Oil Containment Tests of Fire Booms

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Abstract

The US Coast Guard R&D Center and the US Department of Interior Minerals Management Service (MMS) conducted tests on currently available fire booms to provide performance characteristics for use by planners in developing response plans for the in-situ burning of marine oil spills. These tests investigate only the performance of fire booms as oil containment booms, not as fire boom. This paper reports the results of the oil loss tests of five fire booms as measured using actual oil in waves and current at the MMS Ohmsett Facility. Oil Loss Tow Speeds of these fire booms are similar to conventional oil containment booms; that is, oil loss begins between 0.8 - 1.0 knot. The buoyancy-to-weight ratios of the booms were found to have a loose correlation to oil containment performance, however, the material and construction of the booms seem to have a greater effect on performance than buoyancy-to-weight ratio. Steel skirt booms, while having a low buoyancy-to-weight ratio, showed better performance than the fabric booms with somewhat higher buoyancy-to-weight ratios. The Ohmsett test tank performances were compared to offshore tow test performance of fire booms; performance was better in the tank tests than in the at-sea tests.

1.0 Purpose of Paper

The objective of these tests is to measure the oil collection performance of five currently available fire booms for response planners to use in developing plans for the deployment of fire booms. These tests were conducted under tank towing conditions without fire. Test Tank performance will be compared with at-sea tow test results for planing / submergence failure.

2.0 Background

At-sea incineration (in-situ burning) of marine oil spills is an effective response technique. During the Newfoundland Oil Burn Experiment (NOBE) in 1993, scientific measurements were made to increase our technical and operational knowledge of in-situ burning and facilitate its operational use. Several at-sea tests, without oil, have been conducted to measure and characterize the performance of containment and fire booms. In-situ burning of marine oil spills is beginning to appear as a response tool in

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* The opinions or assertions contained herein are the private ones of the writer and are not to be construed as official or reflecting the view of the Commandant or the U.S. Coast Guard at large.

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area contingency plans after many years of experimentation and testing of the concept as a whole. During that time, however, technical development and testing of the equipment necessary to put the concept of in-situ burn into practice has been somewhat limited. Fire booms may be used as oil collection booms and towed by response vessels to collect and concentrating oil into a slick of sufficient thickness to burn. Uniform test and evaluation of fire booms have not been conducted to provide responders with technical information on fire boom performance as oil containment booms. The tests reported in this paper fill this need.

While these tests were undertaken to provide information on current fire booms, the results could also help to advance the technology of fire resistant booms. Boom improvements can be made through design modifications based on observations from these tests. The opportunity to observe underwater how their boom performs provides invaluable insight to the manufacturers.

3.0 Description of Fire Booms

The descriptions are based on information provided by each vendor. Table 1 is a summary table of fire boom tested at Ohmsett.

3.1 American Marine, Inc, American Fireboom

Each 15.2 m boom section is 30.5 cm in diameter, 76.2 cm in height, weighs approximately 192.8 kg and has seven segments. Each segment has a ceramic high temperature resistant flotation core. Two layers of stainless steel, knotted mesh with a layer of ceramic, high temperature-resistant textile fabric (Nextel) surround this core in between. The segments are encased in a tubular PVC outer cover that is extended to form the chain-ballasted skirt. A stainless steel internal tension cable runs the length of the boom section. Riveted vertical and longitudinal stainless steel seaming bars retain the ceramic component to the skirt during burns. Steel cable lift handles are located along the length of the boom and one stainless steel end connector is bolted to each boom section end.

3.2 Dome Boom

The Dome boom was developed during a three-year program. Beginning with a search for the most suitable material of construction, an initial boom design was developed. A prototype boom was fabricated and tested for static flotation and under catenary and straight line towing up to five knots. Based on the test results, towing paravanes were added to the operational model. Fireproof fabric/mesh connector was replaced with 0.4 mm thick, type 321stainless steel flexible panels. The resulting boom was then tested in trial burns in 1980 at Port Melon, B.C. The following year towing tests and burn tests were conducted at Ohmsett. Eleven boom sections and towing paravanes were assembled for testing. Each section weighs 124.7 kg and has a buoyancy-to-weight ratio of 3.5 to 1.

3.3 Applied Fabric Technologies, PyroBoom®

PyroBoom® is a solid flotation barrier that combines wire reinforced refractory fabric for the above surface barrier with conventional GlobeBoom® fabric for the skirt. The glass foam filled, steel hemispheres are mechanically attached to the barrier. Their modular construction allows for salvage, maintenance, and repair in the field.

The boom has a 50.8 cm draft and a 25.4 cm freeboard. The boom is 32 m long. There are galvanized shackles above each flotation hemisphere for lifting. PyroBoom® behaves like GlobeBoom® and no special handling equipment is necessary. A complete kit consists of a boom, a U-configuration sweep assembly with wire cross bridles, and a steel storage kit with retrieval windlass.

3.4 Spill-Tain™ Fireproof Oil Spill Containment Boom - Offshore Version

Spill-Tain™ is an external tension line boom with most of the boom material consisting of thin, type 316L, stainless steel sheet metal, closed cell foam glass flotation, and stainless steel cable. The boom can follow wave action with patented segmented panel design. Boom panels are supported perpendicular to the water by outrigger floats. Adjacent boom panels are attached to each other by integrally formed piano hinges. The tension cable is affixed to outrigger floats. Connecting plates join the 9.14 m sections to one another, with shackles connecting cable eyes at section ends.

3.5 Oil Stop's Inflatable Auto Boom™ Fire Boom

This inflatable fire boom has a 35.6 cm float diameter and 55.9 cm skirt. It is equipped with universal end connectors. The boom is inflated using a patented single-point inflation design. Once inflated, the boom automatically sectionalizes the air chambers into separate compartments, so that individual air chambers stay inflated even if adjacent chambers are damaged or deflated. There are three layers beneath the boom's polyurethane exterior. They are stainless steel screen, ceramic insulation blanket, and a high temperature inflatable membrane. The tension member/ballast is an ½-inch galvanized chain contained in the hem of the boom skirt.

