Re-Engineering of a Stainless Steel Fire Boom for use in Conjunction with Conventional Fire Booms

I. Buist, S. Potter, J. McCourt
SL Ross Environmental Research
Ottawa, ON, Canada
Ian@slross.com

P. Lane, P. Newsom, L. Hillebrand
Applied Fabric Technologies
Orchard Park, NY, USA

S. Buffington
US DOI MMS
Herndon, VA, USA

Abstract

Many existing refractory fabric fire booms will deteriorate quickly in use and may require frequent replacement in a large-scale burn operation. These problems can be minimized, or even eliminated, by using a highly durable and fire-resistant material in the pocket of the boom where the highest heat and stress loads exist.

In this project an existing, large stainless steel boom was re-engineered to reduce its size, weight and cost. The large boom was designed, constructed and tested successfully in the early 1980s; however, because of the rigorous criteria used for the original design, it is expensive, heavy, and cumbersome to deploy.

The project was completed in nine phases: (i) the existing boom was redesigned to reduce its cost, size, weight, and handling problems, and to make it compatible with existing boom systems; (ii) a prototype section of the re-engineered boom was constructed for testing; (iii) the boom was tested in Lake Erie to evaluate its towing and sea-keeping characteristics; (iv) the prototype was tested at Ohmsett to quantify its oil-containment capability; (v) three hours of burn tests in waves were conducted in a diesel fire at the US Coast Guard Fire and Safety Test Detachment in Mobile, AL; (vi) post-burn tow tests were performed at Ohmsett to confirm the containment capability of the boom after the diesel-fire exposure; (vii) three hours of burn tests in waves were carried out in enhanced propane flames at Ohmsett; and, (viii) destructive testing was used to estimate the operational life of the flexible connector sections, and the tensile strength of several key load-bearing components. Finally, the design of the boom was refined and final detailed engineering drawings and a report were produced.

The boom passed all the tests. The final design is presented in the paper. The boom may be purchased commercially from Applied Fabrics Technologies, Inc.

1.0 Introduction

There are two basic types of fire-resistant boom presently available to contain oil for *in situ* burning (ISB): fabric-based and metallic. Only the fabric-based booms have been stockpiled in appreciable quantities, because the metallic versions have been too heavy, cumbersome and expensive. Unfortunately, the operating life of these fabric-based booms has proved to be significantly less than originally thought. The fire-resistant fabrics are woven from mineral, ceramic or glass-like fibres. They are inherently susceptible to abrasion when dry and even more so when wet. The combined stresses of flexure from waves and high temperatures eventually cause the fabric to self-abrade and fail. Also, many of these fabrics are quite porous, even when

Arctic and Marine Oilspill Program (AMOP) Technical Seminar, 22nd. Environment Canada. Volume 2. Proceedings. June 2-4, 1999, Alberta, Canada, Environment Canada, Ottawa, Ontario, 545-565 pp, 1999

intact, and are significantly permeable to thick slicks of hot, low-viscosity oil. A revised operating strategy that calls for frequent replacement of deteriorated sections of fabric boom during ISB operations has been espoused, but there are obvious cost and efficiency problems with this approach.

A technical study of fire booms completed in 1994 by the Southwest Research Institute (Burkes 1994) concluded that there are inherent problems associated with fabric fire booms and that new designs should be researched. A better solution is to design a new boom system that can be used with existing stockpiles of fabric booms to enhance their effectiveness. The concept was to build a small section of special boom to be connected to and used as the pocket of currently available fabric booms. The special boom would have to be highly durable and highly resistant to thermal degradation because it is the apex of a boom that experiences the highest heat and mechanical stress loads. The fabric-based "arms" of this system would be exposed only to transient heat loads and would not be expected to contain thick slicks of burning oil, but only direct oil into the burn pocket area. Higher operational efficiency for controlled *in situ* burning operations would also be expected due to reduced down-time for replacement of degraded boom.

One stainless steel boom, called the Dome boom (Buist *et al.* 1983), was a good candidate as a starting point for the work. This non-commercial product, although it had shortcomings, was "tried and tested" and known to have high durability and high resistance to heat, the two most important qualities needed for the present application.

The Dome boom was originally developed as a high-strength, offshore system for response to blowouts in Arctic seas. As such, it was designed to survive high, steep seas (up to Sea State 5), carry high tensile loads, withstand impacts with ice, and operate in flames for very long periods, for example, at the site of a 45-day blowout (Buist *et al.* 1983). This boom was successfully tested at Ohmsett (Dome 1981) and at sea (Dome 1983) and was found to be capable of surviving exposure to thick slicks of burning oil in waves without any loss in integrity. The final version of the boom presently forms part of the Canadian Coast Guard's Arctic response stockpile. This version was successfully tested again at Ohmsett in 1996 (Bitting and Coyne 1997). The major disadvantages of the Dome boom are that it is expensive, heavy, and difficult to deploy.

This paper provides a summary of the design and testing of the new boom; full details and data from the project may be found in the final report (SL Ross 1999).

2.0 Objective

The objective of this project was to produce a smaller, less expensive, lighter, less cumbersome version of the Dome boom for use as a highly durable burn pocket in conjunction with refractory fabric fire booms.

3.0 Investigation of Boom Compatibility

Although there are as many as ten designs of existing fire containment boom, there are only four that have been commercially produced and that are available in the inventories of various response organizations (Buist *et al.* 1994). These products are:

American Marine (models 1218 and 1824)

- formerly produced by and also known as the 3M boom

- curtain-type boom
- ceramic-based fabric and stainless steel mesh over solid floatation

Applied Fabrics (Pyro30)
- fence-type boom
- ceramic-based fabric and wire mesh with spherical steel floats

Oil Stop (Harbor and Offshore models)
- curtain-type boom
- ceramic-based fabric and stainless steel mesh with pressure inflated floatation

Kepner (models 1418 and 1823)
- curtain-type boom
- ceramic-based fabric with air chambers that automatically inflate (to atmospheric pressure) as the boom is deployed

The purpose of this project was to produce a fire-resistant boom that would complement existing boom products. As such, the proposed boom had to be compatible with existing fire booms in terms of physical dimensions and wave response.The key physical properties of these four boom designs are given in Table 1.

Table 1 Summary of Key Parameters for Existing Booms

Manufacturer	American Marine		AFTI	Oil Stop		Kepner
Model	1218	1824	Pyro30	Harbor	Offshore	1418
Height, cm (in.)	76 (30)	110 (43)	76 (30)	76 (30)	107 (42)	84 (33)
Freeboard, cm (in.)	23 (9)	38 (15)	30 (12)	25 (10)	36 (14)	28 (11)
Draft, cm (in.)	53 (21)	71 (28)	46 (18)	51 (20)	71 (28)	56 (22)
Buoyancy:Weight ratio	3*	3*	3.5	5.5*	6*	>10*
Beam, cm (in.)	25* (10)	38* (15)	15* (6)	20* (8)	29* (11)	18* (7)
Connector	Quick	Quick	ASTM	ASTM	ASTM	ASTM
Estimated inventory, m (ft.)	6900 (22,500)	2300 (7500)	1200 (4000)	1700 (5500)	900 (3000)	900 (3000)

* estimated values

Note: the buoyancy-to-weight ratio of American Marine boom is reported to be 4.8 and 5.7 for the 1218 and 1824 models, respectively. However, observations of this boom in field tests suggest that these higher values are a result of buoyancy contained within the sacrificial cover, and this "additional" buoyancy is lost immediately upon exposure to an oil fire. The estimated buoyancy-to-weight ratio of 3 listed above is more indicative of the boom's performance in a burning operation.

