

Booms*

Edward Tedeschi

7 Border Street, Cohasset, MA 02025, USA

INTRODUCTION

A ‘Boom’ is a floating mechanical barrier used to control the movement of substances that float according to ASTM F-818 Standard Terminology Relating to Spill Response Barriers [1].

Since oil has been transported by sea, accidental spills have occurred from time to time, but only since the 1960s has its spillage along coastlines or within harbor areas caused enough public concern to demand that it be removed immediately. Large disasters, such as the grounding of the *Torrey Canyon* and the Santa Barbara drilling platform blowout, put pressure on the oil producing community to prevent spillage and to develop procedures and equipment to recover the spills that did occur. Experimental booms were introduced in the early 1960s but it wasn’t until later in the decade that their manufacture became commercially viable. Relatively crude booms to contain or control the spread of spilled oil were developed and some were assembled on site. Logs were tied together with old conveyor belting nailed between the ends; oil drums were strapped to plywood sheets connected with rubber or fabric; canvas was sewn over fishing floats knotted along a line. Although these booms were relatively effective in calm water when a small volume of oil was spilled, most of them were cumbersome to maneuver and they quickly failed when waves or current were present.

Spills in the early 1970s, along with growing environmental awareness, prompted legislators, both national and local, to require that the responsible parties clean up their act. World-wide entrepreneurial spirit spawned several dozen small manufacturing enterprises to meet local and, in some cases, international demand for cheap efficient booms.

In the mid-1970s, several events happened which shaped the spill response industry and started the evolution leading to the better products and response techniques which we use today. The Arab Oil Embargo of 1973 raised the price of a barrel of oil to the point that the cost of the product lost in a spill became relevant. US governmental agencies, including EPA, MMS and Coast Guard developed regulations that fined the spillers of even small amounts of oil. Money was spent by government and the oil industry on research and test facilities to understand the limits and differences of boom designs, resulting in improved performance. Oil terminals in most major harbor areas pooled their resources and formed local and regional oil spill response cooperatives [2]. The US Navy, being a large buyer of booms, contacted the American Society of Testing and Materials (ASTM) to see if they had any people working on the subject of spill response products in general and specifically on standardization of boom connectors. They did not, so they issued an invitation to the industry at-large to form a committee to write standards on that subject. Committee F-20 was born. It took 10 years to publish F-962 *Standard Specification for Oil Spill Response Boom Connector*, but along the way, over 40 consensus Standards [1] have been published to aid users and manufacturers alike in the selection of spill response products and guidelines for their use.

This chapter will discuss the types of booms available today, the problems associated with their use under various environmental conditions, special products for unusual situations, and also thoughts regarding future developments.

DESCRIPTION OF TYPICAL BOOMS

To fit the ASTM definition, booms are typically made up of four or five major components. The ‘membrane’

**Pure Appl. Chem.* 71(1) (1999). An issue of special reports reviewing oil spill countermeasures.

forms the barrier, 'flotation' is attached to the upper edge of the membrane to give it buoyancy, 'ballast' is attached to its lower edge to give it stability, one or more 'tension members', or the basic membrane, give the assembly the required strength, and as booms are manufactured in various length sections which have to be joined together during deployment, they are equipped with suitable 'connectors' at each end.

Most booms available today have a polymer coated fabric membrane, although some specialized booms utilize stainless steel or netting. Lightweight booms, for general clean up in harbors and rivers, use PVC or Urethane coated nylon or polyester fabric with total weights of 18–30 oz/sq yd. Typical tensile strengths are 300–600 lbs per inch of width. Open water/ocean booms are manufactured from heavier materials, while maintaining a high degree of flexibility for ease of deployment, retrieval and storage. Typical fabric weights vary between 30 and 100 oz/sq yd and tensile strengths between 500 and 2000 lbs per inch of width or more.

