Phase 2: At Sea Towing Tests of Fire Resistant Oil Containment Booms

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TABLE OF CONTENTS

Page

Appendices

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS, SYMBOLS AND ACRONYMS

Term	Abbreviation, Symbol, or Acronym
American Standard Code for Information Interchange	ASCII
American Society for Testing and Materials	ASTM
buoyancy to weight	B/W
centimeters	cm
Department of the Interior	DOI
feet	ft
inches	in
International Tanker Owners Pollution Federation	ITOPF
knots	kts
pounds	lbs
meters	m
Minerals Management Service	MMS
Marine Spill Response Corporation	MSRC
Newtons	N
Oil Spill Response Vessel	OSRV
overall	O/A
Research and Development	R&D
seconds	sec
Texas General Land Office	TGLO
United States Coast Guard	USCG
United States Navy	USN

Phase 2: At Sea Towing Tests of Fire Resistant Oil Containment Booms

Abstract

A series of at sea towing tests on fire resistant oil containment boom was performed jointly by the Marine Spill Response Corporation (MSRC), the Texas General Land Office (TGLO), Minerals Management Service (MMS), and various boom manufacturers at a site offshore from Galveston, Texas. The main objectives of this test series were to assist MSRC Region III in evaluating fire resistant booms for future acquisition, to continue data collection for further development of American Society of Testing and Materials (ASTM) guidelines on selection of booms, and to provide these results for use in future validation of test tank data. A total of 14 tests were performed in sea state 1 on three booms: the Applied Fabric Pyroboom™, the Oil Stop Auto Boom™ Fire Model, and TGLO's SeaCurtain™ FireGard™ Oil Containment Boom. Navy 3M Fire Boom test results from Phase 1 testing in New Jersey were also included to compare with this set of fire boom results. Tow speed, tow tension, skirt depth, and skirt angle were recorded both electronically and manually and weather parameters were recorded using wind and wave sensors. Comparisons were made between the tow speed and the following parameters: tow tension, skirt draft, skirt tilt, and, when possible, freeboard. Results of these tests agreed with previous tests, indicating that a higher reserve buoyancy to weight ratio allows for a higher tow speed at submergence and better conformance to waves. The geometric shape of the floatation chambers also affects a boom's dynamic response, and consequently, its tow speed at submergence. During testing, if a boom did not submerge, planing or streaming of the skirt would occur. Therefore, all modes of failure must be considered to accurately predict and assess a boom's behavior at sea. Operationally, all the fire booms tested were more difficult to deploy and retrieve than nonfire resistant booms. The materials used for most fire booms are more fragile than those for conventional booms, and they tore and punctured during deployment. Overall, the towing and handling capabilities of commercial fire resistant booms must be improved to meet anticipated operational and environmental conditions at sea. It is recommended that the ASTM standards should be expanded to include dynamic operational parameters in addition to static criteria.

1.0 Introduction

1.1 Test Objectives

The overall efficiency of spilled oil recovery operations is often dependent upon the at sea performance of the boom selected. Very little quantitative work has been done to document boom conformance and efficiency as a function of common boom selection parameters, such as fabric strength, boom buoyancy to weight ratio, freeboard, skirt depth, etc. The Marine Spill Response Corporation (MSRC), in cooperation with the United States Coast Guard (USCG), US Navy (USN), and Minerals Management Service (MMS), tested four booms, including the 3M Fire Boom, off New Jersey in May 1994. Based on the success of those Phase 1 tests, the MSRC Region III office asked MSRC Research and Development (R&D) to conduct additional at sea tests to assist them in the evaluation of fire resistant booms for acquisition. Observations were made during the Phase 2 tests on the ease of deployment, handling, and maintenance of the candidate booms. The Phase 2 information relates to another MSRC study of fire resistant booms which evaluated all fire resistant booms available on the market, focusing on durability, seaworthiness and transportability (Burkes 1994). The Phase 2 testing provided more specific information on the seaworthiness of three fire resistant booms: the Applied Fabric Pyroboom, the Oil Stop Auto Boom Fire Model, and the Texas General Land Office's (TGLO) SeaCurtain FireGard Oil Containment Boom.

These tests collected additional quantitative data on the performance of the three booms at four different tow speeds: 0.5, 1, 1.5 knots and speed at containment failure (i.e., at boom submergence or skirt surfacing). The overall dimensions of the fire booms tested were approximately the same, however, the buoyancy to weight ratios ranged from 2:1 to 13.5:1. The collected data will be used to define the environmental and operational criteria as a function of buoyancy to weight ratio, freeboard, stiffness, and other boom properties. Other objectives of these tests were to continue data collection to provide information for developing the *American Society of Testing and Materials (ASTM) Guideline for the Selection of Booms According to Water Body Classifications* and to provide these results for validation of test tank data collected on the same booms.

1.2 Test Location

The MSRC Region III pre-position location at Galveston, Texas received all of the test equipment and served as the staging area. The location serves as the home port of an MSRC Oil Spill Response Vessel (OSRV), the *Texas Responder*, which served as the command ship for the test. This location appears in the small scale charts in Appendix A. As indicated on Figure A-1, the towing areas is at Lat. 29° 16.4' N, Long. 94° 38.5' W. This site has previously been used by MSRC for field exercises.

1.3 Test Sponsors And Participants

The following groups participated in the tests: MSRC, TGLO, the U.S. Department of the Interior's (DOI) MMS, and boom manufacturers. The test organization chart appears in Figure 1.1.

1.3.1 MSRC

Several MSRC divisions contributed to the test planning and operations. The Research and Development Division sponsored and directed the tests, provided the Project Manager and an Assistant Project Manager, and provided funding for:

- preparation of the test plan,
- miscellaneous costs during mobilization and demobilization,
- on-site contractors to assist with data acquisition and video filming,
- preparation of a video of the project, and
- preparation of the test report.

Contract assistance was provided by Evans Communications, Inc. for preparation of a documentary video; and by PCCI for test planning, logistics support, on site engineering and data acquisition, and final report preparation.

The Operations Division of MSRC's Gulf Region office provided funding for:

- review of the test plan,
- liaison with federal and state regulators,
- receipt and warehousing of test materials,
- responders used to deploy and retrieve the booms,
- use of the *Texas Responder*, the *Gulf Coast Responder* and their crews,
- helicopter overflight, and
- contract vessels used as video platforms.

The Operations Division of MSRC's Southwestern Region office provided the pressure sensors and a data logger from their equipment inventory.

1.3.2 Texas General Land Office

The Texas General Land Office participated in the boom test, and provided funding for:

- delivery and pick-up of 500 feet of SeaCurtain FireGard fire boom on its storage reel and
- two crew members to assist with deployment and retrieval of boom.

1.3.3 U.S. DOI Minerals Management Service

The Technology Assessment & Research Branch of MMS sponsored the tests, provided an Assistant Project Manager, and provided funding for:

- review of the test plan,
- supply of two video cameras and tapes,
- video camera crew leader, and
- review of the final report.

1.3.4 Boom Manufacturers

Representatives from Oil Stop, Inc.; Applied Fabric Technologies, Inc.; and Kepner Plastics Fabricators, Inc. were present for the testing of the fire booms. Each manufacturer provided test sections of their boom and test observers or participants (see Appendix B for manufacturer's specifications).

Oil Stop provided two technicians for on site support during deployment, retrieval, and attachment of instrumentation to the boom. They also provided funding for shipment of the boom, which was stored on its own deployment reel on the *Gulf Coast Responder*.

Applied Fabric Technologies provided a container for storing the boom on the *Texas Responder*. An observer was also present during all tests and provided guidance and assistance during the deployment and retrieval of the Pyroboom. Applied Fabric also provided information on tow force calculation methods and technical background on boom behavior and burn tests.

Kepner Plastics Fabricators, Inc. provided one participant and one observer who provided technical assistance in attaching sensors to the SeaCurtain FireGard boom. They also assisted in the deployment and retrieval of the boom, as well as making any necessary repairs or changes to the boom.

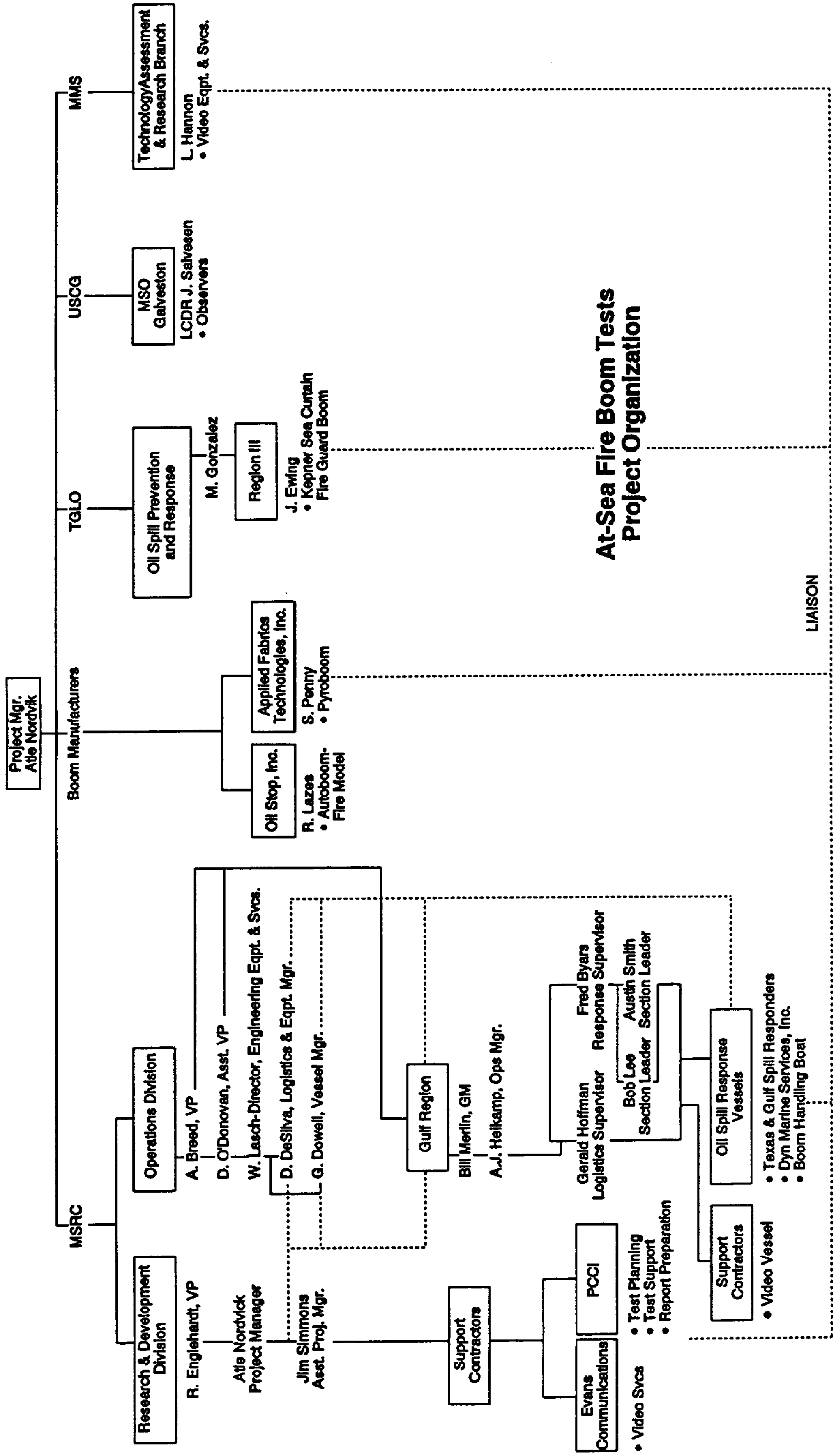


Figure 1.1 Project organization for at sea boom tests

2.0 Oil Containment Boom Descriptions

2.1 Navy 3M Fire Boom

The data for the Navy 3M Fire Boom was taken from the Phase 1 tests in MSRC Region I off New Jersey. During these tests, seven 15 m sections (107 m total) of 3M Fire Boom with a 46 cm diameter floatation and a 61 cm skirt were towed between 46 m lengths of inflatable Navy boom. Sections of Navy Model USS-42 were used on one side of the Navy 3M Fire Boom while sections of Navy Model FUG-1 were used on the other side of the "U" configuration. The Navy 3M Fire Boom uses high temperature components and a unique ceramic float design to allow in-situ containment and burning of oil. This boom is now marketed and manufactured by American Marine, Inc., under license from 3M, as American Fire Boom. The critical boom dimensions are given in Table 2.1. Refer to Appendix B for more specific technical information.

2.2 SeaCurtain FireGard Oil Fire Containment Boom

The following information was taken from the *SeaCurtain FireGard Operational and Maintenance Manual*, provided by the Texas General Land Office. The SeaCurtain FireGard oil fire containment boom consists of a continuous, stainless steel erecting coil which is covered with a high temperature refractory fabric with the trade name Thermotex™. A sacrificial coating on the Thermotex burns away at approximately 315°C during oil-fire containment. The technical specifications state that the boom is operational in temperatures ranging from "-40°C to 1,260°C (-40°F to 2,300°F)". If the fabric is damaged during operations or is unusable after a burn, the covers can be replaced since they are attached using quick-connect connectors.

The skirt of the boom is a heavy-duty polyurethane coated fabric. Tension and ballast are provided by a galvanized chain located throughout the bottom of the skirt. Built-in Polycell™ high temperature foam floatation is also located throughout the skirt, providing more rigidity and some buoyancy. The towing assemblies of the boom were designed to assist the boom in maintaining its freeboard and concentrate towing stresses in the skirt and ballast chain of the boom.

The end connectors of the boom are ASTM standard end connectors, which are covered at the top with the fire resistant material.

The dimensions of the boom tested are given in Table 2.1. More specific technical specifications are provided in Appendix B.

2.3 Applied Fabric Technologies, Inc. Pyroboom

The following description of the Pyroboom was provided by Applied Fabric Technologies, Inc. Pyroboom is a solid floatation, fire resistant floating barrier for oil spills that will allow prolonged deployment before, during and after an in-situ burn of 24 hours or more. The patented, freeboard section of Pyroboom utilizes a blend of Inconel wire mesh and Fiberfax™ ceramic fiber yarn woven into the refractory fabric. The fabric is saturated with a sacrificial, silicone rubber, polymer coating. The polymer transitions from an elastic form to a silane organo-mineral compound which binds the yarns together for thermal stability during a burn. The result is a fully occluded wire screen mesh which suffers no further structural degradation as a result of continued exposure to high thermal energy levels. The thermal resistance of the freeboard does not require any thermal dissipation through wicking or other physical or mechanical cooling mechanisms.

The freeboard section of Pyroboom has a tensile strength of 175 kN per meter (1,000 pounds per inch) width and high associated tear strength even when exposed to temperatures as high as 1,315°C for extended periods. The draft section of Pyroboom is a PVC-coated polyester scrim which has a tensile strength of 263 kN per meter (1,500 pounds per inch) width and a tear strength of 4.2 kN (940 lbs). The total tensile strength of Pyroboom is 222 kN (50,000 pounds).

Buoyancy for Pyroboom is provided by 41 cm (16 inch) diameter, stainless-steel spheres bolted through the freeboard and draft materials on 86 cm (34 inch) centers. Each hemisphere is filled with a temperature resistant, closed cellular material and provides a buoyancy that is temperature independent up to a demonstrated 1,315°C. The static buoyancy to weight ratio of the actual fire boom is 5:1. However, for these tests, a different non-fire resistant material was used rather than the Fiberfax, giving the boom test section a buoyancy to weight ratio (B/W) of 8:1.

Sacrificial plastic handles to aid in handling and launching are located at each float using a shackle which is available for recovery after a burn. Pyroboom has ASTM D963 end connectors and will join with any similarly equipped boom used as a guide boom in "U" or "J" towing configurations.

The dimensions of the boom tested are given in Table 2.1. More specific technical specifications are provided in Appendix B.

2.4 Oil Stop, Inc. Auto Boom Fire Model

The third fire resistant boom tested was the Oil Stop, Inc. Auto Boom Fire Model. The design of the boom is similar to the USCG Oil Stop boom tested in Phase I of the at sea tests of oil containment booms. The main difference is that the Fire Model's floatation chamber is covered with a fire resistant materials. The skirt, however, is not fire resistant, and has the same dimensions as the USCG Oil Stop boom. The boom is stored on a hydraulic reel for rapid deployment and compact storage. It consists of 15 m (50 ft) sections of inflatable containment boom with the stiff, fire resistant cover surrounding the floatation chamber. The internal temperature of the Auto Boom Fire Model is reduced by heat transfer to the surrounding water, as stated in the technical specifications provided by Oil Stop. The high temperature insulating fabric, as well as this process of heat transfer, allows the boom to sustain high temperatures for extended periods. The main tension line of the boom is located at the bottom of the skirt. The combined tensile strength of the offshore boom tested is 270 kN (60,750 lbs).

The dimensions of the boom tested are given in Table 2.1. More specific technical specifications are provided in Appendix B.

Table 2.1 Dimensions of fire resistant booms

Boom Design Specification	SeaCurtain FireGard Boom	Applied Fabric Pyroboom	Oil Stop Auto Boom Fire Model	Navy 3M Fire Boom
Nominal Boom Section Length or O/A Length m (ft)	152.4 (500)	44.62 (146.4)	15.24 (50)	15.24 (50)
# Floatation Chambers Per Section	Continuous	50	2	7
Reserve Buoyancy to Weight (B/W) Ratio	2:1	8:1	13.5:1	5:1
Nominal Floatation Chamber Diameter cm (in)	33.02 (13)	40.64 (16)	43.18 (17)	45.72 (18)
Skirt draft cm (in)	50.8 (20)	58.42 (23)	63.5 (25)	60.96 (24)
O/A Collapsed Height cm (in)	91.44 (36)	96.52 (38)	106.68 (42)	106.68 (42)
Freeboard cm (in)	22.86 (9)	34.29 (13.5)	38.1 (15)	36.83 (14.5)
Draft cm (in)	68.58 (27)	62.23 (24.5)	68.58 (27)	69.85 (27.5)

3.0 Test Configuration And Procedures

3.1 Test Configuration

Two booms were towed in tandem for most of the tests, as shown in Figure 3.1. The *Gulf Coast Responder* and the *Texas Responder's* Munson Boat each towed an end of the boom, with the *Texas Responder* in the center towing the other end of both booms. The sweep width between the towing vessels for each boom was held constant at approximately 91 m (300 ft). This distance was varied for the Applied Fabric boom, which was towed in a U configuration with a distance between vessels of 46 m (150 ft) for most of the tests since the overall length of boom available for testing was only 45 m (146 ft).

