FIRE-RESISTANT BOOMS: FROM TESTING TO OPERATIONS[1]

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ABSTRACT: *A great deal of concern and effort has gone into testing various fire resistant booms since the 1993 Newfoundland Offshore Burn Experiment (NOBE), when it became apparent that there were potential limitations in the performance of commercially manufactured fire booms. One of the major questions that arose after this experiment was the capability of fire booms to adequately support real in situ burn operations. Towing experiments on selected booms both at sea and in test tanks, coupled with data from burn tests based on proposed ASTM-F20 Standards, have begun to new reveal facts about the performance of these booms. Results of the at-sea towing tests indicate that, in general, booms with higher buoyancy-to-weight ratios attained higher critical tow speeds, sustained higher towing tensions, and maintained better wave conformance. Results of towing tests of booms containing oil at the OHMSETT test tank facility suggest that fire booms should perform successfully when tow speeds of less than 1.0 knot is maintained. Burn tests at the U.S. Coast Guard Fire and Test Detachment revealed that fire booms could be expected to maintain some structural stability and freeboard for at least three 1-hour burns during a deployment.*

Introduction

It has been known for quite some time that burning of oil at sea as an oil spill cleanup countermeasure would be successful as long as a 2-5 mm layer of oil above the water surface was maintained. This oil layer acts as an insulator and prevents the water from acting as a thermodynamic heat sink, which decreases temperatures necessary for ignition or continuous burning.

Fire booms have been developed to corral oil and maintain it at a suitable thickness in order to complete a successful burn operation. Several experiments and tests were conducted on a variety of fire booms before 1993, but realistic conditions to test these booms at sea were not possible because permits to spill oil were too difficult to obtain and the cost of tests at sea were too expensive. Finally in August of 1993, the Newfoundland Offshore Burn Experiment (NOBE) not only provided the first major opportunity to test fire booms under realistic wave conditions, but also provided a wealth of information on *in situ* burning at sea. This was essential if *in situ* burning was to continue to be considered a potential major oil spill cleanup countermeasure.

The 3-M Fire Boom was used in the NOBE experiment; however, the efficiency of this boom soon became a subject of debate among scientists. The final, formal report on the experiment explained in detail the effect that burning had on the boom during the exercise (Gennrich and Vick, 1997). In general, the report indicated that two flotation log segments were lost on the boom during the experiment as a result of mechanical failure of the log pocket pieces including the stainless steel wire mesh and Nextel fabric. The fabric was missing in many places above the waterline and the wire was embrittled and torn open.

Other specific details can be found in this report, but what is most significant is that the loss of fabric high above the waterline did not contribute to the loss of flotation or a major loss of oil containment. In addition, it was noted that larger diameter booms are exposed to higher temperatures at the top of the boom than are smaller diameter booms. Thus, their durability is decreased faster than smaller booms, yet their freeboard must be maintained to prevent the loss of oil under wave action. The challenge at NOBE was to determine how long a boom's structure coul remain stable before major loss of oil occurs.

During the NOBE experiment, many scientists observed oil burning on the opposite side of the corralled oil or behind the boom. This phenomenon was associated with boom failure and deterioration of the boom at that time, but new information, discussed later, indicates that there may be another source contributing to this phenomenon. The physical properties surrounding this have not been identified or quantified.

In any case, it became evident from the NOBE experiment that the U.S. Coast Guard as well as other agencies and institutions had to learn more about the operational characteristics of fire booms and their performance in order to successfully implement future *in situ* burns. The ideal situation would be to conduct actual at-sea burn experiments like NOBE; however, the cost of such experiments and the ability to secure an oil spill permit have influenced the effort to obtain this knowledge. The stage was thus set to begin field tests and meso-scale fire burn tests over the next few years that would supply the necessary information to improve fire boom performance and ease of deployment under real *in situ* burn conditions at sea. In order to obtain this information, a series of unique tests were proposed and carried out by the U. S. Coast Guard Research and Development Center and others.