Table 1: Summary of Fire Boom Characteristics

Fire Boom	*American Marine*	*Dome Boom*	*Pyroboom*	*Spill-Tain*	*Oil Stop Inflatable*
Draft (cm)	53.3	111.8	40.64	66.0	63.5
Freeboard (cm)	22.9	66.0	35.6	53.3	45.7
Weight to liner meter (kg/m)	12.65	45.4	11.9	28.9	13.4
Number of Sections	2	11	1	3	2
Overall Length (m)	30.5	30.5	32	27.4	30.5

Fire Boom	*American Marine*	*Dome Boom*	*Pyroboom*	*Spill-Tain*	*Oil Stop Inflatable*
Predominant Material	Refractor fabric	Stainless Steel	Refractory fabric	Stainless Steel	Ceramic Blanket
Buoyancy to Weight Ratio	3.8	3.5	8	2.75	9.5

4.0 Oil Containment Performance Tests

The primary objective of the tests reported in this paper is to provide some comparative measure of the oil collection performance for responders to use when planning response strategies with currently-available fire booms.

The oil containment characteristics of the fire booms were determined from three tests; two oil loss tests and a maximum tow speed test. The first test, the Oil Loss Tow Speed Test, determines the tow speed at which a boom begins to lose oil. The second test, the Oil Loss Rate Test, measures the rate of leakage once it begins. The third test, called the Critical Tow Speed Test, is conducted to measure the highest speed at which the boom can be towed and not fail. This test is conducted without oil. The three tests are described below.

4.1 Test Set-up

These tests were conducted at the Ohmsett facility, operated by the US Department of Interior Minerals Management Service. The test tank is 183 meters long, 20 meters wide, and a water depth of 2.4 meters. It has a wave generator at one end and a beach at the other to dampen waves, if necessary. Tests are conducted by towing systems down the tank with the Main Bridge, which travels on rails. The Auxiliary Bridge travels along the tank on rails, also. Since the Main Bridge and Auxiliary Bridge are fastened to the same cable system, they travel along the tank as a unit. The Main Bridge, used to tow the boom, has oil storage tanks and a manifold system that can distribute oil onto the water surface in front of the boom at a predetermined rate. In these tests, the underwater video camera is mounted on the Auxiliary Bridge and is aimed toward the apex of the boom to observe oil loss. Tow forces are measured with load cells mounted between the boom ends and the tow points on the Main Bridge. A full description of the setup and instrumentation is described in DeVitis (1997.)

The test set up is the same for all tests and is shown in Figure 1. The boom length is approximately 30.5 meters. The gap ratio is 2:1 (Gap ratio defined as the ratio of the length of the boom to the boom opening for a U-configuration.)

4.2 Oil Loss Tow Speed Test Procedure

In these tests, a specified amount of oil (called the Pre-load) is pumped into the boom and towed down the tank to observe First Loss Tow Speed. The first sustained oil loss observation is called the First Loss Tow Speed and, as the speed increases, the speed at which a significant, continuous loss is observed is called the Gross Loss Tow Speed. A preliminary series of tests are conducted to determine what the oil Pre-load should be for each boom. The procedure is described in DeVitis (1997.) In these tests, the Pre-Loads for the various fire booms range from 1325- 2270 liters (350 - 600 gallons.)

Oil Loss Tow Speed Tests are conducted in calm water, and in three wave conditions. Wave #1 is a short-crested, regular wave with a frequency of 1.7 seconds and a steepness (defined as the significant wave height divided by wave length) of 0.050. Wave #2 is a regular wave with a frequency of 2.8 seconds and a steepness of 0.032. Wave #1 is, therefore, approximately twice as steep as Wave #2. Wave #3 is an irregular wave, called Harbor Chop, which is generated by allowing waves to reflect off the end of the tank for 15 minutes. The significant wave height is 22.6 centimeters (8.9 inches.) Table 2 summarizes the wave conditions used at Ohmsett.

The test oil was a blended refined product having a viscosity of approximately 2000 centipoise and a specific gravity of 0.94 - 0.96.

4.3 Oil Loss Rate Tests Procedure

The Oil Loss Rate Tests take the First Loss Tow Speed Test one step farther and actually measures the rate of oil loss from the boom at two predetermined tow speeds. A lower oil loss rate means more oil stays in the boom for burning. Oil loss rates are measured at two speeds: a) First Loss Tow Speed plus 0.1 knots and b) First Loss Tow Speed plus 0.3 knots. The First Loss Tow Speed Plus 0.1 knots give oil loss rates just above the onset of oil loss. This will likely be the speed at which collection will occur. The First Loss Tow Speed plus 0.3 knots is close to the Gross Loss Tow Speed at which oil is escaping from the boom at a high rate. To maintain a somewhat steady state oil load in the boom for the entire test, oil is distributed in front of the boom at 98 lpm or 397 lpm (26 gpm or 105 gpm) during the First Loss Tow Speed plus 0.1 knots or First Loss Tow Speed Plus 0.3 knots, respectively. To reduce cost, tests are conducted only in calm water.

The setup for this test is the same as described in section 4.1. The test begins by pumping the Pre-Load into the apex, starting the makeup oil flow, and proceeding down the tank accelerating the Main Bridge to the First Loss Tow Speed Plus 0.1 knots,. At the end of the test, the oil remaining in the boom is collected and measured. The oil that escaped the boom is skimmed from the tank and measured. The Oil Loss Rate is then calculated knowing the amount of oil in the boom, the amount of oil added during the test, and the amount of oil lost from the boom. The details of the procedure are discussed in DeVitis (1997.)

4.4 Critical Tow Speed Tests Procedure

The Critical Tow Speed Test, the third test to evaluate fire booms as oil collection booms, determines how well the boom can be towed at in higher speeds, still in a U-configuration. It is essential to know if the boom will fail mechanically at connectors between the sections, or whether the boom submerges or planes over the water surface.

