U.S. Coast Guard Research and Development Center
1082 Shennecossett Road, Groton, CT 06340-6096

Report No. CG-D-25-99

Test and Evaluation of Four Fire Resistant Booms at OHMSETT

FINAL REPORT
AUGUST 1999

This document is available to the U.S. public through the
National Technical Information Service, Springfield, VA 22161

Prepared for:
U.S. Department of Transportation
United States Coast Guard
Marine Safety and Environmental Protection (G-M)
Washington, DC 20593-0001

N O T I C E

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report does not constitute a standard, specification, or regulation.

Marc B. Mandler, Ph.D.
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

Technical Report Documentation Page

1. Report No. CG-D-25-99	**2. Government Accession Number** ADA371800	**3. Recipient's Catalog No.**
4. Title and Subtitle TEST AND EVALUATION OF FOUR FIRE RESISTANT BOOMS AT OHMSETT		5. Report Date August 1999 6. Performing Organization Code Project No. 4120.5.1
7. Author(s) David DeVitis, Kathleen Nolan, and William Schmidt		**8. Performing Organization Report No.** R&DC-289-99
9. Performing Organization Name and Address MAR, Inc.-OHMSETT Facility, NWS Earle –Waterfront, Rt. 36, Leonardo, NJ 07737	U.S. Coast Guard, Research and Development Center, 1082 Shennecossett Road, Groton, CT 06340-6096	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** DTCG39--98-X-E00198
12. Sponsoring Organization Name and Address U.S. Department of Transportation, United States Coast Guard, Marine Safety and Environmental Protection (G-M), Washington, DC 20593-0001	U.S. Department of Interior, Minerals Management Service, 381 Elden Street, Herndon, VA 20170-4817	**13. Type of Report & Period Covered** Final Report **14. Sponsoring Agency Code** Commandant (G-MOR), U.S. Coast Guard Headquarters, Washington, DC 20593-0001

15. Supplementary Notes

The R&D Center's technical point of contact is Mr. Kurt Hansen, 860-441-2865.

16. Abstract (MAXIMUM 200 WORDS)

During the period of August 22-October 12, 1998, seven commercial fire booms were involved in burn testing at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama, in accordance with the proposed protocol, American Society for Testing and Materials-F20. Four of the seven booms survived the test sequence and were shipped from Mobile, Alabama, to the Minerals Management Service's OHMSETT facility for additional tests including first loss, gross loss, tow speed, oil loss rate, and critical tow speed. The four booms showed the same trend in response to various wave conditions; the long sinusoidal waves improved containment performance and the short, choppy waves degraded performance. One of the four booms achieved slightly higher first and gross oil loss speeds in each test. Three of the four booms performed comparably during the oil loss rate tests. One boom demonstrated superior stability at high tow speeds.

The results of this test report are consistent with the evaluation of fire booms previously tested at OHMSETT, but also show a slight increase in performance. The tests indicate that the existing fire booms can contain oil in currents up to 1 knot and in various wave conditions after being exposed to multiple burns. This information will be used by the Coast Guard to develop policies and procedures for the In-Situ Burning (ISB) of oil during a spill.

17. Key Words oil, tow speed, critical tow speed, oil loss rate, first loss tow speed, gross loss tow speed		**18. Distribution Statement** This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 2216	
19. Security Class (This Report) UNCLASSIFIED	**20. Security Class (This Page)** UNCLASSIFIED	**21. No of Pages**	**22. Price**

Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized.

[This page left blank intentionally.]

EXECUTIVE SUMMARY

An alternate cleanup method during an oil spill is ignition and burning of the oil at sea. Use of in-situ burning (ISB) has the potential to increase the efficiency of spill responders, lower the cost of spill response and protect marine resources. In order to develop consistent approaches throughout the United States, standard policies and procedures are being investigated and developed by the Coast Guard Research and Development Center. The results of this project will provide information, specifications, guidelines and field manuals to make ISB an operational oil spill response technique.

One of the major concerns of spill planners and responders is the durability of fire booms. Fire booms must function as an oil containment boom so it must withstand the forces of being towed through the water to collect and contain oil. It must also withstand the high heat flux and flexing caused by the burning oil. A major operational concern has been whether fire booms can still be used to collect and contain oil after a burn. This report attempts to answer that question by performing towing tests on fire booms after they have been exposed to burning oil. These tests will determine whether oil escapes under the boom or over the top if the fire has damaged the boom above the waterline.

Seven commercial fire booms were tested to the proposed American Society for Testing and Materials (ASTM) – F20 Fire Boom test protocol in which they were subjected to three hours of burning diesel fuel and waves simultaneously. These tests occurred at the U.S. Coast Guard Fire and Safety Test Detachment (FSTD) in Mobile, Alabama, and were reported in "Second Phase Evaluation of a Protocol for Testing Fire Resistant Oil Spill Containment Booms," Report CG-D-15-99. Four booms that survived the burn test sequence were shipped to OHMSETT, the National Oil Spill Response Test Facility in Leonardo, New Jersey, for further evaluation.

The purpose of the OHMSETT testing was to measure the oil collection/containment performance, ease of handling, and the seakeeping ability of the selected fire booms when subjected to a variety of towing and wave conditions. The test booms were rigged in a catenary configuration with the gap equal to 33% of the length. Tests were conducted at tow speeds up to 1.5 knots in calm water and three wave conditions. The first loss tow speeds, defined as the lowest speed at which oil droplets pass continuously under the boom, ranged from 0.6 to 1.1 knots. Loss rates at first loss plus 0.1 knot ranged from 3 to 9 gpm. The loss rates at first loss plus 0.3 knots were also comparable, ranging from 23 gpm to 36 gpm. Critical Tow Speed of each boom was determined using calm surface conditions and ranged from 2.25-4.6 knots.

The results of this test report are consistent with the evaluation of fire booms that had been previously tested at OHMSETT and are documented in "Test and Evaluation of Six Fire Resistant Booms at OHMSETT", Report CG-D-12-98. These results show a slight increase in the boom's performance in containing oil due to improvements made by the manufacturers. The performance of these fire booms indicates that under the right conditions, they can be used for the burning of oil on the ocean. These results will provide the input needed to develop policies and procedures for the use of ISB.

[This page left blank intentionally.]

TABLE OF CONTENTS

APPENDICES

LIST OF FIGURES

LIST OF TABLES

[This page left blank intentionally.]

1.0 INTRODUCTION

1.1 Background

At-sea incineration (in-situ burning) of marine oil spills is an alternate response technique and has been approved for spill response use in coastal waters off Alaska and in the Gulf of Mexico. During the 1993 Newfoundland Offshore Burn Experiment (NOBE) sponsored by Environment Canada (EC), Minerals Management Service (MMS), Canadian Coast Guard (CCG), and the U.S. Coast Guard (USCG), measurements were made to increase technical and operational knowledge of in-situ burning and to simplify its operational use. One operational research need identified at NOBE was:

> "New test standards, to include dynamic testing of heat stressed, fire-resistant booms, are necessary to evaluate fire booms for effectiveness, and set a benchmark for product improvement. Standards must be developed and validated."

At this time, the most critical scientific and engineering problem to be addressed is improving the process of testing and evaluating fireproof booms to be used offshore. In order to burn spilled oil, it must be collected and maintained in sufficient thickness to support combustion when the fire boom is being towed. Towing is continued at approximately ¾ knot, even after ignition, to maintain sufficient fuel (oil thickness) to support combustion.

The USCG Research and Development Center (R&DC) sponsored previous testing to evaluate the oil containment and seakeeping abilities of select fire-resistant booms in dynamic conditions at OHMSETT, The National Oil Spill Response Test Facility in Leonardo, New Jersey (DeVitis, et. al., 1997). The USCG R&DC, MMS, and CCG are currently participating in a joint project to investigate commercially available, fire-resistant, offshore containment booms for use in multiple in-situ burns.

The first phase of the project was to evaluate the fire-resistant capabilities of seven select fire-resistant booms. These booms were subjected to various in-situ burn trials at the U.S. Coast Guard Fire and Safety Test Detachment (FSTD) Facility in Mobile, Alabama.

Once the candidate fire-resistant booms were tested according to the proposed ASTM F-20 standard (*Standard Guide for In-Situ Burning of Oil Spills on Water: Fire-Resistant Containment Boom*) in Mobile, Alabama, the surviving candidates were sent to OHMSETT where they were tested with oil under various environmental conditions.

This report contains the results of the oil handling capabilities of the fire-resistant boom determined *only* during the tests at OHMSETT. The results of the trials in Mobile, Alabama, are contained in Walz (1999).

1.2 Test Objectives

The purpose of the testing is to measure the oil collection/containment performance, and the seakeeping of the selected fire booms when they are subjected to a variety of towing and wave conditions. The core test methods measure or identify the following boom performance characteristics:

- Boom oil capacity versus relative tow speed.
- Towing speed (relative current speed) at which the boom first loses oil (both in calm water and in various wave conditions).
- Towing speed (relative current speed) at which the boom reaches a gross oil loss condition (both in calm water and in various wave conditions).
- The oil loss rate as a function of tow speed.
- Boom conformance to the surface wave conditions for various wave heights, wavelengths and frequencies, (qualitatively).
- Resulting tow forces for various speeds and wave conditions.
- Identify towing ability at high speeds in calm water and waves.
- Boom seaworthiness relative to its hardware (i.e., connectors, ballast members), and general durability.

1.3 Testing Scope

The purpose of this test is to characterize the oil collection performance of selected fire booms by measuring the tow speed at which the boom begins to lose oil and the rate of oil loss. Other quantitative measurements include the critical tow speeds and the forces exerted on the towing points during the test series. These tests are conducted at a combination of tow speeds, in calm water and with three wave conditions. The baseline loss speed for each boom is first determined in calm water. The candidate boom is then tested using varying wave types to determine the effects on performance. The booms are qualitatively evaluated for overall wave conformance, ease of handling and possible deficiencies in design that could compromise the integrity of the boom section.

1.4 Description of Fire Booms

Descriptions of the booms are presented in the order that the booms were tested. The descriptions are based on information provided by each vendor. Table 1 is a summary of the boom dimensions, materials, and buoyancy-to-weight ratios.

Table 1. Boom Characteristics.

	Elastec/American Marine	Spill Tain™	Applied Fabric Technologies	SL Ross/Applied Fabric Tech[1]
Model	Hydro-Fire	47 inch	PyroBoom (PB-30)	Pocket Boom
Draft (in)	21	23.0	19.0	25.3
Freeboard (in)	10	23.0	11.0	13.7
Wt/LF (lbs/lf)	8	19.4	9	27
No. of sections[2]	12	3	1	7
Test Section Length (ft)	49.3	45	50	56.7
Buoyancy/Wt Ratio	3.6:1	2.75:1	3.2:1	3:1
Predominant Fire Resistant Material	Proprietary information	Stainless steel (SS)	Proprietary woven blend of Inconel® and Fiberfrax®	Stainless steel
Tension Member	3/8” Galvanized chain	Stainless steel cable	5/16” Galvanized chain and boom fabric	Stainless steel
End connector	Universal	Bolt, ASTM adapter	ASTM (D962)	Navy slide
Water Requirements (gpm)	.5 gpm	None	None	None
Reserve buoyancy (lbs/ft)	31.9	44.9	19.3	54
Storage Method	Reel or manually stack	Disconnect at section ends and palletize	Reel or manually stack	Fold and lift using provided beam
Manufacturer’s Boom Length (ft)	100	15 per section	50	56.7
Floatation	Bladders with ¼” turn valves	Foam glass (enclosed in stainless steel chamber)	Foam glass enclosed in stainless steel hemispheres	Ambient pressure, air filled stainless steel float chambers

1 SL Ross Ltd. Was in charge of the boom design lead; Applied Fabric Technologies Inc.-was the manufacturer and fabricated the boom.
2 Number of sections refers to number of floatation sections, or panel sections, in a standard manufacturer supplied length of boom.

1.4.1 Elastec/American Marine Hydro-Fire Boom

The Hydro-Fire Boom is an inflatable water-cooled boom. The 50-foot test section of boom has twelve-four foot long sections that are inflated through a munson type valve to 1–1.5 psi. The boom is equipped with a main tension member located in the skirt (3/8 inch galvanized chain) and a second tension member (1/4 inch stainless steel cable) located along the top of the floatation bladders. The water-cooled jacket is secured to the host boom with thru bolts and large flat washers spaced approximately 2 feet apart. The manufacturer currently holds the specifications of the jacket material as proprietary information. Water is supplied to the refractory boom jacket material to provide continual cooling to the outer surface through vertical water feed lines at fifty-foot intervals as seen in Figure 1.

On the test section of boom, the water was supplied through the main water feed line to the apex of the boom. The feed line supplying cooling water to the distribution system was operated during the test series. The test boom section came equipped with a Universal Slide Type I connector. A mating connector was also provided that was bolted to a male Navy standard connector. This configuration provided a direct connection to the lead boom section.

<u>Statement of Condition Upon Arrival at OHMSETT</u>

Visual inspection of the boom section and refractory cooling jacket indicated that there was no damage to any part of the boom due to the flame exposure. The white refractory material was slightly darkened in various areas due to combusted diesel residue, but did not show any signs of charring, melting or shrinkage due to excessive heat (See Figure 2 and Figure 3).

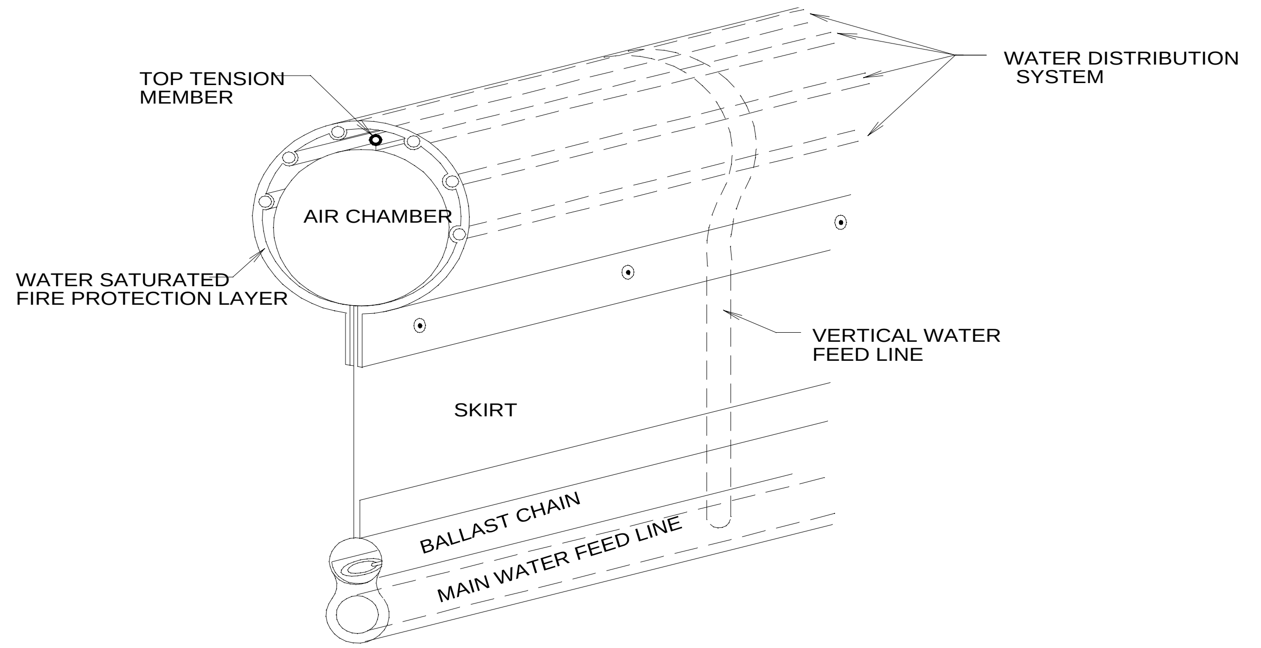

Figure 1. Details of the Elastec/American Marine Hydro-Fire Boom.