Introduction to at-sea trials

Initial full scale, at-sea containment boom tests were conducted to provide the quantitative performance data to predict under what environmental and operational conditions a boom would fail. Two series of at-sea towing tests were performed without oil to determine the dynamic response of conventional containment booms (Phase 1) and fire-resistant booms (Phase 2) at different towing speeds under various sea conditions.

In 1994, the U.S. Coast Guard (USCG), U.S. Navy (USN) and Minerals Management Service (MMS) collaborated in a joint effort with the Marine Spill Recovery Corporation (MSRC) to conduct Phase 1 towing tests for conventional containment booms in lower New York Harbor Bay and in the Atlantic Ocean east of Sandy Hook, New Jersey (Nordvik *et al.*, 1995a; Sloan *et al.*, 1994). The objective of these tests was to measure and characterize the performance of the following booms at existing sea states (calm sea and sea state 2): American Marine 3-M Fire Boom, USCG inflatable oil containment boom manufactured by Oil Stop, and USN Model USS-42 boom. Norlense's barrier boom was also tested but was not included in this comparison since it did not submerge. The *New Jersey Responder*, a 208.5-foot MSRC oil spill response vessel (OSRV) was the main towing vessel supported by the *USCGC Penobscot Bay*, a 140-foot icebreaking tug and the *USCGC Point Francis*, an 82-foot patrol boat.

Phase 2, at-sea towing tests of fire booms, was conducted in 1995 at a site offshore from Galveston, Texas (Nordvik *et al.*, 1995b; Sloan *et al.*, 1995). MSRC led the cooperative effort supported by the Texas General Land Office (TGLO), MMS, and several boom manufacturers. Three fire booms including Kepner Plastic SeaCurtain Firegard, Oil Stop Autoboom, and Applied Fabrics Pyroboom were tested in the same manner as the Phase 1 tests under sea conditions that ranged from a calm sea state to sea state 3. MSRC's *OSRV Texas Responder* and *OSRV Gulf Coast Responder* towed the booms and were assisted by their boom handling boats.

For both phases, three large vessels towed the booms in a side-by-side, catenary configuration while maintaining a constant sweep width between the towing vessels. Data were recorded for 10 minutes during each test once the towing vessels were able to maintain the desired towing speeds. A functional test was also performed for each boom to obtain the speed at which submergence or planing failure at the apex occurred. Other performance parameters, such as splashover, skirt attitude, ease of deployment, and structural failure were also taken into consideration in order to accurately predict and assess each boom's behavior at sea.

Results of at-sea trials

Figure 1 combines the data from Phase 1 and Phase 2 to demonstrate the relationship of the estimated freeboard of conventional and fire-resistant booms as a function of towing speeds. The critical tow speed is the speed at which the boom submerges at the apex and the freeboard is reduced to zero.

Phase 1 booms with higher static B/W (buoyancy versus weight) ratios were able to attain higher critical tow speeds, to sustain higher tow tensions, and to maintain a more accurate wave conformance than booms with lower static B/W ratios. The higher buoyancy provided the booms with more lift and wave following capability to waves both perpendicular and linear to the boom (Sloan *et al.*, 1994). During calm sea conditions, submergence of the booms occurred at tow speeds between 1.5–2.5 knots. The Oil Stop boom, which had the highest B/W ratio (20:1), did not submerge until 2.5 knots when major splashover was observed. Submergence of the USS-42 boom (8:1 B/W ratio) occurred when the boom was accelerating from 1.5–2.0 knots. Two of its flotation chambers were punctured during deployment and deflated during testing. The 3-M Fire Boom, which had the lowest B/W ratio (5:1), sustained mechanical failure of its connectors and submerged at 1.5 knots (Nordvik *et al.*, 1995a).

Materials used for most of the fire booms were found to be more fragile than those of conventional booms. In fact, all of the Phase 2 fire booms were damaged during deployment or retrieval (Sloan *et al.*, 1995). The difficulties experienced while deploying and retrieving the fire booms during Phase 2 suggest improvements are needed to current fire boom designs.

Figure 2 combines the data from Phase 1 and Phase 2 to demonstrate the relationship that exists between a boom's B/W ratio and its critical tow speed. Pyroboom is not included in this comparison since it did not submerge.

