AN EFFECTIVE LOW-COST FIREPROOF BOOM

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ABSTRACT: *The design objectives for a fireproof floating oil-containment barrier were developed, and a boom was designed, produced, and tested. At a cost comparable to that of conventional equipment of similar size, the boom is equally effective at retaining oil in a current, withstands exposure to burning oil, and can easily be restored for reuse if damaged by severe wave action or rough handling.*

In the mid-sixties, *in situ* burning behind an improvised log barrier was the primary oil removal method used to clean up a crude oil spill into a river.[3] Subsequently, a large-scale arctic experiment again demonstrated that floating oil could be effectively burned away *in situ* if certain criteria were met.[1]

One of the conditions essential to the success of this technique is that the oil must be prevented from spreading freely on the surface of the water. In the absence of natural features to provide the required containment, a man-made barrier of adequate fire resistance must be deployed. A number of such devices have been patented and at least two designs have been offered commercially.[4] A durable stainless steel fireproof boom with proven oil retention and fireproof capabilities has been developed by Dome Petroleum.[2] The basic objective of the present project was to develop an economical, lightweight, reusable fireproof boom by making use of less-costly modern materials.

Approach

The project was divided into five phases. The first phase produced a conceptual design. This was followed by a small-scale laboratory testing phase that included subjecting test sections to oil, water, and fire. The third phase subjected a full-size boom assembly composed of seven different segments to prolonged exposure to burning oil. Durability was assessed and oil retention capability was measured in the U.S. Environmental Protection Agency's (EPA) Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) facility in the fourth phase. Finally, following minor structural repairs and modification, operational handling qualities were determined in a sea trial conducted by the Canadian Coast Guard (CCG) at their Mulgrave, Nova Scotia base.

Design

Based on a literature review and discussions with a number of individuals familiar with the use and requirements of oil containment booms, the following design requirements were established.

1. Contain burning oil without severe damage from prolonged exposure to temperatures between 660°C and 904°C
2. Be easily deployed, handled, and recovered by existing ships
3. Have provisions for anchoring and towing, and be easily towed at two knots
4. Be low enough in cost to encourage widespread use
5. Be constructed of standard materials and be able to withstand normal operational wear and tear
6. Have a freeboard of about 300 millimeters (mm) and a draft of about 400 mm (600 mm and 800 mm respectively in the case of a larger version for offshore use)
7. Conform well to waves
8. Be able to be manufactured and deployed quickly in an emergency

A bottom-tensioned fabric skirt suspended from a number of rigid floats strung together on a central tow cable was the basic arrangement adopted. The first concept chosen for withstanding fire was to have an inner wicking layer to continuously cool the outer surface by the evaporation of water. This is the same principle that was used by North American Indians to boil water in birch-bark containers. A polystyrene beadboard flotation core covered by an absorbent wicking material such as phenolic foam was encapsulated by a protective layer of fiber-reinforced refractory cement skin. The skin was perforated to vent the vapor generated. As an alternative, Pittsburgh Corning Limited Foamglas high temperature foam was substituted for the polystyrene beadboard because of its higher maximum service temperature of 482°C instead of the 100°C temperature at which polystyrene begins to soften. A third design combined a Foamglas core with the fiber-reinforced refractory cement cover and omitted the intermediate wicking layer.

A plug-and-socket arrangement was the initial choice for obtaining oil-tight yet flexible joints between boom segments. This soon was abandoned in favor of a simpler ball-and-socket combination.

Test program

Phase 1. Testing in the laboratory evaluated the following for suitability as skin material: sprayed-on phenolic resin; polymer-modified cement with and without glass fabric reinforcement; polymer-modified refractory cement; and glass fabric-reinforced refractory cement. Simple bending, strength, fire resistance, impact, tearing, abrasion, and flexibility tests were performed. Three possible wicking materials were examined for their absorptive properties by measuring the time to saturation and the weight of water absorbed.

Phase 2. Three boom segments, one of each of the three designs just described, were each subjected to a 10-minute burn in a small water tank. The tank was partially filled with water and the oil was added (22 liters —l— of automotive diesel and 4 l of gasoline).