Figure 2. Hydro-Fire Boom, post burn in Mobile.

Figure 3. Illustrates the Hydro-Fire Boom during an oil loss rate test.

1.4.2 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 316 stainless steel sheet metal, closed cell foam glass floatation, and stainless steel cable. The boom can follow wave action due to a patented, segmented panel and hinge design. Deployed boom segments are composed of alternating stainless steel parallelograms and rectangles, separated by trapezoids. Boom panels are supported perpendicular to the water by alternating attached and outrigger floats. Adjacent boom panels are attached to each other by integrally formed piano hinges. The tension cable is affixed to the bottom outer edge of the outrigger floats. Connecting plates with five thumbscrews and accompanying nut plates join the 15-foot sections to one another, with shackles connecting cable eyes at each section end. Figure 4 illustrates how relative motion is achieved between each panel and the continuous hinges.

Three sections were joined to form a 45-foot section for testing. An adapter was fabricated on site to facilitate connecting the test boom section to the lead sections of boom. The adapter consisted of a flat plate that mated to the test boom using five thumbscrews. A male Navy standard connector allowed direct connection to the leading boom sections.

Statement of Condition Upon Arrival at Ohmsett

Visual inspection of the boom revealed that some of the rivets were missing at the hinge to section attachment points. Despite the warping caused during the burn test as shown in Figures 5 and 6, the three section attachment points did mate and the connection for assembly was made with little effort.

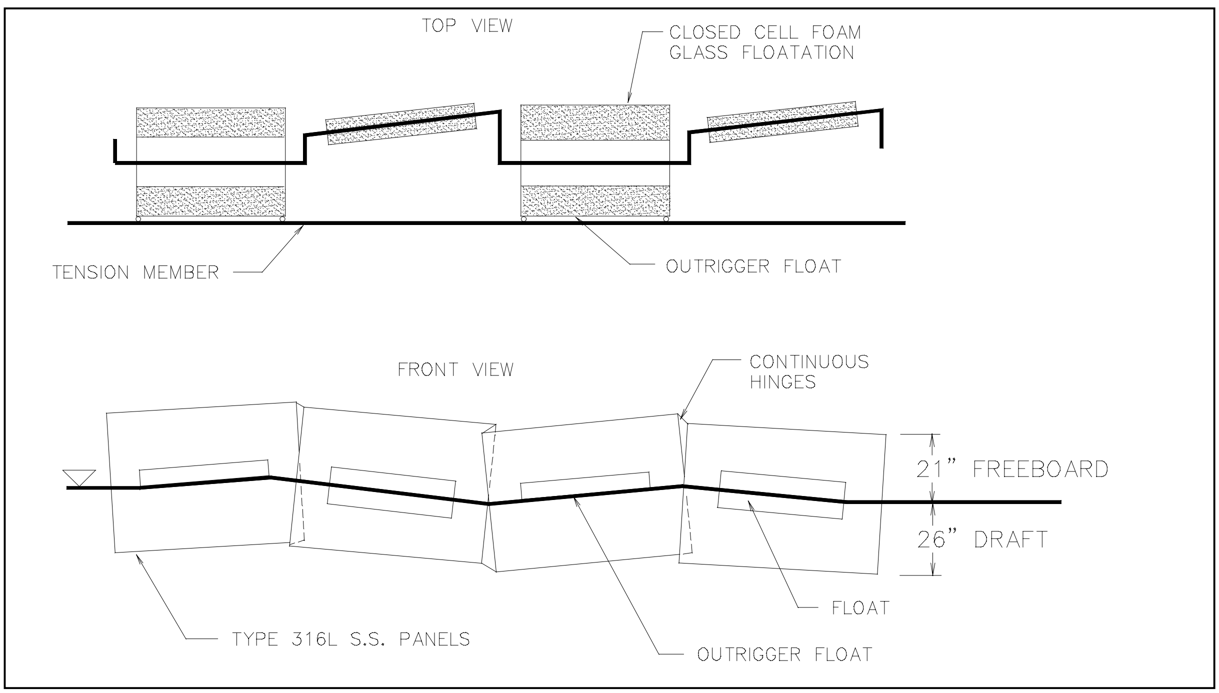

Figure 4. Details of Spill Tain™ Fire Boom Offhore Version.

Figure 5. Spill Tain^{TM} boom, arrival condition of boom.

Figure 6. Spill Tain^{TM} boom construction, shipping configuration.

1.4.3 Applied Fabric Technologies PyroBoom® (PB-30)

PyroBoom® is a solid floatation barrier that combines wire reinforced refractory fabric for the freeboard, and polyester impregnated polyurethane 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 nineteen inch draft and an eleven inch freeboard. The boom is 50 feet long. There are galvanized shackles above each flotation hemisphere for lifting. The PyroBoom® was modeled after Applied Fabric Technologies GlobeBoom®, and because of its light weight, no special handling equipment is necessary. Figure 7 illustrates the boom geometry. The PyroBoom came with American Society for Testing and Materials (ASTM) connectors that were adapted to the lead boom sections with manufacturer supplied adapters. The adapters provided for a direct connection between the ASTM and Navy standard female connector (See Figure 8).

Statement of Condition Upon Arrival at OHMSETT

The PyroBoom was found to have suffered severe degradation to the refractory material above the water line, (Figure 9). The stainless steel floatation globes were intact, but showed signs of material property changes due to the burn test. The manufacturer reported that the barrier material was not fabricated as specified. Mesh reinforcing within the refractory material was not the metal type or proper gauge size requested by Applied Fabric Technologies.

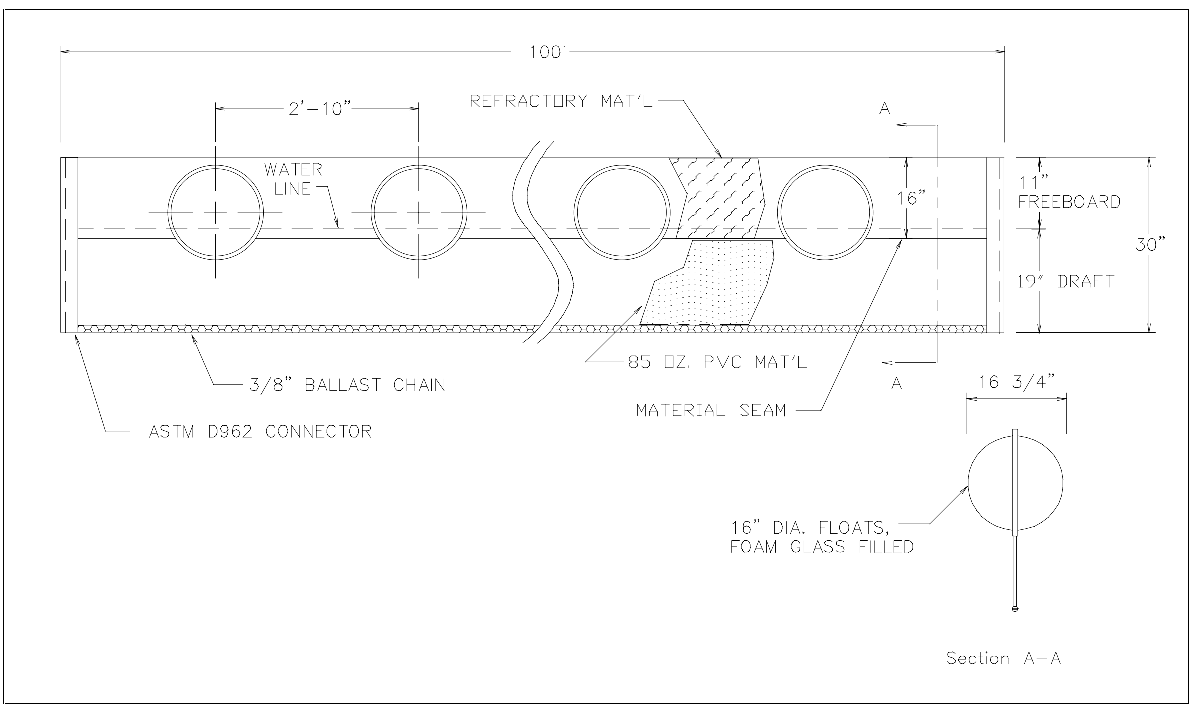

Figure 7. Details of Applied Fabric Technologies PyroBoom® (PB-30).

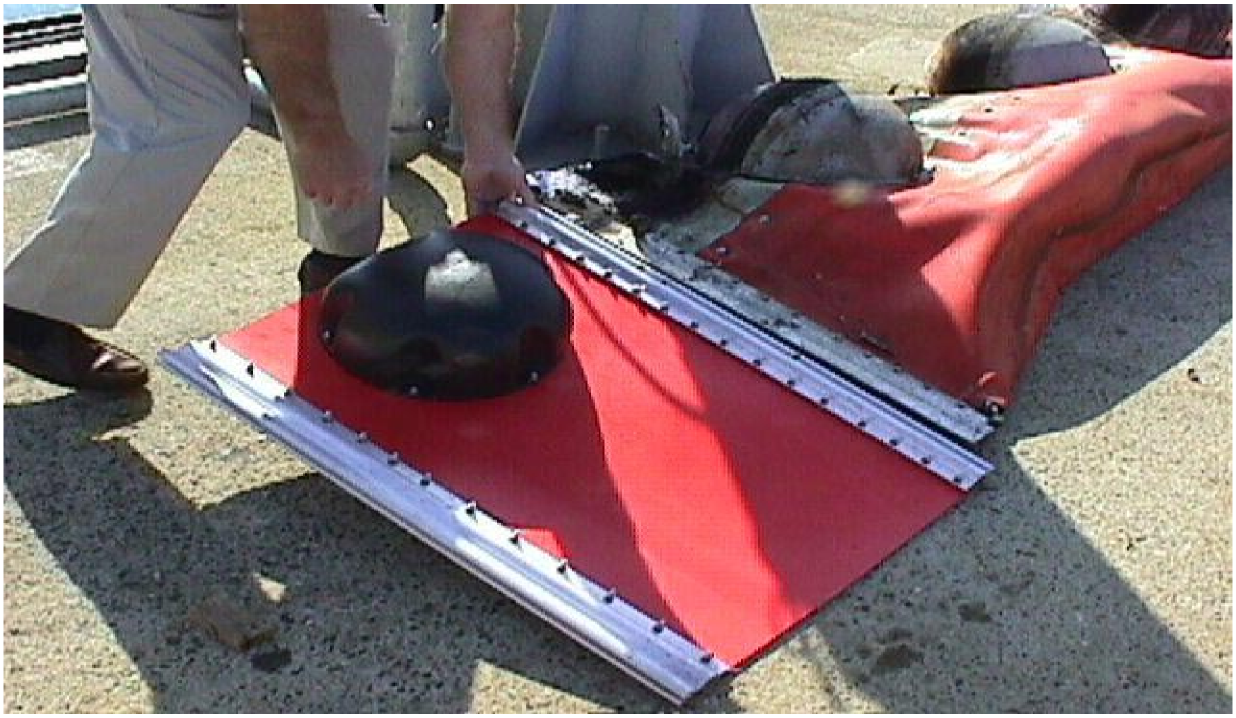

Figure 8. PyroBoom, construction.

Figure 9. PyroBoom, arrival condition.

1.4.4 Pocket Boom

The Pocket Boom is a re-engineered design of the Dome boom, which was previously tested at OHMSETT (DeVitis, et. al., 1997). The overall redesign philosophy was to downsize the boom, reduce its weight, increase its buoyancy and improve its handling while maintaining its strength and durability. See Figure 10. Each boom section measures 8.1 feet. Each float section has a height of 39 inches, and a length of 67.3 inches, with the freeboard measuring 13.7 inches. The thickness of the metal used to construct the floatation chamber was reduced from 14 to 18 gauge, while the grades of stainless steel for the above-water components remained unchanged as type 304SS. Each connector is 36 inches high and 26.3 inches long, and weighs 108 pounds. (See Figure 11) Flexibility of the pleated connectors allows the boom to fold accordian style. Once folded, the 56.7-foot section can be hoisted using one lifting beam. According to the manufacturer, 94 feet of pre-connected stainless steel boom, weighing 2800 pounds; could be stored and ready for deployment in one piece, in a 20-foot long container.

The test section of Pocket Boom was equipped with female Navy standard connectors. Rigging to the lead boom sections was accomplished by direct connection of Navy Standard connectors. Connection to the two bridles was made by interlocking the Navy standard female and tow bridle female, then drilling and pinning the connection.

<u>Statement of Condition Upon Arrival at OHMSETT</u>

The Pocket Boom arrived at OHMSETT with relatively little damage. Several boom sections had floatation units that appeared to crumpling inwards while there was some expansion in other areas. The various boom sections showed slight signs of material property changes due to the burn test. Figure 12 shows a boom section with the most severe heat damage. Manufacturer representatives concluded the vent tube closed off, therefore not allowing internal pressure to equalize with the atmosphere. It should be noted that this specific boom section was previously tested at OHMSETT (SL Ross Environmental Research Ltd) under various towing conditions.