3.1 Overall height

The draft and freeboard of the boom should be appropriate to the intended operating environment. The fabric booms listed above would be applicable to calm or protected water environments according to ASTM F1523, that is, wave heights of up to 1m (3 ft.). It would be unnecessary to design the proposed boom for conditions more severe than this, as the operation would be limited by the performance of the existing booms.

Secondly, the freeboard and draft dimensions of the proposed boom should be close to that of existing booms to limit stress differentials resulting from current, wave, and wind effects. Small differences in freeboard/draft could be accommodated by designing an adapter for the connection point.

3.2 Buoyancy-to-weight ratio

There is a direct relation between a boom's buoyancy-to-weight ratio and its response to waves (i.e., its heave response). The buoyancy-to-weight ratio of the proposed boom should be comparable to that of existing booms to limit stress at the connection point that would result from differing heave response.

3.3 Waterline beam

The waterline beam, defined as the average width of the boom at the waterline, also affects a boom's heave response. As with buoyancy-to-weight ratio, the beam of the proposed boom should be comparable to that of existing booms to limit stress at the connection point that would result from differing heave response.

4.0 The New Design

The overall redesign philosophy was to downsize the Dome stainless steel boom, reduce its weight, increase its buoyancy and improve its handling, while maintaining its superior strength and durability. This involved engineering assessments of materials, scaling, layout, production and operating aspects of the boom system. Handling, sea-keeping, stowage and durability were key characteristics optimized during this re-engineering task.

The cross-sectional profile of the flotation unit was redesigned to maximize reserve buoyancy, minimize weight and improve heave response. The thickness of the metal used to construct the flotation chamber was reduced to 18 gauge from 14 gauge; this was felt to be reasonable since the redesigned boom is not intended to be subjected to severe ice impacts, as was the Dome boom. The grades of stainless steel used for above-water components remain unchanged (primarily 310, with the pleated portion of the connector made from 27 gauge 321); although several flotation sections of the prototype were constructed with 304 stainless instead of 310 to see if the lower cost 304 could perform as well as the 310 does in a high-temperature salt water environment.

Particular attention was paid to the redesign of the connector unit in terms of durability and service life. The fundamental design of the pleated connector with a universally jointed through-beam was retained due to its proven performance characteristics. The location of the through beam was lowered from the centre line of the connector to ensure it remains below the water line with the increased overall buoyancy of the redesigned boom. This relocation should also help resist planing failure of the redesigned boom while being towed in a catenary, a known drawback of the larger boom. The design of the joint in the through-beam itself remains unchanged from the larger boom, although the box beam was reduced in size. The likelihood of oil leaking through the hinges was reduced by adding steel hinge cover strips extending the full height of the hinge. From the top of the foam joint covers to the top of the hinge, a loop (denoted as an "omega") of fire boom fabric was installed to provide further leak protection

The key characteristics of the original Dome boom and the redesigned boom are compared in Table 2 and depicted in Figures 1 and 2.

Table 2 Fire Resistant Boom Redesign Summary

NOMINAL DIMENSIONS	DOME BOOM	NEW DESIGN
Float Section		
height, cm (in.)	178 (70)	100 (39)
freeboard, cm (in.)	58 (23)	35 (14)
beam, cm (in.)	71 (28)	43 (17)
length, cm (in.)	175 (69)	171 (67)
weight, kg (lb.)	100 (224)	50 (110)
Connector Section		
height, cm (in.)	170 (67)	91 (36)
freeboard, cm (in.)	55 (22)	31 (12)
length, cm (in.)	95 (38)	67 (26)
weight, kg (lb.)	127 (279)	49 (108)
Overall		
weight, kg (lbs)	229 (503)	99 (218)
length, m (ft.)	2.8 (9)	2.5 (8)
weight/length, kg/m (lb./ft.)	82 (56)	40 (27)
buoyancy to weight ratio	1.8	3
tensile strength, N (lb_f)	3.3×10^5 (75,000)	1.8×10^5 (40,000)
stored length [11 sections: 11 connectors + 12 floats], m (ft.)	9 (30)	6 (19)

The design of the connector between the Pocket Boom and the fabric fire boom was also considered. Ultimately, the design chosen was a simple metal adapter that converts the stainless steel boom's US Navy standard double-male connector (i.e., the "double-barrelled shotgun" type) to a standard ASTM-type or Quick-type connector for attaching directly to the conventional fabric fire booms. This type of transition connector was selected on the basis of simplicity, ease of connection in the water and acceptable performance during the various tow tests performed throughout the project. The transition connector is intended to connect a floatation section to the