Phase 3. The locale was a small ice-covered pond. The ice was broken over a sufficiently large area to allow the seven test segments to be strung on a steel cable and formed into a shallow catenary. Thermocouples were embedded in three segments just under the refractory cement skin on the side adjacent to the flames. Three segments had the Foamglas core and no wicking layer. Their average

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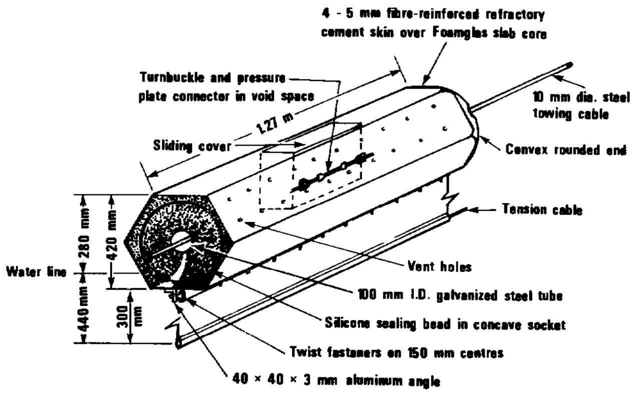

Note: Standard boom segments do not have the void space and towing cable connector assembly

Figure 1. Construction details—GemEng prototype boom segments

before-test dry and wet weights were 68.5 kilograms (kg) and 70.1 kg respectively. The other four segments had the expanded polystyrene beadboard core protected by a 25 mm wicking layer (phenolic foam in two and low density urethane foam in the remainder). One of the last pair had a cavity for a cable connector assembly. A hose was led under the ice at the edge of the pond and automotive diesel fuel was injected underwater within the curve of the boom using a hand-pump. About 295 l was injected before the fire was started and the remaining 930 l was pumped in as necessary to sustain the burn for about 47 minutes.

Phase 4. A 23 m prototype boom was deployed in a catenary from the main OHMSETT towing bridge with 4.6 m leaders attached to tow points 10.4 m apart. It was made up of three sections, each consisting of a fabric skirt suspended beneath a caboose and five of the standard segments as illustrated in Figure 1. A tow-back line was shackled to the central tow cable one segment from the middle of the boom apex and secured to the OHMSETT auxiliary bridge. The segments were manually fabricated without the aid of production tooling, so they were probably slightly heavier than production segments would be. The average dry and wet weights were 60.5 kg and 64.4 kg respectively, a reduction of 6-to-8 kg per segment compared to the Phase 3 version.

A total of fourteen test runs were made to measure oil retention capability. Six were calm water tests, two were with 0.2 m by 9.4 m waves, three with 0.4 m by 7.0 m waves and three with 0.2 m by 1.4 m waves. All waves were regular. Prior to each run the boom was preloaded with 0.19 cubic meters (m^3) of Circo-X heavy oil. This test oil has a normal specific gravity of 0.94 and a viscosity of 1300 centistokes at 28.8°C.

Three calm water burning tests were done using Murban crude oil. A preload of 76 l was augmented during each run with four 23 l additions to sustain burning. These runs were at 0.5 knots, 0.25 knots and 1.25 knots respectively.

Following the tests with burning oil, the boom was towed the length of the tank at 3.5 knots under calm conditions. Then, after allowing time for a 0.63 m harbor chop to build up, the boom was towed slowly back and forth for 45 minutes to further assess its durability.

Phase 5. Although the damage sustained at OHMSETT could easily have been repaired in the field, the work was done at the manufacturer's facility while modifications were made to attach the skirt more securely to the floats and correct the tendency of the caboose segments to tip to one side. A metal backing strip was inserted inside the skin to distribute the load from the skirt support angle, the twist fasteners were replaced by studs and bolts, and the skirt was sandwiched between the original angle and a second one. The caboose sections were inverted in the process, and the beads of silicone were replaced with silicone tubing.

Following reassembly on shore at Mulgrave, the full 30.5 m length (four sections of six segments each) was moored for four days in a shallow catenary between two buoys in about 20 m of water some 300 m from shore. The area is typical of large harbors. Conditions varied during the period and included choppy waves about 0.5 m high that persisted for several hours.

