OIL SPILL RESPONSE PERFORMANCE REVIEW OF BOOMS

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LIST OF ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
B/W	Buoyancy to Weight Ratio
cSt	oil viscosity in centistokes
D	boom draft
IFMT	Institute of Fisheries and Marine Technology
FB	boom freeboard
Kts	knots
lbs	pounds
m/s	meters per second
mm	millimeters
m	meters
m^3	volume in cubic meters
MSRC	Marine Spill Response Corporation
RE	Recovery Efficiency - percent oil in the recovered mixture

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Introduction

A substantial number of test reports exist for oil spill containment booms, but many of these documents are not readily available to potential users. Many formal agency reports of booms tests are long out of print and difficult to find. A substantial number of booms tests never resulted in a published report, only a job order draft report that was never available to the general public. In assembling information for this task, government agencies were requested to provide copies of published test reports as well as job order draft reports. All of this information, much of it not previously available to spill response professionals, was used for analysis. This study reviews all of these studies, analyzes the information, and presents it in a condensed form for the user.

Many early test reports are not easy to use and understand. Important performance parameters are often hard to find and sometimes they are not recorded in the report at all. Further, in most cases raw data are arranged in the order in which the tests were performed instead of grouped according to characteristic performance parameters. This means that the user feels compelled to make up new data sheets to group similar data together so that the impact of important performance characteristics can be analyzed.

This document smooths over many of these problems for the user. Important performance parameters have been found and recorded. Data are arranged in a logical order and in many cases averaged to show the user the general result of the tests. Reports have been condensed, analyzed, and explained. The objective of this study is to make all available test data easily accessible, meaningful, and easy to understand.

Some spill professionals object to including all test data in this manual because they have little confidence in data from early tests. The objective of the project is to include all information that is available, identifying problems as necessary. Some data are not as good as others, but the objective is to be inclusive - this is all that is available. The problems with the early tests have been the catalyst to improve reporting and to do a better job. Caveats are included with early data explaining that it may not be up to current standards. Some researchers will want to see all the data that is available, so all has been included.

BOOM TYPES

The Performance Review of Booms is divided into chapters, one for each boom type. Boom types currently identified include:

- o Fence booms
- o Curtain Booms - which are further identified according to their flotation
  - Internal foam
  - External foam
  - Self-inflatable
  - Pressure-inflatable
- o External Tension Booms
- o Fire Containment Booms
- o Tidal Seal Booms

CHAPTER CONTENT

Each chapter begins with background information including:

- o Description of boom type
- o A list of selection considerations for that boom type
- o A description of operational parameters for that boom type
- o Operational notes

This is followed by a description and analysis of the individual boom tests, arranged in the approximate chronological order in which the tests were performed. The analysis section of the chapter follows the proposed American Society for Testing and Materials (ASTM) "Standard Guide for Collecting Containment Boom Performance Data in a Controlled Environment," F2084-01. Although much of the information required by this Standard was not recorded for some of the earlier tests, test data presented in this Manual, when they are available, include the following:

- o Background and objective of the test
- o Description of the boom tested including the following:
  - - Dimensions of boom freeboard and draft
  - - End connectors
  - - Skirt material
  - - Flotation type and length
  - - Boom weight per unit length
  - - Reserve buoyancy
  - - Reserve buoyancy to weight ratio
  - - Ballast material
  - - Ballast weight
  - - Strength of tension members
  - - Fabric tensile strength
  - - Fabric tear strength
- o Test Configuration and Instrumentation
- o Test oils - type and viscosity
- o Test variables
- o Data precision and accuracy
- o Test Procedures and Results - data recorded include, but are not limited to the following:
  - - Determination of the pre-load volume of test oil
  - - First loss and Gross Loss Tow Speeds in calm water and waves
  - - Oil Loss Rate
  - - Boom oil loss rate at speeds above the First Loss Tow Speed
  - - Critical tow speeds for loss of boom freeboard, planing, or mechanical failure
  - - Booms conformance to waves
  - - Forces on booms in various operational conditions
- o Analysis of test results using tables, graphs, and summaries as required.
- o Overall assessment of performance - unless otherwise noted, this assessment is that of the author

In many of the early tests, procedures had not been standardized. For example, tests were not performed to determine the desired pre-load of oil for a boom tests. The amount of oil used varied, but was fairly arbitrary. Current procedures use preload test runs that determine the minimum volume of test fluid necessary for a containment boom to show loss by entrainment, and at the same time, determine the volume of test fluid a boom holds until the addition of fluid has a minimal effect on the first loss tow speed. As preload volumes are increased, there is a volume at which the addition of test fluid will not change the first loss tow speed. This volume is used in remaining tests as the preload volume. The tests to determine this volume are performed in calm water.

OTHER NOTES ON CHAPTER CONTENT

Fire resistant containment booms are all reported in a separate chapter even though booms that perform this function include many boom types. This arrangement is to help the researcher who is looking for all available information on booms that perform this function. Performance summaries in other chapters refer back to the chapter on fire resistant containment booms to compare the performance of fire booms by type with conventional booms of the same type.

The year in which tests were performed is noted in the bibliography and in chapter text because in some cases tests were performed several years before the test report was issued.

Boom names and manufacturer names are shown as they appear in the test report. In some cases these booms are no longer produced, but these names are still used to identify the product. In other cases the boom is still produced in the same model but the manufacturer has changed, so the new manufacturer's name is provided along with the name that was used in the test report.

FACTORS AFFECTING BOOM PERFORMANCE

The following paragraphs briefly describe factors affecting boom performance. The user is encouraged to obtain a recent edition of the World Catalog of Oil Spill Response Products for a complete exposition of these factors including sketches showing booms in varing conditions of failure. The following paragraphs summarize the booms performance section of the recent (1999-2000) edition of the World Catalog. (Reprinted by permission, Robert Schulze Environmental Consultant Inc., publisher.)

Three physical processes determine how booms operate, they are:

- Buoyancy
- Roll response
- Heave response

Buoyancy

Buoyancy is important to keep the boom afloat and to maintain adequate freeboard. Buoyancy can be measured as:

- Gross Buoyancy - the weight of fresh water displaced by a boom totally submerged.
- Reserve Buoyancy - gross buoyancy minus boom weight.
- Reserve Buoyancy to Weight Ratio - reserve buoyancy divided by boom weight.

This Manual uses <u>reserve buoyancy</u> and <u>reserve buoyancy to weight ratio</u> as measures of buoyancy. Reserve buoyancy can be represented by the volume of the float above the waterline. The American Society for Testing and Materials (ASTM) guideline uses Gross Buoyancy to Weight Ratio which has a value of Reserve B/W Ratio +1.

Roll Response

Roll Response is the rotation of the boom from rest due to wave, wind, or current forces. Oil may be lost under a boom if the skirt is deflected excessively or has "rolled" from the vertical position. Excessive roll may occur if there is not enough ballast weight along the bottom of the skirt, if the primary tension member is too close to the water line, or if a boom with a rigid skirt is deflected from the vertical position by strong currents or high winds. A boom that tends to remain upright is said to have good roll response. Roll response is measured by the torque required to roll the boom away from the vertical position. Roll response can be improved by adding ballast weight along the bottom of the skirt or by moving the float area away from the centerline of the boom. Moving the float area away from the centerline is very effective since roll response is proportional to the area at the waterline times the distance of the center of gravity squared. Positioning the tension cables low on the skirt improves roll response by holding the boom in place in wind, waves, and currents.

Heave Response

Heave Response is the ability of the boom to react to the vertical motion of the water surface. A boom with good heave response is one that can closely follow the water surface as a wave passes. If heave response is poor, the boom may sink below the surface as a wave passes. If a boom has a stiff skirt or solid ballast, the bottom of the skirt may even be suspended above the water surface as a wave passes, which is called broaching. In either case, there may be a loss of oil.

Heave response is proportional to the water plane area. The larger the area, the better the heave response. Since boom floats generally come in sections, it is convenient to use the waterline beam as a measure of heave response. Waterline beam is the water plane area of a standard length divided by the standard length. Waterline beam is therefore a good measure of heave response. Reserve buoyancy and total boom weight are also good indicators of heave response. High reserve buoyancy and low total boom weight indicate good heave response. *Reserve buoyancy to weight ratio is the best single measure of heave response*, which is the ability of the boom to follow the surface of the water. Although a boom with adequate freeboard can compensate to some extent for poor heave response, booms are more effective if they can follow the surface of the waves.

Good flexibility helps a boom to follow the surface of a moving wave. Boom flexibility is generally enhanced by shorter float sections and closer float spacing, providing flex between floats is allowed by the fabric. Good flexibility is also provided by a continuous, but limber flotation material, such as foam pellets held in fabric or an inflated flotation chamber.

HOW BOOMS FAIL

Containment booms can be highly successful in collecting oil on water for recovery; however, they do not perform well in every case. Therefore, to understand how booms operate and what features improve their performance, it is also useful to understand how booms fail.

There are five basic modes of operating failures:

- Entrainment
- Drainage
- Splashover
- Submergence
- Planing

These operating failures occur when the boom is intact and should not be confused with structural failures. Figure 1.0, page 5, shows sketches of the modes of failure.

Entrainment Failure

In strong currents, a headwave often builds upstream of the boom. At high current velocities, turbulence occurs at the downstream side of the headwave. This turbulence causes oil droplets to break away from the headwave, become trapped in the flowing water, and to pass under the boom. Unless the headwave is a considerable distance upstream, oil droplets will not have time to resurface to be contained by the boom. The amount of oil lost in headwave failure depends on the thickness of the oil in the headwave, which is a combination of water velocity and specific gravity of the oil. If oil droplets that have broken away lack buoyancy to rejoin the slick, they will be carried under the boom.

The current velocity at which the headwave becomes unstable and droplets of oil begin to strip off is called critical velocity. At this velocity, droplets are entrained in the water streamlines and flow under the boom. The critical velocity for many crude oils and refined products ranges from 0.7 to 1.2 knots. (Generally 0.7 knots is accepted as a conservative estimate.) Entrainment loss determines how fast a boom can be towed or the maximum current in which it will be effective.

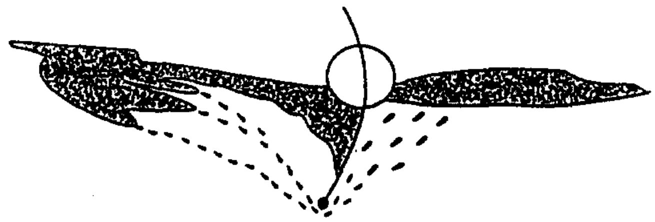
Both currents and waves contribute to critical velocity for entrainment failure. Waves cause oil particles to have a velocity that is added to current velocity. For example, a steady current perpendicular to a boom at 0.6 knots and a transient particle velocity caused by waves of 0.6 knots is likely to result in entrainment failure.

Critical velocity is the component of water speed perpendicular to the boom. Entrainment failure can be delayed by reducing velocity perpendicular to the boom. For example, the boom may be deployed at an angle of less than 90° to the flow.

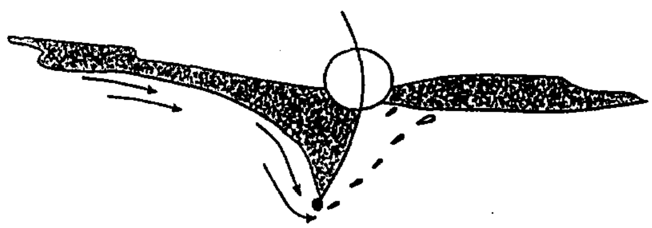
Spill containment performance depends on the angle between the boom and the current. However, a flexible boom cannot be maintained at a fixed angle with the current. It can be expected to take some catenary shape. When the angle with the direction of flow becomes small, the catenary may be more like a J-shape. The curvature of the J presents a greater angle to the flow causing the velocity normal to the boom face to increase, which may then exceed the critical velocity for oil entrainment. As a result, expect failure to occur first in that part of the boom curving to cross the direction of flow. Figure 1.0 (a) shows entrainment failure.

Drainage Failure

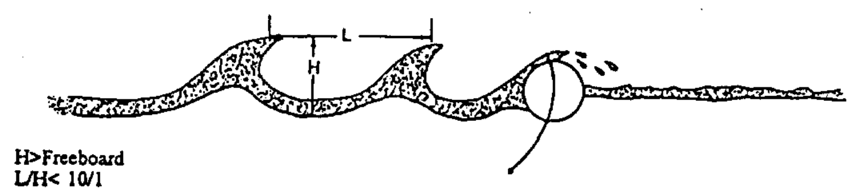
As oil collecting at the boom face increases in depth, it finally flows down the face of the boom, escaping to the other side. This loss is known as drainage failure. Water at the boom face is diverted downward, accelerating to keep up with water flowing directly under the skirt. The problem is aggravated by having a deeper skirt. Increasing skirt depth also increases the distance water on the face of the boom must travel to stay with the flow, which causes drainage failure to occur at a lower critical velocity. A boom that can maintain high critical velocity at higher tow speeds is most resistant to drainage failure, which is favorable.



(a) Entrainment Failure



(b) Drainage Failure



(c) Splashover Failure

(d) Submergence Failure

(e) Planing Failure

Figure 1.0 Boom Failure

The critical velocity at which drainage failure occurs depends on the skirt depth, oil viscosity, specific gravity, and the depth of the oil being retained by the boom. This velocity is generally greater than the critical velocity for entrainment failure, so entrainment failure is most likely in fast currents.

The way the skirt of a curtain type boom is deployed also affects the amount of oil lost. If the bottom of the skirt being drawn upstream developing a pocket with a rather large area for oil to collect, only a small amount of oil escapes under the boom. If the bottom of the skirt is not controlled with a tension member, or if it is poorly ballasted, the boom is not as effective in a strong current and oil may escape beneath it. Figure 1.0 (b) shows drainage failure.

Splashover Failure

Failure also occurs in choppy seas when oil splashes over the boom's freeboard. Splashover failure may occur if wave height is greater than the boom freeboard and the wave length to height ratio is less than 10:1. When the length to height ratio falls below 5:1, as in choppy or rapidly shoaling water, most booms will have some splashover failure. On the other hand, most perform well in a gentle swell, even when the wave height is much larger than the freeboard. In a medium swell "bridging" may occur (unless the boom is very flexible) and oil could pass under it. Figure 1.0 © shows splashover failure.

Submergence Failure

Submergence failure may occur when a boom is deployed or anchored in a fast current, or is being towed at a high velocity in still water. The tendency to submerge at a given velocity is determined by the boom's reserve buoyancy.

Reserve buoyancy is buoyancy/foot in excess of that required to keep a boom afloat in still water. Higher reserve buoyancy reduces the tendency to submerge. Booms with air chamber flotation generally have greater reserve buoyancy than those with solid flotation and are less likely to suffer submergence failure. Figure 1.0 (d) shown submergence failure.

Planing Failure

A strong wind and strong current moving in opposite directions may cause a boom to heel flat on the water surface. The resulting loss of oil is called planing failure. This failure is likely to occur when a boom has inadequate ballasting or when an internal tension member is near or above the waterline. Planing failure can also occur if there is a current relative to the boom face, with or without wind. Further, it can occur for other positions of the tension member. Planing failure can occur when the relative length of the bottom of the boom skirt is longer than the waterline length. If the tension member is at the bottom of the skirt but it is too long, the fabric may then become the true tension member at the central point at or above the waterline. Figure 1.0 (e) shows planing failure.

Structural Failure

Structural failure is the most catastrophic failure mode. Wind and current are approximately proportional to the product of boom area exposed to the flow and the square of relative velocity. Wave action further increases the average forces—normally by a factor of two or three. In addition, local dynamic loads due to the acceleration of boom modules in waves may be many times greater than the static value. Many boom tests record the forces on a boom, but booms are only stressed to failure in static laboratory tests.

Test Facilities

A great many tests described in this document were performed at the National Oil Spill Response Test Facility, OHMSETT, located at the Naval Weapons Station, in Leonardo, New Jersey. A complete description of this facility is provided in the "R & D Users Guide to the Ohmsett Oil Spill Response Test Facility," Joseph V. Mullin and James S. Lane. This document was published by Elsevier Science ltd. in the *Spill Science & Technology Bulletin,* Volume 6, Number 1, pp. 77-87, 2000. All other test facilities are described in the text as they occur.

Appendices

Appendix A - Booms Performance Summaries

Appendix B - References

This Appendix is divided into two sections:

- o References listed according to the test facility in which they were performed or by the sponsoring agency.
- o An annotated bibliography showing the same references with notes listing the booms that were tested and the extend of the test program.
- o All references are shown with a letter and a number. Thus, the first reference for a test performed at OHMSETT is O-1, and so forth. The code letters for test agencies or data sources are shown below.

Test Agency/Source	Code Letter
OHMSETT	O
Environment Canada	E
Canadian Coast Guard	C
International Oil Spill Conference Proceedings	S
Arctic and Marine Oil Spill Conference Proceedings	A
Other Agencies and Industry	I

Appendix C - Forces on Booms

Chapter 1

FENCE BOOMS

1.0 DESCRIPTION

A fence boom is rigid or nearly rigid in the vertical plane, a condition that is achieved either by using vertical stiffeners in flexible boom material or by using heavy fabric that is stiff vertically but free to bend in the horizontal plane to conform to water movement. Fence boom can be further classified according to the type of flotation used:

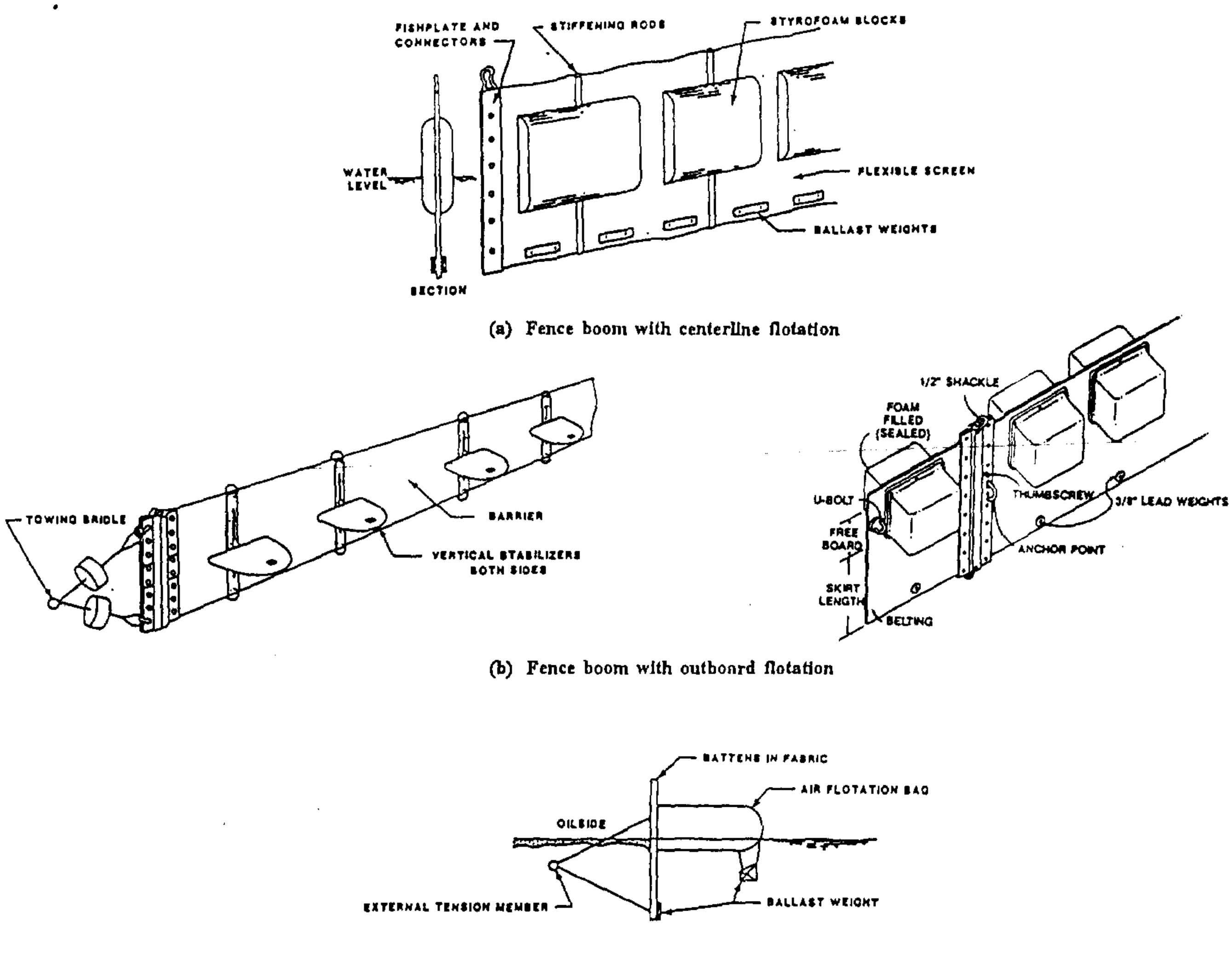
- Centerline flotation
- Outboard flotation
- One-sided outboard flotation

Figure 1.1 shows a generalized sketch of the three basic types of fence booms.

Figure 1.1 (a) illustrates fence boom with centerline flotation using vertical stiffeners in flexible material. This boom has a water plane area that is small and concentrated near the centerline of the boom. This narrow, flat flotation makes the boom easier to store, but both roll response and heave response are likely to be poor. Problems with roll response are relieved somewhat by the ballast weights. Also the high freeboard helps to compensate for low heave response. Some fence booms have centerline flotation extending farther off centerline. This helps with problems of roll and heave response but if the flotation is fixed, the booms may be harder to store. In some cases the flotation is detachable which helps with storage, but increases the time and effort required for boom deployment and recovery. Flotation alternatives involve trade-offs among the various qualities that seem to be most desirable.

Figure 1.1 (b) shows two booms with outboard flotation. The distance of the flotation area from the boom centerline provides a large moment to keep the boom riding vertically, and size of the area at the water line helps heave characteristics. The boom on the left controls roll problems with the configuration of the flotation, so ballast is not required at the bottom of the skirt. Therefore, the boom weight can be lower, which helps to correct problems of heave response. Some booms of this type are made of heavy fabric that is fairly stiff in the vertical plane, but pliable in the horizontal plane. These boom sections can be easily folded for storing. The boom on the left has paddle floats that can be rotated vertically making the boom more compact for storage. The boom on the right has fixed outboard flotation which makes it harder to store; however, this is generally permanent boom that remains in the water so storage is not a problem. In this case durability is its more important feature. Outboard flotation may have the disadvantage of collecting debris and the projecting floats sometimes make the boom hard to clean.

Figure 1.1 (c) a fence boom with one-sided outboard flotation. This particular design was developed by the U.S. Coast Guard for use on the high seas. Roll response is maintained by adjusting external tension to just compensate for the righting moments of the external flotation and the ballast. Heave response is provided by the large surface area of the external flotation. Having the external tension member located away from the boom provides good boom response in waves. Figure 1.1 (c) shows how a boom can follow the waves by rotating about the external tension member. If the tension member is in the boom, this movement is restricted. This boom is generally used as part of a boom skimmer system.



(a) Fence boom with centerline flotation

(b) Fence boom with outboard flotation

(c) Fence boom with one sided outboard flotation

Figure 1.1 Typical Fence Booms

1.1 SELECTION CONSIDERATIONS

Buoyancy	Often not high. Fence boom is often used for permanent installations in harbors so that strength and durability are often increased, with an attendant increase in weight, without a proportional increase in float volume.
Roll Response	Improved with ballast weight and moving the float area away from the centerline.
Heave Response	Improved by increasing the water plane area and the buoyance to weight ratio. Since buoyancy to weight ratio may be low, increasing the waterplane area is the most frequent method of improving heave response.
Mode of Application	Generally used in permanent or semi-permanent applications; e.g., fueling areas, around ships at piers, or at outfalls of power plants.
Other	Fence booms are usually easy to deploy, resistant to damage, but bulky for storage.

2.0 TEST RESULTS

2.1 OHMSETT TESTS 1975 (O-1)

A series of tests were performed on 16 oil spill response devices at the OHMSETT test tank from April 1975 through June 1975. These tests included eight containment booms one of which, the B.F. Goodrich Sea Boom (see Figure 1.2), was a fence boom. Booms were tested in the catenary and diversionary modes. Booms were first tested for stability over a wide range of wave conditions without oil and then in waves within their operational stability envelope. Test data record maximum stable tow speed and maximum no loss tow speed. The no loss tow tests were made with 2 mm of oil.

Boom Description

B.F. Goodrich Sea Boom

Freeboard	6 inches (150 mm)
Draft	12 inches (300 mm)
Boom Height	18 inches (450 mm)
End Connectors	piano hinge with fiberglass pins
Skirt Material	1/4 inch (6.4 mm) thick vinyl sheet reinforced with rib-handles of urethane
Flotation	continuous chambers of closed cell foam, protected by 1/4 inch (6.4 mm) PVC coating and secured at the boom ends with wooden plugs.
Weight	8 lbs/ft (11.9 kg/m)
Reserve Buoyancy	7 lbs/ft (10.4 kg/m)
Reserve B/W Ratio	0.88
Ballast	tubular extrusion filled with lead shot and sand
Tension Member	self-tensioning (skirt material is tension member)

Figure 1.2 shows a sketch of the Sea Boom.

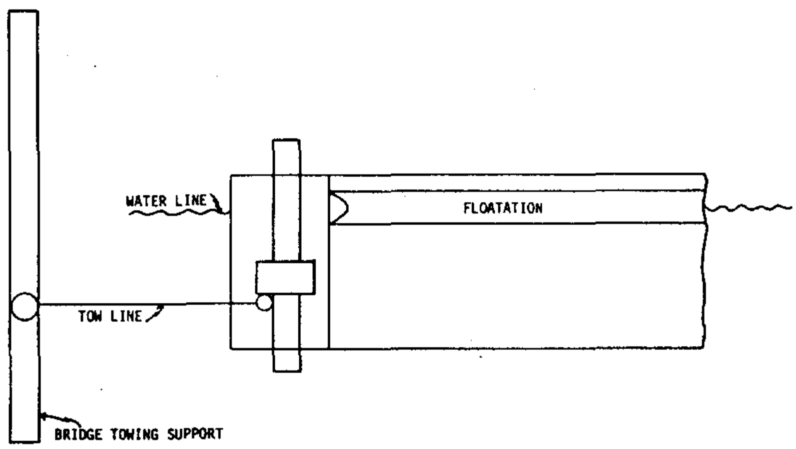


Figure 1.2 B.F. Goodrich SEA Products 18 PYX Permafloat Sea Boom

Test Configuration

Boom was towed in both a catenary (U-shape) and diversionary (J-shape) mode. The length of the boom used for the catenary configuration was approximately 200 feet (61 m) and for the diversionary configuration was approximately 100 feet (30.5 m). Boom towed in the diversionary mode had an angle of 23° to 44° between the boom and the current, but the angle used is not identified for individual runs. Boom sections were joined together and tow connections were rigged according to the manufacturer's recommendations.

Test Oils

Diesel fuel - viscosity 10 cSt, density 0.852
Lube oil - viscosity 510 cSt, density 0.915
Oil thickness - 2 mm

Note that lube oils with other viscosities were used in the tests. These are shown on test results data sheets.

Test Variables

Tow speed, wave conditions, and oil type.

Data Precision and Accuracy

Tow Speed - 0 up to critical tow speed within 0.1 knot (0.05 m/s).

Test Procedure

Performance criteria for booms was intended to determine the tow speed at which oil began to escape the boom in both the catenary and diversionary modes. First, the boom was tested without oil in various wave conditions to determine the maximum stable tow speed in each configuuration. This stability testing determined the tow speeds at which planing, submergence, or other type of failure would occur. Splashover at the boom fluid interface was considered to be a stability failure, since in many cases the loss of freeboard of a boom reflects its inability to maintain an adequate vertical profile. Then the boom was tested with oil in the same waves where its stable performance range was above 0.5 knots (0.25 m/s) tow speed .

In stability tests, the water surface condition was established (wave or no wave), then the boom was towed at continuously increasing speed until judged unstable. After the boom became unstable, the tow speed was decreased in 0.1 knot (0.5 m/s) increments until the boom became stable, and then speed was increased by 0.1 knot increments to reconfirm the failure speed. This speed was then recorded as "critical tow speed" and was the upper limit to be used in the test matrix with oil.

Tow tests in oil were conducted in the same way as stability tests. 350 gallons (1.32 m^3) of oil was distributed as a 2 mm thick spill 50 feet (15.2 m) wide ahead of the boom. In these tests, critical tow speed was defined as the maximum tow speed for either catenary of diversionary configurations at which there was no loss of oil under the boom. In the diversionary mode, a separation boom was deployed behind the test boom so that all oil that had moved down the boom to the apex was contained within the separation boom. The oil collected in the separation boom was judged to be contained.

Test Results

Table 1.1 Test Results OHMSETT TESTS 1975 (O-1)

BOOM	SEA BOOM (B.F. GOODRICH) Freeboard 6 in. Draft 12 in. B/W 0.88	
	TYPE FAILURE	TOW SPEED (kts)
CATENARY		
NO OIL		
CALM WATER	Splashover	2.5
WAVES		
1 X 45' (0.3 X 13.7 m)	Splashover	2.1
1 X 75' (0.3 X 23 m)	Planing	2.2
1 X 9' (0.3 X 2.7 m)	Splashover	0
2 X 30' (0.6 X 9.1 m)	Splashover	1.4
TESTS IN 2 mm OIL	364 cSt	
CALM WATER	Entrainment	0.8
WAVES		
1 X 45' (O.3 X 13.7 m)	Entrainment	0.8
2 X 30' (0.6 X 9.1 m)	Entrainment	0.9
DIVERSIONARY*		
NO OIL		
CALM WATER	Planing	1.6
WAVES		
1 X 45' (0.3 X 13.7 m)	Planing	1.4
1 X 75' (0.3 X 23 m)	Planing	1.5
1 X 9' (0.3 X 2.7 m)	Splashover	0
2 X 30' (0.6 X 9,1 m)	Splashover	1.0
TESTS IN 2 mm OIL	267 cSt	
CALM WATER	Entrainment	1.2
WAVES		
1 X 45' (0.3 X 13.7 m)	Entrainment	1.4
2 X 30' (0.6 X 9.1 m)	Entrainment	1.0

* Boom had an angle of 23 to 44° on diversionary runs, but the angle is not identified for each run.

Overall Assessment of Performance

In a very short 1X 9 foot wave, splashover failure occurs in both catenary and diversionary modes with no forward velocity. This would always result in oil loss behind the boom.

In the catenary mode, entrainment failure occurs at about 0.8 knots in calm water or tested wave conditions. This agrees with the general rule that a boom can be towed at 0.7 to 0.8 knots without loss of oil. Notice that in oil, entrainment failure occurs long before any physical failure such as splashover or planing.

In the diversionary mode, entrainment failure occurs at a higher tow speed, which is expected, but performance at 1.4 knots in a wave while only 1.2 knots in calm water is not expected. This difference is probably in the range of measurement accuracy. It would be enough to say that performance is about 1.3 knots in calm water and small waves in the diversionary mode.

2.2 OHMSETT TESTS 1975 (O-2)

A second series of tests were performed at OHMSETT between September through November 1975, this time with four floatable hazardous materials.

Three containment booms were tested, two of which had been tested previously (O-1). Tests reported here include the B.F. Goodrich Sea Boom, which had been reported previously, and the U.S. Coast Guard High Seas Boom. (See Figure 1.3) As before, booms were tested in the catenary and diversionary modes. Booms were first tested for stability over a wide range of wave conditions without oil and then in waves within their operational stability envelope. Test data record maximum stable tow speed and maximum no loss tow speed. The no loss tow tests were made with 2 mm of test fluid. See section 2.1 of this chapter for the test configuration, test variables, and test procedure. The B.F. Goodrich boom description is also shown in section 2.1. The description of the Coast Guard High Seas Boom is shown below.

Boom Description

U.S. Coast Guard High Seas Boom

Freeboard	21 inches (530 mm)
Draft	27 inches (690 mm)
Boom Height	48 inches (1,220 mm)
End Connectors	eye bolts and clevis connectors
Skirt Material	2 ply elastomer coated nylon
Flotation	air filled cylinders 6 feet long X 14 inches in diameter (1.82 X 0.36 m) equally spaced at 77 inch (1.96 m) intervals
Weight	14 lbs/ft (20.83 kg/m)
Reserve Buoyancy	50 lbs/ft (74.4 kg/m)
Reserve B/W Ratio	3.6:1
Ballast	None
Tension Member	1.32 inch diameter external tension line (rope)

Test Fluids

- o Octanol -viscosity 12 cSt, density 0.827
- o Dioctyl phthalate (DOP) - viscosity 67.5 cSt, density 0.975
- o Naptha - viscosity 5.8 cSt, density 0.710

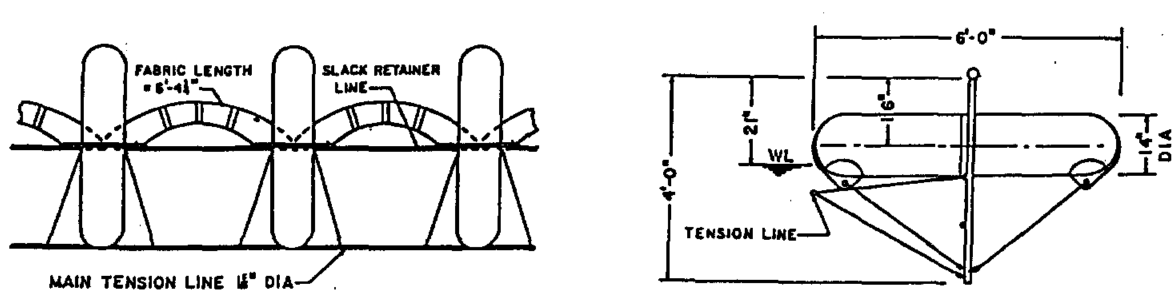


Figure 1.3 U.S. Coast Guard High Seas Boom

Table 1.2 Test Results OHMSETT Tests (O-2)

BOOM	B.F. GOODRICH SEA BOOM Freeboard 6 in. Draft 12 in. B/W 0.88:1		COAST GUARD HIGH SEAS BOOM Freeboard 21 in. Draft 27 in. BW 3.6:1	
	TYPE FAILURE	TOW SPEED (kts)	TYPE FAILURE	TOW SPEED (kts)
CATENARY				
NO OIL				
CALM WATER			Submergence	1.0
WAVES				
2 X 30" (0.6 X 9.1 m)			Submergence	0.9
1' Harbor Chop (0.3 m HC)			Submergence	0.9
TESTS IN 2 mm FLUID	DOP 79.2 cSt		DOP 79.2 cSt	
CALM WATER	Entrainment	0.2	Entrainment	0.2
WAVES				
2 X 30' (0.6 X 9.1 m)	Splashover	0	Splashover	0.3
TESTS IN 2 mm FLUID	Octanol 13.8 cSt		Octanol 13.8 cSt	
CALM WATER	Entrainment	0.5	Entrainment	0.4
WAVES				
2 X 30' (0.6 X 9.1 m)	Entrainment	0.5	Entrainment	0.3-0.4
1 ft. Harbor Chop (0.3 m HC)	Splashover	0		
TESTS IN 2 mm FLUID	Naptha 7 cSt		Naptha 7 cSt	
CALM WATER	Entrainment	0.9	Washover	0.9
WAVES				
2 X 30' (0.6 X 9.1 m)	Entrainment	0.8	Washover	0.4
1' Harbor Chop (0.3 m HC)			Washover	0.1
DIVERSIONARY*				
NO OIL				
CALM WATER			Submergence	1.2
WAVES				
2 X 30" (0.6 X 9.1 m)			Splashover	0.76
1 ft. Harbor Chop (0.3 m HC)			Splashover	0
TESTS IN 2 mm FLUID	DOP 74.9 cSt		DOP 74.9 cSt	
CALM WATER	Entrainment	0.3	Entrainment	0.3
WAVES				
2 X 30' (0.6 X 9.1 m)	Splashover	0.1	Splashover	0.2
TESTS IN 2 mm FLUID	Octanol 13.3 cSt		Octanol 13.3 cSt	
CALM WATER	Entrainment	1.5-1.7	Entrainment	0.7
WAVES				
2 X 30' (0.6 X 9.1 m)	Entrainment	0.9	Splashover	0.2
TESTS IN 2 mm FLUID	Naptha 7 cSt		Naptha 7 cSt	
CALM WATER	Entrainment	1.6	Entrainment	1.0
WAVES				
2 X 30' (0.6 X 9.1 m)	Entrainment	1.3	Splashover	0.9
1 ft Harbor Chop (0.3 m HC)			Splashover	0

*The relative angle used in diversionary tests was not reported.

Overall Assessment of Performance

B.F. Goodrich Boom in Catenary Mode - First loss tow speed tends to be low for both DOP and Octanol in Calm Water and waves. Performance in Naptha in Calm Water and the 2 X 30 foot wave is about the same as the performance in oil. (See Table 1.1 page 1-5.)

B.F. Goodrich Boom in the Diversionary Mode - As in the catenary mode, first loss tow speed tends to be low for DOP in Calm Water and waves, but performance in Octanol is better in Calm Water and somewhat better than average in waves. Performance in Naptha in Calm Water is about the same as performance in Octanol, and performance in the 2 X 30 foot wave is about the same as the performance in oil and waves. (See Table 1.1 page 1-5.)

U.S. Coast Guard Boom in Catenary Mode - As with the B.F. Goodrich boom, first loss tow speed tends to be low for both Dioctyl phthalate (DOP) and Octanol in Calm Water and waves. Calm Water performance in Naptha remains high but washover occurs at a low speed in the 2 X 30 foot wave and almost immediately in the 1 foot harbor chop. (Wave length for harbor chop is not specified in this report.)
U.S. Coast Guard Boom in Diversionary Mode - As in the catenary mode, first loss tow speed tends to be low for Dioctyl phthalate (DOP) in Calm Water and waves, and although performance in Octanol in Calm Water is somewhat better, in waves it remains low. In Naptha, performance is better but not as high as for the B.F. Goodrich boom, and in the harbor chop wave splashover failure occurs with no forward speed.

Comparison of the Performance of the B.F. Goodrich Boom and the Coast Guard High Seas Boom

In 1975, the Coast Guard High Seas boom was a prototype and its configuration changed considerably later. The boom has not been produced in any form for more than 10 years, but may still be stocked at some Coast Guard facilities. Based on these tests, however, the very large, heavy, Coast Guard boom did not perform as well as the much smaller, lighter B.F. Goodrich boom when tested in any of the hazardous materials in any of the environments.

The test report comments that density appeared to be the predominate independent variable that determined performance. First loss tow speed decreased as density increased in both Calm Water and waves. The report concludes that high density fluids (close to 1.0) cannot be controlled with existing containment booms in currents greater than 0.3 knots.

2.3 OHMSETT TESTS 1977 (O-3)

A series of tests were performed using the B.F. Goodrich Seaboom in April and September of 1977. Tests were performed to determine the effects of boom angle, length, and rigging configuration on diversion of oil floating on moving streams. The B.F. Goodrich Seaboom (fence boom) was used in a diversionary mode, in a vee shape, and as a funnel. Results were analyzed in terms of the component of velocity perpendicular to the face of the boom since this is the significant parameter determining the effectiveness of containing oil.

Boom Description The B.F. Goodrich Seaboom had been tested previously. (See Section 2.1 page 1-3.)

Test Configuration

The boom was towed in nine separate configurations; 1) a diversionary mode with an angle to the direction of motion of 20° and 32°, 2) a vee shape with a 20° angle to the direction of motion, 3) two parabolic nozzle configurations, 4) and four belled nozzle configurations. The two diversionary configurations, the vee shape, and one of the parabolic nozzle configurations were most effective and are reported in detail. Parachute cord was attached to the boom flotation to maintain nozzle configurations and spreader bars were used to prevent boom from collapsing in the center because of venturi effect. Figure 1.4 shows boom configurations. The bell shaped nozzle configurations are not shown because results of these tests were not reported in the study.

Test Oil

Circo Medium - Viscosity 190 cSt at 73°F (22.7°C); density 0.921

Test Variables

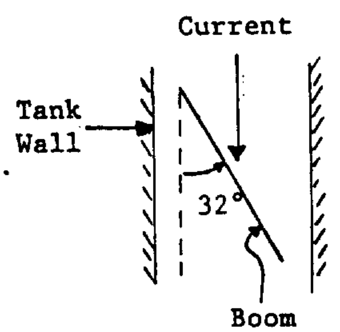
Boom tow speed, boom angle to the direction of motion, and boom configuration.

Data Precision and Accuracy

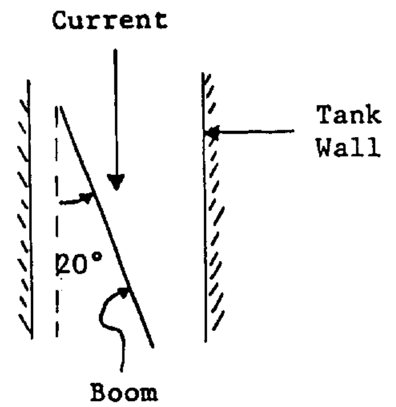
Tow Seed - within 0.1 knot (0.5 m/s)
Oil Loss Estimates - within 10 to 15%

Test Procedure

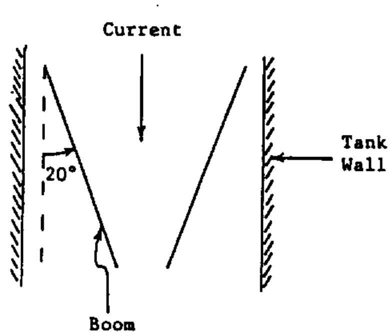
The boom was rigged in the desired configuration and the main bridge was set in motion at the selected tow speed. Oil was pumped from the storage tanks to the distribution points ahead of the boom and maintained a slick of 1 to 2 mm in the boom. Observers on the moving bridge and at the underwater windows recorded the points of failure and the approximate amount of oil loss during the run.



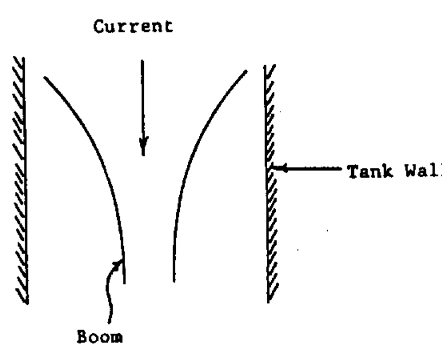
(a) Diversionary - 32° angle to current



(b) Diversionary - 20° angle to current



(c) Vee - 20° angle to current



(d) Parabolic nozzle

Figure 1.4 Test Boom Configurations

Test Results

The percent oil losses under and away from the boom were estimated by observers during the test and re-checked later using photos and video records. Although these estimates are not exact, they are believed to be accurate within 10 to 15% and show trends in performance.

The study points out that oil droplets passing under the skirt are not necessarily lost, but in fact they may be caught in the upwelling eddy and held against the back side of the boom. The report further states that oil held in this relatively quiet zone was diverted along the rear of the boom, and rejoined the oil on the face of the boom at the exit. As a result, the test report shows oil as contained both in the boom and immediately behind the boom. The user must judge for himself whether the oil behind the boom has, in his spill situation, been effectively controlled.

Test results are presented graphically and these graphs are used to describe performance. Tables also show data, but these numbers do not always agree exactly with the graphs. Since the report describes results in terms of the graphs, these data are used in this summary as being the most accurate.

Two parabolic nozzle configurations were tested: one in which the boom simply formed a nozzle and another in which two additional straight boom lengths were add to the exit of the nozzle. The exit area was lifted slightly and the shape of this area was maintained with spreader bars. This parabolic nozzle configuration was the most successful of the two and is the one that is reported. The bell shaped nozzle configurations were not as successful and are not reported in the study.

As test results were recorded it quickly became apparent that the component of velocity normal (perpendicular) to the face of the boom was most significant to the performance of a boom in the diversionary mode. Results are therefore described in terms of this normal velocity. Graphs showing the results of the diversionary boom tests therefore show tow speed in meters/second and also indicate by a title line that there is a second scale showing the normal component of the tow speed, but the second scale is not shown. The normal components of the tow speed are discussed in the report but are not shown on the graphs or on the data sheets. To clarify this matter, data from the graphs have been collected and are shown on Table 1.3. A column has been added showing the normal component of tow speed for the diversionary configuration based on the angle to the direction of flow.

Table 1.3 Test Results - Boom Configurations for Medium-Current (O-3)
Calm Water - 1-2 mm Test Oil

TOW SPEED (kts)	SPEED NORMAL TO BOOM (kts)	% RETAINED BEHIND BOOM	% RETAINED IN BOOM	TOTAL % RETAINED
	DIVERSIONARY 32° TO DIRECTION OF FLOW			
1.4	0.7	1%	99%	100%
1.6	0.8	5%	95%	100%
1.8	0.9	5%	90%	95%
2.0	1.0	30%	50%	80%
2.4	1.3	20%	30%	50%
	DIVERSIONARY 20° TO DIRECTION OF FLOW			
1.1	0.4	0	100%	100%
1.6	0.5	0	100%	100%
2.0	0.7	7%	93%	100%
2.4	0.8	10%	90%	100%
3.0	1.0	22%	69%	91%
3.2	1.1	40%	50%	90%
	VEE 20° TO DIRECTION OF FLOW			
2.0	0.7	0	100%	100%
2.4	0.8	5%	95%	100%
3.0	1.0	5%	90%	95%
3.2	1.1	15%	70%	85%
	PARABOLIC NOZZLE WITH BOOM EXTENDER			
1.6	VARIABLE	0	100%	100%
2.0		3%	97%	100%
2.4		8%	90%	98%
3.0		10%	85%	95%
3.2		13%	80%	93%

Overall Assessment of Performance

Considering the two sets of tests with a boom in the diversionary mode, data show that a higher tow speed can be achieved with a 20° rather than with a 32° angle while still containing a large percent of test oil. The study suggests that a velocity normal to the boom of 1 knot seems to be the maximum before gross losses occur. This is true for the boom being towed with both a 32° and a 20° diversionary angle, although this performance is enhanced by a large percent of "contained" oil behind the boom. The good news of these tests is that tow speeds of 2 and 3 knots are achieved with effective performance using the criteria of a 1 knot component normal to the face of the boom.

This line of reasoning continues to hold true for the vee configuration. Performance remains high up to a velocity of 1 knot normal to the face of the boom, then drops off.

The parabolic nozzle configuration with a boom extender maintained the generally highest performance level of all arrangements tested up to a tow speed of 3.2 knots. The disadvantage of this configuration is that is more difficult to rig and requires separators in the mouth of the boom to maintain its shape.

2.4 ENVIRONMENT CANADA TESTS 1980 (E-1)

Six oil spill containment booms were tested offshore of St. John's, Newfoundland in March and April of 1980. Testing was conducted about 3 nautical miles south of St. John's Harbor in Blackhead Bight. This area, sheltered by cliffs to the west and a peninsula to the south, is at the eastern extremity of the North American continent, with water temperatures, ice conditions, and sea states typical of the Grand Banks oil exploration areas. Currents in the area are 1/4 knot or less and tides average 5 feet (1.5 m). One of the booms tested, the Zooom boom, was later shipped to New Jersey and tested at OHMSETT. The results of these tests are reported separately in Chapter 4 (O-4).

The principal criteria used to evaluate the booms were oil retention characteristics, durability, and towing loads. Although it was intended to deposit a barrel of oil ahead of the towed booms, this was not done in every case because of adverse weather conditions. Data describing towing loads are reported in some detail.

Boom Description

The Albany Oilfence is a flat vertical boom with flat, rotatable, horizontal floats providing buoyancy and stability. The floats are 2 feet (60 cm) wide and spaced 7 feet (2.2 m) apart with handles at every float. Connections between 100 foot (30.5 m) sections are made with a polyethylene slide locked by stainless steel pins. This boom is available in several sizes - the boom tested had a 47 inch (1.2 m) overall height. The boom is symmetrical around the water plane so it can be used either way up. The boom is made of conveyor belt type material that is stiff in the vertical plane and flexible in the horizontal plane. This boom is still manufactured by Applied Fabrics Technologies. The most recent version has a boom height of 48 inches (1.22 m), a tensile strength of 96,000 pounds (432,000 Newtons), and a buoyancy to weight ratio of 4.9:1. Figure 1.5 shows a sketch of the boom tested.

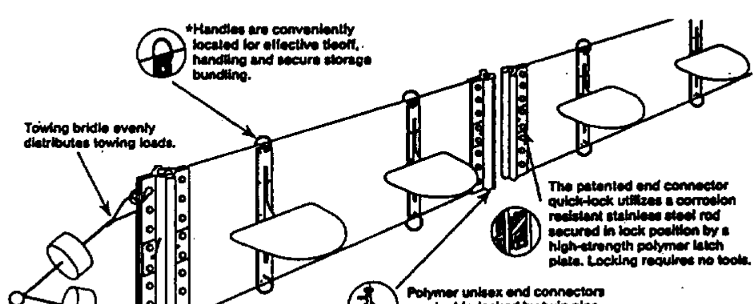


Figure 1.5 Applied Fabric Technologies (Albany) Oil Fence Boom

Test Configuration

The boom was towed in a catenary configuration by two vessels. The distance across the boom opening was measured with an optical range finder. All tows were made into the wind.

Test Oils

Bunker C - viscosity 9.9 cSt, density 0.97
BCF Venezuelan Crude Oil - 30 cSt, density 0.91
(Author's Note: these values for viscosity may not have been reported correctly.)

Data Precision and Accuracy

Forces on booms (not reported here) were to the nearest 10 Newtons. Boom performance is described subjectively.

Test Procedure

The boom was streamed and forces were measured with the boom towed in a straight line. The boom was then rigged in a catenary shape and forces were again measured. Oil was not released for tests because of weather conditions.

Test Results

Wave response was satisfactory when the boom was towed in a catenary shape. During tests in sea state 3-4, the boom bridged between wave crests so that the floats were 12 to 14 inches (30 to 35 cm) above the deepest wave trough. Based on this, the report concluded that oil loss under the boom could be expected in short, steep seas. (Author's note: sea state 3 is defined as a moderate breeze, 7-15 knots with waves about 4 feet [1.2 m]. Sea state 4 is described as having moderate waves, many white caps, with some spray. Moderate to strong breeze, 14 to 27 knots. Waves about 8 feet [2.5 m].)

Overall Assessment of Performance

The following paragraph is paraphrased from the original test report.

The Albany (Applied Fabrics Technology) Oilfence is a well constructed, flat-faced with good stability. The materials chosen and the method of construction are excellent. The boom has a high towing resistance that may be a problem in longer lengths. Some oil underflow might occur above sea state 3, but the boom's freeboard should be adequate under those conditions. Deployment characteristics are excellent and retrieval is easy providing a small crane is available for lifting.

2.5 CANADIAN COAST GUARD TESTS 1991 (C-2)

Seven containment booms were selected and tested to examine how boom type or shape affects oil containment effectiveness in increasing water currents. Tests were performed 11-20 February 1991 in the recirculating flume tank at the Institute of Fisheries and Marine Technology (IFMT) in St. John's Newfoundland.