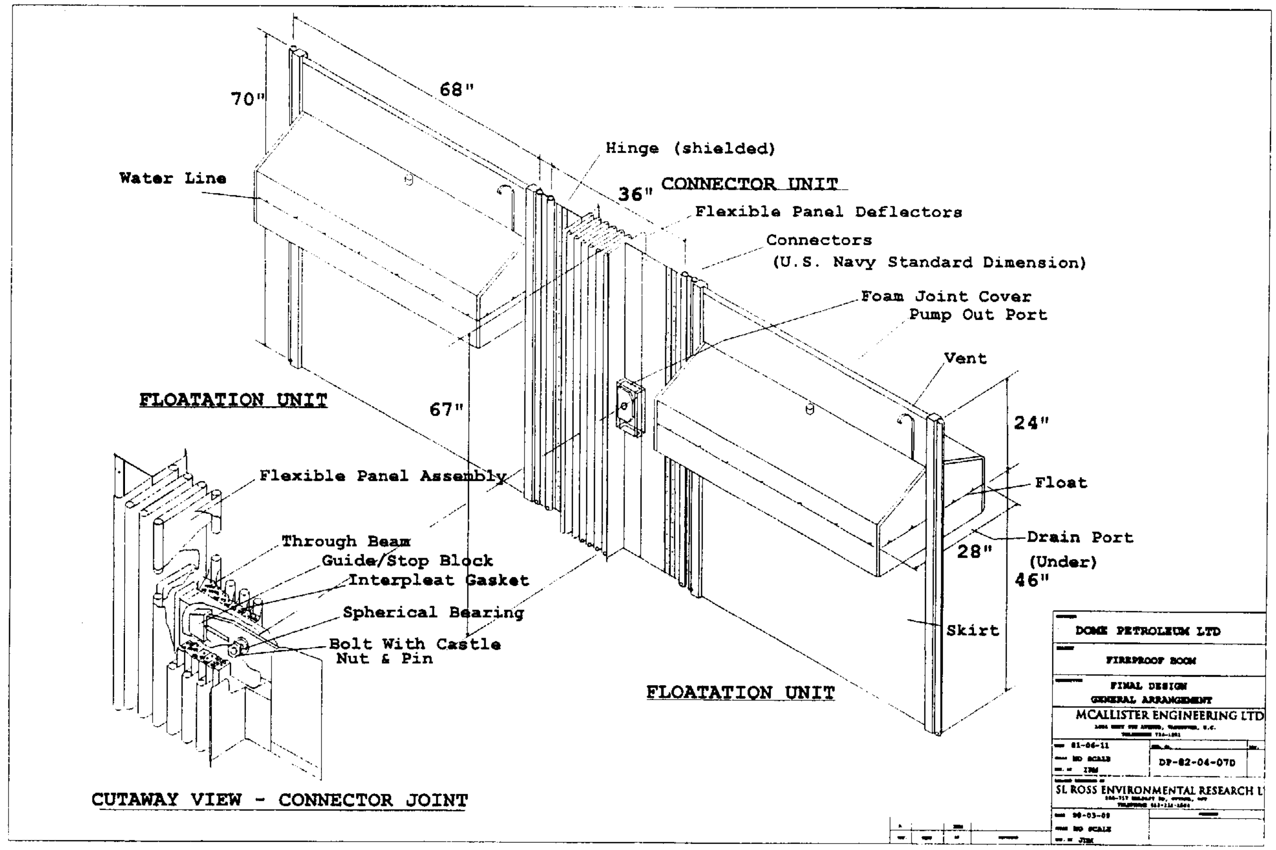

Figure 1 General Layout of Original Dome Boom

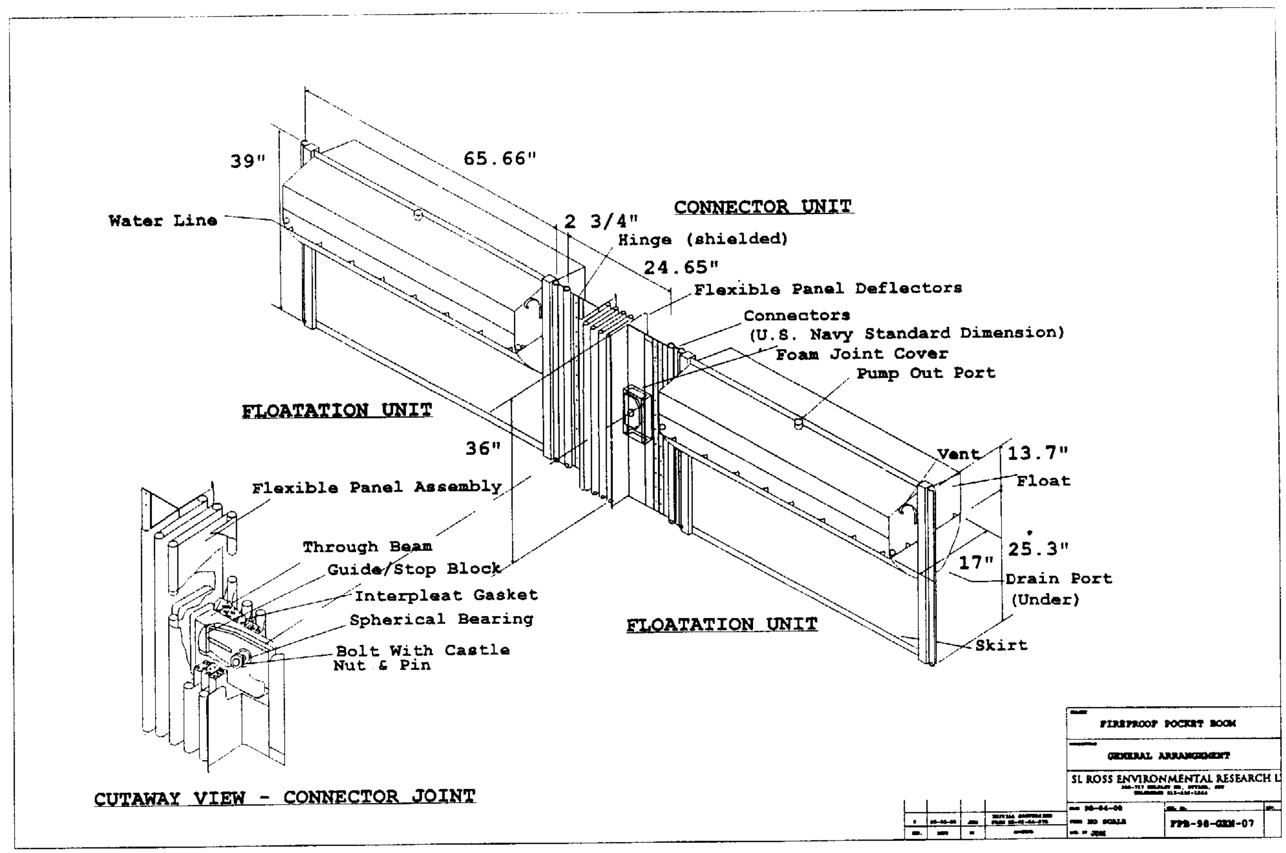

Figure 2 General Layout of Redesigned Pocket Boom

fabric boom.

As designed, 58 m (188 ft.) of pre-connected stainless steel boom, weighing 2600 kg (5600 lb.), could be stored, ready for deployment in two pieces, in a standard 20-foot ISO container.

A prototype length (16 m or 52 ft.) of the new boom , consisting of seven flotation units and seven flexible connector units, was constructed by Applied Fabric Technologies, Inc. in Orchard Park, NY. Figures 3 and 4 show the boom as built.