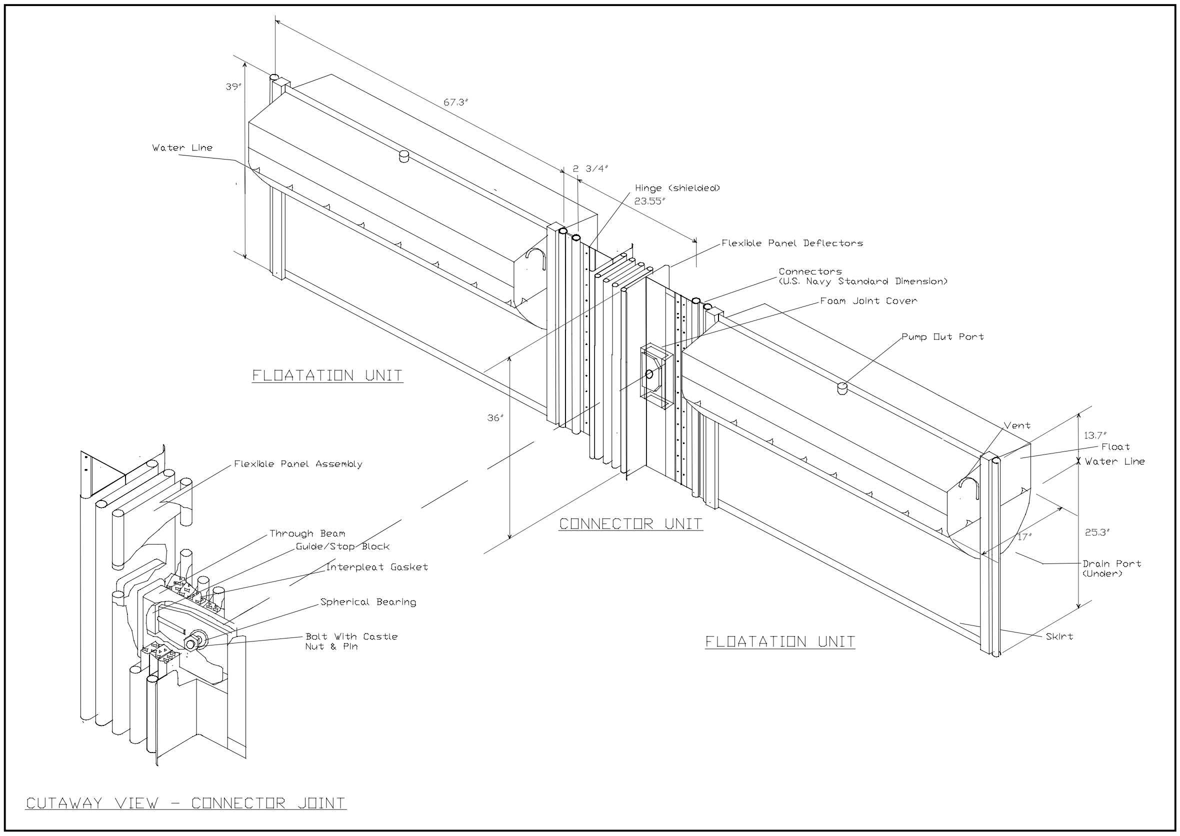

Figure 10. Details of the Applied Fabric Technologies/SL Ross Pocket Boom.

Figure 11. Pocket Boom, construction.

Figure 12. Pocket Boom, arrival condition.

2.0 TEST DESCRIPTIONS

2.1 Typical Test Configuration and Instrumentation

The test setup is illustrated in Figure 13. Each of the electronic meters mentioned in this section are described fully in APPENDIX A, FIRE BOOM INSTRUMENTATION. The test booms were rigged in a catenary configuration with the gap equal to 33% of the length; this is also known as a boom length-to-gap ratio of 3:1. Each manufacturer's section of fire boom was extended by attaching a 25-foot section of Applied Fabric Technologies Globeboom to each end. This provided the additional length necessary to position the test booms as the apex. The bridles were attached to the adjustable tow points located on the Main Bridge. Boom towing force was measured with in-line load cells positioned between the boom towing bridles and tow points. Instrumentation signal cables were attached to terminal blocks located in the Bridge house. The signals (typically 4-20 mA) are hardwired via a festoon system to the data collection computer located on the third floor of the Control Tower.

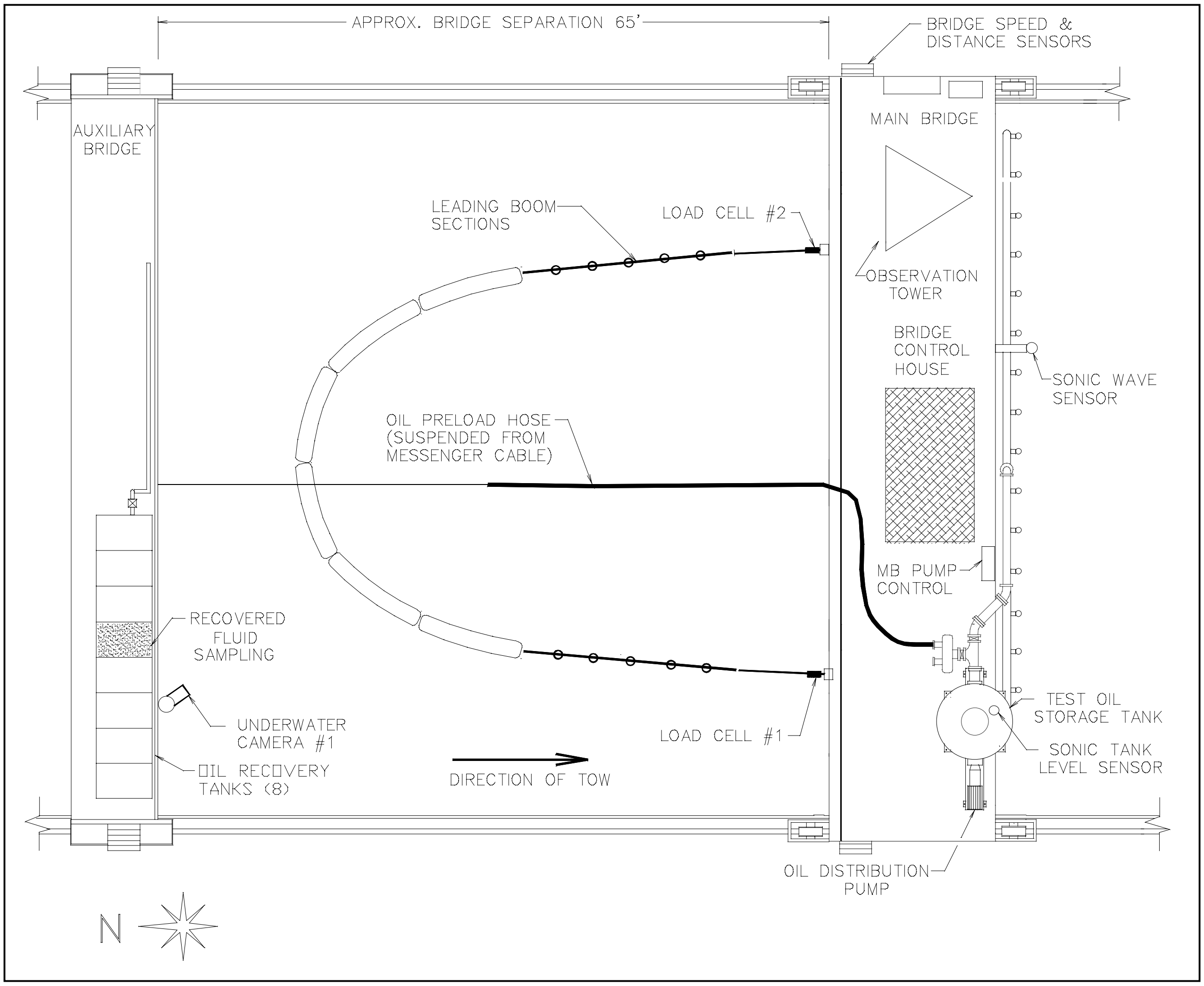

Figure 13. General Test Basin set-up for the fire boom tests.

Preload oil was pumped directly into the boom apex using a hose attached to a messenger cable suspended between the Main Bridge and Auxiliary Bridge. The Main Bridge distribution manifold distributed the oil on the water when the tests required that the boom encounter the oil. Recovered fluids were pumped to the Auxiliary Bridge recovery tanks where volume measurements were recorded and fluid samples taken using a stratified sampling thief or grab sampler.

An underwater camera was suspended from the Auxiliary Bridge and provided complete surveillance of events, occurring in and around the boom. Test personnel observed the oil loss from the boom, while also monitoring the tow speed displayed on the monitor. Video, digital and 35 mm cameras were used to record the testing from various locations on both bridges.

The wave generating system consisted of the wave generator located at the South end of the Basin and the wave dampening beaches located at the North end of the Basin. The wave generating system was operated from the third floor of the Control Tower. A local readout of the wave generator, in cycles per minute, was supplied at the control console, located on the third floor of the control tower. Wave surface profiles were recorded using a Datasonics ultrasonic distance meter shown in Figure 13 as “Sonic Wave Sensor.” The signal from the wave meter was recorded and analyzed after testing to confirm the wave characteristics.

Environmental background data were recorded during each test; including air temperature, wind speed, wind direction and Test Basin water temperature.

2.2 Test Methods - Data Collection and Analysis

Preload Tests

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

The preload volume is determined by performing a series of first oil loss tests. Beginning with a nominal preload volume, the first oil loss tow speed is identified. The preload volume is increased and the first oil loss tow speed obtained again. This process is repeated with increasing volumes until the addition of oil to the preload has minimal or no effect on the first loss speed. A graph of first loss speed versus preload volume is created to visually determine the optimum (minimum) preload volume necessary for the subsequent tests, (first and gross oil loss in wave conditions, oil loss and oil loss rate tests). The graph produced is a curve of boom capacity versus tow speed.

First Oil Loss Tow Speed in Calm Water

First Oil Loss Tow Speed is defined as the lowest speed at which oil droplets shed continuously from the boom. First Oil Loss Tow Speed tests are carried out in both calm water and various wave conditions. In wave conditions, the oil loss may occur in a surging motion. First Oil 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 Figure 13. The preload volume is pumped from the Main Bridge storage tank into the boom apex. The boom is then accelerated to a tow speed of 0.5 knots and held there to allow the boom and oil to stabilize. The tow speed is then increased by 0.1 knots in ten second intervals until the continual first oil loss mode is observed.

First and Gross Oil Loss Tests

Gross Oil Loss Tow Speed is defined as the speed at which massive continual oil loss is observed escaping past the boom. The speed increments are continued beyond first loss until a gross oil loss failure mode is observed. First and Gross Oil Loss Test Speeds are carried out in both calm water and various wave conditions and are used to determine whether the boom can contain oil up to the tow speed that results in oil slick entrainment failure. These tests quantify containment performance, comparing one boom to another under various combinations of current and wave conditions. Speed values in calm water are determined as part of the Preload tests.

Oil Loss Rate

Boom loss rates are determined by towing the boom with its preload volume of oil, determined during the preload tests, at First Loss Tow speed plus 0.1 knots (.05 meters/sec) and 0.3 knots (.154 meters/sec). The tow speed is constant for the length of the Test Basin with oil distributed from the distribution manifold at 26 GPM or 105 GPM, respectively. In order to quantify the oil loss from the boom, the lost oil is skimmed and collected at the conclusion of each loss rate test run. This is accomplished by using the Auxiliary Bridge skimming boom to move lost oil to the North end of the OHMSETT Test Basin. The oil is then removed from the water surface with a skimmer and pumped to the Auxiliary Bridge tanks. Once free water is decanted from the recovery tanks, depth measurements are made for each recovery tank holding emulsion. Samples are then taken for analysis to determine the percent of oil content. The Oil Loss Rate (**OLR**) is then calculated:

$\mathbf{OLR = \Sigma\, d_i * k_i * c_i / t}$ where:

$\mathbf{d_i}$	=	depth measurements of recovery tanks holding emulsion
$\mathbf{k_i}$	=	depth-to-volume factor for recovery tank i
$\mathbf{c_i}$	=	% oil determined by analysis
$\mathbf{t}$	=	lapsed time in minutes that the loss occurred

Critical Tow Speed

This test identifies what happens at excessive tow speeds. The test involves towing the boom without oil, at increasing tow speeds. Critical tow speed is met when the boom exhibits one mode of failure, i.e., loses all freeboard (submerges), planes, mechanically fails, and/or the tow speed reaches three times the measured gross loss tow speed. It has significance in defining the safe operating limit for the boom, recognizing that normal containment tow speeds may be occasionally exceeded in practice.

2.3 Test Oil

The test oil used for these tests was Calsol 8240, which has a target viscosity of 2000 centistokes and a specific gravity of approximately 0.95. This test oil is new to the OHMSETT standard test oil inventory. The actual viscosity at test time is dependant on ambient temperatures. Typical properties of the test oil are listed in APPENDIX B, FLUIDS TESTING.

The volume of oil delivered to the boom is calculated from liquid level measurements made in the Main Bridge storage tank. The liquid level is measured by an ultrasonic meter mounted on the top of the tank. The level meter measures the percent of tank capacity and has a local readout located in the Main Bridge house. A chart is used to convert the reading from percent to gallons. The level meter output signal is also recorded in gallons on the OHMSETT Data Collection Computer in the control tower.

2.4 Wave Conditions

OHMSETT can generate two different wave types. One of the wave types is a regular sinusoidal wave, and the other wave type is a "harbor chop." The harbor chop wave condition is a waveform where the wave reflections are maximized by lowering the wave-absorbing beaches. The wave profile is measured using a sonic level sensor and is recorded by the data collection computer at a typical sample rate of ten data points/second.

Waves are generated from the South end of the test tank. The beach system is located at the North end of the tank, and is employed to dampen reflective waves when generating sinusoidal wave conditions.

Wave Parameters

Four different surface conditions were employed during this test series. Each (except for calm) has been assigned a wave number. A wave analysis was performed for each test and is reported by test number in APPENDIX C, FIRE BOOM WAVE ANALYSIS. For general identification throughout this report, the wave conditions are specified as:

- Calm - no waves generated.

- Wave #1 - is a regular sinusoidal wave with an $H^{1/3}$ of 10.0 inches (.304 meters), wavelength of 14.0 feet (4.27 meters), and an average apparent period (AAP) of 1.8 seconds. Wave dampening beaches are employed during the generation of this wave condition to prevent wave reflection from the tank end.

- Wave #2 - is a regular sinusoidal wave with an $H^{1/3}$ of 12 inches (.419 meters), wavelength of 42.0 feet (12.8 meters), and an AAP of 3.0 seconds. Wave dampening beaches are also employed during the generation of this wave condition.