The Critical Tow Speed Test is conducted with the boom in the U-configuration as in Figure 1 and described in Section 4.1, above. The test is conducted by towing the boom down the tank starting from rest and accelerating uniformly until the boom submerges, planes over the water surface or mechanically fails. The tow tension is measured and the tests are conducted without oil on calm water.

Table 2: Wave Characteristics

Wave Condition	*Wave Type*	*Wave Height (cm)*	*Frequency (seconds)*	*Wave Length (m)*
Wave #1	Regular	25	1.7	4.9
Wave #2	Regular	33.8	2.8	12.8
Wave #3	Harbor Chop	22.6	Not calculated	Not calculated

5.0 Containment Test Results

5.1 Oil Loss Speed Test Results

In calm water, the First Loss Tow Speed for all booms was between 0.85- 1.0 knots. As a group, all booms have somewhat lower First Loss Tow Speeds in short-crested waves (Wave #1) as shown in Figure 2. The average reduction in First Loss Tow Speed for all booms, except Spill-tain, was -18%. The Spill-Tain boom showed a 50% reduction in First Loss Tow Speed. Boom performance was essentially the same in calm water as it was in longer regular waves (Wave #2) and Harbor Chop (Wave #3.) The performance of these fire booms is comparable to the performance of conventional oil containment booms in similar tests.

In observing the performance of these booms with regard to buoyancy-to-weight (B/W) ratio, within the range of the B/W Ratio tested, there is a small increase in First Loss Tow Speed with increase in B/W Ratio, Figure 3. This is true for calm water, Waves #2 and #3. In Wave #1, the short-crested wave, there is essentially no difference between the performance of the booms, with the exception of the Spill-Tain boom, as described above. In treating the high B/W Ratio booms as a group (i.e. Oil Stop and PyroBoom), the average B/W Ratio for that group is 8.75:1 and the average First Loss Tow Speed is 0.95 knots. Combining results for all low B/W Ratio fire booms (i.e. American Marine, Dome Boom, and Spill-Tain), the average B/W Ratio is 3.35:1 and the average First Loss Tow Speed is 0.88 knots. Comparing the results for the high and low B/W Ratio groups suggests that a large increase in B/W Ratio (i.e. 161%) only results in a 7.9% increase in First Loss Tow Speed.

In assessing the results of these tests, it is difficult to determine how much of the difference in performance is attributed to a difference in B/W Ratio and how much might be attributed to other factors such as boom design and materials. These booms represent a variety of designs and material. For example, the Oil Stop and PyroBoom are fabric booms that are flexible and lightweight. The Spill-Tain and Dome Boom are heavier steel booms with rigid skirts, and the American Marine boom is a fabric booms with rigid flotation chambers.

5.2 Oil Loss Rate Results

At First Loss Tow Speed Plus 0.1 knots, the steel skirt booms (i.e. Spill-Tain and Dome Boom) as a group has the lowest oil loss rate of approximately 30.3 lpm (8 gpm.) See Figure 4. American Marine and Oil Stop have the next best at approximately 68 lpm (18 gpm) and PyroBoom has an Oil Loss Rate of approximately 246 lpm (65 gpm), approximately twice the loss rate of the other booms.

The First Loss Tow Speed plus 0.3 knots Oil Loss Rates are much higher than the lower speed (see Fig. 4.) There is no change in the relative performance of the booms from the slower speed tests. The steel skirt booms (i.e. Spill-Tain and Dome Boom) have Oil Loss Rates of 162 lpm (43 gpm), American Marine and Oil Stop average approximately 291 lpm (77 gpm) and PyroBoom had a loss rate of 533 lpm (141 gpm), approximately twice the other booms.

The Oil Loss Rates in the First Loss Tow Speed Plus 0.3 knots are much greater than the Oil Loss Rates at the slower speed because the higher speed is very close to the Gross Loss Tow Speed, the speed at which very rapid lose of oil occurs. An increase in tow speed of approximately 20% results in an increase in Oil Loss Rate of four or five fold.

Figure 5 illustrates the comparison of Oil Loss Rate performance of these fire booms with regard to buoyancy-to-weight ratio. The lower buoyancy-to-weight ratio booms actually have the lowest oil loss rates. As mentioned above, this may be as much a measure of the design and configuration of the boom as it is an indication of the effect of buoyancy-to-weight ratio on Oil Loss Rate.

All Oil Loss Rate Test results are plotted in Figure 6 to illustrate the observation that, while all the booms fall within a relatively narrow band on tow speeds, there is a wide variation in Oil Loss Rates.

5.3 Critical Tow Speed Results

The Critical Tow Speed is shown in Table 3. The highest Critical Tow Speed was achieved by the Spill-Tain boom at six knots. The boom did not fail at that speed, but the test was terminated because six knots is the maximum speed of the Main Bridge at the Ohmsett facility. The American Marine Fireboom gradually lost freeboard until total loss of freeboard occurred at 2.25 knots around the apex. The Dome Boom skirt began planing at 2.0 knots and was towed up to 3.25 knots without damage. The PyroBoom exhibited planing of the boom legs beginning at 2.0 knots with total loss of freeboard occurring at 2.75 knots at the apex. The Oil Stop boom gradually lost freeboard at the apex. Once submergence occurred, the apex began oscillating violently. Tow forces oscillated rapidly from the steady state load of 13344 Newtons (3000 pounds) to approximately 35585 Newtons (8000 pounds.)

Table 3 Critical Tow Speed Test Results.

Test Boom	*Critical Tow Speed (knots)*	*Mode of Failure*
American Fireboom	2.25	Submerged
Dome Boom	2.0	Planing
PyroBoom	2.0	Planing
Spill-Tain	> 6.0	No Failure
Oil Stop Inflatable	3.5	Submerged

Conclusions from recent at-sea tests (Sloan *et al*, 1994) suggests that booms with higher B/W Ratios will have higher Critical Tow Speeds and may have more desirable performance at sea. Critical Tow Speed Tests, however, are conducted without oil so that the actual interaction between the boom and oil is not observed; how higher B/W Ratios translates to better oil collection performance is not quite so clear cut. The result of these tests generally support the conclusion that higher B/W Ratios are better but these results also provide additional insight that may also be somewhat contradictory. Figure 7 illustrates that booms with higher B/W Ratios have higher Critical Tow Speeds and Fig, 3 illustrates that booms with higher B/W Ratios have higher First Loss Tow Speeds. These two factors would seem to enhance oil collection performance. However, Fig 5 indicates that the two low B/W Ratios booms (i.e. Spill-Tain, Dome Boom) have the lowest Oil Loss Rates of all the booms tested. As discussed in Section 5.0, above, the effect of boom design and materials are important and may somewhat mask the effect of the B/W Ratios in these tests.