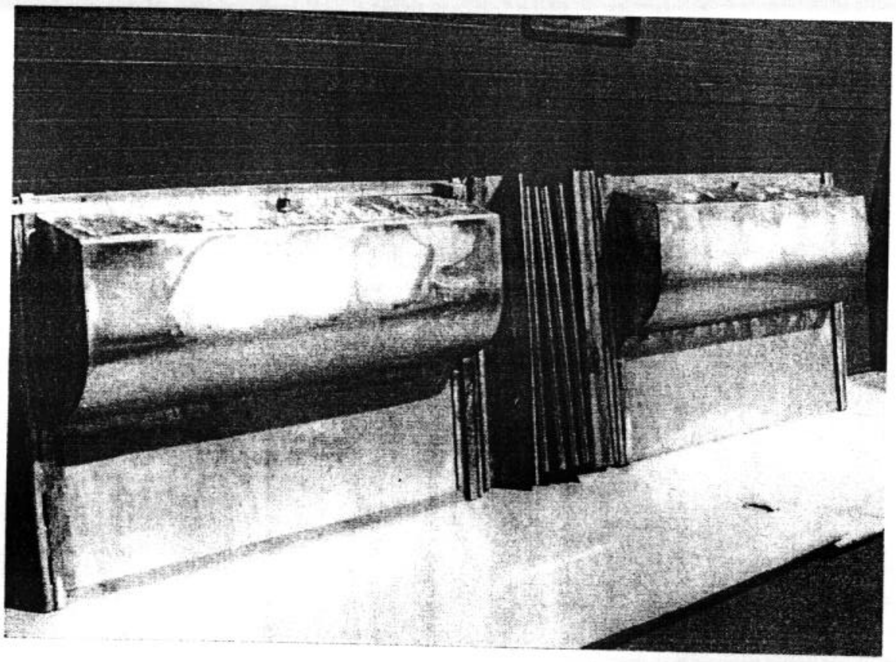

Figure 3 Redesigned Pocket Boom as Built by Applied Fabric Technologies

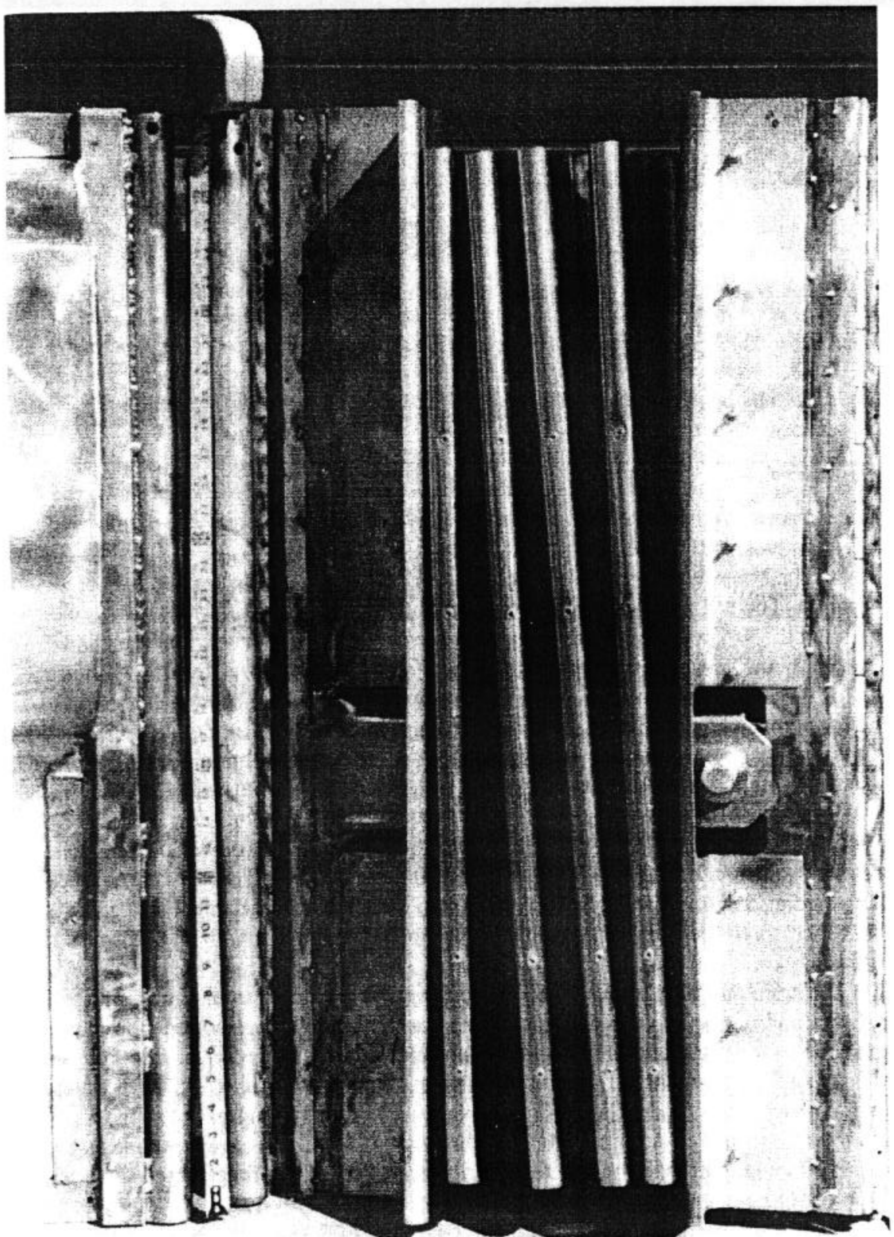

Figure 4 Redesigned Connector for Pocket Boom (Foam Joint Covers and "Omegas" not Installed)

5.0 Towing, Stability and Sea-keeping Trials

Straight line and catenary tow tests of the prototype Pocket Boom section, alone and inserted between two lengths of conventional boom were conducted to assess stability, heave response, flexibility, righting moment, and medium-term durability.

The tests were held on June 17 and 18, 1998 in Lake Erie, just south of Buffalo, NY in the harbor area off the mouth of the Buffalo River. On June 16, a crane was used to launch the pre-connected Pocket Boom from its storage box at the USCG base in Buffalo. The measured freeboard was 35 cm (14 in.), which matched the design specification.

The next day the boom (seven floats and six connecters) was towed, with a towing bridle attached to each end float section, in a straight line by one tow vessel in calm water to evaluate its stability and tendency to "corkscrew". The boom towed well, with only a slight heel to one side or the other, and followed the waves well. The tow speed was approximately 0.75 m/s (1.5 knots). The second tow vessel then took up the other end of the Pocket Boom and the boom was towed in a "U" configuration. In the "U" configuration, the Pocket boom towed well, with only a slight tendency to plane at speeds of 1 m/s (2 knots) or more. Wave conformance was excellent, even in 1-metre waves with a 3-second period.

The boom was then towed back to the USCG dock and left in the water overnight. The following morning it was noted that two float units were riding lower than the others. Their pump-out ports were opened and it was found that they had water in them. These units were pumped dry with a bilge pump. After this, 8-metre (25-foot) sections of conventional 36" Globe boom were added to each end of the Pocket Boom. The entire test series was then repeated, with particular attention being paid to the reaction of the transition from steel to conventional boom, in waves and currents. With the conventional boom attached, the Pocket boom towed even better in a straight line, with no evidence of heel, at speeds of up to 2.5 m/s (5 knots). It also followed the waves very well in this configuration (Figure 5). No overtopping was observed in 0.6 to 1 m (2 to 3 ft.) waves and 30 km/hr (15 knot) winds and no planing was noted at "U" tow speeds up to 0.8 m/s (1.5 knots). The attachment of the Globe boom directly to the Pocket boom end floats worked very well, with no wear or undue motion noted.

The 33 m (100 ft.) combined section was then returned to the dock for recovery and re-packing the next day. When the prototype was removed from the water the following morning it was examined closely for signs of wear, fatigue, leakage and damage. Other than the two float sections having taken on more water, no other damage was noted . The boom had been in the water for a total of 68 hours. The boom was returned to Applied Fabric Technologies, examined closely, the leaks identified and repaired in the two float sections, and the boom repackaged for shipment to Ohmsett for the next test series.

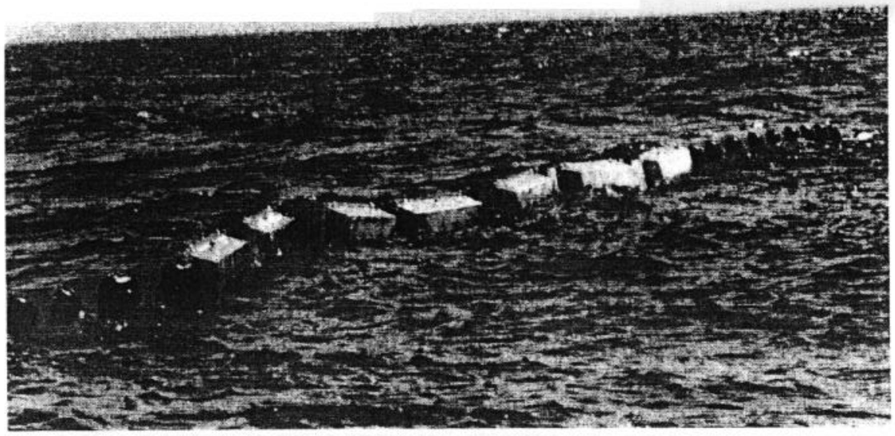

Figure 5 Pocket Boom Towing Trials in Lake Erie

6.0 Oil Containment Testing at Ohmsett

Using the standard protocol for oil containment testing of firebooms (Bitting and Coyne 1997), the Pocket Boom was tested at the Ohmsett test tank from July 20 through 31, 1998. The prototype was connected to two 8-m (25-ft.) lengths of conventional boom to form a 30-m (100-ft.) test section. The tests included: establishing the pre-load volume for subsequent loss tests; tests to determine first and gross loss tow speeds; loss-rate tests; and a critical tow speed test.

