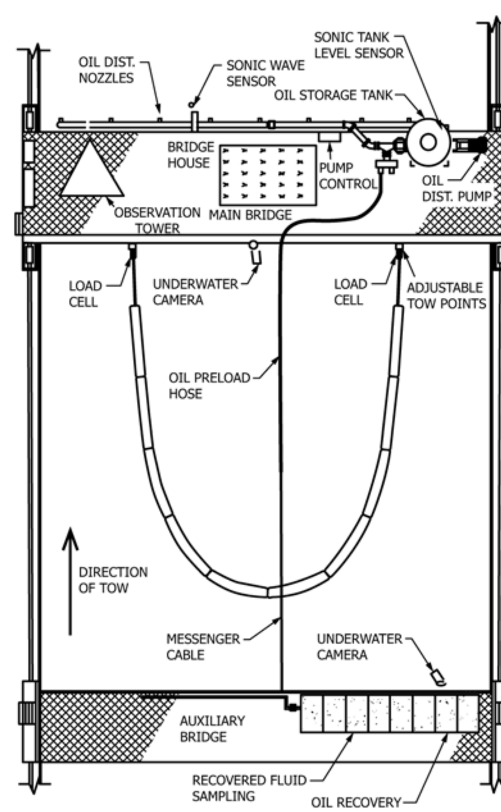

FIG. 1 Typical Boom Test Setup in Tank

TABLE 1 Typical Data Collected During Tests

Data	Typical Instrumentation	Collection Method
Wind Speed, Direction	Wind Monitor	Computer/Data Logger, Manual Readings
Air and Water Temperature	Resistance Temperature Detector (RTD), Themocouples, Thermometer†	Computer/Data Logger, Manual Readings
Tow Speed/Relative Current	Pulse Counter and Digital Input Tachometer, Current Meter	Computer, Control Console, Local Display
Wave Data	Distance Sensor, Capacitance probe, Pressure Sensor	Computer/Data logger
Tow Force, Average (Maximum during Wave Conditions)	Load Cell	Computer/Data logger
Test Fluid (Volume Distributed)	Storage Tank Level Soundings, or Distance Sensor and capacity vs. Volume Conversions	Computer/Data Logger, Manual Readings
Distribution Rate	Positive Displacement Pump with Speed Indicator, Volume Distributed Divided by Time	Pump Control Panel, Computer/Data Logger, Manual Readings

†Editorially corrected.

TABLE 2 Measurement Precision and Accuracy

Measurement	Accuracy (±)	Precision (±)
Bottom solids and Water	To be determined (ASTM)	To be determined (ASTM)
Oil Distribution	0.3 m^3/h	0.05 m^3/h
Salinity	0.01‰	0.01‰
Specific Gravity, Density	0.001 g/cm^3	0.0001 g/cm^3
Surface Tension	0.1 Dyne/cm	0.04 Dyne/cm
Temperature	0.2°C	0.2°C
Tow, Current Speeds (Tank/Open water)	0.051 m/s (0.1 kt)/ 0.255 m/s (0.5 kt)	0.0255 m/s (0.05 kt)/ 0.102 m/s (0.2 kt)
Tow Force	0.25 % of full scale	2.5 lbs/1000 lbs
Viscosity	2.0 %	1.0 %
Wave Meter, (Tank/Open Water)	6 mm/10 mm	1.44 mm/10 mm
Wind Direction	3°	3°
Wind Speed	0.3 m/s [0.6 mph]	0.3 m/s [0.6 mph]

test run. Test oils for use with this guide should be selected to fall within the range of typical oil properties as defined in Appendix X2 of this guide.

8.2 Test fluids should be discharged at ambient water temperatures to reduce variation in fluid properties through a test run.

9. Safety Precautions

9.1 Test operation shall conform to established safety (and regulatory) requirements for both test facility operations and oil handling. Particular caution must be exercised when handling flammable or toxic test fluids.

10. Test Variables

10.1 At the onset of the test the independent or controlled test parameters should be selected. The test evaluator should include a discussion of the procedures that were used to establish calibration and standardization. These procedures typically include initial calibrations, pre-test and post-test checks, sampling requirements and documentation of significant occurrences/variations, and data precision and accuracy.

10.2 Data should be expressed with an indication of variability. Table 2 contains a list of typical measurements showing attainable precision and accuracy values.

10.3 Varying surface conditions should be employed during testing. Conditions should be measurable and repeatable. Examples of achievable surface conditions in controlled test environments are:

10.3.1 *Calm*—No waves generated.