Test results

Phase 1. The laboratory tests showed that all of the candidate coatings would be suitable, but once the polymer-modified materials were exposed to fire and the polymer was burned off, the skins would no longer be strong enough for handling and transportation. The glass-fabric-reinforced refractory cement was chosen for its low cost and high temperature resistance. One type of phenolic foam was found to have superior absorption and wicking properties. Although both materials when dry absorbed diesel fuel almost as well as water, oil absorption was minimal if they were pre-wetted with water.

Phase 2. The heat caused minor surface spalling and the need for venting holes was evident even though the skin was not structurally weakened. The cores were undamaged, indicating that: (a.) the wicking system provided adequate protection for the polystyrene core; and (b.) the Foamglas does not require wicking system protection.

Phase 3. The wicking system reduced the skin temperature to 900°C from 950°C, which was insufficient to preserve the core. The polystyrene was completely destroyed in all segments in which it was used. As in Phase 2, the Foamglas cores were undamaged. Surface spalling still occurred despite the presence of vent holes, but it was clearly less severe in the segment with the closest hole spacing. The average weight loss during the burn was 1.2 kg per segment.

Phase 4. The oil retention performance surpassed expectations as shown graphically by Figure 2. Table 1 gives the measured loss rates for each of the four test conditions. The resulting first loss points as illustrated by Figure 3 are listed in Table 2. There was some loss of oil by splash-over, but only with the 0.2 m by 1.4 m wave. Under all of the other test conditions, the oil loss was the result of entrainment initially, followed by a combination of entrainment and drainage as speed increased. There was no perceptible loss of oil through the joints except when the boom was stationary, and that seepage was only minimal.

The fire tests summarized in Table 3 confirmed the ability of the boom to withstand the heat from a crude oil fire. Some spalling occurred during the first few minutes of each burn but ceased partway through. The cumulative effect was noticeable, but the boom was still

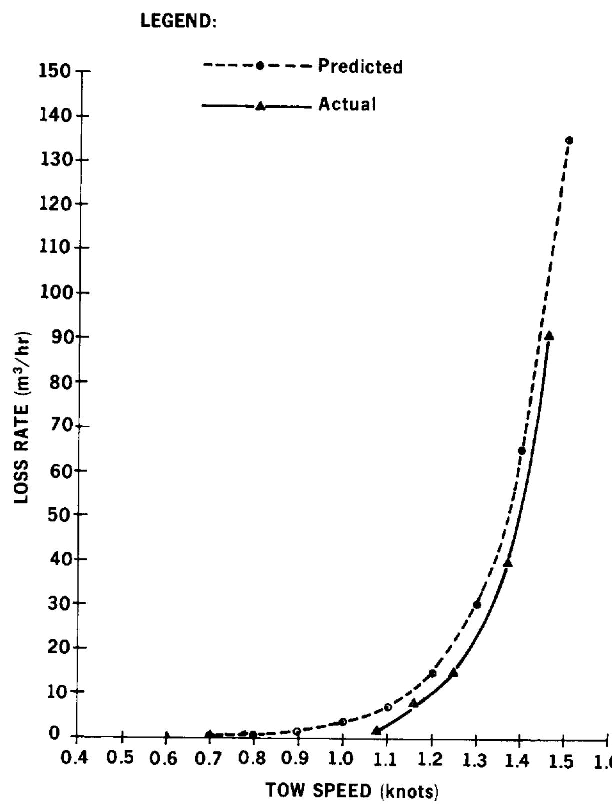

Figure 2. Loss rates—GemEng prototype boom

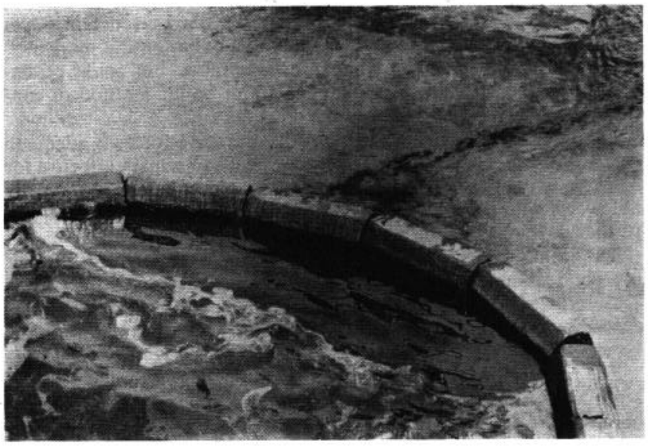

Figure 3. First loss point—GemEng prototype boom

serviceable on completion of this phase of the testing and the damage was easily repaired afterwards.