Most general-purpose booms have rolled sheet polymeric foam floats encapsulated within a pocket of the membrane; some have discreet molded foam floats bolted to the upper portion of an especially high strength fabric membrane (Kevlar[®] or Spectra[®]). Most open water or ocean booms utilize air for buoyancy, captured in a pocket of membrane material. Permanent booms all utilize molded float bolted to conveyor belting type membrane material of 80–200 oz/sq yd weight with tensile strengths of 1200–4000 lbs per inch. Ballast for small general purpose and open water/ocean booms is generally hot dip galvanized chain which doubles as the tension member. Most manufacturers enclose the chain in a pocket at the bottom of the membrane but some ocean boom manufacturers clip the chain intermittently to the membrane to allow it to better follow the wave motions. Several manufacturers of high strength membrane deployable booms and all permanent booms utilize lead weights bolted or self-riveted to the bottom of the membrane for ballast.

When booms are manufactured in sections that need to be joined in the field to make up suitable lengths of boom to surround vessels transferring oil, or for sweeping spills, connectors are required [3]. Many years were spent in order to write a connector consensus standard which fit the following criteria listed by representatives of the industry.

- 1 Possess adequate mechanical strength
- 2 Minimize oil leakage
- 3 Be sexless (neither male or female) or right/left handed
- 4 Be the full height of the boom of which it is part
- 5 Not impair the stability of the boom
- 6 Require no tools for assembly
- 7 Not reduce the freeboard of the boom, i.e. light weight
- 8 Be connectable in the water
- 9 Be readily cleaned of sand and debris
- 10 Be inherently safe to personnel
- 11 Be easy to install or replace
- 12 Not deform in normal usage

The ASTM Standard F-962 connector comes closer to meeting the listed requirements than any other commercially available design but as it is a compromise design, it has not yet been adopted as an international standard. Some connectors meeting the standard suffer from inadequate bending strength and it is hoped that the standard will soon be revised to address that problem.

Most connectors are adequate to transmit the tensile strength of the membrane from boom section to section but are limited by localized stresses to transmitting the loading imposed by high strength tensile members. Typically, tensile loadings above about 5000 lbs must be passed from tensile member to tensile member (around the connectors) through the use of shackles or quick links.

There are many booms designed for special tasks that will be mentioned later in the chapter.

THE ENVIRONMENT AND THE PROBLEMS IT IMPOSES

Imagine a totally calm body of water in which is floating a circle of boom. Oil is poured into the center of the circle. Assuming that the oil being poured has a specific gravity of less than one, the oil will spread rapidly on the surface from gravitational forces until it contacts the boom surrounding it. The boom will continue to contain oil within it until the depth of the membrane is exceeded, at which point the oil will leak under the boom and escape. A fairly small boom, in a reasonably large circle, will hold a large amount of oil.

When the wind blows, surface currents form in the water and oil, causing them to pile up against one side of the barrier, reducing its holding capacity. Waves result, which move the barrier up and down and sometimes the boom does not follow the wave's surface exactly so its holding capacity is further reduced. In other words, it has poor 'heave response.' Now let's introduce a current into the basic water body. Since the oil will all be moved downstream, we don't need the upstream half of our circle of boom. The upstream ends of the boom must be anchored or attached to boats. When so deployed, it is being used in a 'sweeping mode'. The current induced forces on the boom change its shape to a near catenary curve and its holding capacity diminishes rapidly as the current velocity increases. A head wave forms on the leading (upstream) edge of the oil [4] and at a velocity of about 1 ft/s, droplets of oil break away from the main body at the head wave. Some will rise and reunite with the oil retained behind the boom, while some will float under with the water and be lost. This phenomenon is called 'entrainment loss'. As current velocity increases, oil loss rate increases. Depending upon specific gravity, boom design and wave action, total loss of oil ('drainage loss') will occur at a velocity of about 2 ft/s. Forces on booms have been studied by many institutions [5], and can be calculated according to the following equations:

$$D = C_D [YSV^2L]/4g$$

$$\text{or } D = SV^2L$$

$$H = D \tan \theta$$

where D is the drag force, h is the side force, C_D is a drag coefficient (order 2) Y is the specific weight of the water, S is the skirt depth, V is the current velocity, L is the gap or span of the boom facing the current, g is the acceleration due to gravity, and θ is the angle between the boom and shore or between the boom and direction of travel of sweeping boats.