The IFMT tank is 26 feet wide by 74 feet long by 13 feet deep (8 X 22.5 X 4 m). The depth met the requirement of being at least 4 to 6 times boom draft. Water flow through the flume can be varied from 0 to 2.4 knots. Wave generation is not available. Side viewing windows and underwater video record test results. Figure 1.6 shows a sketch of the tank.

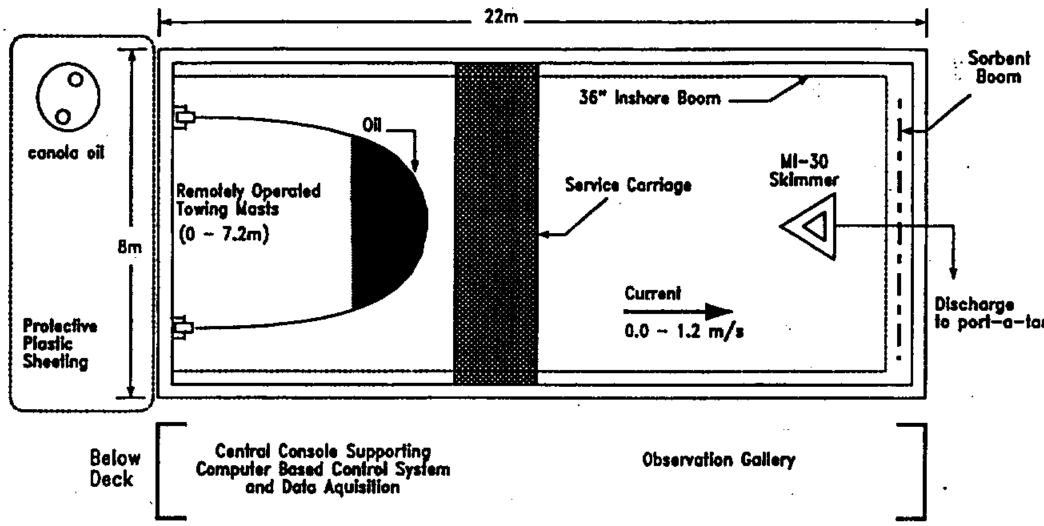


Figure 1.6 IFMT Test Tank

Boom Description

Of the seven booms tested, three were fence booms that are reported here. Table 1.4, page 1-14 provides a description of these booms.

Test Configuration

The boom to be tested was placed in a parabolic (catenary) configuration in the tank with the total boom length being 4 to 6 times the boom opening width. Lighter booms were fixed to the two masts located at the upstream end of the flume. The mast's separation width could be varied from 0 to 24 feet (7.2 m). The heavier booms were secured to the flume side walls at a fixed width of 26 feet (8 m). The booms were placed at the upstream end of the tank to allow maximum rise time for the entrained oil prior to its collection at the downstream end of the flume.

Test Oil

Canola Oil - viscosity 64 cSt, density 0.935
This organic oil (rape seed) is compared to Alberta Sweet Blend Crude that has a viscosity of 12 cSt and a density of 0.840.

Test Variables

Velocity at first loss and loss rates.

Data Precision and Accuracy

Flow velocity to 0.1 knots; loss rate to 0.1 liter/minute (0.026 gpm).

Test Procedure

Boom to be tested was deployed in a parabolic (catenary) configuration. Water current was set on low (0.4 knots) and 8 to 10 gallons (30 to 40 liters) of dyed canola oil was added to the tank to a thickness of several millimeters in the pocket of the boom. The volume of oil was first measured in a calibrated bucket and then carefully poured on the surface of the water. Water velocity was increased by 0.1 knot increments until first loss of oil was observed. The water velocity was reduced, then increased again to first loss to confirm the velocity. Oil was added to the boom to replace the oil lost. The oil loss rate was then determined by timing the loss of approximately 90% of the initial oil volume present in the boom at a velocity of 0.2 knots above the first loss velocity.

Table 1.4 Canadian Coast Guard Tests 1991 (C-2)

BOOM	POL-E-BOOM	FLEXY OIL BOOM	GLOBE BOOM 36 ED
FREEBOARD inches (mm)	17 (430)	6 (150)	12 (300)
DRAFT inches (mm)	19 (480)	12 (310)	24 (610)
HEIGHT inches (mm)	36 (920)	18 (460)	36 (910)
END CONNECTORS	Slide with seal	Slide with seal	Steel plates
SKIRT MATERIAL	PVC 22 oz/yd^2 (746 g/m^2)	PVC 22 oz/yd^2 (746 g/m^2)	PVC coated polyester 85 oz/yd^2 (2,882 g/m^2)
FLOTATION	Solid 2 X 6 X 48 inches (5 X 15 X 122 cm)	Solid foam	Foam filled shells
WEIGHT lbs/ft (kg/m)	[1]	2 (3)	4.2 (6.3)
RESERVE BUOYANCY lb/ft (kg/m)	Not reported	Not reported	Not reported
RESERVE B/W RATIO	13:1 [2]	Not reported	4.2:1 [4]
BALLAST	3/8 inch (10 mm) galvanized chain	Lead weights	3/8 inch (10 mm) chain
TENSION MEMBERS	Fabric/ballast chain	Fabric	fabric/ballast chain
TENSILE STRENGTH lb (N)	1,800 (8,100) [3]	Not reported	45,000 (202,500) [4]

Notes: [1] Weight/foot reported as 31 pounds/foot. This is probably reported in error. Other boom of this size and type produced by the same manufacturer has a weight of about 3 lbs/ft.
[2] This is an estimate based on the B/W ratio of a similar size and type boom produced by the same manufacturer.
[3] A similar size and type boom produced by the same manufacturer has a tensile strength of 15,000 pounds (67,500 N)
[4] Reported for this boom in the 7th Edition of the World Catalog of Oil Spill Response Products.

An initial volume of oil, estimated to give a thickness of 5 mm in the boom apex, was measured using calibrated buckets and recorded prior to each boom test. Before each subsequent run with a given boom, enough oil was added to bring the volume back to the initial volume. The amount of makeup oil required was determined by visually comparing the initial amount of oil in the boom prior to testing, with the oil remaining in the boom following a given run. This was accomplished by using two video screens to simultaneously compare the color intensity of the oil in the boom apex. The volume of oil lost during the loss rate determinations was also estimated visually using the same method.

Test Results

Boom performance was based on oil retention capability described by first loss speed and loss rate at 0.2 knots above first loss velocity. First loss velocity was defined as the first "significant" loss observed as the water velocity was gradually increased. Although smaller losses - occasional droplets - occurred prior to what was judged to be first loss, the loss was not considered significant until a fairly steady stream of oil escaped from the boom.

Most earlier tests have shown oil loss to occur by entrainment from the head wave. While this was occasionally observed, the oil loss mechanism most frequently observed in these tests was that of drainage through vortices formed in the boom pocket. The vortex formation usually appeared at current velocities of 0.2 to 0.3 knots before the first significant loss velocity was reached. Vortices formed at the lower velocities resulted in minimal loss, which was not considered significant. Often a vortex would form, then disappear without any oil loss occurring at all. The side viewing windows were ideally suited for observing oil loss and for determining the mode of oil loss. [Author's note: The formation of vortices and oil loss from vortices has been noted in previous tests and has been noted in the field, therefore this phenomenon should be investigated at OHMSETT and elsewhere.]

Table 1.5 Test Results, Canadian Coast Guard 1991 (C-2)
Booms tested in 5 mm slick, gap ratio 3:1, Oil Viscosity 64 cSt

BOOM	1st LOSS SPEED (kts)	LOSS RATE AT 1st LOSS + 0.2 kts (gpm @ kts)	COMMENT
POL-E-BOOM F 17 inches D 19 inches B/W 13:1	0.9	2.6 @ 1.4	Severe planing occurred at speeds >1 kt.
FLEXY BOOM F 6 inches D 12 inches B/W Not reported	1.0	3.3 @ 1.2	Oil loss from shedding and vortices. Good boom stability at 1.2 kts.
GLOBE BOOM 36 ED F 12 inches D 24 inches B/W 4.2:1	1.2	3.1 @ 1.4	Boom stable at higher velocities. Most loss from vortices, some loss from headwave (entrainment)

Overall Assessment of Results

First loss speeds are high as compared to other booms of this type. Loss rates are low as compared to more recent OHMSETT tests; however, the amount of oil used was very small, which certainly would have affected loss rate.

2.6 Fence Boom Performance Summary

Conventional Fence Booms

Early tests at OHMSETT show that a relatively small fence boom, freeboard 6 inches, draft 12 inches, and B/W ratio of less than 1, can contain a 2 mm slick of moderate viscosity (300 cSt) oil in a catenary mode at a tow speed of about 0.8 to 0.9 knots both in calm water and a long 1 - 2 foot wave with a length to height ratio or more than 15:1. Using a diversionary mode under the same conditions, tow speed without oil loss increases to 1.0 to 1.4 knots. These tests show that a boom with modest physical characteristics can successfully contain oil in the diversionary mode at speeds approaching 1.5 knots. This result suggests the application of booms in a "V" configuration, which has had great success in later years.

The same boom was tested later in three petroleum type hazardous materials. Although these materials had oil-like viscosities and densities, the results were not always the same. The small B.F. Goodrich boom performed as well in Octanol and Naptha as it did in oil. No loss tow speeds were very low in DOP, which the report attributes to its high density, 0.975.

The much larger Coast Guard High Seas Boom, freeboard of 21 inches, draft 27 inches, and B/W ratio of 3.6:1, did not perform nearly as well. No reasons are given for this except that this was a prototype boom. Since this boom was not produced in this form and its successors have not been produced for many years, this condition deserves no further comment.

The small boom described previously was tested again in two diversionary modes, angles of 32° and 20° to the direction of flow, a 20° Vee, and a parabolic nozzle configuration. These tests showed that a high level of containment occurred as long as the flow velocity normal to the face of the boom was less than or equal to 1 knot. In the 20° diversionary mode and the 20° Vee configuration this resulted in a tow velocity of 3 knots. This was a remarkable result. Although the parabolic nozzle worked somewhat better than the Vee, this advantage was not considered to be worth the additional trouble of rigging and deploying the system.

In later tests in a Canadian flume, booms of moderate size (freeboard of 6 and 17 inches, drafts of 12 and 19 inches)deployed in a catenary mode, had first loss flow speeds of 0.9 to 1.0 knots. A larger boom, freeboard 12 inches, draft 24 inches, had a first loss speed of 1.2 knots.

These individual tests of fence booms considered together show that fence booms can contain oil successfully in a catenary mode at tow speeds of just under 1 knot, but in a steep diversionary mode or a steep "V," effective tow speeds can increase up to 3 knots. This is true for either calm water or small waves with a high length to height ratio. In short, choppy waves, failure occurs much earlier. Although these data are not supported by tests of a wide diversity of boom characteristics, these data taken alone do not indicate much performance dependence on either boom size or buoyancy to weight ratio.

Fire Resistant Containment Fence Booms

Three fire resistant containment fence booms have been tested and are reported with other fire containment booms in Chapter 7. The performance of these fence booms is compared to other fence booms here; however, this comparison in terms of seakeeping and oil containment capability is not entirely fair. Fire containment booms must be first impervious to high temperatures. This means that they may be made of very heavy, fire resistant materials. This extra weight often reduces buoyancy to weight ratio and also may make them stiff, which affects heave response. Although we do not want to ignore fire containment booms in the discussion of fence boom performance, the reader must understand that their performance must be considered separately because of their special features needed to survive fire.

Fire containment fence booms tested include the Dome Fire Containment Boom, the SL Ross Pocket Fire Boom (a smaller, lighter version of the Dome boom), and the Applied Fabric Technologies Pyro Boom. In calm water, first loss and gross loss tow speeds were typical of conventional booms, 0.75 to 1.3 knots. This performance was degraded somewhat in a short period regular wave, but performance in a long period wave and also in harbor chop was about the same as in calm water. Thus in spite of the special requirements of fire containment boom, their performance remains about the same as conventional fence booms.

Chapter 2

CURTAIN BOOMS WITH INTERNAL FOAM FLOTATION

1.0 DESCRIPTION

Curtain booms have centerline flotation that may be:

- Internal foam
- External foam
- Self-inflatable
- Pressure-inflatable

They have flexible skirts that are free to move independently of the floats. As a result, skirt depth and freeboard are not necessarily lost at the same time. Whereas a rigid fence boom may lose freeboard and skirt depth because of roll, curtain booms minimize the problem of roll by having tension members at or above the water line and at the bottom of the skirt.

Only curtain booms with internal foam flotation are considered in this chapter. Other curtain booms are described in the chapters that follow.

A curtain boom with internal foam flotation generally uses a flexible, relatively light PVC or polyurethane coated fabric to cover flexible foam flotation. The fabric encloses the flotation and often a ballast chain and top cable. The fabric is joined around these components with either a radio frequency or hot air "weld." The ballast chain and top cable (when provided) serve as strength members. In some cases ballast is provided by lead weights instead of chain. The foam flotation may be either cylindrical or rectangular. "Fast current" versions of the boom sometimes have holes near the bottom of the boom skirt to reduce the velocity of flow down the face of the boom.

Figure 2.1 shows a boom with internal foam flotation. This particular model has rolled foam, a cable tension member on top, and a combination ballast chain/tension member on the bottom.

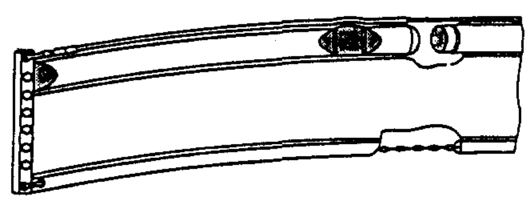


Figure 2.1 Curtain Boom with Internal Foam Flotation

Foam flotation may be either stiff logs, flexible rolled logs, or granules enclosed in the fabric flotation chamber. Foam flotation generally comes in short segments to improve heave response and to provide fold points for storage. Granular flotation provides excellent flexibility for heave response, but the granular foam can become lost or saturated with water if the flotation chamber is torn. Granular foam may also shift in the buoyancy chamber leaving some areas without buoyancy. Solid foam avoids these problems, but heave response is not as good and the solid foam may crumble and break with handling. Flexible rolled foam seems to be the most popular now because it provides a moderate amount of flexibility, is very durable, and maintains a large percent of normal buoyancy even if the flotation chamber is flooded.

1.1 SELECTION CONSIDERATIONS

Buoyancy	Moderate; reserve buoyancy to weight ratios are generally in the range of 2 to 8 but in some cases may be somewhat higher. The higher ranges of buoyancy are adequate for all but the most severe offshore conditions.
Roll Response	Good; roll response is helped by the boom flexibility and use of a bottom tension member.
Heave Response	Good; heave response is improved by using short float sections so that the boom is flexible to follow the surface of waves.
Mode of Application	This is a commonly available spill response boom.
Other	Curtain boom is moderately expensive and fairly easy to store. Fabric often used in this boom may deteriorate if stored in direct sunlight and it may be vulnerable to damage by chaffing or cutting by sharp objects.

2.0 TEST RESULTS

2.1 OHMSETT TESTS 1975 (O-1)

A series of tests were performed on 16 oil spill response devices at the OHMSETT test tank from April 1975 through June 1975. These tests included eight containment booms four of which were curtain booms with internal foam flotation. Booms were tested in the catenary and diversionary modes. Booms were first tested for stability over a wide range of wave conditions without oil and then in waves within their operational stability envelope. Test data record maximum stable tow speed and maximum no loss tow speed. The no loss tow tests were made with 2 mm of oil. Figure 2.2, page 2-3, shows sketches of the booms tested.

Test Configuration

Boom was towed in a catenary (U-shape) and diversionary (J-shape). The length of the boom used for the catenary configuration was approximately 200 feet (61 m) and for the diversionary configuration was approximately 100 feet (30.5 m). Boom towed in the diversionary mode had an angle of 23° to 44° between the boom and the current, but the angle used is not identified for individual runs. Boom sections were joined together and tow connections were rigged according to the manufacturer's recommendations.

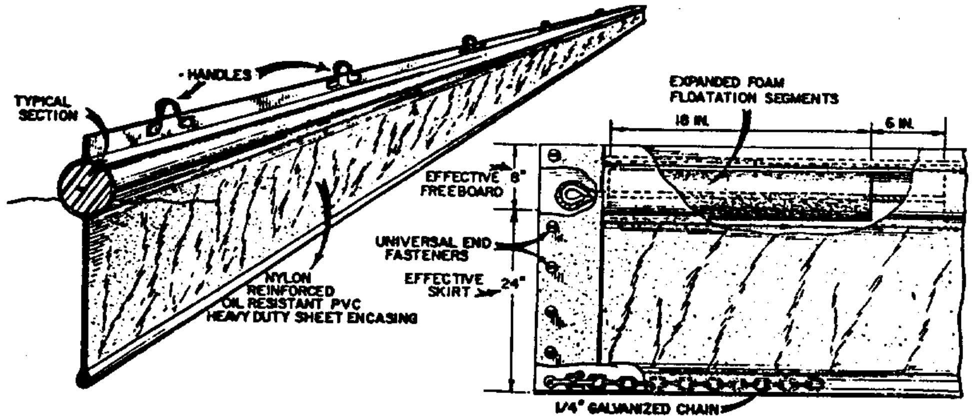
Test Oils

Diesel fuel - viscosity 10 cSt, density 0.852
Lube oil - viscosity 510 cSt, density 0.915
Oil thickness - 2 mm

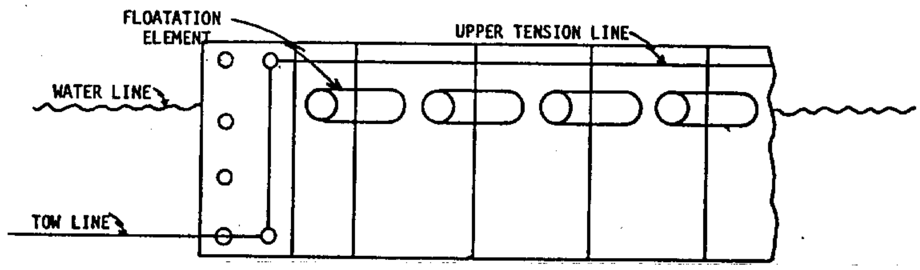
Note that lube oils with other viscosities were used in the tests. These are shown on individual test results data sheets.

Data Precision and Accuracy

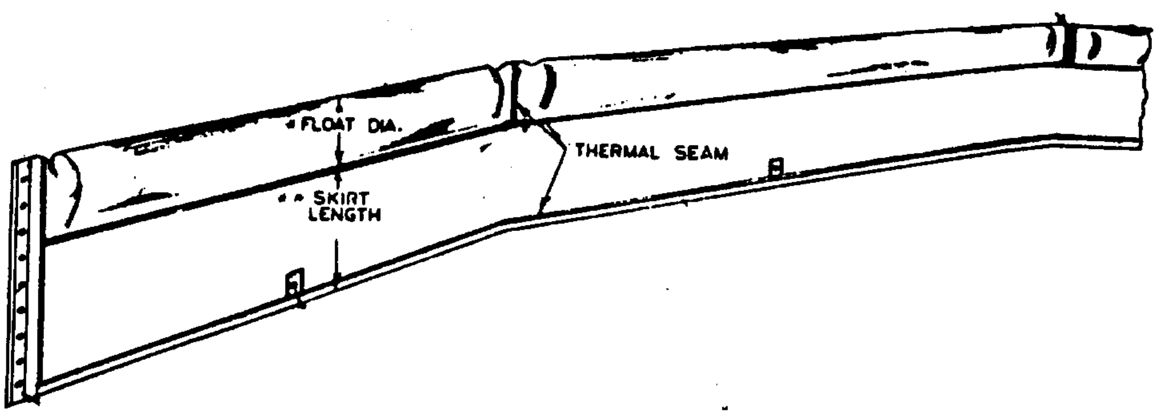
Tow Speed - 0 up to critical tow speed within 0.1 knot (0.05 m/s).



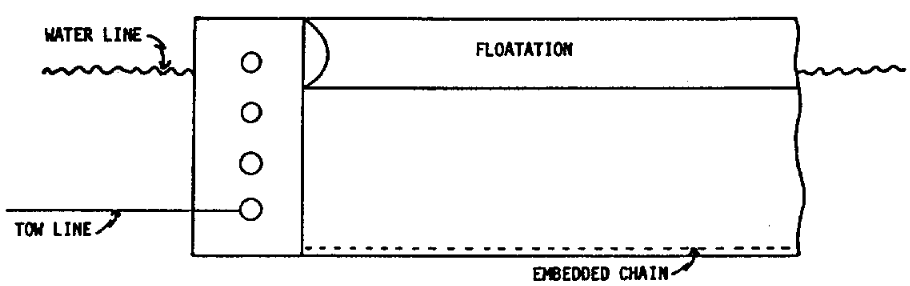
(a) Clean Water Harbour Boom



(b) Coastal Services T-T Boom



(d) ACME O.K. Corral



(e) Kepner Sea Curtain

Figure 2.2 Sketches of Booms Tested

Table 2.1 Boom Description OHMSETT Tests (O-1)

BOOM	HARBOUR BOOM (CLEAN WATER)	T-T BOOM COASTAL SERVICES	O.K. CORRAL ACME	SEA CURTAIN KEPNER
FREEBOARD in (mm)	8 (200)	6 (150)	6 (150)	8 (200)
DRAFT in (mm)	24 (610)	12 (300)	6 (150)	12 (300)
HEIGHT in (mm)	32 (810)	18 (450)	12 (300)	20 (500)
END CONNECTORS	- -	End plates & fast eye snap hooks	Plate	Slot with eyebolt attachments
SKIRT MATERIAL	Nylon reinforced PVC	PVC nylon reinforced fabric	Jaton nylon coated with polyvinyl chloride 0.03 in (0.79 mm) thick	Vinyl coated nylon
FLOTATION	Polyethylene cylinders 18 in. long X 6 in dia.. (0.46 X 0.15 m)	Polyethylene cylinders 9 in. long X 4 in dia. (0.23 X 0.1 m)	Plastic foam thermal sealed into fabric 4.5 ft long X 6 in. dia. (1.4 X 0.2 m)	Close cell foam 8 ft (2.44 m) long
WEIGHT lb/ft (kg/m)	2.04 (3.02)	1.65 (2.4)	2.76 (4.1)	2.5 - 3 (3.7 - 4.4)
RESERVE BUOY-ANCY lb/ft (kg/m)	2.7 (4.02)	2.41 (3.59)	9.07 (13.5)	19.6 (29.2)
RESERVE B/W RATIO	1.3	1.5	3.3	6.5 - 7.8
BALLAST	1/4 in (6.4 mm) galvanized chain enclosed in bottom of skirt	1/4 in (6.4 mm) galvanized chain along bottom of skirt	3/8 in (9.5 mm) chain	1/4 in (6.4 mm) galvanized chain
TENSION MEMBERS	5/16 in (7.9 mm) cable in float cylinders + ballast chain	Self tensioning on skirt	Self-tensioning	Self-tensioning

*Note: Dimensions in millimeters are rounded off broadly. Values reported here are those shown in the test report.

Test Procedure

Performance criteria for booms was intended to determine the tow speed at which oil began to escape the boom in both the catenary and diversionary modes. First, the boom was tested without oil in various wave conditions to determine the maximum stable tow speed in each configuration. This stability testing determined the tow speeds at which planing, submergence, or other type of failure would occur. Splashover at the boom fluid interface was considered to be a stability failure, since in many cases the loss of freeboard of a boom reflects its inability to maintain an adequate vertical profile. Then the boom was tested with oil in the same waves where its stable performance range was above 0.5 knots (0.25 m/s) tow speed .

In stability tests, the water surface condition was established (wave or no wave), then the boom was towed at continuously increasing speed until judged unstable. After the boom became unstable, the tow speed was decreased in 0.1 knot (0.5 m/s) increments until the boom became stable, and then speed was increased by 0.1 knot increments to reconfirm the failure speed. This speed was then recorded as "critical tow speed" and was the upper limit to be used in the test matrix with oil.

Tow tests in oil were conducted in the same way as stability tests. 350 gallons (1.32 m^3) of oil was distributed as a 2 mm thick spill 50 feet (15.2 m) wide ahead of the boom. In these tests, critical tow speed was defined as the maximum tow speed for either catenary of diversionary configurations at which there was no loss of oil under the boom. In the diversionary mode, a separation boom was deployed behind the test boom so that all oil that had moved down the boom to the apex was contained within the separation boom. The oil collected in the separation boom was judged to be contained.

Test Results

Even though this set of tests was performed many years ago, the results are significant because rarely have such an extensive set of tests been performed on so many booms at the same time. Some of these booms are no longer in production, but many similar types still exist and their performance in similar conditions can be expected to be the same. Table 2.2 shows a summary of the results of all tests performed on the curtain booms with internal foam flotation.

Table 2.2 Test Results OHMSETT Tests (O-1)

BOOM	HARBOR BOOM (CLEAN WATER) F 8" D 24" B/W 1.3		T-T BOOM (COASTAL SER.) F 6" D 12" B/W 1.5		O.K. CORRAL (ACME) F 6" D 6" B/W 3.3		SEA CURTAIN (KEPNER) F 8" D 12" B/W 6.5-7.8	
	TYPE FAILURE	TOW SPEED (KTS)	TYPE FAILURE	TOW SPEED (KTS)	TYPE FAILURE	TOW SPEED (KTS)	TYPE FAILURE	TOW SPEED (KTS)
CATENARY								
NO OIL								
CALM WATER	Submarine	1.2	Submarine	1.0	Planing	2.2	Submarine	2.1
WAVES								
1 X 45' (0.3 X 13.7 m)	Splash.	1.0	Submarine	0.7	Planing	1.5	Splash.	1.1
1 X 75' (0.3 X 23 m)	Splash.	1.0	Submarine	0.8	Splash.	1.8	Submarine	1.8
2 X 30' (0.6 X 9.1 m)	Splash.	0.5	Submarine	0.7	Splash.	0.9	Splash.	1.1
1 X 9' (0.3 X 2.7 m)	Splash.	0	Splash.	0	Splash.	0	Splash.	0.5
TESTS IN 2 mm OIL	333 cSt		230 cSt		649 cSt		97 cSt	
CALM WATER	Entrain.	0.9	Entrain.	0.9	Entrain.	0.8	Entrain.	0.9
WAVES								
1 X 45' (O.3 X 13.7 m)	Entrain.	0.9	Entrain.	0.7	Entrain.	0.8	Entrain.	0.9
2 X 30' (0.6 X 9.1 m)	Entrain.	0.5	Entrain.	0.7	Entrain.	0.8	Entrain.	0.9
1 X 9' (0.3 X 2.7m)	Splash.	0	NA	NA	NA	NA	NA	NA
DIVERSIONARY*								
NO OIL								
CALM WATER	Submarine	1.6	Submarine	0.9-1.0	Planing	0.9	Submarine	1.8
WAVES								
1 X 45' (0.3 X 13.7 m)	Submarine	1.3	Submarine	0.9	Planing	0.9	Submarine	1.8
1 X 75' (0.3 X 22.9 m)	Submarine	1.3	Submarine	0.8	Planing	0.9	Submarine	1.8
2 X 30' (0.6 X 9.1 m)	Submarine	0.9	Submarine	0.8	Planing	0.9	Submarine	1.5
1 X 9' (0.3 X 2.7 m)	Splash.	0	Splash.	0-0.5	Splash.	0	Splash.	0
2 X 75' (0.6 X 22.9 m)	NA	NA	Submarine	0.8	NA	NA	NA	NA
TESTS IN 2 mm OIL	1,462 cSt		336 cSt		333 cSt		235 cSt	
CALM WATER	Entrain.	1.2	Entrain.	0.8	Entrain.	0.8	Entrain.	1.4
WAVES								
1 X 45' (0.3 X 13.7 m)	Entrain.	1.2	Entrain.	0.9	Entrain.	0.8	NA	NA
1 X 75' (0.3 X 22.9 m)	NA	NA	Entrain.	0.8	NA	NA	NA	NA
2 X 30' (0.6 X 9.1 m)	Entrain.	0.8	Entrain.	0.75	Entrain.	0.8	Entrain. Splash.	1.4

*The angle between the boom and current was 23° to 44°, but the angle is not identified for individual tests.

Although all booms are of the same type, the reader must be careful in comparing their performance because there are important physical differences among the booms. In order to be sure that these differences are recognized when reviewing test results, boom freeboard, draft, and buoyancy to weight ratio are shown at the top of each column along with boom name. Freeboard and draft are only shown in English units because of space restrictions. Other conventions in summarizing data include:

o Boom tow speeds are shown in knots. The test report records speeds in meters per second, but

knots are used here because that is the custom in most test reports. In conversion of units, values are rounded to the nearest tenth of a knot, which is within the accuracy of data collection.
o Viscosity of oil was somewhat different between runs. The number shown is the average viscosity for all runs.
o Some tests were run in the same environment twice. If the results of these runs were the same, data are shown as a single entry. If data are slightly different, a range of values are shown.
o Types of boom failure include submarine, or submergence, planing, splashover (splash.), and entrainment (entrain.).

Overall Assessment of Performance

Harbor Boom in Catenary Mode - Stability failure (submarine and splashover) occurs at only a slightly higher tow speed than entrainment tow speed in oil, and in the cases of the 2 X 30 foot wave and the short 1 X 9 foot wave, failure speeds are the same. Testing with oil in Calm Water and a 1 X 45 foot wave, entrainment occurs at 0.9 knots, which is slightly better than average. In the 2 X 30 foot wave entrainment occurs at only 0.5 knots and in the short 1 X 9 foot wave splashover occurs with no forward velocity.
Harbor Boom in the Diversionary Mode - Stability failure and failure in oil both occur at a slightly higher tow speed than for the catenary mode, but as before, failure occurs with no forward velocity in the short, choppy wave.
T-T Boom in the Catenary Mode - Stability failure (submarine) occurs at relatively low tow speeds and performance in oil is about average.
T-T Boom in the Diversionary Mode - Stability failure (submarine) occurs at relatively low speeds and there is only a slight improvement in performance in oil. (In Calm Water entrainment occurs sooner than in the catenary mode, but this may be within the range of measurement accuracy.)
O.K. Corral Boom in the Catenary Mode - Stability failure occurs at a relatively high tow speed and it takes the form of planing and splashover instead of submarine failure. This may be due to a higher buoyancy to weight ratio. In oil, performance is about average or slightly better than average.
O.K. Corral Boom in the Diversionary Mode - Stability failure in the form of planing occurs at a relatively low tow speed, which may be because the chain ballast is not used as a tension member. In oil, the diversionary mode does not delay entrainment failure, which may be a result of the shallow draft of the boom.
Sea Curtain in the Catenary Mode - Stability failure occurs at relatively high tow speeds, and the boom even resists splashover in the short wave up to 0.5 knots. In oil performance is slightly better than average.
Sea Curtain in the Diversionary Mode - Stability failure occurs at relatively high tow speeds, and when tested in oil, entrainment does not occur until 1.4 knots, which is very good. This is possibly due to the relatively high buoyancy to weight ratio.

Comparison of All Booms Together

Comparison of the booms together is not completely justified because they have substantial physical differences; however, it may be possible to explain differences in performance based on these differences.

First consider performance in the catenary mode. The Harbor boom and T-T boom have about the same buoyancy to weight ratio but the T-T boom has a draft that is smaller by half. Although the performance of these two units in oil is not substantially different, the smaller draft of the T-T boom may account for the slightly degraded performance in waves.

The O.K. Corral boom is much smaller than any of the others with a draft of only 6 inches, but its performance is almost as good. This may be because of a buoyancy to weight ratio that is higher than for the Harbor boom and the T-T boom. The Sea Curtain performs best overall in the catenary mode, which is probably due to its draft of 12 inches and high buoyancy to weight ratio.

In the diversionary mode, the Harbor boom a greater edge over the T-T boom, which is probably caused by its greater draft. The O.K. Corral boom performance remains good, but no better than in the catenary mode. Entrainment failure probably occurs early because of its small draft. As before, the Sea Curtain is best because of an adequate draft and high buoyancy to weight ratio.

2.2 OHMSETT TESTS 1975 (O-2)

A second series of tests were performed at OHMSETT between September through November 1975, this time with four floatable hazardous materials.

Three containment booms were tested, two of which had been tested previously (O-1). This test involves the Clean Water Harbor Boom. As before, booms were tested in the catenary and diversionary modes. Booms were first tested for stability over a wide range of wave conditions without oil and then in waves within their operational stability envelope. Test data record maximum stable tow speed and maximum no loss tow speed. The no loss tow tests were made with 2 mm of test fluid. See section 2.1 of this chapter for the boom description, test configuration, test variables, and test procedure.

Test Fluids

- o Octanol -viscosity 12 cSt, density 0.827
- o Dioctyl phthalate (DOP) - viscosity 67.5 cSt, density 0.975
- o Naptha - viscosity 5.8 cSt, density 0.710

Table 2.3 Test Results OHMSETT Tests (O-2)

BOOM	CLEAN WATER HARBOR BOOM Freeboard 8 in. Draft 24 in. B/W 1.3:1	
	TYPE FAILURE	TOW SPEED (kts)
CATENARY		
TESTS IN 2 mm FLUID	DOP 74.9 cSt	
CALM WATER	Entrainment	0.2
WAVES		
2 X 30' (0.6 X 9.1 m)	Entrainment	0.3
TESTS IN 2 mm FLUID	Octanol 13.8 cSt	
CALM WATER	Entrainment	0.4-0.76
WAVES		
2 X 30' (0.6 X 9.1 m)	Entrainment	0.3-0.4
TESTS IN 2 mm FLUID	Naptha 7 cSt	
CALM WATER	Entrainment	0.9
WAVES		
2 X 30' (0.6 X 9.1 m)	Entrainment	0.4-0.6
DIVERSIONARY*		
TESTS IN 2 mm FLUID	DOP 74.9 cSt	
CALM WATER	Entrainment	0.2
WAVES		
2 X 30' (0.6 X 9,1 m)	Splashover	0.1
TESTS IN 2 mm FLUID	Octanol 13.3 cSt	
CALM WATER	Entrainment	0.7
WAVES		
2 X 30' (0.6 X 9.1 m)	Splashover	0.2
TESTS IN 2 mm FLUID	Naptha 7 cSt	
CALM WATER	Entrainment	1.1
WAVES		
2 X 30' (0.6 X 9.1 m)	Splashover	0.9

*The relative angle used in diversionary tests was not reported.

Overall Assessment of Performance

Clean Water Boom in Catenary Mode - First loss tow speed tends to be low for both DOP and Octanol in Calm Water and waves. Performance in Naptha in Calm Water and the 2 X 30 foot wave is about the same as the performance in oil. (See Table 2.2 page 2-5.)

Clean Water Boom in the Diversionary Mode - As in the catenary mode, first loss tow speed tends to be low for both DOP and Octanol in Calm Water and waves. Performance in Naptha in Calm Water and the 2 X 30 foot wave is about the same as the performance in oil. (See Table 2.2 page 2-5.)

The test report comments that density appeared to the predominate independent variable that determined performance. First loss tow speed decreased as density increased in both Calm Water and waves. The report concludes that high density fluids (close to 1.0) cannot be controlled with existing containment booms in currents greater than 0.3 knots.

2.3 Curtain Booms With Internal Foam Flotation Performance Summary

Conventional Curtain Booms

In spite of differences in size and buoyancy, the curtain booms tested have similar levels of performance towed in the catenary mode. In calm water, entrainment failure comes at 0.8 to 0.9 knots. In a long wave, these values are reduced to 0.5 to 0.9 knots, with the variation in performance being driven by boom draft and buoyancy to weight ratio, with B/W ratio likely being the controlling variable. In the diversionary mode, failure tow speeds range from 0.75 to 1.4 knots. Again, boom draft and B/W ratio seem to be controlling variables.

Fire Resistant Containment Curtain Booms

Fire resistant boom tests occurred much later than the early tests of curtain booms. In these later tests, the boom had a generally better B/W ratio (almost 4:1) and a larger draft (21 inches). With these differences, performance was slightly better. First loss entrainment failure in calm water was about 0.9 knots and gross loss was about 1.2 knots. (Gross loss was not measured in the earlier tests.) In a long wave (length to height ratio of 20:1), first loss was reduced to 0.7 to 0.8 knots and gross loss to 0.9 to 1.1 knots. In a longer wave (L/H 38:1), first loss was 0.7 to 1.1 knots with gross loss at 1.1 to 1.4 knots. Performance in harbor chop was about the same as in calm water.

These results show that a fire resistant containment boom with adequate physical dimensions and B/W ratio will perform as well as conventional boom with similar characteristics. Complete fire containment boom tests are presented in Chapter 7.

Chapter 3

CURTAIN BOOMS
WITH EXTERNAL FOAM FLOTATION

1.0 DESCRIPTION

Curtain boom with external foam flotation looks exactly like some fence booms except that the skirt material is flexible. Fence boom with external foam is often made of very heavy, stiff conveyor belt material. As new fabrics have been developed, it became possible to have a very strong, but light and flexible skirt to which external foam flotation is attached. This product, with the flexible skirt, is classified as a curtain boom.

These booms generally have rigid foam flotation that comes in fairly short sections for better heave response and ease in storing. They have weights attached for ballast and the boom fabric is the only tension member. Figure 3.1 shows a sketch of a curtain boom with external foam flotation.

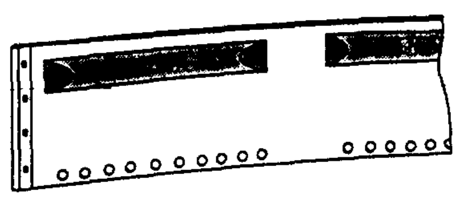


Figure 3.1 Curtain Boom with External Foam Flotation

1.1 SELECTION CONSIDERATIONS

Buoyancy Buoyancy to weight ratio is good, generally 2 or greater, which is better than comparable fence boom because of the light, strong fabric used in the skirt.

Roll Response Good; roll response is helped by the flexible fabric and ballast weights on the bottom of the skirt.

Heave Response Fair to good. Adequate buoyancy to weight ratio and good flexibility.

Mode of Application Industrial, permanent harbor boom, and some spill response situations.

Other The boom is durable, easy to store and deploy. Generally more expensive than curtain boom with internal foam flotation.

2.0 TEST RESULTS

2.1 OHMSETT TESTS 1975 (O-1)

A series of tests were performed on 16 oil spill response devices at the OHMSETT test tank from April through June 1975. These tests included eight containment booms one of which, the, Slickbar MK VI, was a curtain boom with external foam flotation. Booms were tested in the catenary and diversionary modes. Booms were first tested for stability over a wide range of wave conditions without oil and then in waves within their operational stability envelope. Test data record maximum stable tow speed and maximum no loss tow speed. The no loss tow tests were made with 2 mm of oil.

Boom Description

Slickbar MARK VI Boom

Freeboard	6.5 inches (170 mm)
Draft	8 inches (200 mm)
Boom Height	14.5 inches (370 mm)
End Connectors	Mark II end set connector
Skirt Material	polyester woven multi filament fabric impregnated with PVC
Flotation	polyethylene foam with solid polyethylene skin 4.2 feet long by 6.5 inches in diameter (1.27 X 0.17 m). The exterior foam flotation is attached to the skirt with a 1 inch wide PVC coated polyester fabric strap.
Weight	2.57 lbs/ft (3.82 kg/m)
Reserve Buoyancy	3.99 lbs/ft (5.94 kg/m)
Reserve B/W Ratio	2.0
Ballast	hardened lead weights
Tension Member	3/8 inch (9.5 mm) stainless steel cable mounted along the bottom of the flotation

Figure 3.2 shows a sketch of the MARK VI Boom.

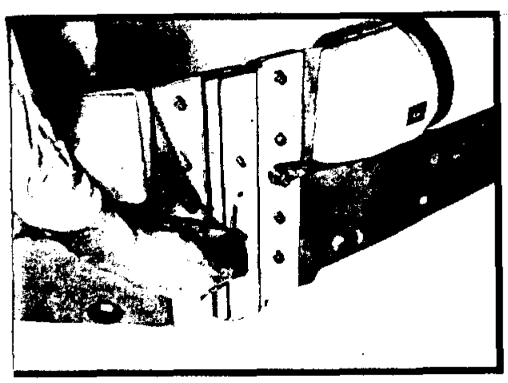


Figure 3.2 Slickbar Mark VI Boom

Test Configuration

Boom was towed in a catenary (U-shape) and diversionary (J-shape). The length of the boom used for the catenary configuration was approximately 200 feet (61 m), and for the diversionary configuration was approximately 100 feet (30.5 m). Boom towed in the diversionary mode had an angle of 23° to 44° between the boom and the current, but the angle used is not identified for individual runs. Boom sections were joined together and tow connections were rigged according to the manufacturer's recommendations.

Test Oils

Diesel fuel - viscosity 10 cSt, density 0.852
Lube oil - viscosity 510 cSt, density 0.915
Oil thickness - 2 mm

Note that lube oils with other viscosities were used in the tests. These are shown on individual test results data sheets.

Test Variables

Boom deployment modes, tow speeds, and wave conditions.

Data Precision and Accuracy

Tow Speed - 0 up to critical tow speed within 0.1 knot (0.05 m/s).

Test Procedure

Performance criteria for booms was intended to determine the tow speed at which oil began to escape under the boom in both the catenary and diversionary modes. First, the boom was tested without oil in various wave conditions to determine the maximum stable tow speed in each configuration. This stability testing determined the tow speeds at which planing, submarining (submergence), or other type of failure would occur. Splashover at the boom fluid interface was considered to be a stability failure, since in many cases the loss of freeboard of a boom reflects its inability to maintain an adequate vertical profile. Following stability testing, the boom was tested with oil in waves where its stable performance range was above 0.5 knots (0.25 m/s) tow speed .

In stability tests, the water surface condition was established (wave or no wave), then the boom was towed at continuously increasing speed until judged unstable. Next, the tow speed was decreased in 0.1 knot (0.5 m/s) increments until the boom became stable, and then speed was increased by 0.1 knot increments to reconfirm the failure speed. This speed was then recorded as "critical tow speed" and was the upper limit to be used in the test matrix with oil.

Tow tests in oil were conducted in the same way as stability tests. 350 gallons (1.32 m^3) of oil was distributed as a 2 mm thick spill 50 feet (15.2 m) wide ahead of the boom. Critical tow speed was defined as the maximum tow speed for either catenary of diversionary configurations at which there was no loss of oil under the boom. In the diversionary mode, a separation boom was deployed behind the test boom so that all oil that had moved down the boom to the apex was contained within the separation boom. The oil collected in the separation boom was judged to be contained.

Test Results

Table 3.1 Test Results (O-1)

BOOM	SLICKBAR MARK VI BOOM Freeboard 6.5 in. Draft 8 in. B/W 2.0	
	TYPE FAILURE	TOW SPEED (kts)
CATENARY		
NO OIL		
CALM WATER	Planing	1.2
WAVES		
1 X 45' (0.3 X 13.7 m)	Planing	0.8
1 X 75' (0.3 X 23 m)	Planing	1.0
1 X 9' (0.3 X 2.7 m)	Splashover	0
2 X 30' (0.6 X 9.1 m)	Planing	0.8
TESTS IN 2 mm OIL	194 cSt	
CALM WATER	Entrainment	0.7
WAVES		
1 X 45' (O.3 X 13.7 m)	Entrainment	0.7
2 X 30' (0.6 X 9.1 m)	Entrainment	0.7
DiVERSIONARY*		
NO OIL		
CALM WATER	Planing	0.9
WAVES		
1 X 45' (0.3 X 13.7 m)	Planing	0.9
1 X 75' (0.3 X 23 m)	Planing	0.9
1 X 9' (0.3 X 2.7 m)	Splashover	0
2 X 30' (0.6 X 9,1 m)	Planing	0.9
TESTS IN 2 mm OIL	134 cSt	
CALM WATER	Entrainment	0.9
WAVES		
1 X 45' (0.3 X 13.7 m)	Entrainment	0.9
2 X 30' (0.6 X 9.1 m)	Entrainment	0.9

*Boom towed in the diversionary mode had an angle of 23° to 44° between the boom and the current, but the angle used is not identified for individual runs.

Overall Assessment of Performance

Mark VI Boom in the Catenary Mode - Tests without oil show that the boom has a flexible skirt that fails by planing at relatively low speeds. This instability is augmented by the tension cable at the bottom of the float rather than the bottom of the skirt, which would help to prevent planing. In oil, however, failure is by entrainment at the nominal effectiveness towing speed of 0.7 knots. As for most booms, splashover occurs with no towing speed in very short, choppy waves.

Mark VI Boom in the Diversionary Mode - In tests without oil, planing still occurs at a relatively low tow speed. Tests in oil show a slight improvement with entrainment occurring at 0.9 knots.

Note that this data is taken from an old report and this boom has been out of production for many years. The results are interesting, however, because tests show how boom with this configuration reacts in spill conditions. Recent versions of this boom do not have a tension member along the bottom of the flotation; fabric is the only tension member. This change may give the boom different performance characteristics.

2.2 Curtain Booms With External Foam Flotation Performance Summary

Tests in 2 mm of oil in calm water and long waves show failure at a tow speed of 0.7 knots, which is just at the minimum expected of a boom. In the diversionary mode, failure speed increases to 0.9 knots, which is also somewhat low. This performance could possibly be improved by increasing ballast weight, but this should not be done at the expense of buoyancy to weight ratio. Since this boom is most likely to be used as a permanent barrier, tow speed losses are not as important unless currents are present.

Chapter 4

SELF-INFLATABLE CURTAIN BOOMS

1.0 DESCRIPTION

Self-inflatable curtain booms have flotation chambers that are compressed in storage and inflated by atmospheric air on deployment through one-way intake valves or covered air ports. The flotation chamber maintains its shape either by atmospheric pressure air alone, or sometimes by collapsible frames and springs, or by a helical coil. An important advantage of these booms is that they can be deployed quickly. Further, since the buoyancy chambers are air-filled and very flexible, they have a high buoyancy to weight ratio and good heave response. Another advantage is that they are compactible and store in a small volume. Some booms of this type may have lower tensile strength and may be more vulnerable to punctures, tearing, or mechanical damage than other curtain booms. Further, in some cases, if valves or covered air ports on top of buoyancy chambers are not kept above water during deployment, the flotation chambers may fill with water and cause the boom to sink. Also for some types, the helical coils may be compressed so that the buoyance chamber flattens resulting in a loss of buoyancy. The disadvantages of some examples of this type are mostly a matter of design, construction, and fabric selection and should not be considered a problem with this class of boom in general. Self-inflatable curtain booms are generally made of flexible, relatively light PVC or polyurethane coated fabric. Figure 4.1 shows typical self-inflatable booms.

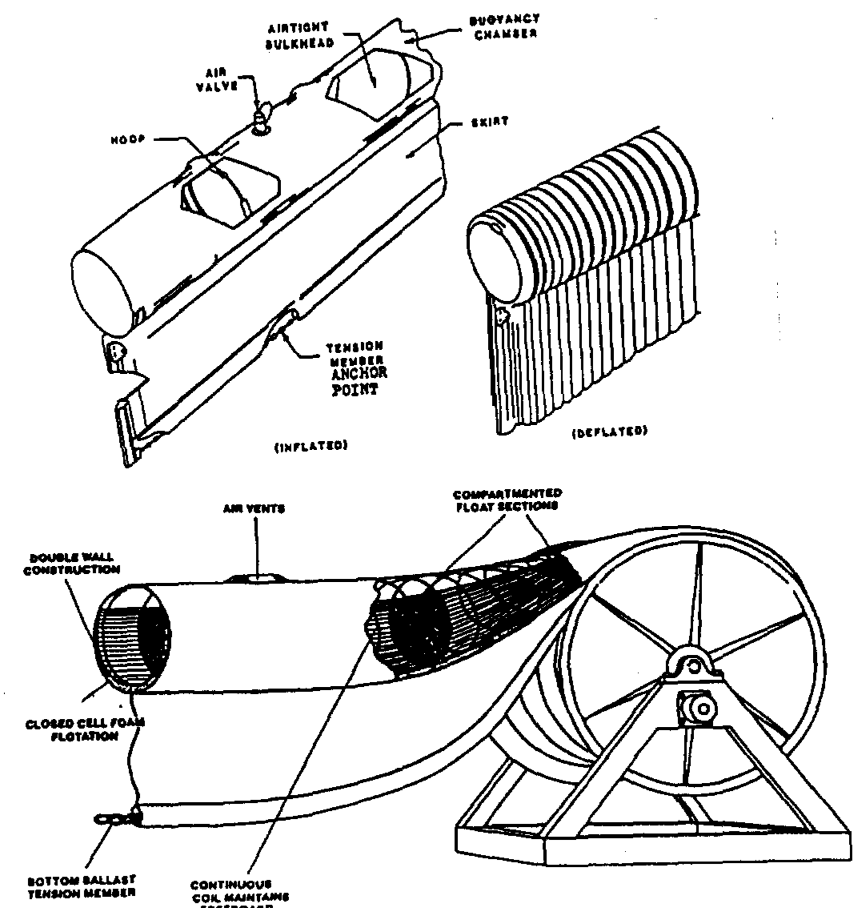


Figure 4.1 Typical Self-inflatable Curtain Boom

1.1 SELECTION CONSIDERATIONS

Buoyancy	Generally very high, often in the range of 20 to 50:1, but buoyancy may be lost as a result of puncture or a leaking air valve
Roll Response	Bottom tension and good flexibility provide good roll response
Heave Response	High buoyancy to weight ratio and good flexibility provide good heave response.
Mode of Application	Since they can be deployed rapidly, they are often used for first response
Other	Generally not used for long term deployment at a spill site. Not generally used in industrial applications

2.0 TEST RESULTS

2.1 OHMSETT TESTS 1975 (O-1)

A series of tests were performed on 16 oil spill response devices at the OHMSETT test tank from April through June 1975. These tests included eight containment booms, one of which was the Whittaker Expandi-Boom, a self-inflatable curtain boom. Booms were tested in the catenary and diversionary modes. Booms were first tested for stability over a wide range of wave conditions without oil and then in waves within their operational stability envelope. Test data record maximum stable tow speed and maximum no loss tow speed. The no loss tow tests were made with 2 mm of oil. (The Expandi-Boom is still being manufactured, most recently by Hans A. Mathiesen A/S of Oslo, Norway.)

Boom Description

Whittaker Expandi-Boom

Freeboard	12.5 inches (280 mm)
Draft	19.5 inches (500 mm)
Boom Height	32 inches (780 mm)
End Connectors	towline was connected to a bottom tensioned ballast chain
Skirt Material	mold impregnated, plastic coated nylon weave
Flotation	self-inflating sections 3.3 to 6.6 feet (1 to 2 m) long
Weight	1.55 lbs/ft (2.31 kg/m)
Reserve Buoyancy	34.4 lbs/ft (44.6 kg/m)
Reserve B/W Ratio	22
Ballast	1/4 inch (4.8 mm) enclosed chain
Tension Member	ballast chain

Figure 4.2, page 4-3, shows a sketch of the Expandi Boom.

Test Configuration

Boom was towed in a catenary (U-shape) and diversionary (J-shape). The length of the boom used for the catenary configuration was approximately 200 feet (61 m) and for the diversionary configuration was approximately 100 feet (30.5 m). Boom towed in the diversionary mode had an angle of 23° to 44° between the boom and the current, but the angle used is not identified for individual runs. Boom sections were joined together and tow connections were rigged according to the manufacturer's recommendations.