Using the three tests together may give a more balanced assessment of how booms will perform with oil:

- The Oil Loss Tow Speed Test - indicates the speed at which oil collection can be conducted; the faster the better so that oil will be collected quicker
- Oil Loss Rate Test - indicates how much oil is being lost at that speed; the lower the better so more oil will be retained in the boom for burning.
- Critical Tow Speed Test - indicates the maximum speed at which the boom can be towed without damage; higher is better for repositioning the boom at a new site, or transient higher speeds caused by the ship operator during maneuvering.

The at-sea test report (Sloan *et al*,1994) concludes that Critical Tow Speed increases exponentially with B/W Ratio. The tank data reported here is not quite that consistent. As discussed earlier in this report, it may be difficult to make strong conclusions on the effect of B/W Ratios because the booms are of such different construction. The Oil Stop boom, with a B/W Ratio of 9.5:1, is a fabric inflatable boom. The lower B/W Ratio booms are fabricated of heavier materials such a steel and solid flotation materials. Almost all of the booms tested at-sea were inflatable fabric booms (with the exception of Navy 3M fire boom which is tested here as American Marine fire boom) that were of the same general configuration but with different B/W Ratios. The B/W Ratios in the at-sea tests varied from approximately 2.5:1 to 20:1, a much great variation than in these tests (maximum B/W Ratio of 9.5:1). Over a wider range of B/W Ratios in a tank test, the results may be more consistent with the at-sea test with regard to the exponential increase of Critical Tow Speed with increase in B/W Ratio.

Three fire booms tested at Ohmsett were also tested at-sea. This provides an opportunity to compare the performance and results from the tank test and the at-sea tests (Sloan *et al*, 1995.) The three booms are the PyroBoom, Oil Stop, and the American Marine Fireboom. The at-sea Critical Tow Speed Test results for these booms are shown in Figure 7, also. It is observed that the relationship between the three booms is the same within the at-sea and tank test data sets and that the tank test results are consistently higher than the at-sea test data by 0.5 - 1.5 knots.

Several factors could contribute to the differences between the at-sea and Ohmsett tank Critical Tow Speeds.

- Critical Tow Speed definition. The definitions of Critical Tow Speed for the two tests are somewhat different. The definition used at Ohmsett focuses on proper towing and defines failure as planing, submergence, or mechanical breakage. This definition looks at the performance of the legs of the boom as well as the apex. Some booms will fail by planing of the legs before the apex will submerge. At Ohmsett, that is a failure. The at-sea test definition (actually called Tow Speed of Submergence) focused only on submergence of the apex, not on planing.

- Observer opinion. The Critical Tow Speed is a subjective decision made by the Test Director. Since it is an opinion, it is inherently variable when made by different observers.
- Speed measurement accuracy. It is always difficult to measure the speed of a ship through the water at very slow speeds (i.e. 1 knot or less.) This could be a significant source of error.
- Sea state difference. The Ohmsett tests were conducted on calm water. The at-sea tests were conducted on somewhat choppy water in the open ocean.
- Planing detection difference at sea.

6.0 Towline analysis

Responders preparing to respond to an oil spill need to plan and prepare their equipment prior to an oil spill. Spill responders determine equipment strength requirements and tow vessel requirements for different environments. For contrast, in an oil boom moored on an inland pond will encounter fewer forces than a boom towed in the open ocean with waves. Equations have been derived by several organizations to assist responders in calculating the tow loads of booms in different environments. These test results provide an opportunity to compare the results of those equations to actual tow tank data and assess their usefulness. The equations evaluated are the World Oil Spill, (Schulze *et al*, 1991) the International Tanker Owners Pollution Federation (ITOPF, 1981), as well as University of New Hampshire software (Wolford, 1995; Swift *et al*, 1992.)

Test tank towline force analysis was performed on five fire booms reported on in this paper. The five fire booms were evaluated with a:

- boom length of 30.5 meters
- U Catenary gap of 15.25 meters
- 2:1 Gap ratio
- constant velocity
- calm and wave conditions
- wind affects are considered negligible in Ohmsett test tank.

During the towline force analysis, the mean values from both load cells, and tow speed were determined. For each data point, the Ohmsett load cells values were averaged together and added to Table 4 at the end of this section, along with analysis of boom force equations and UNH software. Figure 8 is a comparison of each fire boom tested at Ohmsett, actual towline force versus speed.

6.1 World Oil Spill Equations:

The World Oil Spill Equations 1 and 2 (Schulze *et al*, 1991; Sloan *et al*, 1994) uses environmental parameters such as boom dimensions, water density, wave height, water and wind speed to determine the two forces. The equations are designed for the open ocean analysis.

$$T_W = \frac{1}{2} L \tau C_d \rho_w d \left(V_w + \sqrt{H_s}/2 \right)^2 \qquad (1)$$

$$T_A = \frac{1}{2} L \tau C_d \rho_a f V_a^2 \qquad (2)$$

Where:

L = barrier length, feet
τ = Dimensionless tension parameter dependent on gap ratio, (assume 0.12)
C_d = dimensionless drag coefficient (assume 1.5)
ρ_W = water density (1.98 slugs/ft^3)
ρ_A = air density (0.00238 slugs/ft^3)
d = barrier draft, ft
V_W, V_A ; water and air velocities in ft/s
T_W, T_A ; water and air tension in pound-force