The first loss tests consisted of towing the boom at increasing speeds to determine the speed at which oil was first lost from the boom (Figure 6). Subsequently, the boom was towed at a higher speed to determine the speed at which gross amounts of oil were lost past the boom. In each case the mode of failure was noted along with general observations of boom behavior.

A total of 21 tests were run using Calsol 8240 oil (nominal viscosity 2000 mm^2/s [cSt]), followed by an additional 13 tests using Hydrocal 300 oil (nominal viscosity 200 mm^2/s [cSt]). The additional group of tests with the lighter oil was performed to confirm that the results of the previous testing were not solely related to the higher viscosity and higher interfacial tension of the Calsol oil. The full results are contained in the project report (SL Ross 1999).

With both test oils the first loss tow speed was determined to be 0.45 m/s (0.9 knots), with gross loss noted at 0.6 m/s (1.2 knots). In each case, the boom showed only a very minor tendency to plane (i.e., at the apex, the top of the boom tilted forward slightly), which is in itself an improvement over the previous design of the Dome boom. Similar results were obtained in a long regular wave and in a harbor chop. First loss occurred at (0.35 m/s) 0.7 knots and gross loss occurred at 0.45 m/s) 0.9 knots in a short regular wave.

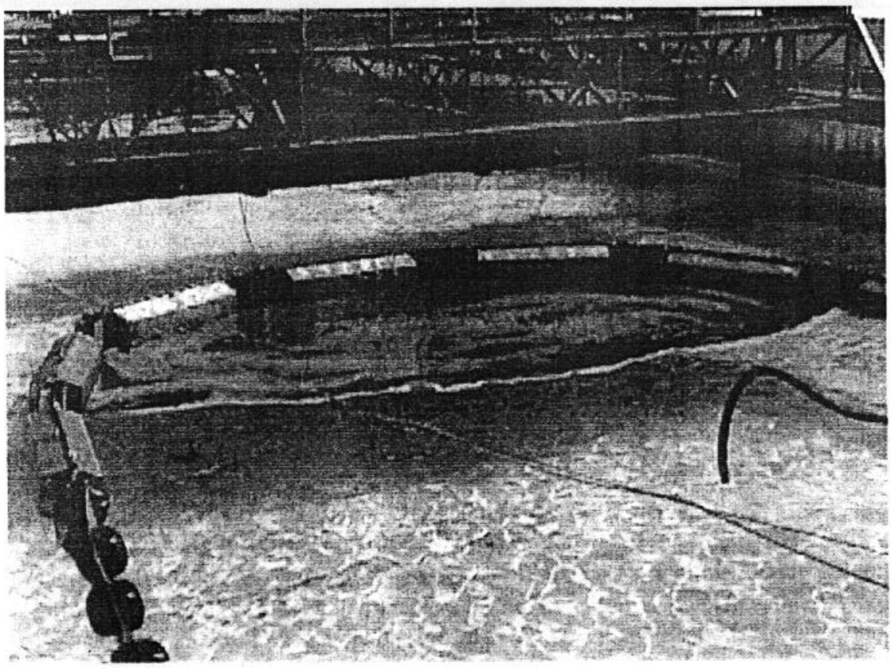

Figure 6 First Loss Tow Test at Ohmsett

In the critical tow speed test, the boom was towed at increasing speeds up to a maximum of 1.5 m/s (3 knots) to determine the ultimate mode of failure of the boom. As the tow speed increased above 0.75 m/s (1.5 knots), the boom began to plane slightly more, but remained stable. (Note that this speed is much greater than would be experienced in a typical containment operation.)

Following the critical tow speed test, the boom was lifted from the water and inspected for damage. Only three minor problems were found:

- one piece of foam, which is used to cover each end of the box beam that passes through the pleats, had separated from the boom mid-way through the test program.
- one of the four rivets used to hold a pleat-backing tube had pulled through the pleat material.
- one of the connector sections had a tear in it where a pleat-backing tube had over stressed the material during the critical tow speed test.

None of this damage was considered critical.

7.0 Fire Testing

Following the Ohmsett testing of the Pocket Boom, it was shipped to the USCG Fire and Safety Test Detachment in Mobile, AL for fire testing in waves. The tests followed the burn test protocol established by the National Institute for Standards and Technology (NIST) for the US Coast Guard and the Minerals Management Service (Walton *et al.* 1998).

A total of four test burns were conducted: a short demonstration burn on September 10, 1998 for a group of VIPs, and three one-hour burns on September 17 that comprised the test protocol. The intervening week was spent waiting for favorable wind conditions for the burns.

The boom was formed into a circle in the middle of the test tank. The diameter of the circle was estimated as 4.8 m (15'10"). The test protocol involved three cycles of one hour of burning followed by one hour of cool-down with waves. The wave paddle was operated with a period of 4.6 s for all tests.

The short demonstration involved burning 114 L (30 gallons) of #2 diesel fuel over a period of approximately three minutes. No leakage or component failure was observed. The second burn consumed 3310 L (874 gallons) of #2 diesel over a period of 58.5 minutes (approximately 51 minutes of full flame coverage). Figure 7 shows the boom during this test, and Figures 8 and 9 show the heat flux from the fire and the temperature of the boom. It was observed that a low flame persisted on the top of the fabric "omega" protecting each connector hinge. This could have been due to the fabric wicking fuel up from the water surface between the "omega" and the hinge. No leaks were observed during the burn test and the boom appeared undamaged afterwards. At the end of the subsequent one-hour cool-down, during the filling of the boomed area with the diesel for the next burn, some minor leakage from the downwind connector sections was noted.

The third burn consumed 3420 L (904 gallons) of fuel over a total time of 62 minutes (approximately 54 minutes of full flame coverage). No leakage or boom failure was noted during the third burn. Just before the flames extinguished, one of the downwind floatation units crumpled inward, apparently due to low pressure developing inside the unit. It was suspected that this was due to the presence of tank sealant used to fill small leaks in the tank during previous tests. Something (perhaps this sealant), under fire conditions, restricted the vent tube (designed to allow the free flow of air into and out of the tank) and caused the crumpling. The crumpling did not appear to detract from the boom's ability to contain oil or float. The vent tube diameter has been increased in the final design to alleviate this problem. No other damage was noted after the second burn. Again, as the boom was filled with the pre-load of diesel for the third one-hour burn, slight leakage from the connectors on the downwind side of the boom was noted.

The fourth burn consumed 3420 L (904 gallons) of fuel and lasted 58 minutes (56 minutes of full flame coverage). Four minutes after ignition the crumpled float unit re-expanded to nearly its original shape: it did not re-crumple at the end of the third one-hour burn. No leakage or boom failure was noted during the third one-hour burn. At the end of the burn the boom was re-inspected and it appeared that a floatation unit adjacent to the one that crumpled had expanded slightly due to over-pressure. Again, the vent tube must have been restricted. Despite this, the boom appeared to be maintaining its freeboard and no other damage was noted.