Wave action, with its inherent energy and internal circular current, adds to the containment problem. It has been shown conclusively that booms with high buoyancy to weight ratios (10:1 and higher) follow the water's surface, where the oil is situated, more closely, i.e. have better heave response, have lower drag forces and therefore hold the oil better than those with lower (5:1 and less) buoyancy to weight ratio (b/w) (see [5-7]).

The movement of oil on water is directly related to water current velocity and is affected by the direction of waves and wind added as vectors. Oil moves at approximately 3.5% of the wind velocity, measured at the standard height of 32 ft above the water's surface. The circular currents within waves tend to move oil in the direction of movement of the waves. Since most waves move with the wind, an additional velocity of about 1.5% of the wind velocity can be added. If the waves are not moving with the wind, there will be a slight deflection in the movement of oil, but the amount is insignificant and difficult to predict accurately.

Since booms start to lose oil in currents of about 1 ft/s, it is evident that it doesn't take much wind (\approx 15-18 knots) to move oil faster than the boom's ability to contain it successfully. It has been shown that there is a distinct advantage to at-sea sweeping of booms downwind [8].

The Netherlands *Oil Spill Slide Rule* [9] gives the relationship between the size of a spill, its spreading rate vs. time, evaporation loss, dispersion loss and emulsification over time. It is available for a small fee.

There are many manuals available on the use and deployment of booms for containment and deflection of spilled oil [10]. Many technical papers have been presented at the biannual International Oil Spill Conference. Environment Canada sponsors the Arctic and Marine Oil Spill Program and their published proceedings should be searched for more specific information.