The total drag force on the boom is given by: $D = 2(T_w + T_a)$

6.2 International Tanker Owners Pollution Federation (ITOPF) tow equations

The International Tanker Owners Pollution Federation (ITOPF) equations 3 and 4 uses simplified boom parameters such as projected underwater boom area and water and wind speed and adds a safety factor to determine the total tow forces. The equation is designed for the open ocean analysis.

$$F_W = 26 \times A \times \left(\frac{V_a}{20.576} \right)^2 \qquad (3)$$

$$F_C = 26 \times A_s \times (1.9456 V_C)^2 \qquad (4)$$

Where:

V_C, V_A ; water and air velocities in m/s
A_S = Subsurface profile area in m^2
F_C and F_W; current and wind forces measured in kg

6.3 Oil Boom Catenary Diversion Model

The University of New Hampshire's (UNH's) Computer Oil Boom Catenary Diversion Model uses a methodology to iteratively solve for the position of the apex and drag per mooring point, given the user specified boom parameters. The boom parameters are the boom mooring points location, boom dimensions, current speed and direction. Equation 5 is used in developing their algorithm and methodology. The program was developed for inland river environments where the wave effects are negligible. Therefore, UNH's program was not evaluated for the Ohmsett tow force analysis with wave conditions.

$$\sum F_N = \frac{1}{2} \rho_w C_d (U \times Cos(\theta + \Delta\theta/2))^2 d \Delta s \qquad (5)$$

Where:

Δs = Boom segment
d = boom skirt depth
U = Water current speed
C_d = dimensionless drag coefficient (assume 1.5)
ρ_W = fluid density

6.4 Tow force data discussion

The steady state mean towline force and speed was calculated and compared to the boom equations for booms tested at Ohmsett during the fire boom test series in calm water, and are presented in Table 4.

The ITOPF equation consistently overestimates the boom tow forces by approximately 34%; the exception is the PyroBoom which was underestimated by approximately 40%. This equation, then, encompasses the actual measured tow forces and provides a sufficient safety factor. Video footage of the PyroBoom showed it was the most flexible of the barriers evaluated and formed an open "box" shape instead of a true catenary. The equations used determine drag for a catenary shape. It is interesting to note that the Applied Fabrics is the lightest barrier tested but had the second highest drag force for the steady state speed. The barrier with the greatest towline force was the Dome boom. The barriers with the lowest towline force are the Oil Stop and American Marine which are both a compliant meshed skirt boom, unlike the other which are ridged plated.

Both UNH and World Oil Spill equations underestimated the Ohmsett tank data by approximately 125%. Both UNH's program and the World Oil Spill calculates and determines the force assuming a planer boom shapes. The barriers tested have out-riggers and other flow obstructions that extend into the free stream and generate uncalculated drag. The drag coefficient (C_d) was assumed 1.5 and could be significantly higher. During the tests at Ohmsett, the instruments record towline tension instead of the tow forces a vessel would "feel." Therefore, the towline forces can be higher than the predicting equations. The UNH program was developed to model deflection configurations and was validated for this purpose in the Piscataqua River, NH (Swift *et al*, 1992.) The "blockage effect" of a containment configuration may also explain the increases in the Ohmsett measured towline force than UNH calculation techniques.

Table 4: Fire Boom Test Series, Tank Tow Speed, and Tow Force on Calm Water Compared to Calculated values.

Boom Manufacture	*Speed (knots)*	*Towline forces (N)*				
		Ohmsett data	*Ohmsett Max data*	*UNH*	*ITOPF*	*World Oil Spill*
American Marine	0	0	0	0	0	0
	0.60	239	289	135	373	143
	0.89	605	649	304	839	321
	1.19	1094	1112	523	1442	552
Dome Boom	0	0	0	0	0	0
	0.51	616	678	186	513	196
	1.12	1879	1973	864	2386	910
	1.30	2191	2246	1206	3332	1271
Applied Fabric Technologies	0	0	0	0	0	0
	0.51	334	400	74	205	78
	1.13	1474	1668	364	1007	383
	1.30	1868	1890	482	1332	508
Spill-Tain	0	0	0	0	0	0
	0.51	253	280	121	333	127
	0.93	728	790	411	1132	432
	1.67	1148	1199	625	1724	658
Oil Stop	0	0	0	0	0	0
	0.51	201	251	112	308	117
	0.97	717	761	428	1184	451
	1.19	907	934	632	1746	665

7.0 Conclusions

These tests have provided detailed oil collection performance data on five fire booms tested. The results are summarized in one table for easy reference, Boom Performance Summary, Table 5.

- The oil collection performance of the fire booms tested is comparable to the performance of other conventional, non-fire resistant oil containment booms.
    - The First Loss Tow Speeds for these booms are 0.85 - 1.0 knots in calm water. The First Loss Tow Speed is relatively unaffected by regular waves; some reduction was measured in short-crested waves.
    - The Critical Tow Speeds range between 2 - 3 knots with the exception of the Spill-Tain boom, which exceeded 6 knots. Booms failed only by submergence or planing, but not mechanically.

Table 5: Boom Performance Summary

Boom Manufacture	*Loss*	*First & Gross Loss Tow Speed (knots)* ** *Wave condition* C	*1*	*2*	*3*	*Loss Rate Test (lpm) @ knots* 1st Loss + 0.1	1st Loss + 0.3	*Critical Tow Speed (knots)*
PyroBoom	First	1.00	0.72	1.07	0.95	246 @ 1.10	534 @ 1.3	2.00
	Gross	1.20	0.93	1.30	1.10			
Spill-Tain	First	0.85	0.40	0.85	0.88	27 @ 0.95	178 @ 1.15	>6.00
	Gross	1.05	0.60	1.05	1.07			
American Marine	First	0.85	0.72	0.87	0.9	64 @ 0.95	303 @ 1.15	2.25
	Gross	1.10	0.90	1.15	1.15			
Dome Boom	First	0.95	0.75	0.95	1.00	32 @ 1.05	151 @ 1.25	2.00
	Gross	1.32	1.05	1.20	1.25			
Oil Stop	First	0.90	0.80	1.07	1.00	74 @ 1.00	286 @ 1.20	3.50
	Gross	1.22						

** Wave Conditions:

C = Calm: no waves generated
1 = Wave #1: regular sinusoidal wave $H^{1/3}$ = 25 cm, L = 4.9 m
2 = Wave #2: regular sinusoidal wave $H^{1/3}$ = 33.8 cm, L = 12.8 m
3 = Wave #3: regular sinusoidal wave $H^{1/3}$ = 22.6 cm, no L or T calculated.