Performance results of Phase 2 were consistent with those of Phase 1, in that booms with higher B/W ratios attained higher critical tow speeds, sustained higher towing tensions, and maintained a more accurate wave conformance. Submergence of the fire booms occurred between 0.6–2.0 knots. Autoboom, which had the highest B/W ratio (13.5:1), attained a critical tow speed of 2.0 knots before submergence occurred. Pyroboom, which was tested using a non fire-resistant material (8:1 B/W ratio), reached a critical tow speed of 1.0 before the boom began to hydroplane. Firegard, which had the lowest B/W ratio (2:1), submerged between 0.5–0.6 knot (Sloan *et al.*, 1995).

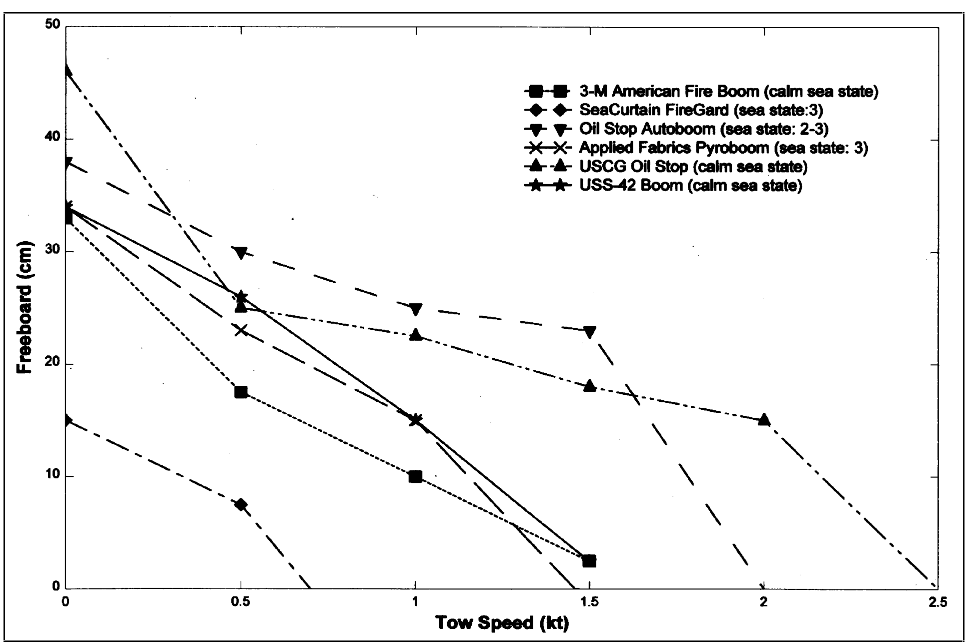

Figure 1: Boom freeboard for conventional booms and fire booms versus tow speed (after Nordvik *et al.*, 1995b).