Wave #3 - is defined as a harbor chop condition with an average $H^{1/3}$ of 10.0 inches (.304 meters). For this wave, reflective waves are allowed to develop for 15 minutes prior to a given test. No wavelength is calculated for this condition.

where: **$H^{1/3}$** = significant wave height = the average of the highest 1/3 of measured waves (in inches)
WL =wavelength = the distance (in feet) on a sine wave from trough to trough (or peak to peak)
AAP = average apparent wave period = the time (in seconds) it takes to travel one wavelength

2.5 Basin Water Properties

Periodic samples of the Test Basin water are taken during a test program to monitor the effectiveness of the filtration system and to document the Test Basin water physical properties. The sampling frequency is dependent on filter operation requirements. The following tests are run at the OHMSETT Oil Analysis Laboratory: oil and grease in water, pH, turbidity, and salinity. A complete description of these test methods can be found in the "Operating Manual for OHMSETT Laboratory Including Laboratory Procedures."

2.6 Test Matrix

Tests were performed as outlined in Table 2. Tests were sequentially numbered and test parameters defined and verified by the Test Director. Data tables/logs were generated and reported identifying test parameters, test numbers, and manually collected data.

Table 2 shows the test matrix depicting tests in the approximate order of execution. Tests are sequentially numbered to keep track of the test data gathered for each specific test run. The test type starts with a dry run to see if the equipment has been properly rigged and all data collection instrumentation is functioning properly. The dry run is followed by the Preload test runs numbered 2 through 8. The Preload test type is defined in section 2.2 and determines the baseline containment performance datum from which improved or diminished containment performance can be measured when encountering other test conditions. The Preload determination is followed by the Gross Loss speed tests, Oil Loss Rate, First & Gross loss speeds in waves, and Critical Tow speed tests.

Table 2. Test Matrix.

TEST NO.	TEST TYPE	TOW SPEED (kts)	WAVE CONDITIONS	PRELOAD VOLUME (gallons)	LOSS SPEED (kts)
1	DRY RUN	1	calm	-	-
2	Preload	variable	calm	60	tbd
3	Preload	variable	calm	120	tbd
4	Preload	variable	calm	180	tbd
5	Preload	variable	calm	240	tbd
6	Preload	variable	calm	300	tbd
7	Preload	variable	calm	360	tbd
8	Preload	variable	calm	420	tbd
9	Gross Loss	variable	calm	determined during Preload test	tbd
10	Oil Loss Rate	1^{st} Loss +0.1	calm	determined during Preload test	Dist. Rate 26 gpm
11	Oil Loss Rate	1^{st} Loss +0.3	calm	determined during Preload test	105 gpm
12	Oil Loss Rate	1^{st} Loss +0.1	calm	determined during Preload test	26 gpm
13	Oil Loss Rate	1^{st} Loss +0.3	calm	determined during Preload test	105 gpm
14	1^{st} & Gross Loss Speeds	variable	calm	determined during Preload test	Loss Speed (kts) tbd
15	1^{st} & Gross Loss Speeds	variable	Wave #1	determined during Preload test	tbd
16	1^{st} & Gross Loss Speeds	variable	Wave #1	determined during Preload test	tbd
17	1^{st} & Gross Loss Speeds	variable	Wave #2	determined during Preload test	tbd
18	1^{st} & Gross Loss Speeds	variable	Wave #2	determined during Preload test	tbd
19	1^{st} & Gross Loss Speeds	variable	Wave #3	determined during Preload test	tbd
20	1^{st} & Gross Loss Speeds	variable	Wave #3	determined during Preload test	tbd
21	Critical Tow Speed	variable	calm	none	tbd
22	Critical Tow Speed	variable	calm	none	tbd

tbd – to be determined

3.0 TEST RESULTS AND OBSERVATIONS

3.1 Summary Results of All Tests

Four of the seven fire booms evaluated in Mobile, Alabama endured the burning and were transported to OHMSETT for oil collection and containment capabilities testing. Of the four booms tested, each was tested in accordance with the schedule defined in Table 2, Test Matrix, except for the PyroBoom. Tests involving waves were excluded for the PyroBoom due to the loss of fabric from above the waterline. APPENDIX D, MASTER DATA TABLE, lists the test parameters and results for all tests performed. An assessment of the data obtained for all tests performed is presented as APPENDIX E, ASSESSMENT OF FIRE BOOM TEST QUALITY.

3.2 Preload Determination Results

An oil preload volume was obtained for each of the fire booms based on the volume at which First Loss Tow Speed became independent of oil contained in the Test Basin. The booms tested were similar in length and, therefore, the boom length-to-gap ratios (3 to 1) remained constant. Variation of boom type and skirt depths were left as parameters influencing the oil containing capacity of each. The preload volumes for each boom tested and the corresponding first loss tow speeds are listed below in Table 3.

Table 3. First Loss Tow Speeds at Preload Volumes.

Preload Vol. (gal)	Hydro-Fire	Spill Tain™	PyroBoom	Pocket Boom
60	1.1	1	1.2	1.25
120	0.9	0.95	1.1	.95-1.15
180	0.95	0.9	0.9	0.95
240	0.85	0.9	0.85	0.95
300	0.9	0.85	0.95	0.95
360		0.9	1	1
420			0.95	0.95

Figure 14 graphically illustrates results of the preload tests performed on each boom. A minimum of five tests were performed for each.

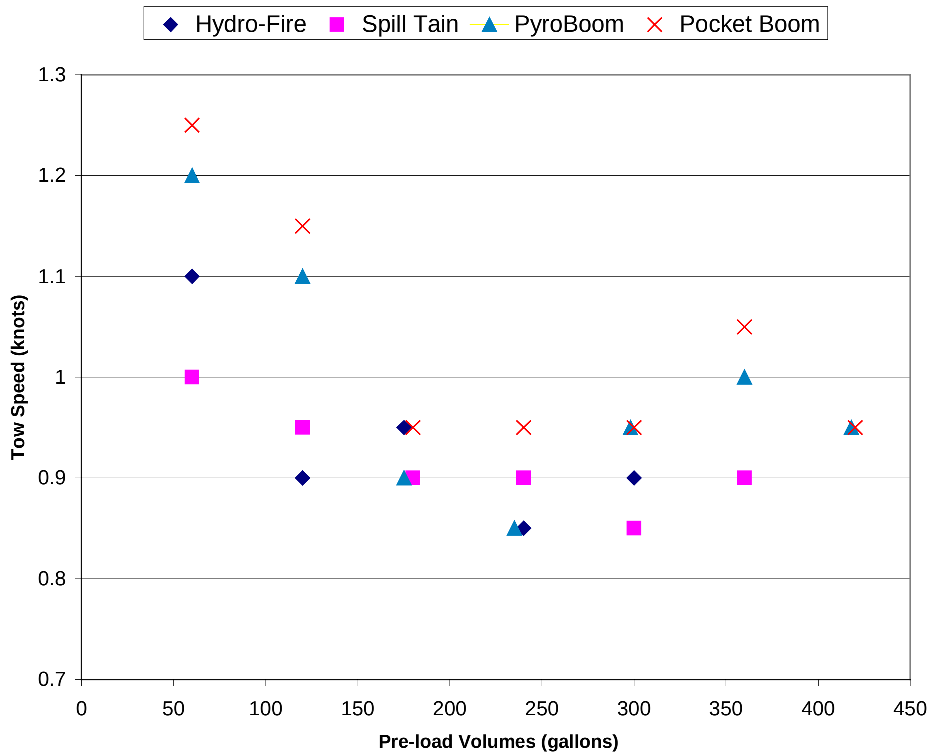

Figure 14. First Loss Tow Speed versus Preload Volume.

The preload volumes used throughout the remainder of the test series are shown in Table 4. The volumes selected were considered the preload volumes at which the entrainment speed of the test oil was reached, independent of boom blockage effects.

Table 4. Preload Determination Results.

Boom	Preload Volume (gal)
Hydro-Fire	300
Spill Tain™	360
PyroBoom	400
Pocket Boom	400

3.3 Oil Loss Speed Tests in Waves

3.3.1 First Loss

The oil containing capability of each boom was determined while experiencing four different surface conditions when loaded with the previously determined volume of oil. The tow speed at which the first oil loss condition occurred was obtained. Each test run was duplicated and the two resulting speeds averaged and plotted as shown in Figure 15. The supporting data is shown in Table 5. Values obtained for duplicate tests, repeated within 0.1 knots for all runs. The wave data presented in Figure 15 has been averaged for all tests performed. Wave analysis data by test number is provided in APPENDIX C, FIRE BOOM WAVE ANALYSIS.

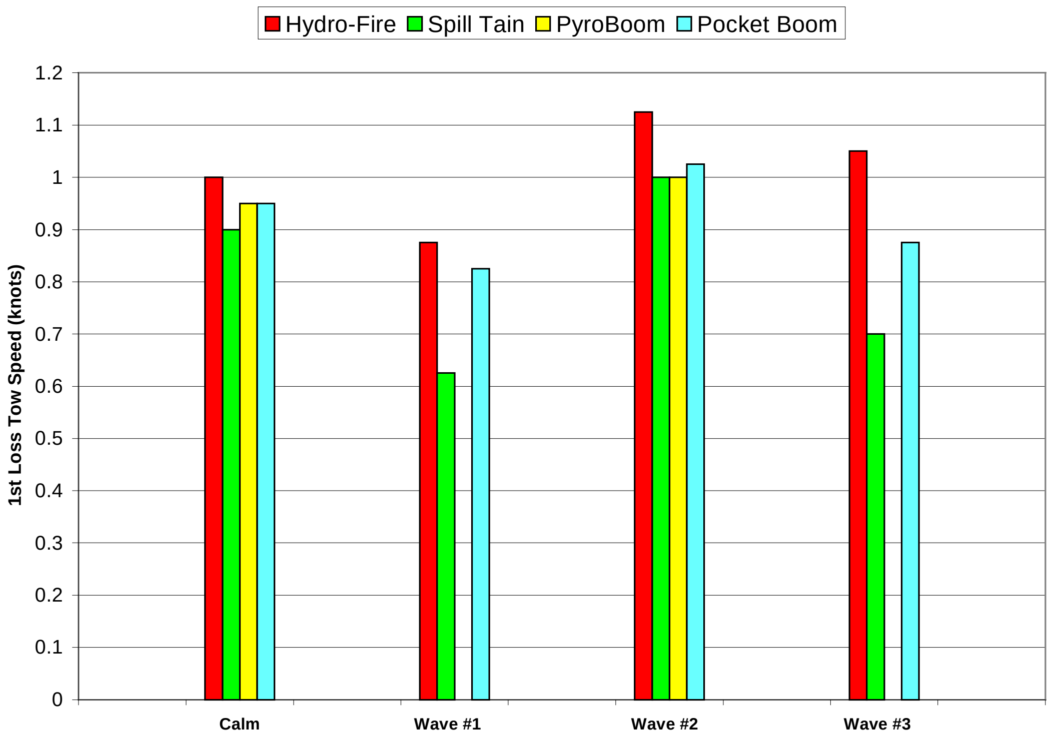

Figure 15. First Loss Tow Speeds versus Wave Condition.

Table 5. First Loss Tow Speed Data versus Wave Condition.

First Loss Tow Speed (knots)								
Boom	Calm		Wave #1		Wave #2		Wave #3	
	1^{st} run	2^{nd} run	1^{st} run	2^{nd} run	1^{st} run	2^{nd} run	1^{st} run	2^{nd} run
Hydro-Fire	0.9	1.0	0.85	0.80	1.1	1.15	1.00	1.1
Spill Tain™	0.9	0.9	0.6	0.65	1	1	0.7	0.7
PyroBoom	0.95	0.95	0.7	At 0.4 knots, there was oil loss over damaged freeboard material. Wave tests not completed due to missing freeboard material due to burn.				
Pocket Boom	0.95	0.95	0.8	0.85	1	1.05	0.85	0.9

In calm surface conditions, the first loss tow speeds for the four test booms ranged from 0.9 to 1.0 knots. These values served as baseline oil containment speeds. For tests performed in wave condition 2, there was an increase in first loss tow speed for three of the four booms. The Hydro-Fire boom first loss speed increased the most significantly to an average of 1.13 knots. From observation, this wave condition affected the typical wedge shape preload contour within the apex in each of the booms tested. Stacking the oil further into the apex resulted in a positive containment effect, allowing each boom to maintain the preload volume at higher speeds. Figures 16-a and 16-b illustrate the observed differences in preload oil configuration between calm surface and wave #2.

Figure 16-a. Oil configuration, calm.

16-b. Oil configuration, wave #2.

Wave #1, which was a relatively short crested sinusoidal wave, lowered the first loss tow speed for each boom tested. The Spill Tain^{TM} boom was the most affected with a containment speed that was .28 knots lower than the baseline. The wave condition appeared to create a condition where the contained oil was reflecting out of the apex in a pulsating mode.

First loss speeds in the third wave condition created mixed results. The Hydro-Fire Boom demonstrated an average increased first loss speed of 0.1 knots. The Spill Tain^{TM} boom loss speed was reduced by 0.2 knots. The Pocket Boom first loss speed was only decreased slightly by this wave condition.

3.3.2 Gross Oil Loss Tow Speed

Gross loss tow speeds for each boom tested are graphically presented in Figure 17. The values are averaged from the results of duplicate test runs. The data obtained on a per test basis are shown in Table 6. The trends for this data are similar to the first loss results. The Hydro-Fire Boom has a better performance than the other booms in all wave conditions.