10.3.2 *Wave #1*—sinusoidal wave with an $H_{1/3}$ of .30 metres [12.0 inches], wavelength of 4.27 metres [14.0 feet], and an average period of t=1.7 seconds. (Wave dampening beaches are employed during the generation of this wave condition).

10.3.3 *Wave #2*—Sinusoidal wave with an $H_{1/3}$ of .42 metres [16.5 inches], wavelength of 12.8 metres [42.0 feet], and an average period of t=2.9 seconds. (Wave dampening beaches are employed during the generation of this wave condition).

10.3.4 *Wave #3*—A harbor chop condition with an average $H_{1/3}$ of .38 metres [15.0 inches]. This is also defined as a confused sea condition where reflective waves are allowed to develop. No wavelength is calculated for this condition.

where:

$H_{1/3}$ = significant wave height = the average of the highest ⅓ of measured waves,
L = wavelength = the distance on a sine wave from trough to trough (or peak to peak), and
T = wave period = the time it takes to travel one wavelength.

11. Procedures

11.1 Prior to the test, select the operating parameters, then prepare the facility and containment boom for the test run. Measure the experimental conditions.

11.1.1 The conventional boom under test should be a full-scale representative section. The boom section's basic physical properties should be measured in accordance with ASTM definitions. Table 3 contains a list of typical measurements and additional specification data.

11.2 Measure or note immediately prior to each test the following parameters:

11.2.1 Wind speed, direction.

11.2.2 Air and water temperature.

11.2.3 General weather conditions, for example, rain, overcast, sunny, etc.

11.2.4 The test fluid used for testing should be characterized from samples taken each time the storage tank is filled. As a minimum, the test fluid should be analyzed for viscosity, surface and interfacial tension, specific gravity and bottom solids and water. The results of each analysis as presented in Table 2 will be reported.

TABLE 3 Typical Basic Physical Properties

Measurement	Specification Data: As reported by Manufacturer	Specification Data: As measured by Tester
Boom Type	Fence, curtain, fire containment, other	
Length m [ft]	Standard section length, total rigged section	
Height mm [in]	Standard section height	
Freeboard mm [in]	Distance above water line	
Draft mm [in]	Distance below water line	
Weight of Section kg/m [lb/ft]	Boom Fabric Type (freeboard and skirt material) and Tensile Strength Characteristics	
Ballast Length m [ft]	Ballast Bottom Tension Member Type/Break Strength and Length[A]	
Ballast Weight kg/m [lb/ft]	Chain, cable or weights	
Gross Buoyancy	Flotation/Buoyancy Type (Air inflatable/foam)	
Buoyancy to Weight Ratio	Calculated/Measured (Method shall be documented)	
Accessories	Anchor points, lights, tow lines, bridles, etc.	
End Connector Type	ASTM Standard, other	
Number of tension members and Location	Top, bottom, middle, other	

[A] All measurements should be taken when member is tensioned to the load expected at a 1 knot tow speed.

TABLE 4 Typical Test Schedule

Test No.	Test Type	Tow Speed (kts)	Wave Conditions	Preload Volume (gallons)
1	Dry Run	1	calm	N/A
2	Preload	variable	calm	60
3	Preload	variable	calm	120
4	Preload	variable	calm	180
5	Preload	variable	calm	240
6	Preload	variable	calm	300
7	Preload	variable	calm	360
8	Preload	variable	calm	420
9	Gross Loss	variable	calm	determined during Preload test
10	1st & Gross Loss Speeds	variable	calm	determined during Preload test
11	1st & Gross Loss Speeds	variable	Wave #1	determined during Preload test
12	1st & Gross Loss Speeds	variable	Wave #1	determined during Preload test
13	1st & Gross Loss Speeds	variable	Wave #2	determined during Preload test
14	1st & Gross Loss Speeds	variable	Wave #2	determined during Preload test
15	1st & Gross Loss Speeds	variable	Wave #3	determined during Preload test
16	1st & Gross Loss Speeds	variable	Wave #3	determined during Preload test
17	Critical Tow Speed	variable	calm	none
18	Critical Tow Speed	variable	calm	none

11.2.5 Periodic samples of the test basin water should be taken to monitor the water properties to include oil and grease, salinity, and turbidity.

11.3 Place the containment boom in the test basin (Fig. 1). Confirm that rigging has been in accordance with manufacturer specifications. Document set-up conditions, for example, tow bridle elevation, boom gap opening, and/or general rigging. Start the oil distribution system, tow mechanism or water flow (if necessary) to begin the test run. The following test parameters will be performed as outlined in Table 4.