Video cameras recorded each test run from four positions: the *Texas Responder*, the *Gulf Coast Responder*, and the two support boats. The two support boats were placed behind the apexes of the booms being towed, with video cameras focusing on the apex. Scales attached on the booms allowed for the freeboard, both forward and aft, to be documented by video.

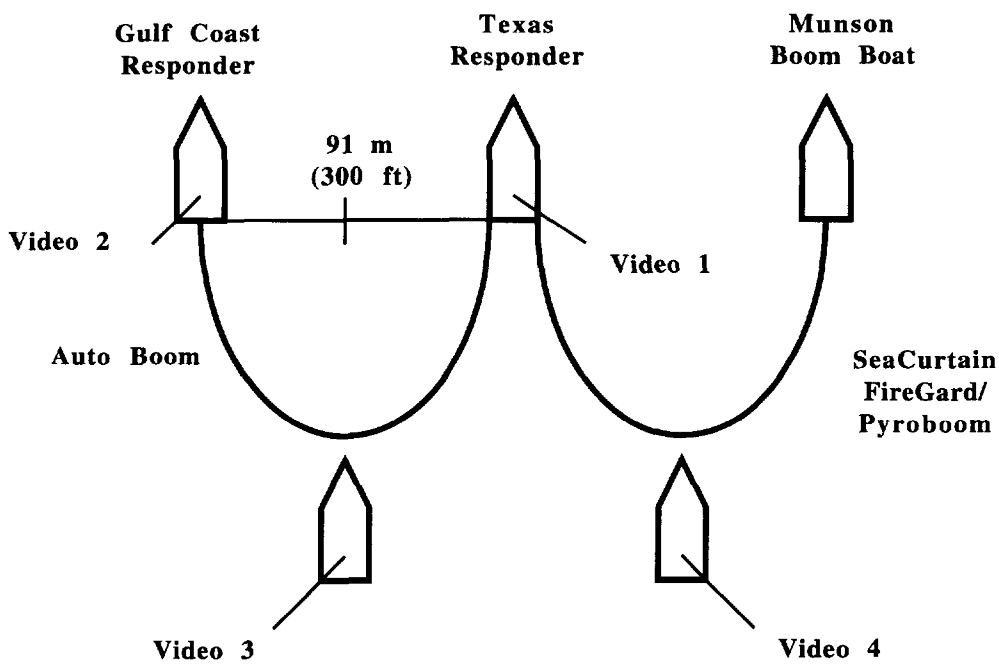


***Figure 3.1** Test configuration with booms towed in tandem*

3.2 Test Procedures

A test run began with the tow vessels lining up in the desired direction to the wind or swell at very slow speeds. Premeasured rope lines between the vessels were used to maintain a constant sweep width between the vessels. The tow vessels accelerated to 0.5 knots, and when the speed was confirmed to be steady, the data for the run was recorded for approximately 10 minutes. Then the speed was increased to 1.0 knot and 1.5 knots, following the same procedure. The entire procedure was repeated for the opposite tow direction, after which the booms were recovered. A functional test was also performed to obtain the speed at which submergence or planing failure at the apex of the boom occurred in calm water conditions. During test runs, the *Texas Responder's* radar was used to record the gap distance.

Figure 3.2 *Towing formation during test runs using the Texas Responder, Gulf Coast Responder, and a boom handling boat.*

4.0 Instrumentation And Data Collection

To further develop a relationship between boom design (specifically, its dimensions) and performance parameters, the following boom parameters were recorded during each test run: tow tension, skirt draft, skirt angle from vertical, freeboard, and tow speed. All booms were towed at steady speeds of 0.5, 1.0, 1.5 knots, and the tow speed at failure.

4.1 Vessel Tow Speed

Both speed over ground and speed relative to the water were measured. These tow speeds were recorded manually on the *Texas Responder* and the *Gulf Coast Responder* at 30 second intervals during the ten minute test runs. For comparison of the test results, an average of the tow speeds was calculated for each test run.

4.2 Boom Sweep Width

The tow vessels maintained their sweep width by using a 91 m (300 ft) line between the vessels for reference. The boom sweep width was recorded manually on the bridge of the *Texas Responder* and the *Gulf Coast Responder* using readings from the ships' radar systems set at 0.5 nm scale. Measurements were taken every 30 seconds on the *Texas Responder* and every minute on the *Gulf Coast Responder*. Again, an average of the gap distance was calculated for comparison with previous results and calculations.

4.3 Skirt Draft

Two In-situ Inc. model PTX-161/D submersible pressure transducers were fastened to the bottom of the skirt of each boom (Figure 4.1). The transducers have a range of 0-7 m (0-23 ft) and an accuracy of ±0.3% of range. The primary transducer was located in the apex of the boom and a back up was located approximately 33 meters from the primary unit. The second transducer was necessary since problems with the pressure transducers occurred during the test. The transducers were hard wired to a data collection station located in the communications center on the *Texas Responder*. A data logger was used to record the conditioned sensor outputs from both pressure transducers, the tow load monitoring cells, and the tilt sensors. For more specific technical specifications on this equipment, refer to Appendix F.

4.4 Skirt Angle

A parameter which was not recorded in Phase I of testing was the skirt angle. For this phase, the skirt angle was recorded using an angle sensor placed 1/3 the length of the skirt down from the floatation chamber (Figure 4.1). The sensor was an AccuStar Clinometer with a total range of ±60°. The output was recorded at 5 second intervals by a data logger in the communications center on the *Texas Responder* and saved in an American Standard Code for Information Interchange (ASCII) file with all other recorded test parameters. See Appendix F for more specific technical information on the angle sensor.

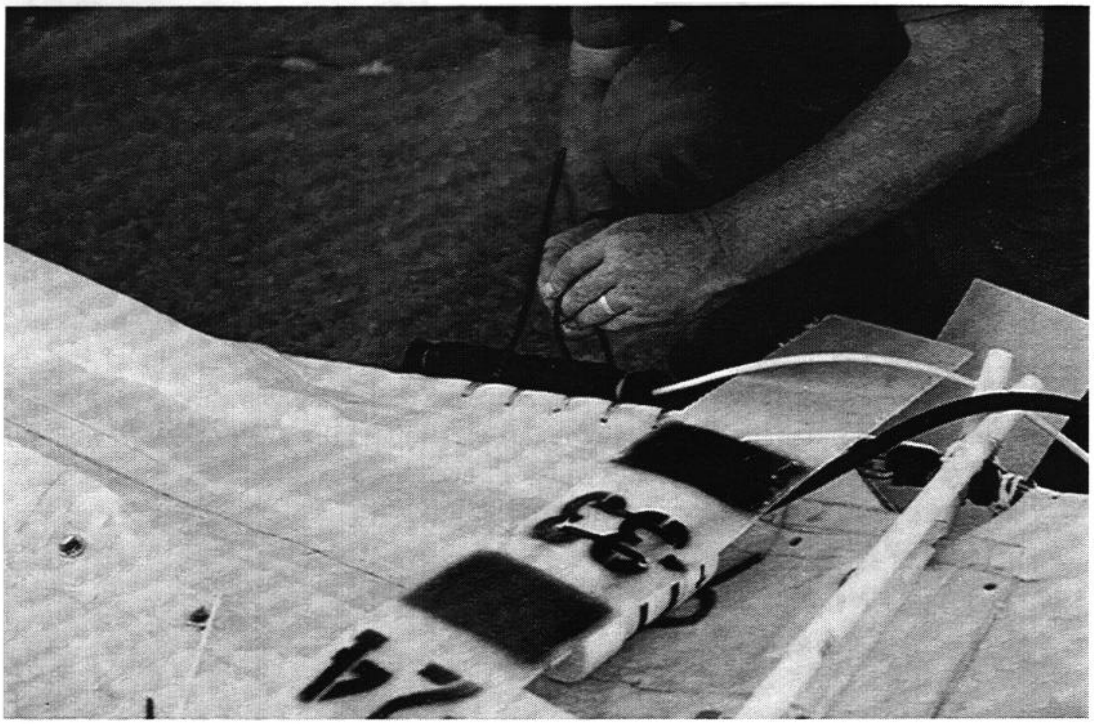


Figure 4.1 *Boom sensor locations*

4.5 Boom Freeboard and Skirt Attitude

The boom's freeboard, skirt attitude, splashover, and wave overtopping were recorded on video tape for post test analysis. The skirt attitude, that is the in-plane angle and relative movement of the skirt compared to the floatation chamber, was visually indicated by the rotation of two poles placed on either side of the boom (Figure 4.2). A linear vertical scale was placed on the floatation chamber of each of the test booms using a template with rectangular marks and numbers in 7.6 cm (3 in) graduations from the topmost point of the boom to the bottom of the floatation chamber. Figures 4.1 and 4.2 show the scales on the booms and the positioning of the skirt attitude pole indicators. These indicators were not used after the first day of testing since the angle sensors provided more accurate readings of the skirt's attitude and movements during towing. Therefore, the change in angle of the skirt from its perpendicular position were monitored by angle sensors attached to the skirt of each boom.

To measure freeboard, each boom was filmed from two vantage points. One camera was positioned on top of the pilothouse of the *Texas Responder* and recorded the wave and water action against the inside of the boom. A second camera was positioned in a small work boat that trailed the boom to record the wave and water action outside of the apex. In addition, general oversight video was shot by Evans Communications, Inc. from a helicopter.

Except for the cameras used by Evans Communications, the cameras utilized were all 8 mm consumer models and were operated by volunteers from MSRC and MMS. Appendix E summarizes the data obtained from the video footage of the test runs.

4.6 Tow Tension

Five load cells were available during testing: two 89 kN (20,000 pound), two 44 kN (10,000 pound) and one 22 kN (5,000 pound). The 5,000 pound load cell was damaged during testing and replaced by the 10,000 pound load cell. The 20,000 pound load cells were used on the *Texas Responder* and recorded using tension meters. The recorded loads were transmitted to data loggers located in the communications suite. The tow forces were sampled every 5 seconds during the test runs and stored in a computer. Tow forces on the other towing vessels were recorded manually by taking readings at one minute intervals from the load cell meters attached to the 10,000 pound load cells.

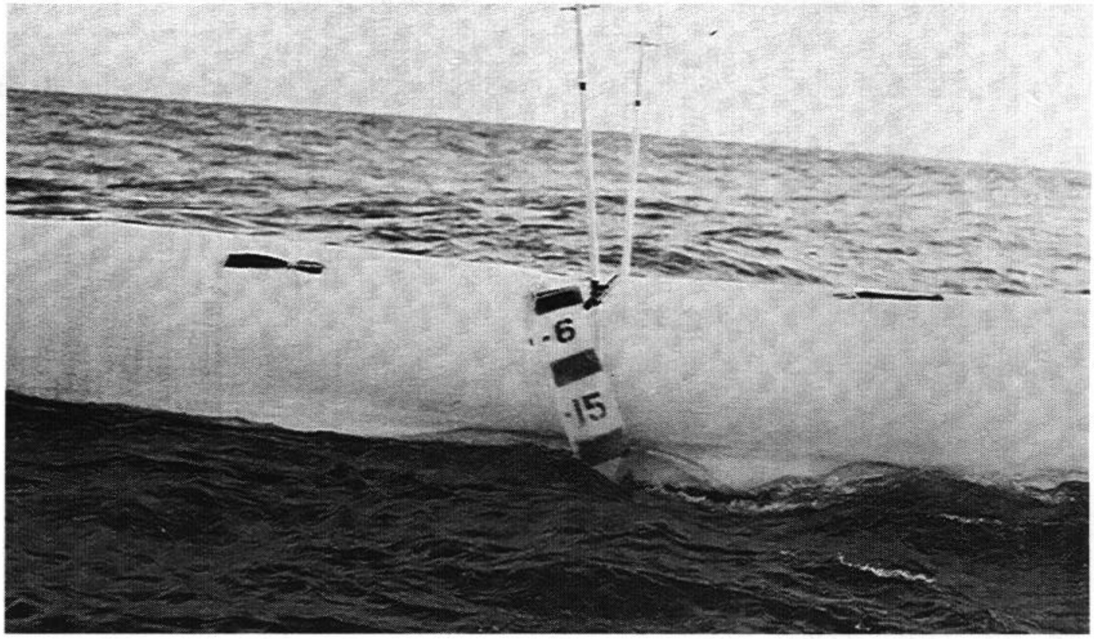


Figure 4.2 *Skirt attitude and freeboard indicators*

4.7 Environmental Conditions

Environmental conditions were recorded both manually and electronically. Wind and current speed and direction were recorded manually on the *Texas Responder* at the beginning and end of each test run. The wind speed and direction sensor on the *Texas Responder* was also hard wired to the data logger in the communications suite, where readings were recorded every 5 seconds. A Datawell B/V WaveRider buoy, shown in Figure 4.3, was also used to record environmental conditions including the following:

- significant wave height,
- average wave period, and
- maximum wave height.

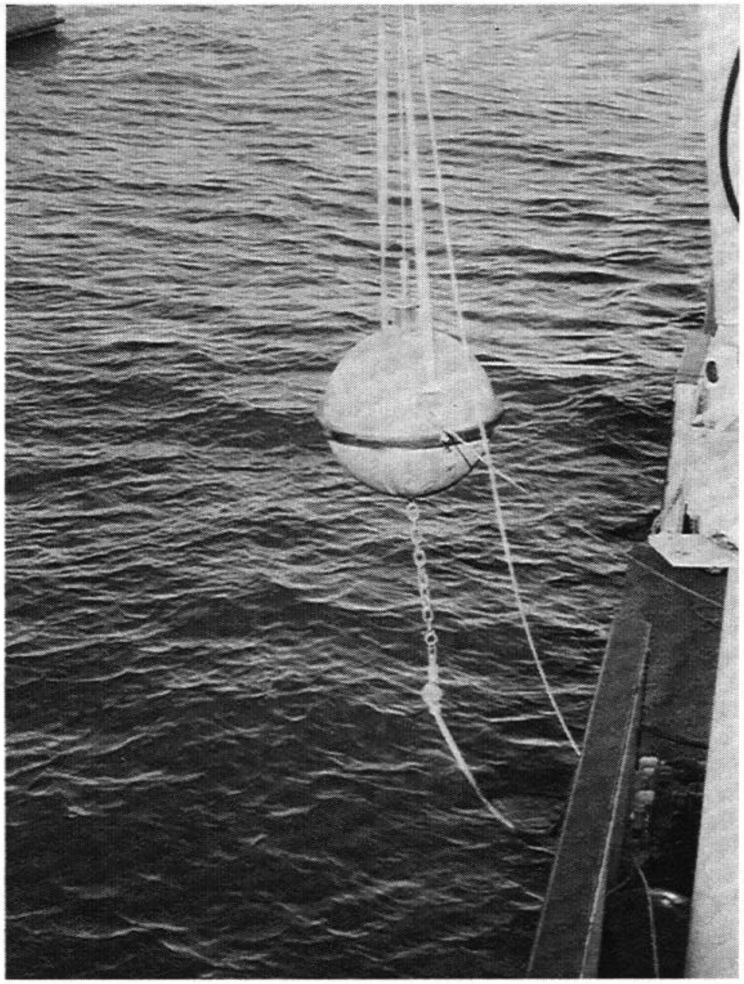


Figure 4.3 *Deployment of WaveRider used for recording environmental conditions*

Table 4.1 summarizes the average environmental conditions on each test day. See Appendix C for the readings taken every half hour on each test day.

Table 4.1 Environmental conditions during test runs

Test Date	Significant Wave Height m (ft)	Wave Period (sec)	Max. Wave Height m (ft)	Sea State*
8/30/94	0.24 - 0.34 (0.814 - 1.115)	3.88 - 4.62	0.40 - 0.68 (1.308 - 2.246)	1
8/31/94	0.31 - 0.38 (1.010 - 1.247)	4.28 - 4.99	0.52 - 0.72 (1.707 - 2.366)	1

* Sea state conditions as defined by the U.S. Navy Oceanographic Office (See Appendix C for definitions of sea state.)

5.0 Results And Conclusions

5.1 General

The test results were analyzed for each boom for all test runs. As in previous at sea tests, the tow force varied during the test runs for each boom because of changes in the distance between the vessels (sweep width), the speed through the water, and the draft of the booms. Therefore, the data that were used in calculations and comparisons was the average data from the most stable test conditions. The test results from Phase I on the Navy 3M Fire Boom are also included in the plots. However, the tow speed used for Phase 1 data was the nominal tow speed of 0.5, 1.0, etc., not the average tow speed.

In order to present the results accurately, all graphs were plotted using the average tow speed of the *Texas Responder*. In addition, plots were made to compare the performance of all booms, incorporating the following data sets for each boom: tow tension vs. tow speed, B/W ratio vs. tow speed at submergence, and skirt draft vs. tow speed compared to the skirt angle vs. tow speed. It is recommended that the ASTM standards should be expanded to include dynamic operational criteria, such as those presented here, in addition to static guidelines. Table 5.1 gives the average test results for all parameters recorded.

5.1.1 Navy 3M Fire Boom

Tests were performed on the Navy 3M Fire Boom only on the second day of testing during the Phase 1 tests off the New Jersey coast. The submergence tow speed in calm seas was determined to be 1.5 knots, at which speed the boom broke apart at one of the connectors (Sloan *et al.* 1994). As shown in Figure 5.1, the boom's freeboard decreases as the speed increases. At 0.5 knot, the overall height of the boom (freeboard plus the draft), is approximately 1 m. Since an increase in draft does not necessarily follow the reduction of freeboard, it is observed that the overall draft of the boom decreases as the speed increases. At 1.0 knots, a large percentage of the freeboard has also been lost. The reserve buoyancy is a function of the freeboard and towing speed. The 3M Fire Boom had a buoyancy to weight ratio of 5:1. The mean values of all test parameters are presented in Table 5.1.

5.1.2 SeaCurtain FireGard Boom

The Kepner SeaCurtain FireGard boom had the lowest buoyancy to weight ratio at 2:1. Tests were performed on this boom only during a single day of testing since sufficient performance results were obtained during the first day. The tow speed at submergence was between 0.5 and 0.6 knots, as major splashover was observed during review of the video test results. As shown in Figure 5.2, the boom's skirt draft decreased at 0.5 knots due to the movement of the skirt. Based on the skirt draft and angle measurements, the skirt of the boom moved inside the apex. Figure 5.3 attempts to illustrate the behavior of the boom at the various test tow speeds by interpreting the skirt draft, freeboard, and skirt angle measurements. At 0.5 knot, the skirt is curved 4° inside the apex, which would allow for a reduction of freeboard and slight increase in skirt draft. At 1 knot, the skirt is angled 22° inside the apex and a submarining effect occurs, causing the boom to completely submerge more than 2 feet below the water surface.