- From the limited data available in this report, it appears that an increased buoyancy-to-weight ratio is beneficial for oil collection performance. It appears that the boom materials and configuration are also very important.

- Three fire booms tested in this report were also tested at-sea. The measured Critical Tow Speeds of the at-sea tests are lower than the Ohmsett tank tests by 0.5 - 1.5 knots.

- Results from previous at-sea tests suggest that higher B/W Ratios may results in better oil collection performance as indicated by the Critical Tow Speed Test. However, these tests show that lower B/W Ratio booms are capable of good oil collection performance when including the Oil Loss Rate test results. Boom design and material selection are also important factors in oil collection performance.

- Using three tests together may give a more balanced assessment of how booms will perform with oil:
  - Oil Loss Tow Speed Test - indicates the speed at which oil loss begins and will, therefore, be the speed at which oil collection operations will be conducted with that boom.
  - Oil Loss Rate Test - indicates how much oil is being lost at that speed
  - Critical Tow Speed Test - indicates the maximum speed at which the boom can be towed without damage;

- Of the three boom tow force equations evaluated, the ITOPF equation overestimated the forces by approximately 34% and would, therefore, provide a good estimation of the forces and an adequate factor of safety. The World Oil Spill Catalogue and the UNH equations both underestimate the tow forces by approximately 125%.

- It is recommended that additional testing with oil be conducted to investigate the effect of B/W Ratio on the oil collection performance and that oil loss rate be included.

- It is recommended that test guidelines be developed for evaluating booms at-sea and in test tanks. These guidelines will assist experimenters in designing tests that measure the necessary parameters. The tank guideline and the at-sea guideline should insure that the results of the two tests can be compared.

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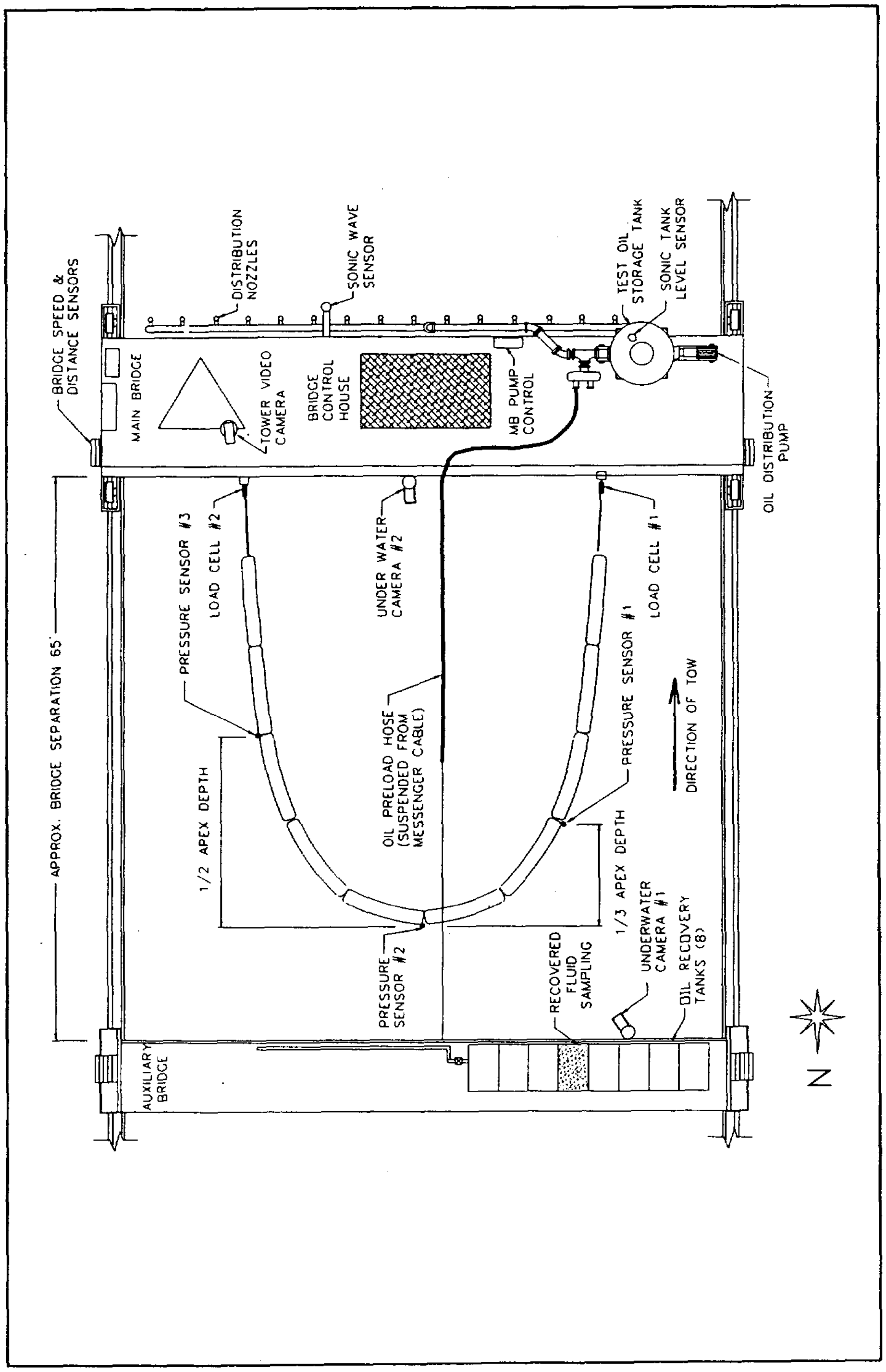