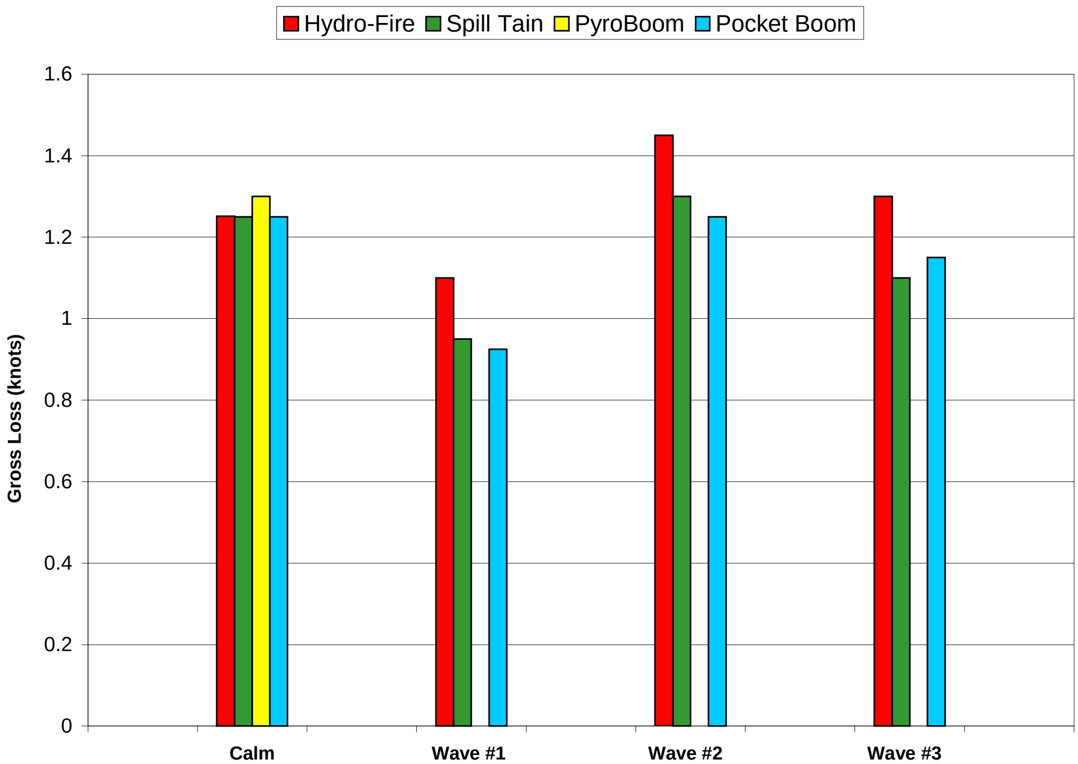

Figure 17. Gross Loss Tow Speeds versus Wave Condition.

Table 6. Gross Loss Tow Speed Data versus Wave Condition.

Gross Loss Tow Speed (knots)							
Boom	Calm	Wave #1		Wave #2		Wave #3	
	1st run	1st run	2nd run	1st run	2nd run	1st run	2nd run
Hydro-Fire	1.25	1.1	1.1	1.4	1.5	1.3	1.3
Spill Tain™	1.25	0.9	1.0	1.3	1.3	1.1	1.1
PyroBoom	1.3	At 0.4 knots, there was oil loss over damaged freeboard material. Wave tests not completed due to missing freeboard material due to burn.					
Pocket Boom	1.25	0.9	0.95	1.3	1.2	1.15	1.15

3.4 Oil Loss Rate Tests

The amount of oil lost from the test booms has been quantified by means of the Oil Loss Rate Test. Each of the test booms were preloaded with the prescribed volume of oil and encountered 26 gpm or 105 gpm, while being towed at First Loss Tow Speed plus 0.1 and plus 0.3 knots, respectively. The results of this test are shown in Figure 18 and Table 7. Each test was performed twice with calm conditions in the tank.

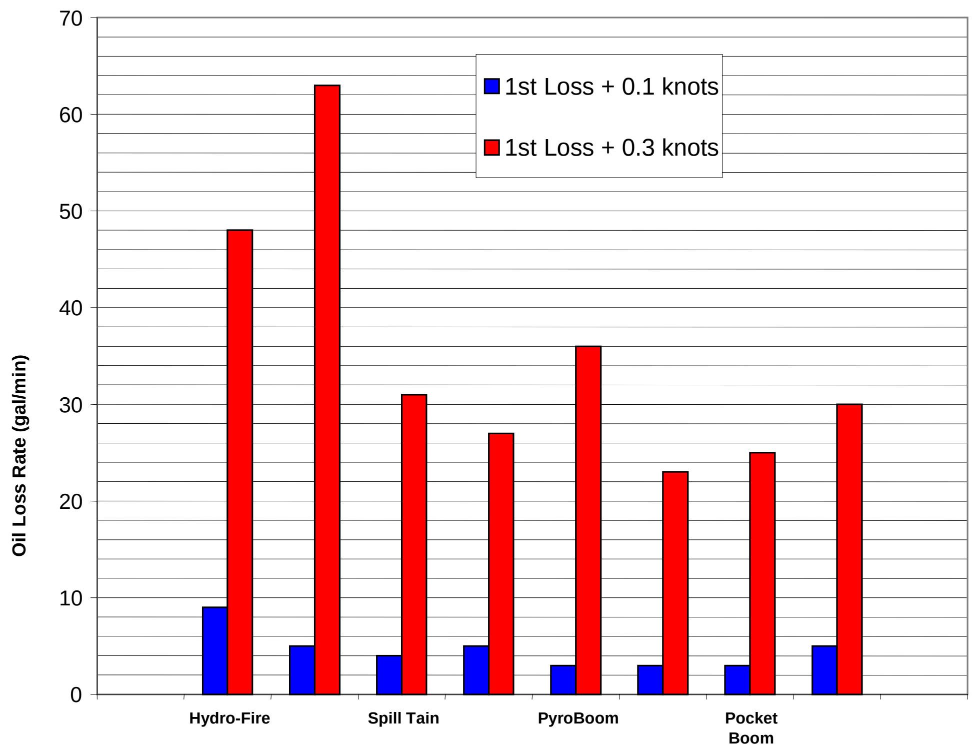

Figure 18. Oil Loss Rates at First Loss Tow Speed Plus 0.1 and 0.3 Knots.

Table 7. Oil Loss Rates at First Loss Tow Speed.

Boom	Oil Loss Rate (gal/min)			
	1st run		2nd run	
	1st + 0.1 knots	1st + 0.3 knots	1st + 0.1 knots	1st + 0.3 knots
Hydro-Fire	9	48	5	63
Spill Tain™	4	31	5	27
PyroBoom	3	36	3	23
Pocket Boom	3	25	5	30

As illustrated in Figure 18, the loss rates at First Loss plus 0.1 knots were comparable and ranged from 3 to 9 gpm. Loss rates at First Loss plus 0.3 knots were also comparable for the Spill Tain™, PyroBoom and Pocket Boom and ranged from 23 to 36 gpm. The Hydro-Fire Boom had a higher than average loss rate of 56 gpm.

3.5 Critical Tow Speed

The Critical Tow Speed of each boom was determined using calm surface conditions and repeated for data confidence. Table 8 contains the Critical Tow Speeds obtained along with the mode of failure.

Table 8. Critical Tow Speed Values for Four Fire Booms.

Test Boom	Critical Tow Speed (knots)	Mode of Failure
Hydro-Fire	3.75	Gradually lost freeboard, submerged at 3.75 knots. Boom remained stable during tow.
Spill Tain™	4.6	None. No noticeable change in Freeboard of boom.
PyroBoom	2.25	Loss of freeboard and submerged at 2.25 knots. Connector to fabric separated at 2.25 knots. Loss of material during exposure to burn test degraded overall tensile strength of boom section.
Pocket Boom	3.0	Boom began to plane at 1.5 knots, once the flexible accordian connectors fanned out at skirt bottom, boom remained stable.

Towing Forces were obtained during each test. Figures 19-a. through 19-h. illustrate the in-line towing forces exerted at the tow points (load cells 1 and 2) during the critical tow tests. The plotted curves are averaged values of load cell 1 and 2 with three-point averaging.

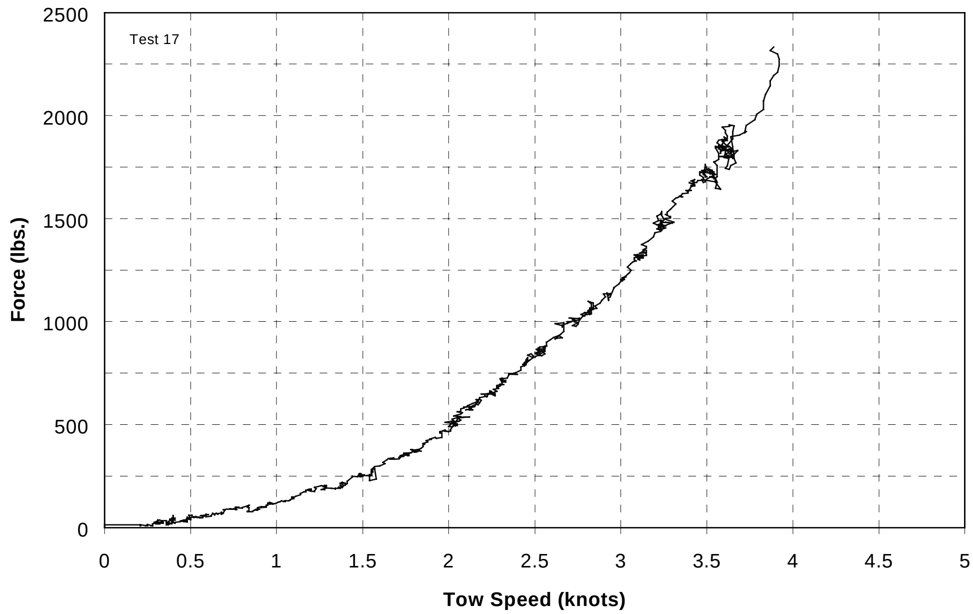

Figure 19-a. Hydro-Fire Boom, Critical Tow Force, Test 17.

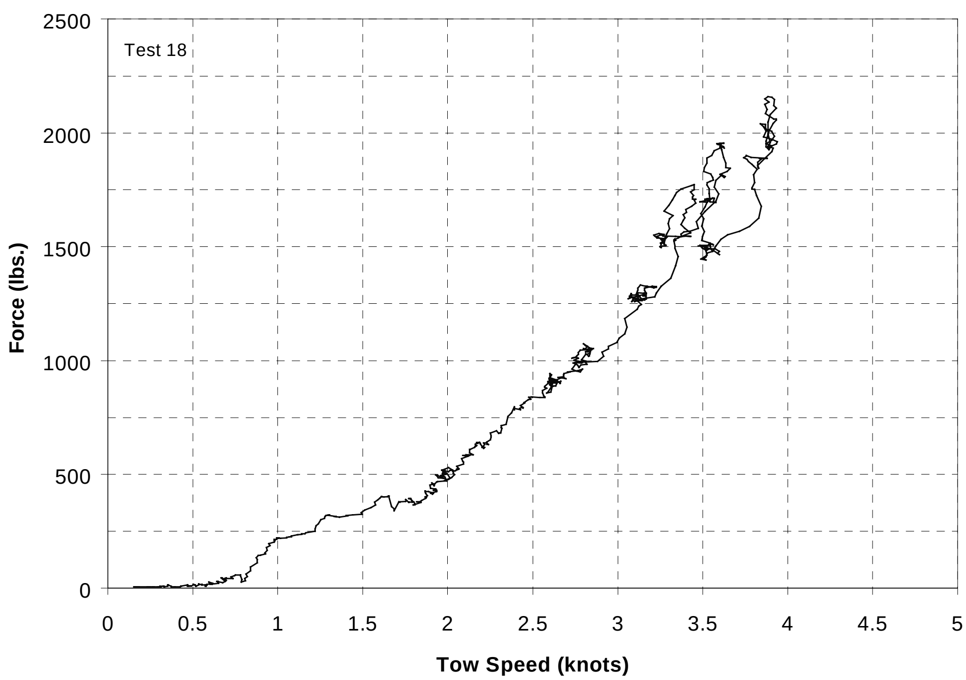

Figure 19-b. Hydro-Fire Boom, Critical Tow Force, Test 18.

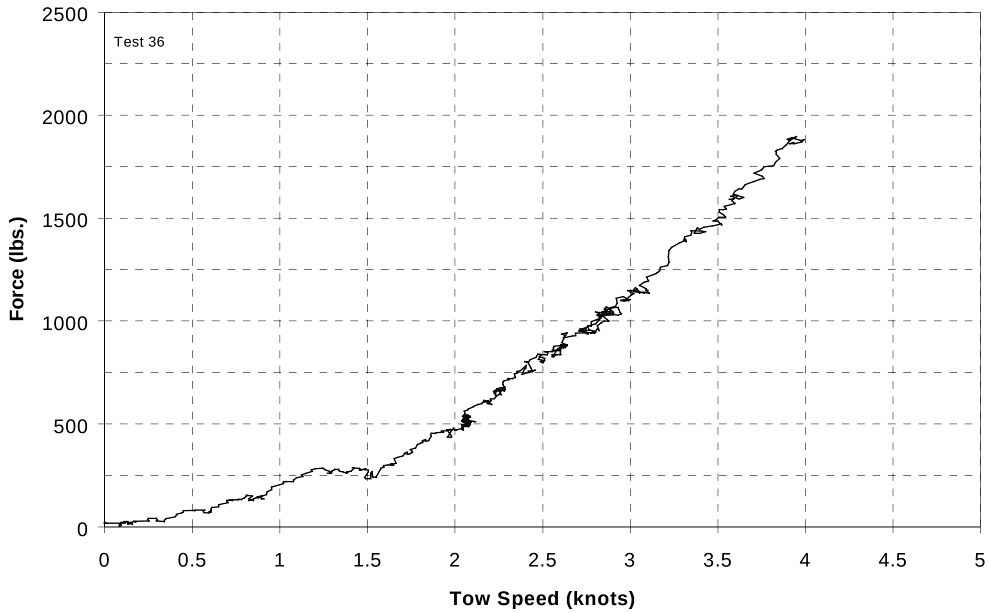

Figure 19-c. Spill Tain™, Critical Tow Force, Test 36.

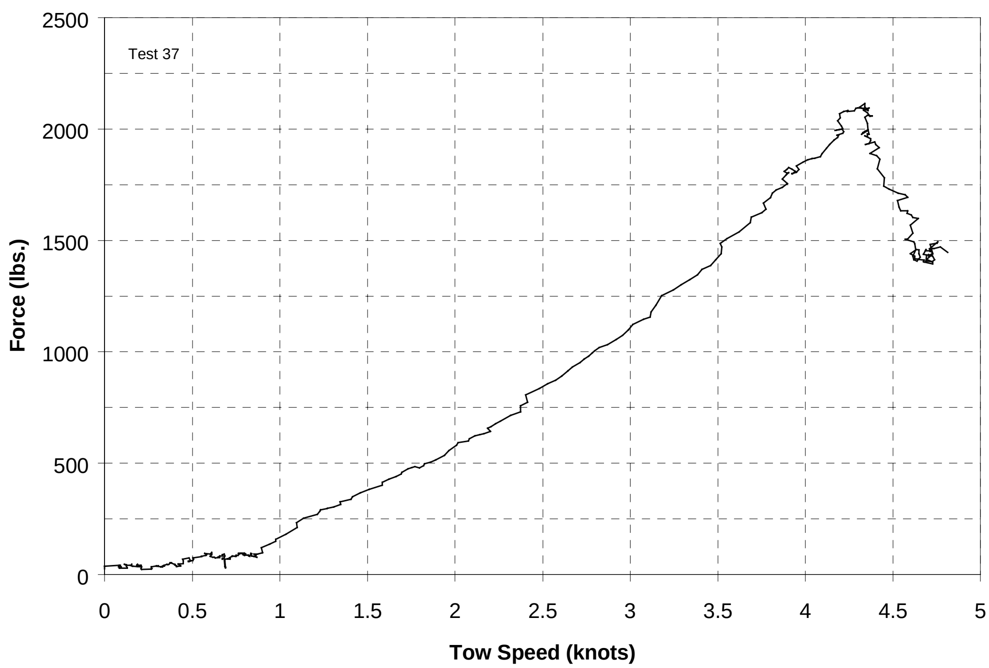

Figure 19-d. Spill Tain™, Critical Tow Force, Test 37.