11.3.1 The test starts with a Dry Run to confirm the equipment has been properly rigged and all data collection instrumentation is functioning.

11.3.2 The Dry Run is followed by Preload test runs. Preload tests determine the minimum volume of test fluid necessary for a containment boom to display loss by entrainment, and simultaneously determine the volume of test fluid a boom holds until the addition of fluid has a "minimal" effect on the first loss tow speed. As preload volumes are increased, there is a volume at which the addition of test fluid will not change the first loss tow speed (test fluid/water interface entrainment speed). This test is performed in calm water conditions and establishes a baseline preload fluid volume. This baseline containment performance serves as a datum from which improved or diminished containment performance can be measured when encountering other test conditions.

11.3.2.1 The preload volume is determined by performing a series of first loss tests. Beginning with a nominal preload volume, the first loss tow speed is identified. Underwater visibility is essential when identifying loss speeds. The preload volume is increased and the first loss tow speed obtained again. This process is repeated with increasing preload volumes until the addition of the test fluid to the preload has minimal or no effect on the first loss speed. A graph of first loss speed versus preload volume should be created to visually determine the optimum preload volume necessary for the subsequent tests, (first and gross loss in wave conditions, loss and loss rate tests). The graph produced should be a curve of boom capacity versus tow speed. For example, Fig. 2 shows data from a typical boom section. An initial preload volume of 227 litres [60 gallons] was pumped into the boom and the first oil loss speed determined. The second preload volume was 454 litres [120 gallons] and the first loss tow speed was again determined. As shown, when preload volumes are increased the first loss occurs at lower tow speeds. This process is continued until the sensitivity of first loss tow speed becomes minimally dependent on preload volume. For this example, the volume of test

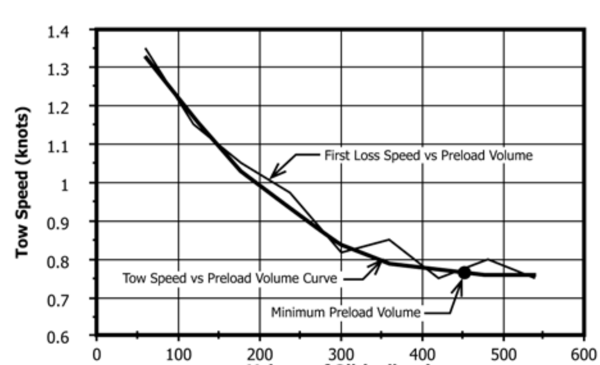

FIG. 2 Boom Preload Determination Test, First Loss Speed versus Preload Volume

fluid at which the addition of more fluid does not affect the first loss tow speed is 450 gallons.

11.3.3 The Preload determination should be followed by the Gross Loss, and 1st and Gross Loss Speed tests with waves.

11.3.3.1 First Loss Tow Speed is the lowest speed at which droplets of the test fluid shed (continuously) from the boom. Minor, non-continuous losses are not considered to be first losses. First Loss Tow Speed tests should be carried out in both calm water and various wave conditions. In wave conditions, the test fluid loss may occur in a surging motion. First Loss Tow speed tests are also used to determine the boom preload volume threshold.

The test is performed with the boom configured as illustrated in Fig. 1. The preload volume is pumped from the storage tank into the boom apex. The boom should then be accelerated to a tow speed of 0.5 knots and held there to allow the boom and test fluid to stabilize. The tow speed should then be increased by 0.1 knots in ten second intervals until the continual first loss mode is observed. Fig. 3 shows a typical first failure mode in calm water.

11.3.3.2 Gross Loss Tow Speed is the speed at which massive continual test fluid loss is observed escaping past the boom. The speed increments should be continued beyond first loss until a gross loss failure mode is observed. Fig. 4 shows a typical gross loss failure mode.

11.3.4 The Critical Tow Speed tests demonstrate boom behavior at speeds in excess of normal containment limits. The test involves towing the boom, without test fluid, at increasing tow speeds. The Critical Tow Speed is met when the boom exhibits one mode of failure, i.e., loses all freeboard (submerges), planes, or mechanically fails and/or has been tested at three times the measured gross loss tow speed. Fig. 5 shows Critical Tow Speed of an oil boom in calm water and illustrates loss of freeboard. Critical tow speed is significant in defining the safe operating limit for the boom, recognizing that normal containment tow speeds may be occasionally exceeded in practice.