However, the boom did come to the surface for a brief time during the tow at 1.5 knot, which is why the mean draft (skirt depth) at 1.5 knots is less than the draft at 1.0 knots.

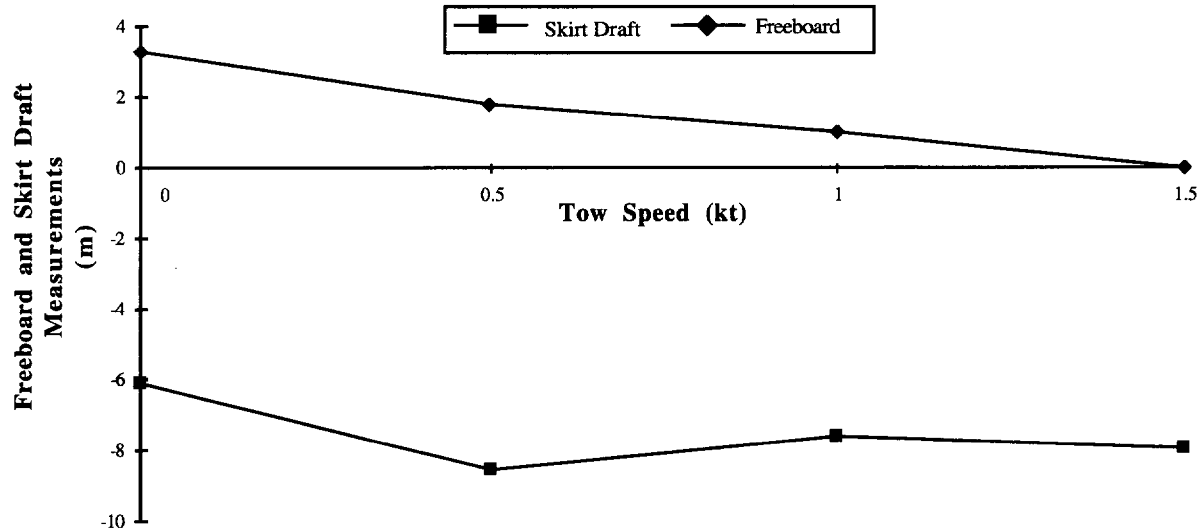


Figure 5.1 *Navy 3M Fire Boom reduction of freeboard and boom draft at various tow speeds in calm seas*

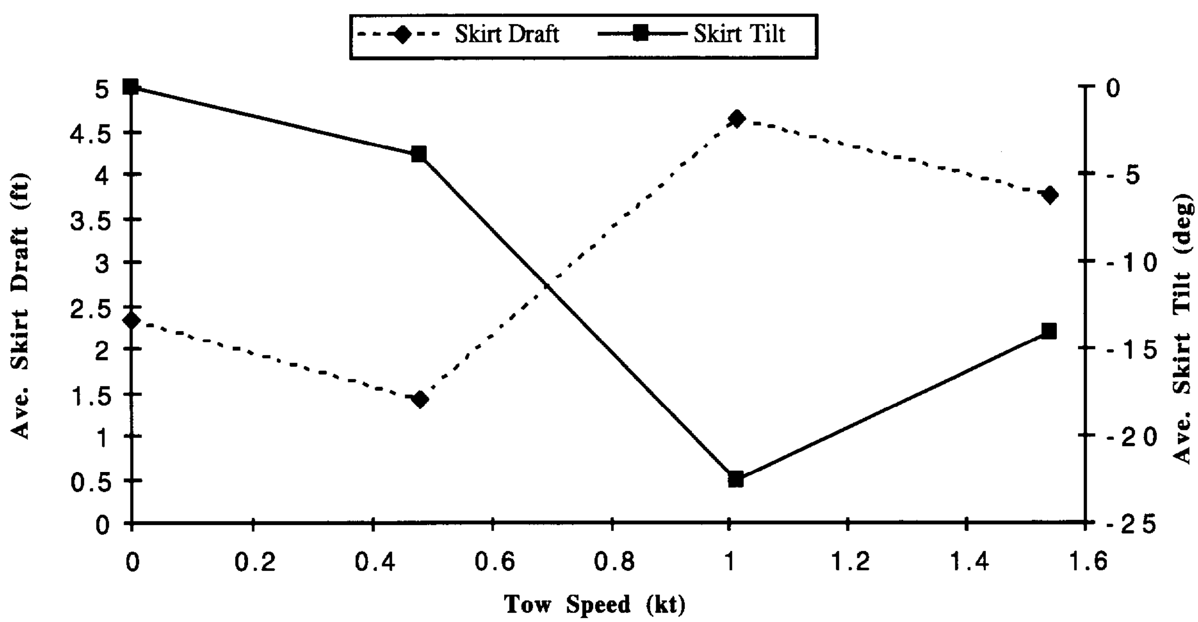


Figure 5.2 *SeaCurtain FireGard Boom's skirt attitude and draft at various tow speeds*

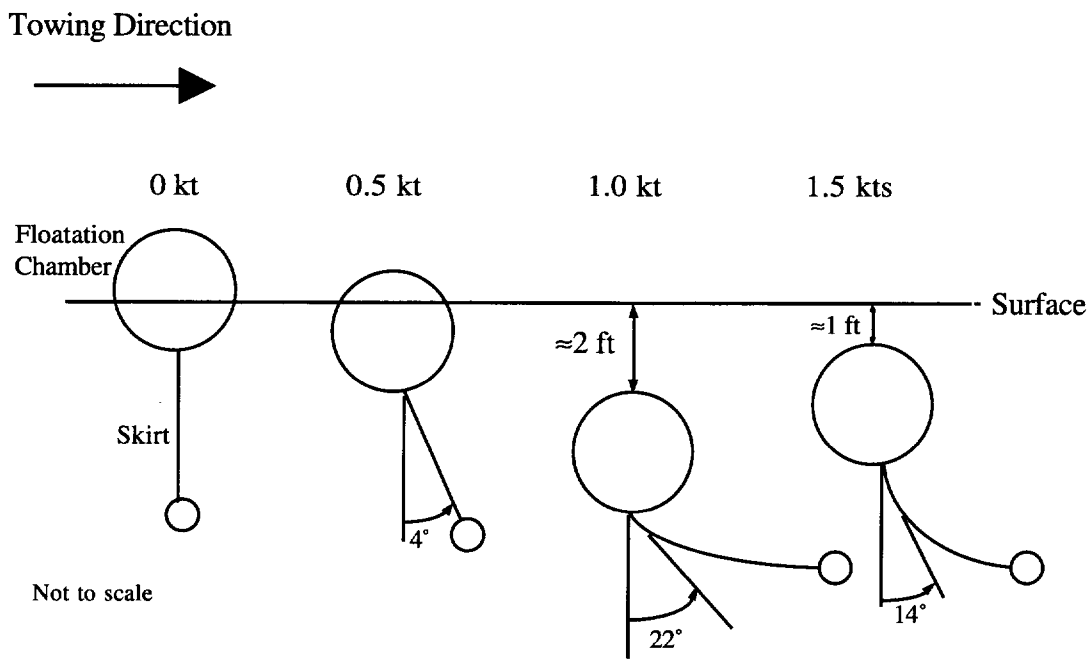


Figure 5.3 *SeaCurtain FireGard behavior at various tow speeds*

5.1.3 Applied Fabric Technologies, Inc. Pyroboom

The as-tested Pyroboom had a buoyancy to weight ratio of 8:1, while the commercially available model has a B/W ratio of 5:1. However, using the commercially available boom would not have significantly changed the boom's behavior. Unlike the other booms tested, this boom did not submerge, due to the hydrodynamic lift caused by the streaming of the boom's skirt. Review of the video results shows that the boom was hydroplaning at a tow speeds of 1 knot (Figure 5.5). Figure 5.4 shows the skirt draft and angle of the boom for all the tests performed on the Pyroboom against the current. The skirt draft measurements show that the boom skirt remained at approximately the same level which may be due to the boom's freeboard reducing as the tow speed increased. However, the skirt angle (Figure 5.6) indicates that the boom's skirt was angled inside the apex (negative angle) and then suddenly, at 1.4 knots, hydroplaned behind the boom. Therefore, the draft readings do not seem accurate based on the video results and the skirt angle measurements.

The freeboard of the Pyroboom was reduced to zero at each side of the apex even though the boom did not submerge. The fire resistant material placed between the floats allowed water to pass over the boom in between the spherical floats when it began to plane. This behavior may be a result of the limited length of boom that was available for testing. To obtain the desired configuration of the boom, longer tow lines were used. Figure 5.6 shows the side and front view when hydroplaning occurs.

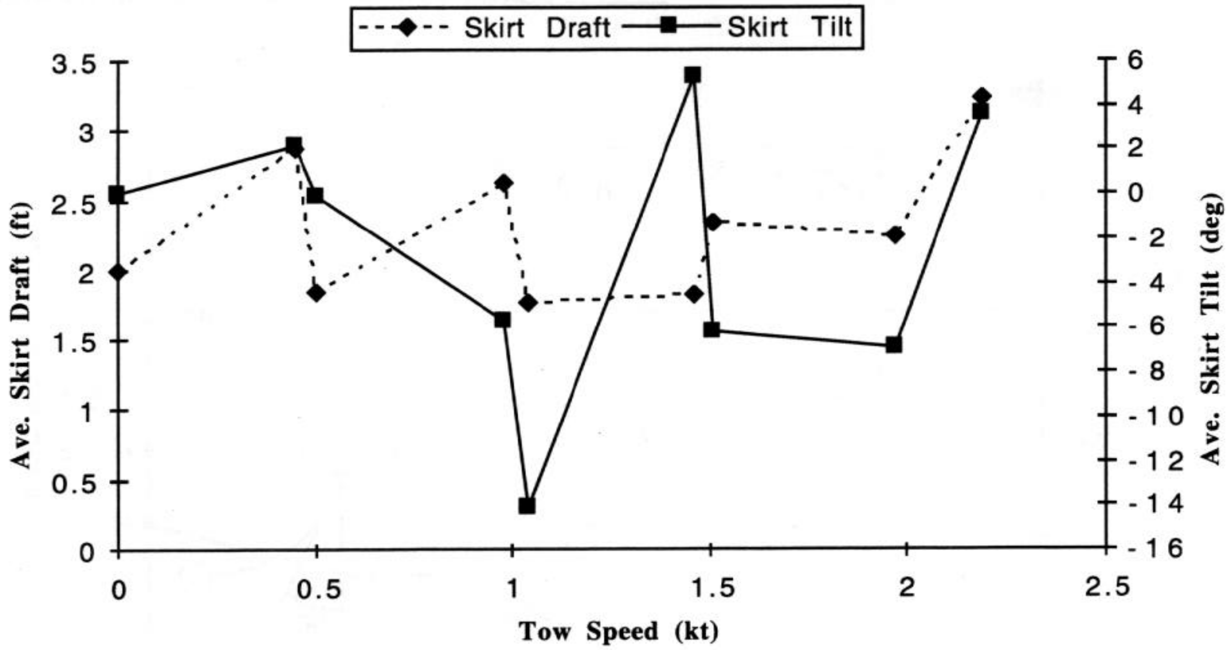


Figure 5.4 *Pyroboom skirt attitude and draft at various tow speeds*

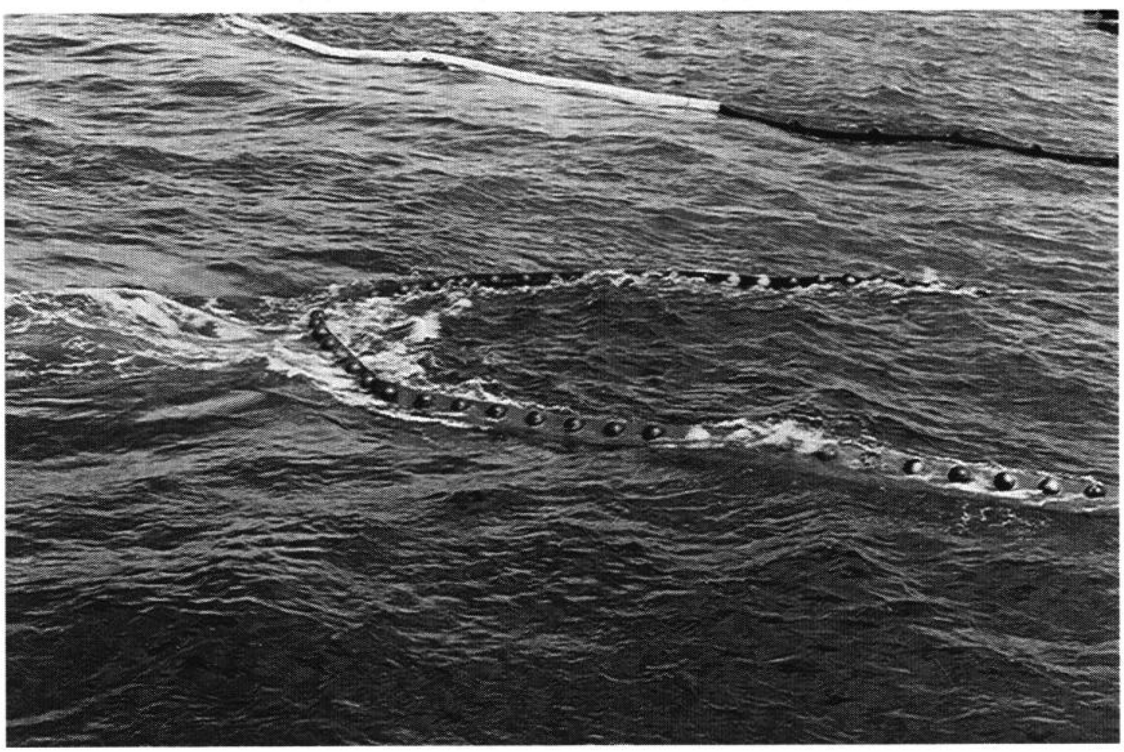


Figure 5.5 *Towing of Pyroboom during at sea tests*

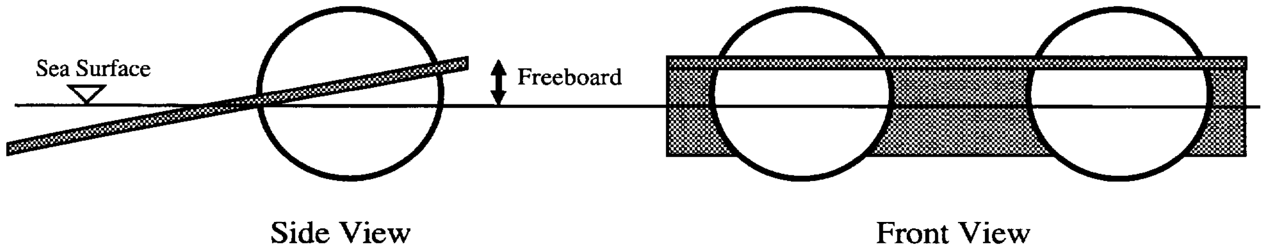


Figure 5.6 Diagram of front and side views of Pyroboom

5.1.4 Oil Stop, Inc. Auto Boom Fire Model

The Auto Boom tested had a buoyancy to weight ratio of 13.5:1. The boom was towed at 0.5, 1.0, 1.5, 2.0, and 2.5 knots with and against the current. The tow speed at submergence was determined to be 2.0 knots. The greatest change in freeboard, skirt draft, and skirt angle from static conditions occurs at approximately 0.5 knots. The most significant change occurs in the skirt angle. At the lowest average tow speed of 0.45 kt, the skirt is angled outside the apex at an angle of 30°. As the tow speed increases, the skirt angle is greatly reduced to the point where the skirt is vertical. Considering only the skirt angle results, it would seem that the skirt remained in this vertical position for the remainder of the tests. However, since the rate of change of freeboard is higher than the rate of change of the skirt draft, the bottom of the skirt must be moving inside the apex to give an angle reading of almost 0°. Figure 5.7 is the plot of the average skirt angle for each tow speed tested. The skirt draft represented in this figure is the average skirt draft measured in the first phase of testing on the non-fire resistant Auto Boom (USCG Oil Stop) since no accurate draft readings were recorded in this phase of testing on the Auto Boom due to an instrumentation malfunction.