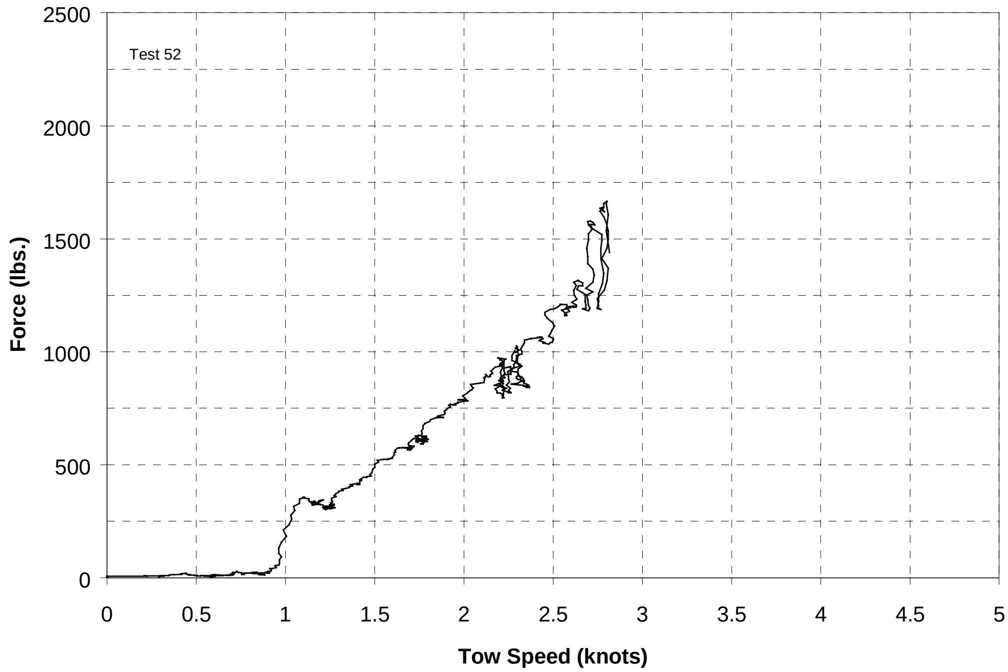

Figure 19-e. PyroBoom, Critical Tow Force, Test 52.

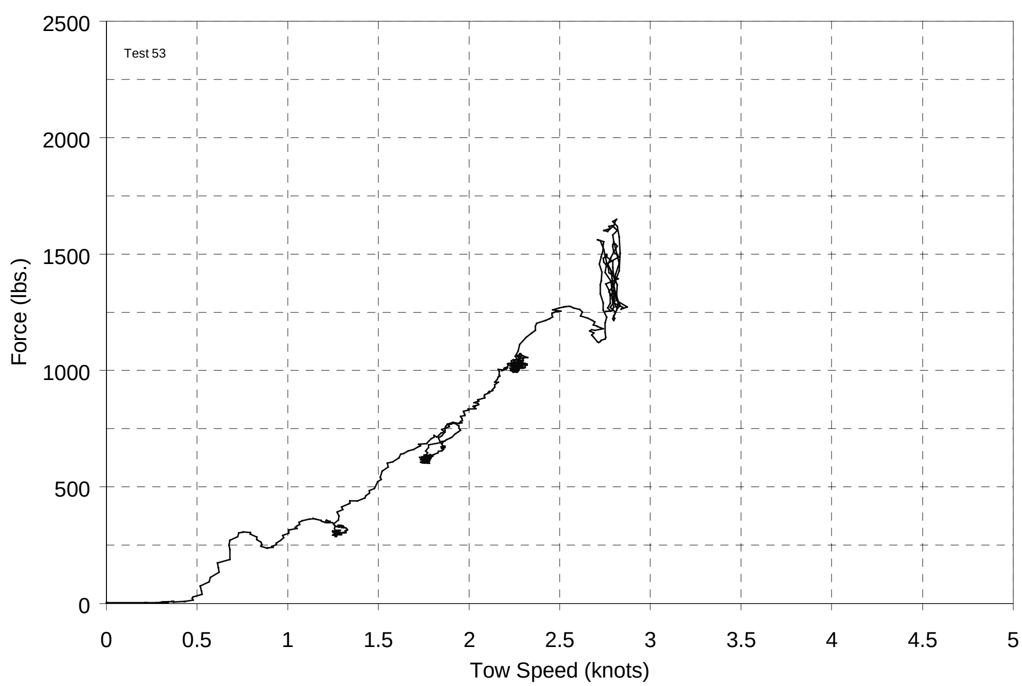

Figure 19-f. PyroBoom, Critical Tow Force, Test 53.

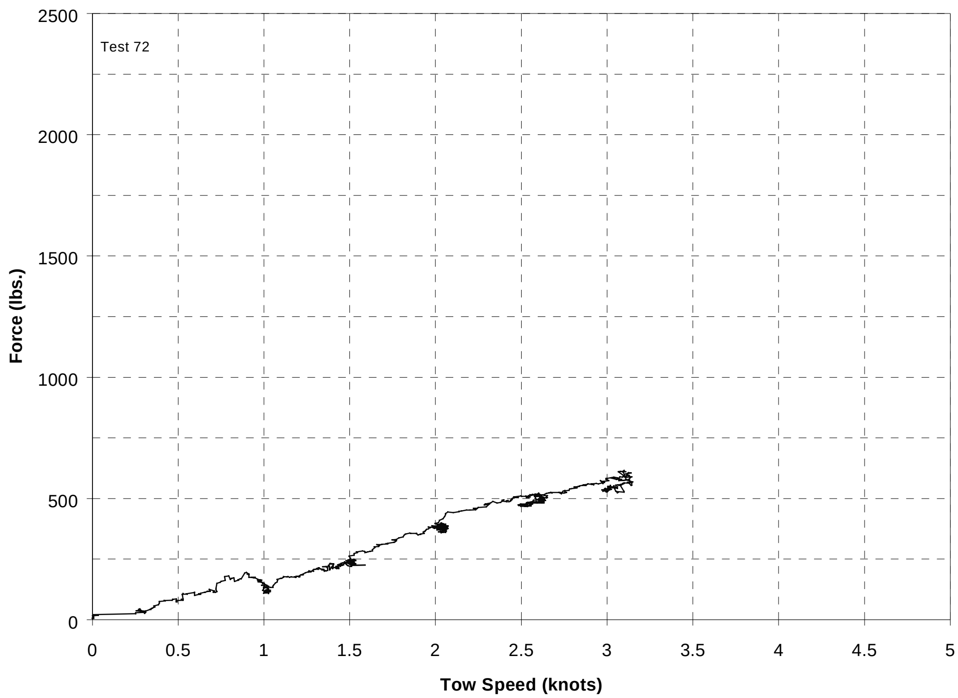

Figure 19-g. Pocket Boom, Critical Tow Force, Test 72.

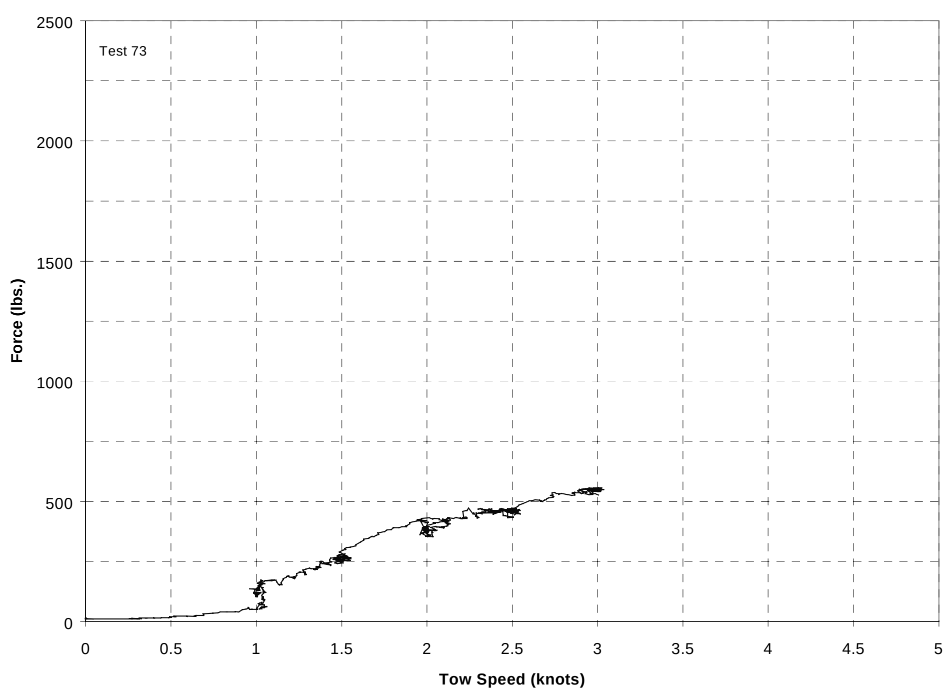

Figure 19-h. Pocket Boom, Critical Tow Force, Test 73.

4.0 SYSTEMS COMPARISON

Boom performance summary data are presented in Table 9.

Table 9. Compiled Boom Performance Data.

BOOM NAME	First Loss Tow Speed (knots) / Gross Loss Tow Speed (knots)				Loss Rate Test gpm @ knots		Critical Tow Speed (Knots)
	Surface Condition				1st Loss + 0.1	1st Loss + 0.3	
	C	Wave 1	Wave 2	Wave 3			
Hydro-Fire	0.95 1.25	0.83 1.1	1.13 1.45	1.05 1.3	9 @ 1.05 5 @ 1.00	48 @ 1.25 63 @ 1.20	3.75
Spill Tain™	0.9 1.25	0.63 0.95	1.0 1.3	0.7 1.1	4 @ 1.00 5 @ 1.00	31 @ 1.20 27 @ 1.20	4.6
PyroBoom	0.95 1.3	0.7	***	***	3 @ 1.05 3 @ 1.05	36 @ 1.25 23 @ 1.25	2.25
Pocket Boom	0.95 1.25	0.83 0.93	1.03 1.25	0.88 1.15	3 @ 1.05 5 @ 1.05	25 @ 1.25 30 @ 1.20	3.0

Wave Conditions: C = Calm: no waves generated
1 = Wave #1: regular sinusoidal wave: $H^{1/3}$ = 9.9", L = 16.2', T = 1.8 sec.
2 = Wave #2: regular sinusoidal wave: $H^{1/3}$ = 13.3", L = 42.1', T = 3.1 sec.
3 = Wave #3: harbor chop: $H^{1/3}$ = 8.9"
*** .4 loss over damage area, .7 first loss, wave tests not run

5.0 DISCUSSION OF RESULTS

5.1 Oil Holding

5.1.1 First Oil Loss Speeds

The first loss speed of each boom tested in calm water was between 0.9 and 1.0 knots. The averaged first loss speed for three of the four booms was 0.95 knots; the fourth 0.9 knots. These comparable baseline first loss values confirm that the preload volumes were appropriately determined.

The first oil loss speed results were mixed when experiencing wave conditions. Wave #1 (short sinusoidal) degraded the performance of each boom. Wave #2 (long sinusoidal) improved containment performance of each boom. Wave #3 (harbor chop) improved performance of one boom while degrading performance of the other two. The Pyroboom was excluded from the oil loss wave tests due to the loss of freeboard material (Fiberfrax) which was severely damaged during the burn tests.

In terms of percentages, and relative to baseline loss speeds, The first wave condition reduced the oil containment ability of the Spill Tain™ boom by 31% and the Pocket Boom and Hydro-Fire by 13%. Wave #2 improved the containment performance of the Hydro-Fire boom by 18%. The Pocket Boom oil loss speed increased by 8%, and the Spill Tain™ boom by 5%. Wave #3 improved the first oil loss containment speed of the Hydro-Fire Boom by 11%, and degraded the loss speed of the Pocket Boom by 8%, and the Spill Tain™ boom by 22%.

5.1.2 Gross Oil Loss Speeds

Similar to the first loss speeds determined in the calm water conditions, the gross loss speed of each boom was comparable. The gross oil loss speeds ranged from 1.25 knots to 1.3 knots. This consistancy indicates that the preload volumes were appropriate and that each boom could contain a specific volume of oil up to the entrainment speed (which is dependant on the oil water interface properties).

It should be noted that the gross oil loss speeds in wave conditions, whether improved or degraded, followed the trend of the first oil loss speeds in waves. When experiencing Wave #1, gross oil loss speeds were reduced for all booms tested. The first loss speed of the Hydro-Fire boom had the least reduction, by a value of 12%, whereas the gross loss speed of Spill Tain™ was reduced by 24% and by 26% for the Pocket Boom. Wave #2 did not affect the gross loss speed of the Pocket Boom at 1.25 knots, whereas the loss speeds improved for the Hydro-Fire and Spill Tain™ booms. The loss speed of the Hydro-Fire boom increased by 16%, and the Spill Tain™ boom by 4%. Wave #3 again yielded mixed results. The gross oil loss speed of the Hydro-Fire boom increased by 4%, whereas the containment performance of the Pocket Boom and the Spill Tain™ boom degraded by 9% and 12%, respectively.

5.1.3 Oil Loss Rates

The four booms were tested to determine the oil loss rates for when the first oil loss speeds were exceeded by 0.1 and 0.3 knots. The oil loss rates measured at First Loss plus 0.1 knots were found comparable, with each boom falling between the range of 3 gpm to 9 gpm. The loss rates for the Spill Tain™ boom, the PyroBoom, and the Pocket Boom were also comparable with the averaged values, falling within the range of 27.5 to 30 gpm. The highest oil loss rate occurred with the Hydro-Fire Boom, loosing an average of 55 gpm.

5.2 Mechanical Stability

Of the four booms tested, three reached a tow speed at which a mode of failure could be identified. The fourth boom reached the maximum speed defined by the test protocol.

The Hydro-Fire boom gradually began to loose freeboard at 1.5 knots and lost all freeboard at 3.75 knots. The boom remained stable throughout the critical speed runs and did not damage the boom itself or the water-cooling supply system.