Figure 1 Test Set Up

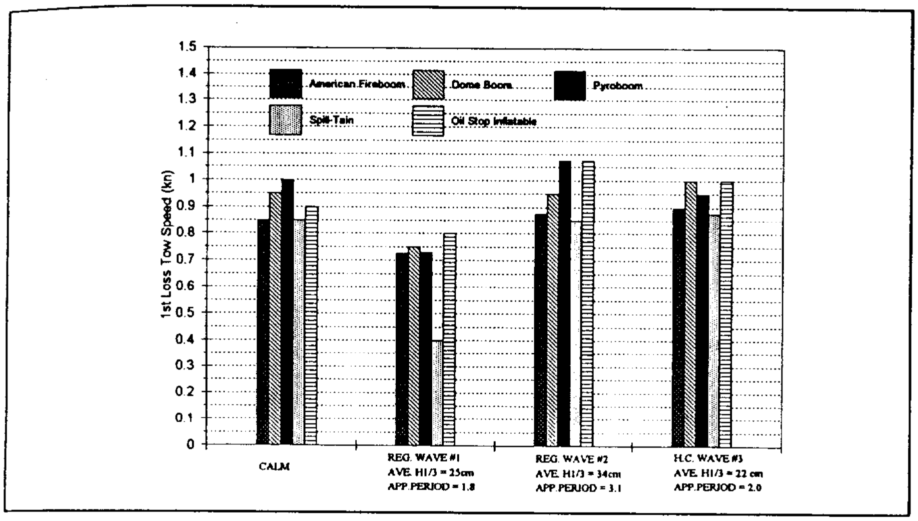

Figure 2 First Loss Tow Speed for various wave conditions

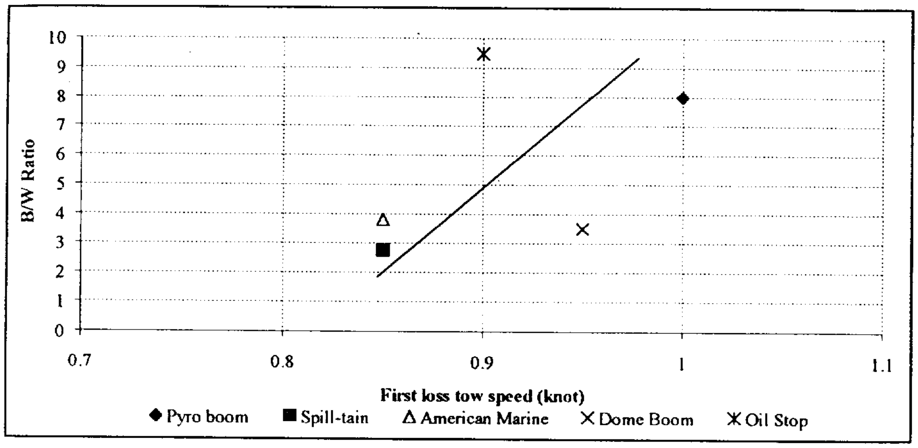

Figure 3 First Loss Tow Speed versus Buoyancy-to-weight ratio, calm water

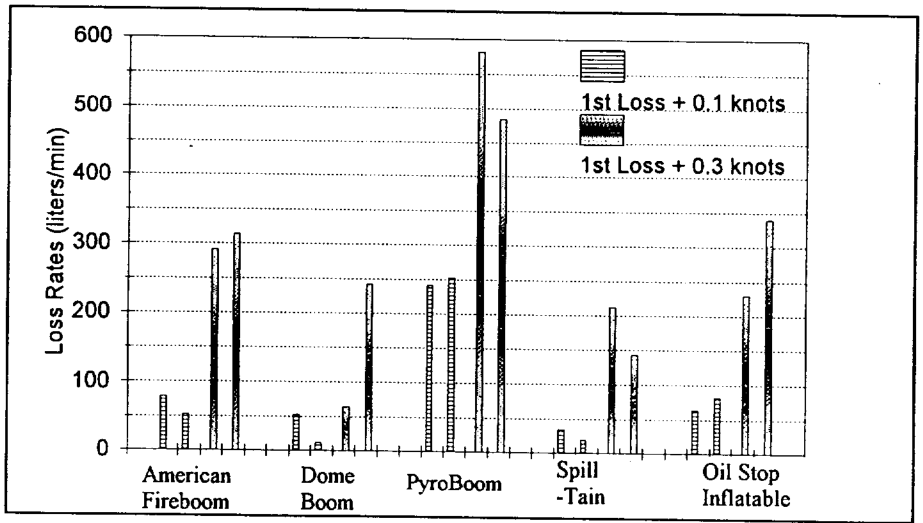

Figure 4 Oil Loss Rate at First Loss Tow Speed Plus .1 and .3 knots

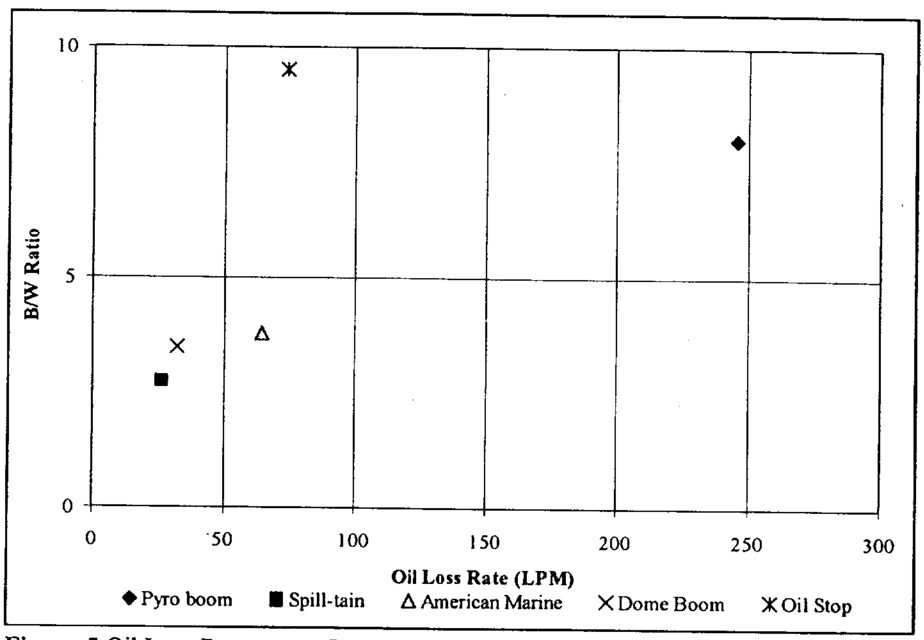