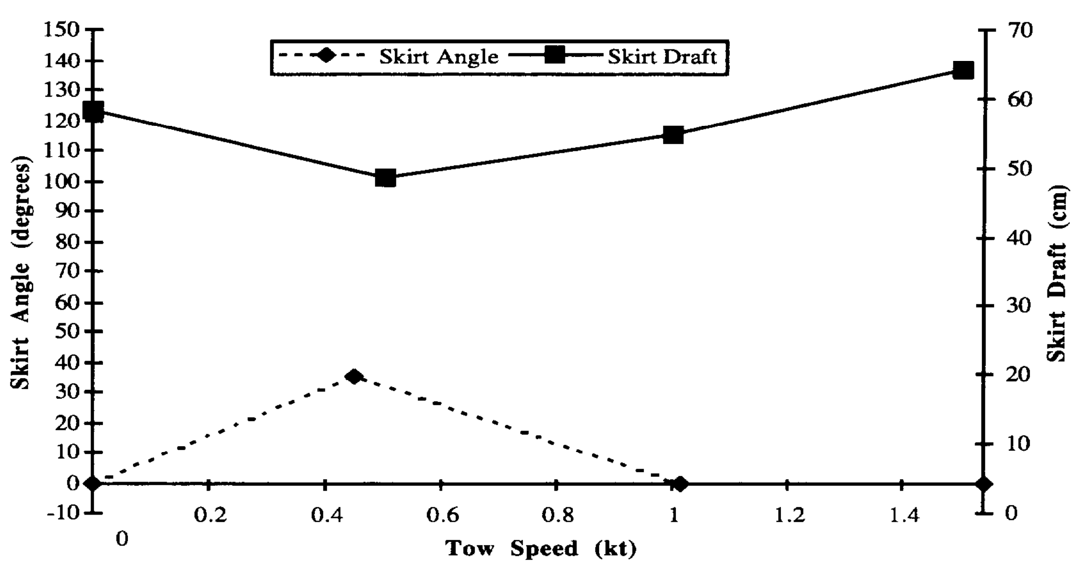


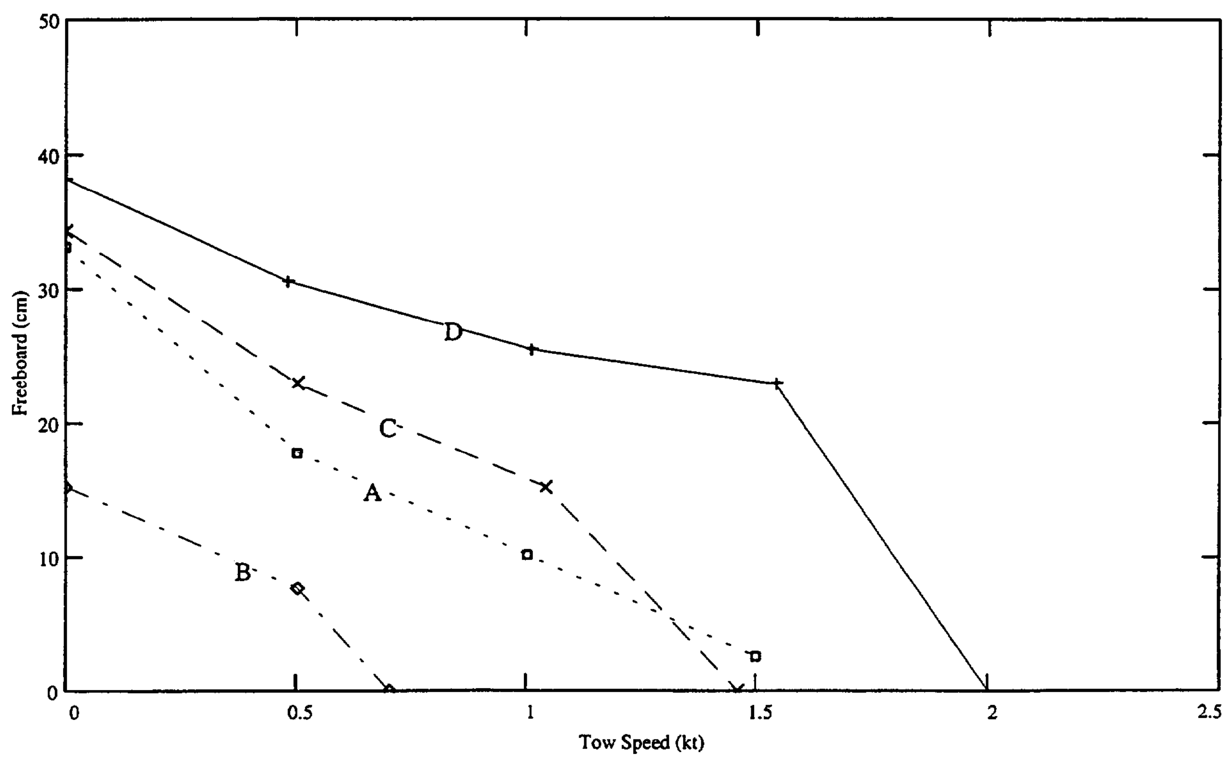
Figure 5.7 Auto Boom skirt attitude and draft at various tow speeds

5.2 Comparison of Boom Performance

After reviewing the behavior and test results of each boom separately, comparisons were made of all the test data recorded using the mean values. Table 5.1 summarizes the average value for each test parameter recorded remotely by the data loggers and manually during Phase 2 tests. All plots in this section use the mean values presented in Table 5.1. For consistency and for showing repeatability of test results, the same plots developed in the Phase 1 at sea tests were also plotted for this report: tow speed vs freeboard, tow speed vs skirt draft, tow speed vs tow force (both theoretical and measured), and tow speed vs B/W ratio.

5.3 Freeboard

For all four fire resistant booms tested, the freeboard under tow was reduced, some more significantly than others. Figure 5.8 is a plot of the estimated freeboard obtained from readings on video tape for all the booms at the tested tow speeds. In accordance with the draft ASTM standard for fire proof booms (presented in Appendix G), the minimum requirement for static freeboard in open water is 53 cm (21 in). None of the booms tested met this requirement. Rather, most of the booms only met the recommended freeboard for protected water, which is 26 cm (10 in). In addition, the standard does not provide any guidance on the relationship between tow speed and freeboard.

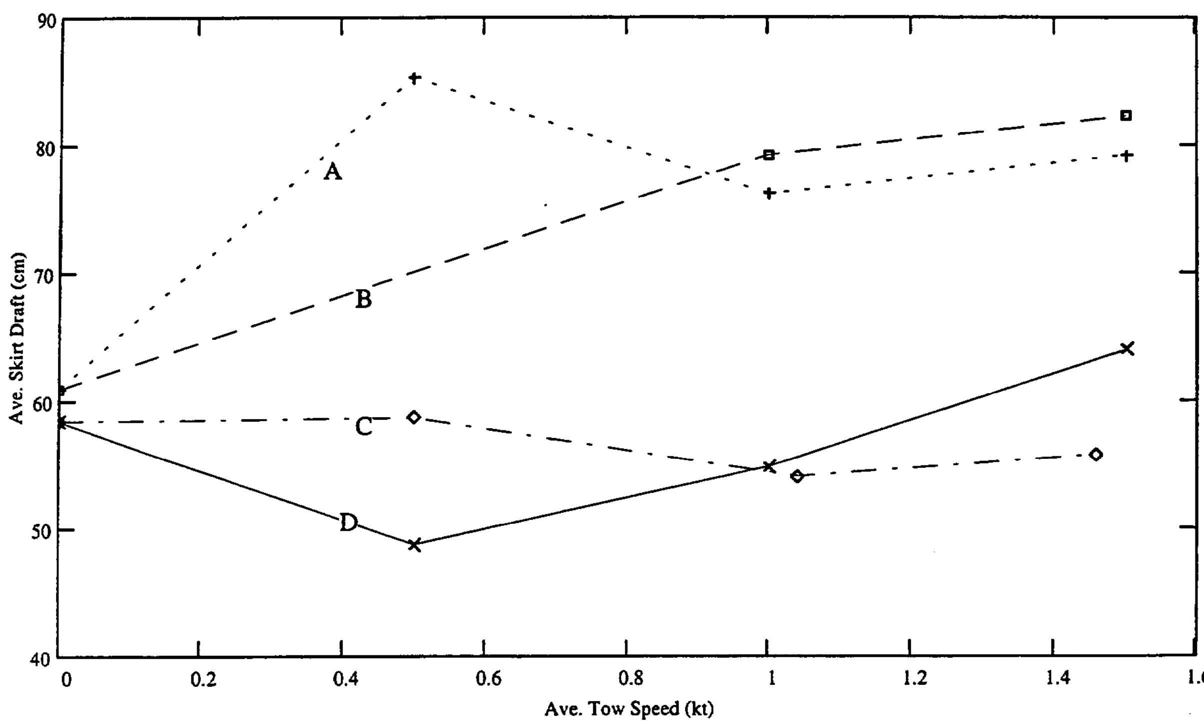


Key: A=Navy 3M Fire Boom, B= SeaCurtain FireGard, C= Applied Fabrics Pyroboom, D= Oil Stop Autoboom

Figure 5.8 *Comparison of estimated freeboard as a function of towing speed for fire resistant booms*

5.4 Skirt Draft

The relationship between tow speed and skirt draft is not as consistent as the relationship between tow speed and freeboard among the different booms tested. The boom with the most drastic change in skirt draft was the SeaCurtain FireGard, which submerged several feet below the water's surface at 1 knot. The other booms had fairly constant skirt depths, indicating that the skirt does not remain vertical because the decreasing freeboard should add draft with increasing tow speed if the skirt remains vertical. Also, the angle sensors indicated that the skirts were angled in or out of the apex. Figure 5.9 plots the skirt draft measurements for each fire resistant boom tested. The USCG Oil Stop measurements were included to represent the Auto Boom, which is basically the same design. The draft ASTM standard for fire resistant booms, included in Appendix G, propose a minimum skirt draft requirement for open water conditions of 66 cm (26 in). The 3M, SeaCurtain FireGard, and the Pyroboom all do not meet this requirement. However, the Auto Boom, if the assumption of similar designs is correct, would be the only boom which would have the recommended skirt depth for the operating tow speeds. This skirt depth is necessary in order to ensure the oil is contained in the apex of the boom and does not pass under the skirt at lower operating tow speeds.



Key: A=Navy 3M Fire Boom, B=USS42 Boom, C=Applied Fabrics Pyroboom, D=USCG Oil Stop Boom

***Figure 5.9** Comparison of average skirt depth measurements of fire resistant booms*

5.5 Tow Force

The average tow force for each boom is presented in Figure 5.10. These were the average tow forces recorded on the *Texas Responder* by the data logger. Unlike Phase 1, which tested booms that were very similar in design, the fire resistant booms tested were all unique. For the most part, excluding the SeaCurtain FireGard curve, the tow forces increased at an exponential rate as the tow speed increases. Comparisons were also made between the Auto Boom and the Pyroboom data at the same two speeds with and against the current and are shown in Figure 5.11. The Auto Boom tow forces against the current were approximately 1780 N (400 lb) more than the forces experienced with current at the same tow speed.

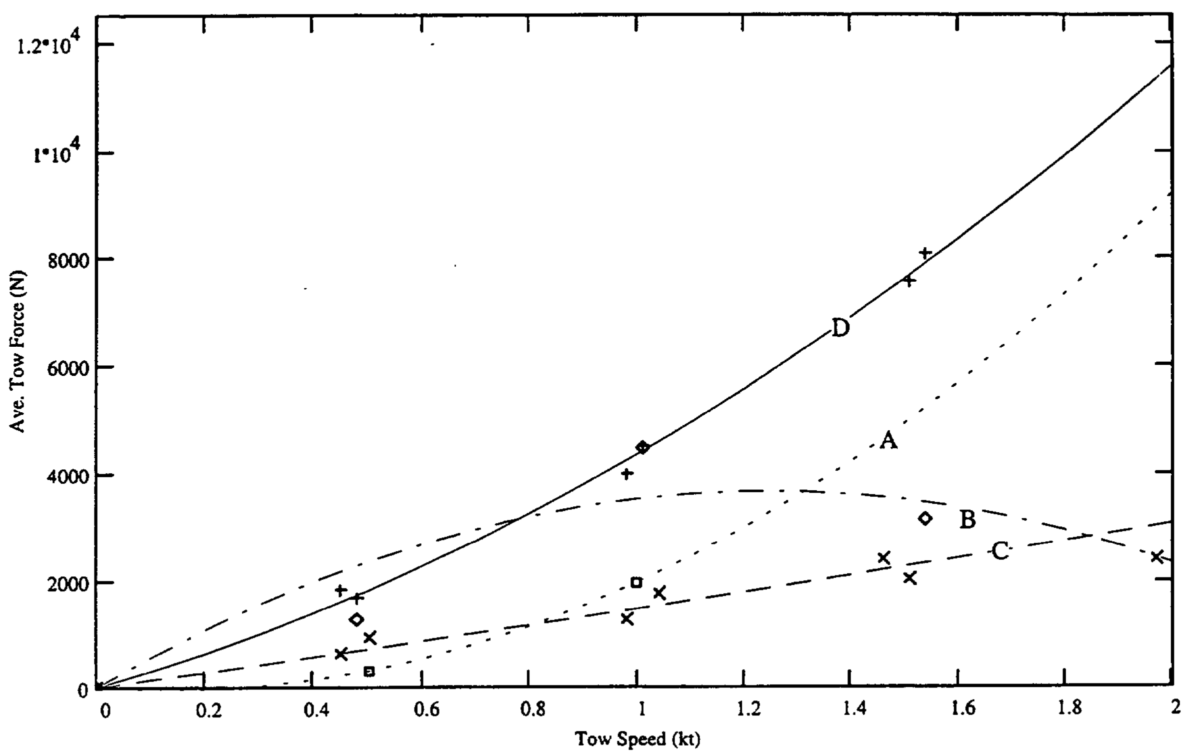


Figure 5.10 *Comparison of the average tow forces for fire resistant booms tested*

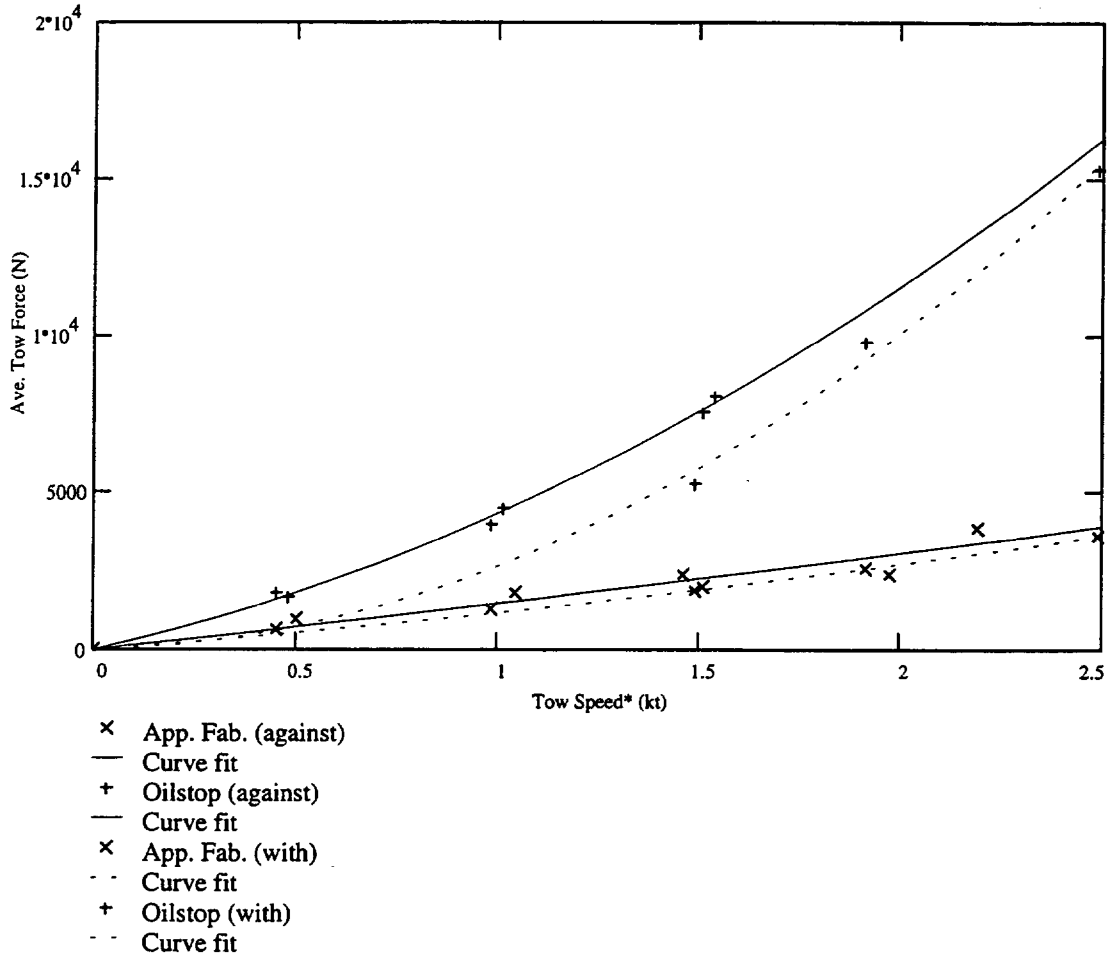
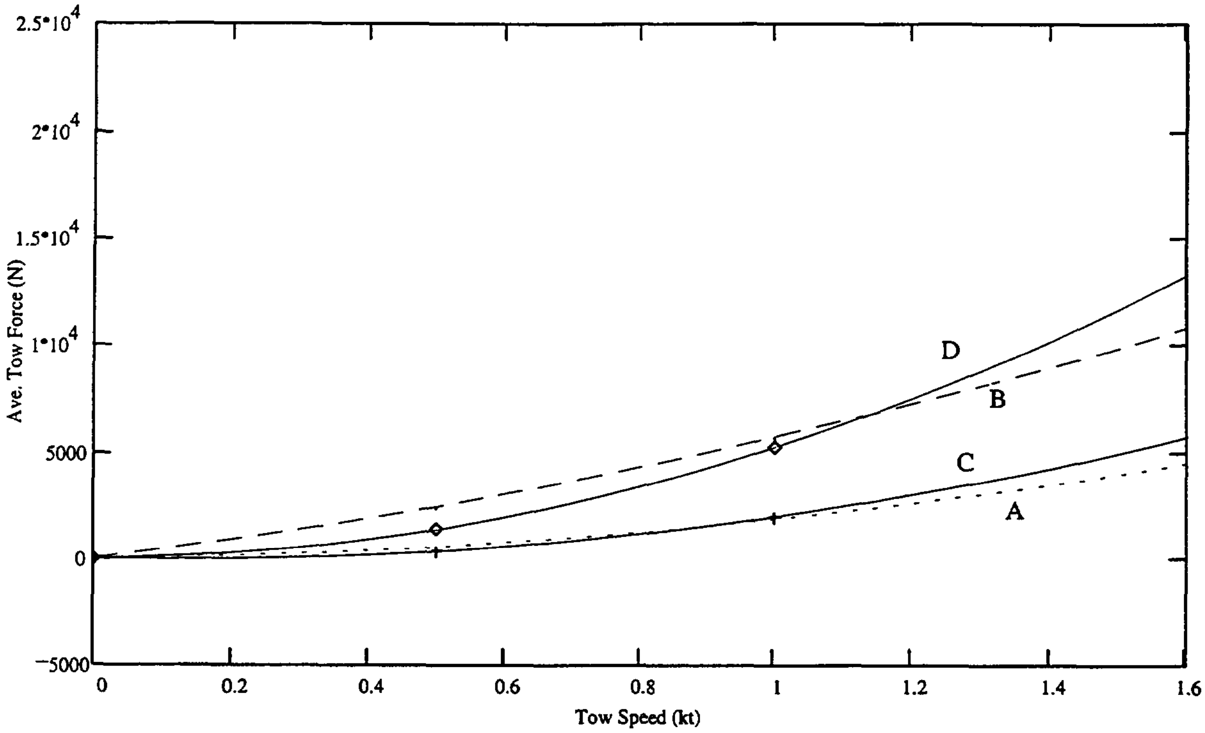