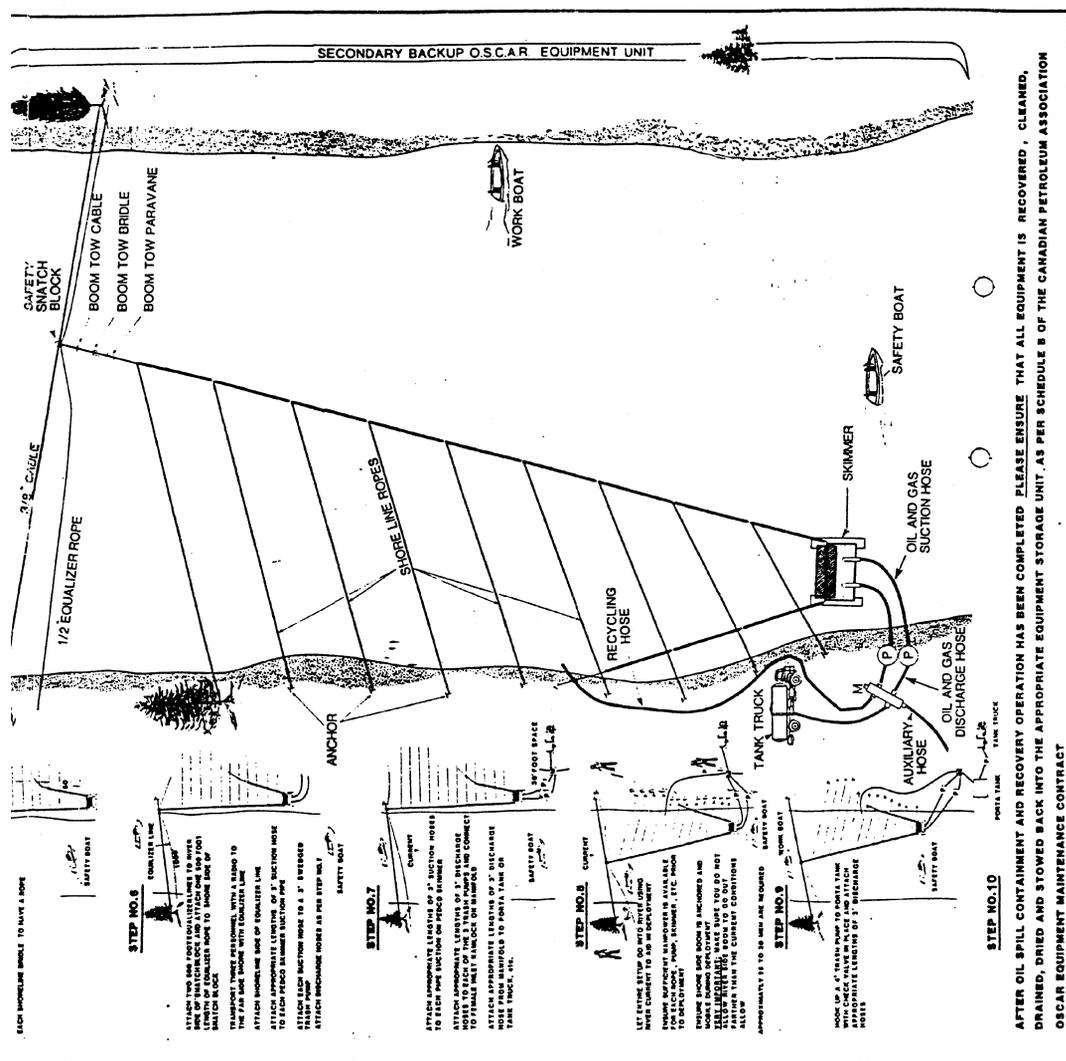


Fig. 1 continued.

volume of the largest expected spill. For safety sake, as the wind always blows during a spill clean up, a figure of one half of the boom's draft should be used to calculate its holding capacity. Do not forget to subtract the ship's water plane area from the surrounding boom's area.

Also to be taken into consideration is whether there is any current present and, in addition, you must assure that the boom be far enough away from the downstream end of the ship (or side of the ship, if it is moored at a finger pier) so that all spilled oil will surface within the boomed areas, keeping in mind that heavy oils surface slower than light ones.

FAST CURRENT BOOMS

If you must chase spilled oil on a river, survey the river for several hours worth of floating distance below the potential spill site and find areas of natural 'back eddies' where the river runs around bends. Places of access for boat launching and equipment set up must be predetermined before a spill occurs so that rapid response to these known sites can happen, and a series of deflection booms and recovery equipment may be set up before the oil arrives.

The 'River Boom', which is one with a minimum b/w ratio of 4:1, a shallow skirt, and a smooth sided flotation pocket, was developed for the fast flowing rivers in the Alberta and British Columbia oil

producing areas. The local cooperatives worked with Vancouver-based Versatech products to design and produce booms which could deflect oil from up to three knot currents to quiet back eddies or nearshore locations, where the oil could be contained and controlled. The basic design parameters are now in common usage, but variations exist between manufacturers. (See PROSCARAC Chart attached as Fig. 1).

INFLATABLE BOOMS

In the mid-1970s it became apparent to the Europeans developing the North Sea fields, the Canadians with their rough ocean scenarios, and the US Navy, that in order for a response vessel to carry enough boom to the scene of an ocean spill, the boom must be collapsible and rely mainly on air for its buoyancy. Many types of compactable, air inflated booms were developed. Some had continuous tubular air chambers several hundred feet long, which were blown up with continuously operating diesel engine-driven blowers. Others were a self-inflating type which utilized coiled springs, or hoops, or spring actuated mechanical frames which caused the fabric air tube to expand and draw in air as the boom was being deployed and tensioned.

All these systems have various amounts of success in the market place and several are still produced today. However, they all suffered from one or more drawbacks. Motor and mechanical maintenance problems plagued the continuous tube style, for if pressure were not maintained, the boom would lose buoyancy and sink. The mechanical spring expansion type suffered from corrosion problems and local fabric wear-points that allowed water to enter the tube and reduce the b/w ratio. The continuous coil spring type was proved somewhat delicate to deploy and retrieve. If the spring became bent or distorted, the boom would not inflate on its next deployment. Both of these aforementioned types of self-inflating booms were storable on mechanical reels which was a great advantage to spill response personnel. The individual boom style, although not reelable, saw great favor for its reliability.