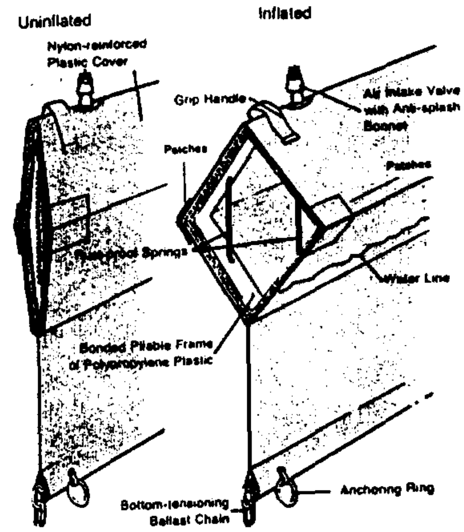


Figure 4.2 Expandi Boom

Test Oils

Diesel fuel - viscosity 10 cSt, density 0.852
Lube oil - viscosity 510 cSt, density 0.915
Oil thickness - 2 mm

Note that lube oils with other viscosities were used in the tests. These are shown on individual test results data sheets.

Test Variables

Boom deployment modes, tow speeds, wave conditions, and test oil viscosities.

Data Precision and Accuracy

Tow Speed - 0 up to critical tow speed within 0.1 knot (0.05 m/s).

Test Procedure

Performance criteria for booms was intended to determine the tow speed at which oil began to escape the boom in both the catenary and diversionary modes. First, the boom was tested without oil in various wave conditions to determine the maximum stable tow speed in each configuration. Stability testing determined the tow speeds at which planing, submarining, or other type of failure would occur. Splashover at the boom fluid interface was considered to be a stability failure, since in many cases the loss of freeboard of a boom reflects its inability to maintain an adequate vertical profile. Following stability tests, the boom was tested with oil in the same waves where its stable performance range was above 0.5 knots (0.25 m/s) tow speed .

In stability tests, the water surface condition was established (wave or no wave), then the boom was towed at continuously increasing speed until judged unstable. Then the tow speed was decreased in 0.1 knot (0.5 m/s) increments until the boom became stable, and then speed was increased by 0.1 knot increments to reconfirm the failure speed. This speed was then recorded as "critical tow speed" and was the upper limit to be used in the test matrix with oil.

Tow tests in oil were conducted in the same way as stability tests. 350 gallons (1.32 m^3) of oil was distributed as a 2 mm thick spill 50 feet (15.2 m) wide ahead of the boom. Critical tow speed was defined as the maximum tow speed for either catenary of diversionary configurations at which there was no loss of oil under the boom. In the diversionary mode, a separation boom was deployed behind the test boom so that all oil that had moved down the boom to the apex was contained within the separation boom. The oil collected in the separation boom was judged to be contained.

Test Results

Table 4.1, below, shows results of tests.

Overall Assessment of Performance

Expandi Boom in the Catenary Mode - In tests without oil, instability occurred late, generally at more than 2 knots except in the short, steep wave. In lube oil, performance was below average, 0.5 to 0.6 knots except in the long, 2 X 30 foot wave, where loss occurred at 0.8 knots. In low viscosity oil, first loss tow speed was still lower, 0.4 knots except in the long 2 X 30 foot wave, where it was an average 0.7 knots.
Expandi Boom in the Diversionary Mode - Tests without oil showed a high speed for stability failure, more than 2 knots and even 0.5 knots in the short, choppy wave. In the more viscous lube oil, performance was better than average, 1 to 1.6 knots and even 0.4 knots in the short wave where most booms had splashover failure with no boom movement.

Table 4.1 Test Results (O-1)

BOOM	EXPANDI BOOM Freeboard 12.5 in. Draft 19.5 in. B/W 22	
	TYPE FAILURE	TOW SPEED (kts)
CATENARY		
NO OIL		
CALM WATER	Planing	2.5
WAVES		
1 X 45' (0.3 X 13.7 m)	Planing	2.0
1 X 75' (0.3 X 23 m)	Planing	2.0
1 X 9' (0.3 X 2.7 m)	Splashover	0
2 X 30' (0.6 X 9.1 m)	Planing	2.0
TESTS IN 2 mm OIL	177 cSt	
CALM WATER	Entrainment	0.5
WAVES		
1 X 45' (0.3 X 13.7 m)	Entrainment	0.6
2 X 30' (0.6 X 9.1 m)	Entrainment	0.8
	10 cSt	
CALM WATER	Entrainment	0.4
1 X 45' (0.3 X 13.7 m)	Entrainment	0.4
2 X 30' (0.6 X 9.1 m)	Entrainment	0.7
DIVERSIONARY*		
NO OIL		
CALM WATER	None	2
WAVES		
1 X 45' (0.3 X 13.7 m)	None	2
1 X 75' (0.3 X 23 m)	None	2
1 X 9' (0.3 X 2.7 m)	Splashover	0.5
2 X 30' (0.6 X 9,1 m)	None	2
TESTS IN 2 mm OIL	238 cSt	
CALM WATER	Entrainment	1.4-1.6
WAVES		
1 X 45' (0.3 X 13.7 m)	Entrainment	1.0
2 X 30' (0.6 X 9.1 m)	Entrainment	1.2-1.6
1 X 9' (0.3 X 2.7 m)	Splashover	0.4

*The diversionary angle was 23° to 44° between the boom and the current, but the angle used is not identified for individual runs.

2.2 OHMSETT TESTS 1980 (O-4)

The self-inflating Zooom Boom was tested for ease of deployment, abrasion resistance, and towability off the Newfoundland coast in March 1980. The boom was then shipped to the OHMSETT test facility for one week of oil testing beginning 10 November 1980.

Boom Description

The boom tested had a cylindrical flotation section with an 18 inch (457 mm) diameter. The flotation was the freeboard supporting an 18 inch (457 mm) skirt with a 3/8 inch (10 mm) ballast chain that also served as a tension member. The boom was designed to self-inflate with one-way valves along the top that allow air to enter the cylindrical flotation chamber as the boom is deployed. Internal plastic rings maintain shape and section dividers prevent total loss of air in the event of a puncture. The report provides no other information about the physical characteristics of the boom. This type of boom is still in production, although there are none with the exact dimensions described here. The Versatech 12/18 Zooom boom has design features closest to the boom tested in 1980. This unit is described below.

<u>Versatech 12/18 Zooom Boom (World Catalog of Oil Spill Response Products 1999)</u>

<u>Freeboard</u>	11 inches (279 mm)
<u>Draft</u>	19 inches (483 mm)
<u>Boom Height</u>	30 inches (762 mm)
<u>End Connectors</u>	ASTM
<u>Skirt Material</u>	PVC coated nylon
<u>Flotation</u>	self-inflating 100 foot (30 m) long sections with an internal bulkhead every 10 feet (3 m)
<u>Weight</u>	2.0 lbs/ft (3.0 kg/m)
<u>Reserve Buoyancy</u>	47 lbs/ft (70 kg/m)
<u>Reserve B/W Ratio</u>	23.5
<u>Ballast</u>	9/32 inch (7 mm) enclosed chain
<u>Tension Member</u>	ballast chain and fabric

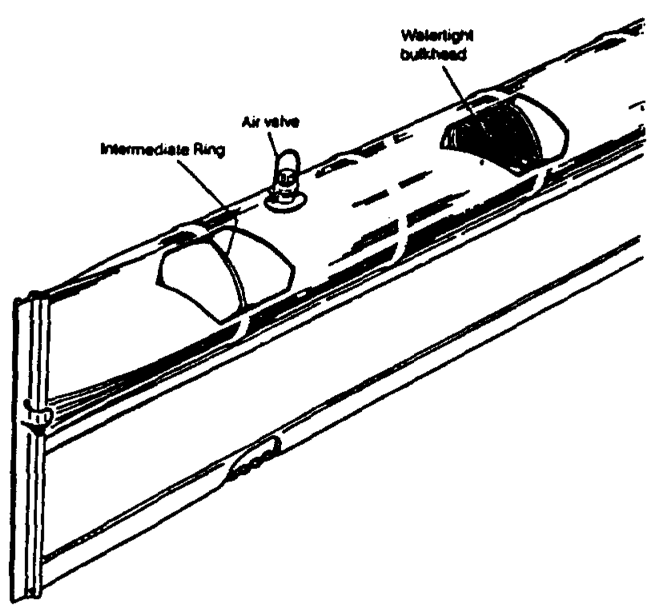


Figure 4.3 Versatech Zooom Boom

Test Configuration

The OHMSETT tests were conducted with one of the 100 foot (30.5 m) lengths of boom used in the offshore trials. The boom was deployed in the catenary configuraton and tested with heavy oil. The objectives of the tests were 1) to determine if the oil-keeping properties of the boom could be increased by adjusting the length of the chain tension member and 2) to quantify the loss rate of the boom in terms of tow speed and wave conditions.

Test Oils

Circo X heavy oil was used with viscosities varying from 2,600 to 4,200 cSt and density of 0.930 to 0.938. Average viscosity was 2,763 cSt and density was 0.936.

Test Variables

Boom tow speed, wave conditions, and oil viscosity.

Data Precision and Accuracy

Tow Speed - 0 up to critical tow speed within 0.1 knot (0.05 m/s).

Test Procedure

The test series had two parts. First the boom was tested with three tension member (ballast chain) lengths to determine if performance improved with a shorter chain. Tests were run with the chain shortened by three and six links. Tests were run with 500 gallons (12 BBL - 1.89 m^3) Circo X heavy oil, viscosity about 3,000 cSt. The boom and oil were towed in calm water noting first loss and gross loss tow speeds.

The second set of tests were run with the tension chain at optimum length as determined by the first set of tests. The boom was in the catenary configuration with 1,028 gallons (24.5 BBL - 3.89 m^3) pre-load of oil. Notice that this is a little more than twice as much oil as was used in the first part of the test. The reason for this difference was not noted.

The second set of tests were divided into five groups corresponding to each wave condition. The boom was initially towed at 0.5 knots and the speed increased in 0.1 knot increments to gross failure. The speed of first loss and the speed of gross loss was noted. The remaining tests were conducted for the quantification of the loss.

Test Results

The first set of tests were to determine if shortening the tension member would improve performance. The shorter ballast chain did improve performance, but only marginally. These results are shown on Table 4.2

Table 4.2 Tests to Determine Best Tension Member Length (O-4)

Freeboard 18 inches Draft 18 inches - B/W Ratio 24:1

	1st LOSS TOW SPEED (kts)	GROSS LOSS TOW SPEED (kts)
ORIGINAL LENGTH	0.9	1.2
3 LINKS SHORT	1.0	1.2
6 LINKS SHORT	0.9	1.1

It was determined that the booms with three links removed from the ballast chain gave the best performance and this configuration was used for phase two testing.

For the second phase of testing, the boom was towed with 1,028 gallons of oil at varying speeds to determine the gross loss tow speed and the loss rate at that speed. The point of gross loss was not designated in the report but rather selected by the author as the point at which a very substantial increase in loss rate occurred. Table 4.3 shows these results.

Overall Assessment of Performance

Zooom Boom in the Catenary Mode - Table 4.3 shows that performance is best in Calm Water and the long, 0.6 X 63 foot (0.19 X 19.22 m) wave. Although these results are not identical, they are within the measuring range of the apparatus. Performance is worst in the short, choppy 0.6 X 9 foot (0.19 X 2.77 m) wave and improves as the wave lengthens, and even increases in height. Comparing these results with those of the similar Expandi boom, Table 4.1, is not quite proper because all environmental conditions other than Calm Water, are different and oil viscosity is appreciable different; however, performance of the Zooom boom in Calm Water is clearly better and performance in the other wave conditions is better as well.

Table 4.3 Test Results with Optimum Tension Member Length (O-4)

BOOM	VERSATECH ZOOOM BOOM - FREEBOARD 18 inches DRAFT 18 inches B/W 24:1 (Estimated)			
	TYPE FAILURE	1ST LOSS TOW SPEED (kts)	GROSS LOSS TOW SPEED (kts)	LOSS RATE AT GROSS LOSS gpm (BBL/hr)
CATENARY				
1,028 gal. (24.5 BBL) OIL	3,000 cSt			
CALM WATER	Entrainment	0.78	1.13	52.5 (75.0)
WAVES				
0.6 x 9' (0.19 x 2.77 m)	Entrainment	0.5	0.68	27 (39)
0.6 X 27' (0.19 X 8.31 m)	Entrainment	0.9	0.90	36.7 (52.4)
0.6 X 63' (0.19 X 19.22 m)	Entrainment	0.8	1.20	85.3 (122)
1.3 X 63' (0.41 X 19.22 m)	Entrainment	0.8	1.11	82 (117)

2.3 ENVIRONMENT CANADA TESTS 1980 (E-1)

Six oil spill containment booms were tested offshore of St. John's, Newfoundland in March and April of 1980. Testing was conducted about 3 nautical miles south of St. John's Harbor in Blackhead Bight. This area, sheltered by cliffs to the west and a peninsula to the south, is at the eastern extremity of the North American continent, with water temperatures, ice conditions and sea states typical of the Grand Banks oil exploration areas. Currents in the area are 1/4 knot or less and tides average 5 feet (1.5 m). One of the booms tested, the Zooom boom, was later shipped to New Jersey and tested at OHMSETT. The results of these tests are reported separately in Section 2.2, preceding.

The principal criteria used to evaluate the booms were oil retention characteristics, durability, and towing loads. Although it was intended to deposit a barrel of oil ahead of the towed booms, this was not done in every case because of adverse weather conditions. Data describing towing loads are reported in some detail.

Boom Description

Two similar booms were tested together, the Arctic and Marine Oilspill Program (AMOP) boom and the Zooom boom. Because these booms were nearly the same, they were described together.

The AMOP boom (a prototype) came in 100 foot (30.5 m) sections and had an overall height of 42 inches (107 cm), freeboard of 26 inches (66 cm), and a draft of 16 inches (41 cm). A self-inflating cylinder provides the flotation and supports a straight wall curtain. Tension is provided by a enclosed ballast chain. The boom is made of an elastomer-coated nylon fabric. The flotation cylinder is divided into multiple water tight compartments each with its own one-way valve in a plastic housing.

The Zooom boom is not described in greater detail in the report except to say that it was the same as the AMOP boom except somewhat lighter. The AMOP boom was never produced beyond the prototype, however the Zooom boom is still produced. A model similar to that tested has an overall height of 48 inches (1,220 mm), a tensile strength of 74,300 pounds (331,300 Newtons), and a buoyancy to weight ratio of 43:1. The model tested at OHMSETT later (Section 2.2 of this chapter) had an overall height of 36 inches and therefore may have been smaller than the model tested offshore Newfoundland. Figure 4.3 shows a sketch of the Zooom boom. The AMOP boom is the same except for a slightly different air valve.

Test Configuration

The boom was towed in a catenary configuration by two vessels. The distance across the boom opening was measured with an optical range finder. All tows were made into the wind.

Test Oils

Bunker C - viscosity 9.9 cSt, density 0.97
BCF Venezuelan Crude Oil - 30 cSt, density 0.91
(Author's Note: these values for viscosity may not have been reported correctly.)

Data Precision and Accuracy

Forces on booms were to the nearest 10 Newtons. (See Appendix C for an analysis of forces on booms.) Boom performance is described subjectively.

Test Procedure

Sections of the AMOP and Zooom booms were towed individually to confirm that their drag was identical. The two booms were then connected to a skimmer with the intention of containing and deflecting two barrels of oil that had been spilled upwind.

Test Results

About half of the oil eventually entered the skimmer where it was recovered. The remainder, about one barrel, passed under the boom in about 15 minutes (A-1). The loss was unexpected because a smaller version of the boom had performed effectively in a previous test. The loss was apparently caused by oil entrapment, drainage, and some splashover. Adverse weather prevented a more comprehensive examination of the boom performance. The decision was made at this point to test the Zooom boom later at OHMSETT. The report notes that both of the booms towed well at all speeds.

Overall Assessment of Performance

The following paragraph is paraphrased from the original test report.

The sea trials of these booms demonstrated the difficulty of making a quantitative evaluation of oil containment products in open water conditions. The tests disclosed a valve leakage problem, particularly in the AMOP boom, and confirmed the importance of having a valve that allows air to pass but not water. Deployment characteristics and durability were satisfactory for both booms.

An earlier (1980) paper (A-1) commenting on the same set of tests concluded that the AMOP and ZOOOM booms were too small to be seriously considered for offshore use. This paper noted that small waves (height of 1.5 to 3 inches) were reflected back from the cylindrical air chambers rolling back in an outward and downward direction. Test observers speculated that this roll-back and mixing action would produce emulsification and a downward velocity that would together carry oil under the boom rapidly. It was further surmised that a boom that was at least twice as large would be more effective.

2.4 CANADIAN COAST GUARD TESTS 1991 (C-2)

Seven containment booms were selected and tested to examine the relative merits of boom type or shape as they affect oil containment effectiveness in increasing water currents. Testing was performed 11-20 February 1991 in the recirculating flume tank at the Institute of Fisheries and Marine Technology (IFMT) in St. John's Newfoundland.

The IFMT tank is 26 feet wide by 74 feet long by 13 feet deep (8 X 22.5 X 4 m). The depth met the requirement of being at least 4 to 6 times boom draft. Water flow through the flume can be varied from 0 to 2.4 knots. Wave generation is not available. Side viewing windows and underwater video record test results. Figure 4.4 shows a sketch of the tank.

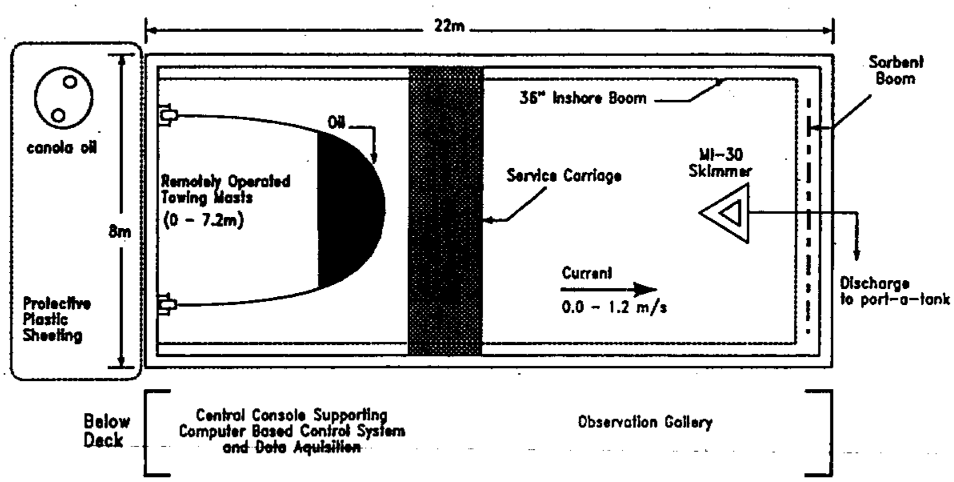


Figure 4.4 IFMT Test Tank

Boom Description

Of the seven booms tested, one was a self-inflatable curtain boom that is reported here. Table 4.4, page 4-10, provides a description of this boom.

Test Configuration

The boom to be tested was placed in a parabolic configuration in the tank with the total boom length being 4 to 6 times the boom opening width. Lighter booms were fixed to the two masts located at the upstream end of the flume. The mast's separation width could be varied from 0 to 24 feet (7.2 m). The heavier booms were secured to the flume side walls at a fixed width of 26 feet (8 m). The booms were placed at the upstream end of the tank to allow maximum rise time for the entrained oil prior to its collection at the downstream end of the flume.

Test Oil

Canola Oil - viscosity 64 cSt, density 0.935
This organic oil (rape seed) is compared to Alberta Sweet Blend Crude that has a viscosity of 12 cSt and a density of 0.840.

Test Variables

Velocity at first loss and loss rates.

Data Precision and Accuracy

Flow velocity to 0.1 knots; loss rate to 0.1 liter/minute (0.026 gpm).

Table 4.4 Canadian Coast Guard Tests 1991 (C-2)

BOOM	KEPNER SEA CURTAIN
FREEBOARD inches (mm)	16 (410)
DRAFT inches (mm)	25 (640)
HEIGHT inches (mm)	41 (1,080)
END CONNECTORS	KEPNER
SKIRT MATERIAL	Kepelastex™ polyurethane
FLOTATION	Self-inflating single chamber + closed cell foam
WEIGHT lbs/ft (kg/m)	4.5 (6.7)
RESERVE BUOYANCY lb/ft (kg/m)	106 (157) [1]
RESERVE B/W RATIO	25:1 [1]
BALLAST	Chain
TENSION MEMBERS	Fabric/ballast chain
TENSILE STRENGTH lb (N)	61,500 (276,750)

Notes: [1] Data from the World Catalog of Oil Spill Response Products describing similar boom produced by the same manufacturer.

Test Procedure

Boom to be tested was deployed in a parabolic (catenary) configuration. Water current was set on low (0.4 knots) and 8 to 10 gallons (30 to 40 liters) of dyed canola oil was added to the tank to a thickness of several millimeters in the pocket of the boom. The volume of oil was first measured in a calibrated bucket and then carefully poured on the surface of the water. Water velocity was increased by 0.1 knot increments until first loss of oil was observed. The water velocity was reduced, then increased again to first loss to confirm the velocity. Oil was added to the boom to replace the oil lost. The oil loss rate was then determined by timing the loss of approximately 90% of the initial oil volume present in the boom at a velocity of 0.2 knots above the first loss velocity.

An initial volume of oil, estimated to give a thickness of 5 mm in the boom apex, was measured using calibrated buckets and recorded prior to each boom test. Before each subsequent run with a given boom, enough oil was added to bring the volume back to the initial volume. The amount of makeup oil required was determined by visually comparing the initial amount of oil in the boom prior to testing, with the oil remaining in the boom following a given run. This was accomplished by using two video screens to simultaneously compare the color intensity of the oil in the boom apex. The volume of oil lost during the loss rate determinations was also estimated visually using the same method.

Test Results

Boom performance was based on oil retention capability described by first loss speed and loss rate at 0.2 knots above first loss velocity. First loss velocity was defined as the first "significant" loss observed as the water velocity was gradually increased. Although smaller losses - occasional droplets - occurred prior to what was judged to be first loss, the loss was not considered significant until a fairly steady stream of oil escaped from the boom.

Most earlier tests have shown oil loss to occur by entrainment from the head wave. While this was occasionally observed, the oil loss mechanism most frequently observed was that of drainage through vortices formed in the boom pocket. The vortex formation usually appeared at current velocities of 0.2 to 0.3 knots before the first significant loss velocity was reached. Vortices formed at the lower velocities resulted in minimal loss, which was not considered significant. Often a vortex would form, then disappear without any oil loss occurring at all. The side viewing windows were ideally suited for observing oil loss and for determining the mode of oil loss. [Author's note: Formation of vortices and oil loss from vortices has been noted in previous tests and it has been noted in the field, therefore this phenomenon should be investigated at OHMSETT and elsewhere.]

Table 4.5 Test Results, Canadian Coast Guard 1991 (C-2)
Boom tested in 5 mm slick, gap ratio 3:1, Oil Viscosity 64 cSt

BOOM	1st LOSS SPEED (kts)	LOSS RATE AT 1st LOSS + 0.2 kts (gpm @ kts)	COMMENT
KEPNER SEACURTAIN F 16 inches D 25 inches B/W 25:1	1.0	3.1 @ 1.2	Loss by shedding (entrainment). Boom remained stable throughout tests

Overall Assessment of Results

First loss speeds are good as compared to other booms of this type. Loss rates are low as compared to more recent OHMSETT tests; however, the amount of oil used was very small, which certainly would have affected loss rate.

Section 2.5 MSRC, Coast Guard, Navy, and MMS Tests Offshore 1994 (I-6,S-3)

In May 1994 the Marine Spill Response Corporation (MSRC), the U.S. Coast Guard, U.S. Navy, and Minerals Management Service (MMS) conducted a joint test of oil containment booms in Lower New York Bay and in the Atlantic Ocean east of Sandy Hook New Jersey. These tests were performed to collect data on boom performance, including tow forces, skirt draft, and boom freeboard, as a function to tow speed and environmental forces caused by currents, wind, and waves. Four booms were tested:

- o 3M Fire Boom (Presently the Elastec/American Marine Fireboom)
- o Barrier Boom
- o USCG/Oil Stop Inflatable Boom
- o U.S. Navy USS-42 Boom

Use of these booms permitted collection of data over a range of buoyancy to weight ratios of 5:1 to 52:1, skirt drafts from 24 top 60 inches (610 mm to 1,500 mm) and freeboards from 14 to 47 inches (350 mm to 1,190 mm). Data collected were also used to compare calculated boom loads (force) and measured loads. This part of the analysis is covered in Appendix C, Forces on Booms. Tests of the Barrier Boom are described here. Tests of the other booms are described in other appropriate chapters.

Boom Description

The Barrier Boom model number 1370-R is manufactured by Norlense A/S, Norway. The boom is inflated as it is deployed from a reel, a continuous process except that the end buoyancy chambers are inflated by hand. The boom shape is maintained by separate flexible rings that are also inflated as the boom is deployed. The buoyancy chambers are inflated from a low pressure hose between a double skirt below the chamber. They are open to the sea at this point. The flexible rings are inflated with high pressure air. The flotation chamber has transverse bulkheads that divide it into 5 meter (16 foot) sections so that damage or leakage will be confined to a single section. The boom has a flexible skirt ballasted by chain. In addition, water is permitted to enter between the boom's double skirt as it is deployed, which increases stability. The boom components automatically deflate as the boom is recovered. Boom dimensions are shown on Table 4.6, page 4-12.

Test Configuration

In most tests booms were towed in tandem as shown in Figure 4.5 below. The Oil Spill Response Vessel (OSRV) *New Jersey Responder*, the center vessel, towed two booms and acted as the command vessel. The USCG vessels *Penobscot Bay* and *Point Francis* towed the outer ends of the booms. The sweep width for one boom was held constant at approximately 300 feet (91.5 m).

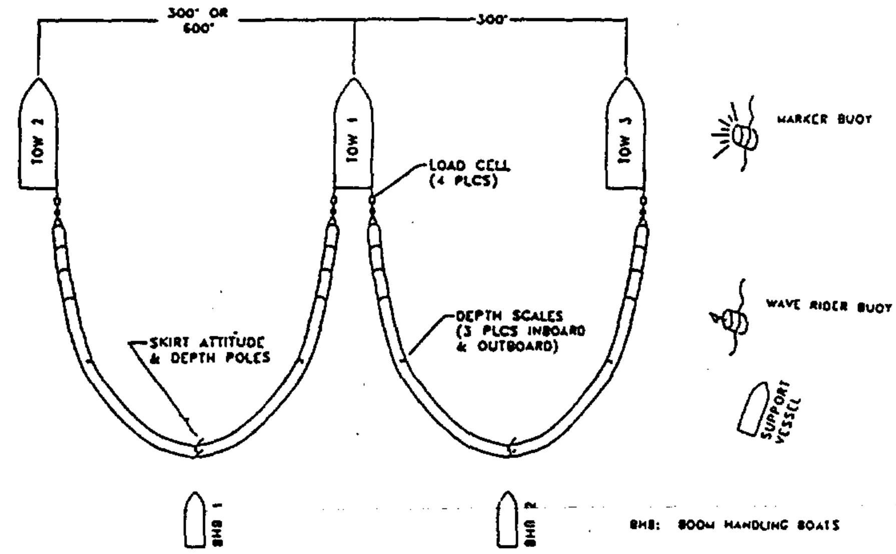


Figure 4.5 Boom Towing Configuration

Table 4.6 Norlease Barrier Boom

BOOM	BARRIER BOOM
BOOM TYPE	Self-inflatable curtain
FREEBOARD in (mm)	47.2 (1,200)
DRAFT in (mm)	59.0 (1,500)
HEIGHT in (mm)	106.2 (2,700)
END CONNECTORS	Not reported
SKIRT MATERIAL	32.4 oz/yd^2 (1,100 g/m^2)
FLOTATION	Continuous air chamber
WEIGHT lb/ft (kg/m)	24.9 (37.0)
RESERVE BUOYANCY lb/ft (kg/m)	1,295 (1,943)
RESERVE B/W RATIO	52:1
BALLAST	5/8 inch (16 mm) chain
TENSION MEMBERS	Fabric, ballast chain
TOTAL STRENGTH lb (N)	25,000,000 N/m^2

Test Oils

No oil was used in testing.

Test Variables

Boom tow speed, skirt draft, tow tension, boom freeboard, and environmental conditions.

Data Precision and Accuracy

Boom Tow Speed - Tow speed was recorded manually on all three tow vessels. Speed was also recorded electronically on the *New Jersey Responder* using the vessels satellite navigation system.
Skirt Draft - Submersible pressure transducers were fastened to the bottom of the boom skirt and the reading was recorded on a data logger.
Tow Tension - Tension was recorded on both ends of towed booms.
Boom freeboard, overtopping, and skirt attitude - Each boom was marked vertically in 3 inch (76 mm) graduations from the top of the boom to two feet below the flotation chamber. This scale was monitored with a video recorder showing water action on the inside of the boom.
Environmental Conditions - Water current and wind direction and speed were recorded manually on the control ship. Wave height and period, average wind speed and direction were recorded every half hour from a Coast Guard climate buoy.

Test Procedure

Video cameras recorded each test run from three positions: the *New Jersey Responder*, and each of the trailing boom handling boats. One of these two support boats was placed behind the apex of one of each of the booms being towed, focusing on the apex of the boom. Scales painted on the booms allowed the freeboard, both forward and aft, to be documented for later review and comparison with the collected data.

A test run consisted of the tow vessels lining up in the desired direction to the wind or swell at near zero speed. Radar was used to determine and control the required sweep width between each pair of vessels. The tow vessels accelerated to 0.5 knots. When the speed was confirmed the data for the run was recorded for approximately 10 minutes. The test director then instructed the tow vessels to accelerate to 1 knot, and the process was repeated then and again at 1.5 knots. Finally, a functional test was performed to determine the speed at which either the flotation submerged or the skirt surfaced. This tow sequence was repeated so that data was acquired towing both into the sea and with the sea.

Test Results

The Barrier Boom was tested in calm water and sea state 2 (4-10 knot winds, waves about 3 feet [1 m]) for a total of 27 tests. Although the boom never submerged, it did begin to deflate slightly at 3.5 knots. Higher tow speeds could have been achieved, however the tension greater than the 22,000 pounds (99,000 N) measured at 3.5 knots would have exceeded the safe working load of the load cell. The boom conformed well to waves perpendicular and parallel to the center axis of the flotation chambers. Boom freeboard was reduced slightly at higher tow speeds; however, because of the boom design, distribution of the loads, and the high buoyancy to weight ratio, the change in freeboard was insignificant. The boom behaved well in all sea states tested and at all tow speeds. Table 4.7, page 4-14, shows the changes in freeboard and draft with tow speed. Note that the decreases in freeboard up to a tow speed of 1.5 knots are small. The report attributes this to the high B/W ratio of the boom.

Table 4.7 Barrier Boom - Freeboard/Draft vs. Tow Speed (I-6)

TOW SPEED (kts)	FREEBOARD Inches (mm)	DRAFT inches (mm)
0	54.3 (1,380)	59 (1,500)
0.5	49.6 (1,260)	Not reported
1.0	46.5 (1,180)	66.1 (1,680)
1.5	43.3 (1,100)	66.9 (1,700)

The study finds that a boom with a higher B/W ratio will be able to sustain higher tow speeds and perform in rougher sea conditions. A higher buoyancy provides the boom more lift and wave following capability to waves both perpendicular and linear to the boom. This was definitely the case for the Barrier Boom, which conformed well in all sea states tested. (Note: B/W ratio 52:1) A higher B/W ratio allows the boom to maintain its freeboard forward and aft of the apex.

2.6 Self-Inflatable Curtain Booms Performance Summary

Conventional Self-Inflatable Curtain Booms

Towed in the catenary mode and calm water, these booms have a first loss tow speed of about 0.5 to 0.8 knots with the better performance in more viscous oil. Gross loss tow speed in a single test was 1.1 knots. In a long wave, first loss speeds are 0.6 to 0.9 knots. In a short, steep wave, first loss is 0.4 to 0.5 knots, which compares favorably to some booms that have loss to splashover with no forward speed. In the diversionary mode, first loss tow speed increases to 1.0 to 1.6 knots in both calm water and long waves.

This performance assessment was made based on tests of several self-inflatable curtain booms. Some observers would point out that these results may not be typical of this class of boom but rather of the specific booms tested. In fact, performance may have more to do with the design features of the skirt rather than the fact that the flotation is self-inflating.

Fire Resistant Containment Self-Inflatable Boom

This type boom has not had a controlled test in oil. A boom was tested for sea-keeping offshore, and although this device had typical dimensions, buoyancy to weight ratio was only 2:1, which is low for a self-inflatable boom. In tow tests this device submerged at about 0.7 knots.

Chapter 5

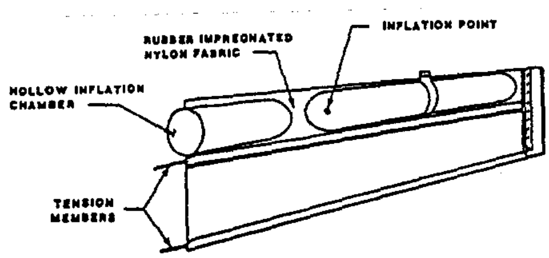
PRESSURE-INFLATABLE CURTAIN BOOMS

1.0 DESCRIPTION

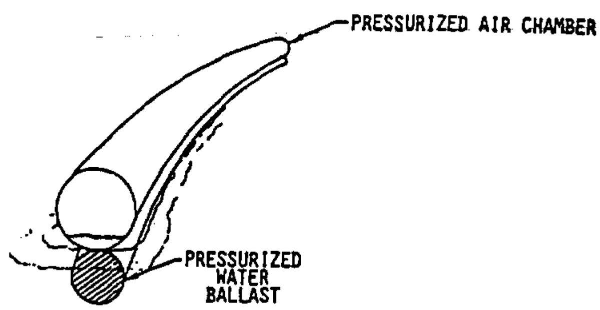
Pressure-inflatable curtain booms have chambers that are inflated to provide buoyancy. Some versions have segmented buoyancy chambers that are inflated individually by hand using a compressor or air blower. Other versions have continuous buoyancy chambers that are inflated by an air blower. Newer versions of the continuous buoyancy boom have compartmented chambers with check valves and are inflated by an air manifold from an air blower. Pressure-inflatable booms may be made of light PVC or polyurethane coated fabric, or sometimes heavy neoprene or nitrile rubber-nylon.

Pressure-inflatable boom has the advantages of having a high buoyancy to weight ratio and relatively good heave response. Although it may be somewhat vulnerable to damage, it can generally be made of much stronger material than self-inflatable boom. When deflated, it can be stored in a small volume. It has the disadvantage of being deployed more slowly than the self-inflatable boom.

On the other hand, the operational advantages of having a high buoyancy to weight ratio and good heave response in a durable boom are so great that the deployment time may not be significant. Figure 5.1 shows typical pressure inflatable curtain boom.



Pressure-Inflatable Boom



Pressurized Chamber Boom

Figure 5.1 Pressure-Inflatable Curtain Booms

1.1 SELECTION CONSIDERATIONS

Buoyancy	Generally very high, in the range of 2 to 70:1, with a large majority greater than 10:1. Buoyancy may be lost as a result of puncture or a leaking air valve
Roll Response	Bottom tension and good flexibility provide good roll response
Heave Response	High buoyancy to weight ratio and good flexibility provide good heave response.
Mode of Application	Deployment is somewhat slower than for self-inflatable and other types of boom coming off a reel or out of a box
Other	May be used for first deployment or long term. Some models are used in industrial applications.

2.0 TEST RESULTS

2.1 OHMSETT TESTS 1975 (O-1)

A series of tests were performed on 16 oil spill response devices at the OHMSETT test tank from April through June 1975. These tests included eight containment booms, one of which was the Steltner Pace pressure-inflatable curtain boom. Booms were tested in the catenary and diversionary modes. Booms were first tested for stability over a wide range of wave conditions without oil and then in waves within their operational stability envelope. Test data record maximum stable tow speed and maximum no loss tow speed. The no loss tow tests were made with 2 mm of oil. (The boom tested has not been produced for many years.)

Boom Description

Steltner Pace Pressure-inflatable Curtain Boom

Freeboard	12 inches (300 mm)
Draft	20-28 inches (510-710 mm)
Boom Height	32-40 inches (810-1,010 mm)
End Connectors	connector bar
Skirt Material	tear resistant nylon
Flotation	cured vinyl inflated to 12 inch (0.3 m) diameter
Weight	4.2 lbs/ft (6.25 kg/m)
Reserve Buoyancy	92.9 lbs/ft (138.3 kg/m)
Reserve B/W Ratio	22:1
Ballast	no ballast
Tension Member	a tow line attached to a connector bar at the base of the flotation

The Pace boom had a non-standard configuration that included two floats separated by a connection bar and a skirt that was cupped with nylon netting. Oil moves through the nylon netting and is collected in the attached skirt and along the edge of the rear float. Figure 5.2 shows the Pace Boom being towed from right to left.

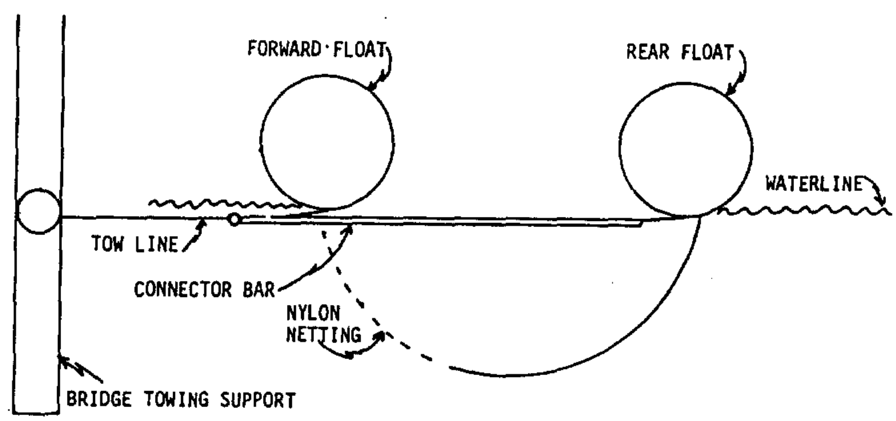


Figure 5.2 Pace Pressure-Inflatable Boom

Test Configuration

Boom was towed in a catenary (U-shape) and diversionary (J-shape). The length of the boom used for the catenary configuration was approximately 200 feet (61 m) and for the diversionary configuration was approximately 100 feet (30.5 m). Boom towed in the diversionary mode had an angle of 23° to 44° between the boom and the current, but the angle used is not identified for individual runs. Boom sections were joined together and tow connections were rigged according to the manufacturer's recommendations.

Test Oils

Diesel fuel - viscosity 10 cSt, density 0.852
Lube oil - viscosity 510 cSt, density 0.915
Oil thickness - 2 mm

Note that lube oils with other viscosities were used in the tests. These are shown on individual test results data sheets.

Test Variables

Boom deployment mode, wave conditions, test oil viscosity, and boom tow speed.

Data Precision and Accuracy

Tow Speed - 0 up to critical tow speed within 0.1 knot (0.05 m/s).

Test Procedure

Performance criteria for booms was intended to determine the tow speed at which oil began to escape the boom in both the catenary and diversionary modes. (In later tests this was called first loss tow speed. This was followed by observing a gross loss tow speed, a data point that was not collected in early tests.) First, the boom was tested without oil in various wave conditions to determine the maximum stable tow speed in each configuration. Stability testing determined the tow speeds at which planing, submarining (submergence), or other type of failure would occur. Splashover at the boom fluid interface was considered to be a stability failure, since in many cases the loss of freeboard of a boom reflects its inability to maintain an adequate vertical profile. Following the stability testing, the boom was tested with oil in the same wave environment where its stable performance range was above 0.5 knots (0.25 m/s) tow speed .

In stability tests, the water surface condition was established (wave or no wave), then the boom was towed at continuously increasing speed until judged unstable. Next, the tow speed was decreased in 0.1 knot (0.5 m/s) increments until the boom became stable, and then speed was increased by 0.1 knot increments to reconfirm the failure speed. This speed was then recorded as "critical tow speed" and was the upper limit to be used in the test matrix with oil.

Tow tests in oil were conducted in the same way as stability tests. 350 gallons (1.32 m^3) of oil was distributed as a 2 mm thick spill 50 feet (15.2 m) wide ahead of the boom. Critical tow speed was defined as the maximum tow speed for either catenary of diversionary configurations at which there was no loss of oil under the boom. In the diversionary mode, a separation boom was deployed behind the test boom so that all oil that had moved down the boom to the apex was contained within the separation boom. The oil collected in the separation boom was judged to be contained.

Test Results

Table 5.1 on the next page shows results of tests.

Overall Assessment of Performance

Pace Boom in the Catenary Mode - In tests without oil, stability failure occurred at relatively high tow speeds, but in oil the failure tow speed of 0.4 knots is below average.
Pace Boom in the Diversionary Mode - Similarly, tests without oil show a high tow speed for stability failure, but in oil the failure tow speeds of 0.5 to 0.6 knots are below average.

This unusually configured experimental boom was probably discontinued because of poor performance.

Table 5.1 Test Results O-1

BOOM	Pace Boom Freeboard 12 in. Draft 20-28 in. B/W 22	
	TYPE FAILURE	TOW SPEED (kts)
CATENARY		
NO OIL		
CALM WATER	Submarine	1.8
WAVES		
1 X 75' (0.3 X 23 m)	Splashover	1.4
2 X 30' (0.6 X 9.1 m)	Splashover	1.5
TESTS IN 2 mm OIL	136-329 cSt	
CALM WATER	Entrainment	0.4
WAVES		
2 X 30' (0.6 X 9.1 m)	Entrainment	0.4
DIVERSIONARY*		
NO OIL		
CALM WATER	Submarine	1.7
WAVES		
1 X 45' (0.3 X 13.7 m)	Submarine	1.7
1 X 75' (0.3 X 23 m)	Submarine	1.8
1 X 9' (0.3 X 2.7 m)	Splashover	0.4
2 X 30' (0.6 X 9,1 m)	Splashover	1.4
TESTS IN 2 mm OIL	195-411 cSt	
CALM WATER	Entrainment	0.6
WAVES		
1 X 45' (0.3 X 13.7 m)	Entrainment	0.5
2 X 30' (0.6 X 9.1 m)	Entrainment	0.5

*The diversionary angle was 23° to 44° between the boom and the current, but the angle used is not identified for individual runs.

2.2 OHMSETT TESTS 1992 (O-6)

NOFI Vee-Sweep 600 and 600S booms were tested at OHMSETT between August and October 1992 to determine if skimming could be performed at speeds higher than 0.75 knots. Test objectives included measurement of:

- o Critical Tow Speed without oil; that is, the speed at which failure occurs by submergence, planing, splashover, or mechanical (physical) failure
- o First Loss and Gross Loss tow speeds in oil
- o Boom wave conformance
- o Oil Loss rate at various speeds above the First Loss Tow Speed

The NOFI Vee-Sweep is an inflatable oil collection boom held in a "V" configuration by cross netting attached to the skirt of the boom. The NOFI 600S is an inflatable oil boom used to divert oil into the NOFI Vee-Sweep. The lower section of the NOFI 600S skirt consists of a feather net and a ballast chain (A-3). *Tests were performed in two steps, first the Vee-Sweep 600 boom then the 600S boom.* The report of these tests is therefore presented as follows:

- o Tests of the Vee-Sweep Boom
  - - Phase 1 - tests without a skimmer
  - - Phase 2 - tests with a skimmer
  - - Wave conformance tests
  - - Oil loss rate tests
- o Tests of the NOFI 600S connector boom

This set of tests was performed for the U.S. Coast Guard in the development of a vessel-of-opportunity (VOSS) skimming system. In a 1993 AMOP paper, Bitting (A-3) describes the intent of these tests and the possible impact that a successful system would have on response effectiveness. Some of his comments in that paper are pertinent to understanding these tests and are therefore quoted here.

"The current Coast Guard VOSS system has a conventional fence boom to collect oil. This type of boom operates effectively up to approximately 0.75 knots. If the collection speed can be increased to 1.5 knots or above, while maintaining an equivalent recovery efficiency, oil recovery rates could be doubled."

"Higher collection/skimming speeds are more compatible with the operating speeds of oil skimming vessels. Many vessels cannot maneuver or maintain headway at speeds as low as 0.75 knots. The only way for the vessel to operate is to continually engage and disengage the clutch to apply short bursts of power. This can result in momentary bursts of speed causing the containment boom to either dive or plane over the surface of the water. Either situation results in the boom dumping its oil."

"Conventional containment booms used to contain oil on the high seas are used in a 'U' configuration. The innovative feature of the Vee-Sweep is its 'V' shape held together by a subsurface net. The oil flows from the mouth to the apex where it begins to build up in thickness. At the same time, water escapes through the net bottom. A skimmer is placed in the apex to remove the collected oil. The NOFI 600S extension boom can be attached to one side of the Vee-Sweep mouth to divert oil toward the Vee-Sweep. When used in this configuration, the Vee-Sweep width is dramatically increased. The use of a guide boom may also increase the efficiency of the skimmer by guiding more oil into the Vee-Sweep and creating a thicker oil layer. Skimming efficiency normally increases with oil thickness."

Boom Description - NOFI Vee-Sweep

The Vee-Sweep is a boom for use with a skimmer at the apex of the V-shaped configuration. Oil is funneled back to the skimmer by the converging sides of the V. The 60 meter (197 foot) length of the sweep is doubled over to form the V and held in this shape by cross netting at the bottom of the skirt. The bottom netting is intended to help stabilize the oil in the sweep. Because both sides of the booms are held taunt at a fixed angle with the direction of tow, this configuration is described as a "diversionary Vee." Figure 5.3 shows a sketch of the NOFI Vee-Sweep.

<u>NOFI Vee-Sweep 600 Boom</u>

The test report does not describe the boom's physical characteristics or show a sketch. The table below shows data published in the 1999-2000 edition of the World Catalog of Oil Spill Response Products.

<u>Freeboard</u>	24 inches (600 mm)
<u>Draft</u>	39 inches (1,000 mm) This is the normal draft. Because of the depth of the test tank, a draft of 27.6 inches (700 mm) was used.
<u>Boom Height</u>	63 inches (1,600 mm) normal; boom height for the tests was 51.6 inches (1,300 mm)
<u>End Connectors</u>	NOFI DEC. - G-hooks with flexible fabric sealing
<u>Skirt Material</u>	PVC/polyester
<u>Flotation</u>	pressure inflatable sections 10 feet (3 m) long
<u>Weight</u>	6.2 lbs/ft (9.3 kg/m)
<u>Reserve Buoyancy</u>	157 lbs/ft (236 kg/m)
<u>Reserve B/W Ratio</u>	25:1 (Bitting [A-3] shows B/W of 15:1)
<u>Ballast</u>	galvanized chain
<u>Tension Member</u>	Two chains and a cable

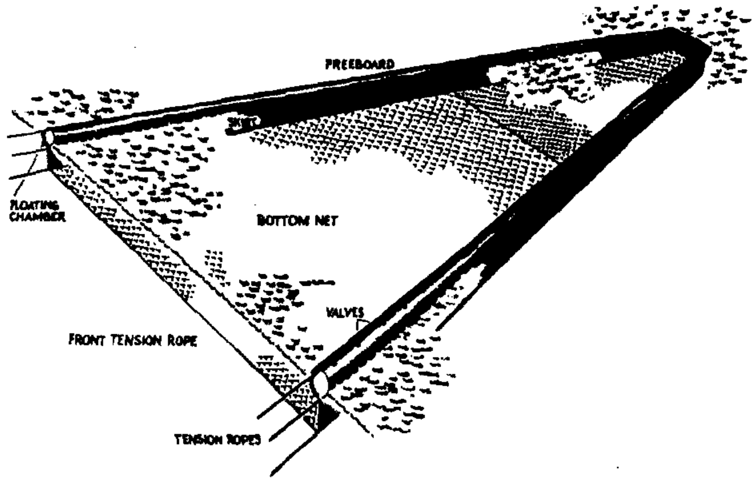


Figure 5.3 NOFI Vee-Sweep 600 Boom

Test Configuration

The 197 foot (60 meter) length of the sweep was doubled over to form a V and held in this shape by cross netting at the bottom of the skirt. The bottom netting was intended to stabilize the oil in the sweep. The sweep was towed with a 27.6 inch (700 mm) depth and a mouth opening (gap) of 52 feet (16 meters). The gap was reduced from the designed 65 feet (19.8 meters) to fit in the tow basin's width without causing excessive blockage. (The Vee-Sweep would normally be used with a 39 inch [1,000 mm] skirt depth but this would result with bottom effects in the tow tank.)

Test Oils

SUNDEX 8600T - Viscosity 1,763 cSt @ 40°C (104°F) - Density 0.962 (This is equivalent to approximately 10,000 cSt at 25°C [77°F], however, the conversion graph is not accurate above 5,000 cSt.)
Hydrocal 300 - Viscosity 140 cSt @ 25°C (77°F) - Density 0.899
Specific oil viscosities are shown on tables with test results.

Test Variables

- o Test oil type
- o Tow speed
- o Wave patterns

Data Precision and Accuracy

Tow Speed - 0 up to critical tow speed to 0.1 knot (0.05 m/s)

Test Procedure

First the boom was tested without oil to determine the critical tow speed. The critical tow speed is the speed at which failure occurs by submergence, planing, splashover, or mechanical (physical) failure. For this boom, the critical tow speed was judged to have occurred when the apex of the Vee-Sweep submerged. These tests were performed in calm water and various wave conditions without oil. The tow began at about 0.5 knots and continued until the boom formed the diversionary Vee sweep. Next, the speed was increased in 0.5 knot increments up to 2.0 knots. The speed was then increased slowly until the critical tow speed was reached. The critical tow speed was recorded to the nearest 0.1 knot along with the mode of failure.

Tests were performed in calm water and four waves conditions. Three wave conditions represented regular waves of a single frequency. Three wave frequencies were chosen to span the test range possible with the OHMSETT wavemaker. The fourth represented a harbor chop condition at a frequency that permitted the maximum amplitude to be generated. To the extent practical, the wave conditions for the critical speed tests were the same as in the oil loss and wave conformance tests. The nominal significant wave heights were:

Wave height - *inches* (ft - m)	Period seconds
Regular Waves	
8.9 (0.7 - 0.2)	4.5
4.8 (0.4 - 0.12)	2.5
8.1 (0.7 - 0.2)	1.6
Harbor Chop	
18.6 (1.6 - 0.5)	2.0

Earlier OHMSETT test reports show waves in height and length. This report does not show wave length, only period.

Tests were conducted in two phases. In Phase 1, only the Vee-Sweep was towed. In Phase 2, a DESMI-250 oil skimmer was positioned in the Vee-Sweep with its center about 6 to 8 feet (1.8 to 2.4 meters) forward of the Vee-Sweep apex.

During the oil loss tests it became obvious that the 100 gallon (0.38 m^3) preload was not sufficient to have oil at the skimmer position. As a result, additional tests were added using a 900 gallon (3.41 m^3) preload. The larger preload was used for all Phase 2 tests and some Phase 1 tests.