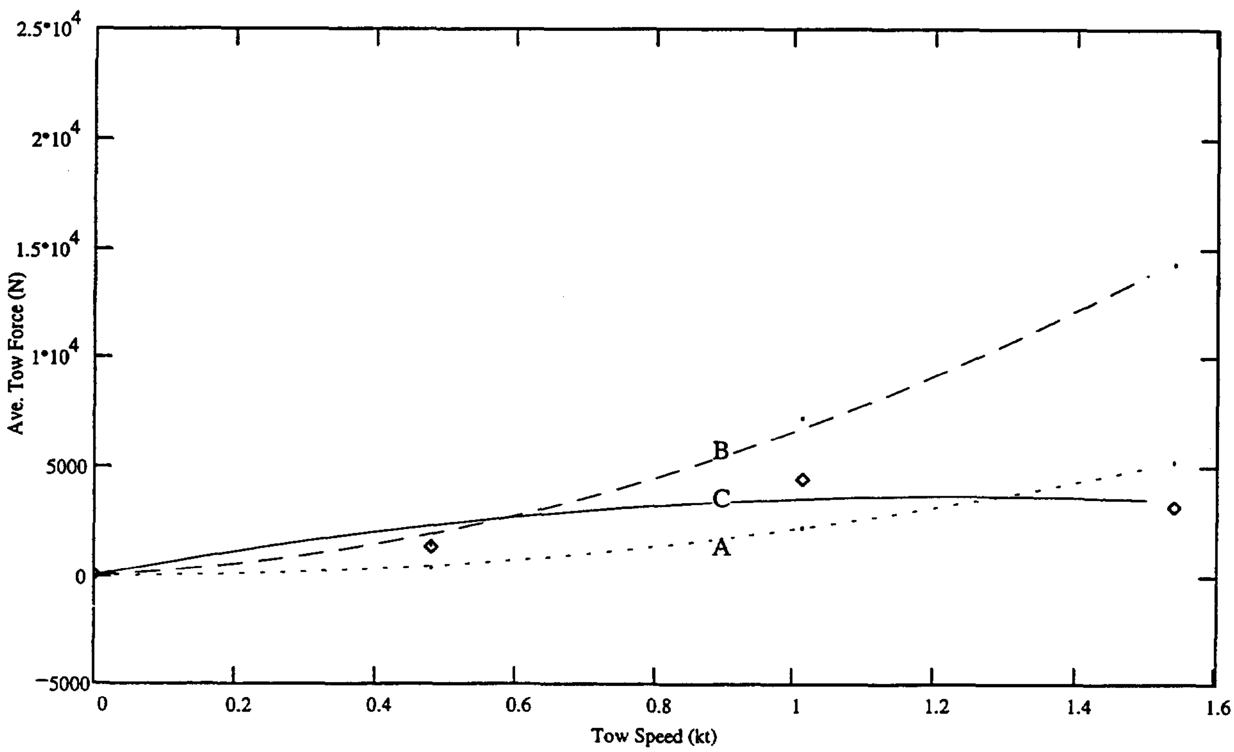
***Figure 5.11** Comparison of the Auto Boom and Pyroboom tow forces with and against the current*

The manual tow force readings for the opposite towing vessel, particularly those from the *Gulf Coast Responder*, were consistent with the electronic readings. These readings are a significant improvement from the Phase 1 test, which did not show any correlation between the tow forces on either end of the boom. Since the tow forces are relatively the same on either end, the assumption that half of the total drag force is equal to the tow force measured on one towing vessel is correct. This assumption was used in the previous tests when calculating the theoretical tow forces given by the World Catalog and International Tanker Owners Pollution Federation (ITOPF) drag force equations. The theoretical tow forces for the SeaCurtain FireGard and Auto Boom were calculated and plotted in comparison with the average tow forces measured during testing. The results from Phase 1 tests of the 3M Fire Boom are also included. The Pyroboom was not included since only 45 m (146 ft) of boom was towed using long tow lines. The gap ratio could not be determined accurately for this boom for comparison with the other fire resistant booms. Figures 5.12 through 5.14 are the plots of the theoretical and average tow forces. Appendix D lists the equations used for the World Catalog and ITOPF calculations.



Key: ITOPF Formula=A, World Catalog Formula=B, Ave. Tow Force=C, Max. Tow Force=D

Figure 5.12 *Comparison of theoretical and measured average tow forces for the Navy 3M Fire Boom*

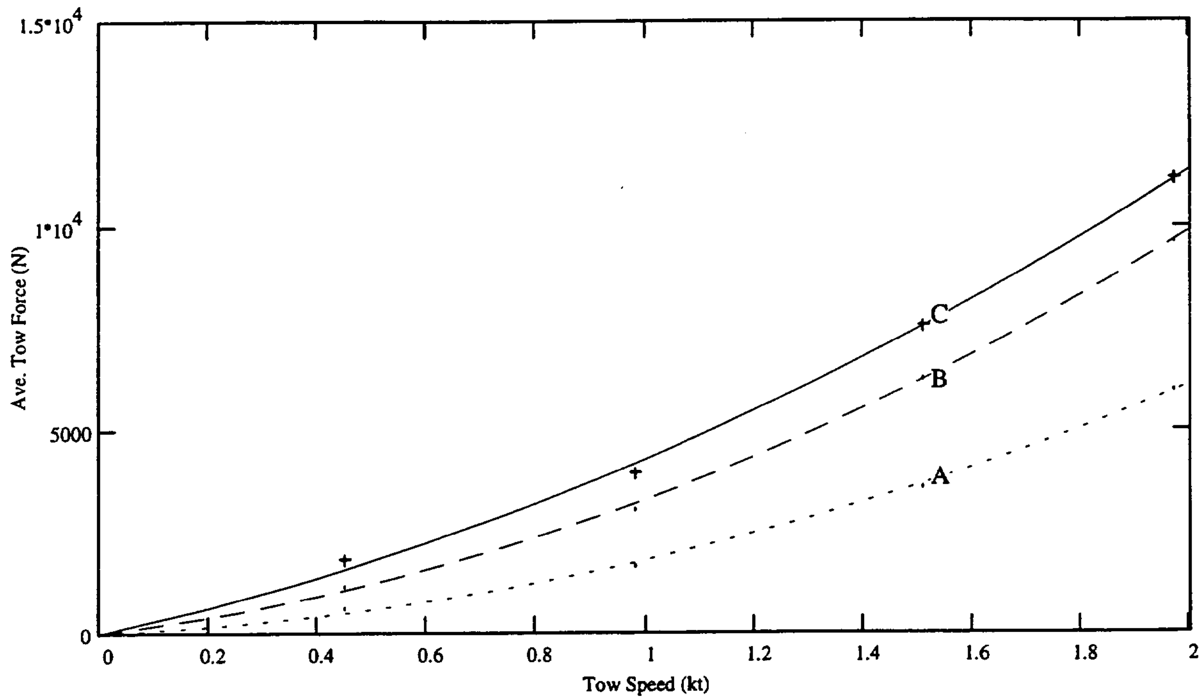


Key: ITOPF Formula=A, World Catalog=B, Ave. Tow Force=C

Figure 5.13 *Comparison of theoretical and measured average tow forces for the SeaCurtain FireGard boom*

Table 5.1 Summary of Averages of Test Data Collected

Test / Tow Dir.	Boom	Tow Speed (kt) Texas	Tow Speed (kt) Gulf	Sweep Width (nm) Gulf	Sweep Width (nm) Munson	Tow Force (N) Texas	Tow Force (N) Gulf/Mun.	Skirt Depth (cm)	Skirt Tilt (deg)	Freeboard (cm)
1	Autoboom	0.48	0.46	0.04035	x	1688	17508.2	no reading	27.72	30.48-38.10
against	SeaCurtain	0.48	x	x	0.046	1282.64	x	43.62	-4	0-7.62
2b	Autoboom	1.012	1.11	0.043	x	4488.21	3904.2	no reading	-0.0475	22.86-30.48
against	SeaCurtain	1.012	x	x	0.046	4458.94	x	141.77	-22.54	0
3	Autoboom	1.54	1.68	0.0412	x	8066.88	8063.29	no reading	-0.045	22.86
against	SeaCurtain	1.54	x	x	0.0467	3132.6	x	114.33	-14.0809	0
4/a	Pyroboom	0.5	x	x	0.0425	948.92	x	56.17	-0.045	15.24
5/a	Pyroboom	1.04	x	x	0.0422	1770.35	x	54.108	-14.0809	15.24
6/a	Pyroboom	1.46	x	x	0.0438	2390.16	x	4.6536	5.27689	planing
7/a	Pyroboom	2.19	x	x	0.044	3859.37	x	98.854	3.62199	planing
8	Autoboom	0.45	0.48	0.0375	x	1822.08	1113.4	no reading	3.4935	30.48-35.56
against	Pyroboom	0.45	x	x	0.0213	630	x	87.76	2.15978	15.24
9	Autoboom	0.98	1.07	0.037	x	3966.92	3955.8	no reading	-0.59208	~30.48
against	Pyroboom	0.98	x	x	0.0225	1265.92	x	79.87	-5.66663	10.16
10	Autoboom	1.51	1.48	0.042	x	7534.57	6892.52	3.534	2.070472	0
against	Pyroboom	1.51	x	x	0.023	2015.4	x	71.03	-6.17217	planing
11	Autoboom	1.97	1.98	0.0391	x	11122.42	13431.45	1.5236	4.722639	~7.62
against	Pyroboom	1.97	x	x	0.0212	2386.07	x	68.349	-6.90613	planing
12	Autoboom	1.49	1.52	0.0396	x	5282.86	5107.89	0.9495	4.78708	22.86
with	Pyroboom	1.49	x	x	0.0231	1848.72	x	79.09	-8.60163	10.16
13	Autoboom	1.91	2.03	0.0416	x	9779.68	11297.5	no reading	-62.289	~22.86
with	Pyroboom	1.91	x	x	0.0232	2577.47	x	28.65	-5.66656	planing
14	Autoboom	2.49	2.48	0.0398	x	15288.58	17586.49	no reading	-74.5114	0
with	Pyroboom	2.49	x	x	0.0236	3587.8	x	62.35	-4.58642	planing

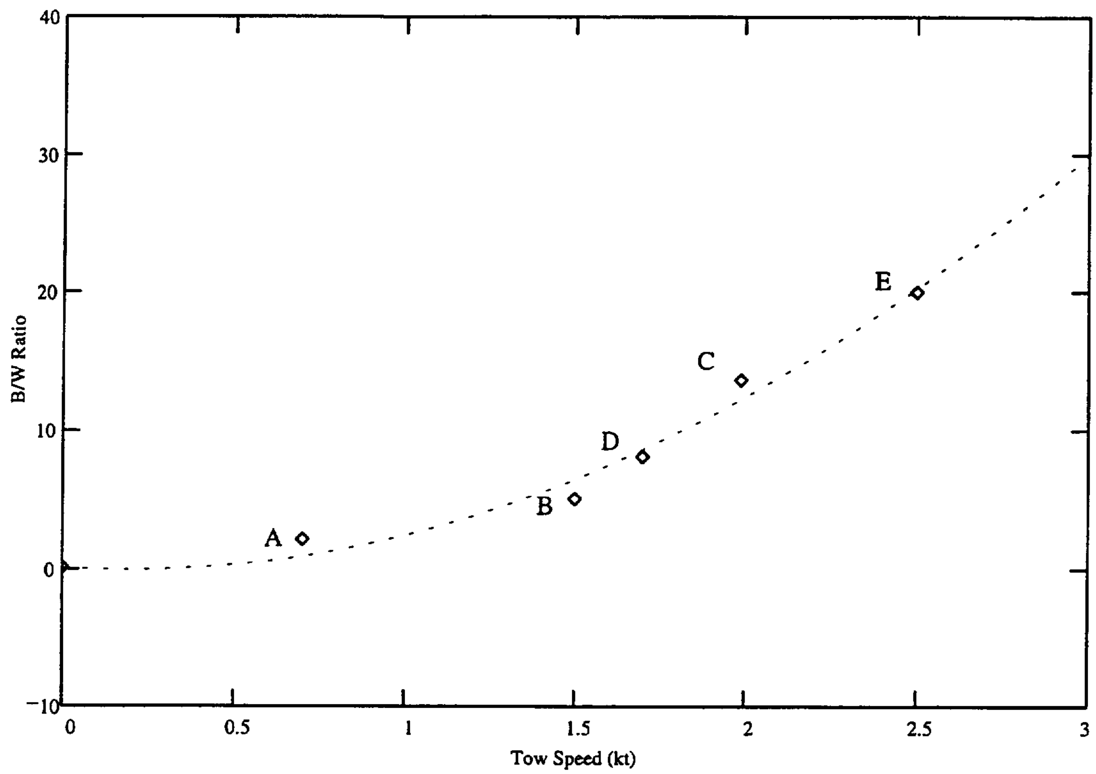


Key: ITOPF Formula=A, World Catalog Formula=B, Ave. Tow Force=C

***Figure 5.14** Comparison of theoretical and measured average tow forces for the Auto Boom*

5.6 Tow Speed at Submergence

The tow speed at submergence is defined as the tow speed at which the boom becomes submerged at the apex. In order to represent all the results of booms tested, a plot was created using the tow speed at submergence and the buoyancy to weight ratio of each boom. The Pyroboom is not included since a tow speed at submergence was not recorded. In addition, all booms tested in Phase I were included in this plot, except the Barrier Boom which never submerged. The new data points from Phase 2 seem to correlate with the earlier test results which show an exponential relationship between the B/W ratio and the tow speed at submergence (See Figure 5.15). According to the draft ASTM standard for booms, the recommended required B/W ratio for fire resistant boom is 3:1. If this ratio were to be used as the design criteria for booms, the resulting booms would not be able to be towed above 1 knot, which is below the normally encountered range of towing speeds (up to 1.5 kts) for containment operations. Therefore, a higher B/W ratio should be recommended which would result in booms that could withstand towing speeds of at least 2.0 knots prior to submergence. This B/W ratio would provide reserve buoyancy for wave conformance during containment operations.



Key: A=SeaCurtain FireGard, B= Navy 3M Fireboom, C=Oilstop Autoboom,
D=Navy USS42 Boom, E=USCG Boom

***Figure 5.15** Relationship of a boom's tow speed of submergence and its B/W ratio*

5.7 Boom Damage

Some of the booms suffered damage during deployment procedures or towing operations. This damage did not effect the results significantly, since tow forces and skirt drafts measured on both days of testing were fairly consistent for all of the booms.

The Navy 3M Fire Boom was deployed for the first time during the Phase 1 tests. While being launched, the material of the boom was scraped and scratched by the deck. Since then, the Navy has designed a container for launching the boom into the water so as to prevent damage to the surface of the boom. However, any boom material should be capable of being handled under normal operating conditions, i.e., sea state 4. While being towed, the Navy 3M Fire Boom connectors broke apart at the apex of the boom formation. This structural failure occurred after the boom had been towed at 1.5 knots for 10 minutes. Other connectors throughout the boom were also damaged, although they did not fail.

All the booms tested were damaged, usually during deployment or retrieval of the boom. Tears or holes were made in the fire resistant material or fabric and were visible in video footage (see Appendix F for the video results and descriptions). The MSRC study on fire resistant booms addresses this issue and evaluates the fire resistant materials available for use with containment booms (Burkes 1994).

6.0 References

ASTM (American Society of Testing and Materials). 1994. Standard Guide for the Selection of Booms in Accordance with Water Body Classification. Standard F1523. ASTM, Philadelphia, PA, 2 p.

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Sloan, S.L., K.R. Bitting, and A.B. Nordvik. 1994. Phase 1: Oil Containment Boom At Sea Performance Tests. Marine Spill Response Corporation, Washington, D.C. MSRC Technical Report Series 94-007, 85 p.

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Glossary[1]

apex (pocket) pocket formed at the downstream end of U, V, J, or W shaped configuration

ballast weight applied to the skirt to improve boom performance

boom floating mechanical barrier used to control the movement of substances that float

boom planing heeling over of a boom and loss of draft

boom section length of boom between tow end connectors

boom segment repetitive identical portion of the boom section

boom submergence (submarining) containment failure due to loss of freeboard

boom weight dry weight of a fully assembled boom section including end connectors

buoyancy chamber (floatation chamber) enclosed compartment of air or other buoyant material providing floatation for the boom

catenary configuration (U, J configuration) booming configuration formed by towing or anchoring each end of a length of boom, resulting in a characteristic U or J shape

conformance ability of a boom to maintain freeboard and draft when subjected to a given set of environmental conditions

containment mode placement of a boom to prevent free movement of a floating substance

deployment placing a boom in the water and making it operational

draft minimum vertical depth of the membrane below the water line

drag force the retarding force acting on a body moving through a fluid parallel and opposite to the direction of motion

end connector device permanently attached to the boom used for joining boom sections to one another or to other accessory devices

floatation portion of a boom that provides buoyancy

freeboard minimum vertical height of the boom above the water line

gap ratio sweep width divided by boom length

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[1] All terms and definitions unless otherwise indicated are taken from ASTM standard F 818-93 "Standard Terminology Relating to Spill Response Barriers"

gross buoyancy weight of fresh water displaced by the boom totally submerged

gross buoyancy to weight ratio gross buoyancy divided by boom weight

height sum of draft and freeboard

inflatable boom boom that uses inflated gas-filled chambers as the floatation

internal floatation floatation element located within the boom membrane

maximum draft maximum vertical dimension of boom below the water line

overall height maximum vertical dimension of the boom

performance ability of a boom to contain or deflect oil under a given set of environmental conditions

pressure inflated inflatable boom that required pressurized gas for its floatation

reserve buoyancy gross buoyancy minus boom weight

reserve buoyancy to weight ratio reserve buoyancy divided by boom weight

self-inflating boom that automatically inflates as it is deployed

skirt continuous portion of the boom below the floats

solid floatation boom that uses solid buoyant material for the floatation element

splashover oil splashing over a boom's freeboard

stability resistance to overturning moment

sweeping mode movement of a boom relative to the water for the purpose of controlling or collecting a floating substance

sweep width (swath) width intercepted by a boom in collection mode, the projected distance between the ends of a boom deployed in a U, V, or J configuration

tensile strength resistance to lengthwise stress, measured (in force per unit of cross-sectional area) by the greatest load pulling in the direction of length that a given substance can bear without tearing apart (Webster 1988)

tension member any member that carries horizontal (axial) tension loads imposed on the boom