Several styles have been introduced which require sources of low pressure, high volume air to inflate individual compartments through valve systems. Excellent b/w ratios of from 8:1 to 30:1 have been achieved in standard and most Coast Guard and major spill cooperatives employ this type of boom for rough water service.

As always, there are trade-offs between fabric durability, size, strength, speed of inflation and cost. The *World Catalog of Oil Spill Response Products* [11] lists characteristics of most products on the market and the *International Oil Spill Control Directory* [12] carries advertising by most boom manufacturers.

FIRE BOOMS

In the mid to late 1980s, the concept of protecting adjacent or threatened facilities from a spill on fire led engineers to design flexible metallic booms. Tank tests were successful but the booms suffered from mechanical fatigue failures when tested in longer lengths in harbor environments.

The concept of '*in situ*' burning of oil was thought to be a very reasonable control and disposal technique and is now an accepted practice as long as the burn can take place away from a populous area. The 3M Corporation invented a foam glass floated boom which had glass fiber and stainless steel mesh membranes under a PVC coated fabric skin which was trialed very successfully by Environment Canada. In recent years, other water-blanket protected air inflated booms have come on the market. These models have the advantage of reusability, reliability and compact storage.

PERMANENT BOOMS

In the early years, 1960–70, booming was only done after a spill had occurred. The concept of placing a boom around a vessel prior to an oil transfer as a safety and cost saving measure was only accepted after booms durable enough to survive years in the water were developed in the early 1970s. In order to be economically viable, these products had to be adaptable to the individual configuration of each pier at which they were to be used.

Many accessories were designed and developed to flexibly attach booms to piers and the shore. Towing devices, quick and easy connectors, anchoring and mooring attachments, bulkheads to reach beyond the low tide mark, roller end plates and tracks to allow the boom to be sealed to the shore at all tide levels were commonly utilized in the design of these systems. Their extra expense was often well justified as oil that spilled during a transfer or accident was contained on the spiller's property and recovered at minimal expense.

Typically permanent booms are fabricated from a stiff membrane manufactured from conveyor belting. Buoyancy is provided by molded floats bolted or riveted through the membrane in pairs with the ballast provided from lead weights bolted or riveted along the bottom edge. No tension members are required as the belting has the inherent tensile strength required.

It has been found that all metallic parts should be of stainless steel, hard coat anodized aluminum, or lead since the seawater in the splash zone causes galvanized steel or unprotected aluminum to corrode and fail within 2–3 years. It has been noted that around steel piers with cathodic protection, and in the vicinity of electrical generating stations, the corrosion of metallic boom components is particularly severe. Unfortunately in some areas, hard fouling marine growth, such as mussels, barnacles and oysters grow on the boom and even cause it to sink. Mechanical scraping or high-pressure water cleaning is required annually, and, in some locations, more often.

MATERIALS

Base fibers

Nylon, polyester, Kevlar[®], Spectra[®], glass and other polyamide fibers have been used for boom fabrics depending upon the strength, durability and cost desired [13]. Most manufacturers of general purpose and air inflated booms choose nylon fibers for their fabric because of its inherent high tensile strength, good resistance to shock loading, adequate tear strength and low cost. Polyester fiber is typically used in permanent booms because of its higher modulus of elasticity and low water absorption, Kevlar[®] has been used for high strength, low stretch, and lightweight booms, and Spectra[®] is finding favor with manufacturers of net booms and some lightweight inflatable booms. Glass fibers have been used in some experimental fire resistant booms.

Coatings

PVC has been used for the coating of most general purpose and inflatable booms. If these PVC coated booms are to be used in temperatures below 40 °F, then the coating must have special plasticizers to provide flexibility at low temperatures. The coating even seems to resist hard fouling on permanent booms. Neoprene[®] and Hypalon[®] synthetic rubbers are also used on some heavy duty inflatable booms. A special adhesive in autoclaves during the manufacturing process tends to increase both the initial and repair costs when compared to PVC or urethane coated fabrics.