Phase 1 Procedure - Tests Without a Skimmer

After the oil preload was positioned in the apex of the boom with a fire hose, the boom was accelerated to about 0.8 knots. The speed was then increased in 0.1 knot increments until the first loss tow speed was reached. The first loss and gross loss tow speeds were recorded to the nearest 0.1 knot based on underwater observations. Table 5.2, page 5-8, shows the results of these tests.

Phase 2 Procedure - Tests With a Skimmer

The Vee-Sweep and DESMI-250 skimmer were towed in calm water and one wave condition with a pre-load of 900 gallons (3.41 m^3) of oil. The tow began at about 0.5 knots below the first loss tow speed determined without the skimmer and continued until the oil pre-load had been distributed and had stabilized at the apex of the sweep. Once the oil was stabilized, oil was distributed across the mouth of the sweep at a rate that varied between 146 to 270 gpm (0.55 to 1.02 m^3/min). The skimmer was started when the oil reached the preload. The skimmer was regulated to pump oil at about 250 gpm (0.95 m^3/min). With the skimmer set, tow speed was increased in 0.1 knot increments until the first loss tow speed was reached and continued until the gross loss tow speed was reached. Table 5.3, page 5-8, shows the results of these tests.

Test Results - Vee-Sweep Boom

In tests without oil, critical tow speed was determined to be the point at which the apex of the boom submerged. The critical tow speed in calm water was 3.4 to 3.6 knots. In a regular wave with a height of 4.4 inches (0.4 feet - 0.12 m) and a 1.85 second period, critical tow speed was 3.5 knots. In a harbor chop wave 14.4 inches (1.2 feet - 0.36 m) high and a period of 2.3 seconds, critical tow speed was 2.4 knots.

Reported speeds were more diverse in seven other tests in which results were not termed critical tow speed but rather as the speed at which there were "waves over the apex," which is generally called splashover. In a 10 inch (0.8 foot - 0.25 m) high wave with a 5 second period and with a 2.5 second period, splashover occurred at 3 knots. One would have expected splashover to occur at a higher speed in the longer period wave. In a 7.6 inch (0.6 foot - 0.2 m) high wave, splashover occurred at 3.2 knots in a 4.5 second period wave and 2.6 knots in a 2.5 second period wave, which is as expected. In a 4.5 inch (0.375 foot - 0.11 m) wave with a 1.6 second period, splashover occurred at 2.4 to 2.6 knots.

These results show, therefore, that in calm water and a regular wave, expect a critical tow speed for full submergence in the range of 3.4 to 3.6 knots. In a higher amplitude harbor chop wave , the critical speed is about 2.4 knots. A "wave over the apex" (splashover) can occur at diversely lower speeds ranging from about 2.4 to 3.2 knots.

In oil loss speed tests, the first loss tow speed is the speed at which droplets of oil first begin to escape under the sweep. The first gross loss tow speed is the speed at which large amounts of oil begin to be lost under the sweep. With lighter oils, the first gross loss speed usually results in streams of oil appearing from under ths sweep. With the high viscosity oil used in the NOFI tests, the oil remained in droplets but the number of droplets increased very rapidly once first gross loss speed was reached. Determination of both oil loss speeds is subjective based on observations using an underwater camera. The first loss speed was easy to determine. The first gross loss speed was also much easier to determine than might be expected because the increase in oil loss rate at first gross loss speed was very dramatic.

Table 5.2 Test Results - Phase 1 Tests (O-6)

BOOM	NOFI VEE-SWEEP Freeboard 24 inches Draft 27.6 inches B/W 25:1 (Bitting [A-3] shows B/W 15:1)				
	WAVE HT. feet (m)	AV. WAVE PERIOD (sec)	1st LOSS SPEED (kts)	GROSS LOSS SPEED (kts)	OIL PRELOAD/ VISCOSITY (gallons/cSt)
DIVERSIONARY (Vee)					
CALM WATER	0	0	1.0-1.1	1.3-1.4	100/370
	0	0	1.4	1.8	100/9,300 &16,500
REGULAR WAVE	0.74 (0.2)	4.6	1.3-1.4	1.6-1.7	100/9,900
	0.4-0.5 (0.12-0.15)	2.5	1.5	1.7	100/9,900
	0.36 (0.11)	1.6	1.3	1.65	100/9,700
CALM WATER	0	0	1.2-1.3	1.6	900/7,500 & 8,300
REGULAR WAVE	0.68 (0.2)	1.6	1.0	1.35	900/9,700 & 13,700

Table 5.3 Phase 2 Tests - Vee-Sweep with a Skimmer (O-6)
Pre-load of 900 gallons before oil distribution

BOOM	NOFI VEE-SWEEP Freeboard 24 inches Draft 27.6 inches B/W 25:1 (Bitting [A-3] shows B/W 15:1)							
	WAVE HT. feet (m)	AV. WAVE PERIOD (sec)	1st LOSS SPEED (kts)	GROSS LOSS SPEED (kts)	OIL DISTRIBUTION RATE gpm (BBL/hr)	RE* %	Recovery Rate gpm (BBL/hr)	OIL VISCOSITY (cSt)
DIVERSIONARY								
(Vee)	0	0	1.3	1.5	270 (386)	74	175 (250)	10,400
CALM WATER	0	0	1.1	1.6	146 (209)	59	129 (184)	4,700
WAVES								
REGULAR	0.36 (0.1)	1.5	1.2	1.3	211 (302)	83	162 (232)	3,600
	0.35 (0.1)	1.6	1.2	1.4	173 (247)	80	186 (266)	5,900

* Recovery efficiency - not exact because the test was designed for boom performance.

Tables 5.2 and 5.3 show that with a preload of 900 gallons of oil, first and gross loss tow speeds are about the same in calm water with and without a skimmer present. In a 1.6 second period regular wave, first loss tow speed is a little higher with a skimmer than without (1.2 knots vs. 1.0 knots, but gross loss tow speed remains about the same at 1.35 knots.

Overall Assessment of Results - NOFI Vee-Sweep

Tests Without Oil Phase 1 - Critical tow speed (boom submerged) in tests without oil was high; 3.4 to 3.6 knots in calm water and 2.4 knots in a harbor chop wave. Splashover occurred at somewhat lower speeds in waves, 2.4 to 3.2 knots.

Tests With Oil Phase 1 - With an oil pre-load of 100 gallons, first and gross loss speeds in calm water and low viscosity oil were about 1 and 1.35 knots respectively. With high viscosity oil, these speeds increased to 1.4 and 1.8 knots. In regular waves and high viscosity oil, first loss speeds varied from 1.3 to 1.5 knots and gross loss 1.6 to 1.7 knots. Tests with low viscosity oil were not performed in waves.

With an oil pre-load of 900 gallons of high viscosity oil, loss speeds were about the same on an average in calm water, but maximums were somewhat lower. In calm water first loss was 1.25 knots and gross loss 1.6 knots. In a regular wave first loss was 1.0 knots and gross loss 1.35 knots, which is significantly lower than performance with a lower oil pre-load in a regular wave.

Phase 2 Tests With a Skimmer - In calm water, first loss tow speed (1.1 to 1.3 knots) was about the same as Phase 1 when a skimmer was not present and a 900 gallon pre-load of oil was used. Gross loss speed in calm water, 1.5 to 1.6 knots, was also about the same as in Phase 1.

In a regular wave, first loss speed in Phase 2, 1.2 knots, is slightly higher than the regular wave result, 1.0 knots, with a 900 gallon pre-load in Phase 1. Similarly, gross loss speed in Phase 2, 1.4 knots, could be considered identical to the corresponding 900 gallon pre-load result in Phase 1, 1.35 knots.

Based on these results, one could conclude that the presence of a skimmer in the Vee-Sweep did not degrade the performance of the system.

In the Phase 2 tests, the gross loss speed seems to be higher with a lower oil distribution rate, but this relationship is not clear and perhaps only a coincidence.

General Comment on Vee-Sweep Tests - The report notes that the Vee-Sweep could be tested with reasonable accuracy only with the 27.6 inch (700 mm) skirt (the normal skirt length is 39 inches [1,000 mm]). With the 700 mm skirt, the water depth to boom draft ratio is 3.5:1, lower than the recommended 4:1 minimum ratio, but reasonably close. The flow velocity under the Vee-Sweep was slightly higher than in the open ocean as a result. The observed critical tow speed, first loss tow speed, and first gross loss tow speed in the tank are therefore likely to be slightly lower than would occur in the open ocean because of this higher flow velocity under the sweep. The author notes here that following this reasoning, first loss tow speed and first gross loss tow speed may be higher in the field than in the tank for all booms tested.

NOFI Vee-Sweep Wave Conformance Tests

These tests were to determine motions of the Vee-Sweep to allow correlation with oil loss.

Test Procedure

The boom was towed in various wave conditions without oil present. The tests were conducted at the first loss tow speed (without a skimmer) determined during the oil loss test for each wave condition tested. Changes in local sweep depth were measured by pressure sensors mounted to the bottom of the sweep skirt. The vertical motion at the sweep apex is the most critical, therefore, two pressure sensors were located at the sweep apex.

Test Results

Vee-Sweep skirt pressure measurements were presented in the form of relative amplitude spectra. Only amplitude differences were shown. Thus, if the bottom of the skirt was following the wave exactly, there would be no relative amplitude. Data show that significant relative motion of the boom varied between 34 and 92 percent of the significant wave height, which the report concedes is a reasonable range for this data.

NOFI Vee-Sweep Oil Loss Rate Tests

These tests were intended to quantify the steady state oil loss rate in calm water. This requires maintaining the quantity of oil in the preload as the oil is being lost. This was done by replacing oil as it was being lost in two runs and using a large pre-load of oil in the third run.

Test Procedure - Oil Loss Rate Tests

The Vee-Sweep was towed in calm water at four speeds that span the interval from the first loss speed up to 0.4 knots above the first loss speed. Speeds above the first loss speed of 0.1, 0.2, 0.3, and 0.4 knots were to be tested. Because of time limitations, only three of these conditions were tested. In the first test, the boom was preloaded with 100 gallons (0.38 m^3) of oil. The oil distribution system was activated and the boom gradually accelerated allowing the oil front to reach the apex. Once this occurred, the boom was accelerated to the first loss speed plus 0.48 knots. For the next run, the pre-load volume of oil was increased to 400 gallons (1.51 m^3) and the test was run at first loss speed plus 0.27 knots. In the last run the preload was increased to 900 gallons (3.41 m^3) and no oil was distributed during the run. Tow speed was about 0.42 knots above first loss speed.

All oil lost behind the Vee-Sweep was skimmed from the water and collected in a calibrated settling tank. The oil loss rate was computed from the amount of oil recovered in the settling tank.

Test Results

Table 5.4 Oil Loss Rate Summary - NOFI Vee-Sweep Boom (O-6)

TOW SPEED (knots)	OIL DISCHARGE RATE gpm (BBL/hr)	OIL LOSS RATE gpm (BBL/hr)	OIL PRELOAD/VISCOSITY gallons/ cSt
1.67	126 (180)	28.1 (40)	400/8,900
1.88	260 (372)	26.4 (38)	100/7,500
1.67	0	215 (307)	900/9,300

Overall Assessment of Performance - Oil Loss Rate

When oil was discharged for the tests, oil loss rates were quite close even though the discharge rates varied by more than 100% and oil pre-load 75%. In these conditions tow speeds were different, but close. With a large pre-load of oil and no discharge during the test, the loss rate was almost 700% higher while tow speed remained about the same. These data are perhaps useful individually but so highly variable that they do not show a trend. [Author's note: Preliminary tests to determine the proper oil pre-load were not conducted, a practice that has been the custom in more recent projects. Table 5.4 data suggest that the desired oil pre-load was probably about 400 gallons or even slightly more, but that 900 gallons was far too much, which probably accounts for the extremely high oil loss rate.]

The test report notes that only limited testing was conducted on oil loss rates and results are inconclusive. It was planned to regulate the oil discharge rate to be equal to the oil loss rate during these tests. This would have required several trial and error runs for each data set, but time did not permit this approach. As a result, the oil discharge rates were not equal to the oil loss rates and this undoubtedly had some effect on the test results. Data collected during the oil loss speed tests show that the oil loss speeds (that is, the tow speed at which the oil loss occurs) decrease when more oil is added to the sweep. This indicates that the oil loss rate at a given speed will increase as more oil is added to the sweep, which is what one would expect.

Boom Description - NOFI 600S

The NOFI 600S Oilboom was designed to direct oil into the Vee-Sweep. A support boat tows the end of the Oilboom while the skimming vessel tows the other side of the Vee-Sweep. The Oilboom is similar in cross section to the Sweep with a buoyancy chamber above a skirt. A feather net is attached to the bottom of the skirt between the skirt and the bottom tension member. The bottom tension member is a chain that also provides ballast to the skirt bottom.

NOFI 600S Oilboom
The test report does not describe the boom's physical characteristics or show a sketch. The table below shows data published in the 1999-2000 edition of the World Catalog of Oil Spill Response Products and Figure 5.3 shows a sketch from the World Catalog.

Freeboard	24 inches (600 mm)
Draft	45 inches (1,150 mm) This is the normal draft. Because of the depth of the test tank, a draft of 27.6 inches (700 mm) was used.
Boom Height	69 inches (1,750 mm) normal; boom height for the tests was 51.6 inches (1,300 mm)
End Connectors	NOFI DEC. - G-hooks with flexible fabric sealing
Skirt Material	PVC/polyester
Flotation	pressure inflatable sections 10 feet (3 m) long
Weight	6.7 lbs/ft (10 kg/m)
Reserve Buoyancy	157 lbs/ft (236 kg/m)
Reserve B/W Ratio	24:1 (Bitting [A-3] shows 28:1)
Ballast	galvanized chain
Tension Member	Two cables and a chain

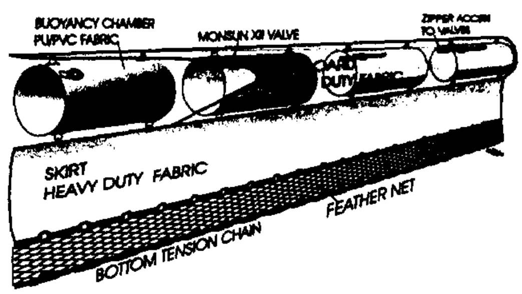


Figure 5.4 NOFI 600S Boom

Test Configuration

The 600S boom was rigged to the tow points at the same positions used in the Vee-Sweep tests. A gap of 55 feet (16.8 m) was used initially. The boom bladder pressure was kept constant throughout the test series. The test series was shortened to include calm water, a 2.5 second regular wave, and harbor chop with and without the bottom netting.

Test Oils

Test oil viscosity varies and is given for each test run.

Test Variables

Independent variables for these tests were wave patterns and tow speed.

Data Precision and Accuracy

First loss and gross loss tow speeds were observed visually. Tow speed is measured within 0.1 knot except for harbor chop waves for the boom without the netting. In this case the difference in speed between runs was 0.2 knots.

Test Procedure

The boom was initially tested with a pre-load of 100 gallons (0.38 m^3) of oil. The first loss speed was difficult to determine because of a wake of entrained air behind the boom. Also, the first gross loss speed was not reached below 2 knots. At that speed there was a significant hydraulic drop across the boom. The gap was therefore reduced to 46 feet (14 m) to reduce the wake effects. Further, pre-load was increased to 300 gallons (1.14 m^3), tests were repeated, and all following tests used this pre-load. A considerable amount of air was still entrained in the wake making it difficult to determine speeds accurately. The boom was tested both with and without bottom netting.

Test Results - NOFI 600S Boom

Table 5.5 Test Results NOFI 600S (O-6)

BOOM	NOFI 600S Freeboard 24 inches Draft 27.6 inches B/W 24:1 (Bitting [A-3] shows 28:1)				
	WAVE HT. feet (m)	AV. WAVE PERIOD (sec)	1st LOSS SPEED (kts)	GROSS LOSS SPEED (kts)	OIL PRELOAD/ VISCOSITY (gallons/cSt)
DIVERSIONARY (Vee) WITH NETTING					
CALM WATER	0	0	1.45	1.5-2.0	100/870
	0	0	1.25	1.4	300/870
REGULAR WAVE	0.7 (0.2)	4	1.3	1.6	300/870
HARBOR CHOP	1.2 (0.4)	2	1.25	1.5	300/630
DIVERSIONARY (Vee)					
WITHOUT NETTING	0	0	1.2	1.4	300/1,050)
CALM WATER	0.38 (0.11)	9	1.2	1.4	300/1,050)
REGULAR WAVE	1.6 (0.5)	2	1.0	1.25	300/1,050)
HARBOR CHOP					

Overall Assessment of Performance - NOFI 600S Boom

First and gross loss tow speeds are high as compared to ordinary booms, all well above the norm of about 0.8 knots. With an oil pre-load of 300 gallons, the boom with bottom netting performed as well or better in a regular wave and harbor chop as it did in calm water. For the boom without netting, performance is degraded somewhat in the harbor chop wave.

Comparing the boom with and without netting at the 300 gallon oil pre-load level, performance of the boom without netting is about the same in calm water but slightly degraded in waves.

Performance of the 600S boom is somewhat lower than the Vee-Sweep boom, but not appreciably. These two units are intended to be used together and are shown by these tests to be compatible.

The report concludes that the Vee-Sweep and 600S Oilboom were both very stable up to the critical tow speed. The sweep had substantial reserve buoyancy and the apex sank gradually as the tow speed increased. The shape of the sweep was constant throughout the speed range. The oil loss tests demonstrated that the NOFI Vee-Sweep can contain and concentrate oil at speeds above 1 knot, which is a significant improvement over most other boom designs.

2.3 ENVIRONMENT CANADA TESTS 1980 (E-1)

Six oil spill containment booms were tested offshore of St. John's, Newfoundland in March and April of 1980. Testing was conducted about 3 nautical miles south of St. John's Harbor in Blackhead Bight. This area, sheltered by cliffs to the west and a peninsula to the south, is at the eastern extremity of the North American continent, with water temperatures, ice conditions and sea states typical of the Grand Banks oil exploration areas. Currents in the area are 1/4 knot or less and tides average 5 feet (1.5 m). Two pressure inflatable booms were tested, the U.S. Coast Guard (B.F. Goodrich) boom and the Vikoma Seapac boom.

The principal criteria used to evaluate the booms were oil retention characteristics, durability, and towing loads. Although it was intended to deposit a barrel of oil ahead of the towed booms, this was not done in every case because of adverse weather conditions. Data describing towing loads are reported in some detail.

Boom Description

The U.S. Coast Guard (B.F. Goodrich) pressure inflatable boom had a freeboard of 14 inches (360 mm), a draft of 18 inches (460 mm), and an overall height of 32 inches (820 mm). Each 50 foot (15 m) section had 10 foot (3 m) segments each with an inflation chamber. Each inflation chamber had a valve and was inflated individually with a blower. A 800 foot (244 m) length of boom was tested. Tension was provided by three chains, two right below the flotation and one at the bottom of the skirt, which also served as ballast. Although this specific boom has not been produced for many years, similar types remain on the market. A similar boom currently produced by Engineered Fabrics Corporation has a freeboard of 12 inches (305 mm), a draft of 24 inches (610 mm), and an overall height of 36 inches (915 mm). This boom has a total strength of 35,000 pounds 157,500 Newtons) and a buoyancy to weight ratio of 3.9:1. Figure 5.5 shows a sketch of the boom.

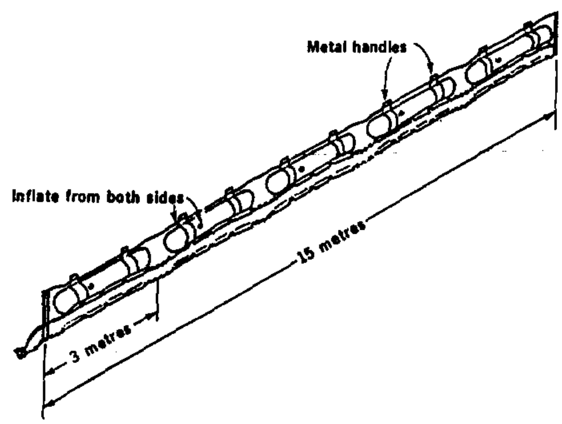


Figure 5.5 U.S. Coast Guard (B.F. Goodrich) Boom

The Vikoma Seapac is a complete system consisting of a boom and inflation gear stored in a towable deployment vessel. The boom has three tubes, one for air flotation, one water filled ballast tube, and a third flotation cuff that is filled with compressed air to prevent the boom from twisting prior to inflation. The boom fabric is butaclor-coated nylon and has a freeboard of 30 inches (760 mm), a draft of 17 inches (430 mm) and an overall height of 47 inches (1,190 mm). The boom is a single 1,600 foot (488 m) barrier and has no connectors except the end tow bridles. This boom has been produced commercially and is still available. Figure 5.6 shows a sketch of the boom.

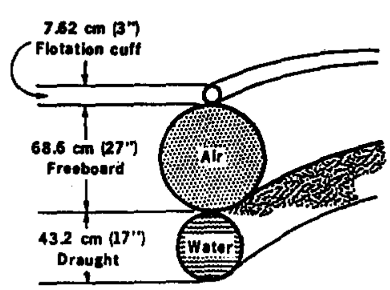


Figure 5.6 Vikoma Seapac Boom

Test Configuration

The boom was towed in a catenary configuration by two vessels. The distance across the boom opening was measured with an optical range finder. All tows were made into the wind.

Test Oils

Bunker C - viscosity 9.9 cSt, density 0.97
BCF Venezuelan Crude Oil - 30 cSt, density 0.91
(Author's Note: these values for viscosity may not have been reported correctly.)

Data Precision and Accuracy

Forces on booms (not reported here) were to the nearest 10 Newtons. (See Appendix C for a complete description of forces on booms.) Boom performance is described subjectively.

Test Procedure

As a measure of containment performance, a barrel of oil was pumped into the catenary from the control vessel. The oil/boom interaction was observed from a small open boat at the apex of the boom and the time for all the oil to escape was measured. The principal criteria to evaluate the booms were oil retention characteristics, durability, and towing loads.

Test Results

U.S. Coast Guard (B.F. Goodrich) Boom - Forces on the boom were recorded for straight line and catenary towing. During sea trials winds were 10-15 knots and sea state was reported as 2-3. (This range corresponds to wave heights of 3 to 4 feet [0.9 to 1.2 m]). The report states that the boom's relatively low freeboard led to noticeable water splashover prior to spilling oil. A barrel of oil spilled upwind of the boom escaped from the boom in about 10 minutes. Oil losses due to splashover and underflow could not be quantified, but in a 1980 AMOP paper (A-1) it was estimated that 2/3's of the oil was lost to underflow and 1/3 to splashover.
Vikoma Seapac - The boom was deployed between the control vessel and a smaller boat. Because of the length and weight of the boom, no forward velocity was achieved, but this was considered to be typical of offshore spill conditions. The wind was 7 to 8 knots and the sea had a 4 to 6 inch wave (10 to 30 cm) on a 6 foot (2 m) swell.

One end of the boom was secured to a mooring buoy then the control vessel spilled a barrel of oil into the mouth of the catenary. The report notes that the upper and lower cylinders set up currents as the boom moved up and down with the waves. This produced a surface velocity normal to the line of the boom and away from it that resulted in the oil being kept 4 to 12 inches (10 to 30 cm) away from the face of the boom. The oil was not touching the boom's surface even in 8 knots of wind. This was true even at the apex of the boom. Although there had been earlier reports of this boom producing a pumping action in waves causing oil to be forced under the boom. This was not noted in these tests. The test reports that there was very little oil flowing under the boom or splashing over the top. After 45 minutes approximately two thirds of the oil remained inside the boom. This was the best performance of all the booms tested in oil at this location. The oil was concentrated in the apex of the boom and was still being held away from the face of the boom by the surface currents noted previously.

Overall Assessment of Performance

The following paragraph is paraphrased from the original test report.

The U.S. Coast Guard boom is a rugged, well-constructed pressure inflatable product. The boom materials were well chosen although the rough fabric surface was difficult to clean after contact with oil. The boom exhibited good wave following characteristics except in short, breaking waves. Oil retention tests were inconclusive in the offshore conditions; however, an earlier AMOP paper (A-1, 1980) suggests that losses resulted from the reflection of waves off the flotation cylinder. Further, it was suggested that a larger boom would have been more effective. Overall, the boom featured many characteristics that would be desirable in pressure inflatable boom, particularly the sectionalized buoyancy compartments and the excellent connection system.

The report does not offer a separate assessment of performance of the Vikoma boom.

2.4 CANADIAN COAST GUARD TESTS 1991 (C-2)

Seven containment booms were selected and tested to examine the relative merits of boom type or shape as they affect oil containment effectiveness in increasing water currents. Testing was performed 11-20 February 1991 in the recirculating flume tank at the Institute of Fisheries and Marine Technology (IFMT) in St. John's Newfoundland.

The IFMT tank is 26 feet wide by 74 feet long by 13 feet deep (8 X 22.5 X 4 m). The depth met the requirement of being at least 4 to 6 times boom draft. Water flow through the flume can be varied from 0 to 2.4 knots. Wave generation is not available. Side viewing windows and underwater video record test results. Figure 5.7 shows a sketch of the tank.

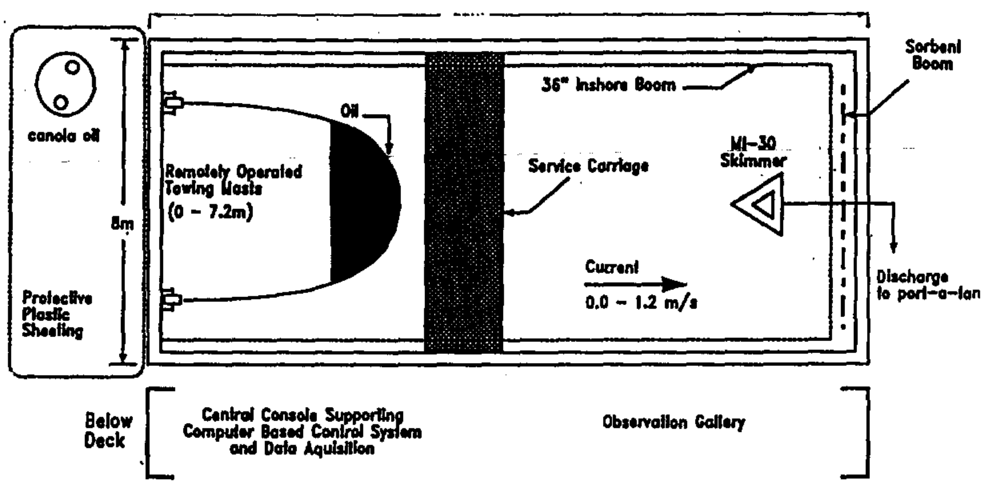


Figure 5.7 IFMT Test Tank

Boom Description

Of the seven booms tested, three were pressure-inflatable curtain booms that are reported here. Table 5.6 page 5-16 provides a description of these booms. Figure 5.6, page 5-13, shows a sketch of the Vikoma boom. Figure 5.4, page 5-11, shows the NOFI boom, The RO-BOOM is similar to the NOFI boom except it does not have the feather net on the bottom of the skirt.

Test Configuration

The boom to be tested was placed in a parabolic (catenary) configuration in the tank with the total boom length being 4 to 6 times the boom opening width. Lighter booms were fixed to the two masts located at the upstream end of the flume. The mast's separation width could be varied from 0 to 24 feet (7.2 m). The heavier booms were secured to the flume side walls at a fixed width of 26 feet (8 m). The booms were placed at the upstream end of the tank to allow maximum rise time for the entrained oil prior to its collection at the downstream end of the flume.

Test Oil

Canola Oil - viscosity 64 cSt, density 0.935
This organic oil (rape seed) is compared to Alberta Sweet Blend Crude that has a viscosity of 12 cSt and a density of 0.840.

Test Variables

Velocity at first loss and loss rates.

Data Precision and Accuracy

Flow velocity to 0.1 knots; loss rate to 0.1 liter/minute (0.026 gpm).

Table 5.6 Canadian Coast Guard Tests 1991 (C-2)

BOOM	RO-BOOM	VIKOMA	NOFI X-F11
FREEBOARD inches (mm)	26 (660)	30 (760)	35 (900)
DRAFT inches (mm)	43 (1,100)	17 (430)	43 (1,100)
HEIGHT inches (mm)	69 (1,760)	47 (1,190) [2]	78 (2,000) [4]
END CONNECTORS	Hinge and pin	Only on ends for towing	"G" hooks with fabric seals
SKIRT MATERIAL	Rubber reinforced with polyester/polyamide	Butaclor coated nylon	Flotation - polyform PVC Skirt - PVC coated polyester Net - braided polyamid
FLOTATION	Pressure-inflatable, multiple chambers	Single pressure-inflatable chamber	Pressure-inflatable, multiple chambers
WEIGHT lbs/ft (kg/m)	11 (16)	7 (10.5) [3]	10 (16) [5]
RESERVE BUOYANCY lb/ft (kg/m)	87.6 (130.3) [1]	Not reported	Not reported
RESERVE B/W RATIO	7.4:1 [1]	Not reported	30:1 [1]
BALLAST	Chain	Water	Chain
TENSION MEMBERS	Fabric/chain ballast	Fabric	Fabric, chain, cable
TENSILE STRENGTH lb (N)	45,000 (200,000) [1]	Not reported	76,000 (342,000)

Notes: [1] Data from the World Catalog of Oil Spill Response Products describing similar boom produced by the same manufacturer.
[2] Boom height is shown to be 57 inches in the report, which is believed to be in error. Combining freeboard and draft gives 47 inches, which is the boom height reported in other documents.
[3] Report shows boom weight to be 31 pounds per foot, which is believed to be in error. A similar boom produced by the same manufacturer has a weight of about 7 pounds per foot.
[4] Report shows boom height to be 157 inches, which is believed to be in error. The sum of the reported freeboard and draft is 78 inches, which is the approximate height of a similar boom produced by the same manufacturer.
[5] Report shows boom weight to be 32.4 kg/m (about 22 lbs/ft), which is believed to be in error. A similar boom produced by the same manufacturer has a weight of about 10 pounds/foot (15 kg/m).

Test Procedure

Boom to be tested was deployed in a parabolic (catenary) configuration. Water current was set on low (0.4 knots) and 8 to 10 gallons (30 to 40 liters) of dyed canola oil was added to the tank to a thickness of several millimeters in the pocket of the boom. The volume of oil was first measured in a calibrated bucket and then carefully poured on the surface of the water. Water velocity was increased by 0.1 knot increments until first loss of oil was observed. The water velocity was reduced, then increased again to first loss to confirm the velocity. Oil was added to the boom to replace the oil lost. The oil loss rate was then determined by timing the loss of approximately 90% of the initial oil volume present in the boom at a velocity of 0.2 knots above the first loss velocity.

An initial volume of oil, estimated to give a thickness of 5 mm in the boom apex, was measured using calibrated buckets and recorded prior to each boom test. Before each subsequent run with a given boom, enough oil was added to bring the volume back to the initial volume. The amount of makeup oil required was determined by visually comparing the initial amount of oil in the boom prior to testing, with the oil remaining in the boom following a given run. This was accomplished by using two video screens to simultaneously compare the color intensity of the oil in the boom apex. The volume of oil lost during the loss rate determinations was also estimated visually using the same method.

Test Results

Boom performance was based on oil retention capability described by first loss speed and loss rate at 0.2 knots above first loss velocity. First loss velocity was defined as the first "significant" loss observed as the water velocity was gradually increased. Although smaller losses - occasional droplets - occurred prior to what was judged to be first loss, the loss was not considered significant until a fairly steady stream of oil escaped from the boom.

Most earlier tests have shown oil loss to occur by entrainment from the head wave. While this was occasionally observed, the oil loss mechanism most frequently observed was that of drainage through vortices formed in the boom pocket. The vortex formation usually appeared at current velocities of 0.2 to 0.3 knots before the first significant loss velocity was reached. Vortices formed at the lower velocities resulted in minimal loss, which was not considered significant. Often a vortex would form, then disappear without any oil loss occurring at all. The side viewing windows were ideally suited for observing oil loss and for determining the mode of oil loss. [Author's note: Although formation of vortices and oil loss from vortices has not been noted in any previous tests, it has been noted in the field and therefore this phenomenon should be investigated at OHMSETT and elsewhere. This may be a new, and as yet undocumented, form of oil loss.]

Table 5.7 Test Results, Canadian Coast Guard 1991 (C-2)
Booms tested in 5 mm slick, Oil Viscosity 64 cSt

BOOM	1st LOSS SPEED (kts)	LOSS RATE AT 1st LOSS + 0.2 kts (gpm @ kts)	COMMENT
RO-BOOM F 26 inches D 43 inches B/W 7.4:1	1.2	4.6 @ 1.4	Gap ratio 0.42. Boom rises out of water 1 foot at higher velocities. Most oil loss with vortices.
VIKOMA F 30 inches D 17 inches B/W Not reported	0.9	3.3 @ 1.1	Gap ratio 0.53. Boom kinked in two places. Most loss at kinks.
NOFI X-F11 F 35 inches D 43 inches B/W 30:1	1.5	2.9 @ 1.7	Gap ratio 0.6. Entrainment loss and vortex loss.

Overall Assessment of Results

First loss speeds were good as compared to other booms of this type. Loss rates were low as compared to more recent OHMSETT tests; however, the amount of oil used was very small, which certainly would have affected loss rate. Although gap ratios were somewhat larger than the more usual 3:1 (0.33), this probably did not have an important affect on first loss speed or loss rate. The larger gap ratio could have had a significant affect on the force measured on the boom, but this was not reported here.

The RO-BOOM tested had been damaged when used in a spill before the test. As a result, the bottom ballast/tension chain was longer than design length. A shorter chain would have pursed the boom at the bottom which may have resulted in a better performance.

For the Vikoma boom, first loss speed and oil loss rate could have been affected by the kinks in the boom. The kinks suggest that the boom was not deployed normally because of the size of the test tank, and this could have affected the result.

In the NOFI boom test, it was noted that the slick did not reach the edge of the boom, leaving a gap or colorless film between the leading edge of the slick and the boom wall. This phenomenon was also noted during a field test of the Vikoma boom. (See Test Results Section 2.3 page 5-14.) The report also notes that the NOFI boom was very stable at the highest current velocities tested, which was attributed to skirt design. The boom had a deep draft with the bottom section made of netting that restrained but did not block the flow of water beneath it. It was speculated that this had a greater stabilizing effect than a skirt made entirely of solid material.

2.5 Offshore Tests Performed for the Canadian Coast Guard Reported in AMOP 1988 (A-2)

A series of offshore oil spill containment tests were performed for the Canadian Coast Guard by S.L. Ross Environmental Research Ltd. to determine if equipment stockpiled by the Coast Guard would be effective in response to spills of the waxy crude oils typical of the Grand Banks area. Tests were performed during September and October 1987 at a site 25 miles east of St. John' s, Newfoundland. Booms tested were the RO-BOOM and Vikoma Ocean Pack, both pressure-inflatable booms but of different configurations. The purpose of the tests was to evaluate and compare the performance of each boom. Although it has been the practice of this study to describe each boom separately, this policy will be altered for this set of tests. All data in this test report are considered together and therefore the summary and analysis of this data will be performed in the same way.

Boom Description

Booms are not described except by name in the AMOP paper, but data developed from the 1987 edition of the World Catalog are shown on Table 5.8, page 5-19.

Test Configuration

Booms were towed in a catenary configuration by the M/V *Triumph Sea* and the M/V *Beinir.* Oil was pumped from the stern of the M/V *Terra Nova Sea.* A total of 67.7 m^3 (17,885 U.S. gallons) of oil were released during the test period. All of the oil entered the mouth of the boom catenary.

Test Oils

Not enough Grand Banks crude was available for the tests, therefore, Brent crude from the North Sea was modified to simulate this oil. The modified Brent crude had a viscosity of 24 cSt and density of 0.84 at 12°C (54°F).

Test Variables

Boom tow speed, wind and wave conditions.

Test Procedure

Relative boom/surface water velocity was measured by timing the drift of wood chips over a known distance along the side of the boom tow vessels. The rate of oil leakage from the booms was estimated from aerial video and still photography by determining the width of sheen leaking past the boom and multiplying by the relative boom/water velocity and an assumed slick thickness (10 μm for sheen, 1 mm for dark oil). This technique provides a reasonable relative comparison of boom leakage rates for booms tested under similar conditions. The estimate relative oil leakage rates were given dimension less numbers for comparison of performance.

Table 5.8 S.L. Ross Tests Performed for the Canadian Coast Guard 1987 (A-2)

BOOM	VIKOMA OCEAN BOOM	RO-BOOM
FREEBOARD inches (mm)	22 (560)	24 (600)
DRAFT inches (mm)	36 (900)	51 (1,300)
HEIGHT inches (mm)	58 (1,460)	75 (1,900)
END CONNECTORS	Bolt	Hinge and pin
SKIRT MATERIAL	Double faced nylon reinforced neoprene	Neoprene
FLOTATION	Single pressure inflatable chamber	Pressure inflatable, multiple chambers
WEIGHT lbs/ft (kg/m)	11.0 (16.4)	12.8 (19.0)
RESERVE BUOYANCY lb/ft (kg/m)	157.0 (233.6)	88.0 (131.0)
RESERVE B/W RATIO	14.3:1	6.9:1
BALLAST	Water/chain	½ inch (13 mm) chain
TENSION MEMBERS	Chain/fabric	Chain, fabric
TENSILE STRENGTH lb (N)	36,000 (160,000)	161,800 (720,000)

Test Results

Results of offshore testing cover deployment and recovery, maneuverability and durability, sea keeping, and oil retention. The paper compares the performance of both booms, which is the format that is used here.

Deployment and Recovery - Two 656 foot (200 m) sections of RO-BOOM were deployed in about 100 minutes while recovery took 80 minutes. Deployment of the Vikoma Ocean boom took 20 minutes and recovery onto the hydraulic reel took 30 minutes; however, after recovery the boom was removed from the reel and stowed in a box, which took an hour. Although deployment of the Vikoma boom was faster, considering the requirements of offshore response, both were considered to be acceptable. At the time of this report, the RO-BOOM manufacturers were improving the inflation valving system, so it is likely that deployment times have also been reduced.

Maneuverability and Durability - Both booms were judged to be easily maneuverable and had no problems with overturning or twists. No damage to the RO-BOOM was noted after nearly 18 hours of deployment including 3 hours of skimming operations. All flotation chambers were fully inflated when the boom was recovered. The Vikoma boom suffered one incident of sinking when excessive strain caused the band holding the air chamber to the power unit to slip off. This problem was fixed in a half hour and the boom was not damaged. Overall, the RO-BOOM was judged to be somewhat more durable for long term offshore deployment because it does not depend on the continuous operation of a power source and the loss of a single flotation unit does not affect the overall integrity of the boom. Compressor power failure or large tears can cause a loss of containment capability for the Vikoma boom.

Sea Keeping and Oil Retention - Oil was in contact with the RO-BOOM for two time periods: the first during the oil release and the during the skimmer trials, a total period of about 4 hours. During this time, the RO-BOOM followed the waves and swell very well and maintained its desired configuration.

The estimated relative oil leakage rate was low initially because only small amounts of oil were reaching the boom pocket. By the time most of the oil reached the boom pocket, the leak rate had increased from a relative rate of 0.1 up to 0.5 to 1.0. This leak rate remained relatively constant during the test period. Some splashover was noted at the boom joints between flotation sections near the end of the test period when the wind had increased to about 15 knots. The relative boom/water velocity was calculated to be around 0.6 knots. The paper reports that only small volumes of oil were lost. One slick thickness measurement was made in the pocket of the boom near the end of the test period, when it was estimated to be 300 mm thick. At that time a photograph showed the oil to cover an area of about 200 m^2 (2,150 ft^2). Assuming the slick thickness to be relatively constant in the area, the volume of oil contained in the boom would be about 60 m^3, which is 89% of the 67.7 m^3 discharged. The paper concludes that virtually all the oil released into the RO-BOOM was contained for the duration of its test and the slick thickness was relatively constant. Tow speed was not increased to determine first loss tow speed and the only losses noted at the test site were splashover.

Before the test began, the Vikoma boom contained small volumes of oil, velocity was low, and the relative measure of the leak rate was 0.1. Later the boom contained about 300 m^2 (3,230 ft^2) of oil with an estimated thickness of 20 to 50 mm, which would indicate an accumulation of 6 to 15 m^3 (1,584 to 3,960 gallons) of oil. At this time the relative leak rate was estimated as 1.0 with a boom velocity of 0.5 knots. A small breaking wave at the joint between the air and water chambers was observed. Previous tests with the Vikoma boom reported that these waves prevented the oil from touching the boom; this was not observed in these trials. As the tow vessels maneuvered the Vikoma boom into a "J" configuration, the relative leak rate increased to 200. This number may be conservative because it was estimated that oil trailing the boom was 3 to 4 mm thick, which would have been equivalent to a leak rate of 600 to 800. All of the oil was lost under the boom pocket in about 5 to 10 minutes by entrainment. Very little splashover was noted.

Overall Assessment of Results

The paper concludes that, based on estimated leak rates, both booms performed equally well while maintaining station into the wind. The high loss rate from the Vikoma Ocean Pack while maneuvering upwind was caused by high relative boom/water velocities (about 1 knot) that exceeded the containment limits of the boom. The winds at the test sight during this period (15 to 20 knots) were near the maximum limits for any containment boom operating in a stationary upwind mode. Wind driven wave heights continued to increase from 4 feet (1.3 m) to 5 to 6.5 feet (1.5 to 2 m) by the end of the trials. While being towed upwind, the RO-BOOM seemed to be more likely to have splashover failure and the Vikoma boom had wave induced dispersion losses.

Both booms were judged to be acceptable for use offshore. The limiting wind and sea conditions for their use in containing oil in a stationary mode, oriented into the wind, would be only slightly higher than the conditions encountered during the trials. The booms could be used in higher wind/sea conditions but only towed downwind. Towing downwind would be satisfactory chasing individual slicks but would not be effective when trying to keep the oil from leaving a spill source such as a blowout.

2.6 NOFO Offshore Tests 1992 and 1993 (I-3 and I-4)

The Norwegian Clean Seas Association For Operating Companies (NOFO) conducts offshore spill response trials with oil annually. Although the results of these tests are significant, data are sparse and test results only descriptive, therefore the results of these two tests are grouped together.

Boom Description

The RO-Boom 3500 was used in both sets of tests. Table 5.9, page 5-21, shows boom details taken from the 7th edition of the World Catalog of Oil Spill Response products.

Test Configuration

Test boom was towed in a catenary configuration by two offshore response vessels.

1992 - Significant wave height 5 feet (1.6 m); maximum wave height 10 feet (3 m).
1993 - Maximum wave height 5 feet (1.6 m).

Test Oil

1992 - Water in oil emulsion, 30% water. Viscosity of fluid 320 cSt.
1993 - Water in oil emulsion, 68% water. Viscosity of fluid 1,200 cSt.

Test Procedure

1992 - 50 m^3 (13,200 gallons) of emulsion were discharged directly into the boom.
1993 - 95 m^3 (25,080 gallons) of emulsion were discharge directly into the boom.

Table 5.9 RO-BOOM 3500

BOOM	RO-BOOM 3500
FREEBOARD inches (mm)	51 (1,295)
DRAFT inches (mm)	60 (1,524)
HEIGHT inches (mm)	111 (2,819)
END CONNECTORS	Hinge and pin
SKIRT MATERIAL	Neoprene
FLOTATION	Pressure inflatable, multiple chambers
WEIGHT lbs/ft (kg/m)	24.5 (36.5)
RESERVE BUOYANCY lb/ft (kg/m)	570 (850)
RESERVE B/W RATIO	23.3:1
BALLAST	Chain
TENSION MEMBERS	Ballast chain/fabric
TENSILE STRENGTH lb (N)	90,000 (40,000)

Test Results

1992 - During the oil discharge a normal towing speed of 0.2 to 0.5 knots was used. The discharging vessel reported that the boom was holding the oil effectively during this period. Oil leakage only was observed after tow speed was increased to 1.3 knots.
1993 - The slick thickness in the boom was an average of 140 mm towing at a speed of 0.5 to 0.7 knots. This speed was increased to 1.2 knots during the oil recovery operation. The discharging vessel reported that the boom was holding the oil effectively during this period. Based on the amount of oil that was recovered, it was determined that oil lost to evaporation and leakage was 1.5 m^3 (396 gallons) and the loss rate was 0.4 m^3 (106 gallons) per hour.

2.7 Scaled Basin Tests Performed by Stevens Institute of Technology 1994 (I-5)

A series of scaled tests were performed by the Davidson Laboratory at Stevens Institute of Technology in 1994 under a grant of the U.S. Coast Guard through the New Jersey Science Consortium. The purpose of the tests was to determine how to improve the performance of oil spill containment boom in waves.

Boom Description

A series of generic model booms were developed, constructed and tested. Boom sizes were 0.5, 1.0, and 1.5 feet (150, 300, and 460 mm) giving a constant scaled boom height of 4 feet (1,220 mm). The test boom was provided by Slickbar Products Corporation of Seymour, Connecticut. Tests were performed using light weight air filled boom. Air pressure was maintained and monitored while buoyancy to weight ratio was changed by adding and deleting ballast weights. Three different buoyancy to weight (B/W) ratios were tested for each boom sample.

Test Configuration

Scales of 1/8, 1/4, and 3/8 were used with a constant 24 foot (7.3 m) length of boom giving scaled boom lengths of 192, 96, and 64 feet (58.5, 29.3, and 19.5 m). Wave heights were 0.5, 1.0, and 1.5 feet (0.15, 0.3, and 0.5 m) giving scaled values of 4, 8, and 12 feet (1.2, 2.4, and 3.6 m). The width of the test tank limited the sweep width to 8 feet (2.4 m) which permitted a gap ratio of 2/3 for a 12 foot (3.6 m) boom and 1/3 for a 24 foot (7.3 m) boom. Most tests were run with a gap ratio of 1/3. Data were recorded at scaled tow speeds of 0.5 and 1.0 knots. The results of tests showed no scale effects on heave response to the various types of waves.

Test Oils

Oil was not used in any of the tests.

Test Variables/Data Precision and Accuracy

Measurement	Precision
Heave	±0.30 inches (7.6 mm)
Wave height	±0.10 inches (2.5 mm)
Drag force	±0.30 lbs (0.14 kg)
Speed	±0.01 fps (0.006 kts)
Wave period	±0.002 seconds

Test Procedure

Each test run was made by starting the waves, then starting the tow carriage when the waves reached the beach and filled the tank. Three different buoyancy to weight (B/W) ratios were tested for each boom sample. The length of the bottom tension cable of each new boom had to be adjusted to provide the optimum towing attitude in calm water trials prior to running in waves.

Test Results

Test results show relatively small differences in heave response between booms with buoyancy to weight ratios of 34 and 10, but conformance to waves is noticeably lower when B/W ratio decreases to 5. Tow drag increases with the lower B/W because the booms sit deeper in the water exposing a greater area to the moving water.

Wave height is not the limiting parameter for good wave following but rather wave steepness. The boom fails to respond fast enough to the rapid vertical motions of short period waves. This causes problems, particularly at low B/W ratios. Booms with B/W ratios of 10 and greater perform better in these conditions.

Drag forces on the boom increase rapidly with increasing tow speed and increasing boom length at a fixed gap ratio. Increasing gap ratio from 1/3 to 2/3 did not have a significant effect on heave response but increased drag forces for the same buoyancy to weight ratio.

The report notes some effects of waves inside the boom envelope. For example, short length waves focus and amplify as a result of waves either reflecting and/or being refracted off the inner boom surfaces. As a result, waves measured inside the catenary tow were higher than the waves measured outside the boom. This makes containment of oil collecting at the apex of the boom more difficult. The report suggests that light weight, highly flexible booms with a high B/W ratio and sufficient freeboard are recommended for open sea operations.

Inspection of data summaries show other results of the tests that may be helpful to operators.

- o At a B/W ratio of 10 and speed of 0.5 knots, heave response was better with shorter lengths of boom. At 1 knot and other conditions remaining constant, heave response was nearly constant with shorter lengths of boom.
- o As mentioned previously, heave response is much better at higher B/W ratios and drag force is much lower. This is true at both 0.5 and 1.0 knots. There is not a great difference in performance between B/W ratios of 34 and 10 but a substantial change when B/W ratio drops to 5.
- o For a buoyancy ratio of 10 and tow speeds of both 0.5 and 1.0 knots, heave response is better is higher waves. This unusual result happens because the higher waves were longer and easier for the boom to follow. The small waves had a higher frequency and were difficult to follow.
- o At a B/W ratio of 10 and speeds of both 0.5 and 1.0 knots, heave response was slightly better at a gap ratio of 2/3 than at 1/3. Since boom length was reduced for the larger gap ratio, the improved heave response could have been a result of the shorter boom length (as mentioned earlier) as well as the larger gap ratio.

The results of tests showed no scale effects on heave response to the various types of waves.

2.8 MSRC, Coast Guard, Navy, and MMS Tests Offshore 1994 (I-6,S-3)

In May 1994 the Marine Spill Response Corporation (MSRC), the U.S. Coast Guard, U.S. Navy, and Minerals Management Service (MMS) conducted a joint test of oil containment booms in Lower New York Bay and in the Atlantic Ocean east of Sandy Hook New Jersey. These tests were performed to collect data on boom performance, including tow forces, skirt draft, and boom freeboard, as a function to tow speed and environmental forces caused by currents, wind, and waves. Four booms were tested:

- o 3M Fire Boom (Presently the Elastec/American Marine Fireboom)
- o Barrier Boom
- o USCG/Oil Stop Inflatable Boom
- o U.S. Navy USS-42 Boom

Use of these booms permitted data collection over a range of buoyancy to weight ratios of 5:1 to 52:1, skirt drafts from 610 mm to 1,500 mm (24 top 60 inches), and freeboards from 350 mm to 1,190 mm (14 to 47 inches). Data collected were also used to compare calculated boom loads (force) and measured loads. Tests of the U.S. Coast Guard Inflatable Boom and the U.S. Navy USS-42 boom, are described here. Tests of the other booms are described in other appropriate chapters. Analysis of the forces on booms is found in Appendix C.

Boom Description

US Coast Guard Inflatable Boom - Two hundred meters (656 feet) of the USCG inflatable containment boom, manufactured by Oil Stop Inc., was deployed off its storage reel, which was mounted on the stern of the USCG vessel *Penobscot Bay*. The 25 m (82 foot) length boom section contained eight flotation chambers per section that were made separate from the boom and were installed inside a long pocket that runs the length of the boom. Each chamber was inflated while being deployed using a diesel powered blower. The main tension line was located at the bottom of the skirt. Table 5.10, page 5-24, shows the dimensions of the boom.

US Navy Model USS-42 Boom - The Navy USS-42 boom came in 17.7 m (58 foot) sections, with five flotation chambers per section. Each flotation chamber was inflated while being deployed using a diesel powered blower. The USS-42 boom was wound on top of the NOFI Oil Trawl reel located on the weather deck of the

MSRC vessel New Jersey Responder. Sections of the boom were towed in the apex between sections of an older model of Navy boom, the FUG-1. Table 5.10, page 5-25, shows the dimensions of the boom.