towing transporting a boom from one place to another by pulling from one end

Appendix A

Test Site Location

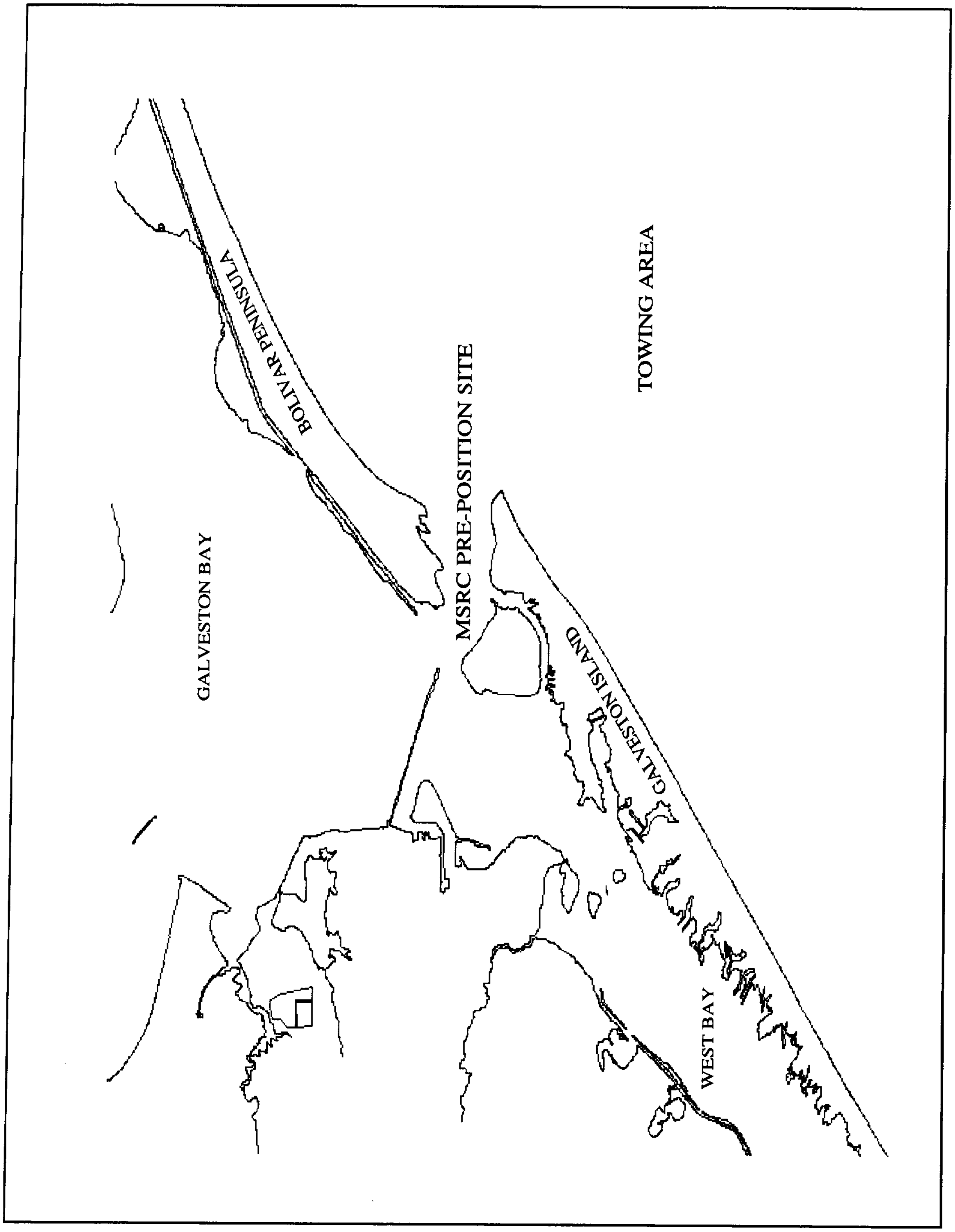


***Figure A.1** Galveston Bay test site location*

Appendix B

3M Fire Boom, SeaCurtain FireGard Boom, Applied Fabric Technologies Pyroboom, And Oil Stop Inc. Auto Boom Fire Model Manufacturer's Technical Descriptions

B.1 Navy 3M Fire Boom Description

The following boom design details are summarized from 3M product literature:

- The floatation core for each boom element is actually comprised of several shorter, columnar segments of "ceramic foam. The short segments of foam are stacked end to end and sleeved with a stainless steel "sock" to ultimately form a standard flotation unit, approximately 7 feet long.

- The foam is produced under a proprietary process involving volcanic ash and select oxides. While the resulting product is capable of withstanding temperatures on the order of 2100°F, it cannot handle the thermal stress induced by wave splash. As a consequence, the core material is often broken into many smaller pieces. There is no significant loss in flotation, however, as the particles are confined by the wire mesh.

- The foam material has a density of 10 to 12 pounds per cubic foot. As such, the core makes up a major part of the boom weight, approaching 80 percent of the total weight for an 18-inch boom.

- Each boom unit terminates with a metal "clip". This clip has been the subject of extensive development as it must transfer tensional load into the NEXTEL fabric and wire mesh and also serve as a coupling mechanism between elements. The system is based around a captive tongue and groove configuration with shear pins providing a mechanical look once the two pieces are aligned. The coupling has no flexibility; all movement of the boom in response to wave action must come from the limited flexibility of the "stacked" flotation core and the fabric/mesh transition area between the core and the end clip.

Table B.1 Navy 3M Fire Boom manufacturer specifications

Boom Type	Fire containment (18")
Cost $/m ($/ft)	886 (270)
Freeboard cm (in)	37 (14.5)
Draft cm (in)	70 (27.5)
Standard Length m (ft)	15.2 (50)
End Connectors	Hinged plate & pin
Skirt Material	Reinforced PVC
Floatation	CS-S-Ceramic
Weight kg/m (lb/ft)	25.3 (17)
Res. Buoyancy kg/m (lb/ft)	108 (72.6)
Reserve Buoyancy /wt	4.3:1
Water Line Beam cm (in)	37 (14.6)
Vertical CG cm (in)	37 (14.6)
Ballast Material	10 mm (3/8 in) galvanized chain
Ballast Weight kg/m (lb/ft)	3.7 (2.5)
Tension Member1/ Strength$_1$ N (lb)	Chain 47,000 (10,600)
Tension Member$_2$/Strength$_2$ N (lb)	Fabric 231,000 (52,000)
Fabric Tear Strength kg (lb)	68 (150)
Storage Volume m^3/m (ft^3/ft)	0.3 (3.2)
Operating Environment	Harbor-Ocean
Sea State	2
Tow Speed (knots)	0.5 - 0.75
Personnel Required	2
Deployment	Towed from tray

B.2 SeaCurtain FireGard Boom Systems Description

The following text was provided by Kepner Plastics Fabricators, Inc.

SeaCurtain FireGard Boom Systems are oil-fire resistant boom systems constructed of high temperature Thermotex refractory fabric covers over a continuous, heavy-gauge stainless steel erecting coil.

The heavy-duty polyurethane coated polyester fabric skirt and galvanized Hi Test chain ballast/tension system are supported by continuous built-in reserve Polycell™ high temperature and Resistex foam flotation. Because of multiple layers of flotation, the boom is unsinkable and not dependent on pressurized air. No auxiliary equipment other than the storage reel is needed to effect operating or storage configuration of the boom system.

The coating on the refractory fabric provides good abrasion resistance for handling and will burn away at about 600°F when used in oil fire containment. The boom is fully operational in temperatures from -40°F to +2,300°F. FireGard Boom Systems have been satisfactorily tested in continuous 24-hour diesel burn fires at 2,300°F at test sites in Alaska and Texas. If any of the refractory covers should become damaged in operations, they are readily and very easily replaceable at a fraction of the cost of new boom.

Standard flotation chamber diameters are 8", 11", 14" and 18", and skirt length is generally about 1.5 times the float diameter. Both float diameter and skirt length can be varied to meet customer requirements. To ensure highest performance of the boom, the chain ballast also operates as a bottom tension member and is over 30% of the total weight of all models of FireGard Boom.

Operating freeboard is approximately 85% of the float diameter. Gross tensile strength is very high. The FireGard Boom System is quickly and easily deployed form the reel for use under all conditions suitable for spill containment and recovery operations. The boom requires some manual assistance to assure proper compaction and winding back onto the reel during recovery, but provides one-man high speed deployment.

FireGard Boom Systems have no environmentally damaging components, and all parts of the booms system remain intact and fully recoverable after in-situ burning use.

The design and rugged construction of the boom provides sweeping and skimming boom capabilities and superior articulation and surface conformance in containment operations.

Table B.2 SeaCurtain FireGard Boom manufacturer specifications

Description

Flexible, containment boom system designed to with stand extended exposure to oil fires at over 2,000°F (1,100°C). Automatic float chamber expansion enables high speed boom deployment from storage reel by a single operator. Refractory covers are easily replaceable, if damaged.

Materials

Flotation elements:	Self-inflated float chambers and multiple layers of Resistex closed-cell foams
Freeboard:	Double layered Thermotex™ refractory fabric covers over a continuous stainless steel coil and protected, flexible floatation elements
Skirt:	100% polyurethane Kepelastex or PVC Keptex coated polyester or nylon fabric
Ballast:	Galvanized steel chain
Tension:	Tensile strength provided by combination bottom chain and boom fabric

Specifications

Color:	High-visibility yellow
Flotation shape:	Cylindrical floats
Flotation size:	20, 28, 36, and 45 cm diameters available
Freeboard:	18 to 42 cm
Standard length:	76 cm
Draft:	33 to 65 cm
Weight:	2 to 6 kg/m
End connectors:	Quikconnect (or build to suit)
Tensile strength:	6,000 to 13,000 kg
Fabric grab:	3,850 N/ 5 cm or more
Fabric tear:	700 N or more
Storage volume:	0.023 - 0.056 m^3/m

Operation

Towing speed:	Over 10 kt
Sweeping speed:	Over 1 kt
Temperature - Low:	-60°F (-51°C)
- High:	160°F (71°C)
Personnel required:	1 to deploy, 2 to 4 to recover (depending on model, type and size of recovery equipment)
Deployment:	Manually or mechanically (booms self-inflate while being deployed)
Recovery/Storage:	Manually or mechanically (booms require assistance to control compaction while being rewound)

B.3 Design Criteria and Development History of Pyroboom

The following information was written and provided by the manufacturer of the Pyroboom; Applied Fabric Technologies, Inc.

Applied Fabric Technologies, Inc. of Orchard Park, New York has been developing fire proof boom for in-situ burning since 1983 when Globe International, its predecessor, was approached by Exxon Production Research Company to submit an idea for a fireproof boom for potential use on the North Slope of Alaska. Exxon and others were required by Alaska Department of Environmental Conservation to have a fire boom on hand to conduct in-situ burning if they were to continue offshore drilling in Alaska.

Exxon took the novel approach of asking boom producers to submit ideas and proposals for a sample fire boom for which the vendor would be paid. The results of their tests would be proprietary to Exxon, but the vendors were allowed to attend the tests of their own products.

The approach that Globe took was to invent materials and combinations of materials that would work for the required burn duration of 24 hours, but were still formed in a proven boom design. Pyroboom was fashioned after the highly successful Globeboom product in general arrangement and utilized unique refractory materials in those places where standard boom materials would not work.

The system design criteria were:

- The boom had to have a size and shape that was familiar to current users.
- The boom had to be tough and durable both before and after burning.
- There had to be some salvage value after the fire, i.e., modular construction that could be rebuilt and put back into service.
- The boom had to be able to stand up to a 24 hour burn and maintain structural integrity.
- The boom had to maintain its standard configuration when put into water without gaining weight through wicking or absorbing water or oil. Moreover, while in use it had to exhibit normal sea-keeping characteristics and be recoverable in a usable fashion.

The refractory components design criteria were:

- Withstand the wide variation in temperatures associated with a 24 hour burn, and
- Possess the tensile, tear abrasion strengths of conventional boom material.

The flotation design criteria were:

- Very long term storage life,

- Zero maintenance, and
- Withstand the wide variations in temperatures associated with a 24 hour burn.

Previous designs illustrated that barriers which relied on a wicking refractory cover for heat protection were not feasible. They gained too much weight and were not usable after the first few hours of use due to water logging. While they were successful to a degree in fresh water, their operation in salt water was limited by a barrier of salt crystals which reduced the flow of cooling water to a trickle. The same was the case when oil was present. Steel float designs using air filled chambers were bulky and not seaworthy. Our goal was to address these shortcomings with a boom that could be used as a conventional boom when necessary but was still fire proof. In this way, we would possess all of the seaworthiness of a regular boom while meeting the requirements for a 24 hour fire boom.

Our unique, patented refractory fabric utilizes a blend of monel wire and Fiberfax yarn and meets tensile, flex and abrasion requirements. The silicone rubber coating eliminated any chance of water logging and held bind the Fiberfax yarns together with the wire warp and composite fill materials. Flex tests of the warp indicated that the fabric could sustain several hundred thousand flex cycles before failure due to fatigue. Tensile strength approximated that of the Oilfence fabric and elongation was nil due to the wire members.

The flotation was simple. Spun stainless steel shells with glass foam would be very tough and completely non water absorptive while at the same time providing positive buoyancy without chance of failure or burn through. Initially, we overdid this with 16 gage Stainless Steel. We have since modified this to 22 gage. These floats provided all of the buoyancy needed while protecting the refractory material from the rigors of boom handling on the deck of an OSV or OSRV.

The balance of the design incorporated standard fabrics and connectors for those portions of the barrier that would not see fire.

For the Exxon trial, we made 150 feet of barrier fabric. A 30 foot length was sent to Texas A&M for a tank test burn test. We were able to obtain photos and movies of the burn but the balance of the technical data remains proprietary to Exxon. We do know that, at times, temperatures of 2,400 degrees F were recorded at the top edge of the boom. Internal temperatures in the floats were about 500 degrees F and everything below the water line remained like new.

The tests were open burning of 6-8 hours at 3 gallons per minute of diesel fuel. The boom was inspected after each burn cycle. The tests were run for a total burn time of 24 hours. The burn tests were discontinued after 24 hours because no further deterioration was noted.

The second set of trials were done for Shell Western E&P in Alaska. The test report is a matter of public record and is also included with this proposal. In this test, we provided the barrier at no charge and SWEPI conducted the entire test with their consultant Mr. Al Allen. Wave tank tests were also done in Friendswood, Texas at the Shell Test Tank. As a result of the tank test we changed the below surface barrier to a bottom tension member that is more flexible than the fabric originally selected. This latest generation design, as tested this past month in the Gulf of Mexico, is the result of everything learned in both the test tank tests and the burn tests.

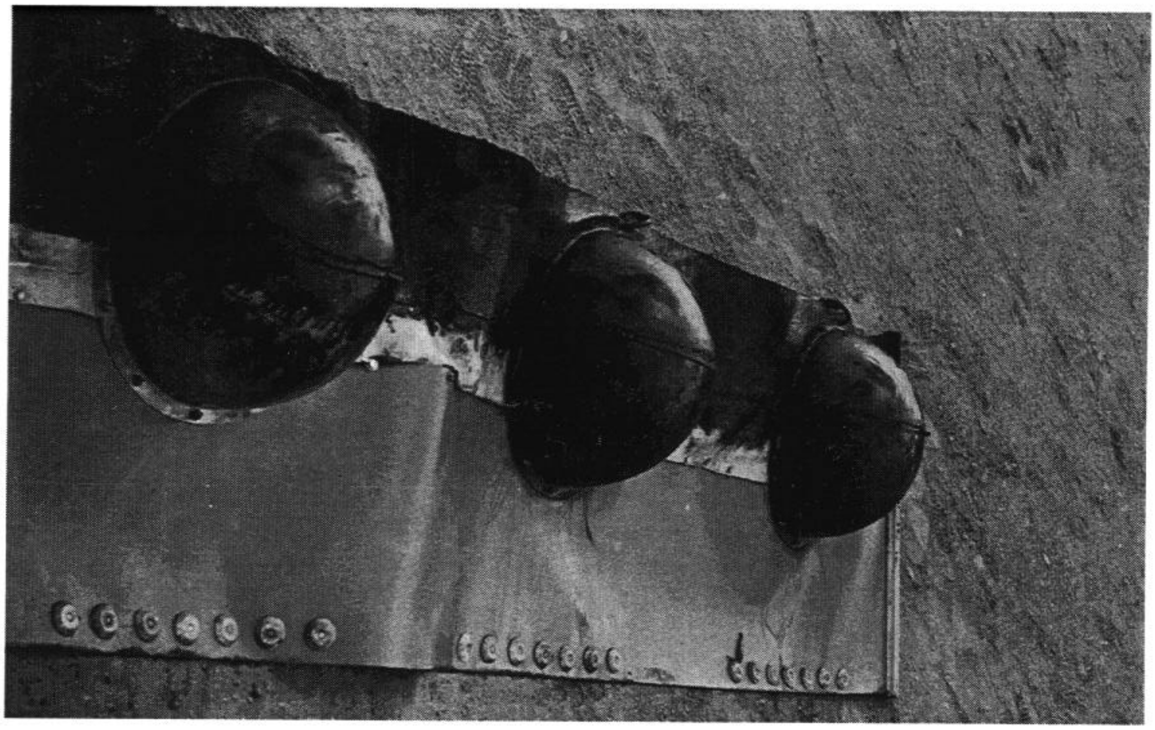


***Figure B.1a** Pyroboom after burn*

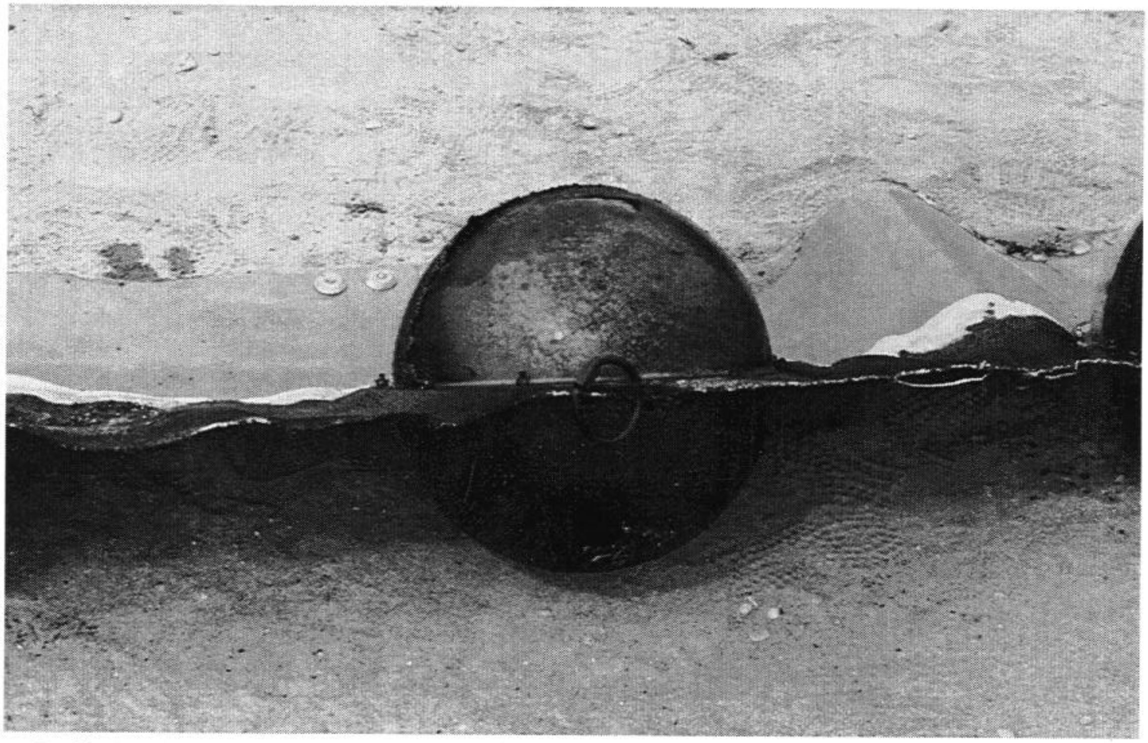


***Figure B.1b** Pyroboom after burn*

B.4 Oil Stop, Inc. Auto Boom Fire Model

The following information was taken directly from the manufacturer's specifications.