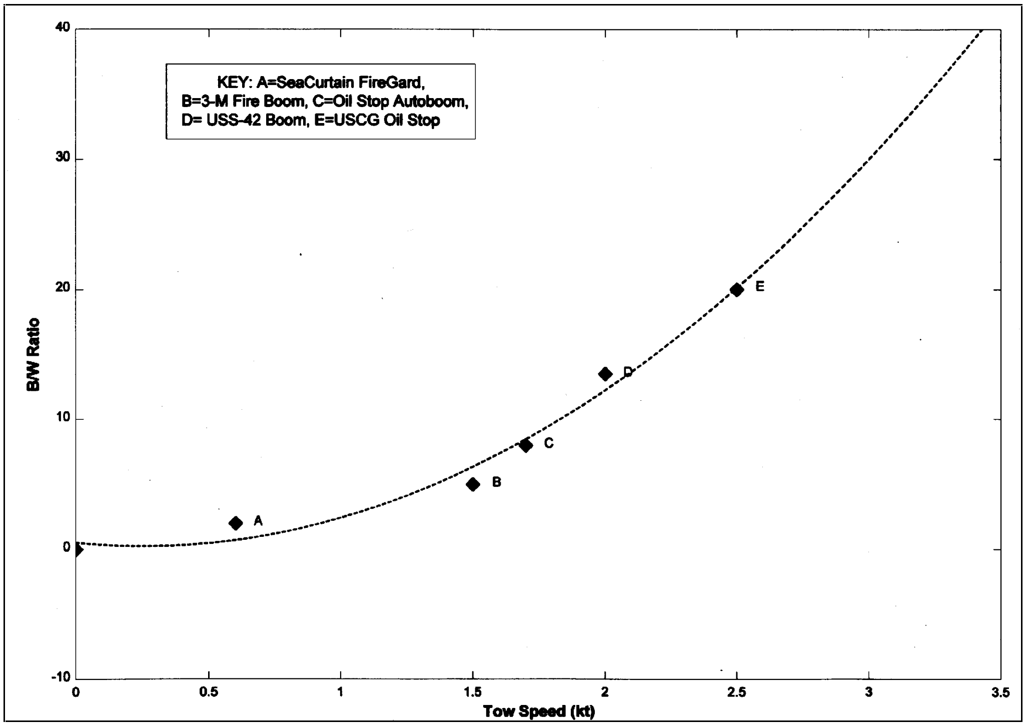

Figure 2: Buoyancy to weight (B/W) of conventional booms and fire booms versus tow speed (after Nordvik *et al.*, 1995b).

From these tests, it became evident that booms with higher B/W ratios will be able to sustain higher boom tow speeds and to perform in higher sea states by maintaining an acceptable freeboard and reserve buoyancy (Nordvik *et al.*, 1995b).

OHMSETT tests

Because facilities to simultaneously conduct towing and burning tests do not exist, it was essential to first test the towing and containment characteristics of commercial fire booms at the OHMSETT facility in Leonardo, New Jersey. Approximately five (5) commercial fire booms were tested in 1996, under a variety of conditions (Bitting and Coyne, 1997; DeVitis *et al.*, 1998).

In general, conclusions can be interpreted from the critical tow speed of these booms during calm surface conditions as expressed in Table 1. The booms failed at tow speeds between 2.0 and >6.0 knots due to planing and submergence of the boom. Mechanical failure did not occur. Oil loss tow speeds were also conducted on the five booms. Results (Figure 3) indicate that oil loss begins at about 0.75 knot under four different wave conditions. Additional information indicates a gross loss of oil at about 1.0 knot. This information is in agreement with measurements taken in the field.

Tests in the field with the OHMSETT instrumented boom, Ro-Boom and Vikoma ocean boom conducted near Newfoundland in 1987 indicated no significant loss of oil from the booms until currents on the boom reached approximately 0.75-1.0 knot with wind speeds of approximately 15 knots and a Sea State between 3 and 4 (Buist and Potter, 1988). Although these booms have more freeboard and a higher buoyancy/weight ratio, and are structurally more sound than fire booms, they display the same inherent engineering properties as fire booms in their ability to lose oil at approximately 0.75–1.0 knot of current.

Table 1. Critical tow speed values for five fire booms.

Test boom	Critical tow speed (kts)	Mode of failure
American Fire-boom	2.25	Submerged
Dome Boom	2	Planing
PyroBoom	2.75	Submerged
Spill-Train	> 6.0	No Failure
Oil Stop	3.5	Submerged

Source: DeVitis *et al.* (1998).

Burn tests

The U.S. Coast Guard spent over a year trying to find an adequate location and facility to test fire booms in North America. Difficulties encountered included finding an outdoor wave tank that could accommodate oil, satisfying burn permits requirements, and reducing prohibitive costs. Finally, in 1997, the USCG decided to build a wave tank capable of evaluating 15m sections of fire boom by subjecting a 5m-diameter circle of the boom to diesel fire and waves of approximately 0.15 m.