Repairability in the field is important and if patches can be secured with adhesive or portable heat sealing (hot air gun) methods, this is a desirable attribute when selecting a fabric.

Flotation

Air is cheap and very desirable as the flotation material for any boom, but it must be contained to be useful! The slightest leak in the boom's flotation tube will render it inoperable in a short time. Therefore, only those booms that have been designed for rapid response, have maximum b/w ratios, utilize abrasion and tear-resistant fabrics, and have been very carefully manufactured and tested have proved successful.

For permanent booms which must survive for many years in the water, molded, medium density foam floats are the preferred flotation material. Those floats with a densified skin have proven to be more durable than those which utilize a two-part float. Typically, a skin of unsupported PVC or other polymeric resin is blow molded, vacuum formed or rotary molded. The cavity is filled with an expanded urethane foam. If the shell cracks from impact or UV exposure, the foam is exposed, leading to a rapid reduction in b/w ratio.

Inexpensive general purpose booms almost always use polyethylene planks, logs or rolled sheet foam or other rolled 'packaging' sheet foam. A density of about 2 lb/cu ft is typical of quality products. Foams with lower densities tend to crush and compress even in storage.

Bagged loose foam chips or Styrofoam flotation materials, although cheap, should be avoided. The former can cause a mess on the water if the fabric is punctured and the latter can dissolve if exposed to hydrocarbons.

Tension members

Galvanized chain is the most commonly used material for tension members on general purpose and air inflatable booms. Typically, unrated chain is used. For large ocean booms, tensile strength rated chains, or in some cases, high tensile stainless steel wire rope must be used.

High strength fabric booms and permanent booms do not require tension members but must add some ballast for stability, commonly lead weights.

Connectors

Although connectors were mentioned earlier in the chapter, their importance to the success of a working boom system should again be emphasized. They must also be the attachment points for lifting, anchoring, mooring and towing the boom. Only at a properly designed connector can the point loadings mentioned above be distributed to the tension member and membrane so as to minimize the possibility of structural failure of the assembly. The only exception to this rule is that permanent boom systems have attachments to the boom, which must conform to the dimensions of the piers. Clamping devices called strong backs, placed as necessary along the length of the boom, accept point loadings and distribute them evenly across the membrane.

ASTM and ISO standards

So much time and effort has been spent by the manufacturing industry, user community and regulating bodies that the standards published should receive proper recognition [3]. Adhering to their definitions, testing methods, dimensional standards and usage guides will greatly simplify the work of any specifier or user of spill response booms and other equipment.

As of this writing, several ASTM Standards have been presented to the ISO and IMO for international adoption.

Laboratory tank and model testing

For the designers of new products, or for proof of existing products, there are several excellent test facilities in the US Stevens Institute has one of the country's finest model towing basins and has recently developed instrumentation to accurately measure the heave response of model boom assemblies [14].

Slickbar Products Corporation in Seymour, CT has a 75 000 lb capacity tensile machine which can simultaneously exert side loadings of up to 8000 lbs on full size sections of boom up to 10 ft long and 6 ft in overall height.

The US Government's OHMSETT facility in New Jersey has a 600 ft long tank and bridge for towing full size booms in several wave conditions, at speeds of up to 6 knots, with light or heavy oil in the water. Underwater cameras can record oil behavior and loss conditions with booms being towed in sweeping modes. They have developed an excellent protocol for testing full scale booms and other spill response equipment [15].

CONCLUSION

Given the fact that booms operate efficiently within a narrow band of naturally occurring sea states and current velocities, it is a wonder that they are used at all! Potential spillers are motivated to deploy them for public relations considerations, as well as to comply with the law, as much as for economic or cost effective reasons. The fact that they can and do work well much of the time, in spite of adverse environmental conditions, is a tribute to the designers and manufacturers of today's products.

Future trends are, whenever possible, to keep the spilled oil from coming ashore, either by in-situ burning, containment and mechanical removal, or by dispersing it at sea. To accomplish this task with any degree of efficiency, large, self-inflated booms will be required which will have a b/w ration of at least 30:1. They will be stored on reels, air dropped at the scene and towed into place by remotely controlled or autonomous vessels which have also been air dropped. Today's 12-knot vessel response speed will be replaced by tomorrow's 150-knot cargo aircraft speed.