Test Configuration

In most tests booms were towed in tandem as shown in Figure 5.8, page 5-24. The Oil Spill Response Vessel (OSRV) *New Jersey Responder,* the center vessel, towed two booms and acted as the command vessel. The USCG vessels *Penobscot Bay* and *Point Francis* towed the outer ends of the booms. The sweep width for one boom was held constant at approximately 300 feet (91.5 m).

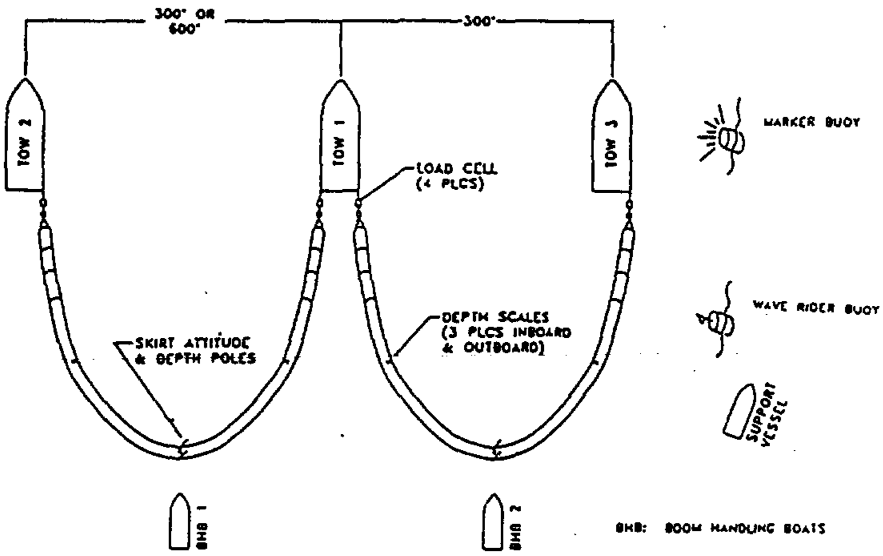


Figure 5.8 Boom Towing Configuration

Test Oils

No oil was used in testing.

Test Variables

Boom tow speed, skirt draft, tow tension, boom freeboard, and environmental conditions.

Data Precision and Accuracy

Boom Tow Speed - Tow speed was recorded manually on all three tow vessels. Speed was also recorded electronically on the *New Jersey Responder* using the vessels satellite navigation system.
Skirt Draft - Submersible pressure transducers were fastened to the bottom of the boom skirt and the reading was recorded on a data logger.
Tow Tension - Tension was recorded on both ends of towed booms.
Boom freeboard, overtopping, and skirt attitude - Each boom was marked vertically in 3 inch (76 mm) graduations from the top of the boom to two feet below the flotation chamber. This scale was monitored with a video recorder showing water action on the inside of the boom.
Environmental Conditions - Water current and wind direction and speed were recorded manually on the control ship. Wave height and period, average wind speed and direction were recorded every half hour from a Coast Guard climate buoy.

Table 5.10 USCG Inflatable Boom and the Navy USS-42 Boom

BOOM	USCG Inflatable Boom	NAVY USS-42
BOOM TYPE	Pressure inflatable curtain	Pressure inflatable curtain
FREEBOARD in (mm)	18 (457)	14 (356)
DRAFT in (mm)	27 (686)	28 (711)
HEIGHT in (mm)	45 (1,143)	42 (1,067)
SKIRT MATERIAL	Urethane coated nylon fabric	Reinforced nitrile/vinyl rubber
FLOTATION	Pressure inflatable, multiple chambers	Pressure inflatable, multiple chambers
WEIGHT lb/ft (kg/m)	6 (9)	6.5 (9.8)*
RESERVE BUOYANCY lb/ft (kg/m)	120 (180)	56.5 (84.8)*
RESERVE B/W RATIO	20:1	8:1
BALLAST	Chain*	Chain
TENSION MEMBERS	Chain, fabric*	Chain, fabric
TOTAL STRENGTH lb (N)	56,000 (252,000)*	45,000 (200,000)

*Based on data for similar models produced by the same manufacturer.

Test Procedure

Video cameras recorded each test run from three positions: the *New Jersey Responder* and each of the trailing boom handling boats. One of these two support boats was placed behind the apex of one of each of the booms being towed, focusing on the apex of the boom. Scales painted on the booms allowed the freeboard, both forward and aft, to be documented for later review and comparison with the collected data.

A test run consisted of the tow vessels lining up in the desired direction to the wind or swell at near zero speed. Radar was used to determine and control the required sweep width between each pair of vessels. The tow vessels accelerated to 0.5 knots. When the speed was confirmed, the data for the run were recorded for approximately 10 minutes. The test director then instructed the tow vessels to accelerate to 1 knot, and the process was repeated then and again at 1.5 knots. Finally, a functional test was performed to determine the speed at which either the flotation submerged or the skirt surfaced. This tow sequence was repeated so that data was acquired towing both into the sea and with the sea.

Test Results

USCG Inflatable Boom - The boom was tested in calm water and a sea state of 2 (winds of 4-10 knots, waves about 3 feet) for a total of 21 tests. The boom conformed well to waves that flowed along the center axis of the boom. Submergence was recorded at 2.5 knots. The report notes that the overall operational height of the boom seems to have remained constant for the range of tow speeds form 0.5 to 1.5 knots. (Table 5.11 shows that there was actually a slight, but regular reduction of freeboard in this range of tow speeds. Based on assumed freeboard and draft of the boom at rest, there was a substantial reduction of freeboard between 0 and 0.5 knots.) At submergence, the downward forces exceeded the buoyant forces, which resulted in less wave following capability. A static test of freeboard was not performed, therefore the freeboard recorded at rest was taken from technical specifications. Table 5.11 shows the changes in freeboard and draft during testing.
Navy Model USS-42 Boom - Tests performed on the first day of operations consisted of a series of dry runs.

Some data were collected on performance in sea state 2 conditions. Ten tests were performed on the third day of operations. Based on these limited tests, the boom submerged while accelerating from 1.5 to 2.0 knots, which was recorded as 1.7 knots. The report notes that overall, the boom did not conform to wave swells along the center axis of the boom (i.e., the length of the boom) or to waves that flowed perpendicular to the boom. Further, that up to a tow speed of 1 knot, the skirt depth did not change at the same rate as the freeboard. (Table 5.11 shows that freeboard decreases at a fairly uniform rate as tow speed increases to 1 knot and that most of that change appears as an increase in draft.) Therefore, the report concludes, the skirt must not have been vertical at these higher tow speeds. The freeboard reduction appears to be linear. This difference in freeboard was most likely due to the shape of the flotation chamber, which was more oval than round in shape. This means that a smaller area was available to support the boom when it started to submerge. Table 5.11 shows the changes in freeboard and draft during testing.

Table 5.11 Freeboard/Draft vs. Tow Speed (I-6)

TOW SPEED (kts)	USCG Inflatable Boom		NAVY USS-42 Boom	
	FREEBOARD Inches (mm)	DRAFT Inches (mm)	FREEBOARD Inches (mm)	DRAFT Inches (mm)
0	18 (460)	22.8 (580)	13.8 (350)	23.6 (600)
0.5	9.8 (250)	19.7 (500)	9.8 (250)	Not reported
1.0	8.7 (220)	21.3 (540)	5.1 (130)	31.5 (800)
1.5	6.7 (170)	25.6 (650)	0.8 (20)	33.5 (850)
2.0	4.7 (120)	Not reported	Not reported	Not reported
2.5	0	Not reported	Not reported	Not reported

Overall Assessment of Performance

U.S. Coast Guard Inflatable Boom - This boom performed well in 3 foot seas at tow speeds up to 2 knots. At this point freeboard was reduced appreciably and submergence occurred at 2.5 knots.
Navy Model USS-42 Boom - Freeboard was reduced significantly at a tow speed of 1 knot and the boom nearly submerged at 1.5 knots. This shows a likely effective performance in these environmental conditions at a tow speed of less than 1.5 knots.

2.9 Pressure-Inflatable Curtain Booms Performance Summary

Conventional Pressure-Inflatable Curtain Booms

Early (1975) prototype versions of this boom type did not perform well. Although stability failure occurred at relatively high speeds, failure to contain oil when towed in the catenary mode occurred at 0.4 knots in the diversionary mode 0.5 to 0.6 knots.

Later (1992) the NOFI Vee-Sweep boom was tested at OHMSETT with much better results. This modern, fully operational device is constrained in a straight "V" shape by netting attached to the skirt of the boom. The netting permits water to flow through but helps to keep the oil in the boom, Further, by holding the boom in a steep "V" shape, performance is typical of a boom deployed in a diversionary mode. The advantages of this configuration are evident in the result. With a large pre-load of high viscosity oil, first loss tow speed in calm water was 1.25 knots and gross loss was 1.6 knots. In a regular wave, first loss was 1 knot and gross loss was 1.35 knots. Performance was nearly the same when the boom was towed with a skimmer present. These results show a very high level of performance. Tests of the NOFI 600S, the boom used to connect to the Vee-Sweep skimming system, showed performance that was about the same in calm water and somewhat better in a regular wave.

Offshore tests of pressure-inflatable curtain boom generally only show sea-keeping characteristics and the potential to contain oil. In tests off the coast of Newfoundland in which oil was used, most was lost behind the boom in 10 to 45 minutes. Although these data have operational significance, they cannot be compared directly to performance from controlled testing.

On a smaller scale, three booms were tested in calm water in a flume. In this case the conventional pressure-inflatable booms experienced a first loss speed of 1.2 to 1.5 knots, similar to the NOFI Vee-Sweep at OHMSETT. A third boom, with a single pressure-inflatable chamber, had a first loss speed of 0.9 knots, but this one was probably not deployed properly because of the narrow width of the flume.

In offshore tests in 5 to 10 foot waves, a very large pressure-inflatable boom (freeboard 51 inches, draft 61 inches) was able to effectively contain oil up to 0.5 knots and only experienced noticeable oil leakage at 1.3 knots.

Scaled basin tests performed without oil show that buoyancy to weight ratio is a significant parameter in boom performance in waves. In testing booms with B/W ratios of 5 to 30:1, it was found that booms with higher B/W ratios perform better, but that performance doesn't change much with decreasing B/W ratio down to 10:1. Below a ratio of 10:1, performance is seriously degraded.

Fire Resistant Containment Pressure Inflatable Boom

In a 1996 controlled test (O-8), a pressure inflatable fire resistant boom experienced first loss at 0.9 knots and gross loss at 1.2 knots in calm water. In a regular wave, first loss occured at 0.8 knots and in a longer wave at 1.07 knots. First loss in harbor chop was at 1 knot. These data tend to show that fire containment booms perform at least as well as conventional booms of the same type.

In 1998 tests of a water cooled pressure inflatable fire resistant containment boom performed somewhat later show basically the same result (O-9). First loss and gross loss tow speeds in calm water were 0.95 knots and 1.25 knots respectively. In a long wave, these speeds were 0.8 knots and 1.1 knots; in a longer wave speeds were 1.13 knots and 1.45 knots. In harbor chop speeds were 1.05 and 1.3 knots. It is interesting to note that in a long wave and even in harbor chop wave, performance reported was better than in calm water. These tests provide additional evidence that fire containment booms perform as well or even better than similar conventional booms of the same type.

In a test offshore without oil, a pressure inflatable fire boom maintained adequate freeboard and draft at tow speeds up to 1.5 knots and a speed of submergence of 2 knots.

Additional details on fire containment boom is contained in Chapter 7.

Chapter 6

EXTERIOR TENSION BOOMS

1.0 DESCRIPTION

An external tension boom has its shape and strength provided by a tow bridle. It is a fence type boom that is flexible in the horizontal plane. Narrow, rectangular foam flotation elements are attached alternately to the back and front sides of the boom while the boom shape and strength are provided by a tow bridle. Vertical stiffeners in the boom fabric help to maintain shape. Figure 6.1 shows a sketch of a typical exterior tension boom.

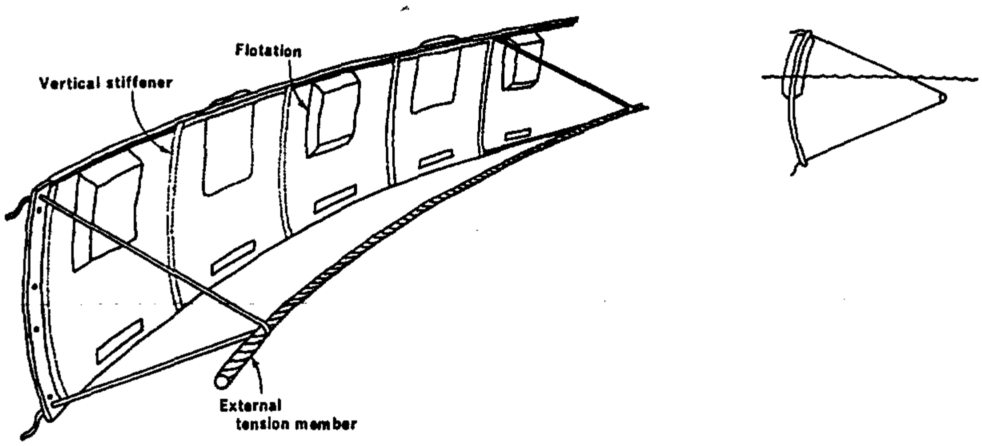


Figure 6.1 Typical External Tension Boom

1.1 SELECTION CONSIDERATIONS

Buoyancy	In the range of 2 to 5:1. The effect of this buoyancy is enhanced by the stability provided by the external tension lines.
Roll Response	The external tension line virtually eliminates the problem of roll because it maintains the boom in a vertically upright position.
Heave Response	The external tension helps the boom to follow the water surface, therefore heave response is also good.
Mode of Application	Must be either towed or used in a current. Boom will not maintain its shape at rest. Often used with a jib over the side of a vessel-of-opportunity.
Other	The boom is particularly good for towing in areas of high winds and seas; however, it is fairly difficult to rig, deploy, and clean. It has the advantage of a relatively low storage volume.

2.0 TEST RESULTS

2.1 ENVIRONMENT CANADA TESTS 1980 (E-1)

Six oil spill containment booms were tested offshore of St. John's, Newfoundland in March and April of 1980.

Testing was conducted about 3 nautical miles south of St. John's Harbor in Blackhead Bight. This area, sheltered by cliffs to the west and a peninsula to the south, is at the eastern extremity of the North American continent, with water temperatures, ice conditions, and sea states typical of the Grand Banks oil exploration areas. Currents in the area are 1/4 knot or less and tides average 5 feet (1.5 m). Of the booms tested, one was an external tension boom. The Zooom boom, which was also tested, was later shipped to New Jersey and tested at OHMSETT. The results of these tests are reported separately in Chapter 4 (O-4).

The principal criteria used to evaluate the booms were oil retention characteristics, durability, and towing loads. Although it was intended to deposit a barrel of oil ahead of the towed booms, this was not done in every case because of adverse weather conditions. Data describing towing loads were reported in some detail and are analyzed in Appendix C.

Boom Description

The Troilboom external tension boom, manufactured by Trelleborg A/B, Sweden, was not described in detail in the test report, and since this model is not presently manufactured, data are not available from other sources. The boom had a flat vertical fence design with flotation provided by solid foam panels spaced about 1.6 feet (0.5 m) intervals along its 240 foot (75 m) length. Tension was taken by a separate external line located at the water surface. There was a pocket at the apex for use with a skimmer. Boom fabric was polyamide coated with PVC/nitrile rubber and the external tension lines were polypropylene. Vertical fiberglass reinforced polyester strips 2 inches (5 cm) wide supported the boom fabric on either side of each flotation unit. Boom height was 4 feet (1.2 m) except in the pocket area where it was 4.9 feet (1.5 meters). Based on information known about other booms of this type, it probably had a very high tensile strength and a buoyancy to weight ratio of about 4:1.

Test Configuration

The boom was towed in a catenary configuration by two vessels. The distance across the boom opening was measured with an optical range finder. All tows were made into the wind.

Test Oils

Bunker C - viscosity 9.9 cSt, density 0.97
BCF Venezuelan Crude Oil - 30 cSt, density 0.91
(Author's Note: these values for viscosity may not have been reported correctly.)

Data Precision and Accuracy

Forces on booms (not reported here) were to the nearest 10 Newtons. Boom performance is described subjectively.

Test Procedure

As a measure of containment performance, a barrel of oil was pumped into the catenary from the control vessel. The oil/boom interaction was observed from a small open boat at the apex of the boom and the time for all the oil to escape was measured. The principal criteria to evaluate the booms were oil retention characteristics, durability, and towing loads.

Test Results

A barrel of oil was spilled in front of the catenary and the boom was maneuvered to entrap it. The oil was deflected into the pocket of the boom where it was stabilized. Thirty-five minutes after the oil was added, an estimated half barrel still remained in the boom. (This was the best performance of the booms that were tested in oil.) Some entrainment of oil under the boom was noted but the skimmer head at the apex did not adversely affect oil retention. The towing speed was 1 knot so it was assumed that some headwave shear was taking place. It was noted that there were vortices in the pocket of the boom. It appeared that more oil was leaking from the pocket of the boom than from other areas, and it was therefore suggested that it would be better to eliminate the pocket and instead position the skimmer in the apex of the catenary.

Overall Assessment of Performance

The following paragraph is paraphrased from the original test report.

The Troilboom is a well-constructed, well-designed boom. The freeboard-to-draft ratio seems appropriate and the boom is large enough to be used offshore. The buoyancy-to-ballast ratio has been well thought out, resulting in a boom that is light and easy to handle for its size. The boom stows compactly for a non-inflatable type, although care is required if entanglement of the tension lines and bridles is to be avoided during deployment. The boom is smooth surfaced, which makes cleaning easier. Boom connectors are adequate, however disassembling a section of boom could be awkward if the ropes and binder loops are saturated with oil and icy.

2.2 External Tension Booms Performance Summary

Fire Containment External Tension Booms

In controlled tests performed in oil, an external tension fire boom had first loss and gross loss tow speeds of 0.85 and 1.05 knots in calm water. In a regular wave, these speeds decreased to 0.4 knots and 0.6 knots and in a longer regular wave they were 0.85 and 1.05 knots. First loss in harbor chop was 0.88 knots and gross loss was 1.07 knots. Thus in harbor chop, generally the most severe environment for most booms, performance was nearly the same as in calm water.

The tow speeds for first loss and gross loss were all lower than for other booms tested at the same time, but the boom had other qualities that were superior. For example, the critical tow speed of failure without oil present was greater than 6 knots, which was the best of any tested. Further, in tests of oil loss rate, the rate at first loss +0.1 knots and first loss +0.3 knots was much lower than all other booms tested except the Dome boom.

In a later controlled test in oil, performance of the exterior tension boom was somewhat better than before. In calm water first loss was 0.9 knots and gross loss was 1.25 knots. In a long wave, first loss was 0.63 knots and gross loss 0.95 knots, while in a longer wave first loss was 1 knot and gross loss was 1.3 knots. In harbor chop these values were 0.7 knots and 1.1 knots respectively. These results show a boom that performed nearly as well as all others, had a low oil loss rate, and a high critical velocity in the test without oil.

Additional details on fire containment boom is contained in Chapter 7.

Chapter 7

FIRE RESISTANT CONTAINMENT BOOMS

1.0 DESCRIPTION

Fire resistant containment booms are special devices designed to withstand the heat and stress of *in situ* burning. Some early models were intended to be fire-proof booms. These heavy, stainless steel fence booms were intended to withstand the heat of the fire and be used many times. More recently booms have been developed that are lighter, easier to deploy, and less expensive. These are predominately <u>fire resistant</u> booms that are designed to survive a single burn or perhaps a series of burns at the same site without being taken out of the water.

Fire resistant booms include several of the standard boom types that have been adapted for *in situ* burning. A curtain boom with internal foam has been developed that has a high temperature flotation core covered with high temperature ceramic textile material and enclosed in abrasion resistant stainless steel knitted mesh in a PVC cover. A self-inflatable boom is enclosed with Thermotex high temperature fabric. A pressure inflatable curtain boom uses a urethane coated polyester skirt material designed to withstand high temperatures. Fence booms are available that use a temperature resistant refractory covering and one model is made of stainless steel. Recently a curtain boom has been developed that has a casing in which water is circulated for cooling.

The oil containment characteristics of these booms are likely to resemble other devices in their type class; however, they are grouped together here because they all have the special purpose of being fire resistant. Oil containment performance is described here, but the user can also check typical oil containment capability in the chapters describing each boom type. Figure 7.1 shows a typical curtain boom with internal foam flotation designed for *in situ* burning.

1. **High Temperature Flotation Core**
2. **Aluminum Seam**
3. **High Temperature Ceramic Textile**
4. **Abrasion Resistant Stainless Steel Knitted Mesh**
5. **PVC Cover**
6. **Bottom Tension Member/Ballast**

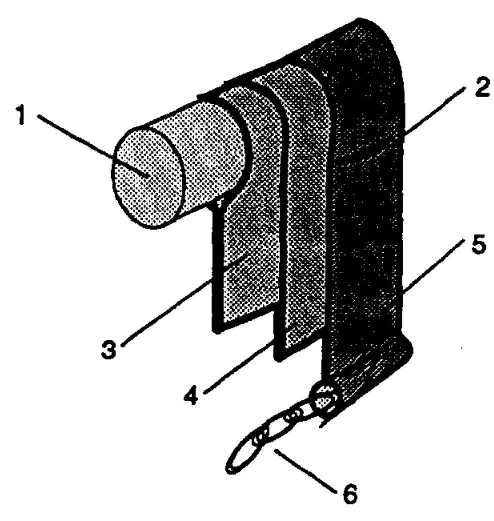


Figure 7.1 Typical Fire Containment Boom
Curtain Boom with Internal Foam Flotation

1.1 SELECTION CONSIDERATIONS

Buoyancy	Generally in the range of 2.5 to 10:1 with the higher buoyancy ratios in the self-inflatable and pressure inflatable booms.
Roll Response	Depends of boom type, but generally good. Curtain types have good roll response with their flexibility and bottom tension member; fence booms use ballast or flotation moved away from the centerline for good roll response.
Heave Response	Depends on boom type. Curtain booms with good flexibility and high buoyancy to weight ratios are best. Stiff fence booms with lower buoyancy will not perform as well.
Mode of Application	Most devices are designed for a single burn incident. Some heavier fence booms can be stored and used again.
Other	These devices may be used with conventional booms that direct oil into a small pocket for burning.

2.0 TEST RESULTS

2.1 OHMSETT TESTS 1983 (O-5)

The Gem Engineering lightweight fireproof boom was tested at OHMSETT in 1983. Tests were performed in three phases. First, the boom was towed in calm water and waves to determine its ability to survive in heavy seas. Next, the boom was tested in oil without burning to determine its containment capability. Finally, the boom was towed with burning oil to evaluate its designed function of containing oil during *in situ* burning. These tests were performed for Environment Canada at the OHMSETT test facility.

Boom Description

GemEng Lightweight Fireproof Boom

Freeboard	11 inches (280 mm)
Draft	16.5 inches (440 mm)
Boom Height	17.5 inches (720 mm)
End Connectors	ball and socket joint
Skirt Material	Foamglas core surrounded by a 1/8 inch (4 mm) fiber reinforced refractory cement skin
Flotation	Hexagonal with a maximum diameter of 19 inches (484 mm) and a minimum diameter of 16.5 inches (420 mm) in 4 foot (1.2 m) lengths. The center of the flotation sections is hollow and lined with a 3 inch (75 mm) galvanized steel tube. A 3/8 inch (10 mm) steel cable runs through a train of six sections that provides a tension member along with a tension line enclosed in the bottom of the skirt.
Weight	Not reported
Reserve Buoyancy	Not reported
Reserve B/W Ratio	Not reported
Ballast	Not reported; appears to not have separate ballast
Tension Member	a tow line attached to a connector bar at the base of the flotation

Figure 7.2 shows a sketch of the GemEng fireproof boom. This boom was not produced commercially and is not in use today.

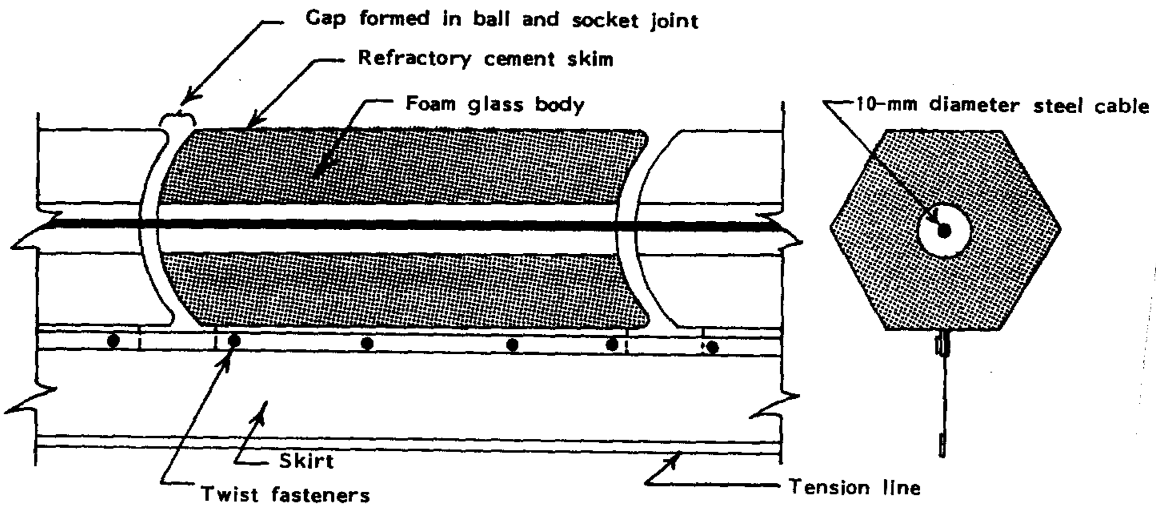


Figure 7.2 GemEng Fireproof Boom

Test Configuration

Three boom sections were joined together and a 15 foot (4.6 m) leader was connected to each end. Tow cables were connected to tow points 34 feet (10.4 m) apart on the main bridge. The main cable was connected at the waterline, and the skirt was connected 15.7 inches (400 mm) below the water line. A tow-back cable was connected to the boom between the eighth and ninth boom sections.

Test Oils

Containment testing was performed with Circo-X heavy oil. The properties of this oil were not reported but in other studies oil with this designation had a viscosity of about 3,000 cSt. Fire testing was performed with Murban crude oil. Properties of this oil were not reported.

Test Procedure

Three type tests were performed; survival testing, containment testing, and fire testing. Procedures were slightly different for each test.
Survival Testing - The boom was towed at speeds up to 3.5 knots to determine the strength of the materials and tendencies to plane or submerge. The boom was exposed to a 2 foot (0.63 m) harbor chop wave for 45 minutes to determine if the boom would survive in heavy seas.
Containment Testing - The boom was pre-loaded with 50 gallons (1.2 BBL) of Circo-X heavy oil and brought to the test speed. The time required to cover 100 feet (30.5 m) was measured after the boom achieved the desired speed. When the boom had traveled 80% of the available tank length, tow speed was reduced to 0.5 knots. The difference between the time of reaching test speed and slowing to 0.5 knots was recorded as the test time.
Fire Testing - The boom was pre-loaded with 20 gallons (0.5 BBL) of Murban crude oil. The boom was brought to 0.25 knots to begin the test. A 6 inch square (150 mm) ethafoam float was wrapped with polypropylene sorbent and secured to a wire to form a wick. The wick was soaked in oil and sprayed with an ether-based starting fluid, then was lit and placed on the water surface. The pre-load of oil was then towed into the wick to ignite the oil. The test began after the oil in the boom was burning. Oil depleted by burning was replaced from the main bridge.

Test Results

Survival Testing

As the boom was towed at 3.5 knots, water rose against the face of the boom until it began to escape over the top. At that point, the boom popped up and rode at its normal level in the water.

The boom rode well in the waves during a 45 minute test in 2 foot (0.63 m) harbor chop wave. Some flotation elements slid along the central cable colliding with each other.

During the testing the skirt tore and several support lengths became separated from the flotation.

Containment Testing

Loss rate for this boom was predicted using earlier tests of a similar boom. First loss tow speed and loss rates compared favorably with the earlier tests, and in fact, the GemEng boom had a slightly higher first loss tow speed and about an equal loss rate. Table 7.1 shows performance in oil.

Table 7.1 Test Results - First Loss and Gross Loss Tow Speeds in Oil

BOOM	GEMENG FIREPROOF BOOM FREEBOARD 11 in. DRAFT 16.5 in. B/W Unknown			
	TYPE FAILURE	1ST LOSS TOW SPEED (kts)	GROSS LOSS TOW SPEED (kts)	LOSS RATE AT GROSS LOSS gpm (BBL/hr)
CATENARY TESTS IN OIL	CIRCO-X HEAVY			
CALM WATER	Entrainment	1.1	1.16	36.1 (51.6)
WAVES				
0.6 x 4.6' (0.2 X 1.4 m)	Splashover	0.7	0.78	30 (42.8)
0.6 X 30' (0.2 X 9.4 m)	Entrainment	1.1	1.15	35.2 (50.3)
1.3 X 23' (0.4 X 7.0 m)	Entrainment	0.9	1.06	66.5 (95.0)

Fire Testing

The boom withstood exposure to fire in three tests. The surface of the boom spalled and cracked but was serviceable after the exposure. The boom contained the burning oil completely during the lower speed runs. During the high speed fire test (1.25 knots), the oil was entrained and lost behind the boom as well as between the connectors. The escaping oil continued to burn close to the rear boom face within about 1 meter (3 feet). As the resurfacing entrained oil ignited as it encountered this oil. Results of the fire testing are shown in Table 7.2. Note that burn times are dependent on tow speed because of the fixed length of the test basin.

Table 7.2 Test Results - Burn Tests

BOOM	GEMENG FIREPROOF BOOM FREEBOARD 11 in. DRAFT 16.5 in. B/W Unknown			
	TYPE FAILURE	TOW SPEED (kts)	BURN DURATION (minutes:sec.)	WIND SPEED (kts)
CATENARY	MURBAN CRUDE			
CALM WATER	None	0.5	4:21	2-3
	None	0.25	7:25	1-2
	Entrainment	1.25	1:44	1-2

Overall Assessment of Performance

Seaworthiness testing in waves shows that the boom can be expected to withstand moderate sea conditions without complete deterioration. The damage incurred suggests, however, that immediate reuse of the boom after exposure to waves should not be anticipated. After the tests, the boom was returned to the manufacturer who reported that the damaged sections were readily repaired.

The GemEng boom contains oil as well as other non-fireproof booms tested. The first-loss tow speed of 1.1 knots is somewhat better than the average.

Burn tests show that the boom performs well in calm water at low tow speeds. The fact that oil lost under that boom continues to burn after surfacing is encouraging, however operating at these higher speeds would probably not be considered safe at a spill site.

The test report concludes with a series of recommendations on how to improve the durability and performance of the boom, but since the boom has not been produced, these recommendations are not relevant.

2.2 OHMSETT TESTS 1996 (O-8)

Six fire resistant oil containment booms were tested at OHMSETT between July and October 1996. Tests were sponsored by the U.S. Coast Guard Research and Development Center and Minerals Management Service. Booms tested included

- o American Fire Boom, American Marine, Inc.
- o Dome Boom, Dome Petroleum
- o PyroBoom, Applied Fabric Technologies
- o Paddle Wheel Boom, Oil Stop Inc.
- o Spill-Tain™ Fireproof Oil Spill Containment Boom - Offshore Version
- o Inflatable Auto Boom™ Fire Boom, Oil Stop Inc.

Five of the six booms were tested for their oil holding capability by determining oil pre-load, first and gross loss tow speed, oil loss rate, and critical tow speed, which measures mechanical stability. No tests in fire were performed in this series. The Paddle Wheel Boom was found to need further development and did not go through the full series of tests.

Boom Description

Table 7.3 describes the physical characteristics of the tested booms. Properties of fire control boom are described below and sketches are shown in Figure 7.3, page 7-7.

American Fire Boom - Each flotation segment has a ceramic high temperature resistant flotation core. This core is surrounded by two layers of stainless steel knitted mesh with a layer of ceramic, high temper-resistant fabric (Nextel) in between. The segments are encased in a tubular PVC outer cover that is extended to form the chain-ballasted skirt. A stainless steel tension cable runs the length of the boom section. Riveted vertical and longitudinal stainless steel seaming bars retain the ceramic component to the skirt during burns. Steel cable lift handles are located along the length of the boom and one stainless steel end connector is bolted to each boom section end. Figure 7.3 (a) shows a sketch of this boom.

Dome Boom - The Dome boom was constructed of high-chromium stainless steel with refractory blanket material for the skirt (S-2). Pentagonal steel flotation units were vented and supported a steel sail for freeboard and a flexible skirt for draft. Each 1.5 m flotation unit was joined by a flexible panel enclosed in steel mesh to provide good heave response. Stainless steel cables were used as tension members to take the load off the flexible panels. Figure 7.3 (b) shows the Dome boom.

Applied Fabric Technologies PyroBoom® - This solid flotation barrier combines wire reinforced refractory fabric above the surface barrier with conventional GlobeBoom® fabric in the skirt. Flotation is provided by glass foam filled steel hemispheres that are mechanically attached to the barrier. Galvanized shackles are located above each flotation hemisphere for lifting. Figure 7.3 © shows the PyroBoom®.

Spill-Tain™ Fireproof Oil Spill Containment Boom - This external tension boom is made of thin, type 316L stainless steel sheet metal, closed cell foam glass flotation, and stainless steel cable. Deployed segments are composed of alternating stainless steel parallelograms and rectangles, separated by trapezoids. Boom panels are supported perpendicular to the water by alternating outrigger floats. Adjacent boom panels are attached with piano hinges. A tension cable is attached to the bottom outer edge of the outrigger floats. Figure 7.3 (d) shows the Spill-Tain™ boom.

Oil Stop's Inflatable Auto Boom™ Fire Boom - The boom has single-point inflation access. Once inflated, the boom automatically sectionalizes into separate air filled compartments that maintains buoyancy if adjacent chambers are damaged. Three temperature resistant layers are located below the polyurethane exterior; a stainless steel screen, a ceramic insulation blanket, and a high temperature inflatable membrane. Figure 7.3 (e) shows the Inflatable Auto Boom™ Fire Boom.

Table 7.3 Boom Description OHMSETT Tests (O-8)

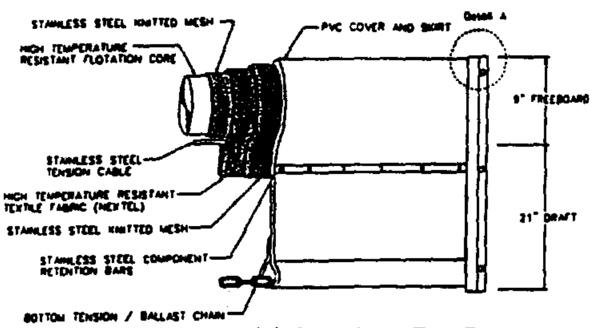
BOOM	AMERICAN MARINE	DOME	APPLIED FABRICS PYRO BOOM®	SPILL-TAIN™	OIL STOP INFLATABLE AUTO BOOM™
BOOM TYPE	Curtain, internal foam flotation	Fence	Fence	External Tension	Pressure-inflatable
FREEBOARD in (mm)	9 (229)	26 (660)	14 (356)*	21 (533)	18 (457)
DRAFT in (mm)	21 (533)	44 (1,118)	16 (406)*	26 (660)	25 (635)
HEIGHT in (mm)	30 (762)	70 (1,778)	30 (762)	47 (1,193)	43 (1,092)
END CONNECTORS	Fireboom U; stainless steel	stainless steel flexible panels	ASTM	Bolt, ASTM adapter	Customer's request
SKIRT MATERIAL	Vinyl-coated polyester	stainless steel	Refractory	Stainless steel	Urethane-coated polyester
FIRE RESISTANT MATERIAL	Ceramic flotation; refractory fabric; stainless steel mesh	Stainless steel	Refractory fabric; glass foam filled floats	Stainless steel	Refractory fabric/stainless steel
FLOTATION	Internal foam (ceramic)	Hollow steel	Glass foam filled steel hemispheres	Rectangular outrigger floats	Segmented inflatable cylinders
WEIGHT lb/ft (kg/m)	8.4 (12.6)	30.5 (45.8)	8.0 (12)	19.4 (29.1)	9 (13.5)
RESERVE BUOYANCY lb/ft (kg/m)	31.9 (48.0)	106.8 (160.2)	64 (96)	53.4 (80.1)	85.5 (128.3)
RESERVE B/W RATIO	3.8:1	3.5:1	8:1**	2.75:1	9.5:1
BALLAST	3/8" (10 mm) galvanized chain	---	½" (13 mm) chain	---	Chain
TENSION MEMBERS	Chain, 1/4" (6 mm) stainless steel cable	Steel boom	Chain, fabric	Cable, steel skirt	½" (13 mm) galvanized chain

Notes: *The manufacturer later determined that the freeboard was actually 11 inches and the draft 19 inches for the same boom height of 30 inches.

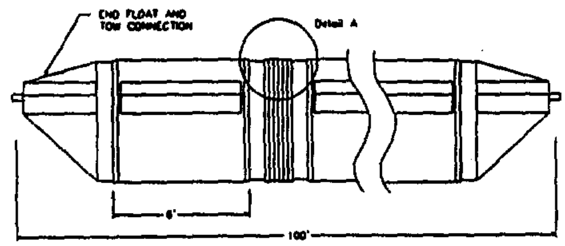
**In a later test, the B/W ratio was determined to be 3.2:1. (See Table 7.6 page 7-12.)

Test Configuration

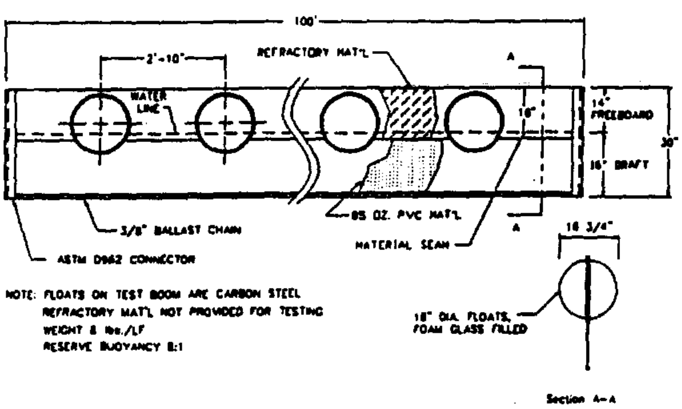
In each case, the boom was rigged with a 2:1 boom length-to-gap ratio. In-line load cells were attached at each tow bridle between the bridle and the main bridge tow points. Pre-load oil was pumped directly into the boom apex using a hose suspended from the messenger cable. Recovered fluids were pumped to the auxiliary bridge recovery tanks where volume measurements were recorded and fluid samples taken.



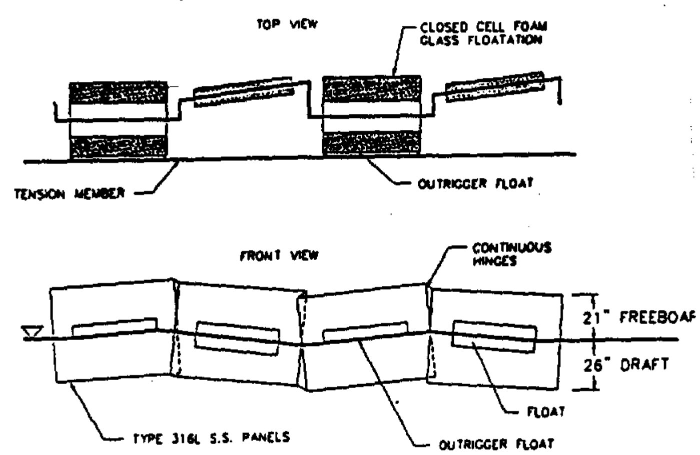
(a) American Fire Boom



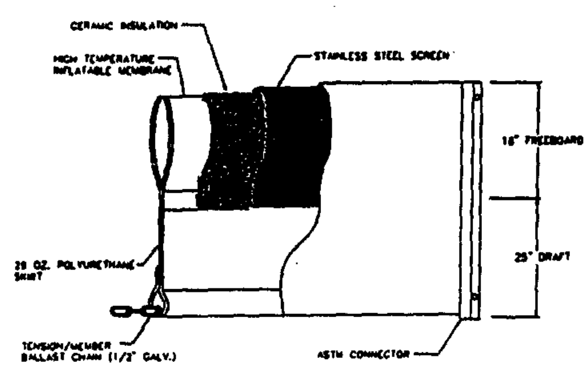
(b) Dome Boom



(c) Applied Fabric Technologies PyroBoom®



(d) Spill-Tain™ Boom



(e) Oil Stop's Inflatable Auto Boom™ Fire Boom

Figure 7.3 Fire Boom Sketches

A single underwater camera was suspended from the auxiliary bridge and focused on the apex of the boom. This camera recorded oil loss from the boom. A second underwater camera was mounted on the main bridge and focused on the apex of the boom from the boom mouth.

Test Oils

American Marine Fire Boom - viscosity 1,566, 3,350, and 5,360 cSt; density 0.942 to 0.956
Dome Boom - viscosity 2,766 to 3,015 cSt; density 0.939 to 0.975
Applied Fabrics PyroBoom® - viscosity 2,644 to 3,465; density 0.937 to 0.949
Spill-Tain™ - viscosity 2,182 to 2,310; density 0.935
Oil Stop Inflatable Auto Boom™ - viscosity 1,715 to 2,400 cSt; 1,132 to 2,330 cSt; density 0.928 to 0.934

Test Procedure

Pre-load Tests - A series of first loss tow speed tests using increasing amounts of oil to determine the volume of oil a boom holds until the addition of more oil has a minimal affect on first loss tow speed. Beginning with a nominal pre-load of oil, the test is repeated with increasing pre-load volumes until the addition of oil has minimal or no effect on the first loss tow speed. The desired pre-load of oil is obtained from a plot of first loss tow speed vs. volume of oil pre-load.
Oil Loss Tests - The tow speed at which the boom first begins to lose oil is called the first loss tow speed. At a higher tow speed, oil is lost at a significantly greater rate, and is called the gross loss tow speed. These speeds are determined using an underwater video camera image.
Oil Loss Rate Tests - Boom loss rates are obtained by towing the boom with its pre-load of oil at the first loss tow speed plus 0.1 knots and 0.3 knots. The tow speed is constant for the length of the test basin while oil is distributed at a rate of 26 gpm (37 BBL/hr) for the lower speed and 105 gpm (150 BBL/hr) for the higher speed. The lost oil is collected and skimmed at the end of each test run. Free water is drained from the collection tanks and the amount of oil is measured.
Critical Tow Speed - This is the maximum speed at which the system can be towed before losing freeboard or draft. Towing speed typically begins at 1 knot and is increased in 0.25 knot increments until failure is observed. The failure occurs when the boom submerges or comes out of the water. This test is run in calm water without oil.
Tow Force - Two load cells were used to continuously measure the tension forces in each of the boom tow lines. An analysis of tow force is contained in Appendix C.
Wave Conditions - Tests were performed in calm water and in three wave conditions shown on Table 7.4.

Table 7.4 Wave Conditions

WAVE	$H^{1/3}$ ft (m)	LENGTH ft (m)	PERIOD (seconds)	LENGTH/HEIGHT RATIO
#1	1 (0.3)	14 (4.3)	1.7	14:1
#2	1.375 (0.4)	42 (12.8)	2.9	30:1
#3	1.25 (0.38)	---	2.0	

$H^{1/3}$ - Significant wave height; the average of the highest 1/3 of measured waves.

Waves #1 and #2 are regular, sinusoidal waves. Wave #3 is a harbor chop wave in which reflective waves are allowed to develop. No wave length is calculated.

Test Results

Table 7.5 summarizes test results.

Table 7.5 Fire Boom Test Results (O-8)

BOOM	FIRST & GROSS LOSS TOW SPEED (kts)				LOSS RATE TEST (gpm @ kts)		CRITICAL TOW SPEED (kts)/ TYPE FAILURE	OIL PRE-LOAD/ VISCOSITY (gallons/cSt)
	CALM	WAVE #1	WAVE #2	WAVE #3	FIRST LOSS +0.1 kts	FIRST LOSS +0.3 kts		
PYRO BOOM FB 14" D 16" B/W 8:1 FIRST LOSS GROSS LOSS	1.00 1.20	0.72 0.93	1.07 1.30	0.95 1.10	65 @ 1.10	141 @ 1.30	2.75/ SUBMERGED	600/3,000
SPILL-TAIN FB 21" D 26" B/W 2.8:1 FIRST LOSS GROSS LOSS	0.85 1.05	0.40 0.60	0.85 1.05	0.88 1.07	7 @ 0.95	47 @ 1.15	>6.0/ PLANING	350/2,300
AM. MARINE FB 9" D 21" B/W 3.8:1 FIRST LOSS GROSS LOSS	0.85 1.10	0.72 0.90	0.87 1.15	0.90 1.15	17 @ 0.95	80 @ 1.15	2.25/ SUBMERGED	360/1,600; 3,400; 5,400
DOME BOOM FB 26" D 44" B/W 3.5:1 FIRST LOSS GROSS LOSS	0.95 1.32	0.75 1.05	0.95 1.20	1.00 1.25	8.5 @ 1.05	40 @ 1.25	2/0/ NO FAILURE	500/2,900
OIL STOP FB 18" D 25" B/W 9.5:1 FIRST LOSS GROSS LOSS	0.90 1.22	0.80 --	1.07 --	1.00 --	19.5 @ 1.00	75.5 @ 1.20	3.5/ SUBMERGED	500/1,730

Actual Measured Wave Conditions:
Wave #1: regular sinusoidal wave: H = 0.8', L = 16.2', T = 1.8 sec
Wave #2: regular sinusoidal wave: H = 1.1', L = 42.1', T = 3.1 sec
Wave #3: harbor chop: H = 0.7', L and T not calculated
FB = Freeboard, D = Draft, B/W = Buoyancy/weight ratio

Overall Assessment of Performance

All booms tested had a high critical tow speed showing them to be stable and not likely to suffer losses because of instability or physical failure. In calm water, first loss and gross loss tow speeds were typical of conventional booms. First loss speeds were 0.85 to 1.0 knots and gross loss speeds were 1 to 1.3 knots. This performance was degraded in Wave #1, the shorter period regular wave. (The performance of the Spill-Tain boom was degraded substantially.) In Wave #2, the longer period regular wave, performance was basically the same as in calm water. Performance in Wave #3, harbor chop, was also about the same as in calm water and the long period regular wave, but better than performance in the short period regular wave, which is a result that is not expected.

In a 1997 AMOP paper, Bitting and Coyne (A-4) note that the performance of these fire booms is comparable to the performance of conventional oil containment booms in similar tests. Bitting further notes that there was a slight increase in first loss tow speed with a higher buoyancy/weight ratio. This was true for calm water and Waves #2 and #3. Considering the higher B/W ratio booms together (Oil Stop and PyroBoom), the average ratio was 8.75:1 and the average first loss tow speed was 0.95 knots. Combining results for the lower B/W ratio booms (American Marine, Dome, and Spill-Tain), the average B/W ratio was 3.35:1 and the average first loss tow speed was 0.88 knots. Comparing the results of these two groups together suggests that a large increase in B/W ratio (161%) only resulted in a 7.9% increase in first loss tow speed. The author notes here that since tow speed accuracy was only within ±0.1 knot, these apparent differences in performance may not be real.

Bitting goes on to say that in considering these results, it is difficult to determine how much of the difference in performance is attributed to a difference in B/W ratio and how much might be attributed to other factors such as boom design and materials. Some booms were flexible and lightweight while others were rigid and heavy.

Bitting's comments only concern first loss tow speed relative to boom performance parameters. Looking for other relationships that may cause a difference in performance, consider oil loss rate in terms of buoyancy to weight ratio and boom draft. Oil loss rate does not seem to be positively related to buoyancy to weight ratio based on this test data because the Pyro Boom and Oil Stop boom, with the highest buoyancy to weight ratios, also have the highest loss rates. On the other hand, test data tend to indicate that oil loss rate is related to boom draft, with booms having the smallest draft experiencing the greater losses. Figure 7.4 shows a plot of oil loss rate versus boom draft. These curves show that loss rates for both first loss speed plus 0.1 knots and first loss plus 0.3 knots increase rapidly when the boom draft is less than about 25 inches. Of course this judgement is based on only a few data points, but it would be worth while to perform additional tests to determine if this relationship persists a broad range of conventional booms.

Since the booms tested in this program were so different in physical and operational characteristics, it is difficult to determine the exact cause of varying levels of performance. In order to determine exactly what boom feature causes a change in performance it would be necessary to perform tests changing one feature at a time. For example, test a single boom then increase the B/W ratio of that boom and test it again. Also, test a single boom with a varying draft. Tests of this type would produce more convincing data relating boom performance to physical characteristics. Tests of this type have been performed in a small test basin using scaling factors to relate results to real wave and equipment conditions. Comments on these tests are offered in another section.

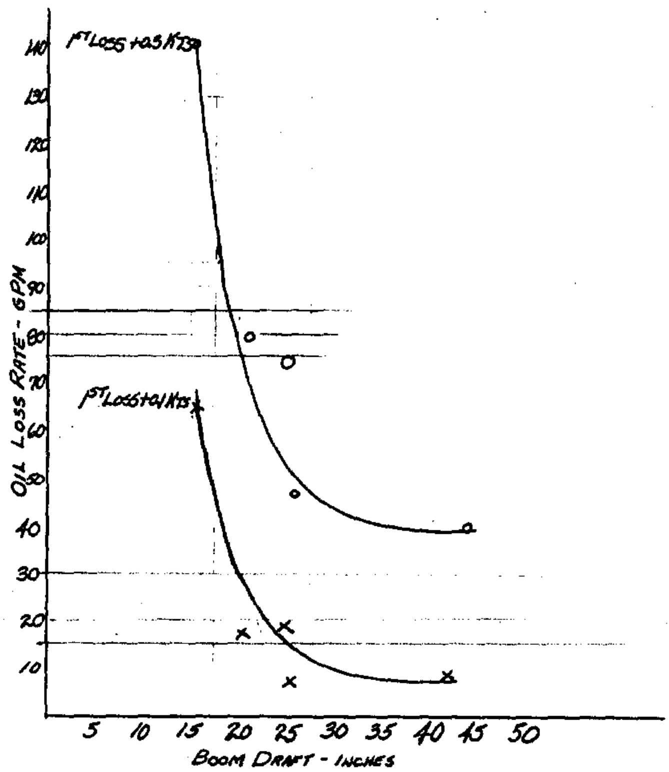


Figure 7.4 Oil Loss Rate vs. Boom Draft

2.3 OHMSETT TESTS 1998 (O-9)

Seven commercial fire booms were burn tested at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama from August to October 1998. Four of these seven booms passed the test sequence described in American Society for Testing and Materials (ASTM) F20 Fireboom test protocol and were shipped to the OHMSETT facility for further testing.