This tank was constructed at the U.S. Coast Guard Fire and Test Detachment on Little Sand Island, Mobile, Alabama. In 1997, tests were conducted at this site on five different fire booms according to draft ASTM-F20 Standards Guide for In Situ *Burning of Oil Spills on Water: Fire Resistant Containment Boom*" This draft provides only general guidelines to be used, but the series of experiments conducted at the Mobile facility helped evaluate the protocol outlined, and at the same time produced new data on fire boom performance (Walton *et al.*, 1998). [To avoid confusion, readers should refer to the finalized procedures when they become published by ASTM.]

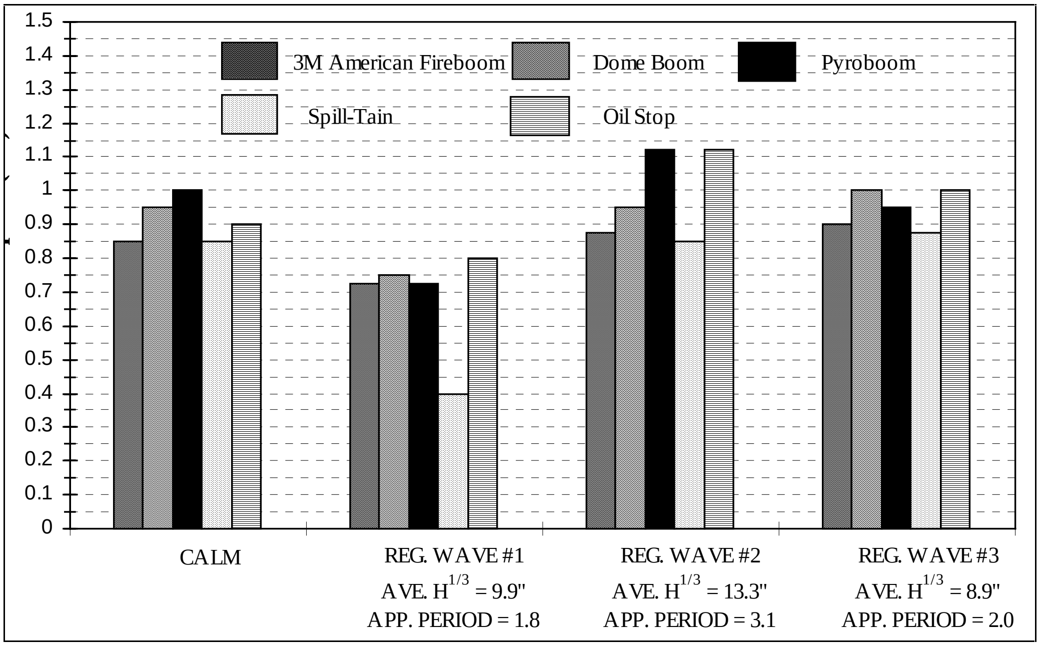

Figure 3: First loss tow speeds versus wave condition (after Bitting *et al.*, 1997).

The draft ASTM-F20 procedures that were used call for a burn exposure and cool-down cycle, consisting of one hour of burning followed by one hour of cooling the boom while it is subjected to wave action. This cycle consists of 3 1-hour burn periods and two 1-hour cool-down periods. The booms are required to maintain adequate flotation during the experimental series and hopefully contain 10mm–20mm in thickness of oil without loss.

The wave tank, test configuration, instrumentation, boom description, and test procedure conducted at the Mobile facility have been adequately discussed (Walton *et al.*, 1998).

Three of the five booms tested completed the proposed draft ASTM-F20 procedure. Degradation and destruction of materials in these booms occurred as each successive burn was implemented on the boom. The structural stability of these booms was maintained below the waterline and as high as 100 mm above the waterline. However, the top portion of each boom which was subjected to higher temperatures, received enough destruction as to reduce the amount of freeboard available for holding oil on subsequent burns.

Two of the three booms completing the test procedure were held together in sections. Very little oil was identified as penetrating or leaking through these sections at their connections during the tests. The relatively rigid stainless steel boom did exhibit more loss of oil at these locations. This was attributed to its rigid design for the short turn radius it was subject to during the test procedure. Under operational conditions one would not expect this particular type of stress on that boom.