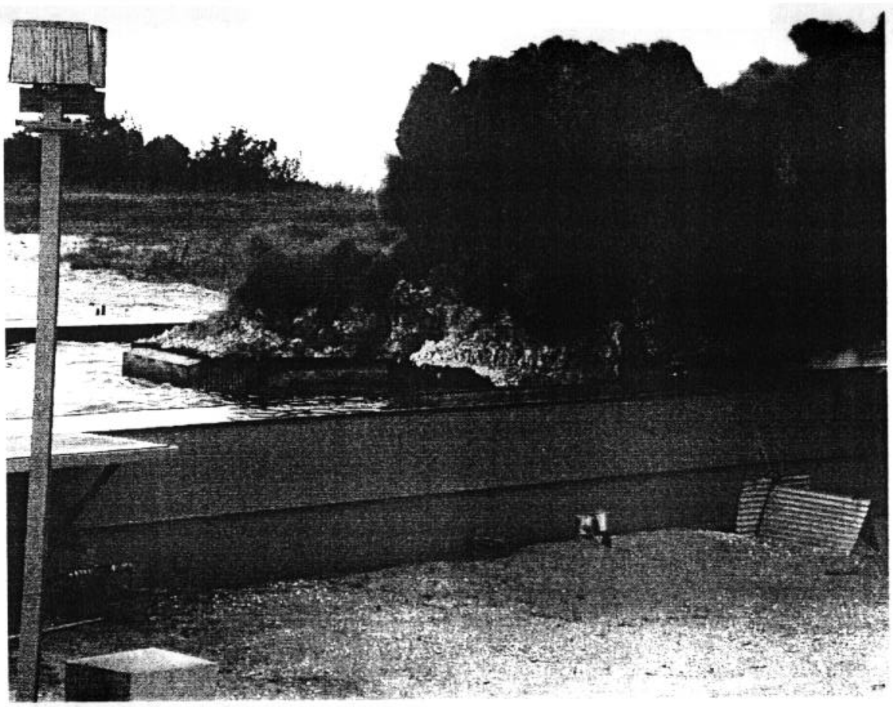

Figure 7 Second Pocket Boom Fire Test at Mobile, AL

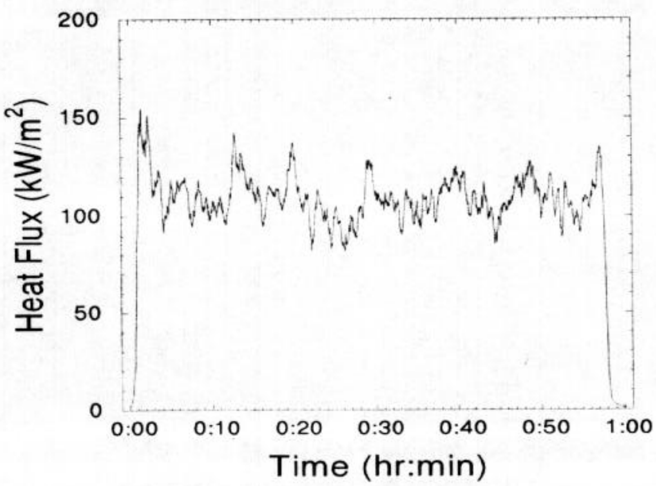

Figure 8 Total Heat Flux Measured from Downwind Side of Boom - 2[nd] Burn

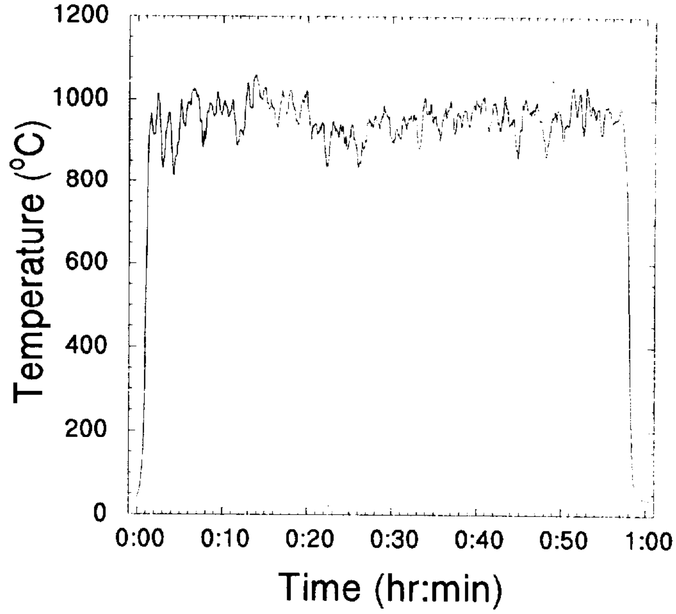

Figure 9 Temperature Measured during Second Test Burn with Pocket Boom

8.0 Post-burn Tow Testing at Ohmsett

Following the burn testing in Mobile, AL, the Pocket Boom was shipped back to Ohmsett for more tow testing.

The boom was unpacked and inspected on October 5. Two of the float sections had suffered minor damage from the burn tests in Mobile as noted above, but were considered sound. The fire resistant fabric that formed the "omegas" at the hinges of the connectors had degraded somewhat, but was also deemed serviceable.

The Ohmsett fire boom tow testing protocol (see 6.0 above) was completed. The boom performed in the same manner as during the initial tow testing. First loss in calm conditions and long, regular waves occurred at 0.45 m/s (0.9 knots) with gross loss recorded at 0.6 m/s (1.2 knots). In short regular waves, first loss occurred at 0.35 m/s (0.7 knots) and gross loss occurred at 0.45 m/s (0.9 knots).

9.0 Enhanced Propane Burn Tests at Ohmsett

On November 24, 1998 the prototype Pocket Boom was put through Ohmsett's new enhanced propane fire test protocol (see McCourt *et al.* 1999). These tests involved three cycles of one hour of exposure to compressed air-enhanced propane flames in waves, followed by a one-hour cool-down period in waves alone. Figure 10 shows one of the burn test cycles and Figure 11 shows the total heat flux measured from the downwind side. After several of the fire tests the boom was observed to be glowing bright cherry red, an indication that the temperature of the