The four booms selected were tested at OHMSETT between September and November 1998. Tests were sponsored by the U.S. Department of Transportation and the U.S. Coast Guard R&D Center. Booms tested include:

o Elastec/American Marine ,Hydrofire
o Spill-Tain
o Applied Fabrics Pyroboom®
o Applied Fabric Technologies/SL Ross Pocket Boom

The Spill-Tain boom and Applied Fabrics Pyroboom® were both tested at OHMSETT in 1996 (O-8). The Applied Fabrics Technologies/SL Ross Pocket Boom is a smaller version of the Dome boom previously tested. It was re-engineered by SL Ross and manufactured by Applied Fabrics Technologies. The Elastec/American Marine Hydrofire boom is a newly developed prototype that circulated water as a cooling agent.

The purpose of the test was to measure the oil collection and containment performance and sea keeping performance of the booms in a variety of towing and wave conditions. Specific test results include:

o Individual oil pre-load required for testing
o First and gross loss tow speeds
o Oil loss rate
o Critical tow speed at which the boom loses freeboard or draft
o Tow forces on booms during tests

Tests were performed in calm water and three wave conditions.

Boom Description

Table 7.6 describes the physical characteristics of the tested booms. Additional information on the fire containment properties of these booms is shown below. The description of the Applied Fabric Technologies PyroBoom® and the Spill-Tain™ booms is contained in Section 2.2 pages 7-5 and 7-6 and therefore is not repeated here. Table 7.6 describes tested booms.

Elastec/American Marine Hydrofire Boom - This water cooled boom has 12 - 4 foot long inflatable sections. Each section is inflated through a munson valve to a pressure of 1 to 1 ½ psi. The main tension member is a 3/8 inch (10 mm) galvanized chain and a 1/4 inch (6 mm) stainless steel cable located along the top of the flotation bladders. The water cooled jacket is secured to the host (towing) boom with bolts spaced about 2 feet (0.6 m) apart. Water is pumped through the boom jacket to provide continual cooling to the boom's surface. The boom that arrived from the burn test did not show damage due to flame exposure. The white refractory material was slightly darkened, but did not show signs of charring, melting, or shrinkage because of excessive heat. Figure 7.4 (a) shows a sketch of the Hydrofire Boom.

A description of the Spill-Tain™ and the PyroBoom® is contained in Section 2.2, pages 7-5 and 7-6, and not repeated here.

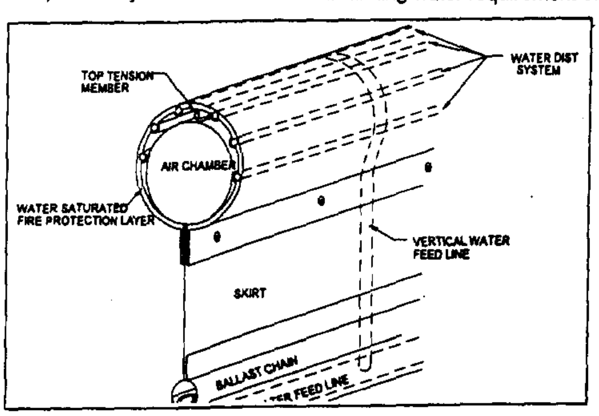
Applied Fabrics Technologies/SL Ross Pocket Boom - This is a re-engineered design of the existing stainless steel (Dome) boom. The overall redesign philosophy was to downsize the boom, reduce its weight, increase its buoyancy, and improve its handling while maintaining its strength and durability. The boom section tested was 8.1 feet (2.5 m) long with a weight of 218 pounds (100 kg). The thickness of the metal used to construct the flotation chamber was reduced while the grades of stainless steel used for above-water components remained relatively unchanged. The fundamental design of the pleated connector was retained.

The boom arrived from the burn test with relatively little damage. Several boom sections appeared to show some inward crumpling at the flotation units, while some expansion was noted. Some boom sections showed slight signs of damage from the burn, but no other damage was observed. Figure 7.4 (b) shows a sketch of the Fireproof Pocketboom.

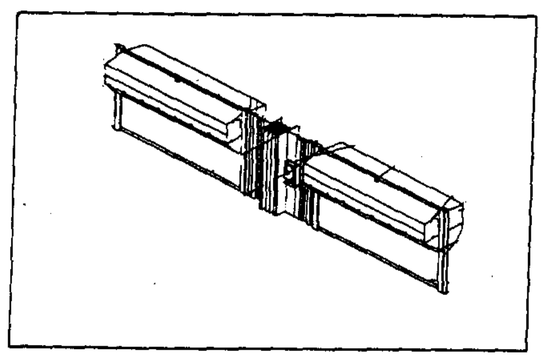
Table 7.6 Boom Description OHMSETT Tests (O-9)

BOOM	ELASTEC/AM MARINE HYDROFIRE	SPILL-TAIN™	APPLIED FABRICS PYRO BOOM®	APPLIED FABRIC/SL ROSS POCKET BOOM
BOOM TYPE	Curtain, pressure-inflatable	External Tension	Fence	Fence
FREEBOARD in (mm)	10 (254)	21 (533)	11 (279)	13.7 (348)
DRAFT in (mm)	21 (533)	26 (660)	19 (483)	25.3 (643)
HEIGHT in (mm)	31 (787)	47 (1,193)	30 (762)	39 (991)
END CONNECTORS	Universal	Bolt, ASTM adapter	ASTM	Navy slide
SKIRT MATERIAL	Not reported	Stainless steel	Refractory	Stainless Steel
FIRE RESISTANT MATERIAL	Not reported	Stainless steel	Refractory fabric; glass foam filled floats	Stainless Steel
FLOTATION	Pressure inflatable	Rectangular outrigger floats	Glass foam filled steel hemispheres	Hollow steel
WEIGHT lb/ft (kg/m)	8.9 (13.3)	19.4 (29.1)	9 (13.5)	27 (40)
RESERVE BUOYANCY lb/ft (kg/m)	31.9 (47.8)	53.4 (80.1)	28.8 (43.2)	81 (121.5)
RESERVE B/W RATIO	3.6:1	2.75:1	3.2:1	3:1
BALLAST	3/8 inch (10 mm) chain	---	5/16" (8 mm) chain	----
TENSION MEMBERS	Ballast chain	Cable, steel skirt	Chain, fabric	Steel boom

Note: The Spil Tec Hydrofire boom has a circulating water requirement of 0.5 gpm/ft (0.38 m^3/hr/m).



(a) Elastec/American Marine Hydrofire Boom



(b) SL Ross Pocket Fireboom

Figure 7.5 Fire Resistant Booms

Test Configuration

Each boom was rigged in a catenary configuration with a gap ratio of 3:1. Each manufacturer's section of fireboom was extended by attaching a 25 foot (7.6 m) section of curtain boom at each end. This provided the additional length necessary to position the test booms at the apex of the system. Boom towing force was measured with in-line load cells positioned between the boom towing bridles and tow points. Preload oil was pumped directly into the boom apex using a hose attached to the main bridge. Recovered fluids were pumped to the bridge recovery tanks where volume measurements were recorded and fluid samples were taken. A single underwater camera was suspended from the auxiliary bridge and focused on the apex of the boom. This camera recorded oil loss from the boom. A second underwater camera was mounted on the main bridge and focused on the apex of the boom from the boom mouth.

Test Oils

Calsol 8240 - target viscosity 2,000 cSt, density 0.95. Actual viscosities are reported with test data.

Test Procedure

Pre-load tests, oil loss tests, oil loss rate tests, critical tow speed, and tow force tests are all performed as in the previous fire boom tests described on page 7-8 (O-8). Wave conditions were as shown on Table 7.4, page 7-9, and are also shown as a note on Table 7.7 Test Results.

Test Results

Table 7.7 Fire Boom Test Results (O-9)

BOOM	FIRST & GROSS LOSS TOW SPEED (kts)				LOSS RATE TEST (gpm @ kts)		CRITICAL TOW SPEED (kts)/ TYPE FAILURE	OIL PRE-LOAD/ VISCOSITY (gallons/cSt)
	CALM	WAVE #1	WAVE #2	WAVE #3	FIRST LOSS +0.1 kts	FIRST LOSS +0.3 kts		
ELASTEC HYDROFIRE FB 10" D 21" B/W 3.6:1 FIRST LOSS GROSS LOSS	0.95 1.25	0.83 1.1	1.13 1.45	1.05 1.3	7 @ 1.05	55 @ 1.25	3.75/ submersion	300/1,940
SPILL-TAIN FB 21" D 26" B/W 2.8:1 FIRST LOSS GROSS LOSS	0.9 1.25	0.63 0.95	1.0 1.3	0.7 1.1	4.5 @ 1.0	29 @ 1.2	4.6/no failure	360/2,064
PYRO BOOM FB 14" D 16" B/W 8:1 FIRST LOSS GROSS LOSS	0.95 1.3	0.7	(4)	(4)	3 @ 1.05	30 @ 1.25	2.25/ submersion & fabric separation	400/1,833
SL ROSS POCKET FIRE BOOM FB 14" D 25" B/W 3:1 FIRST LOSS GROSS LOSS	0.95 1.25	0.83 0.93	1.03 1.25	0.88 1.15	4 @ 1.05	28 @ 1.25	3/planing @ 1.5 kts then accordion connectors extended & boom became stable	400/1,827

Actual Measured Wave Conditions:
Wave #1: regular sinusoidal wave: H = 0.8', L = 16.2', T = 1.8 sec
Wave #2: regular sinusoidal wave: H = 1.1', L = 42.1', T = 3.1 sec
Wave #3: harbor chop: H = 0.7', L and T not calculated
FB = Freeboard, D = Draft, B/W = Buoyancy/weight ratio
Notes: 1) First loss tow speed is the average of two runs. Averaged data were very close and in some cases identical.
2) For gross loss tow speed, there was one run for each boom in calm water and two runs in waves. Averaged data are shown here for runs in waves. In all cases data were very close or identical.
3) Loss rates at first loss +0.1 and +0.3 knots are the average of two runs. These loss rates are all for calm water.
4) At 0.4 knots there was oil loss over damaged freeboard material, therefore remaining tests in waves were not repeated.

Overall Assessment of Performance

In calm water performance of all booms was nearly the same; first loss speed was about 0.9 knots and gross loss speed was 1.25 knots. In Wave #1, the short period sinusoidal wave, first loss speed was reduced by 12 to 30% with the greatest reduction for the Spill-Tain™ boom. Similarly gross loss speed was reduced by 12 to 26%, with the greatest loss sustained by the Pocket Fire Boom. The least reduction of speed for both the first loss and gross loss, only 12 %, was for the Elastec Hydrofire Boom. In Wave #2, the long period sinusoidal wave, first loss tow speed increased by 8 to 19% while gross loss speed increased 4 to 16% and remained the same for the Pocket Fire Boom. In Wave #3, harbor chop, performance increased slightly for the Hydrofire Boom and decreased slightly for the Pocket Fire Boom and somewhat more (12 to 22%) for the Spill-Tain™ Boom. Data were not taken for the Pyro Boom.

Oil loss rate for the first loss speed +0.1 knots was close, ranging from 3 to 7 gpm with an average of 4.6 gpm. Loss rates at first loss +0.3 knots for the Spill-Tain, Pyro Boom, and Pocket Boom were very close, 28 to 30 gpm with an average of 29 gpm. Loss rate for the Elastec Hydrofire Boom was somewhat higher at 55 gpm. The previous set of tests with fire boom (O-9) notes a relationship between oil loss rate and boom draft. This relationship is not evident here. Considering loss rate for first loss +0.1 knots, loss rate for the Pyro Boom, which has the least draft, is the lowest. Loss rates for the Spill-Tain boom and the Pocket Boom, with drafts of 25 and 26 inches, are nearly the same. Loss rate for the Elastec Hydrofire, with a 21 inch draft, is the highest. The Elastec Hydrofire has the highest loss rate for first loss +0.3 knots while loss rates for the three other booms, even the Pyroboom with the least draft, are nearly the same. For these tests, oil loss rate does not seem to be related to draft.

Booms were tested for mechanical stability measured in terms of the critical tow speed. Tow speed at failure was recorded for three of the booms and the fourth did not fail at the maximum speed available in the tow tank.

The Hydro-Fire boom gradually began to lose freeboard at 1.5 knots and lost all freeboard at 3.75 knots. The boom remained stable and was not damaged during the runs. The Spill-Tain™ experienced only a minimal change in freeboard up to the maximum tow speed of the system, 4.6 knots. The boom remained stable throughout the tow and did not sustain any damage.

The Pyro Boom had damaged fabric above the waterline and the flotation began to submerge at 2.25 knots. The Pocket Boom began to plane at 1.5 knots, but at that point the accordion connectors extended and the boom became stable up to 3 knots.

2.4 OHMSETT TESTS 1998 (O-10)

Beginning in 1980 and over the next few years Dome Petroleum developed a high-strength, offshore fire containment boom for *in situ* burning at blowouts in Arctic seas. This boom was designed to survive high, steep seas, carry high tensile loads, withstand impact with ice, and operate in flames for long periods of time. This boom was successfully tested at OHMSETT in 1981 and at sea in 1983 where it was found to survive long-term exposure to waves without any loss in integrity. This version of the boom was tested again at OHMSETT in 1996. (See Section 2.2 of this chapter [O-8]). This boom has been produced and is in the inventory of the Canadian Coast Guard. Although the boom is capable of doing its job well, there are recognized disadvantages in that it is expensive, heavy, and difficult to deploy. A project was therefore undertaken to develop a smaller, less expensive, lighter, and less cumbersome version of the Dome boom for use as a highly durable burn pocket in a system using other refractory fabric fire booms. This test report describes the development of this new version of the boom and preliminary test results. This is the SL

Ross/Applied Fabrics Technologies Pocket Boom described in Section 2.3, preceding (O-9).

This report describes two sets of tests, the first in Lake Erie, just south of Buffalo, New York, in June of 1998 and a second set at OHMSETT in July of that year. Although the tests at OHMSETT just preceded the more complete tests of four fire containment booms reported in Section 3, they are reported here as being supplemental to those tests, confirming the later results and describing additional information on performance in a lower viscosity oil. These tests describe the development of the Pocket Boom, the later tests evaluate the finished product.

Boom Description

The boom developed from these tests is described on page 7-12 and on Table 7.6. Figure 7.5 (b) shows a sketch.

Test Configuration

Tests in Lake Erie are described separately. In the OHMSETT tests, the boom was rigged in a catenary configuration with a gap ratio of 3:1. The test section of Pocket Boom was extended by attaching a 25 foot (7.6 m) section of curtain boom at each end. This provided the additional length necessary to position the test booms at the apex of the system. Pre-load oil was pumped directly into the boom apex using a hose attached to the main bridge. Recovered fluids were pumped to the bridge recovery tanks where volume measurements were recorded and fluid samples were taken. A single underwater camera was suspended from the auxiliary bridge and focused on the apex of the boom. This camera recorded oil loss from the boom. A second underwater camera was mounted on the main bridge and focused on the apex of the boom from the boom mouth.

Test Oils

No oil was used in the Lake Erie tests. Two oils were used in the OHMSETT tests:

Calsol 8240 - viscosity 1,200 cSt @ 27°C (80°F)
Hydrocal 300 - viscosity 200 @ 27°C (80°F)

Test Procedure

In the OHMSETT program, pre-load tests, oil loss tests, oil loss rate tests, critical tow speed, and tow force tests were all performed as in the previous fire boom tests described on page 7-8 (O-8). Wave conditions are shown below Table 7.8, Test Results.

Test Results

Preliminary sea-keeping tests were held on 17 and 18 June 1998 in Lake Erie, just south of Buffalo, New York, in the harbor area off the mouth of the Buffalo River. The test boom, consisting of seven floats and six connectors, was towed with a bridle attached to each end float section in a straight line by one 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 1.5 knots. A second tow vessel then took up the other end of the Pocket Boom and the boom was towed in a "U" configuration. Again the boom towed well with only a slight tendency to plane at speeds of 2 knots or more. Wave conformance was excellent even in 3 foot (1 m) waves with a 3 second period.

In the next set of tests, 25 foot (8 m) sections of conventional 36 inch (1 m) Globe boom were added to each end of the Pocket Boom to simulate the way the boom would be rigged in an actual burn operation. The entire test series was then repeated, with particular attention 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 up to 5 knots. It also followed waves well in this configuration. No splash over was observed in 2 to 3 foot waves (0.6 to 1 m) and 15 knot winds.

No planing was noted in a U configuration at tow speeds up to 1.5 knots. The attachment of the Globe boom directly to the Pocket Boom end floats worked well with no wear or extreme motion. The boom was then sent to OHMSETT for tests in oil. The results of tests in oil at OHMSETT are shown below on Table 7.8.

Table 7.8 Fire Boom Test Results (O-10)

BOOM	FIRST & GROSS LOSS TOW SPEED (kts)				LOSS RATE TEST (gpm @ kts)		CRITICAL TOW SPEED (kts)/ TYPE FAILURE	OIL PRE-LOAD/ VISCOSITY (gallons/cSt)
	CALM	WAVE #1	WAVE #2	WAVE #3	FIRST LOSS +0.1 kts	FIRST LOSS +0.3 kts		
SL ROSS POCKET FIRE BOOM FB 14" D 25" B/W 3:1 FIRST LOSS GROSS LOSS	0.9 1.2	0.75 0.9	0.9 1.2	0.9 1.2	3 @ 1.0	50 @ 1.2	3/planing @ 1.5 kts then accordion connectors extended & boom became stable	400/1,200
SL ROSS POCKET FIRE BOOM FB 14" D 25" B/W 3:1 FIRST LOSS GROSS LOSS	0.9 1.2	0.7 0.85	0.85 1.2	0.9 1.15	6 @ 1.0	152 @ 1.2		400/200

Actual Measured Wave Conditions:
Wave #1: regular sinusoidal wave: H = 0.8', L = 14.1' T = 1.7 sec
Wave #2: regular sinusoidal wave: H = 0.9' L = 42.1', T = 3.1 sec
Wave #3: harbor chop: H = 0.7', L and T not calculated
FB = Freeboard, D = Draft, B/W = Buoyancy/weight ratio
Notes: (1) All data points are an average of two runs. Data were identical or very close in all cases.

Overall Assessment of Performance

Table 7.8 shows a fence boom that performs as well as any other of its type and perhaps better than some. A first loss tow speed to 0.9 knots is better than average and the gross loss speed of 1.2 knots is quite satisfactory. Performance is degraded somewhat in Wave #1, but still in the acceptable region of "normal" performance. Performance in Wave #2, the longer sinusoidal wave, and Wave #3, the harbor chop, is nearly equal to performance in calm water, which is quite acceptable. A comparison of loss rates between the medium viscosity oil (1,200 cSt) and the lower viscosity oil (200 cSt) is interesting. The loss rate for the lower viscosity oil at first loss plus 0.1 knots is double that of the higher viscosity oil and the rate for the lower viscosity oil is more than three time that of the higher viscosity oil for a tow speed of first loss plus 0.3 knots. This confirms what one would expect intuitively, that a lighter oil will be pulled under a boom more readily than a heavier oil.

A comparison of these results with the more detailed tests with four booms is also instructive. Comparing the test results for the Pocket Boom between Tables 7.7 and 7.8 shows first that the tests are repeatable because the results in similar conditions are very close to being the same. (The wave patterns for these two sets of tests were nearly identical.) Tow speeds for the various results are no more than 0.1 knots apart, which is just within the measuring accuracy of the system. Oil loss rates for the developmental boom testing are very close for first loss +0.1 knots, but the loss rate for first loss +0.3 knots for the slightly less viscous oil (1,200 cSt) is about double that of the later boom tests.

The report concludes that the re-design of the Dome boom in the form of the Pocket Boom was successful. The final design resulted in considerable cost, weight, and size reductions over the original boom with an improvement in ease of handling. The final design produced a boom with a buoyancy to weight ratio of 3, a tensile strength in excess of 40,000 pounds of force (1,800,000 Newtons), and an overall height of

39 inches (1000 mm). Tests determined that this boom will perform effectively in its intended operating environment, calm or protected waters with waves up to 3 feet (1 m), joined to commercially available fabric booms.

The boom was also exposed to burn tests. The boom was exposed to six hours of fire with full-scale heat fluxes: three hours of diesel fires at the Mobile, Alabama Coast Guard Fire and Safety Test Detachment and three hours of enhanced propane fires at OHMSETT. The boom survived this heat exposure with only minor damage, none of which would have detracted significantly from its oil containment capabilities. It was found that exposure to burning oil does not affect the oil containment characteristics of the boom. The final design of the connector section incorporates modifications to ensure that the boom will have a service life of at least 1,000,000 wave cycles, equivalent to more than 45 days at sea in Sea State 3.

2.5 Tests of the Dome Fireproof Boom at OHMSETT 1981 (S-2)

Dome Petroleum, with the sponsorship of the Canadian Offshore Oil Spill Research Association (COOSRA), developed a fireproof boom for *in situ* burning. This boom was designed to withstand high flame temperatures, to be able to contain burning oil in a catenary configuration in sea state 4, to be compact, abrasion resistant, easy to deploy, and to have a high tensile strength. This boom was tow tested offshore, tested offshore in a continuous burn with crude oil, and later tested for stability, oil containment effectiveness, and burn efficiency at OHMSETT. This section reports on the tests performed at OHMSETT in 1981.

Boom Description

This prototype boom was basically the same as the later version described in Table 7.3 page 7-6, except that the later version had improved section connectors and a stainless steel skirt instead of one made of fire resistant mesh and PVC fabric.

Test Configuration

The boom was towed in a catenary configuration from the main bridge. Although the reference paper does not provide more details, the boom gap ratio was probably about 2:1 as in the later tests and the test oil was loaded directly into the boom apex.

Test Oils

Circo 4X light - Viscosity 12 cSt, density of 0.9 at 22°C (72°F)
Murban crude - Viscosity 11 cSt, density 0.85 at 14°C (57°F)

Test Variables

Wave conditions, tow speed, oil types and amount.

Data Precision and Accuracy

Tow speeds measured to 0.1 knots.

Test Procedure

Tests were performed in calm water and four wave conditions. Oil loss tests were performed to determine the speed at which the boom first loses oil. In one case a gross loss is also recorded. Burn tests were performed to determine if a burn could be maintained at a variety of tow speeds and in various wave conditions.

Test Results

Table 7.9 Dome Boom Tests at OHMSETT 1981 (S-2)
Boom freeboard 26 inches draft 44 inches B/W 3.5:1

WAVE	TEST SPEED/ RANGE (kts)	1st LOSS SPEED (kts)	OIL AMOUNT/ VISCOSITY (gallons/cSt)	COMMENT
CALM WATER 1.3 X 62 ft (0.4 X 19 m)	0.5 - 2.0 0.5 - 2.0	0 0	0 0	Stable in catenary Stable; good wave conformance
CALM WATER	0.5 - 4.0 0.5 - 2.0	0.8 0.8	20/12 10/12	Oil loss in vortex between floats; oil kept from boom by reflected waves
CALM WATER	0.5 - 1.5	0.8	1,000/12	Gross loss at 1 kt.
2 ft (0.6 m) HARBOR CHOP	0.5 - 2.0	Not reported	1,000/12	Durability trial; no oil loss reported. Excellent stability , good survival.
1.3 X 62 ft (0.4 X 19 m) 0.7 ft (0.2 m) HARBOR CHOP	0.5 - 2.0 0.5 - 2.0	1.6 0.8	20/12 20/12	Oil held out from boom Oil dispersed by turbulence in catenary
CALM WATER	0.3 - 0.7	Not reported	10/11	Three trials; intense burn for about 5 minutes; >90% efficiency
0.7 ft (0.2 m) HARBOR CHOP	0.5	Not reported	10/11	No ignition of oil
0.7 & 1.3 X 62 ft (0.2 & 0.4 X 19 m)	0.5	Not reported	10/11	Intense burn for about 3 minutes; more residue left than before
1.3 X 62 ft (0.4 X 19 m)	0.5 - 1.0	Not reported	15/11	Ignited in waves; intense burn for about 3 minutes.
CALM WATER	0.7 - 2.0	Not reported	15/11	Intense burn for 3 minutes
0.7 ft (0.2 m) HARBOR CHOP	0.5	Not reported	15/11	Successful ignition; poor combustion, extinguished by a breaking wave
CALM WATER	0.5	Not reported	15/11	Emulsified oil from the previous test burned for 7 minutes.

Overall Assessment of Performance

First loss tow speed was 0.8 knots in all cases but one and that doubled to 1.6 knots. These data may not be directly comparable to later tests because of the small amount of oil that was used; however, in one case 1,000 gallons (3.8 m^3) of oil was used and the first loss speed remained at 0.8 knots.

Burn tests showed that in calm water combustion could be sustained at tow speeds up to 2 knots; however, the report suggests that if larger volumes of oil had been used, combustion efficiency would have been reduced at speeds greater than 1 knot because of oil losses under the boom. The report shows that increasing swell height did not affect slick ignition or burn intensity; however, the report notes that there was more burn residue with increasing swell height. The report suggests that this result was a function of the small amounts of oil used in the tests and that combustion efficiency in a large scale burn would not be affected. Data also show that burn intensity in a swell condition was not affected by tow speed up to a speed of 1 knot at which point burn efficiency was drastically reduced. Of the three burn tests performed in a harbor chop wave, ignition was only achieved once. In this case flame spread was slow and ignition was poor. Before the entire surface of the slick could ignite, a breaking wave extinguished the flame.

Following these tests the boom was redesigned to include a stainless steel skirt and improved flexible panels connection flotation segments. The boom was then again tested for durability offshore in sea states of 3 to 4 (waves of 4 to 8 feet.)

2.6 MSRC, Coast Guard, Navy, and MMS Tests Offshore 1994, Phase I (I-6,S-3)

In May 1994 the Marine Spill Response Corporation (MSRC), the U.S. Coast Guard, U.S. Navy, and Minerals Management Service (MMS) conducted a joint test of oil containment booms in Lower New York Bay and in the Atlantic Ocean east of Sandy Hook New Jersey. These tests were performed to collect data on boom performance, including tow forces, skirt draft, and boom freeboard, as a function to tow speed and environmental forces caused by currents, wind, and waves. Four booms were tested:

- o 3M Fire Boom (Presently the Elastec/American Marine Fireboom)
- o Barrier Boom
- o USCG/Oil Stop Inflatable Boom
- o U.S. Navy USS-42 Boom

Use of these booms permitted collection of data over a range of buoyancy to weight ratios of 5:1 to 52:1, skirt drafts from 610 mm to 1,500 mm (24 top 60 inches) and freeboards from 350 mm to 1,190 mm (14 to 47 inches). Data collected were also used to compare calculated boom loads (force) and measured loads. (An analysis of the forces on booms is contained in Appendix C.) Tests of the 3M Fireboom are described here. Tests of the other booms are described in other appropriate chapters.

Boom Description

The fireboom tested is basically the same design as the one tested at OHMSETT (O-8) and shown in Figure 7.3 (a) page 7-7. Specific details are given on Table 7.10 page 7-20.

Test Configuration

In most tests booms were towed in tandem as shown in Figure 7.5 below. The Oil Spill Response Vessel (OSRV) *New Jersey Responder,* the center vessel, towed two booms and acted as the command vessel. The USCG vessels *Penobscot Bay* and *Point Francis* towed the outer ends of the booms. The sweep width for one boom was held constant at approximately 300 feet (91.5 m).

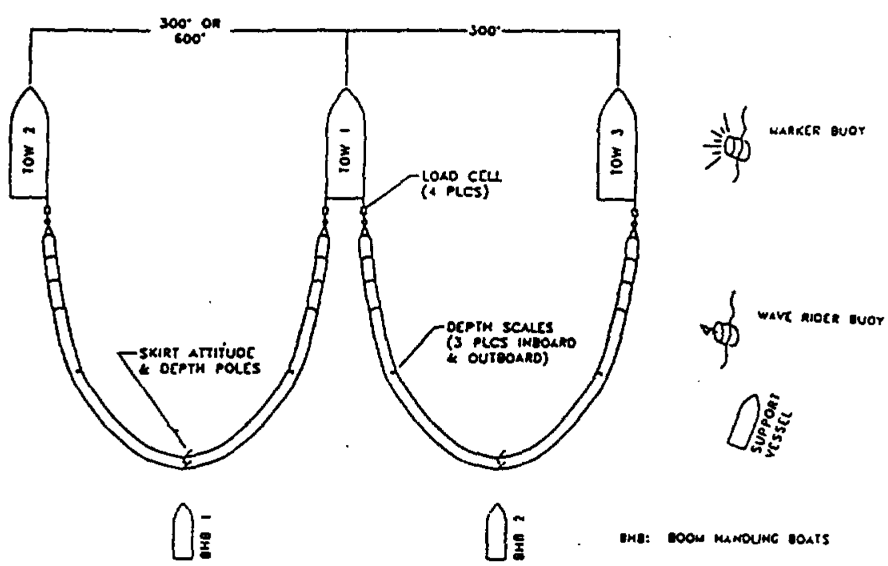


Figure 7.6 Boom Towing Configuration

Table 7.10 3M (Elastec/American Marine) Fire Boom

BOOM	3M Fireboom
BOOM TYPE	Curtain, Internal foam flotation
FREEBOARD in (mm)	15 (381)
DRAFT in (mm)	27 (685)
HEIGHT in (mm)	42 (1,066)
END CONNECTORS	Fireboom U
SKIRT MATERIAL	Vinyl-coated polyester
FIRE RESISTANT MATERIAL	Stainless steel mesh & tem. resistant ceramic textile
FLOTATION	Temperature resistant core
WEIGHT lb/ft (kg/m)	15.3 (23.0)
RESERVE BUOYANCY lb/ft (kg/m)	76.5 (115)
RESERVE B/W RATIO	5:1
BALLAST	½ inch chain
TENSION MEMBERS	Chain, fabric, steel cable
TOTAL STRENGTH lb (N)	70,000 (315,000)

Test Oils

No oil was used in testing.

Test Variables

Boom tow speed, skirt draft, tow tension, boom freeboard, and environmental conditions.

Data Precision and Accuracy

Boom Tow Speed - Tow speed was recorded manually on all three tow vessels. Speed was also recorded electronically on the *New Jersey Responder* using the vessels satellite navigation system.
Skirt Draft - Submersible pressure transducers were fastened to the bottom of the boom skirt and the reading was recorded on a data logger.
Tow Tension - Tension was recorded on both ends of towed booms.
Boom freeboard, overtopping, and skirt attitude - Each boom was marked vertically in 3 inch (76 mm) graduations from the top of the boom to two feet below the flotation chamber. This scale was monitored with a video recorder showing water action on the inside of the boom.
Environmental Conditions - Water current and wind direction and speed were recorded manually on the control ship. Wave height and period, average wind speed and direction were recorded every half hour from a Coast Guard climate buoy.

Test Procedure

Video cameras recorded each test run from three positions: the *New Jersey Responder*, and each of the trailing boom handling boats. One of these two support boats was placed behind the apex of one of each of the booms being towed. Scales painted on the booms allowed the freeboard, both forward and aft, to be documented for later review and comparison with the collected data.

Tow vessels lined up in the desired direction to the wind or swell at near zero speed for a test run. Radar was used to determine and control the required sweep width between each pair of vessels. The tow vessels accelerated to 0.5 knots. When the speed was confirmed the data for the run was recorded for approximately 10 minutes. The test director then instructed the tow vessels to accelerate to 1 knot, and the process was repeated again at 1.5 knots. Finally, a functional test was performed to determine the speed at which either the flotation submerged or the skirt surfaced. This tow sequence was repeated so that data were acquired towing both into the sea and with the sea.

Test Results

Of the four booms tested, the 3M boom had the lowest buoyancy to weight ratio, 5:1. Six tests were performed at low towing speeds and in calm seas. At towing speeds of 0.5 and 1.0 knots, performance was satisfactory; however, at a towing speed of 1.5 knots the boom could not sustain the towing force which resulted in mechanical failure of the end connector. The tow speed of full submergence was also 1.5 knots. At a tow speed of 0.5 knots, the overall height of the boom was about 1 meter (39 inches). Because of the placement of the tension lines on the boom, the reduction in freeboard did not result in an increase in boom draft. In fact the overall draft of the boom decreased as the speed increased above 0.5 knots. At 1 knot, a large percentage of the freeboard and the reserve buoyancy had been lost. The reserve buoyancy is a decreasing function of the freeboard and towing speed. The relationship between tow speed, freeboard and draft is shown on Table 7.11 below. All values were taken from graphs with a very large scale and therefore are only approximate.

(Author's note: This boom is presently being offered commercially so it is likely that the problems that occurred in this test have been corrected.)

Table 7.11 3M Fireboom - Freeboard/Draft vs. Tow Speed (I-6)

TOW SPEED (kts)	FREEBOARD Inches (mm)	DRAFT inches (mm)
0	12.6 (320)	24 (610)
0.5	6.7 (170)	33.5 (850)
1.0	3.5 (90)	29.5 (750)
1.5	0.8 (20)	30.7 (780)

The report comments on the relationship between buoyancy to weight ratio of the booms tested and the tow speed of submergence. For the booms with the lowest buoyancy to weight ratios, the tow speed of submergence was about 1.5 knots. This value increased remarkably for the booms with higher B/W ratios. For the Barrier Boom with a B/W ratio of 52:1, submergence did not occur at 4.5 knots, the highest tow speed the support ships were able to achieve. Further, the report suggests that reserve buoyancy is dependent on freeboard, therefore, like the freeboard, it is also a decreasing function of tow speed. Reserve buoyancy, however, is not a linear function of freeboard reduction, since the reserve buoyancy is also dependent on the cross sectional area of the portion of the boom that is still above water.

2.7 MSRC, Coast Guard, Navy, & MMS Offshore Tests 1994, Phase II (I-7, S-3)

A series of at sea towing tests on fire resistant oil containment boom was performed by the Marine Spill Response Corporation (MSRC), the Texas General Land Office, Minerals Management Service (MMS), and various boom manufacturers at a site offshore of Galveston, Texas in August 1994. These tests were to assist MSRC Region III in evaluating fire resistant booms for future acquisition, to continue data collection for further development of ASTM guidelines on selection of booms, and to compare offshore results with test tank data. Fourteen tests were performed in sea state 1 on three booms: Applied Fabric Pyroboom™, Oil Stop Auto Boom™ Fire Model, and a SeaCurtain™ Fire Guard. The Navy 3M Fire Boom test results for Phase 1 testing in New Jersey were also included to compare with this set of fire boom results. Tow speed, tow tension, skirt depth, and skirt angle were recorded both electronically and manually and weather parameters were recorded using wind and wave sensors. Comparisons were made between the tow speed and the following parameters: tow tension, skirt draft, skirt tilt, and freeboard.

Boom Description

Navy Elastec/American Marine (3M) Fireboom - This boom was not part of this set of tests, so data taken offshore New Jersey in Phase I was used to compare results with the booms used in the Phase II tests. A description of this boom is given in Table 7.12, page 7-23.
Kepner SeaCurtain FireGard Oil Fire Containment Boom - This test boom was provided by the Texas General Land Office. The boom consists of a continuous, stainless steel erecting coil that is covered with a high temperature refractory fabric with the trade name Thermotex™. A sacrificial coating on this fabric burns away at about 315°C (600°F). If the fabric is damaged during operation or is unusable after a burn, the covers can be replaced because they are attached using quick connectors. The skirt is a polyurethane coated fabric. Tension and ballast are provided by chain on the bottom of the skirt. High temperature foam floatation along the bottom of the skirt provides rigidity and additional buoyancy.
Applied Fabric Technologies Pyroboom - This is a solid flotation, fire resistant floating barrier. The freeboard is a blend of wire mesh and ceramic fiber yarn woven into the refractory fabric. The fabric is saturated with a sacrificial, silicone rubber polymer coating. The polymer transitions from an elastic form to a saline organo-mineral compound that binds the yarns together for thermal stability during a burn. Buoyancy is provided by stainless-steel spheres bolted through the freeboard and draft materials. Each hemisphere is filled with a temperature resistant, closed cellular material and provides a buoyancy that is independent to temperature up to 1,315°C (2,400°F).
Oil Stop Auto Boom Fire Model - This pressure-inflatable boom has flotation chambers covered with stiff, fire resistant materials. The skirt is not fire resistant. The boom is stored on a hydraulic reel for rapid deployment. The internal temperature of the boom is reduced by heat transfer to the surrounding water. The high temperature insulating fabric and the heat transfer process allows the boom to sustain high temperatures for extended periods. The main tension line of the boom is attached to the bottom of the skirt.

Table 7.12, page 7-23, describes these booms in detail.

Test Configuration

Two booms were towed in tandem for most of the tests, as shown in Figure 7.7. The *Gulf Coast Responder* and the *Texas Responders's* Munson Boat each towed an end of the boom, with the *Texas Responder* in the center towing the other end of both booms. The sweep width between the towing vessels was held constant at approximately 91m (300 feet) using radar. This distance was varied for the Applied Fabric boom, which was towed in a "U" configuration with a distance of 46 m (150 feet) between vessels. Video cameras recorded each test run from four positions: the *Texas Responder*, the *Gulf Coast Responder*, and the two support boats. The two support boast were placed behind the apexes of the booms being towed, with video cameras focusing on the apex. Scales attached on the booms allowed the freeboard, both forward and aft, to be documented by video camera.

Test Oils No oil was used during the tests.

Table 7.12 Boom Description MSRC, Coast Guard, Navy, MMS Tests 1994 (I-7)

BOOM	Sea Curtain FireGard	Pyroboom	Auto Boom Fire Model	Elastec/Am. Marine (3M) Fireboom
BOOM TYPE	Self-inflatable curtain	Fence	Pressure-inflatable curtain	Curtain, Internal foam flotation
FREEBOARD in (mm)	9 (230)	13.5 (343)	15 (381)	15 (381)
DRAFT in (mm)	27 (686)	24.5 (622)	27.5 (698)	27 (685)
HEIGHT in (mm)	36 (916)	38 (965)	42 (1,067)	42 (1,066)
END CONNECTORS	Coated ASTM	Not reported	Not reported	Fireboom U
SKIRT MATERIAL	Polyurethane coated fabric	Refractory fabric	Polyurethane coated polyester fabric	Vinyl-coated polyester
FIRE RESISTANT MATERIAL	Double layered Thermotex	Refractory fabric	Fire resistant fabric	Stainless steel mesh & tem. resistant ceramic textile
FLOTATION	Self-inflatable w/layers of foam	Stainless steel shells over glass foam	pressure inflatable	Temperature resistant core
WEIGHT lb/ft (kg/m)	Not reported	Not reported	10 (15)*	15.3 (23.0)
RESERVE BUOYANCY lb/ft (kg/m)	Not reported	Not reported	135 (202.5)	76.5 (115)
RESERVE B/W RATIO	2:1	8:1	13.5:1	5:1
BALLAST	Chain	Lead weights	3/8 inch (10 mm) chain	½ inch (13 mm) chain
TENSION MEMBERS	Chain, fabric	Fabric	Chain, fabric	Chain, fabric, steel cable
TOTAL STRENGTH lbs (N)	28,000 (126,000)	50,000 (222,000)	60,750 (274,000)	62,600 (278,000)

*Data taken from a similar boom produced by the same manufacturer.

Test Variables

Vessel Tow Speed - Booms were towed at steady speeds of 0.5, 1.0, 1.5 knots, and tow speed at failure. Speed over the ground and speed relative to the water were measured. These speeds were recorded manually on the *Texas Responder* and the *Gulf Responder* at 30 second intervals during the ten minute test runs. For comparison of the test results, an average of the tow speeds was calculated for each test run.
Boom Sweep Width - Boom sweep width was recorded manually on the bridge of the tow ships using the ship's radar set to the 0.5 nm scale. Measurements were taken every 30 seconds to determine the average gap distance.

Skirt Draft - Two submersible pressure transducers were fastened to the bottom of the skirt of each boom. The transducers have a range of 0 - 7 m (0 - 23 feet) with an accuracy of ±0.3% of range. The primary transducer was located in the apex of the boom and a back up was located approximately 33 meters from the primary unit. Data from the transducers were collected on the *Texas Responder.*
Skirt Angle - The skirt angle was recorded using an angle sensor placed one-third the length of the skirt down from the flotation chamber. The sensor had a recording range of ±60° and the output was recorded at 5 second intervals by a data logger in the communications center on the *Texas Responder.*
Boom Freeboard and Skirt Attitude - The boom's freeboard, skirt attitude, splashover, and wave overtopping were recorded on video tape. The skirt attitude, that is, the in-plane angle and relative movement of the skirt compared to the floatation chamber, was visually indicated by the rotation of two poles placed on either side of the boom. The change in angle of the skirt from its perpendicular position was monitored by angle sensors attached to the skirt of each boom. A vertical scale with marks 3 inches apart was inscribed on both faces of the boom. Boom freeboard was measured by recording water height against these marks using a video camera.
Tow Tension - Five load cells were used to record tow tension. Recorded loads were transmitted to data loggers on the control ships. Tow forces were sampled every 5 seconds during the test runs and stored in a computer. The results of tow tension measurements are not a part of this analysis.

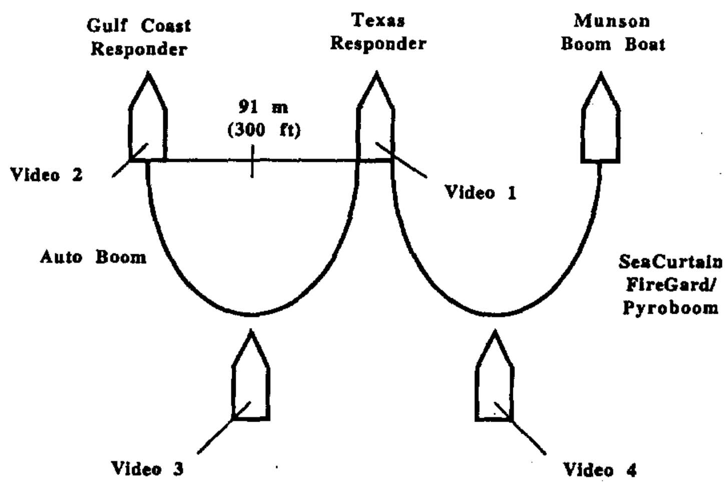


Figure 7.7 Test Configuration with Booms Towed in Tandem

Test Procedure

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

Test Results

**Table 7.13 Results of MSRC, Coast Guard, Navy, MMS Tests 1994 (I-7)
Boom Freeboard and Draft vs. Tow Speed**

TOW SPEED kts	0	0.5	1.0	1.5	2.0
Navy Fireboom Freeboard in. (mm) Draft in. (mm) F + D in. (mm) Measured Height in. (mm)	 13.4 (340) 24.4 (620) 37.8 (960) 42 (1,066)	 6.9 (175) 33.5 (850) 40.4 (1,025) 42 (1,066)	 4 (100) 29.9 (760) 33.9 (860) 42 (1,066)	 1 (25) 31.5 (800) 32.5 (825) 42 (1,066)	 Submerged 1.65 kts
Seacurtain FireGard Freeboard in. (mm) Draft in. (mm) F + D in. (mm) Measured Height in. (mm)	 5.9 (150) 24.4 (620) 30.3 (770) 36 (916)	 3.0 (75) Not reported	0.7 knots submerged 31.1 (790)	 32.7 (830)	
Pyroboom Freeboard in. (mm) Draft in. (mm) F + D in. (mm) Measured Height in. (mm)	 13.8 (350) 22.8 (580) 36.6 (930) 38 (965)	 9 (230) 22.8 (580) 31.8 (810) 38 (965)	 6.1 (155) 21.7 (550) 27.8 (705) 38 (965)	1.4 kts submerged 22.0 (560)	
Auto Boom Fire Model Freeboard in. (mm) Draft in. (mm) F + D in. (mm) Measured Height in. (mm)	 15.0 (380) 22.8 (580) 37.8 (960) 42 (1,066)	 12.2 (310) 18.9 (480) 31.1 (790) 42 (1,066)	 10.2 (260) 22.0 (560) 32.2 (820) 42 (1,066)	 9.4 (240) 25.6 (650) 35.0 (890) 42 (1,066)	 Submerged

Note: All data are taken from a summary graph and therefore are approximate. Several graphs in the report use different units of measure, i.e., feet, meters, and centimeters. In some, values do not agree with the summary graph. All values shown here were taken from the summary graph. In one case, a boom on a graph is not named properly.

Navy Elastec/American Marine (3M) Fire Boom - Results are taken from the Phase 1 tests off the New Jersey coast. Submergence tow speed in calm seas was 1.5 knots, at which point there was a boom connector failure. The report notes that at 0.5 knots, the overall height of the boom was about 1 meter. Since an increase in draft does not necessarily follow the reduction of freeboard, it is observed that the overall draft of the boom decreases as the speed increases. (Author's note: this is true in a general way, but not exactly using the data from the summary graph. Table 7.13 shows that measured boom height in the water at 0 knots is not quite 1 m, increases slightly at 0.5 knots, and then decreases again at 1.0 and 1.5 knots. The general trend is a decreasing draft with increasing speed. This trend may not be exact because of the measuring accuracy, and perhaps the variations in measurements in the pressure sensor at the bottom of the boom skirt.)

SeaCurtain FireGard Boom - This boom buoyancy to weight ratio, 2:1, was the lowest of the booms tested. The report notes the tow speed of submergence at 0.5 to 0.6 knots. (Interpolation of the graph showing freeboard would put submergence at about 0.7 knots.) The report notes that the draft decreased at 0.5 knots because of the movement of the skirt. (The summary graph of boom draft does not show a point at 0.5 knots.) The position of the skirt with increasing tow speed was also noted by the angle the skirt made with the vertical. At 0.5 knots, the skirt tends 4° in the towing direction. At 1 knot the angle is 22° and at 1.5 knots it is 14°. (At 1 knot and 1.5 knots the boom was submerged.)

Applied Fabric Technologies Pyroboom - The report notes that the boom did not submerge, but was hydroplaning at a speed of 1 knot. Table 7.13 shows that the skirt decreased gradually with increasing tow speed. The report shows that the skirt angle was inside the apex of the boom (toward the direction of tow) by +2° at 0.5 knots and began to hydroplane at about 1 knot. The boom draft remains relatively constant, probably due to the reduction of freeboard.

Oil Stop Auto Boom Fire Model - The Auto Boom was towed at all speeds with and against the current. Tow speed of submergence was 2.0 knots. Table 7.13 shows a fairly large reduction in draft at 0.5 knots, at which point there was also a sharp increase in skirt angle up to 30° in the direction of tow. At higher speeds, the skirt returned to a near vertical position. Table 7.13 shows that at higher tow speeds, the draft actually increased, which indicates that the draft increased as the freeboard decreased and the skirt was probably drawn up in a curve toward the direction of tow.

Assessment of Freeboard and Draft Changes - The report shows graphs of freeboard and draft separately and does not combine them to show the overall height of the boom. Table 7.13 shows the measured and operational freeboard and draft, combines them to give an overall height of the boom, and compares that with the nominal, or advertised boom height. This shows some interesting relationships. First, the measured height of the boom in the water, even at rest, is always less than the advertised boom height, sometimes by as much as six inches. This may be partly due to inaccuracies in measuring freeboard and draft in the water, but it also shows that boom never stretches out to its full advertised height when in the water. Second, as the boom is towed, freeboard decreases, sometimes by a large amount as is the case of the Navy Fireboom. Third, the decrease in freeboard does not necessarily show up as an increase in draft. This means that the boom skirt is either being curved into a cup-like shape into the direction of the tow or it is planing. This, of course, affects the way oil is being contained in the boom. (The draft of the Auto Boom Fire Model does increase somewhat at tow speeds of 1.0 and 1.5 knots, so in this case some of the decrease in freeboard may be resulting in an increase in draft.)

This change in boom height with tow speed also has an important impact on the tow forces on the boom. The tow force is proportional to the cross sectional area presented to the direction of tow. A changing cross sectional area will change the forces being measured on load cells and also it will change the results of computations of the forces on the boom. All formulas for computing the forces on a boom use the cross sectional area in the water as a major computational element. These tests show that this area is changing with tow speed. This change is not generally made in computations, which will have an important affect on their accuracy. To compare measured forces with computed forces, the computational method should provide for changing the cross sectional area at every tow speed. Using this method is likely to increase the accuracy of computation for most analytical methods.

Buoyancy to Weight Ratio and Speed of Submergence - Figure 7.8 shows a plot of buoyancy to weight ratio vs speed of submergence. Just considering the four boom used in this set of tests, the graph shows that a buoyancy to weight ratio of 3:1 is likely to cause submergence at about 1 knot and a buoyancy to weight ratio about 6:1 is needed to delay submergence to 1.5 knots. This clearly indicates that higher buoyancy to weight ratios are needed to permit reasonable tow speeds without submergence.

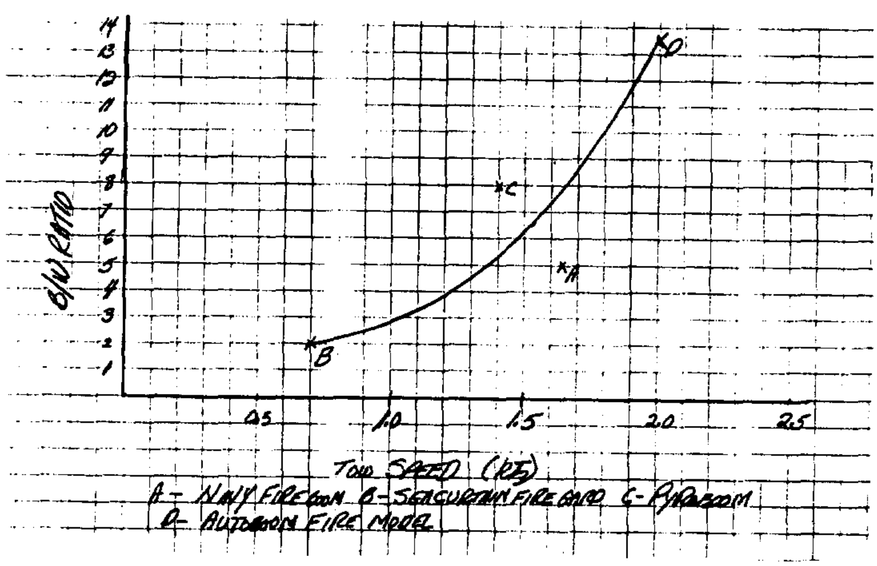


Figure 7.8 Buoyancy to Weight Ratio vs Tow Speed

Overall Assessment of Results

Results of these tests show that of booms tested, only one, the Auto Boom Fire Model, could be towed at 1.5 knots without submerging or suffering a substantial reduction in freeboard. Further, the reduction in freeboard that occurs as tow speed increases is not generally accompanied by an increase in draft. Finally, tow speed of submergence is related to buoyancy to weight ratio, with data suggesting that a B/W ratio of about 6:1 is required to delay the speed of submergence to 1.5 knots.

2.8 Fire Containment Booms Performance Summary

Fire containment booms are of diverse types and therefore performance in containing oil may vary widely. The performance of fire containment types has already been described along with each individual boom type; however, these summaries, with some editing, are presented again here so that the user can assess the performance of all booms that are used for this purpose.

Comparing the performance of fire containment booms with conventional booms in terms of seakeeping and oil containment capability is not entirely fair. Fire containment booms must first be impervious to high temperatures. This means that they may be made of very heavy, fire resistant materials. This extra weight often reduces buoyancy to weight ratio and also may make them stiff, which affects heave response. This is why all fire containment booms have been listed separately and can be compared with other booms that have the same function.