The Spill Tain™ boom was towed up to 4.6 knots, at which, there was only a minimal change in freeboard. The boom remained stable throughout the tow, and did not appear to cause any damage.

Due to the damaged boom fabric above the waterline of the PyroBoom, the loss speed at which total loss of freeboard occurred could not be determined. The reported value of 2.25 knots for the first test run indicates that this was the speed at which the hemisphere globes submerged. During the repeated test run, the barrier fabric parted at the connector at 2.25 knots.

The Pocket Boom was the only test boom to plane during the critical tow tests. At 1.5 knots, the boom began to plane in the apex by the accordian type connectors fanning out at the bottom. This mode exaggerated with increased tow speed. The maximum tow force obtained was 600 pounds, which was significantly lower than the other three booms.

5.3 General

The results of this test are consistent with those of the previous fire boom tests conducted at OHMSETT, report CG-D-12-98, <u>Test and Evaluation of Six Fire Resistant Booms at OHMSETT</u> (DeVitis, 1997). The trends, for the most part, remained the same, with the average performance values improving from the previously tested booms.

6.0 REFERENCES

DeVitis, D., Cunneff, S. and Nash, J. (1997). <u>Test and Evaluation of Six Fire Resistant Booms at OHMSETT</u> (CG-D-12-98). Groton, CT: Research & Development Center. (NTIS No. AD-A 344642).

SL Ross Environmental Research Ltd, Summary Report: Phase 3, Task 3.2, 1998.

Walz, Michael A. (1999). <u>Second Phase Evaluation of a Protocol for Testing a Fire Resistant Oil Spill Containment Boom</u> (CG-D-15-99). Groton, CT: Research & Development Center.

APPENDIX A FIRE BOOM INSTRUMENTATION

Data obtained during each test includes electronically collected data and manually collected data. The electronically collected data are recorded at the computer console located on the third floor of the Control Tower. Some electronically collected data are monitored at locations other than the data collection computer in order to control test conditions. Instrumentation output signals are directed to the computer and stored by sequential file numbers. A data collection rate of 10 Hertx (Hz) is standard but may be changed for specific data collection needs. There are Bridge speed readouts at the control console and on a panel meter in the Bridge House. The Bridge speed is also displayed on the underwater camera monitor and recorded on the video. The distribution pump rate and test fluid volume are monitored on the Main Bridge, as well as recorded on the data collection computer.

Manually collected data are measured and recorded by assigned technicians. Oil and water properties' data are based on fluid samples obtained during the test period. Data to be collected during tests is listed in Table 1 along with the method of collection. Computer collected data and manually collected data are randomly checked by the Quality Assurance (QA) Engineer for completeness and accuracy.

Table A-1. Typical Data Collected During Tests

Data	***Collection Method***
Wind speed, direction	Computer
Air and water temperature	Computer
Bridge speed	Computer, Control Console, Main Bridge panel meter, video
Wave generator cycles/min.	Computer, Control Console
Sonic wave meter	Computer
Tow force, load cells	Computer
Distribution tank level	Computer, Main Bridge panel meter
Distribution pump rate	Pump control panel
Recovered fluid depths	Auxiliary Bridge recovery tanks, manual stick measurement

1. Bridge Speed and Distance

The Main Bridge is powered by a cable drum system and travels along rails which parallel each tank wall. The bridge system is capable of traveling from 0.1 knots to 6.5 knots (.052 meters/sec to 3.34 meters/sec) in increments of 0.1 knots (.052 meters/sec). Bridge speed is measured by a pulse-type tachometer sensor monitoring the rotational motion of a wheel on the Main Bridge. The sensor is an Airpax Magnetic Pickup for Bridge Speed, Model # 70087-3040-012S. The output is recorded and displayed by the data collection system during tests in the Main Bridge house and at the data collection console on the third floor of the Control Tower. The speed is recorded at 10 Hz and displayed in knots. .

2. Wind Speed, Wind Direction, and Air Temperature

These meteorological instruments are located on the West side of the OHMSETT Test Basin, at approximately mid-length. The instruments are located on a tower approximately 3 meters (10 feet) above the Test Basin deck. The output of all three instruments is available to the data collection system for recording before, during, and after tests, and is also displayed on a panel at the data collection console in the Control Tower. .

The temperature sensor is a Model 41350 manufactured by R.M. Young, Inc. It is located in a Gill Multi-Plate radiation shield (protected and naturally ventilated to prevent direct sunlight from hitting the thermal sensor and giving a false temperature reading.

The wind speed and direction sensor is a Model 5103, also manufactured by R.M. Young, Inc. It is an outdoor, high performance, rugged, four-blade, helicoid propeller wind speed sensor.

The signals from the wind and temperature feed a wind and temperature translator, Model 26302, manufactured by R.M. Young, Inc. A wind and temperature translation unit in the data collection console feed data to the data collection system during tests.

3. Basin Water Temperature

The water temperature is monitored continuously by a temperature dependent resistor probe. An Omega RTD Probe, Model # PR-11-2-100-1/4-6E, is used. The output is displayed as degrees Farenheit on a meter at the data collection console and recorded during tests by the data collection system.

4. Wave Height Meter

The wave height meter is a Datasonics Sonar Air Altimeter, 27 kHz, Model PSA 900-A, S/N 335. The wave profile is measured by an acoustic altimeter specifically designed for use in air. It is mounted on a support structure extending from the South side of the Main Bridge at a nominal height of 121 inches (3.05 meters) above the mean Basin water surface level. The output of the sensor is available to the data collection system during tests and is also displayed during test runs on the data collection system screen. The output readout is in inches.

5. Oil Tank Level

The Main Bridge oil tank level is measured by an ultrasonic level sensor at the top of the Main Bridge oil storage tank. The tank level, in percent, is available during tests at the Main Bridge pump control panel and is recorded during tests, in inches, on the data collection system. The percent and inch values are converted to gallons using calculated tables. “The (sonic) Probe” is manufactured by Milltronics, Model PL-396, S/N 005827.

6. Tension Load Links

Tension load cells rated at 2000, 5000, and 10,000 pounds are used during tow tests and are selected based on boom size and sensitivity required. Their outputs are conditioned and provide a 4-20 milli amperes (mA) loop output to the data collection system in the Control Tower. The load cells are typically placed in series with the boom towing bridles measuring forces obtained during towing tests, (refer to Figure 12 in the main body of this report).

7. Remote Marker Button

This is a portable button that is used to mark events during test runs. The output provided by the pressing of the button, sends a pulse DC voltage that is identifiable within a data channel of the test file. The event mark typically identifies a specific event or the beginning and end time of a steady state test condition.

[This page intentionally left blank.]

APPENDIX B FLUIDS TESTING

The oils selected for boom evaluations are stable and have properties that do not vary during a test run. The test oils are refined products and do not have the volatile organic compounds associated with crude oils, however, this does not preclude the test facility from using crude oils if required. Current standard test oils are Hydrocal 300, Calsol 8240, and a heavy Sundex 8600T. Test oils are typically deployed at ambient temperatures which allow for closer tracking of viscosities during the tests. Table B-1. contains a list of the typical oil properties. Each of the test oils is characterized in the OHMSETT laboratory using applicable ASTM standards. The measurements include surface and interfacial tension, viscosity, specific gravity, and bottom solids and water. A description of these ASTM test methods is described below. The measurements made in the chemistry laboratory at the OHMSETT Facility are as follows:

Table B-1. Standard Test Tank Oil Properties.

Test Oils Types	Oil Properties at 25°C				
	Viscosity (cPs)	Specific Gravity	Interfacial Tension (dyne/cm)	Surface Tension (dynes/cm)	Bottom solids and H_20
Hydrocal 300	150	0.90	26.7	32.8	< 2%
Calsol 8240	1,400	0.93	31.0	36.2	< 2%
Sundex 8600T	14,000	0.96	32.1	35.5	< 2%

1. Viscosity - ASTM D2983-87 Standard Test Method for Low-Temperature Viscosity of Automotive Fluid Lubricants Measured by Brookfield Viscometer

Viscosity is measured using a Brookfield Engineering Model LV Viscometer. The samples are collected in 600 ml beakers, the contents are cooled to 10°C (50°F), then the temperature is raised to 60°C (140°F) using a Brookfield Constant Temperature Bath. Viscosity measurements are made every 10°C (50°F), yielding a Temperature versus Viscosity curve for each sample collected. This is done to find the viscosity at variable test temperatures and is done for the oil in the test tank.

2. Surface & Interfacial Tension - ASTM D971-91 Standard Test Method for Interfacial Tension of Oil Against Water by the Ring Method

Surface and interfacial tensions are measured with a Fisher Scientific Tensiomat. Approximately 50 mls of oil is needed to determine both surface and interfacial tensions. Measurements are made under standardized nonequilibrium conditions in which the measurement is completed one minute after formation of the interface.

3. Specific Gravity - ASTM D1298-85 (1990)e Standard Practice for Density, Relative Density (Specific Gravity), or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

This analysis is performed using the hydrometer method. The oil sample is transferred to a 500 ml cylinder and the appropriate hydrometer is lowered into the sample and allowed to settle. The hydrometer scale is read and the temperature is recorded.

4. Water and Sediment - ASTM D 1796-97 Standard Test Method for Water and Sediment in Fuel Oils by the Centrifuge Method (Laboratory Procedure)

A recovered oil sample of approximately 100 mls is mixed with an appropriate solvent (toluene), heated to 60°C (140°F) if necessary to assure sample uniformity, and rotated at 2,000 rpms in a centrifuge for 15 minutes. The amount of water and sediment is measured and the percentages calculated from the amount of sample used.

5. Oil And Grease - ASTM 3921-96 Standard Test Method for Oil and Grease and Petroleum Hydrocarbons in Water

A 500 - 1000 ml water/oil sample is acidified to a pH less than 2.0 and the oil is extracted with carbon tetrachloride. The oil and grease concentration is determined by comparison of the infrared absorbance of the sample extract with a known-oil reference standard, using a Shimadzu IR-435 Spectrophotometer.

Table B-2. Fire Boom Oil Analysis Log.

TEST INFO		TEST OIL @ 25° C						RECOVERED FLUID		
TEST NO.	DATE	SAMPLE NUMBER	SPECIFIC GRAVITY	S.T.(dynes/ cm)	I.F.T. (dyne/cm)	VISC (cPs)	BS&W (%)	SAMPLE	BS&W (%)	% OIL
ELASTEC/AMERICAN MARINE (HYDRO-FIRE)										
10	9-9-98	9-9-0750(BT1)	0.935	36.5	28.5	1,875	9.6			
11	9-10-98	9-10-0730(BT11)	0.937	36.5	29.5	1,750	16.0			
		9-10-0730D (BT11)	0.936	36.0	30.0	1,825	11.5			
12								12-8	20.2	79.8
13								13-5G	16.0	84.0
								13-6	11.2	88.8
								13-7	26.2	73.8
15								15-4	28.4	71.6
								15-4G-D	28.5	71.5
16								16-2	9.2	90.8
								16-3	5.7	94.3
SPILL TAIN™										
19	9/22/98	9-22-1038	0.935	35.2	26.2	1,800	1.0			
24		9-22-1300	0.935	35.7	27.5	1,900	0.4			
29	9/23/98	9-23-0925	0.935	35.7	26.9	1,950	0.2			
		09-23-0925D	0.935	36.3	27.8	2,000	0.2			
								29-8G	25.2	74.8
30								30-6	3.7	96.3
								30-6D	5.1	94.9
33		9-23-1335	0.935	35.8	26.6	2,000	0.2			
34								34-5G	9.7	80.3
35								35-3	3.0	97.0

D = Duplicate sam ple, AT = After test
MT = Mixing tank sample BT = Before Test
MB = Main Bridge sample

TEST INFO		TEST OIL @ 25 C						RECOVERED FLUID		
TEST NO.	DATE	SAMPLE	SPECIFIC GRAVITY	S.T.(dynes /cm)	I.F.T. (dyne/cm)	VISC (cPs)	BS&W (%)	SAMPLE	BS&W (%)	% OIL
APPLIED FABRIC TECHNOLOGIES (PYROBOOM)										
41	9-28-98	9-28-1415(BT41)	0.934	35.7	27.8	1,700	2.0			
47								47-8G	16.2	83.8
48								48-7	18.0	82.0
49	9-29-98	9-29-1141(AT49)	0.934	35.9	25.0	1,725	2.5			
								49-6G	15.4	84.6
50								50-5	6.0	94.0

APPLIED FABRIC TECHNOLOGIES/SL ROSS (POCKET BOOM)										
54	10-5-98	10-5-1130 (AT54)	0.935	36.0	28.6	1,775	0.5			
60	10-6-98	10-6-0750 (BT60)	0.934	36.7	29.2	1,675	0.2			
62								62-8G	3.5	96.5
63								63-6G	2.5	97.5
								63-7	6.0	94.0
64								64-5G	6.3	93.7
65								65-4	4.8	95.2
								65-4D	3.1	96.9
66	10-6-98	10-6-1345 (BT66)	0.934	36.1	28.8	1,725	0.6			
		10-6-1345D (BT66)	0.933	35.6	29.0	1,650	0.6			

D = Duplicate sample　　AT = After test
MT = Mixing tank sample　　BT = Before Test
MB = Main Bridge sample

Table B-3. Test Basin Water Properties.

Sample	Date	Salinity (ppt)	Turbidity (ntu)	pH	Temp (°C)
Hydro-Fire	9-9-98	15	0.45	8.01	28.0
Spill Tain™	9-24-98	14.5	0.8	7.96	26.0
PyroBoom	9-29-98	14	0.85	7.98	20.0
Pocket Boom	10-7-98	14	1.1	8.07	17.0

[This page intentionally left blank.]

APPENDIX C FIRE BOOM WAVE ANALYSIS

Table C-1. Fire Boom Wave Analysis.

Boom Type	Test No.	Wave Type	$H^{1/3}$ (in)	Apparent Period	Wavelength (ft)
Hydro-Fire	7	Wave #1	9.4	1.75	15.7
	8	Wave #1	10.3	1.72	15.1
	9	Harbor Chop	11.7	---	---
	10	Harbor Chop	11.7	---	---
	11	Wave #2	9.3	2.6	31.9
	14	Wave #2	10.9	3.1	42
Spill Tain™	26	Harbor Chop	9.86	---	---
	27	Harbor Chop	9.86	---	---
	28	Wave #1	9.3	1.8	16.6
	31	Wave #1	10.4	1.8	16.8
	32	Wave #2	13.2	3.0	38.9
	33	Wave #2	13.8	3.1	41.7
PyroBoom	Wave tests not run				
Pocket	66	Wave #1	10.5	1.7	15.4
	67	Wave #1	11.1	1.7	15.2
	68	Harbor Chop	9.3	---	---
	69	Harbor Chop	9.3	---	---
	70	Wave #2	11.9	3.1	40.7
	71	Wave #2	11.9	3.1	40.7

- Combined data for Harbor Chop test runs
- Combined data for Test 70 & 71

Table C-2. Averaged Wave Data.