Oil Stop, Inc.'s Inflatable Fire Boom rolls up on a reel for compact storage. The Auto Boom technology creates a heat transfer with the water which reduces the internal temperature of the Fire Boom. This process, combined with high temperature insulating fabrics, makes it possible for the boom to sustain high temperatures for extended periods. The Auto Boom Fire Model is designed for rapid deployment where in-situ burning of oil is employed. The Auto Boom Fire Model is covered under U.S. Patent Nos. 5,022,785; 5,195,844; and 5,312,204 and other patents pending.

Table B.3 Oil Stop Auto Boom manufacturer's specifications

Specification	River Boom	Harbor Boom	Bay Boom	Offshore Boom*
Float Diameter	8 in.	12 in.	14 in.	17 in.
Skirt Length	10 in.	18 in.	22 in.	25 in.
Standard Section Lengths	50 ft.	50 ft.	50 ft.	50 ft.
Ballast Weight per Foot	1 lbs	1.4 lbs	2.4 lbs	2.4 lbs
Combined Tensile Strength (Boom Plus Chain)	21,000 lbs	35,000 lbs	41,500 lbs	60,750 lbs
Inflation Pressure @ 70°F	1 psi	1 psi	1 psi	1 psi
Working Temperature Range	-50°F to 2,400°F	-50°F to 2,400°F	-50°F to 2400°F	-50°F to 2,400°F
Towing Speed	12 knots	10 knots	8 knots	6 knots
Hydrocarbon Resistance	Excellent	Excellent	Excellent	Excellent
Weather Resistance	Excellent	Excellent	Excellent	Excellent
U.V. Resistance	Excellent	Excellent	Excellent	Excellent

* Boom Tested During This Series of Tests

Appendix C

Weather Buoy Data

Table C.1 Weather buoy data for August 30-31, 1994 test runs

Date	Time	Significant Wave Ht (ft)	Wave Period (sec)	Max. Wave Ht (ft)
8/30/94	1107	0.814	3.93	1.308
	1135	0.837	3.89	1.428
	1203	0.842	3.88	1.398
	1230	0.870	3.95	1.318
	1257	0.855	3.95	1.567
	1325	0.909	3.96	1.637
	1352	0.965	4.06	1.877
	1420	0.958	4.02	1.967
	1447	0.904	4.08	1.528
	1524	0.914	4.17	1.538
	1551	0.946	4.28	1.637
	1619	0.996	4.14	2.246
	1649	1.028	4.27	1.627
	1731	1.110	4.45	1.767
	1758	1.045	4.52	1.877
	1826	1.041	4.37	1.667
	1853	1.053	4.44	1.697
	1921	1.028	4.38	1.817
	1948	1.085	4.34	1.897
	2015	1.016	4.62	2.157
	2114	1.048	4.39	1.957
	2141	1.053	4.24	1.687
	2209	0.982	4.29	1.807
	2236	1.078	4.40	2.077
	2304	1.115	4.26	2.396
	2331	1.081	4.26	1.867
	2358	1.050	4.33	1.597

Table C.1 Weather buoy data for August 30-31, 1994 test runs (cont.)

Date	Time	Significant Wave Ht (ft)	Wave Period (sec)	Max. Wave Ht (ft)
8/31/94	0026	1.157	4.51	2.366
	0053	1.010	4.36	1.807
	0121	1.067	4.39	1.707
	0148	1.041	4.34	1.727
	0216	1.074	4.38	2.276
	0243	1.138	4.31	2.117
	0310	1.129	4.32	2.007
	0338	1.125	4.31	1.837
	0405	1.154	4.40	1.757
	0432	1.063	4.36	1.757
	0500	1.149	4.50	1.887
	0527	1.043	4.29	1.967
	0555	1.107	4.45	1.987
	0622	1.097	4.43	1.947
	0649	1.111	4.28	1.947
	0717	1.154	4.45	1.977
	0744	1.081	4.35	2.196
	0811	1.143	4.61	2.037
	0839	1.082	4.43	1.947
	0906	1.125	4.64	1.747
	0934	1.247	4.80	2.047
	1001	1.140	4.50	2.266
	1028	1.109	4.40	1.987
	1056	1.139	4.69	2.356
	1123	1.117	4.83	2.107
	1151	1.128	4.65	1.867
	1240	1.124	4.57	1.947
	1307	1.187	4.74	1.907
	1349	1.098	4.67	2.097
	1417	1.072	4.63	1.877
	1445	1.151	4.89	2.007
	1512	1.196	4.96	2.107
	1553	1.174	4.79	1.907
	1633	1.184	4.99	1.957

DEFINITIONS OF SEA CONDITIONS: WAVE AND SEA FOR FULLY ARISEN SEA

Sea — General		Wind				Sea								
Sea State	Description	(Beau fort) Wind force	Description	Range (knots)	Wind Velocity (knots)	Wave Height (ft) Average	Wave Height (ft) Significant	Wave Height (ft) Average of One-Tenth Highest	Significant Range Periods [sec]	Periods of maximum Energy of Spectra $T_{max}=T_c$	Average Period $\bar{T}_z$	Average Wave-length $\bar{L}_w$ [ft unless otherwise indicated]	Minimum Fetch (nautical miles)	Minimum Duration [hr unless otherwise indicated]
0	Sea like a mirror	U	Calm	1	0	0	0	0	—	—	—	—	—	—
	Ripples with the appearance of scales are formed, but without foam crests	1	Light airs	1-3	2	0.04	0.01 0.01	0.09	1.2	0.75	0.5	10 in	5	18 min
1	Small wavelets; short but pronounced crests have a glossy appearance, but do not break.	2	Light breeze	4-6	5	0.3	0.5	0.6	0.4-2.8	1.9	1.3	6.7 ft	8	39 min
	Large wavelets; crests begin to break. Foams of glossy	3	Gentle	7-10	8.5	0.8	1.3	1.6	0.8-5.0	3.2	2.3	20	9.8	1.7
	appearance. Perhaps scattered with horses.		breeze		10	1.1	1.8	2.3	1.0-6.0	3.2	2.7	27	10	3.4
2					12	1.6	2.6	3.3	1.0-7.0	4.5	3.2	40	18	3.8
	Small waves, becoming larger;	4	Moderate		13.5	2.1	3.3	4.2	1.4-7.6	5.1	3.6	52	24	4.8
3	fairly frequent white horses.		breeze	11-16	14	2.3	3.6	4.6	1.5-7.8	5.3	3.8	59	28	5.2
					16	2.9	4.7	6.0	2.0-8.8	6.0	4.3	71	40	6.6
					18	3.7	5.9	7.5	2.5-10	6.8	4.8	90	55	8.3
4	Moderate waves, taking a more	5	Fresh	17-21	19	4.1	6.6	8.4	2.8-10.6	7.2	5.1	99	65	9.2
	pronounced long form; many white horses are formed (chance of some spray).		breeze		20	4.6	7.3	9.3	3.0-11.1	7.5	5.4	111	75	10
5					22	5.5	8.8	11.2	3.4-12.2	8.3	5.9	134	100	12
	Large waves begin to form;	6	Strong	22-27	24	6.6	10.5	13.3	3.7-13.5	9.0	6.4	160	130	14
6	white crests are more extensive everywhere (probably some spray).		breeze		24.5	6.8	10.9	13.8	3.8-13.6	9.2	6.6	164	140	15
					26	7.7	12.3	15.6	4.0-14.5	9.8	7.0	188	180	17
					28	8.9	14.3	18.2	4.5-15.5	10.6	7.5	212	230	20
	Sea heaps up, and white foam from breaking waves begin to be blown in	7	Moderate gale	28-33	30	10.3	16.4	20.8	4.7-16.7	11.3	8.0	250	280	23
7	streaks along the direction of the wind (Spindrift begins to be seen).				30.5	10.6	16.9	21.5	4.8-17.0	11.5	8.2	258	290	24
					32	11.6	18.6	23.6	5.0-17.5	12.1	8.6	285	340	27
					34	13.1	21.0	26.7	5.5-18.5	12.8	9.1	322	420	30
7					36	14.8	23.6	30.0	5.8-19.7	13.6	9.6	363	500	34
	Moderate high waves of greater length; edges of crests break into spindrift. The	8	Fresh gale	34-40	37	15.6	24.9	31.6	6-20.5	13.9	9.9	376	530	37
	foam is blown in well-marked streaks				38	16.4	26.3	33.4	6.2-20.8	14.3	10.2	392	600	38
	along the direction of the wind. Spray affects visibility.				40	18.2	29.1	37.0	6.5-21.7	15.1	10.7	444	710	42
8					42	20.1	32.1	40.8	7-23	15.8	11.3	492	830	47
	High waves. Dense streaks of foam along the direction of the wind. Sea	9	Strong gale		44	22.0	35.2	44.7	7-24.2	16.6	11.8	534	960	52
	begins to roll. Visibility affected.			41-37	46	24.1	38.5	48.9	7-25	17.3	12.3	590	1110	57
9	Very high waves with long over-hanging crests. The resulting foam is in				40	26.2	41.9	53.2	7-26	18.1	12.9	650	1250	63
	great patches and is blown in dense	10	Whole * gale	48-55	50	28.4	45.5	57.8	7-27	18.8	13.4	700	1420	69
	white streaks along the direc-tion of the wind. On the whole, the surface of the				51.5	30.2	48.3	61.3	8-28.2	19.4	13.8	736	1560	73
	sea takes on a white appearance. The rolling of the sea becomes heavy and shocklike. Visibility is affected				52	30.8	49.2	62.5	8-28.5	19.6	13.9	750	1610	75
	Exceptionally high waves. Sea completely covered with long white	11	Storm *	56-63	56	35.7	57.1	72.5	8.5-31	21.1	15	910	2100	88
	patches of foam lying in direction of wind. Everywhere edges of wave crests are blown into froth. Visibility affected.				59.5	40.3	64.4	81.8	10-32	22.4	15.9	985	2500	101
	Air filled with foam and spray. Sea white with driving spray. Visibility very seriously affected.	12	Hurricane *	64-71	>64	>46.6	74.5	94.6	10-35	24.1	17.2	—	—	—

* For hurricane winds (and often whole gale and storm winds) required durations and reports are barely attained. Seas are therefore not fully arisen.
† Revised December 1964 by L. Moskowitz and W Pierson. Used courtesy of The Navy Oceanographic Office.

Appendix D

Theoretical Equations And Calculations Of Tow Force

From the World Catalog of Spill Response Products (Schulze 1991):

$$\mathbf{T_a=0.5\ L\tau C_d\rho_a f V_a^2}$$

T_a= tension due to wind, lbs
L=length of boom, ft
τ = tension parameter due to gap ratio
C_d=drag coefficient, dimensionless, assume 1.5
ρ_a=fluid density (for air)
f= boom freeboard, ft
V_a=wind speed ft/sec

$$\mathbf{T_w=0.5L\tau C_d\rho_w d(V_w+0.5*(H_s)^{1/2})^2}$$

T_w=tension due to waves and current, lbs
L= length of boom, ft
τ= tension parameter due to gap ratio
C_d= drag coefficient, dimensionless, assume 1.5
ρ_w=fluid density (for air)
d= boom draft, ft
V_w= wind speed, ft/sec
H_s= wave height in ft

The total drag force on the boom is therefore given by:

$$\mathbf{D=\ 2(T_a\ +\ T_w)}$$

From ITOPF publication (ITOPF, 1981):

$$F_c=26*A_sV_c^2$$

F_c= drag force due to the current in kg
A_s= subsurface area
V_c= speed of the current in knots

$$F_w=26*A_s(V_a/40)^2$$

F_w= drag force due to the wind in kg
V_a= speed of the wind in knots

Appendix E

Video Test Results

Table E.1 Video test results

Test	Date	Boom	Test Tow Speed (kt)	Sea State	Camera Position	Free-board (in)	Comments
1	8/30/94	Oilstop	0.5/a	1	forward	12— 15	Choppy waves inside apex only. Can see fireproof skirt
1	8/30/94	Oilstop	0.5/a	1	trailing		when boom follows waves. Water smooth behind boom.
1	8/30/94	Kepner	0.5/a	1	forward	0—3	Splashover at 0.5 kts. Skirt is inside of apex. Turbulence
1	8/30/94	Kepner	0.5/a	1	trailing		pattern same inside and outside of apex.
2	8/30/94	Oilstop	1/a	1	forward	9—12	Some splashover. Major splashover at 5:11:26 (occurs
2	8/30/94	Oilstop	1/a	1	trailing		every 30 seconds). Can't read trailing measurements.
2	8/30/94	Kepner	1/a	1	forward	0	Submerged, sometimes over 1' below water. 200' of boom
2	8/30/94	Kepner	1/a	1	trailing		submerged.
3	8/30/94	Oilstop	1.5/a	1	forward	9 (w/o waves)	Splashover every 2 seconds. When waves aren't hitting
3	8/30/94	Oilstop	1.5/a	1	trailing		boom, 9" of freeboard. Major splashover from trailing view
3	8/30/94	Kepner	1.5/a	1	forward	0	Again, completely submerged. 1 to 2 feet under water.
3	8/30/94	Kepner	1.5/a	1	trailing		
4	8/31/94	App. Fabrics	0.5/a	1	forward	6	
4	8/31/94	App. Fabrics	0.5/a	1	trailing		
5	8/31/94	App. Fabrics	1/a	1	forward	6	
5	8/31/94	App. Fabrics	1/a	1	trailing		
6	8/31/94	App. Fabrics	1.5/a	1	forward	planing	
6	8/31/94	App. Fabrics	1.5/a	1	trailing		
7	8/31/94	App. Fabrics	2.0/a	1	forward	planing	
7	8/31/94	App. Fabrics	2.0/a	1	trailing		
8	8/31/94	Oilstop	0.5/a	1	forward	12—14	Choppier sea conditions. Tears all over top of boom.
8	8/31/94	Oilstop	0.5/a	1	trailing		Camera not steady due to sea state.
8	8/31/94	App. Fabrics	0.5/a	1	forward	6	
8	8/31/94	App. Fabrics	0.5/a	1	trailing		

Table E.1 Video test results (cont.)

Test	Date	Boom	Test Tow Speed (kt)	Sea State	Camera Position	Free-board (in)	Comments
9	8/31/94	Oilstop	1/a	1	forward	~ 12	No clear picture of freeboard. Estimate 12" of freeboard
9	8/31/94	Oilstop	1/a	1	trailing		Skirt moving inside of apex.
9	8/31/94	App. Fabrics	1/a	1	forward	4	
9	8/31/94	App. Fabrics	1/a	1	trailing		
10	8/31/94	Oilstop	1.5/a	1	forward	0	Major splashover 2 seconds. Skirt moving inside apex.
10	8/31/94	Oilstop	1.5/a	1	trailing	~3	Part of fireproof material coming loose at apex.
10	8/31/94	App. Fabrics	1.5/a	1	forward	planing	
10	8/31/94	App. Fabrics	1.5/a	1	trailing		
11	8/31/94	Oilstop	2/a	1	forward	0	Skirt at tow ends of boom turned in. No frbd. from front.
11	8/31/94	Oilstop	2/a	1	trailing	~3	Scale not at apex. ~ 3" fat apex. Water flow over boom.
11	8/31/94	App. Fabrics	2/a	1	forward	planing	
11	8/31/94	App. Fabrics	2/a	1	trailing		
12	8/31/94	Oilstop	1.5/w	1	forward	~9	Sea state calmer. Apex conforming to waves. Fire material
12	8/31/94	Oilstop	1.5/w	1	trailing		still exposing air chamber at apex.
12	8/31/94	App. Fabrics	1.5/w	1	forward	4	
12	8/31/94	App. Fabrics	1.5/w	1	trailing		
13	8/31/94	Oilstop	2/w	1	forward	~9	Sea state mostly due to swells, not waves. Possible air
13	8/31/94	Oilstop	2/w	1	trailing		chamber has deflated at apex.
13	8/31/94	App. Fabrics	2/w	1	forward	planing	
13	8/31/94	App. Fabrics	2/w	1	trailing		
14	8/31/94	Oilstop	2.5/w	1	forward	0	Boom is submerged at apex. Fireproof material coming off in
14	8/31/94	Oilstop	2.5/w	1	trailing		several places. 30' section of boom submerged.

Appendix F

Technical Specifications Of Test Equipment

MSRC OIL BOOM TEST

DATA LOGGER FILE FORMATS

CR-10 File Format:

Type:

Comma-delimited ASCII. Units are volts, degrees, pounds, feet, and knots. Time is set to local (Galveston, TX). Scan interval = 5 seconds.