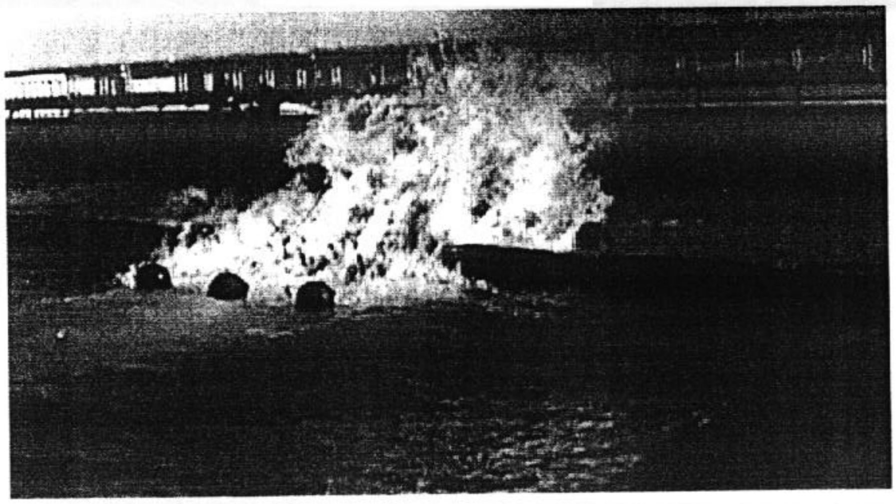

Figure 10 Pocket Boom in Enhanced Propane Flames at Ohmsett

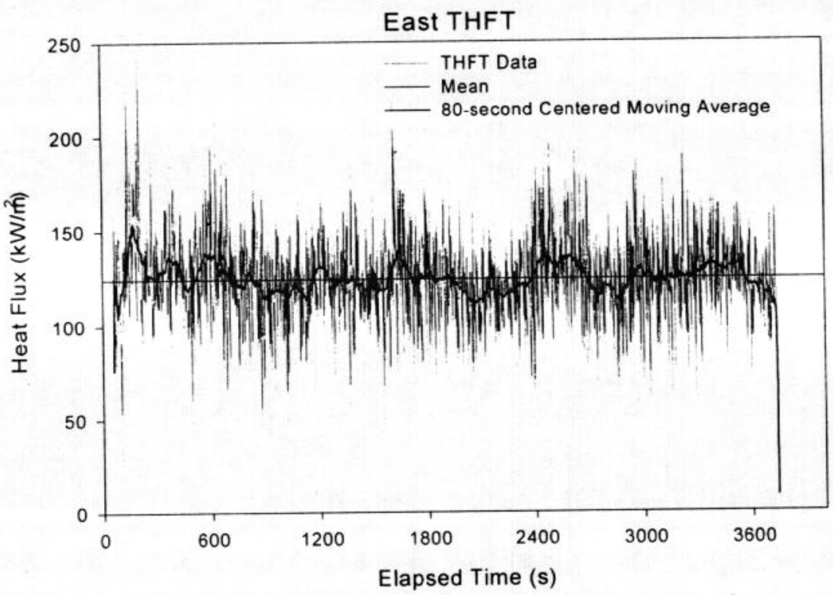

Figure 11 Total Heat Flux Measured from Downwind Side - 3rd Ohmsett Burn

metal was on the order of 900°C. Following the completion of the tests the boom was examined closely. Three instances of degradation were found:

- Three of the six connectors had developed a small (3 to 6 cm) crack or tear down from the top of the 321 stainless steel sheet at the second pleat. One of these is known to have resulted from tearing during the July critical velocity tow tests (see Section 6.0). None of the cracks/tears would have compromised the containment integrity of the boom.
- The second degradation was the detachment and deformation above the waterline of several of the steel hinge cover-strips at each end of the connector sections. This too was considered to be minor damage.
- The third and final degradation observed was the substantial deterioration of the "omegas" covering the hinges at each end of the connector sections. Much of the refractory fibre material was gone, leaving behind only the inner stainless steel mesh matrix. A better, more durable grade of "omega" material will be specified for subsequent versions.

The damage noted was minor and it was clear that the boom could have successfully contained oil after the completion of the enhanced propane burn test protocol.

10.0 Component Destructive Testing

Over the month of January 1999, five of the pleated connector sections were tested, three to failure. The test involved mounting the connector in a specially-constructed jig that held one side of the connector (the side opposite the universal bearing) immobile and cycled the other side through its range of motion in the vertical plane. One end of the connector was cycled by a push rod mounted on an off-centre wheel driven by a variable-speed electric motor (Figure 12). All five connector sections had been exposed to six hours of flames during the diesel fire tests in Mobile, AL and the enhanced-propane fire tests at Ohmsett.

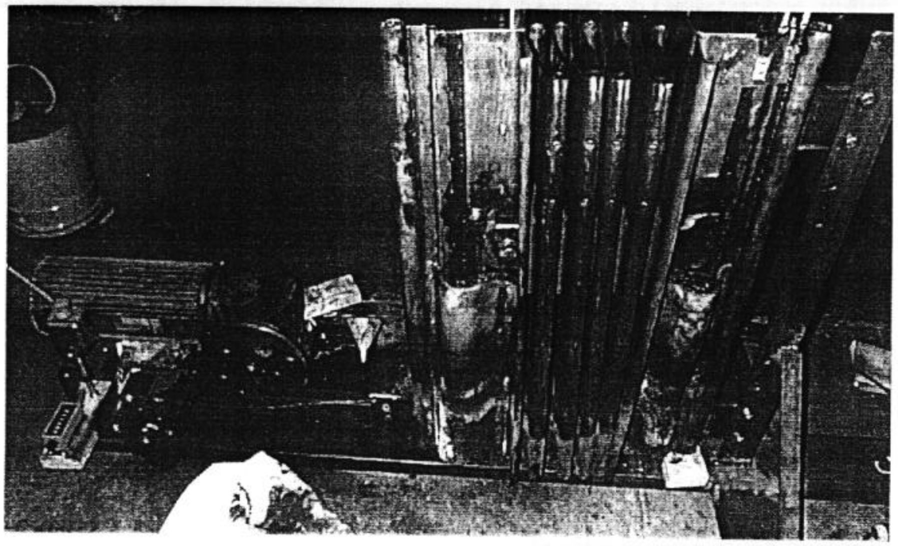

Figure 12 Jig for Cycling Connector Sections (Connector is mounted upside down)

All the connectors showed distinct signs of heat stress, including slight warping of the deflector panels, dimpling of the pleated sheet metal, and oxidation and embrittlement of the pleated 321 stainless sheet exposed to the flames. Three of the connector sections already had small cracks at the tops of the pleated sheet metal, one of which was the result of a tear that occurred during the critical tow speed tests at Ohmsett in July, 1998 (see 6.0 above).

The test jig cycled the connector at a rate of approximately 1 Hz. The lengthening of cracks in the pleated sheet was measured periodically. Failure was defined as the intersection of any crack with the waterline (340 mm = 13.7 in. down from the top of the boom). The first three connectors were cycled with a 15-cm (6-in.) stroke; defined as the total linear movement of the one side of the top of the pleated connector. The first connector failed after 572,000 cycles (equivalent to 26.5 days in Sea State 3- which has an average wave period of 4 sec.). The second failed after 348,00 cycles (16 days) and the third failed after 451,000 cycles (21 days). The mean time to failure was 457,000 cycles, approximately equivalent to 21 days in Sea State 3.

The fourth connector was operated with a stroke of 10 cm (4 in.). This connector survived 1,000,000 cycles (equivalent to 45 days in Sea State 4) without any cracking. At 1,000,000 cycles the stroke was increased to 15 cm (6 in.); cracks began to appear and propagate in the next 100,000 cycles. The fifth connector was cycled with a stroke of 13 cm (5 in.). Afer 1,000,000 cycles only minor cracks, the longest being 57 mm, had appeared. The final design of the connector through beam has been modified to restrict the stroke to 13 cm (5 in.). This will not impede the ability of the boom to respond to waves in its design operating environment (protected and semi-protected waters, up to Sea State 3 with a 1-m, 4 s significant wave).

In addition to these tests, a series of tensile tests were conducted on the perceived "weak links" in the boom design, the connector hinges and the Navy slide connector, to determine their strength. The hinges, as designed and built with one tack weld holding each knuckle shut, proved to have a yield strength of 2.2×10^5 N/m (1250 lb_f/in.) as desired. The mode of failure was the hinge knuckles uncurling. Without the tack weld the strength of the hinge was only 9×10^4 N/m (500 lb_f/in.), well below specification. The yield strength of the Navy slide connector proved to be 2.2×10^5 N/m (1260 lb_f/in.). The mode of failure was the male pipe pulling through the slot in the female pipe.