Fire Containment Fence Booms

Three fire containment fence booms have been tested: the Dome Fire Containment Boom, the SL Ross Pocket Fire Boom (a smaller, lighter version of the Dome boom), and the Applied Fabric Technologies Pyro Boom. In calm water, first loss and gross loss tow speeds were typical of conventional booms, 0.75 to 1.3 knots. This performance was degraded somewhat in a short period regular wave, but performance in a long period wave and also in harbor chop was about the same as in calm water.

Fire Containment Curtain Booms

Tests of fire containment curtain booms showed a first loss entrainment failure in calm water of about 0.9 knots and gross loss of about 1.2 knots. In a long wave (length to height ratio of 20:1), first loss was reduced to 0.7 to 0.8 knots and gross loss to 0.9 to 1.1 knots. In a longer wave (L/H 38:1), first loss was 0.7 to 1.1 knots with gross loss at 1.1 to 1.4 knots. Performance in harbor chop was about the same as in calm water.

Fire Containment Self-Inflatable Boom

This type boom has not had a controlled test in oil. A boom was tested for sea-keeping offshore, and although this device had typical dimensions, buoyancy to weight ratio was only 2:1, which is low for a self-inflatable boom. In tow tests this device submerged at about 0.7 knots.

Fire Containment Pressure Inflatable Boom

In a relatively recent controlled test, a pressure inflatable fire boom experienced first loss at 0.9 knots and gross loss at 1.2 knots in calm water. In a regular wave, first loss occured at 0.8 knots and in a longer wave at 1.07 knots. First loss in harbor chop was at 1 knot.

Tests of a water cooled pressure inflatable fire containment boom performed somewhat later show basically the same result. First loss and gross loss tow speeds in calm water were 0.95 knots and 1.25 knots respectively. In a long wave, these speeds were 0.8 knots and 1.1 knots; in a longer wave speeds were 1.13 knots and 1.45 knots. In harbor chop speeds were 1.05 and 1.3 knots. It is interesting to note that in a long wave and even in harbor chop wave, performance reported was better than in calm water.

In a test offshore without oil, a pressure inflatable fire boom maintained adequate freeboard and draft at tow speeds up to 1.5 knots. Speed of submergence was 2 knots.

Fire Resistant Containment External Tension Booms

In controlled tests performed in oil, an external tension fire resistant boom had first loss and gross loss tow speeds of 0.85 and 1.05 knots in calm water. In a regular wave, these speeds decreased to 0.4 knots and 0.6 knots and in a longer regular wave they were 0.85 and 1.05 knots. First loss in harbor chop was 0.88 knots and gross loss was 1.07 knots. Thus in harbor chop, generally the most severe environment for most booms, performance was nearly the same as in calm water.

The critical tow speed of failure without oil present was greater than 6 knots, which was the best of any tested. Further, in tests of oil loss rate, the rate at first loss +0.1 knots and first loss +0.3 knots was much lower than all other booms tested except the Dome boom.

In a later controlled test in oil, performance of the exterior tension boom was somewhat better than before. In calm water first loss was 0.9 knots and gross loss was 1.25 knots. In a long wave, first loss was 0.63 knots and gross loss 0.95 knots, while in a longer wave first loss was 1 knot and gross loss was 1.3 knots. In harbor chop these values were 0.7 knots and 1.1 knots respectively.

Performance of all Fire Containment Booms Taken Together

The range of values representing the performance of fire containment booms is broad and, in some cases, strongly affected by a single performance that produced a very high result or a very low result. Nevertheless, this is what all tests show and represents a range of values to be expected based on existing tests.

Table 7.14 Performance of All Fire Containment Booms

TEST CONDITIONS	1ST LOSS TOW SPEED (kts)	GROSS LOSS TOW SPEED (kts)
CALM WATER	0.85 - 1.0	1.05 - 1.32
SHORT REGULAR WAVE	0.4 - 0.83	0.6 - 1.1
LONG REGULAR WAVE	0.85 - 1.13	1.05 - 1.45
HARBOR CHOP WAVE	0.7 - 1.05	1.0 - 1.3

Chapter 8

TIDAL SEAL BOOMS

1.0 DESCRIPTION

Tidal seal booms use air or foam for buoyancy and water for ballast. They float free at high tide and seal to the mud or sand at low tide. When grounded, the heavy water ballast seals the boom to the shoreline and prevents oil from moving along the intertidal zone. Figure 8.1 shows a typical tidal seal boom.

1.1 SELECTION CONSIDERATIONS

Buoyancy	Only requires enough buoyancy to rise with the tide. Buoyancy can be controlled by the amount of water ballast added.
Roll Response	Generally good. High buoyancy and adequate ballast will prevent excessive roll
Heave Response	Good flexibility and high buoyancy to weight ratios permit the boom to move easily with the surface of the water.
Mode of Application	Used in a tidal area parallel to the shoreline to prevent oil from coming ashore or perpendicular to the shoreline to prevent oil from moving along the shoreline
Other	

2.0 TEST RESULTS

Although tidal seal booms have been manufactured for many years, there are no know performance tests or reports of effectiveness in spill situations. They are, however, known to be effective and are widely used.

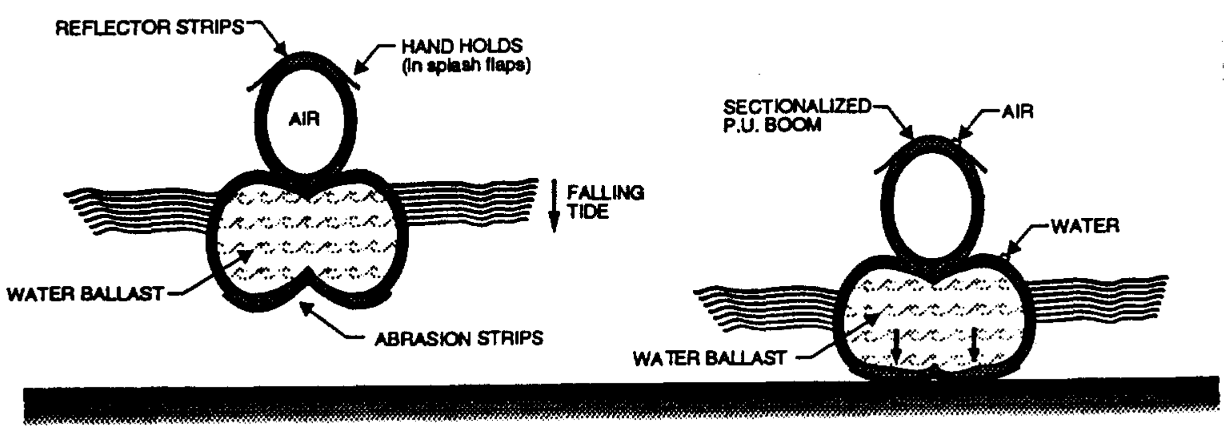


Figure 8.1 Tidal Seal Boom

APPENDIX A

BOOMS PERFORMANCE SUMMARY

Test Procedures

Early tests of booms only recorded first loss tow speed. In later tests gross loss tow speed was also reported. Still later, oil loss rate was recorded at first loss speed +0.1 knots and first loss speed +0.3 knots. These new test parameters greatly expand insight into boom performance.

Recent tests have also included a preliminary series of trials to determine proper oil pre-load for testing. This is important because an exact pre-load is determined for each boom type, which increases the validity of testing. In early tests oil pre-load was fairly arbitrary and the amount of oil used in testing was quite small. This had a substantial affect on test results, particularly first loss tow speed and oil loss rate.

Controlled testing of containment boom has now reached a level of sophistication at which it may be possible to determine more exactly the test parameters that most affect boom performance and to what extent. Tests could be performed that would permit boom to be designed with a more predictable performance over a wide range of deployment conditions. Developing this level of knowledge would require an extensive series of tests that change only one variable at a time. Tests designed to develop this data could include the following:

o *Buoyancy to weight ratio* - This has been recognized by many as a key parameter is boom performance, although specific limits or requirements have not been determined. In a series of scaled tests it was determined that booms with higher buoyancy to weight ratios perform better but that the difference is not significant until the buoyancy to weight ratio falls below 10:1. Full scale tests could be performed at OHMSETT using a boom with fixed physical characteristics and a varying buoyancy to weight ratio. This may confirm the scaled data and establish requirements for buoyancy to weight ratio for various response situations.

o *Boom Draft* - some test data suggest that oil loss rate may be directly related to boom draft. Tests could be performed using a boom with fixed physical characteristics and a varying draft to determine if this relationship exists.

o *Spilled Oil Viscosity* - many tests have been run using oils of widely varying viscosities, but none have related boom performance directly to oil viscosity with all other conditions remaining the same. Tests could be performed with a boom of fixed dimensions and varying oil viscosities. These tests could be repeated with changing boom characteristics, specifically buoyancy to weight ratio and draft. Oil loss rate seems to be related to boom draft and therefore it seems reasonable to speculate that loss rate may be related to both boom draft and oil viscosity. These tests might be able to show if there is an optimum or minimum boom draft required for specific viscosity oils at various tow speeds.

o *Wave Conditions* - Early boom tests described waves in terms of length and height. Recently some tests show only wave height and period. Since the wave length is not given, it is very difficult to visualize the effects of different wave patterns on booms. Test reports should go back to reporting wave height and length. Since nearly all tests show reduced boom performance in short, choppy waves, the relationship between boom performance and wave steepness could also be investigated in controlled tests.

In the Phase 3 Oil Containment Boom At Sea Performance Tests (I-8), Nordvik comments that at sea boom tests have indicated that the limiting factor to boom performance is not wave height, but wave period. Further, Van Dyck notes in his report of scaled boom tests (I-5), that "wave height is not the limiting parameter, provided the wave length/height ratio is greater than 12:1." To establish the relationship between boom performance and wave steepness, tests could record the wave length to height ratio. Further, tests could be performed to determine if there is a limiting length to height ratio that seriously degrades boom performance and what boom properties are needed to perform well in steep waves.

Test Results

Tables A.1 and A.2 summarize representative data from tests of conventional containment booms. Table A.3 summarizes the performance of fire containment booms of various types. The booms tested include a variety of types, sizes, buoyancy to weight ratios, and were tested in varying wave environments, oil preloads, and oils of widely varying viscosities. This diversity of boom types and test conditions makes broad generalizations on boom performance difficult. Some comments on these summaries are, however, appropriate.

When towed in the catenary mode, tests show that a boom with a draft of at least 12 inches (300 mm) can be towed in calm water up to 0.9 knots before experiencing loss of oil under the boom. This level of performance can generally be maintained in a long regular wave but performance may decrease to 0.7 to 0.8 knots in a short regular wave or a harbor chop wave. The curtain boom with external foam flotation may be the exception to this rule because oil is lost somewhat sooner in both the catenary and diversionary modes.

Boom towed in a diversionary mode, that is, fairly flat and at an angle with the direction of movement, has a higher speed at which first loss occurs. The first loss speed depends on the angle to the direction of movement - the smaller the angle the greater the possible tow speed - and also the boom type. In the diversionary mode, towing without oil loss up to 1.2 knots is possible and this may even extend up to the 2 to 3 knot range in some cases. Booms deployed in a Vee configuration are basically in a double diversionary mode and achieve similar results. Recent tests of these systems show first loss tow speeds in the range of 1 to 1.5 knots in calm water and a wide range of wave conditions. A boom with bottom netting designed to divert oil into the Vee sweep system also has relatively high speeds of first oil loss, in the range of 1.2 to 1.5 knots. The netting seems to delay the loss of oil under the boom up to a higher tow speed.

Fire containment booms are of various physical types, and although their performance is thought to suffer somewhat because of the excess weight needed to survive the fire, their performance remains about the same as conventional booms. They generally have first loss tow speeds of 0.9 knots in calm water and somewhat less in short waves and choppy seas.

One early set of tests of booms in the diversionary and Vee shape determined that a velocity of 1 knot normal to the boom face is the maximum that can be maintained without a gross loss of oil under the boom. Using varying angles to the direction of movement, tow speeds of 2 and 3 knots were achieved while maintaining a speed of 1 knot normal to the face of the boom. Additional tests to either confirm or disprove this observation would be helpful.

Early tests also used fluids of widely varying densities, 0.71 to 0.975. These tests showed that first loss tow speed decreased as density increased, and concluded that high density fluids (close to 1.0) cannot be controlled with existing containment booms in currents or at tow speeds greater than 0.3 knots. Some field experience tends to support this observation.

Tests in a tank in Newfoundland and Vee sweep tests suggest that there may be another oil loss mechanism, namely vortex loss. This loss can occur at low tow speeds, in the range of 0.3 to 0.4 knots. This type of loss has been observed on at least two occasions in controlled tests and in the field.

TABLE A.1 Booms Performance Summary
Fence Booms - Curtain Internal Foam - Curtain External Foam

BOOM TYPE MODE OF DEPLOYMENT WAVE TYPE	1ST LOSS TOW SPEED (kts)	GROSS LOSS TOW SPEED (kts)	OIL VISCOSITY (cSt)	FREEBOARD DRAFT (inches) B/W RATIO
FENCE BOOMS CATENARY CW, LRW SRW DIVERSIONARY CW LRW SRW	 0.8 0.9 1.2 1.4 1.0	 [1]	 300	 F 6 D 12 B/W 0.9:1 (O-1)
CALM WATER DIVERSIONARY 32° DIVERSIONARY 20° VEE 20°	 1.8 2.4 3.0		 190	 F 6 D 12 B/W 0.9:1 (O-3)
CATENARY CALM WATER (FLUME)	 0.9 1.0 1.2	 [1]	 64	 F 17 D 19 B/W 13:1 (C-2) F 6 D 12 B/W (not reported) F 12 D 24 B/W 4.2:1
CURTAIN - INTERNAL FOAM CATENARY CW, LRW SRW DIVERSIONARY CW, LRW SRW	 0.9 0.5 1.2 0.8		 333 1,462	 F 8 D 24 B/W 1.3:1 (O-1)
CATENARY CW LRW, SRW DIVERSIONARY CW LRW SRW	 0.9 0.7 0.8 0.9 0.75		 230 336	 F 6 D 12 B/W 1.5:1 (O-1)
CATENARY CW, LRW, SRW DIVERSIONARY CW, LRW, SRW	 0.8 0.8		 649 333	 F 6 D 6 B/W 3.3:1 (O-1)
CATENARY CW, LRW, SRW DIVERSIONARY CW, LRW	 0.9 1.4		 97 235	 F 8 D 12 B/W 7:1 (O-1)
CURTAIN - EXTERNAL FOAM CATENARY CW, LRW, SRW DIVERSIONARY CW, LRW, SRW	 0.7 0.9		 194 134	 F 6.5 D 8 B/W 2:1 (O-1)

WAVE PATTERNS
CALM WATER (CW)
LONG REGULAR WAVE (LRW) - 1 X 45 feet - Length to height ratio 45:1
SHORT REGULAR WAVE (SRW) - 2 X 30 feet - Length to height ratio 15:1

[1] Early tests did not record Gross Loss Tow Speed.

Table A.2 Booms Performance Summary
Self-Inflatable - Pressure-Inflatable

BOOM TYPE MODE OF DEPLOYMENT WAVE TYPE	1ST LOSS TOW SPEED (kts)	GROSS LOSS TOW SPEED (kts)	LOSS RATE @ GROSS LOSS gpm (BBL/hr)	OIL PRELOAD/ VISCOSITY (cSt)	FREEBOARD DRAFT (inches) B/W RATIO
SELF-INFLATABLE CATENARY CW LRW SRW CW, LRW SRW DIVERSIONARY CW LRW SRW HC	 0.5 0.6 0.8 0.4 0.7 1.5 1.0 1.2-1.6 0.4	 [1]	 [1]	 300/177 300/10 300/238	 F 12.5 D 19.5 B/W 22:1 (O-1)
CATENARY CW LRW [2] LRW [3]	 0.8 0.9 0.8	 1.1 0.9 1.15	 52.5 (75) 36.7 (52.4) 83 (116)	 1,028/3,000	 F 18 D 18 B/W 24:1 (O-4)
CATENARY CW (Flume)	 1.0		 3.1 (4.4) [4]	 10/64	 F16 D 25 B/W 25:1 (C-2)
PRESSURE INFLATABLE DIVERSIONARY (VEE) CW CW LRW [5] SRW HC CW HC	 1.0 1.4 1.35 1.5 1.3 1.25 1.0	 1.35 1.8 1.65 1.7 1.6 1.6 1.35		 100/370 100/9,300;16,500 100/9,900 100/9,900 100/9,900 900/7,500;8,300 900/9,700;13,700	 F 24 D 27.6 B/W 25:1 (O-6)
DIVERSIONARY (VEE) CW SRW	 1.2 1.2	 1.6 1.35		 900/10,400;4,700 900/3,600;5,900	 Vee Sweep with Skimmer (O-6)
DIVERSIONARY (VEE) CW (With netting) CW LRW HC CW, LRW (W/O netting) HC	 1.45 1.25 1.3 1.25 1.2 1.0	 1.5 - 2.0 1.4 1.6 1.5 1.4 1.25		 100/850 300/870 300/870 300/630 300/1,050 300/1,050	 F 24 D 27.5 B/W 24:1 (Tow boom for Vee sweep) (O-6)
CATENARY CW (Flume) CW CW	 1.2 0.9 1.5		 4.6 [4] 3.3 2.9	 10/64 10/64 10/64	 F 26 D 43 B/W 7:1 F 30 D17 B/W (NA) F 35 D 43 B/W 30:1 (C-2)

WAVE PATTERNS
CALM WATER (CW)
LONG REGULAR WAVE (LRW) - 1 X 45 feet - Length to height ratio 45:1
SHORT REGULAR WAVE (SRW) - 2 X 30 feet - Length to height ratio 15:1

[1] Early tests did not record Gross Loss Tow Speed.
[2] Long regular waves somewhat different from before:
0.6 X 27 feet - length to height ratio 45:1

0.6 X 63 feet - length to height ratio 105:1
1.3 X 63 - length to height ratio 48:1
Harbor Chop wave - length to height ratio 15:1
[3] This averages two data points that are nearly the same.
[4] 1st loss + 0.2 knots. Only 8 to 10 gallons of oil were used which probably caused a low loss rate.
[5] Wave lengths are not given in this study, only height and period. Waves with the longest period are ther3efore called Long Regular Waves and waves with approximately half that period are called Short Regular Waves. Waves with a very short period (1.6 seconds), are called Harbor Chop.

Table A.3 Booms Performance Summary
Fire Containment Booms - Catenary Mode

BOOM	FIRST & GROSS LOSS TOW SPEED (kts)				LOSS RATE TEST (gpm @ kts)		CRITICAL TOW SPEED (kts)/ TYPE FAILURE	OIL PRE-LOAD/ VISCOSITY (gallons/cSt)
	CALM	WAVE #1	WAVE #2	WAVE #3	FIRST LOSS +0.1 kts	FIRST LOSS +0.3 kts		
FENCE BOOMS FB 14" D 16" B/W 8:1 FIRST LOSS GROSS LOSS	1.00 1.25	0.7 0.9	1.1 1.3	0.95 1.10	65;3 @ 1.1 [1]	141;30 @ 1.3 [1]	2.75/ SUBMERGED	600;400/ 3,000 (O-8)
FB 26" D 44" B/W 3.5:1 FIRST LOSS GROSS LOSS	0.95 1.32	0.75 1.05	0.95 1.20	1.00 1.25	8.5 @ 1.05	40 @ 1.25	2/0/ NO FAILURE	500/2,900 (O-8)
FB 14" D 25" B/W 3:1 FIRST LOSS GROSS LOSS	0.9 1.2	0.76 0.9	0.9 1.2	0.9 1.2	4.3 @ 1.0	77 [2] @ 1.2	3/planing @ 1.5 kts	400/1,827 to 200 (O-9, O-10)
INTERNAL FOAM FB 10" D 21" B/W 3.6:1 FIRST LOSS GROSS LOSS	0.95 1.25	0.83 1.1	1.1 1.45	1.05 1.3	7 @ 1.05	55 @ 1.25	3.75/ SUBMERGED	360/1,940 (O-9)
PRESSURE INFLATABLE FB 18" D 25" B/W 9.5:1 FIRST LOSS GROSS LOSS	0.90 1.22	0.80 --	1.07 --	1.00 --	19.5 @ 1.00	75.5 @ 1.20	3.5/ SUBMERGED	500/1,730 (O-8)
EXTERIOR TENSION FB 21" D 26" B/W 2.8:1 FIRST LOSS GROSS LOSS	0.9 1.25	0.60 0.95	1.0 1.3	0.7 1.1	4.5 @ 1.0	29 @ 1.2	4.6/NO FAILURE	360/2,064 (O-9)

Actual Measured Wave Conditions:
Wave #1: regular sinusoidal wave: H = 0.8', L = 16.2', T = 1.8 sec
Wave #2: regular sinusoidal wave: H = 1.1', L = 42.1', T = 3.1 sec
Wave #3: harbor chop: H = 0.7', L and T not calculated
[1] In two runs with differing amounts of oil pre-load, first and gross loss speeds were very close; however, the tests with the larger oil pre-load had much larger oil loss rates. The two numbers shown for loss rate correspond to the larger and smaller oil pre-loads shown in the last column.
[2] This is the average of three trials. On the third trial, speeds of first loss and gross loss remained close to others but loss rate increased substantially to 152 gpm. This is likely due to the viscosity of the pre-load oil, which was reduced from 1,200 to 2,000 cSt down to 200 cSt.

APPENDIX B - TEXT REFERENCES

References are listed according to the test facility in which they were performed or by the sponsoring agency. Tests performed by or for other agencies in the OHMSETT Facility are listed with OHMSETT Reports. The list of references is followed by an Annotated Bibliography that lists the booms that were examined in each test and a brief statement describing the extent of the test program.

OHMSETT TESTS

(O-1) McCracken, William E., "Performance Testing of Selected Inland Oil Spill Control Equipment," EPA-600/2-77-150, August 1977. (Tests were performed from April 1975 through June 1975; work was completed in March 1976.)

(O-2) McCracken, William E. and Sol H. Schwartz, "Performance Testing of Spill Control Devices on Floatable Hazardous Materials," EPA-600/2-7-222, November 1977. (Tests were performed from September 1975 through November 1975; work was completed in September 1977.)

(O-3) Breslin, Michael K., "Boom Configuration Tests for Calm-Water, Medium-Current Oil Spill Diversion," EPA-600/2-78-186, August 1978. (Tests were performed in April and September 1977.)

(O-4) Borst, M., and R.A. Griffiths, "Quantified Performance Testing of the Zoom Boom," 1980. (Tests were performed in November 1980.)

(O-5) Borst, Michael, "GemEng Lightweight Fireproof Boom: Oil Containment Testing at OHMSETT," EPS 4-EP-83-5, November 1983.

(O-6) Goodwin, Michael J., David S. DeVitis, Roland L. Custer, Donald L. Backer, Susan L. Cunneff, and Edward F. McClave, "OHMSETT Tests of NOFI Vee-Sweep 600 and NOFI 600S Oilboom," Contract Report OHM-93-001, September 1993. (Tests performed August through October 1992.)

(O-7) Nash, James, David DeVitis, Don Backer, and Susan Cunneff, "Pacific Link Multi Boom Tests," Draft Report, Contract Report No. OHM-95-013, March 1996. (Tests performed June to November 1995.)

(O-8) Devitis, David, Susan Cunneff, and James Nash, "Test and Evaluation of Six Fire Resistant Booms at OHMSETT," U.S. Coast Guard Report CG-D-12-98, December 1997. (Tests performed July through October 1996.)

(O-9) Burk, Christine, David DeVitis, Kathleen Nolan, and William Schmidt, "Test and Evaluation of Four Fire Resistant Booms at OHMSETT," Work Order 24, MAR, Incorporated, July 1999. (Tests performed September through November 1998.)

(O-10) Buist, Ian, James McCourt, Stephen Potter, Larry Hillebrand, and Sharon Buffington, "Re-engineering of a Stainless-steel Fire Boom for Use in Conjunction with Conventional Fire Booms," Final Report prepared for the U.S. Department of the Interior, Minerals Management Service Engineering and Research Branch, August 31, 1999.

ENVIRONMENT CANADA TESTS

(E-1) Solsberg, L.B., R. Abdelnour, B. Roberts, W. Wallace, and W. Purves, "A Winter Evaluation of Oil Skimmers and Booms," EPS 4-EP-84-1, February 1984. (Tests were performed near St. John's, Newfoundland during March and April 1980; one boom was tested in November at OHMSETT; see reference O-4.)

CANADIAN COAST GUARD TESTS

(C-1) Solsberg, L.B. and R.C. Belore, "The Field Evaluation of Five Prototype Lightweight Booms," S.L. Ross Environmental Research Limited, September 1982.

(C-2) Guenette, Chantal, "Canadian Coast Guard Oil Containment Boom Testing Program," S.L. Ross Environmental Research Limited, Ottawa, Ontario, March 1991. (Tests performed in February 1991.)

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(Conference Proceedings Reviewed 1981 through 1999)

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(S-2) Buist, Ian A. William M. Pistruzak, *et al*, "The Development and Testing of a Fireproof Boom," Proceedings of the 1983 Oil Spill Conference, 28 February - 3 March 1983, San Antonio, Texas, p.43.

(S-3) Nordvik, Atle, Paul Hankins, Ken Bitting, and Larry Hannon, "Full Scale Oil Containment Boom Testing at Sea," Proceedings of the 1995 Oil Spill Conference, 27 February - 2 March 1995, Long Beach, California, p. 31.

(S-4) DeVitis, David S. and Larry Hannon, "Resolving the Tow Speed that Causes Boom Oil Loss," Proceedings of the 1995 Oil Spill Conference, 27 February - 2 March 1995, Long Beach, California, p. 865.

(S-5) Hiltabrand, Robert R. and Gail S. Roderick, "Fire-Resistant Booms: From Testing to Operations," Proceedings of the 1999 Oil Spill Conference, 8-11 March 1999, Seattle, Washington.

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(Conference Proceedings Reviewed 1980 through 1999)

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(A-2) Buist, I.A. and S.G. Potter, "Offshore Testing of Booms and Skimmers, "Proceedings of the Eleventh Arctic and Marine Oil Spill Program Technical Seminar (AMOP), 7-9 June 1988, Edmonton, Alberta, p 229.

(A-3) Bitting, Kenneth and James Vicedomine, "NOFI Oil Vee-Sweep and Extension Boom Test at OHMSETT," Proceedings of the Sixteenth Arctic and Marine Oil Spill Program Technical Seminar (AMOP), 7-9 June 1993, Calgary, Alberta, p. 393.

(A-4) Bitting, Kenneth R. And Phillip M. Coyne, "Oil Containment Tests of Fire Booms," Proceedings of the Twentieth Arctic and Marine Oil Spill Program Technical Seminar (AMOP), 11-13 June 1997, Vancouver, British Columbia, p. 735.

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(I-2) Roberts, Archie C., "Shore Termination for Oil Spill Booms," EPA-R2-73-114, 1973.

(I-3) Summary Report of NOFO Exercises 1992.

(I-4) Summary Report of NOFO Exercises 1993.

(I-5) Van Dyck, Robert L., "Improving the Performance of Oil Spill Containment Booms in Waves," Report No. CG-D-43-95, September 1995. (Tests were performed 1993 under contract to the U.S. Coast Guard Research and Development Center, Groton, Connecticut.)

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(I-10) Walz, Michael A. "Second Phase Evaluation of a Protocol for Testing a Fire Resistant Oil Spill Containment Boom," Report No. CG-D-15-99. (Tests were performed at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama during August and September 1998.)

(I-11) Coe, Thomas and Brian Burr, "Control of Oil Spills in High Speed Currents - A Technology Assessment," Report No. CG-D-18-99, U.S. Coast Guard Research and Development Center, Groton, Connecticut, May 1999.

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(0-1) McCracken, William E., "Performance Testing of Selected Inland Oil Spill Control Equipment," EPA-600/2-77-150, August 1977. (Tests were performed from April 1975 through June 1975; work was completed in March 1976.)

Program Note

A series of booms and skimmers tests were performed together. Booms were tested in the catenary and diversionary modes. Test data record maximum stable tow speed and maximum no loss (oil) tow speed. The no loss tow tests were made with 2 mm of oil. Booms tested include the following:

- o *Harbour Boom (Clean Water Inc.)* - internal foam curtain boom
- o *T-T Boom (Coastal Services)* - internal foam curtain boom
- o *O.K. Corral Boom (Acme)* - internal foam curtain boom
- o *Sea Boom (B.F. Goodrich)* - fence boom
- o *Mark VI Boom (Slickbar Inc.)* - external foam curtain boom
- o *Sea Curtain Boom (Kepner)* - internal foam curtain boom
- o *Pace Boom (Steltner)* - pressure-inflatable curtain boom
- o *Expandi-Boom (Whittaker)* - self-inflatable curtain boom

(O-2) McCracken, William E. and Sol H. Schwartz, "Performance Testing of Spill Control Devices on Floatable Hazardous Materials," EPA-600/2-7-222, November 1977. (Tests were performed from September 1975 through November 1975; work was completed in September 1977.)

Program Note

A series of booms and skimmers tests were performed together. Booms were tested in the catenary and diversionary modes. Test data record maximum stable tow speed and maximum no loss tow speed. The no loss tow tests were made with 2 mm of three hazardous floating substances; i.e., naptha, octanol, and dioctyl phthalate. Booms tested include the following:

- o *Harbor Containment Boom (Clean Water Inc.)* - internal foam curtain boom
- o *Sea Boom (B.F. Goodrich)* - fence boom
- o *High Seas Barrier (Prototype - U.S. Coast Guard)* - pressure inflatable fence boom

(O-3) Breslin, Michael K., "Boom Configuration Tests for Calm-Water, Medium-Current Oil Spill Diversion," EPA-600/2-78-186, August 1978. (Tests were performed in April and September 1977.)

Program Note

Tests were performed to determine the effects of boom angle, length, and rigging configuration on diversion of oil floating on moving streams. The B.F. Goodrich Seaboom (fence boom) was used in a diversionary mode, in a vee shape, and as a funnel.

(O-4) Borst, M., and R.A. Griffiths, "Quantified Performance Testing of the Zoom Boom," 1980. (Tests were performed in November 1980.)

Program Note

This self-inflatable curtain boom was tested as a part of a co-operative research and development project of the Environmental Impact Control Directorate. This unedited report was distributed to people working in related research. Results show oil loss rates for the boom towed at various velocities in calm water and four wave patterns.

(O-5) Borst, Michael, "GemEng Lightweight Fireproof Boom: Oil Containment Testing at OHMSETT," EPS 4-EP-83-5, November 1983.

Program Note

The GemEng Ltd internal foam fire containment boom was tested to determine oil loss rates at various tow speeds in calm water and regular waves. The boom was also tow-tested in burning crude oil. Tests also evaluated the boom's ability to sustain exposure to a harbor chop wave for an extended period of time.

(O-6) Edward F. McClave, "OHMSETT Tests of NOFI Vee-Sweep 600 and NOFI 600S Oilboom," Contract Report OHM-93-001, September 1993. (Tests performed August through October 1992.)

Program Note

This pressure inflatable curtain boom is designed to be towed at higher than normal speeds because of the "V" configuration. Netting across the bottom of the skirt helps to maintain the V configuration and stabilizes the oil in the sweep. Detailed tests show first loss and gross loss tow speed for the Vee-Sweep boom and also for the 600S diversionary boom.

(O-7) Nash, James, David DeVitis, Don Backer, and Susan Cunneff, "Pacific Link Multi Boom Tests," Draft Report, Contract Report No. OHM-95-013, March 1996. (Tests performed June to November 1995.)

Program Note

Special boom was tested as a part of a boom skimmer system. Data records tow force, wave conformance, first loss and gross of oil at three tow speeds and wave conditions. (This information was not used for analysis because the boom type could not be determined.)

(O-8) Devitis, David, Cunneff, Susan, and Nash, James, "Test and Evaluation of Six Fire Resistant Booms at OHMSETT," U.S. Coast Guard Report CG-D-12-98, December 1997. (Tests performed July through October 1996.)

Program Note

Six booms produced by five manufacturers were tested during July to October 1996. Booms were tested for first loss tow speed, oil loss rate, and critical tow speed. No fires were used during these tests. Four of the booms performed within speed and rate loss ranges that have been measured for commercial non-fire booms. One boom was found to be superior in critical tow speed, but was at the lower edge of the range for first loss tow speed. Booms tested include the following:

- o *American Fire Boom (American Marine)* - curtain boom with internal foam flotation
- o *Dome Boom* - stainless steel fence boom developed in an early program by Dome Petroleum
- o *Pyroboom (Applied Fabric Technology)* - fence boom
- o *Paddle Wheel Boom (Oil Stop)* - non-standard boom designed to contain oil in high currents
- o *Fireproof Oil Containment Boom (Spill-Tain)* - stainless steel fence boom with closed cell foam glass flotation
- o *Fire Boom (Oil Stop)* - pressure inflatable curtain boom

(O-9) Burk, Christine, David DeVitis, Kathleen Nolan, and William Schmidt, "Test and Evaluation of Four Fire Resistant Booms at OHMSETT," Work Order 24, MAR, Incorporated, February 1999. (Tests performed August through October 1998.)

Program Note

Four fire containment booms passed an initial burn test at the Coast Guard test facility in Mobile, Alabama and were tested at OHMSETT to measure the oil collection and containment performance and sea keeping performance in a variety of towing and wave conditions. Booms tested include:

- o *Elastec/American Marine Hydrofire*
- o *Spill-Tain*
- o *Applied Fabrics Technologies Pyroboom®*
- o *Applied Fabrics Technologies/SL Ross Pocket Boom*

(O-10) Buist, Ian, James McCourt, Stephen Potter, Larry Hillebrand, and Sharon Buffington, "Re-engineering of a Stainless-steel Fire Boom for Use in Conjunction with Conventional Fire Booms," Final Report prepared for the U.S. Department of the Interior, Minerals Management Service Engineering and Research Branch, August 31, 1999.

Program Note

The large, stainless steel Dome fire containment boom was redesigned to be cheaper, lighter, and easier to handle. The result of this effort was the Applied Fabrics Technologies/SL Ross Pocket Boom. This report documents the results of tests in Lake Erie, at OHMSETT, and at the U.S. Coast Guard Fire and Safety Test Detachment at Mobile, Alabama.

ENVIRONMENT CANADA TESTS

(E-1) Solsberg, L.B., R. Abdelnour, B. Roberts, W. Wallace, and W. Purves, "A Winter Evaluation of Oil Skimmers and Booms," EPS 4-EP-84-1, February 1984. (Tests were performed near St. John's, Newfoundland during March and April 1980; one boom was tested in October at OHMSETT.)

Program Note

Containment booms were tested in the Atlantic Ocean for streamed and catenary towing resistance, seakeeping characteristics, ease of handling, and oil retention capability. In many cases severe offshore weather precluded taking precise numerical data. The Zooom boom was tested separately with oil at OHMSETT in October of 1980. These tests determined oil loss rate for varying tow speeds and wave conditions. At sea, tow forces on booms were recorded and booms were tested with a barrel of oil. Performance in oil was assessed by the length of time required for oil to completely pass under the boom. The six booms tested include the following:

- o *U.S. Coast Guard Boom (B.F. Goodrich)* - pressure-inflatable curtain boom
- o *Troilboom (Trelleborg)* - external tension boom
- o *Albany Oilfence (Albany International)* - fence boom
- o *Zooom Boom (Versatech Products)* - self-inflatable curtain boom
- o *AMOP Boom (McAllister Engineering)* - self-inflatable curtain boom
- o *Seapack (Vikoma International)* - pressure inflatable, water ballast boom

CANADIAN COAST GUARD TESTS

(C-1) Solsberg, L.B. and R.C. Belore, "The Field Evaluation of Five Prototype Lightweight Booms," S.L. Ross Environmental Research Limited, September 1982.

Program Note

A series of sea trials were performed by the Canadian Coast Guard at Mulgrave, Nova Scotia in August 1982. Five low cost, semi-disposable booms were tested in various tow and wave conditions with and without organic oil (rapeseed). Booms varied greatly in size and configuration, but all were curtain booms with internal foam flotation. Booms were tested and rated for general performance. Recorded data includes weather conditions, wave heights, tow speeds, and forces on booms. Booms tested include:

- o *Morris Boom* - internal foam curtain boom
- o *MRD Boom* - internal foam curtain boom
- o *Versatech El Cheapo Segundo* - internal foam curtain boom
- o *Hurum Boom* - internal foam curtain boom
- o *Saniboom* - internal foam curtain boom

Some of the booms tested were highly rated; however, tests only graded booms for seakeeping ability, adequacy of freeboard, durability, ease of handling, and in some limited cases, ability to contain oil. Since none of these booms are currently being produced commercially, these results are not significant. This study has therefore, not been included in the analysis.

(C-2) Guenette, Chantal, "Canadian Coast Guard Oil Containment Boom Testing Program," S.L. Ross Environmental Research Limited, Ottawa, Ontario, March 1991. (Tests performed in February 1991.)

Program Note

Tests were performed in February 1991 in a recirculating flume tank located at the Institute of Fisheries and Marine Technology in St. John's, Newfoundland. Test results include first loss tow speed and oil loss rate plus a subjective evaluation of each boom's performance. Booms tested include:

- o *POL-E-BOOM* - fence boom with solid flotation
- o *Ro-Boom* - pressure inflatable curtain boom
- o *Vikoma* - pressure inflatable boom with water tube ballast
- o *Flexy Oil Boom* - fence boom with solid flotation
- o *SeaCurtain ReelPak Offshore (Kepner)* - self-inflatable curtain boom
- o *NOFI Oil Boom X-F11* - pressure-inflatable curtain boom
- o *Globe Boom 36 ED (Applied Fabrics Technology)* - fence boom with spherical flotation

TEST DATA FROM INTERNATIONAL OIL SPILL CONFERENCES
(Conference Proceedings Reviewed 1981 through 1999)

(S-1) Meikle, K.M., "An Effective Low-Cost Fireproof Boom," Proceedings of the 1983 Oil Spill Conference, 28 February - 3 March 1983, p.39.

Program Note

This paper summarizes the test report shown as O-5 and since it does not present any new material, it is not used in analysis..

(S-2) Buist, Ian A. William M. Pistruzak, *et al*, "The Development and Testing of a Fireproof Boom," Proceedings of the 1983 Oil Spill Conference, 28 February - 3 March 1983, p.70.

Program Note

Tow tests at OHMSETT show boom stability and first loss of four test oil types at several tow speeds and wave conditions using the Dome stainless steel fence boom. These results are reported in the analysis.

(S-3) Nordvik, Atle, Paul Hankins, Ken Bitting, and Larry Hannon, "Full Scale Oil Containment Boom Testing at Sea," Proceedings of the 1995 Oil Spill Conference, 27 February - 2 March 1995, Long Beach, California, p. 31.

Program Note

This paper summarizes the MSRC at sea tests, commenting on the forces on booms and the requirements for buoyancy/weight ratio for boom stability during towing.

(S-4) DeVitis, David S. and Larry Hannon, "Resolving the Tow Speed that Causes Boom Oil Loss," Proceedings of the 1995 Oil Spill Conference, 27 February - 2 March 1995, Long Beach, California, p. 865.

Program Note

This paper examines first oil loss tow speeds for all tests performed at OHMSETT to determine if tank wall and bottom effects influence speed and whether these effects can be minimized. The paper concludes that although investigation of these effects is not complete, data suggest that boom capabilities reported in earlier tests are likely to be conservative. This paper is not used for containment boom analysis.

(S-5) Hiltabrand, Robert R. and Gail S. Roderick, "Fire-Resistant Booms: From Testing to Operations," Proceedings of the 1999 Oil Spill Conference, 8-11 March 1999, Seattle, Washington.

Program Note

This paper summarizes the MSRC Phase 1 and 2 test results together (references I-6 and I-7) and compares them to the OHMSETT tow tank results (O-8). It further reports on the results of static burn tests performed at Mobile, Alabama. This paper provides an excellent commentary on the results of these tests, but since all of the tests mentioned are analyzed from the basic references, this paper is not used for additional analysis.

TEST DATA FROM AMOP CONFERENCES
(Conference Proceedings Reviewed 1980 through 1999)

(A-1) Purves, W., R. Abdelnour, B. Roberts and W. Wallace,"Booms Offshore," Proceedings of the Third Arctic and Marine Oil Spill Program Technical Seminar (AMOP), 3-5 June 1980, Edmonton, Alberta, p 222.

Program Note

Six offshore booms were tested in the Atlantic Ocean near St. Johns, Newfoundland during February, March, and April of 1980. The report shows tow forces on the booms and in tests with oil measures performance by the amount of time required for the oil to pass under the boom. The report also comments on how boom appeared to perform based on boom shape and configuration. Booms tested include:

o *MacAllister/AMOP Boom* - self-inflatable curtain boom
o *Zooom Boom (Versatech)* - self-inflatable curtain boom
o *U.S. Coast Guard Boom (Goodyear)* - pressure-inflatable curtain boom
o *Seapack (Vikoma)* - pressure-inflatable water ballast boom
o *Troilboom* - external tension boom
o *Oilfence (Albany)* - fence boom

This paper provides an early report on tests that are a later subject of a complete test report (E-1). This paper is therefore not used as a separate part of the booms analysis; however, the paper does contain some comments and insights into boom performance that were not published in the final report. As a result, some specific information and comments have been entered in this study along with the analysis of the final test report (E-1). In addition, the AMOP paper has some interesting observations on boom performance in general, and not specifically related to the subject test. For example, the paper offers an interesting discussion of splashover loss in rough offshore seas, information on handling equipment needed to deploy large booms, boom performance as a function of heave response, and boom effectiveness and a function of boom shape. The interested reader should consult this paper for of these observations.

(A-2) Buist, I.A. and S.G. Potter, "Offshore Testing of Booms and Skimmers," Proceedings of the Eleventh Arctic and Marine Oil Spill Program Technical Seminar (AMOP)," 7-9 June 1988, Edmonton, Alberta, p. 229.

Program Note

This paper describes trials offshore Newfoundland in September and October 1987 intended to evaluate the containment and recovery capability of Canadian Coast Guard stockpiled response equipment. RO-BOOM and Vikoma Ocean Pack, both pressure inflatable curtain booms, were tested with samples of crude oil. Test data recorded sea keeping performance and estimated oil leakage rates at varying tow speeds.

(A-3) Bitting, Kenneth and James Vicedomine, "NOFI Oil Vee-Sweep and Extension Boom Test at OHMSETT," Proceedings of the Sixteenth Arctic and Marine Oil Spill Program Technical Seminar (AMOP), 7-9 June 1993, Calgary, Alberta, p. 393.

Program Note

This paper describes the tests reported in reference (O-6).

(A-4) Bitting, Kenneth R. And Phillip M. Coyne, "Oil Containment Tests of Fire Booms," Proceedings of the Twentieth Arctic and Marine Oil Spill Program Technical Seminar (AMOP), 11-13 June 1997, Vancouver, British Columbia, p. 735.

Program Note

This paper describes the tests reported in reference (O-8).

TESTS PERFORMED BY OTHER AGENCIES AND INDUSTRY

(I-1) Cunningham, John, "A Rapidly Deployable Oil Containment Boom for Emergency Harbor Use," EPA-R2-73-112, 1973.

Program Note

A description of boom performance requirements for emergency harbor use based on the experience of the Marine Division of the New York City Fire Department. The report contains some interesting anecdotal information on New York City spills but no hard data. This report has not be used in the final review of booms.

(I-2) Roberts, Archie C., "Shore Termination for Oil Spill Booms," EPA-R2-73-114, 1973.

Program Note

This report describes a device that can be used to prevent oil spill leakage between the end of the boom and the adjacent shoreline, deck, or bulkhead. This work is noted, but because it does not involve containment boom performance, it has not been used in the analysis.

(I-3) Summary Report of NOFO Exercises 1992.

Program Note

At sea trials of the RO-BOOM 3500 pressure inflatable curtain boom were held off Norway using oil emulsion. Tow velocity was increased until oil leakage was observed.

(I-4) Summary Report of NOFO Exercises 1993.

Program Note

At sea trials of the RO-BOOM 3500 pressure inflatable curtain boom were held off Norway using oil emulsion. Tow velocity was increased until oil leakage was observed.

(I-5) Van Dyck, Robert L., "Improving the Performance of Oil Spill Containment Booms in Waves," Report No. CG-D-43-95, September 1995. (Tests were performed in 1993 under contract to the U.S. Coast Guard Research and Development Center, Groton, Connecticut.)

Program Note

A series of scaled tests were performed by the Davidson Laboratory at Stevens Institute of Technology in 1993 using pressure inflatable curtain boom. Air pressure was varied to produce changing buoyancy to weight ratios.

Scales of 1/8, 1/4, and 3/8 were used with a constant 24 length of boom. Tests were performed using varying wave heights, tow speeds, and buoyancy to weight ratios in the Davidson Laboratory tow tank. Results show drag forces and heave response as a function of tow speed, wave height, wave steepness, and buoyancy to weight ratio of the boom tested. Tests show scaled drag forces that could be used to confirm forces on booms equations.

(I-6) Sloan, Stacey L., Kenneth R. Bitting, and Atle B. Nordvik, "Phase I: Oil Containment Boom At Sea Performance Tests," Marine Spill Response Corporation Technical Report Series 94-0077, 1994.

Program Note

Thirty seven tests were conducted in Lower New York Harbor Bay and in the Atlantic Ocean east of Sandy Hook, New Jersey. Tests were performed in calm water and in sea state two, which corresponds to the ASTM definition of Open Water. Tests provided data on boom performance at sea based on physical properties of the booms, hydrodynamic forces, and environmental conditions. Oil was not used during tests. Results show the relationship between buoyancy to weight ratio and tow speed producing submergence as well as boom conformance to waves. Data recorded shows tension on the boom, freeboard, draft, and submergence as a function of tow speed. Booms tested include the following:

- o *Navy 3M Fireboom* - this internal ceramic float curtain boom is presently called American Fireboom and manufactured by Elastec/American Marine.
- o *Norlense A/S Barrier Boom Model No.-1370-R* - self inflatable curtain boom
- o *USCG Inflatable Oil Containment Boom* - pressure inflatable curtain boom manufactured by Oil Stop Inc.
- o *US Navy Model USS-42 Boom* - pressure inflatable curtain boom

(I-7) Sloan, Stacey L., Daniel F. Pol, and Atle B. Nordvik, "Phase 2: At Sea Towing Tests of Fire Resistant Oil Containment Booms," Marine Spill Response Corporation Technical Report Series 95-001, 1995.

Program Note

A series of at sea towing tests of fire resistant oil containment boom were performed at a site offshore of Galveston, Texas. Booms were evaluated for acquisition and data were collected to verify ASTM guidelines for selection of booms as well as to validate future test tank data. Fourteen tests were performed in sea state 1 recording tow tension, skirt depth, skirt angle, skirt tilt, and freeboard as a function of tow speed. Booms tested include:

- o *Navy 3M Fire Boom (American Marine)* - internal foam curtain boom
- o *Pyroboom (Applied Fabric Technology)* - fence boom
- o *Oil Stop Auto Boom Fire Model* - pressure-inflatable curtain boom
- o *SeaCurtain FireGard (Kepner)* - self-inflatable curtain boom

(I-8) Nordvik, Atle B., Stacey L. Sloan, Joe Stahovec, Ken Bitting, and Daniel F. Pol, "Phase 3: Oil Containment Boom At Sea Performance Tests," Marine Spill Response Corporation Technical Report Series 95-003, 1995.

Program Note

A series of at sea towing tests were conducted in lower New York Harbor Bay and east of Sandy Hook, New Jersey. These tests collected data on boom performance at sea in higher sea states and to develop boom selection criteria based on typical modes of boom failure. Recommendations were made to improve the ASTM guidelines for boom selection. Data were collected to show how irregular tow speeds affect tow force; tow force as a function of tow speed; comparison of buoyance to weight ratio to tow speed of submergence; and boom freeboard and draft as a function of tow speed. Four booms were tested in a four day test series:

o *Norlense A/S Barrier Boom Model No.-1370-R* - self inflatable curtain boom
o *USCG Inflatable Oil Containment Boom* - pressure inflatable curtain boom manufactured by Oil Stop Inc.
o *US Navy Model USS-42 Boom* - pressure inflatable curtain boom
o *MSRC Sea Sentry II Boom (Engineered Fabrics)* - pressure inflatable curtain boom

This report is not used in the general analysis because it only deals in forces on boom, however, forces on booms information is used in the special forces section in Appendix B. This report also makes recommendations for ASTM Standards. These recommendations are reviewed in the summary chapter at the end of the report.

(I-9) Eisenberg, Kedric C., Jon F. Etxegoien,, and Deborah A. Furey, "At-Sea Evaluation of the Coast Guard Voss, NOFI-V and FIOCS Oil Recovery Systems," Report No. CG-D-19-96. (Tests were performed for the U.S. Coast Guard in May 1993 by Carderock Division, Naval Surface Warfare Center, Bethesda, Maryland.)

Program Note

At sea trials evaluate the seaworthiness, handling, and towing characteristics of three containment booms used with Vessel-of-opportunity (VOSS) skimming systems. Systems include:

o *Coast Guard VOSS* - external tension boom
o *NOFI-V Sweep* - pressure-inflatable curtain boom
o *FIOCS System* - pressure-inflatable curtain boom

The system outriggers were instrumented to measure strain during standard operations and maneuvers. Load cells were attached to handling lines to determine tensions in the various systems during operations. Graphical data shows loads over periods of several minutes for varying tow speeds and sea conditions. Tabulated data show mean, maximum, and minimum forces in these conditions. Conclusions are reached and the performance of each of these systems is described in detail.

Boom performance is noted relative to how systems ride the waves and this performance is related to buoyancy to weight ratio, but there are no specific data showing this relationship. Data presented here are not used in the general analysis but instead are used in the forces on booms analysis in Appendix B.

(I-10) Walz, Michael A. "Second Phase Evaluation of a Protocol for Testing a Fire Resistant Oil Spill Containment Boom," Report No. CG-D-15-99. (Tests were performed at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama during August and September 1998.)

Program Note

This test series was designed to develop a standard method to evaluate the ability of fire resistant booms to withstand both fire and waves. The results were used to finalize an ASTM Standard Guide for In-Situ Burning of Oil Spills on Water: Fire-Resistant Containment Boom. This report describes the burn tests, the heat and temperature conditions that existed during the tests, and the condition of the tested booms after the burns were complete. These results are not used for analysis in this study.

(I-11) Coe, Thomas and Brian Burr, "Control of Oil Spills in High Speed Currents - A Technology Assessment," Report No. CG-D-18-99, U.S. Coast Guard Research and Development Center, Groton, Connecticut, May 1999.

Program Note

This report provides an excellent description of the requirements and methods of responding to oil spills in fast current situations. It shows how to boom off difficult high current areas, describes innovative containment systems, and high current skimming systems. It is an excellent "how to" manual but since it does not contain test data for boom systems, it is not used for analysis.