ID#, year, julian day, hour/minute, battery voltage, porttilt1, strbdtilt1, porttilt2, strbdtilt2, portdepth1, strbddepth1, portdepth2, strbddepth2, porttension, strbdtension, windspeed, winddirection <crlf>

Coefficients:	Multiplier:	Offset:
All tilt:	0.0333	0.0000
All depth:	0.1444	-5.775
Porttension:	6.25	-2500
Strbdtension:	13.777	-5511
WindSpd:	0.12	0.00
WindDir:	0.36	0.00

Channel Input Networks:		Input Range:
All tilt:	2:1 Attenuator	+/- 1800 mv = +/- 60 degrees
All depth:	100 ohm shunt	400 to 2000 mv = 0 to 10 psig
Porttension:	100 ohm shunt	400 to 2000 mv = 0 to 10,00 lbs
Strbdtension:	100 ohm shunt	400 to 2000 mv = 0 to 10 metric tons
WindSpd:	none	0 to 1000 mv = 0 to 120 knots
WindDir:	none	0 to 1000 mv = 0 to 360 degrees

MSRC OIL BOOM TEST

DATA LOGGER FILE FORMATS

WaveRider File Format:

Type:

Space-delimited ASCII. Units are meters and seconds. Time is set to local (Galveston, TX). 4096 point FFT.

Line 1:

buoy #, # of unlocks, date, time <crlf>

Line 2:

# of waves, significant wave height, average wave period, average deviation from mean height, average wave height, root mean square wave height <crlf>

Line 3:

maximum wave height, significant wave period, period of maximum wave, longest wave period <crlf>

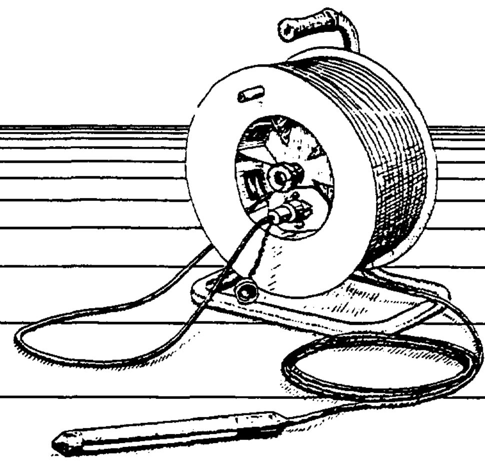
Line 4:

Tucker-Draper wave statistics <crlf>

Lines 5-8:

64 spectral coefficients of wave height

In-Situ Inc.
The Solutions People



PTX-161D Pressure Transducer

The PTX-161D Pressure Transducer is designed to simplify water depth measurements in aquifers, reservoirs, streams, lakes, oceans, and other water bodies. The design of the probe permits long cable lengths of up to 4500 feet without loss of accuracy. The PTX-161D's small diameter allows it to fit in drop pipes as small as 3/4", and its short length helps prevent hang-ups downhole. The titanium body is electron-beam welded for added durability. Polyurethane cable is attached to the probe in a high integrity waterproof assembly. The cable is vented to the atmosphere to allow the transducer to compensate for barometric pressure. Within the specifications listed, the probe is insensitive to electrical interference and ground currents from power line, power stations, or operating equipment in the field.

Features:

- High accuracy (±0.05% with HERMIT Data Loggers)
- Good thermal stability (±0.3% total error band)
- Totally submersible
- Excellent overpressure rating (2x full range)
- Titanium construction
- One-year warranty
- Calibration documentation is included

Rentals Available

The PTX-161D can be rented. Contact In-Situ for details and availability.

PTX-161D Pressure Transducer

Specifications

General

Transduction principle:	Integrated silicon strain gauge bridge
Wetted materials:	Titanium, quartz, Delrin*, silicone RTV, neoprene, stainless steel
Size:	0.69 in. (17.5 mm) diameter, 8.5 in. (21.6 cm) long
Weight:	4 oz. (0.12 kg)
Output:	4-20 mA (typical) over pressure range
Tolerance for mechanical shock:	1000 g for 1 mS in each of three mutually perpendicular axes will not affect callibration

Ranges

Standard:	10 PSIG (=23 ft. water, 68.9 kPa)
	15 PSIG (=35 ft. water, 103.4 kPa)
	20 PSIG (=46 ft. water,137.9 kPa)
	30 PSIG (=69 ft. water, 206.8 kPa)
	50 PSIG (=115 ft. water, 344.7 kPa)
	100 PSIG (=231 ft. water, 689.5 kPa)
Special:	Contact In-Situ Inc. for available ranges
Over pressure tolerance:	2x full range

Accuracy

At reference temperature (15°C, 59°F):	±0.10% of range-linear coefficients
	±0.05% of range-quadratic coefficients
Over other temperatures (quadratic coefficients):	0°C to 30°C (32°F to 86°F), ±.3% of range

Cable

Wetted materials:	Polyurethane
Size:	0.26" (6.7 mm) OD nominal
Weight Polyurethane:	3 lb./100 ft. (1.35 kg/30 m)
Reels:	ABS plastic, up to 350 ft. (107 m) capacity (standard)
	Small steel, up to 550 ft. (168 m) capacity
	Large steel, up to 1500 ft. (450 m) capacity

Temperature Range

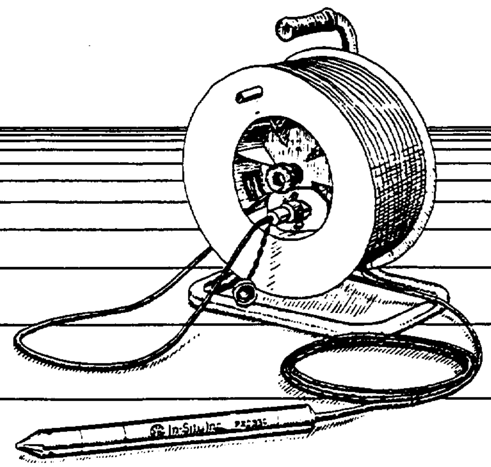
Operating:	-20°C to 80°C (-4°F to 176°F)
Storage:	-40°C to 125°C (-40°F to 257°F)

*Delrin is a registered trademarks of E.I. DuPont de Nemours Co.
Due to continuing product development this information is subject to change without notice.

In-Situ Inc.
The Solutions People

210 S. Third Street
P.O. Box I
Laramie, WY 82070-0920 USA
Tel: (307) 742-8213
(800) 446-7488
FAX: (307) 721-7598

In-Situ Inc.
The Solutions People



Absolute Pressure Transducer

Model PXD-330

The PXD-330 Absolute Pressure Transducer provides an accurate measurement of absolute pressure in a variety of PSIA ranges. When used as a system with In-Situ's Data Loggers, the probe can operate unattended in extreme weather conditions over extended periods of time. The PXD-330 can be used when monitoring partial vacuums, such as in soil vapor extraction applications.

Designed and manufactured by In-Situ, the PXD-330 comes with a one-year warranty and is factory repairable. Calibration documentation is included.

Features:

- High accuracy
- Good thermal stability
- No field calibration required
- Excellent overpressure rating
- Constructed of 316 Stainless steel and Viton
- 1/4" male NPT adapter for installing in instrument piping

Rentals Available

The PXD-330 can be rented. Contact In-Situ for details and availability.

PXD-330 Absolute Pressure Transducer

Specifications

General

Transduction principle:	Integrated silicon strain gauge bridge
Wetted materials:	316 stainless steel, Viton*
Size:	1 in. (25.4 mm) diameter, 10.9 in. (277 mm) long
Weight:	1.5 lb. (0.68 kg)
Output:	4-20 mA (typical) overpressure range

Ranges

Standard:	Contact In-Situ Inc. for available ranges
Overpressure tolerance:	2x full range

Accuracy

At reference temperature (15°C, 59°F):	±0.15% of range-linear coefficients ±0.05% of range-quadratic coefficients
Over other temperatures (quadratic coefficients):	10°C to 20°C (50°F to 68°F), ±0.08% of range 5°C to 25°C (41°F to 77°F), ±0.16% of range 0°C to 30°C (32°F to 86°F), ±0.30% of range

Cable

Wetted materials:	Polyurethane, Teflon*, Surlyn*
Size:	0.26" (6.7mm) OD nominal
Weight	
Polyurethane & Surlyn:	3.01 lb./100 ft. (1.35 kg/30 m)
Teflon:	3.50 lb./100 ft. (1.58 kg/30 m)
Reels:	ABS plastic, up to 350 ft. (107 m) capacity (standard) Small steel, up to 550 ft. (168 m) capacity Large steel, up to 1500 ft. (450 m) capacity

Temperature Range

Operating:	-40°C to 80°C (-40°F to 176°F)
Storage:	-40°C to 125°C (-40°F to 257°F)

*Viton, Teflon and Surlyn are registered trademarks of E.I. DuPont de Nemours Co.
Due to continuing product development this information is subject to change without notice.

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AccuStar®
Clinometer Installation Analog

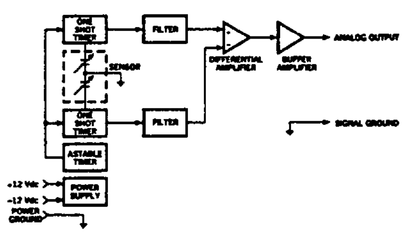
Operating Instructions and Installation Information

CAUTION
ELECTROSTATIC SENSITIVE DEVICE

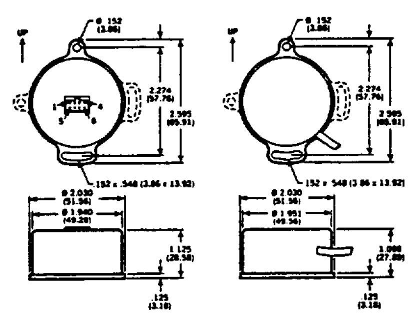
North American Operations
Lucas Control Systems Products
1000 Lucas Way
Hampton, Virginia 23666
804/766-1500
FAX: 804/766-4258

Lucas

ANALOG I/O BLOCK DIAGRAM



DIMENSIONS



Measurements in inches and (millimeters)
Weight: 3.0 ounces (.085 kg)

ELECTRICAL CONNECTIONS

PIN	WIRE		
8	Black	Power Ground	DC Power Supply
6	Red	+12 Volts DC	DC Power Supply
5	Gray	- 12 Volts DC	DC Power Supply
1	Brown	Signal Ground	DC Voltmeter
2	Blue	Signal Output	DC Voltmeter

CLINOMETER SPECIFICATIONS

Performance

Total Range	± 60 deg.
Linear Range	± 45 deg.
Threshold & Resolution	.001 deg.
Linearity Null to 10 deg.	±.1 deg.
10 to 45 deg.	± 1% angle
45 to 60 deg.	Monotonic
Null Repeatability	.05 deg.
Cross Axis Error	<1% up to 45° cross axis angle
Time Constant	.3 second
Frequency Response	.5 Hz

CLINOMETER SPECIFICATIONS

Electrical

Voltage Supply – nominal	± 12 Vdc
Voltage Supply Range	±8 to ±20 Vdc
Current – each nominal supply	5 milliamps
Scale Factor – to linear range	60 millivolts/deg. nom
Load Resistance – minimum	10K ohms

Environmental

Temperature Range Operating	-40 to +65°C
Storage	-55 to +65°C
Temperature Coefficient of Null	.008 deg. per °C
Temperature Coefficient of Scale Factor	.1 percent per °C

Specifications are subject to change without notice.

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Appendix G

Draft Standard Guide For In-Situ Burning Of Oil Spills On Water: Fire-Resistant Containment Boom

DRAFT #6
Standard Guide for In-Situ Burning of Oil Spills On Water: Fire-Resistant Containment Boom

Source: ASTM, In preparation

1.0 Scope

1.1 This guide provides the recommended criteria to evaluate performance requirements, material characteristics and essential features for fire-resistant oil spill containment boom. This guide is not intended to be restrictive to a specific configuration.

1.2 This guide covers conventional, fire-resistant oil containment boom and may not be fully applicable to other fixed boom systems or systems such as water spray.

1.3 This guide is related to in-situ burning of oil spills. Another guide concerns the ecological considerations for use of in-situ burning.

1.4 Containment for in-situ burning of oil spills may involve hazardous materials, operation and equipment. This guide does not purport to address the safety problems associated with such activities. It is the responsibility of the user of this guide to establish appropriate safety and health practices and to determine the applicability of regulatory limitations prior to use.

2.0 Applicable Documents

2.1 ASTM Standards:

F625	Standard Practice for Classifying Water Bodies for Spill Control Systems
F715	Standard Methods of Testing Spill Control Barrier Membrane Materials
F818	Definition of Terms Related to Spill Response Barriers
F1093	Standard Test Methods for Tensile Strength Characteristics of Oil Spill Response Boom
F1523	Standard Guideline for the Selection of Oil Spill Barriers According to Environmental Conditions
FXXX-XX	Standard Guide for Ecological Considerations for In-Situ Burning of Oil Spills

3.0 Terminology

3.1 Definitions:

3.1.1 *fire containment boom* - barrier intended for containment of burning oil floating on water.

3.1.2 *in-situ burning* - combustion conducted within the localized area of an oil spill source.

3.1.3 *burn-life* - one or more direct exposures to distinctly separate ignite/extinguish sequences.

3.1.4 *burn exposure*- direct exposure to flame or heat source with an equivalent radiation density.

3.1.5 *burn hours* - number of hours of direct exposure to flame or heat source with an equivalent radiation density.

3.1.6 *fire resistant* - minimal degradation due to exposure to fire or heat source with an equivalent radiation density.

3.1.7 *pre-burn condition* - condition prior to burn exposure.

3.1.8 *post-burn condition*- condition after a burn exposure.

4.0 Equipment Description

4.1 Fire-resistant oil spill containment booms or fire containment booms are floating mechanical barriers used to control and/or contain movement of burning oil on water.

4.2 Fire containment boom should be able to contain oil floating on water before, during, and after exposure to in-situ burning of oil. The in-situ burning could be a result of either accidental ignition during an oil spill or a deliberate, controlled oil spill clean-up procedure.

4.3 Fire containment booms should demonstrate similar characteristics to those outlined for oil containment booms as stated in FXXX-XX except the buoyancy to weight ratios and the tensile strengths may be less. Performance characteristics should be calculated by similar methods used in the selection of oil spill barriers, FXXX-XX.

5.0 Equipment Testing

5.1 Without artificially induced flexure
-designate if conducted in salt or fresh water
-time elapsed
-test oil type used
-tensile strength: before and after
-buoyancy: before and after

6.0 Minimum Equipment Characteristics

6.1 Fire-resistance Characteristics

Fire-resistant oil spill containment booms should be able to withstand oil fires on calm or turbulent, fresh or salt water. Minimum requirements should include the following:

6.1.1 Performance and survival in temperatures (radiation density equivalent) of up to 1300°C.

6.1.2 Containment of burning oil throughout exposure to the fire, with peak temperatures (radiation density equivalent) of up to 1300°C, for a total burn time of 8 continuous hours (Multiple burns are increments of at least 8 hour continuous burn exposure).

6.1.3 Maintain a post-burn positive freeboard.

6.1.4 Maintain a post burn minimum Buoyancy to Weight Ratio of 1.5:1.

6.2 Boom Characteristics

Fire-resistant oil spill containment boom, before exposure to an oil fire, should display similar oil containment characteristics expected of oil spill containment booms described in FXXX-XX Guideline for the Selection of Oil Spill Barriers According to Environmental Conditions.

6.2.1 Due to the material demands necessary to provide fire resistance, these classifications of booms are not expected to meet the same levels of hydrodynamic performance required of non-fire resistant containment equipment.

6.3 The fire containment barrier system, will not create or add to the hazardous waste pollution nor will it otherwise require any special handling beyond that normally required of oil spill booms.

7.0 Equipment Design

7.1 Minimum Fire Resistant Boom Performance and Design Requirements

7.1.1 Survive direct fire exposure with peak temperatures up to 1300°C.

7.1.2 Survive burning oil throughout exposure to peak temperatures (radiation density equivalent) of up to 1300°C, for a total burn time of 8 continuous hours (Multiple burns are increments of at least 8 hour continuous burn exposure).

7.1.3 Contain a layer of oil at least 2 mm in thickness without loss before or during direct exposure to burning oil.

7.1.3.1 A multiple-burn-life fire resistant boom will contain a layer of oil at least 2 mm in thickness without loss throughout the manufacturer's recommended maximum number of burn exposures.

7.1.4 Towing

7.1.4.1 Accomplish single line towing of a minimum 150 meter system at 5 knots for 2 hours.

7.1.4.2 Accomplish straight line towing of a minimum 150 meter system at 5 knots for 2 hours.

7.2 Minimum Operational Boom Design Requirements

7.2.1

Freeboard (cm)	Calm Water	Protected Water	Open Water	Fast Current
Pre-burn condition	12	26	53	13
Post-burn condition	6	13	27	7

Notes: (A) operational freeboard is estimated based on the assumed minimum freeboard implied in the boom selection guideline.

7.2.2

	Calm Water	Protected Water	Open Water	Fast Current
Draft (cm)	15	33	66	16

7.2.3 Buoyancy to weight ratio

7.2.3.1 Maintain a buoyancy to weight ratio of 3 : 1 for the pre-burn condition and 1.5:1 for the post-burn condition.

7.2.4 Flotation
Fire resistant boom should have continuous flotation in the pre-burn condition and maintain adequate flotation in a post-burn condition to facilitate salvage.

7.2.5 Total tensile strength

7.2.5.1 Fire resistant boom in their pre-bum conditions should meet the minimum total tensile strength for various environmental categories outlined in FXXX-XX the boom selection guideline.

7.2.5.2 Post-burn total tensile strengths for fire resistant booms would decrease after each burn exposure. The lower limit should be 33% of the original tensile strength prior to exposure to fire and be adequate to allow for removal for salvage or disposal.

7.2.6 Fire resistant boom skirts should meet the skirt fabric tensile strengths as stated in F1523 for each boom environmental category.

7.2.7 Fire resistant boom skirts should meet the skirt tear strengths as stated in F1523 for each boom environmental category.

7.3 Ends of the fire resistant boom system must interconnect to the ASTM Standard Connector. The fire resistant boom segment interconnections must meet boom tolerance standards.

7.4 Storage and handling procedures should be provided by the manufacturer.

7.5 Documentation must be provided by the manufacturer addressing: storage, handling, maintenance, health and safety, test results and recommended repair procedures.

8.0 Material Characteristics

8.1 Corrosion Resistance

Fire-resistant oil spill containment boom systems stored or used in a marine environment should be manufactured of components which maintain the fire resistance characteristics while exposed to the environmental conditions without significant degradation (less than 5 percent per year for at least 5 years).

8.2 Extreme Temperature Properties

Systems to be used or stored at extreme temperatures, -40°C to +40°C, should be constructed of materials which are not adversely affected by those temperatures for at least five years.

KEY WORDS

oil spill disposal	fire-resistant booms	burn hours
oil spill burning	fire containment booms	burn life
in-situ burning	oil spill containment	