The fabric on some of the booms melted at several points exposing metal mesh and other materials. However, the booms containing polymers did not rupture when exposed to high temperatures and cooling. These booms did not become brittle enough when cooled to undergo abundant fractures at the macroscale. Microscopic investigation may prove otherwise.

The three booms that completed the proposed draft ASTM-F20 sequence sustained some charring during the tests, but maintained enough structural integrity below the waterline to hold the oil which is necessary for successful *in situ* burn operations.

Two of the fire booms tested at Mobile in 1997 did not finish the proposed ASTM-F20 sequence. A water-cooled boom ruptured during the first hour of burning. This was an experimental boom, the first of its kind to be rigorously tested. The boom operated effectively, as long as the water was pumping through it. Once the water supply failed, the boom collapsed. Mechanical difficulty between water hoses and the boom connections may have existed since all were under great stress from wave action. In addition to this, water filtration problems affecting the pump's performance may have also influenced the collapse of the boom.

The second boom that did not complete the test sequence was a boom with a fabric covering and a flexible metal flotation. This boom completed the first 1-hour burn, but during the first cooling period, the manufacturer called for a halt in the test. The fabric of the boom deteriorated and failure in the boom was imminent. Two sections of the boom were inadequately held together by a wire-tie which was eventually considered a quality control problem for this particular boom and test. This connection was on the verge of disintegration.

Finally, the wind speed and direction impinging on the fire influenced the burn characteristics of all the booms tested. Maximum thermal exposure to the booms varied during each test. Its greatest effect on the boom was in the downwind direction of the burn. However, this direction could shift as much as 90° during a burn.

One particular phenomenon observed for all of the booms during the tests was intermittent burning outside the boom, always in the downwind direction even when the wind was perpendicular to the direction of wave travel. It did not appear that this was a result of oil leaking through a boom. It is now believed that a small quantity of oil is being transported over the boom by fire and wind. The oil outside or behind the booms would burn for a brief time and extinguish as the vapors were consumed. The mechanism for this is unknown at this time and subject to further scientific investigation. However, future users of booms during *in situ* burn operations can expect this to occur during the early phases of burning at sea and should not necessarily believe that the boom has failed at this point in time.

Conclusions

A synopsis of the scientific research and testing that has taken place on the performance of fire booms since the 1993 Newfoundland Oil Burn Experiment (NOBE) reveals information that may be used as a temporary guideline for future *in situ* burn operations:

Fire booms should perform successfully while they are being towed during an *in situ* burn operation if they maintain a speed through the water not exceeding 0.75-1.0 knot. In this range, oil loss from the boom can be expected, with a major loss of oil occurring near 1.0 knot. Speeds in excess of 1.0 knot may cause submergence of the boom when waves are present and speeds in excess of 2.0 knots may cause submergence of the boom during calm water conditions. It is advised that the towing speed of fire booms should not exceed 1.0 knot during towing operations.

Operational personnel must evaluate the power of the ship they wish to use for towing fire booms to make sure they have the force to tow their booms in the water and still be able to maintain a maximum speed of 1.0 knot without effecting the ship's performance up to or during that speed. It is anticipated a minimum bollard force of 10,000 lbs would be required of 41-foot support vessels to tow booms successfully (Nash and Molsberry, 1995).

The three fire booms that have completed the draft ASTM-F20 sequence in Mobile could be used by operational personnel during an *in situ* burn operation. It is expected at this time that these booms would maintain some structural stability and freeboard for at least three 1-hour burns and perhaps longer, during a deployment. However, this structural stability is still subject to a determination of whether the booms are capable of being towed after they have been introduced to multiple burns. The U.S. Coast Guard plans to test this by 1999 at the OHMSETT facility.

Biography

Robert R. Hiltabrand is a 1970 graduate of Louisiana State University and has a Ph.D. in Geochemistry. He spent 2 years teaching environmental sciences at the University of Washington and at Eastern Washington University. He has 28 years of experience at the U.S. Coast Guard Research and Development Center in Connecticut as a senior scientist, involved with research in marine environmental protection.

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