The boom contained the burning oil completely during the two slow-speed runs as shown in Figure 4. The speed of the fast run was chosen to ensure that oil would be entrained, and the amount of entrainment appeared to be similar to that experienced during the earlier tests with the Circo X heavy oil. A small amount of burning oil escaped through the ball-and-socket joints and ignited some of the

Table 1. Measured loss rates for the GemEng prototype boom

Condition	Tow speed (knots)	Loss rate (m^3/hr)
Calm	1.08	1.5
	1.16	8.2
	1.25	15.0
	1.37	39.8
	1.46	90.8
Regular waves		
(a.) 0.2 m × 9.4 m	1.15	8.0
	1.24	8.6
(b.) 0.4 m × 7.0 m	0.90	3.1
	0.97	4.8
	1.06	15.1
(c.) 0.2 m × 1.4 m	0.67	4.4
	0.78	6.8
	0.88	5.3

Table 2. First loss speeds for the GemEng prototype boom

Surface condition	Speed (knots)
Calm	1.1
0.2 × 9.4 m wave	1.1
0.4 × 7.0 m wave	0.9
0.2 × 1.4 m wave	0.7

Table 3. Summary of crude oil fire tests

Tow speed (knots)	Burn duration (min:sec)
0.50	4:21
0.25	7:25
1.25	1:44

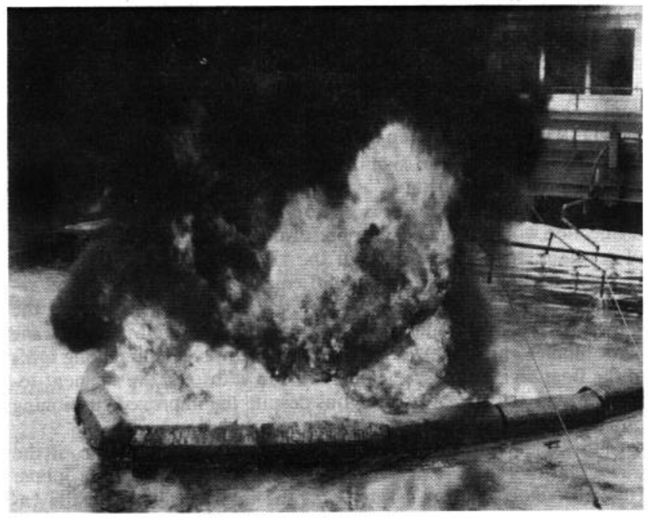

Figure 4. GemEng prototype boom and burning crude oil

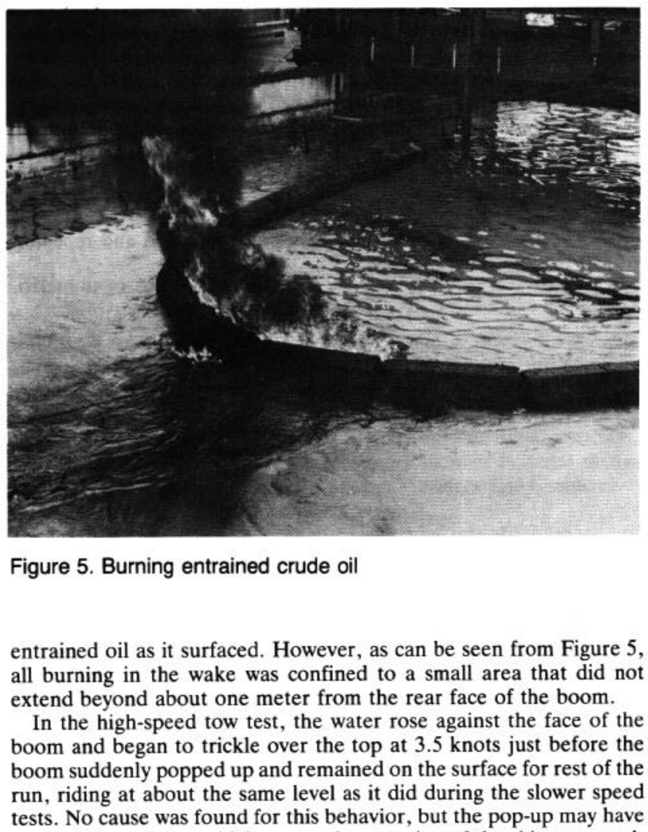

Figure 5. Burning entrained crude oil

entrained oil as it surfaced. However, as can be seen from Figure 5, all burning in the wake was confined to a small area that did not extend beyond about one meter from the rear face of the boom.

In the high-speed tow test, the water rose against the face of the boom and began to trickle over the top at 3.5 knots just before the boom suddenly popped up and remained on the surface for rest of the run, riding at about the same level as it did during the slower speed tests. No cause was found for this behavior, but the pop-up may have marked the point at which some minor tearing of the skirt occurred.

The boom rode the 0.63 m harbor chop well in both tow directions. However, the individual segments slid back and forth along the cable passing through them and frequently collided with each other. The impacts caused some deterioration of the ends, including the detachment of two of the reinforcing fiber "dishes." The most severe damage occurred at the point where the tow-back cable was attached by a large shackle to the central tow cable. The resulting misalignment caused the nose of one segment to impact the edge of the mating cavity, breaking it away and eroding some of the Foamglas core.

Early in the testing there were problems with the method used to attach the skirt to the floats. Some of the bolts securing the aluminum angles to the floats pulled through the skin and most of the others required retightening on occasion. Eventually the skirt had to be wired to three of the segments to complete the oil retention tests in waves; somewhat surprisingly, that temporary fix also survived the burn runs and the subsequent abuse. The combination of oil and water made the twist fasteners totally ineffective in short order, and they were converted to bolts to hold the skirt to the angles. The only other design problem encountered was instability of the caboose sections: once the cavity filled with water they tipped to one side. Weights were added to keep these segments upright during the trials.