11.0 Deployment and Retrieval

The Pocket Boom has been designed so that long, pre-connected lengths of the boom can be removed from storage and deployed by crane. The boom is folded back on itself and each float section is connected to a lifting beam with chains and snaps (Figure 13). The section is lifted from its container and into the water, the chains are unhooked, and the boom unfolded for connection to lengths of conventional boom. The process is reversed to retrieve the boom. Over the life of the project the 15 m (50 ft.) prototype boom was deployed and retrieved five times with relative ease using this system.

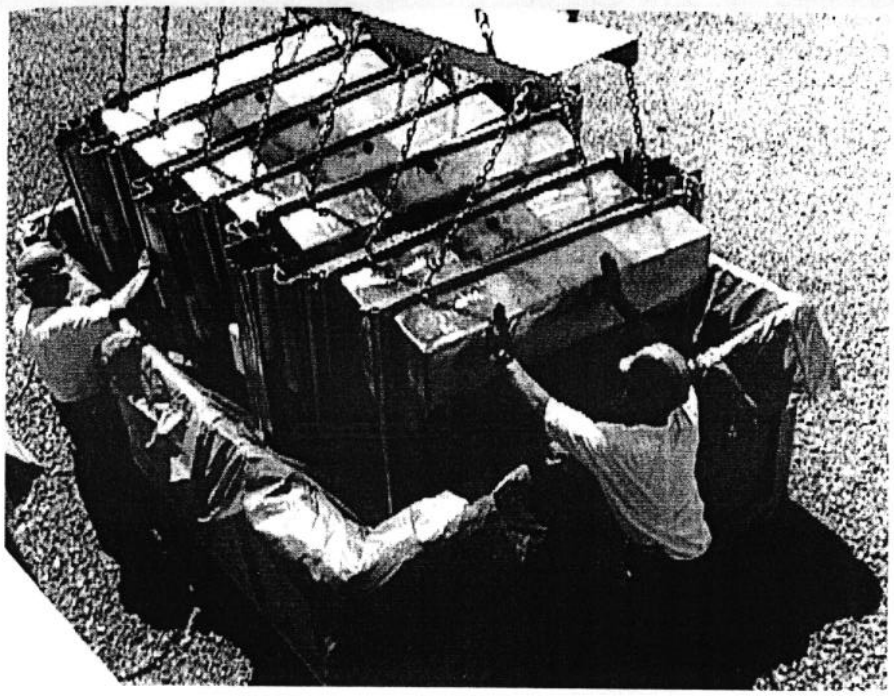

Figure 13 Deployment of 15 m (50 ft.) of Pre-Connected Pocket Boom

12.0 Summary

A large offshore stainless steel boom was redesigned to serve as a high-strength, durable burn pocket inserted between two lengths of conventional fabric fire boom. The final design of the Pocket Boom has resulted in considerable cost, weight and size reductions over the original design and a commensurate increase in ease of handling. With a buoyancy-to-weight ratio of 3, a tensile strength in excess of 1.8×10^5 N (40,000 lb_f) and an overall height of 100 cm (39 in.) the boom will perform well in its intended operating environment (calm or protected environments with waves up to 1 m [3 ft]) in conjunction with commercially-available fabric booms.

Deployment, sea-keeping, towing and retrieval characteristics of the Pocket Boom are all good. Oil containment tests at Ohmsett showed that the boom will contain oil up to the normal limits (0.4 m/s = 0.75 knots) and can withstand catenary tow speeds up to 1.5 m/s (3 knots) without failure. Exposure to burning oil does not affect the oil containment characteristics of the boom.

The boom was exposed to six hours of fire with full-scale heat fluxes: three hours of diesel fires in Mobile, AL and three hours of enhanced propane fires at Ohmsett. The boom survived this heat insult with only minor damage, none of which would have detracted significantly from its oil containment abilities. The final design of the connector section incorporates modifications to ensure that the boom's service life will be at least 1,000,000 wave cycles. This is equivalent to greater than 45 days at sea in Sea State 3.

The complete design and fabrication drawings for the boom are contained in the project report. The boom may be obtained commercially from Applied Fabric Technologies, Inc.

13.0 Acknowledgements

The authors would like to acknowledge the late Ian R. McAllister, P.Eng. for his design of the original Dome boom.

The authors would like to thank the expert staffs of MAR, Inc, who operate Ohmsett for MMS, and also NIST and the USCG Fire and Safety Test Detachment, who operate the Little Sand Island test tank in Mobile, AL.

The project was funded by the following sponsors, listed in alphabetical order: Alaska Clean Seas; the Alaska Department of Environmental Conservation; Amoco Canada; the Canadian Coast Guard; Clean Sound; Cook Inlet Spill Prevention and Response Inc.; Exxon; the Minerals Management Service; the New York State Energy Research and Development Authority, Petro-Canada; and, the U.S. Coast Guard.

14.0 References

Bitting, K.R. and P.M. Coyne, "Oil Containment Tests of Fire Booms", *Proceedings of the Twentieth AMOP Technical Seminar*, Environment Canada, Ottawa, ON, pp 735-754, 1997

Buist, I.A. ,S.L. Ross, B.K. Trudel, E. Taylor, T.G. Campbell, P.A. Westphal, M.R. Myers, G.S. Ronzio, A.A. Allen and A.B. Nordvik. *The Science, Technology and Effects of Controlled Burning of Oil Spills at Sea*, Marine Spill Response Corporation Technical Report Series 94-013, Marine Spill Response Corporation, Washington, DC, 382 p, 1994.

Buist, I.A., W.M. Pistruzak, S.G. Potter, N. Vanderkooy and I.R. McAllister, "The development and testing of a fireproof boom", *Proceedings of the 1983 Oil Spill Conference*, API/EPA/USCG, Washington, DC, pp 43 - 51,1983.

Burkes, J.M., *Formulation of new fireproof boom designs*, Southwest Research Institute Project No. 06-6075, Draft Report to Marine Spill Response Corporation, Washington, DC, 1994.

Dome Petroleum Ltd., *Fireproof boom development - OHMSETT Trials*, Canadian Offshore Oil Spill Research Association Report CS3, Calgary, AB, 1981.

Dome Petroleum Ltd., *Fireproof boom field trials*, Canadian Offshore Oil Spill Research Association Report CS9, Calgary, AB, 1983.

McCourt, J., I. Buist, B. Urban, W. Schmidt, D. Devitis and J. Mullin. "Ohmsett's Propane-fuelled Test System for Fire-Resistant Boom". *Proceedings of the Twenty-Second AMOP Technical Seminar*, Environment Canada, Ottawa, ON, 1999

SL Ross Environmental Research, *Re-engineering of a Stainless Steel Fire Boom for use in Conjunction with Conventional Fire Booms*, Draft Report to MMS *et al.*, Herndon, VA, 1999

Walton, W.D., W.H. Tilley, J.V. Mullin and R.R. Hiltabrand, "Evaluating a Protocol for Testing Fire-resistant Oil Spill Containment Boom", *Proceedings of the Twenty-First AMOP Technical Seminar*, Environment Canada, Ottawa, ON, pp 651-672, 1998