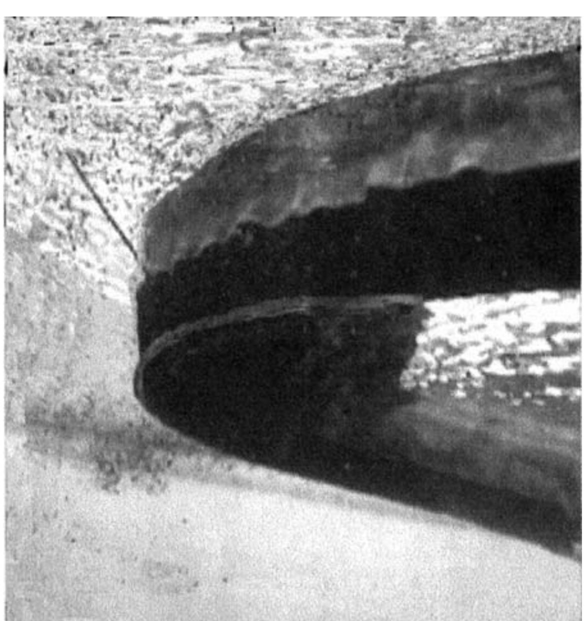

FIG. 3 First Loss

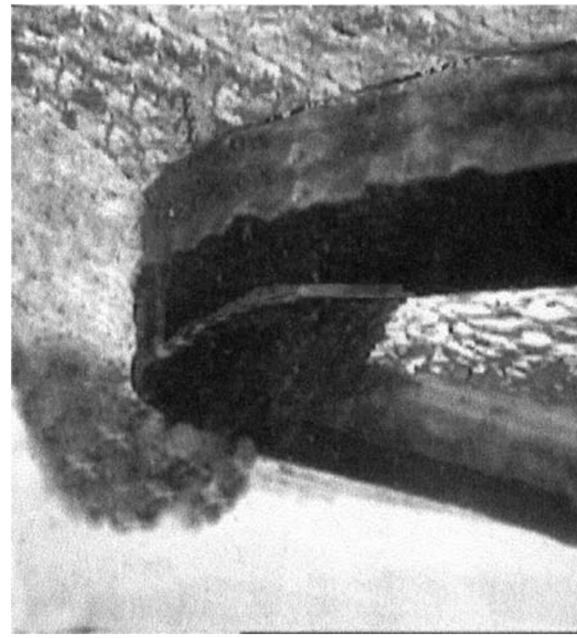

FIG. 4 Gross Loss

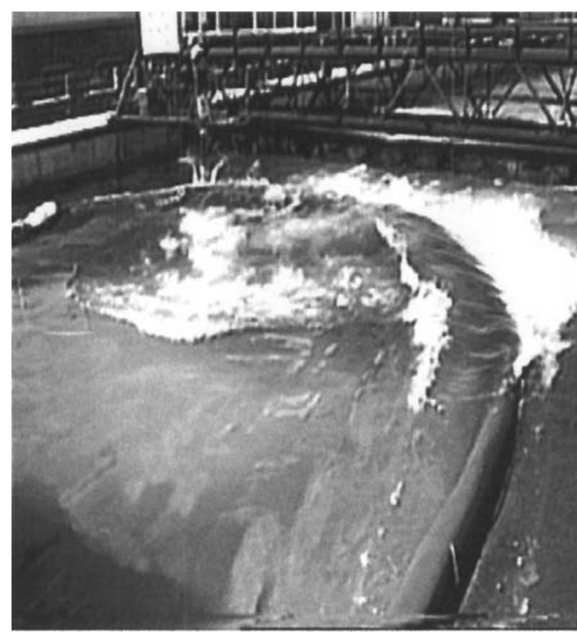

FIG. 5 Critical Tow Speed in Calm Water

11.3.5 Tow the boom in a straight line measuring straight-line tow forces. This test is significant in that it provides useful operational information to manufacturers and potential users when in open-water deployment.

12. Report

12.1 The test report shall provide a description of the test set-up, test methods, and significant observations or concerns noted by the test personnel. The report will contain tables, graphs, charts, etc. that accurately describe boom containment and recovery performance based on data collected under specific towing conditions.

12.1.1 Prepare a schematic diagram of the layout for the test series.

12.1.2 Describe the containment boom and basic physical properties.

12.1.3 Prepare a table of results for the test runs, containing information as outlined in Table 4.

12.1.4 Report Ambient conditions, including air temperature, surface water temperature, wind speed, wind direction, and brief statement of weather conditions during the test run. Report tow force measurements and corresponding independent test parameters.