Wave Type	OHMSETT Wave Generator Setting	$H^{1/3}$ (inches)	AAP (seconds)	W.L. (feet)
Wave #1 Sinusoidal	3” stroke, 35 cycles/minute	10	1.8	14
Wave #2 Sinusoidal	6” stroke, 19 cycles/minute	12	3.0	42
Wave #3 Harbor Chop	3” stroke, 30 cycles/minute	10	---	---

[This page intentionally left blank.]

APPENDIX D MASTER DATA TABLE

Table D-1. Master Data Table.

Test No.	Test Type	Surface Condition	Preload Vol (gal)	1st Loss Speed (knots)	Gross Loss Speed (knots)	Oil Loss Rate (gpm)	Dist. Rate (gpm)	Tow Speed (knots)	Comments
Elastec/American Marine (Hydro-Fire boom)									
1	Preload	calm	60	---	---	---	---	1.15	did not reach full 1st loss condition
2	Preload	calm	120	---	---	---	---	0.9+	---
3	Preload	calm	180	---	---	---	---	0.95	---
4	Preload	calm	240	---	---	---	---	0.85+	---
5	Preload	calm	300	---	---	---	---	0.9	---
6	1st & Gross	calm	300	1.0	1.25	---	---	---	---
7	1st & Gross	Wave #1	300	0.85	1.1	---	---	---	splashover when stationary, & throughout run
8	1st & Gross	Wave #1	300	0.8	1.1	---	---	---	boom response lagged waves allowing oil to washover
9	1st & Gross	Wave #3	300	1.00	1.3	---	---	---	severe cross winds, splashover at .8 conformed to waves
10	1st & Gross	Wave #3	300	1.1	1.3	---	---	---	minor splashover
11	1st & Gross	Wave #2	300	1.1	1.4	---	---	---	---
12	Loss Rate 1st + .1	calm	300	---	---	9	26	1.05	---
13	Loss Rate 1st + .3	calm	300	---	---	48	105	1.25	---
14	1st & Gross	Wave #2	300	1.15	1.5	---	---	---	---
15	Loss Rate 1st + .1	calm	300	---	---	5	26	1.00	---
16	Loss Rate 1st + .3	calm	300	---	---	63	105	1.2	---
17	Critical Tow	calm	none	---	---	---	---	3.6	just reached submergence speed
18	Critical Tow	calm	none	---	---	---	---	3.75	---

e = estimated value
---- = not measured during this test
* Each boom was rigged using Applied Fabric Globe Boom as extension boom and the same tow bridle

Test No.	Test Type	Surface Condition	Preload Vol (gal)	1st Loss Speed (knots)	Gross Loss Speed (knots)	Oil Loss Rate (gpm)	Dist. Rate (gpm)	Tow Speed (knots)	Comments
Spill Tain™ (Fireproof Oil Spill Containment boom, Offshore Version)									
19.	Preload	calm	60	---	---	---	---	1	---
20.	Preload	calm	120	---	---	---	---	0.95	---
21.	Preload	calm	180	---	---	---	---	0.9	---
22.	Preload	calm	240	---	---	---	---	0.9	---
23.	Preload	calm	300	---	---	---	---	0.85	---
24.	Preload	calm	360	---	---	---	---	0.9	entrainment at .85 knots, but oil recaptured before escaping boom
25.	1st & Gross Loss	calm	360	0.9	1.25	---	---	---	---
26.	1st & Gross Loss	Wave #3	360	0.7	1.1	---	---	---	---
27.	1st & Gross Loss	Wave #3	360	0.7	1.1	---	---	---	---
28.	1st & Gross Loss	Wave #1	360	0.6	0.9	---	---	---	---
29.	Loss Rate 1st + .1	calm	360	---	---	4	26	1	---
30.	Loss Rate 1st + .3	calm	360	---	---	31	105	1.2	---
31.	1st & Gross Loss	Wave #1	360	0.65	1	---	---	---	---
32.	1st & Gross Loss	Wave #2	360	1	1.3	---	---	---	---
33.	1st & Gross Loss	Wave #2	360	1	1.3+	---	---	---	---
34.	Loss Rate 1st + .1	calm	360	---	---	5	26	1	---
35.	Loss Rate 1st + .3	calm	360	---	---	27	105	1.2	---
36.	Critical Tow	calm	---	---	---	---	---	3.75	boom stable, minimal change in freeboard
37.	Critical Tow	calm	---	---	---	---	---	4.6	boom stable, minimal change in freeboard

e = estimated value

---- = not measured during this test

- Each boom was rigged using Applied Fabric Globe Boom as extension boom and the same tow bridle

Test No.	Test Type	Surface Condition	Preload Vol (gal)	1st Loss Speed (knots)	Gross Loss Speed (knots)	Oil Loss Rate (gpm)	Dist. Rate (gpm)	Tow Speed (knots)	Comments
Applied Fabric (PyroBoom)									
38.	Preload	calm	60	---	---	---	---	1.2	---
39.	Preload	calm	120	---	---	---	---	1.1	---
40.	Preload	calm	180	---	---	---	---	0.9	---
41.	Preload	calm	240	---	---	---	---	0.85	---
42.	Preload	calm	300	---	---	---	---	0.95	---
43.	Preload	calm	360	---	---	---	---	1	---
44.	Preload	calm	420	---	---	---	---	0.95	---
45.	1st & Gross Loss	calm	420	0.95	1.3	---	---	---	---
46.	1st & Gross Loss	calm	400	0.95	no value obtained	---	---	---	---
47.	Loss Rate 1st + .1	calm	400	---	---	3	26	1.05	---
48.	Loss Rate 1st + .3	calm	400	---	---	36	105	1.25	---
49.	Loss Rate 1st + .1	calm	400	---	---	3	26	1.05	---
50.	Loss Rate 1st + .3	calm	400	---	---	23	105	1.25	---
51.	1st & Gross Loss	Wave #1	400	.7	1	---	---	---	.4loss over damaged area, .7 first loss, wave tests not run
52.	Critical Tow	calm	---	---	---	---	---	1.25-2.75	Washover damage area of boom
53.	Critical Tow	calm	---	---	---	---	---	1.25-2.75	2.25 went under, boom separated from connector

e = estimated value
---- = not measured during this test
Each boom was rigged using Applied Fabric Globe Boom as extension boom and the same tow bridle

Test No.	Test Type	Surface Condition	Preload Vol (gal)	1st Loss Speed (knots)	Gross Loss Speed (knots)	Oil Loss Rate (gpm)	Dist. Rate (gpm)	Tow Speed (knots)	Comments
Applied Fabric/SL Ross(Pocket Boom)									
54.	Preload	calm	60	---	---	---	---	1.25	---
55.	Preload	calm	120	---	---	---	---	1.15	---
56.	Preload	calm	180	---	---	---	---	0.95	---
57.	Preload	calm	240	---	---	---	---	0.95	---
58.	Preload	calm	300	---	---	---	---	0.95	---
59.	Preload	calm	360	---	---	---	---	.90	---
60.	Preload	calm	420	---	---	---	---	0.95	---
61.	1st & Gross Loss	calm	400	0.95	1.25	---	---		---
62.	Loss Rate 1st + .1	calm	400	---	---	3	26	1.05	abort first try
63.	Loss Rate 1st + .3	calm	400	---	---	25	105	1.25	---
64.	Loss Rate 1st + .1	calm	400	---	---	5	26	1.05	---
65.	Loss Rate 1st + .3	calm	400	---	---	30	105	1.25	---
66.	1st & Gross Loss	Wave #1	400	0.8	0.9+	---	---	---	connector separation at .78 knots, east side dropped slide up in itself
67.	1st & Gross Loss	Wave #1	400	0.85	0.95	---	---	---	wave data before & after, splashover on & off the entire run
68.	1st & Gross Loss	Wave #3	400	0.85	1.15	---	---	---	
69.	1st & Gross Loss	Wave #3	400	0.9	1.15+	---	---	---	full gross loss speed is greater than 1.15
70.	1st & Gross Loss	Wave #2	400	1	1.3	---	---	---	---
71.	1st & Gross Loss	Wave #2	400	1.05	1.2+	---	---	---	full gross loss speed is greater than 1.15
72.	Critical Tow	calm	---	---	---	---	---	3	boom planing started at 1.5, globe boom influence very stable
73.	Critical Tow	calm	---	---	---	---	---	3	boom planing started at 1.5, globe boom influence very stable

e = estimated value

---- = not measured during this test

* Each boom was rigged using Applied Fabric Globe Boom as extension boom and the same tow bridle

APPENDIX E   ASSESSMENT OF FIRE BOOM TEST QUALITY

General

The testing was performed in accordance with OHMSETT "General Quality and Procedures and Documentation Plan" Manual, December 1996; and the "Operating Manual for OHMSETT Laboratory Including Laboratory Procedures," January 1997. The following is a description of the various elements as they relate to the accuracy, precision and validity of the test data presented.

Initial Calibration Data

All instrumentation utilized during testing was verified to be within the acceptable calibration limits for the test period by the OHMSETT Quality Control (QC) Engineer.

Pre- and Post-Checks and Conditions

Prior to testing, the instrumentation used to collect data for the automated data collection system was checked by the OHMSETT Instrumentation Technician to assure proper operation. Similarly, this instrumentation was also checked upon completion of testing. Both pre- and post-checks were made each test day to provide assurance that the instrumentation was functioning normally during the test period. Any anomalies were brought to the attention of the OHMSETT Test Director for appropriate action. Weather was observed and recorded continuously during testing by the automated data collection system. This instrumentation was also included in the pre- and post-checks performed by the OHMSETT Instrument Technician.

In addition to the above, independent, random observations were made and recorded by the OHMSETT QC Engineer on the Quality Checklists for pre- and post-test conditions. These observations of pre- and post-test conditions were randomly compared to other data to assure data accuracy.

Test Checks and Conditions

Test data were continuously recorded by the automatic data collection system and by manual methods during testing. Random over-checks were used to observe and record data independently of both the automated data collection system and manual methods. This data were recorded on the Quality Checklist by the OHMSETT QC Engineer.

Sampling

Sampling were checked for compliance with the instructions in the Test Plan and the "Operating Manual for OHMSETT Laboratory Including Laboratory Procedures." Sampling included Basin water analysis, test oil analysis, and recovered fluid analysis. The Test Plan requirement for a minimum of 10% duplicate sampling for these analyses was met or exceeded in all instances.

Significant Occurrences/Variations

Any significant occurrences/variations which may have affected any of the test results are reported and discussed in the appropriate sections of the test report.

Data Reduction and Validation

All data reduction and validation were performed in accordance with approved and accepted methods. When non-standard methods were utilized, they are included in the test/data report and sufficiently described so that they can be used by independent sources to duplicate the results.

Data Precision and Accuracy

Data precision was accomplished by measuring variances between and among redundant sampling and repetitive testing.

Data accuracy was achieved through the use of calibrated and verified instrumentation and through cross-checks between collected data (both automated and manual) and the independent observations made and recorded on the Quality Checklists.

Basin Water Analysis

Basin water analysis performed during the testing is reported in APPENDIX B. Review and analysis of the data confirmed that Basin Chemistry was within the precision requirements of the Test Program.

Test Oil Analysis

The analysis of test oils used during the test program was reviewed for overall variations and for variations between original and duplicate samples. During this analysis, it was noted that both the original samples (9-9-0750, 9-10-0730 and 9-10-0730D) contained a slightly higher than nominal bottom solids and water (BS&W), i.e., 9.6 to 16.0% versus the typical less than or equal to 2.0% for the other test oil samples. This higher than normal BS&W may have slightly reduced the percent of the oil content of the recovered fluid analysis for Test Sample Number 12-8 through 16-3. However, because this test program concentrated more on 1st and Gross Loss Rates, Critical Tow Speeds, and Oil Loss Rates versus Recovery Efficiencies, this slight variation is considered to be insignificant to the test results. Based on this assessment, the test oil data is considered to be within the precision requirements of the Test Plan.

Recovered Fluid Analysis

The recovered fluid analytical techniques described in APPENDIX B, FLUIDS TESTING, were used to determine the values also reported in that appendix in Table B-2. In order to assess the validity/reliability of the data, recovered fluid analyses were reviewed and analyzed for variations for both within-test samples (where more than one sample was analyzed per test) and between original and duplicate samples.

In all instances, variations within test and original and duplicate samples were statistically insignificant and satisfied the precision requirements of the Test Program.

Repetitive Test Runs

In order to assess the precision of the testing performed, 29 sets of repetitive tests were statistically analyzed for variances regarding Oil Loss Rates, First and Gross Loss, and Critical Tow Speeds. The repetitive test data can be found in Appendix D. For the convenience of the reader, the repetitive test sets are listed below by test type and boom manufacturer:

Table E-1. List of Repetitive Tests.

TEST TYPE	MANUFACTURER	TEST SET NO.
1st/Gross Loss	Elastec/American Marine (Hydro-Fire)	7&8, 9&10, 11 & 14
"	Spill Tain™	26&27, 32&33, 28&31
"	Applied Fabric (PyroBoom)	45&46
"	SL Ross/Applied Fabrics (Pocket Boom)	66&67, 68&69, 70&71
Oil Loss Rate	Elastec/American Marine (Hydro-Fire)	12&15, 13&16
"	Spill Tain™	29&34, 30&35
"	Applied Fabric (PyroBoom)	47&49,48&50
"	SL Ross/Applied Fabrics (Pocket Boom)	62&64, 63&65
Critical Tow Speed	Elastec/American Marine (Hydro-Fire)	17&18
"	Spill Tain™	36&37
"	Applied Fabric (PyroBoom)	52&53
"	SL Ross/Applied Fabrics (Pocket Boom)	72&73

The statistical variance between the repetitive test sets was found to be insignificant. Therefore, based on the precision of these test sets, all testing for Oil Loss Rate, First and Gross Loss, and Critical Tow Speeds is considered to be within the precision requirements of the Test Program. Based on the discussion above in this appendix on Basin water analysis, test oil analysis, recovered fluid analysis, and repetitive test runs, the data presented in this test report are considered to be accurate, precise and valid within the prescribed requirements of the Test Program.

Documentation of Tests

All analytical laboratory testing results, calibration data, pre and post checks, test checks and conditions, quality checklist, test run data, automated and manually recorded data, as well as above-water and below-water visual documentation used to prepare this Test Report, are on file at the OHMSETT Facility.