Phase 5. Although no significant problems were encountered assembling the boom on shore and deploying it from there, handholds would have helped and it was obvious that an improved method of connection would be needed for performing those tasks from the deck of a vessel. Insufficient slack in the skirt in way of the junctions between sections caused minor difficulty during assembly, and resulted in some skirt tearing during the exposure to waves and the subsequent recovery operation. As in the tank at OHMSETT, wave conformance and response was excellent. However, the mating faces of the float segments were again unable to withstand the segment-to-segment impacts in wave conditions despite the improved cushioning provided by the silicone tubing.

Cable clamps and turnbuckles loosened under the action of the waves and there was at least some deterioration at all of the joints. However, most damage occurred at the interface between the cabooses and the adjacent standard segments. While the inversion of the cabooses cured the tilting experienced during Phase 4, the resulting loss of buoyancy caused the cabooses to float several centimeters lower than the other segments. This misalignment resulted in skin failure and core erosion similar to that sustained at the tow-back cable connection point at OHMSETT. The modifications to attach the skirt more securely proved effective and no loosening or detachment occurred.

Conclusions

The GemEng boom is able to withstand prolonged and repeated contact with burning oil.

Its ability to contain oil in a current and in the presence of waves is at least equal to that of any conventional boom on the market.

Operational handling qualities are acceptable, but could be improved by the addition of handholds and a better method of connecting the cables.

The boom's structural ability to withstand wave forces is adequate for short-term applications when it only needs to remain effective for a few hours. However, its capability in this respect is still substantially below what is considered to be attainable at reasonable cost and further development to that end is required.

The 45-minute exposure to the 0.63 m chop in the OHMSETT tank is a good simulation of real-world conditions.

Deterioration resulting from exposure to fire and structural damage caused by rough handling and environmental forces would normally be repairable at field level.

The materials used and the simplicity of the design should result in a production cost that is comparable to that of current conventional booms.

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