12.1.5 Report tank test fluid properties.

12.1.6 Describe Test instrumentation.

12.1.7 Report Wave conditions.

12.2 Record analytical testing results, automated and manual data, as well as above-water and below-water video documentation (digital camera pictures) should be included and used to prepare the test report/data summaries. Testing results include test run data (test logs), raw computer data files, oil recovery and distribution logs, oil analyses test reports, calibration data, pre and post test checks, and QA checklists.

12.2.1 Graph and table data shall be grouped by test characteristics, the test fluid type, wave type and tow speed. The reports shall include a complete data table containing test numbers, independent variables, and all significant variations and occurrences.

APPENDIXES

(Nonmandatory Information)

X1. RATIO OF BOOM DRAFT TO WATER DEPTH DISCUSSION

X1.1 It is known that if the distance between the bottom of a boom in a test tank and the bottom of the tank decreases below some minimum the tow forces on the boom can be affected. Larrabee and Brown determined that, for such tests, the ratio of boom draft to water depth could not be less than 1:8 (**1**)[3].

X1.2 For oil containment testing, it is generally recommended that the ratio of the boom draft to the water depth in the test tank is greater than some minimum value. Unfortunately, there appears to be no universally-accepted minimum ratio.

X1.3 Values in the literature range from 1:4 (**2**), to 1:6 (**3**), to 1:10 used in a number in flume tanks (**4, 5**), to 1:12 (**6**).

X1.4 If the draft-to-depth ratio is near the lower end of, or below, the ranges given above, users should confirm that their results are not biased as a consequence.

[3] The boldface numbers in parentheses refer to the list of references at the end of this standard.

X2. STANDARD TEST OILS[4]

X2.1 Values in Table X2.1 refer to test fluid properties at test temperatures.[4] Test methods for fluid properties are specified as follows: viscosity, Test Methods D445 and D2983 (report shear rate for viscosity measurement, should be in the range of 1 to 10 s^{-1}); density, Test Method D1298 and D4052; interfacial tension, Test Method D971; pour point, Test Method D97. For all test oils (with the exception of emulsions), maximum sediment and water (BSW) of 0.1 %, Test Method D4007 and D1796.

X2.2 Of the five viscosity ranges, numbers I, II, and IV are especially recommended as being indicative, respectively, of lightly weathered, moderately weathered, and significantly weathered crude oils.

X2.3 The following lists examples of hydrocarbon oils that could be used to fall within the specified ranges. This list is intended for guidance only; it should be noted that viscosities of all oils will vary greatly with both temperature and the specific product. Selected oils may be crude, refined, or simulated. In the case of crudes and light refined products, it is acceptable and may be desirable to pre-weather the oil in order

[4] This Appendix has been adapted from F631-93, Standard Guide for Collecting Skimmer Performance Data in Controlled Environments, to make it applicable to the testing at the Ohmsett Facility (located at the Navy Weapon Station Earle, in Leonardo, New Jersey). For comparison purposes, testing at Ohmsett has been completed with standard test oils Hydrocal 300, Calsol 8240, and Sundex 8600 which fall into categories I, II, and III, respectively.

TABLE X2.1 Candidate Test Oils

NOTE 1—Test Oils should be selected to fall within these five categories.

Category	Viscosity, mm^2/s	Density, g/mL	Oil-Air Interfacial Tension, mN/m	Oil-Water Interfacial Tension, mN/m	Pour Point °C
I[A]	150-250	0.90 to 0.93	28 to 34	20 to 30	< -3
II[B]	1500-2500	0.92 to 0.95	30 to 40	20 to 30	< -3
III[C]	17 000 to 23 000	0.95 to 0.98	20 to 40	20 to 40	< 10
IV[D]	50 000 to 70 000	0.96 to 0.99	20 to 40	20 to 40	. . .
V[E]	130 000 to 170 000	0.96 to 0.99	20 to 40	20 to 40	. . .

[A] *1*) Alaska North Slope crude oil, 10 to 15 % weathered by volume.
2) Fuel oil No. 4 (heavy); can be prepared by blending 40 % fuel oil No. 2 and 60 % fuel oil No. 6.
[B] Fuel oil No. 5 can be prepared by blending 20 to 25 % fuel oil No. 2 with 75 to 80 % fuel oil No. 6.
[C] Residual fuel oil (that is, fuel oil No. 6 prepared to above criteria).
[D] Residual fuel oil (that is, heavy cut of fuel oil No. 6).
[E] Emulsified crude oil, 50 to 80 % water content. The oil may be emulsified by blowing compressed air through water on which the oil is floating.

to produce a desired viscosity, increase the oil's flash point to a safe level, and produce a more stable test fluid.

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