Figure 5 Oil Loss Rate versus Buoyancy to Weight Ratio

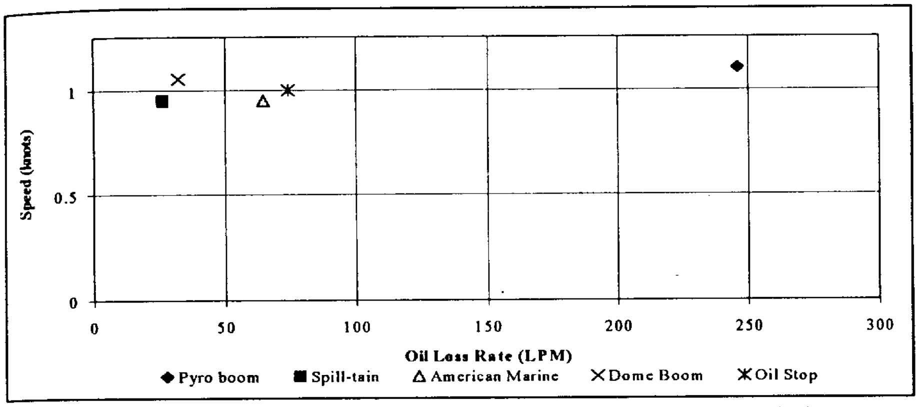

Figure 6 Oil Loss Rate versus Speed, calm water, First Loss Tow Speed Plus .1 knots

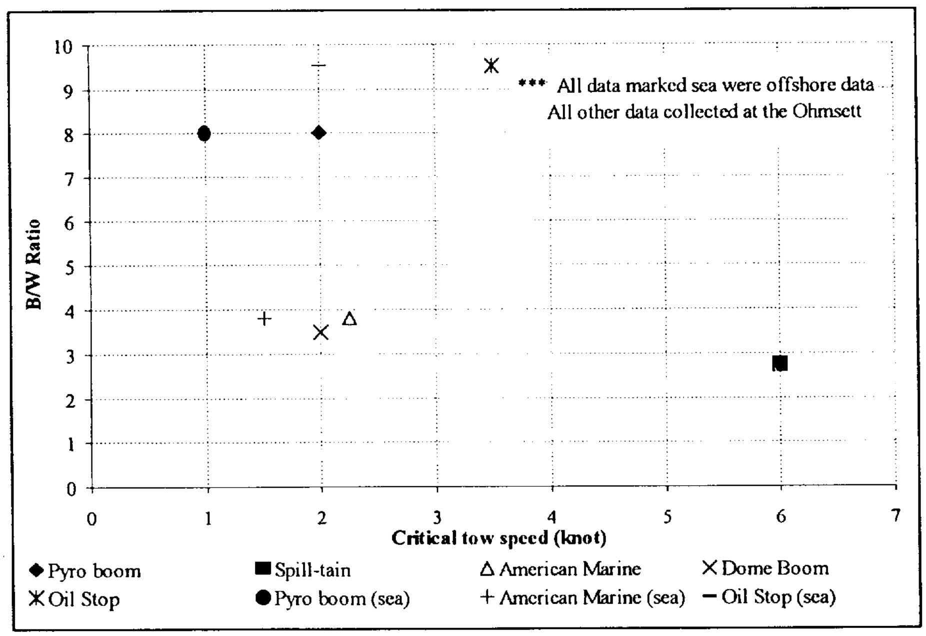

Figure 7 Critical Tow Speed versus Buoyancy-to-Weight-Ratio

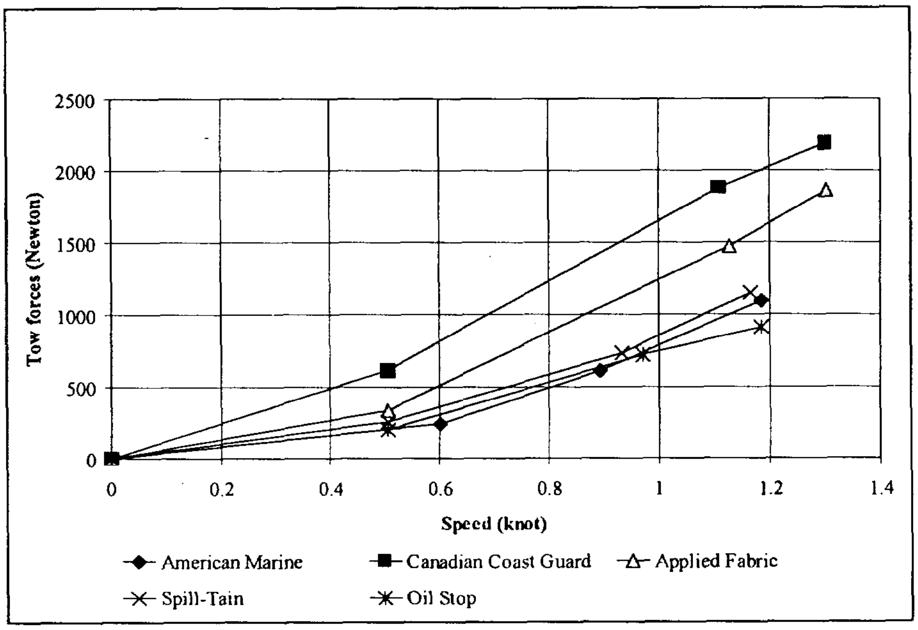

Figure 8 Comparison of Fire boom evaluated at Ohmsett: Tow Force versus Speed