No one wants to risk human life at the scene of a spill. Remotely controlled and autonomous craft are being developed to tow booms, attach themselves to stricken tankers, deploy skimmers within the pools of contained or free floating oil, pump that oil into floating fabric containers, spray dispersants or fire fighting foam and even rescue personnel trapped on distressed vessels. Miniature autonomous 'torpedoes' that can cruise under a slick and monitor its thickness, boundaries and the amount of oil dispersed in the water column below it are on the drawing board.

As long as man produces, transports, refines and uses petroleum-based fuels, he will spill some on the water! Its removal is demanded and this industry will meet the requirement with faster response time and accomplish the task with even more efficient equipment.

REFERENCES

- 1 ASTM. *ASTM standards on hazardous substances and oil spill response*. ASTM, W. Conshohocken, PA. ASTM publication code number (PCN) 03-620094-48 (1994).
- 2 D. S. Etkin. *Oil Spill cooperatives in the U.S. & Canada*. for Cutler Information Corp., Arlington, MA (1991).
- 3 Tedeschi, E. In *Oil and Petrochemical Pollution 0143-7127/85*, Elsevier Applied Sciences Publishers Ltd, UK (1985).
- 4 E. R. Miller, W. T. Lindenmuth, W. E. Lehr, R. N. Abraham. Meetings of the Chesapeake Section of the Society of Naval Architects and Marine Engineers (1979).
- 5 R. L. Van Dyck. *Improving the performance of oil spill containment booms in waves*. Report CG-D-43-95, prepared for US Coast Guard Ntl. Technical Information Service, Springfield, VA (1994).
- 6 O. B. Nordvick, J. L. Simmons. *At sea testing of fire resistant oil containment boom designs*. Marine Spill Response Corporation, Washington, DC, for the Second International Research and Development Forum (1994).
- 7 A. B. Nordvick, K. Bitting, P. Hankins, L. Hannon, R. Urban. Full scale oil containment boom at-sea testing. In *Proceedings of the 1995 International Oil Spill Conference* (1995).
- 8 Tennyson, E. Recent results from oil spill response research. In *Proceedings of the 1991 International Oil Spill Conference* (1991).
- 9 Netherlands Ministry of Transport Public Works. *Oil Spill Slide Rule*. Government Publishing Office, The Hague, Netherlands. Order no. LBOSSR1085 (1985).
- 10 L. A. Robertson. *Oil spill barriers and their use*. Economic and Technical Review. Report EPS3-EC-81-5. Environment Canada, Ottawa, Canada, December (1981).
- 11 *World Catalog of Oil Spill Response Products*. Annapolis, MD. Updated annually.
- 12 *The International Oil Spill Control Directory*. Oil Spill Intelligence Report. Cutler Information Corp, Arlington, MA. Published annually.
- 13 D. E. Brunner. *Materials for oil spill containment boom*. Naval Facilities Engineering Command, Civil Engineering Laboratory, Naval Construction Battalion Center, Port Hueneme, CA. June 1976 (1976).
- 14 M. S. Bruno, R. L. Van Dyck. Experimental study of containment boom behavior in waves. *J. Mar. Technol.* **34**(1), 24–30 (1997).
- 15 Minerals Management Service. *Test protocol for the evaluation of oil-spill containment booms*, Report 14-35-30551 (1992).
- 16 S. F. Bartlett. *In situ measurements of oil barrier shapes, loads and motions*. MSc Thesis, Ocean Engineering, University of Rhode Island (1973).
- 17 Luchun, R. E. Open river spills. *Proc. Marine Safety Council of the USCG*, **49**(5), Washington, DC (1992).
- 18 R. E. Luchun. Open river spills, strategies tactics, a primer. In *Proceedings of the 1992 Conference on Physical Recovery of Spills Corpus Christi*, State University, Corpus Christi, TX (1992).