APPENDIX C
FORCES ON BOOMS

INTRODUCTION

Many controlled tests measure forces on containment booms; however, most of these reports do not attempt to develop a means of computing forces on booms that follow test results. Recently controlled tests were performed with the specific purpose of comparing measured forces with those computed with existing formulae, and, further, developing a more exact means of computation using the new formulae developed from these measured results. Before this work was complete, there were only two methods of computing forces on booms. First, the simple formula developed by the International Tanker Owners Pollution Federation and a second a formula developed by Exxon Production Research Company and published since 1986 in the World Catalog of Oil Spill Response Products. The former is referred to the ITOPF formula and the latter is referred to as the World Catalog formula. Comparing computations using both of these formulae and measured results from tests at sea has shown that both only follow measured results in rather limited areas and generally underestimate the actual forces on booms. The new Minerals Management Service(MMS) 1999 test program, "Estimation of Towing Forces on Oil Spill Containment Booms (1)," was specifically designed to develop a means of computing forces on booms that follow measured results more exactly. This is done by:

- o Making a great many measurements of forces on seven different booms towed at a progression of generally four speeds
- o Checking results with ITOPF and World Catalog formulas
- o Developing a new set of empirical equations in the ITOPF format that match measured results

This present study begins by examining the MMS report in detail to determine how well the new empirical equations (referred to hereafter as the MMS equations) follow measured results and if the ITOPF and World Catalog equations have potential for producing similar results. This is done by:

- o Computing forces on booms using the MMS equations and comparing these results with measured results
- o Computing forces on booms using the World Catalog equations and comparing these results with measured results
- o Using measured results to adjust the World Catalog equations so that they produce results that more nearly follow measured values
- o Assessing the performance of these two computation methods to determine which serve the user best and in what circumstances

Additional computations were not made using the ITOPF equations because it was determined that they are simply a special sub-set of the MMS empirical equations.

Having completed this preliminary work, all other boom test reports are reviewed and measured values of boom tension are compared with computations using the MMS equations and the adjusted World Catalog equations. In each case there is an assessment of results to determine which equations match measured values best. Finally, there is a summary section that assesses all results together and suggests the best methods of computing forces on booms using presently available computational methods. Test reviews are grouped according to the facility/location where tests were performed and further arranged in order of the year in which they were performed.

1.0 Minerals Management Service Tests at OHMSETT 1999 (1)

The U.S. Department of the Interior, Minerals Management Service, sponsored a series of tests carried out at OHMSETT during the period of 24 June to 10 July 1998. These tests measured the towing forces on booms using 7 containment booms, a range of gap ratios, wave conditions, and tow speeds. The data from these tests were used to develop equations that predict tow force and required boom tensile strength based on these results. A comparison was made between these results and the ITOPF equations, the World Catalog equations, and forces measured in the Marine Spill Response Corporation/U.S. Coast Guard tests performed at sea.

1.1 Test Description

Booms were deployed in the OHMSETT test tank for full scale tests. A load cell was mounted on each of the tow points on the towing bridge. The load cells had a capacity to 2000 pounds force with an accuracy of ± 10 pounds force. The load cells were calibrated prior to the tests and checked to confirm their accuracy. Data from the load cells, wave height, and tow speed, were recorded by computer every 0.1 seconds. Visual observations recorded boom behavior including submergence, planing, wave conformance, and splash over.

1.2 Boom Description

Table 1.1 MMS Tests of Booms at OHMSETT (1)

BOOM	FREEBOARD (ft)	DRAFT (ft)	BUOYANCY /WEIGHT RATIO
CCG 18 in curtain boom	0.5	1.125	5:1
CCG 18 in fence boom	0.58	0.92	3:1
CCG 24 in curtain boom	1.1	0.92	14:1
CCG 36 in fence boom	1.0	2.0	5:1
USCG Oil-Stop curtain boom	1.42	2.5	20:1
CCG Ro-Boom curtain boom	2.8	3.7	20:1
US Navy curtain boom	1.33	3.0	8:1

1.3 Test Variables

The test matrix included four variables: tow speed, wave conditions, boom length, and gap ratio. Most booms were towed at four speeds, 0.5, 1.0, 1.5, and 2.0 knots. Some of the larger booms were only towed at three speeds. Tests were conducted in calm water, a regular wave with a height of 7.3 inches, and a harbor chop wave with a height of 12.3 inches. A total of 358 test runs were made, in most cases 48 runs per boom.

Average tension was recorded as half the sum of the tension on each of the two tow points. It should be noted that this is half the total tension, or drag, generally computed in the World Catalog formula. It was noted that the tension experienced by a boom is not constant, particularly when towed through waves. As the boom follows the crests and troughs of waves the tension fluctuates, peaking as the boom catches the front of the wave. Peak and mean tension values were recorded, with the peak loads defined as the 95th percentile of the tension readings recorded for each run. Because a boom must be designed to be able to withstand these peak tensions, the focus of the analysis is on these 95th percentile tension loads.

1.4 Discussion of Existing and New Empirical Equations

The ITOPF equation for computing forces on booms is perhaps the best known and is shown below (2).

$$F_w = 26\ A_w\ (V_w/40)^2$$
$$F_c = 26\ A_c\ V_c^2$$

where:
- F_w = force on a boom due to wind, kg
- A_w = freeboard area, m^2
- V_w = wind velocity, knots
- F_c = force on a boom due to waves and current, kg
- A_c = submerged area, m^2
- V_c = current/tow velocity, knots

Although not specified in some references, the submerged area is clearly what is generally called the "projected area," which is either the boom draft times the towing gap or the boom length times the draft times the gap ratio.

Comparison of the results using the ITOPF formula and other computations is difficult because of the units of force. Further, the force computed here is the total force, not tension (one half of total force) used in the MMS equations. Other computations used here have the result in pounds of force. Converting the ITOPF equation to tension and pounds of force, the constant multiplier becomes approximately 2.64 instead of 26. It turns out that this is just a special case in the equations developed in the MMS study. This relationship is discussed later along with the MMS equations.

The World Catalog/Exxon equations have been published in editions of the Catalog since 1986 and most recently in 1999 (3,4). These formulas are shown by the following:

$$T_a = 0.5\ L\ \tau\ C_d\ \rho_a\ f\ V_a^2$$
$$T_w = 0.5\ L\ \tau\ C_d\ \rho_w\ d\ (V_w + 0.5\ \sqrt{H_s})^2$$
$$D = 2\ (T_a + T_w)$$

where:
- D = total drag force, in pounds force
- T_a = tension due to wind, in pounds force
- T_w = tension due to waves, in pounds force
- V_a = wind speed in ft/sec
- V_w = current/tow speed, ft/sec
- ρ_a = density of air (0.00238 slugs/ft^3)
- ρ_w = density of water (1.98 slugs/ft^3)
- L = length of the boom, ft
- τ = tension parameter, dimensionless
- C_d = drag coefficient (assumed to be 1.5), dimension less
- f = boom freeboard, ft
- d = boom draft, ft
- H_s = significant wave height, ft

Note that unlike other formulas, all velocities are in feet/second; therefore most towing velocities must be converted. (1 kt = 1.69 ft/sec)

The MMS study notes that the force of wind is generally a very small part of the force on the boom. Since winds were light during the OHMSETT force measurement tests, the force of the wind was not considered in the computations.

Tension parameter (τ) in the World Catalog equation is a function of the gap ratio and discrete values can be taken from the curve in Figure 1.1. Note that in the simple ITOPF formula, and in the MMS empirical formulas that are described later, the force is proportional to the projected area of the boom, which means that it is directly proportional to the gap ratio. The curve for tension parameter is not a straight line function, so the force is increasing exponentially with the gap ratio. Measured values of tension on booms tend to support this concept.

The source of the curve for tension parameter is not known. Most important, it is not known whether this is a theoretical curve or one determined by measuring forces on booms in testing. Users of the World Catalog equation have long suspected that results of computations could be improved by adjusting the tension parameter curve, or drawing a series of curves, based on carefully measured values of boom tension taken from full scale tests. This had never been done because test data were not available; however this is what has been done with considerable success using MMS data. This procedure is described in detail in paragraphs that follow.

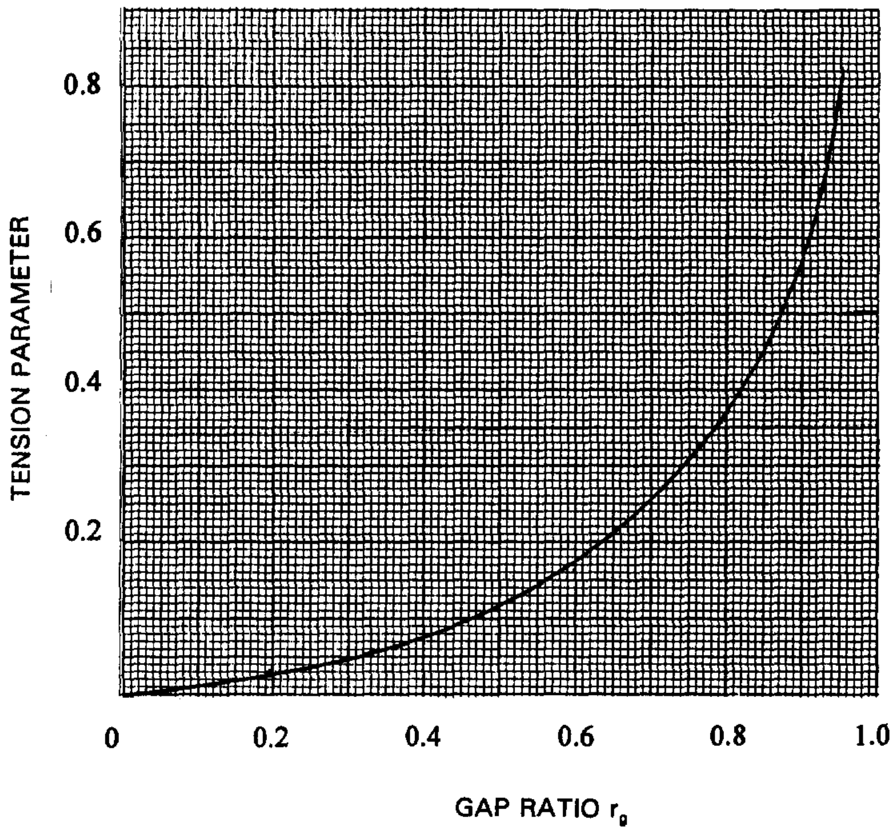


Figure 1.1 Tension Parameter vs. Gap Ratio

1.5 MMS Formulas for Boom Tension (1)

Measured data for the booms tested were tabulated for the various tow speeds, gap ratios, and wave conditions. These data were then used to develop a simple set of formulas to compute the tensile force on a boom in terms of the projected area of the submerged portion of the boom and tow speed. Since the force of the wind was determined to be small, it was not included. The equations developed take the form of the ITOPF equation with a special set of constants developed for each boom and environmental condition. The study notes that the correlation was done using a least-squares fit with all but a few R-squared values of 0.95 or greater. The original equation had a conversion factor to maintain consistent units. Only the converted equation is considered here, and the constant K is the converted valued called K' in the report. The basic equation developed for tension is shown by:

$$T = K A V^2$$

where: T = tensile force in pounds

K = constant with the units $lb_f/(ft^2 \times knots^2)$

A = projected area of the submerged portion of the boom, ft^2
V = tow speed, knots

(Note here that the projected area is defined as either the boom draft times the towing gap or the boom length times the draft times the gap ratio.)

This basic equation becomes a whole series of equations by giving values to K that permit the computed values of tension to follow measured values always taken at the 95th percentile. Table 1.2 shows the computed values of K to be used in the equation.

Table 1.2 Values of K for Booms Tested

BOOM	CALM WATER	REGULAR WAVES	HARBOR CHOP
CCG 18 in curtain boom	1.7	2.8	3.1
CCG 18 in fence boom	1.7	4.9	5.5
CCG 24 in curtain boom	2.0	2.8	3.5
CCG 36 in fence boom	3.2	5.7	7.0
USCG Oil-Stop curtain boom	2.0	2.9	2.9
CCG Ro-Boom curtain boom	4.8	6.0	6.6
US Navy curtain boom	3.4	4.5	4.6
MAXIMUM VALUES	4.8	6.0	7.0
AVERAGE VALUES	2.7	4.2	4.7

As was noted previously, the ITOPF equation converted to English units is identical to the MMS equation with K = 2.64. This is close to the constant used in the MMS equation for 18 inch curtain boom in regular waves. Of course where the ITOPF constant is very close to the constant used in the MMS equation, the computed results will be very close to the measured values. Where the constant is not close to the MMS constants, the computed values will not be at all close to the measured values. This shows that the ITOPF equation is just a sub-set of the new MMS equations. This is not to detract from that original effort to produce that equation. This equation is perhaps twenty years old or more and those who developed it did not have access to the wealth of data that were used to produce the MMS equations. In any case, the ITOPF equation is not used in this report to compare computed values of tension because it either follows measured values or does not depending on whether the ITOPF constant is close to the MMS constant used to follow the measured values from the tests.

The MMS report suggests that averaged values for the constant K could be used to compute boom tension for the basic spill environments, that is, calm water, protected water, and open water, using a typical boom size for each of these environments. The suggested values are shown on Table 1.3.

Table 1.3 Values of the Constant K for Standard Water Body Classifications

WATER BODY CLASSIFICATION	AVERAGE VALUES OF K
CALM WATER (WAVE HT. 0 - 1 ft) 18 inch BOOMS	1.7
PROTECTED WATER (WAVE HT. 0 - 3 ft) 24 and 36 inch BOOMS	4.3
OPEN WATER (WAVE HT. 0 - 6ft) 47, 52, and 67 inch BOOMS	4.7

In a table that follows in this section these average values of K are used to compute boom tension on the boom sizes typical for the three wave environments and compared to similar calculations of tension for wave heights of 1, 3, and 6 feet using the adjusted World Catalog equation. The user can be the judge of which method is better.

1.6 Adjustment of the World Catalog Equation

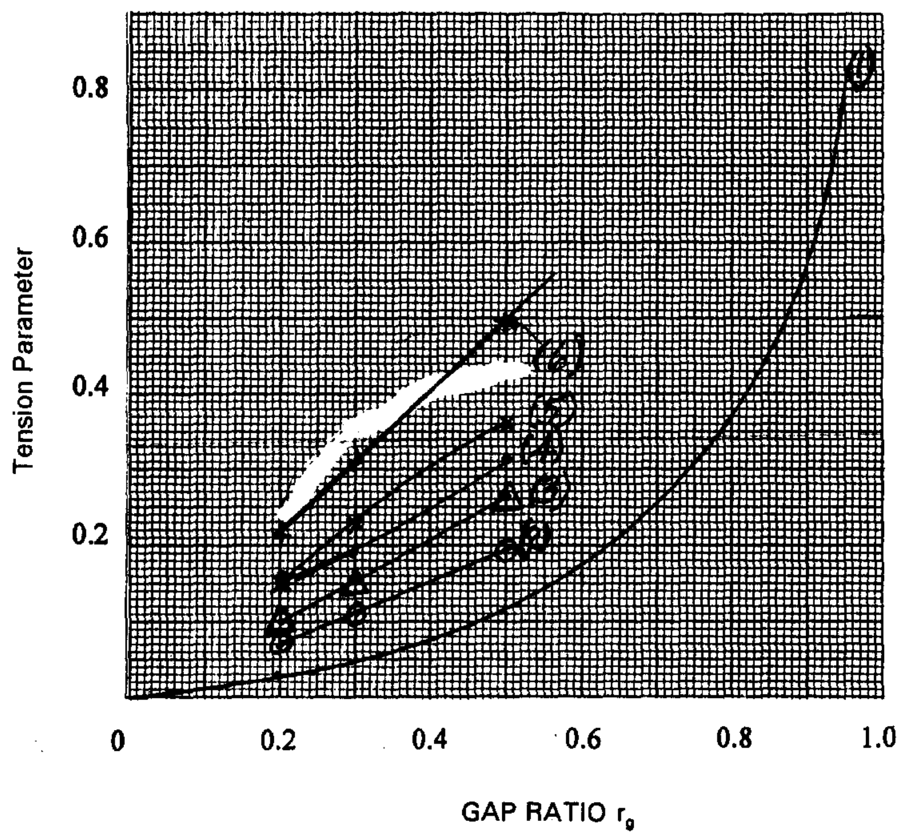
It was noted previously that the World Catalog equation follows measured values of tension well in some cases but gives values that are quite low in many cases. It has been suspected that the low values produced were caused by an inappropriate form of the curve for tension parameter. This curve may not have been confirmed with detailed measured data, but that opportunity presents itself here.

Taking steps to improve the World Catalog equation is justified for at least two reasons. First, since the equation uses a curve to determine a tension parameter as a function of gap ratio, the computed result of the tension on a boom does not have to be a straight line function directly proportional to gap ratio. The curve provides some room for adjustment. Second, the World Catalog equation has a term to account for wave height. This is important because any wave height can be entered. The MMS equations adjust computed values using a separate constant for wave height, but the wave sizes are small and limited to those that could be used in the full scale tank tests. The only wave heights tested were 7.3 inches and 12.3 inches, roughly ½ foot and 1 foot. How these equations represent tension in higher waves is not known. The World Catalog equations were adjusted by using the MMS 95th percentile measured result at 1 knot in calm water for each boom tested as a solution to the equation and computing a new value of tension parameter for each gap ratio tested. The calm water result was used to determine the new tension parameter curve because the World Catalog equations have an entry for wave height. Further, one knot was selected as the best place to center data because that is where most of the boom towing is done. Further, since all of these equations have a term of velocity squared, using a higher towing speed, such as two knots, may tend to increase any errors there may be in the equations. Using this information, a set of curves was drawn for tension parameter for each boom size, but not for each boom type. These new values of tension parameter were then used to compute a result corresponding to measured values taken during tests. The results of these computations are very encouraging. The adjusted World Catalog equations follow measured results as well as the MMS empirical equations and sometimes better. The MMS empirical equations are easier to use, but they are less universal. The constants for these equations only include calm water and waves of 7 and 12 inches, which is rather restrictive in that Protected Water is defined by waves of up to 3 feet and Open Water by waves of up to 6 feet. The World Catalog equation has a term for wave height, therefore this equation shows potential for use in a far wider range of sea conditions.

Figure 1.2 shows the new curves for tension parameter based on the computations described above. The same curve is used for the Canadian Coast Guard 18 inch curtain boom and the 24 inch curtain boom because the measured values follow the same pattern and the draft is both cases is about the same. A new curve is not drawn for the 18 inch fence boom because the measured values at 1 knot are about the same. At higher tow speeds, particularly in waves, the fence boom has some very high measured values of force. In fact, neither the MMS equations or the adjusted World Catalog equations follow the tension on the fence boom at higher tow speeds, particularly in waves. Attempting to follow measured values at higher speeds is likely to result in values that are much too high at lower speeds, particularly around one knot where most of the towing is likely to be done. This leads to the decision to make the equations fit measured values for fence booms as well as possible up to 1 knot then allow a larger deviation for higher tow speeds. This concept is discussed in some detail in the overall evaluation to the equation performance for the 18 inch fence boom.

1.7 Comparing Measured and Computed Tension

The tables that follow show average measured tension and the 95th percentile for all runs performed for the MMS study. In addition, they show the computed tension using the appropriate MMS formulae, the computed tension using the World Catalog formula with the original tension parameter and the adjusted formula using the new curves for tension parameter that were determined from the MMS measured data. The table for each boom type tested is followed a commentary table describing how well the computed data follow the measured data, and an overall evaluation commenting on the performance of both methods of computation. These results are tied together with a final comment on overall performance evaluating how well both formulas predict performance across the entire spectrum of the seven booms tested. The sections that follow review all available test reports that record measured tension on booms. These measured results are then compared with computed results using both the MMS equations and the World Catalog equations. This is followed by an evaluation on how well the equations simulate recorded results.



1) Original curve
2) 18 and 24 inch curtain boom
3) 47 inch curtain boom
4) 36 inch fence boom
5) 52 inch curtain boom
6) 78.5 inch curtain boom

Figure 1.2 Tension Parameter vs Gap Ratio
New curves corresponding to measured results.

Table 1.4 Canadian Coast Guard 18 inch Curtain Boom

TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
Calm Water - Freeboard 0.5 ft, Draft 1.125 ft, Length 150 ft						
0.5	0.3	18	21	22	9	22
1.0		75	81	86	34	82
1.5		179	195	194	77	185
2.0		330	373	344	137	329
0.5	0.2	14	18	14	6	17
1.0		58	64	57	22	64
1.5		115	126	129	48	139
2.0		199	209	230	86	249
Freeboard 0.5 ft, Draft 1.125 ft, Length 100 ft						
0.5	0.3	16	20	14	6	14
1.0		61	66	57	23	55
1.5		116	128	129	52	125
2.0		229	242	230	91	218
0.5	0.5	23	27	24	14	24
1.0		84	95	96	57	97
1.5		195	208	215	128	218
2.0		399	461	383	228	388
0.6 FT WAVE - Freeboard 0.5 ft, Draft 1.125 ft, Length 150 ft						
0.5	0.3	31	58	35	18	43
1.0		95	190	142	52	125
1.5		201	387	319	103	247
2.0		349	555	567	170	408
0.5	0.2	18	40	24	12	35
1.0		61	125	94	33	96
1.5		134	280	213	64	186
2.0		203	355	378	106	307
Freeboard 0.5 ft, Draft 1.125 ft, Length 100 ft						
0.5	0.3	22	44	24	12	29
1.0		63	131	95	35	85
1.5		128	270	213	68	166
2.0		234	376	378	114	278
0.5	0.5	28	55	40	31	53
1.0		96	215	158	86	146
1.5		218	397	355	171	291
2.0		403	573	630	284	483
1.0 FT WAVE - Freeboard 0.5 ft, Draft 1.125 ft, Length 150 ft						
0.5	0.3	27	59	39	22	52
1.0		93	196	157	58	140
1.5		205	381	353	111	270
2.0		383	624	628	181	440
0.5	0.2	21	47	26	14	39
1.0		61	125	105	36	104
1.5		126	243	235	69	200
2.0		220	368	419	113	326
Freeboard 0.5 ft, Draft 1.125 ft, Length 100 ft						
0.5	0.3	21	57	26	15	35
1.0		70	138	105	39	94
1.5		136	266	236	74	179
2.0		259	441	419	120	293
0.5	0.5	29	65	44	36	61
1.0		103	234	175	96	163
1.5		239	464	393	184	313
2.0		451	687	698	301	512

Table 1.5 Canadian Coast Guard 18 inch Curtain Boom
Freeboard 0.5 ft, Draft 1.125 ft

WAVES	GAP RATIO/ BOOM LENGTH (ft)	MMS COMPUTED TENSION	ADJUSTED WORLD CATALOG TENSION
CALM WATER	0.3/150	Follows measured values, somewhat low at 2 kts.	Follows measured values, somewhat low at 2 kts.
	0.2/150	Close to measured values, slightly high at 2 kts.	Close, slightly high at 1.5 & 2 kts.
	0.3/100	Close, slightly low at 2 kts.	Close, slightly low at 2 kts.
	0.5/100	Close, slightly low at 2 kts.	Close, slightly low at 2 kts.
0.6 ft WAVE	0.3/150	Somewhat low up to 2 kts.	Somewhat low for all values.
	0.2/150	Somewhat low up to 2 kts.	Slightly low throughout.
	0.3/100	Somewhat low up to 2 kts.	Slightly low throughout.
	0.5/100	Slightly low up to 2 kts.	Slightly low throughout.
1.0 ft WAVE	0.3/150	Slightly low up to 2 kts.	Slightly low throughout.
	0.2/150	Slightly low up to 2 kts.	Very slightly low throughout.
	0.3/100	Slightly low throughout.	Slightly low throughout.
	0.5/100	Slightly low up to 2 kts.	Slightly low throughout.

OVERALL EVALUATION

Both the MMS computed tension and the World Catalog adjusted computation of tension represent measured values in a reasonable way. The World Catalog values are not quite as close in wave conditions.

Table 1.6 Canadian Coast Guard 18 inch Fence Boom

TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
Calm Water - Freeboard 0.58 ft, Draft 0.92 ft, Length 150 ft						
0.5	0.3	12	15	18	7	17
1.0		50	55	71	28	68
1.5		110	122	158	63	154
2.0		205	221	281	112	273
0.5	0.2	7	10	12	5	13
1.0		38	43	47	18	51
1.5		88	94	106	40	115
2.0		151	165	188	70	203
Freeboard 0.58 ft, Draft 0.92 ft, Length 100 ft						
0.5	0.3	10	15	12	5	11
1.0		44	51	47	19	45
1.5		91	99	106	42	102
2.0		382	559	188	75	182
0.5	0.5	20	26	20	12	20
1.0		74	86	78	47	79
1.5		206	225	176	105	179
2.0		632	831	313	187	317
0.6 FT WAVE - Freeboard 0.58 ft, Draft 0.92 ft, Length 150 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	13	23	51	15	37
1.0		54	90	203	43	104
1.5		119	198	456	84	204
2.0		420	690	812	139	339
0.5	0.2	11	26	34	10	28
1.0		42	84	135	27	77
1.5		90	159	304	53	152
2.0		441	697	541	87	252
Freeboard 0.58 ft, Draft 0.92 ft, Length 100 ft						
0.5	0.3	10	30	34	10	24
1.0		44	102	135	28	68
1.5		249	368	304	56	137
2.0		452	633	541	93	226
0.5	0.5	20	43	57	25	43
1.0		81	162	226	71	120
1.5		431	580	507	140	237
2.0		520	632	902	232	394
1.0 FT WAVE - Freeboard 0.58 ft, Draft 0.92 ft, Length 150 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	18	41	57	18	43
1.0		67	125	228	47	115
1.5		172	317	512	90	220
2.0		541	758	911	148	360
0.5	0.2	16	36	38	11	32
1.0		48	100	152	30	86
1.5		112	215	342	57	164
2.0		476	682	607	92	267
Freeboard 0.55 ft, Draft 0.92 ft, Length 100 ft						
0.5	0.3	14	35	38	12	29
1.0		54	116	152	32	77
1.5		311	467	342	60	146
2.0		436	637	607	99	240
0.5	0.5	24	64	64	30	50
1.0		91	159	253	79	133
1.5		430	573	570	150	256
2.0		536	663	1012	246	418

Table 1.7 Canadian Coast Guard 18 inch Fence Boom
Freeboard 0.58 ft, Draft 0.92 ft

WAVES	GAP RATIO/ BOOM LENGTH (ft)	MMS COMPUTED TENSION	ADJUSTED WORLD CATALOG TENSION
CALM WATER	0.3/150	Slightly high throughout.	Slightly high throughout.
	0.2/150	Slightly high throughout.	Slightly high throughout.
	0.3/100	Good to 2 kts, then measured value becomes very high.	Good to 2 kts, then measured value becomes very high.
	0.5/100	Good to 2 kts, then measured value becomes very high.	Good to 2 kts, then measured value becomes very high.
0.6 ft WAVE	0.3/150	Overshoots measured value at 2 kts & is very high through out.	Close up to 2 kts when measured value becomes very high.
	0.2/150	Very high for all values up to 2 kts, then low.	Close up to 2 kts when measured value becomes very high.
	0.3/100	Close then slightly low at 1.5 and 2 kts.	Low throughout.
	0.5/100	Close at 0.5 & 1 kt, somewhat low at 1.5 kts., then overshoots at 2 kts.	Very low at 1.5 and 2 kts.
1.0 ft WAVE	0.3/150	Very high throughout.	Slightly low to 2 kts, then very low.
	0.2/150	Follows fairly well, high at 1.0 and 1.5 kts, low at 2 kts.	Slightly low to 2 kts, then very low.
	0.3/100	Somewhat low at 1.5 and 2 kts.	Low throughout.
	0.5/100	Close to 2 kts, then overshoots.	Somewhat low to 1.5 kts, then very low.

OVERALL EVALUATION

Measured tension values for the 18 inch fence boom have a peculiar pattern in that they increase gradually with tow speed then become very high at 2 knots. In calm water this is only evident for the shorter 100 foot boom. Both the MMS and World Catalog equations follow measured values very well up to 2 knots, so one could conclude that either is suitable for making computations since towing a fence boom at 2 knots or more is not likely.

In the 0.6 foot wave and the longer boom, the MMS equation attempts to follow the unusual tension pattern of the fence boom and as a result shows values that are much too high up to 2 knots, then overshoots and goes well above measured values. (There is no overshoot for 2 knots and a gap ratio of 0.2; here it is slightly low.) In this same range, the World Catalog equation follows measured values very well up to 2 knots, then values are very low.

In the 0.6 foot wave with the shorter boom, the measured tension values start going very high at 1.5 knots. The MMS equation attempts to compensate for this and does fairly well for the gap ratio of 0.3, but overcompensates substantially at 2 knots. In this range the World Catalog is slightly low at 0.5 and 1 knot but substantially low at 1.5 and 2 knots.

In the 1 foot wave, the measured values are again irregular in that they increase gradually up to 1.5 knots then jump to very high values. The MMS equation tries to follow this pattern and does fairly well for the gap ratio of 0.2 but is much too high then overshoots substantially at 2 knots for the gap ratio of 0.3. In this case the World Catalog computations are close at 0.5 and 1 knot, slightly low at 1.5 knots, then very low at 2 knots. For the shorter boom, the MMS results are good for a gap ratio of 0.3, but at gap ratio of 0.5 they are close up to 2 knots then very high. In this range the World Catalog results are somewhat low for 0.5 and 1 knot then very low for 1.5 knots and 2 knots.

These tests show that the 18 inch fence boom has some vastly different hydrodynamic characteristics at higher tow speeds than the 18 inch curtain boom. These characteristics are very difficult to simulate with an equation. Attempts to emulate the measured result at the higher tow speeds generally result in the computed values being much too high throughout. The World Catalog equation was adjusted for the 18 inch curtain boom but was not changed again for the fence boom even though these large differences at high tow speeds were noted. It appears that the best solution to the problem is to not make a large change in the equations for the fence boom secure in the idea that the existing equations for the 18 inch boom are quite close for 0.5 knots and 1 knot, which is likely to be the most important tow range for this type of boom. In this case it seems that making adjustments for these unusual conditions would do more harm than good in establishing reliable computed results for most 18 inch booms.

Table 1.8 Canadian Coast Guard 24 inch Curtain Boom

TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
Calm Water - Freeboard 1.1 ft, Draft 0.92 ft, Length 150 ft						
0.5	0.3	18	23	25	9	21
1.0		80	88	101	34	83
1.5		177	195	228	77	188
2.0		342	413	405	137	334
0.5	0.2	15	19	17	6	16
1.0		56	64	68	22	62
1.5		114	120	152	48	139
2.0		198	213	270	86	248
Freeboard 1.1 ft, Draft 0.92 ft, Length 100 ft						
0.5	0.3	19	24	17	6	13
1.0		70	77	68	23	56
1.5		119	127	152	52	126
2.0		219	230	270	91	222
0.5	0.5	20	23	28	14	24
1.0		81	90	113	57	97
1.5		180	192	253	128	218
2.0		329	347	450	228	388
0.6 FT WAVE - Freeboard 1.1 ft, Draft 0.92 ft, Length 150 ft						
0.5	0.3	25	43	35	18	44
1.0		85	151	142	52	126
1.5		185	300	319	103	250
2.0		341	501	567	170	415
0.5	0.2	17	30	24	12	33
1.0		60	105	94	33	94
1.5		111	175	213	64	186
2.0		194	301	378	106	307
Freeboard 1.1 ft, Draft 0.92 ft, Length 100 ft						
0.5	0.3	19	36	24	12	29
1.0		58	108	95	35	84
1.5		122	219	213	68	166
2.0		206	304	378	114	277
0.5	0.5	28	60	40	31	52
1.0		94	184	158	86	146
1.5		203	341	355	171	290
2.0		346	443	630	284	482
1.0 FT WAVE - Freeboard 1.1 ft, Draft 0.92 ft, Length 150 ft						
0.5	0.3	28	59	44	22	53
1.0		105	207	177	58	140
1.5		192	334	399	111	270
2.0		371	562	709	181	440
0.5	0.2	20	43	30	14	39
1.0		66	113	118	36	104
1.5		119	197	266	69	200
2.0		224	369	473	113	326
Freeboard 1.1 ft, Draft 0.92 ft, Length 100 ft						
0.5	0.3	16	42	29	15	35
1.0		67	132	118	39	94
1.5		132	226	266	74	179
2.0		243	412	473	120	293
0.5	0.5	29	63	49	36	61
1.0		113	230	197	96	163
1.5		230	368	443	184	313
2.0		483	776	788	301	511

Table 1.9 Canadian Coast Guard 24 inch Curtain Boom
Freeboard 1.1 ft, Draft 0.92 ft

WAVES	GAP RATIO/ BOOM LENGTH (ft)	MMS COMPUTED TENSION	ADJUSTED WORLD CATALOG TENSION
CALM WATER	0.3/150	Slightly high to 2 kts.	Good to 1.5 kts, slightly low at 2 kts.
	0.2/150	Slightly high beginning at 1.5 kts.	Very slightly high beginning at 1.5 kts.
	0.3/100	Slightly high beginning at 1.5 kts.	Slightly low at 0.5 & 1 kts, then close.
	0.5/100	Slightly high beginning at 1.0 kts.	Close throughout.
0.6 ft WAVE	0.3/150	Close, slightly high at 2 kts.	Close up to 2 kts, then slightly low.
	0.2/150	Close then slightly high at 2 kts.	Close throughout.
	0.3/100	Close then slightly high at 2 kts.	Slightly low throughout.
	0.5/100	Low at 0.5 & 1.0 kts, then high at 1.5 & 2.0 kts.	Slightly low at 0.5 to 1.5 kts then slightly high at 2 kts.
1.0 ft WAVE	0.3/150	Close then slightly high at 2 kts.	Slightly low throughout.
	0.2/150	Close then slightly high at 2 kts.	Close at 1.5 kts then very slightly low at other speeds.
	0.3/100	Slightly low at 0.5 & 1 kts; slightly high at 1.5 & 2 kts.	Slightly low to 1.5 kts then quite low at 2 kts.
	0.5/100	Slightly low at 0.5 & 1 kts, then slightly high at 1.5 & 2 kts.	Somewhat low to 1.5 kts, then low.

OVERALL EVALUATION

Measured and computed data are quite close throughout. Either computation system would be satisfactory for this boom in the described environments.

Table 1.10 U.S. Coast Guard Oil-Stop 47 inch Curtain Boom

TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
Calm Water - Freeboard 1.4 ft, Draft 2.5 ft, Length 164 ft						
0.5	0.3	74	81	62	21	69
1.0		259	274	246	83	274
1.5		524	550	554	181	617
2.0		897	931	984	333	1097
0.5	0.2	51	62	41	13	52
1.0		200	215	164	54	216
1.5		372	403	369	117	468
2.0		677	693	656	208	830
Freeboard 1.4 ft, Draft 2.5 ft, Length 82 ft						
0.5	0.3	45	51	31	11	35
1.0		148	160	123	42	137
1.5		295	314	277	94	309
2.0		499	520	492	166	548
0.5	0.5	66	73	52	26	60
1.0		232	241	205	104	239
1.5		468	486	462	234	537
2.0		744	769	820	416	956
0.6 FT WAVE - Freeboard 1.4 ft, Draft 2.5 ft, Length 164 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	89	129	89	44	145
1.0		273	359	357	126	414
1.5		562	726	803	249	820
2.0		971	1337	1427	413	1362
0.5	0.2	51	62	59	28	110
1.0		200	215	238	79	314
1.5		372	403	535	156	622
2.0		677	693	951	258	1032
Freeboard 1.4 ft, Draft 2.5 ft, Length 82 ft						
0.5	0.3	54	80	45	22	73
1.0		152	247	179	63	208
1.5		335	500	402	125	411
2.0		557	828	714	207	681
0.5	0.5	79	116	75	56	128
1.0		223	304	298	157	361
1.5		479	680	670	311	714
2.0		794	1143	1190	517	1188
1.0 FT WAVE - Freeboard 1.4 ft, Draft 2.5 ft, Length 164 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	85	136	89	53	173
1.0		290	430	357	140	460
1.5		527	702	803	268	884
2.0		1005	1341	1427	438	1445
0.5	0.2	67	115	59	33	132
1.0		218	303	238	88	350
1.5		397	556	535	168	670
2.0		696	977	951	274	1096
Freeboard 1.4 ft, Draft 2.5 ft, Length 82 ft						
0.5	0.3	51	99	45	27	87
1.0		160	268	179	70	231
1.5		327	505	402	134	442
2.0		570	834	714	219	723
0.5	0.5	88	172	75	66	152
1.0		249	379	298	175	401
1.5		468	656	670	335	771
2.0		792	1112	1190	548	1259

Table 1.11 U.S. Coast Guard Oil-Stop 47 inch Curtain Boom
Freeboard 1.4 ft, Draft 2.5 ft

WAVES	GAP RATIO/ BOOM LENGTH (ft)	MMS COMPUTED TENSION	ADJUSTED WORLD CATALOG TENSION
CALM WATER	0.3/164	Slightly low at 0.5 & 1.5 kts; close beyond	Close then slightly high at 1.5 & 2 kts.
	0.2/164	Slightly low throughout.	Low at 0.5 kts, close at 1 kt, slightly high at 1.5 kts and quite high at 2 kts.
	0.3/82	Slightly low throughout.	Slightly low at 0.5 & 1.0 kts; close at 1.5 kts and slightly high at 2 kts.
	0.5/82	Slightly low to 1.5 kts then slightly high at 2 kts.	Close, slightly high at 1.5 kts, then quite high at 2 kts.
0.6 ft WAVE	0.3/164	Low at 0.5 kts, close at 1 kt, then slightly high at 1.5 & 2 kts.	Slightly high to 1.5 kts, close at 2 kts.
	0.2/164	Close to 1 kt, slightly high at 1.5 kts, & quite high at 2 kts.	Fairly high throughout.
	0.3/82	Slightly low throughout.	Slightly low to 1.5 kts, then quite low at 2 kts.
	0.5/82	Slightly low at 0.5 kts then very close.	Slightly high throughout.
1.0 ft WAVE	0.3/164	Slightly low at 0.5 & 1.5 kts, then slightly high.	Slightly high throughout.
	0.2/164	Slightly low at 0.5 & 1.5 kts, then close.	Slightly high throughout.
	0.3/82	Slightly low throughout.	Slightly low throughout.
	0.5/82	Quite low at 0.5 & 1 kts, then close.	Slightly low at 0.5 kts, close at 1.0 & 1.5 kts, then slightly high at 2 kts.

OVERALL EVALUATION

Measured and computed data are quite close throughout. Either system of computation would be satisfactory for this boom in the described environments.

Table 1.12 U.S. Navy 52 inch Curtain Boom

Calm Water - Freeboard 1.3 ft, Draft 3.0 ft, Length 166 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	122	129	127	25	130
1.0		492	525	508	101	525
1.5		1038	1184	1143	227	1180
2.0		2259	2264	2032	404	2098
0.5	0.2	78	98	85	16	98
1.0		334	387	339	63	384
1.5		683	783	762	142	866
1.8		1056	1124	1355	205	1247
Freeboard 1.3 ft, Draft 3.0 ft, Length 111 ft						
0.5	0.3	85	97	85	17	88
1.0		300	331	340	68	351
1.5		680	715	764	152	790
1.7		874	934	982	195	1014
0.5	0.5	127	137	142	42	130
1.0		500	522	566	169	522
1.3		690	736	1274	285	884
1.5		978	1090	1636	379	1176

0.6 FT WAVE - Freeboard 1.3 ft, Draft 3.0 ft, Length 166 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	151	202	168	54	278
1.0		518	703	672	153	793
1.3		681	1065	1136	236	1227
1.5		1250	1762	1513	302	1570
0.5	0.2	88	123	112	34	204
1.0		325	501	448	96	583
1.5		674	961	757	189	1150
1.7		1088	1638	1008	235	1434
Freeboard 1.3 ft, Draft 3.0 ft, Length 111 ft						
0.5	0.3	96	137	113	36	187
1.0		287	436	450	102	530
1.5		660	927	1012	202	1050
1.8		868	1377	1457	278	1446
0.5	0.5	124	147	188	90	279
1.0		460	681	750	255	791
1.2		676	982	1686	345	1070
1.5		928	1354	2428	505	1564

1.0 FT WAVE - Freeboard 1.3 ft, Draft 3.0 ft, Length 166 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	141	198	172	64	333
1.0		513	736	687	170	881
1.3		720	1002	1161	257	1336
1.5		1213	1676	1546	326	1693
0.5	0.2	114	173	115	40	244
1.0		361	581	458	106	647
1.5		644	971	1031	204	1241
1.8		1116	1683	1484	277	1690
Freeboard 1.3 ft, Draft 3.0 ft, Length 111 ft						
0.5	0.3	90	123	115	43	224
1.0		305	429	460	114	590
1.5		666	990	1034	218	1134
1.8		920	1388	1489	297	1542
0.5	0.5	150	231	192	107	332
1.0		547	829	766	284	879
1.2		702	1027	1103	378	1172
1.5		1019	1488	1723	545	1688

Table 1.13 U.S. Navy 52 inch Curtain Boom
Freeboard 1.3 ft, Draft 3.0 ft

WAVES	GAP RATIO/ BOOM LENGTH (ft)	MMS COMPUTED TENSION	ADJUSTED WORLD CATALOG TENSION
CALM WATER	0.3/166	Close to 2 kts, then low.	Close to 2 kts, then low.
	0.2/166	Close to 1.8 kts, then slightly high.	Close to 1.5 kts, then slightly high.
	0.3/111	Slightly high at 1.5 & 1.7 kts.	Slightly high at 1.5 & 1.7 kts.
	0.5/111	Close at 0.5 & 1 kt, then very high.	Slightly high at 1.3 & 1.5 kts.
0.6 ft WAVE	0.3/166	Slightly low at 0.5 & 1 kt, slightly high at 1.3 kts & low at 1.5 kts.	Slightly high to 1.3 kts, then low.
	0.2/166	Slightly low at 0.5 & 1 kt, then quite low at 1.5 & 1.7 kts.	Slightly high to 1.5 kts, then low at 1.7 kts.
	0.3/111	Slightly low at 0.5 kts, then slightly high for 1 to 1.8 kts.	Slightly high throughout.
	0.5/111	Slightly high at 0.5 & 1.0 kts, then extremely high at 1.2 & 1.5 kts.	Slightly high at 0.5 & 1.0 kts, then quite high at 1.2 & 1.5 kts.
1.0 ft WAVE	0.3/166	Slightly low at 0.5 & 1 kt, slightly high at 1.3 kts & slightly low at 1.5 kts.	High up to 1.3 kts, then close.
	0.2/166	Slightly low at 0.5 & 1.0 kts, then slightly high at 1.5 kts & low at 1.8 kts.	Slightly high at 0.5 & 1.0 kts, high at 1.5 kts, & close at 1.8 kts.
	0.3/111	Close through 1.5 kts, then slightly high at 1.8 kts.	Slightly high through 1.5 kts then quite high at 1.8 kts.
	0.5/111	Slightly low through 1.0 kts, slightly high at 1.2 kts, then high at 1.5 kts.	Slightly high through 1.2 kts, then high at 1.5 kts.

OVERALL EVALUATION

Although computed values are not quite as close to measured results as in some other cases, they are close enough for most purposes. Either system of computation would be satisfactory for this boom in the described environments.

Table 1.14 Canadian Coast Guard 78.5 inch RO-BOOM Curtain Boom

TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	MEASURED TENSION (lb_f) 95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
Calm Water - Freeboard 2.8 ft, Draft 3.7 ft, Length 196 ft						
0.5	0.3	278	298	261	37	255
1.0		1319	1462	1044	147	1014
1.2		1288	1467	1504	212	1463
1.5		2628	2770	2350	331	2284
0.5	0.2	180	194	174	23	196
1.0		728	779	696	92	782
1.5		1112	1404	1566	207	1755
1.7		1840	2590	2012	266	2257
Freeboard 2.8 ft, Draft 3.7 Length 98 ft						
0.5	0.3	148	157	131	19	131
1.0		540	565	522	74	511
1.5		1005	1077	1174	166	1145
1.7		1418	1453	1509	213	1470
0.5	0.5	262	282	218	46	198
1.0		755	784	871	184	789
1.3		1109	1158	1471	311	1335
1.5		1598	1665	1958	414	1778
0.6 FT WAVE - Freeboard 2.8 ft, Draft 3.7 ft, Length 196 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	300	426	326	78	538
1.0		1130	1319	1305	222	1532
1.3		1504	2007	2206	344	2374
1.5		2587	3320	2937	440	3036
0.5	0.2	310	553	218	49	417
1.0		884	1346	870	139	1182
1.5		1769	2180	1958	275	2338
1.8		2251	3073	2819	379	3217
Freeboard 2.8 ft, Draft 3.7 ft, Length 98 ft						
0.5	0.3	197	267	163	39	269
1.0		655	855	653	111	766
1.5		1163	1399	1469	220	1518
1.7		1473	1811	1886	274	1891
0.5	0.5	333	445	272	98	421
1.0		871	1138	1088	278	1195
1.3		1263	1565	1839	430	1849
1.5		1812	2187	2448	550	2363
1.0 FT WAVE - Freeboard 2.8 ft, Draft 3.7 ft, Length 196 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	317	416	359	93	642
1.0		1300	1539	1436	247	1704
1.2		1640	2031	2068	329	2270
1.5		3061	3715	3231	475	3278
0.5	0.2	317	438	239	59	497
1.0		759	1016	957	155	1313
1.5		1949	2402	2154	297	2520
1.7		2675	3298	2766	366	3111
Freeboard 2.8 ft, Draft 3.7 ft, Length 98 ft						
0.5	0.3	219	294	179	47	324
1.0		663	901	718	124	856
1.5		1267	1595	1616	237	1635
1.8		1574	1936	2326	323	2229
0.5	0.5	340	477	299	117	501
1.0		913	1170	1197	309	1329
1.3		1321	1673	2022	468	2012
1.5		1901	2393	2693	593	2550

Note: The 95th percentile measured value for a gap ratio of 0.3 in calm water at 1 knot seems to be very high, therefore, the solution for a new value of tension parameter is taken at 1.2 knots in this case

Table 1.15 Canadian Coast Guard 78.5 inch RO-BOOM Curtain Boom
Freeboard 2.8 ft, Draft 3.7 ft

WAVES	GAP RATIO/ BOOM LENGTH (ft)	MMS COMPUTED TENSION	ADJUSTED WORLD CATALOG TENSION
CALM WATER	0.3/196	Low at 0.5 & 1 kt; close at 1.2 kts then low at 1.5 kts.	Low at 0.5 & 1 kt; close at 1.2 kts then low at 1.5 kts.
	0.2/196	Slightly low at 0.5 & 1 kt; high at 1.5 kts, then quite low at 1.7 kts.	Close at 0.5 & 1 kt; high at 1.5 kts and low at 1.7 kts.
	0.3/98	Slightly low at 0.5 & 1.0 kts; high at 1.5 & 1.7 kts.	Slightly low at 0.5 & 1.0 kts, then slightly high at 1.5 kts & close at 1.7 kts.
	0.5/98	Low at 0.5 kts, slightly high at 1 kt and quite high at 1.3 & 1.5 kts.	Low at 0.5 kts, close at 1 kt and slightly high at 1.5 & 1.7 kts.
0.6 ft WAVE	0.3/196	Low at 0.5 kts, close at 1 kt, slightly high at 1.3 kts. and low at 1.5 kts.	High at 0.5 to 1.3 kts, then low at 1.5 kts.
	0.2/196	Very low at 0.5 & 1 kt.; slightly low at 1.5 & 1.8 kts.	Low at 0.5 & 1 kt; high at 1.5 & 1.8 kts.
	0.3/98	Low at 0.5 & 1 kt; high at 1.5 kts and close at 1.7 kts.	Close at 0.5 kts & low 1 kt; high at 1.5 kts & close at 1.7 kts.
	0.5/98	Low at 0.5 kts; close at 1 kt, and quite high at 1.3 & 1.5 kts.	Close at 0.5 & 1 kt; high at 1.3 & 1.5 kts.
1.0 ft WAVE	0.3/196	Slightly low at 0.5 & 1 kt; close at 1.2 kts & low at 1.5 kts.	Quite high at 0.5 to 1.2 kts then low at 1.5 kts.
	0.2/196	Quite low at 0.5 kts; slightly low at 1 kt then quite low at 1.5 & 1.7 kts.	Slightly high at 0.5 to 1.5 kts then slightly low at 1.7 kts.
	0.3/98	Quite low at 0.5 & 1 kt; close at 1.5 kts then quite high at 1.8 kts.	Close at 0.5 kts, slightly low at 1 kt, close at 1.5 kts & high at 1.8 kts.
	0.5/98	Low at 0.5 kts, close at 1 kt, then quite high at 1.3 & 1.5 kts.	Slightly high at 0.5 kts then quite high at 1.0 to 1.5 kts.

OVERALL EVALUATION

Measured data on this large boom is much more irregular than on the smaller booms, or, equations are much less likely to follow the measured data as well. Even though tow speeds were closer together, (there were no trials at 2 kts.) measured values were highly variable. In spite of there differences, both equations were able to compute the forces on the booms well enough to be useful in all tests reported.

Table 1.16 Canadian Coast Guard 36 inch Fence Boom

TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
Calm Water - Freeboard 1.0 ft, Draft 2.0 ft, Length 150 ft						
0.5	0.3	56	63	72	15	62
1.0		241	254	288	61	254
1.5		1589	2262	648	137	570
2.0		1871	2266	1152	243	1011
0.5	0.2	43	55	48	10	61
0.7		111	130	94	19	118
1.0		214	242	192	38	243
Freeboard 1.0 ft, Draft 2.0 Length 100 ft						
0.3	0.3	12	16	17	4	15
0.7		62	66	94	20	83
1.0		201	213	192	41	169
0.5	0.5	71	80	80	26	80
0.8		165	177	205	65	203
1.0		298	318	320	102	318
0.6 FT WAVE - Freeboard 1.0 ft, Draft 2.0 ft, Length 150 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	70	140	128	33	135
1.0		359	606	513	92	383
1.5		1420	2262	1154	182	757
2.0		1964	2267	2052	302	1256
0.5	0.2	43	55	86	20	128
0.7		111	130	168	33	211
1.0		214	242	342	58	368
Freeboard 1.0 ft, Draft 2.0 ft, Length 100 ft						
0.5	0.3	46	84	86	22	89
0.8		114	190	219	43	179
1.0		220	351	342	62	256
0.5	0.5	74	121	143	54	169
0.7		163	267	280	88	274
1.0		412	632	570	153	479
1.0 FT WAVE - Freeboard 1.0 ft Draft 2.0 ft, Length 150 ft						
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lb_f) Average	95 Perc.	MMS COMPUTED TENSION (lb_f)	WC TENSION (lb_f)	ADJUSTED WC TENSION (lb_f)
0.5	0.3	54	102	158	39	160
1.0		337	626	630	102	424
1.5		1682	2265	1418	196	815
2.0		1874	2267	2520	321	1333
0.5	0.2	51	122	104	24	154
0.7		108	241	206	38	240
1.0		226	386	420	64	410
Freeboard 1.0 ft, Draft 2.0 ft, Length 100 ft						
0.5	0.3	50	108	105	26	106
0.8		117	218	269	49	202
1.0		231	390	420	68	283
0.5	0.5	73	147	175	65	202
0.8		189	329	448	122	382
1.0		490	868	700	171	534

Table 1.17 Canadian Coast Guard 36 inch Fence Boom
Freeboard 1.0 ft, Draft 2.0 ft

WAVES	GAP RATIO/ BOOM LENGTH (ft)	MMS COMPUTED TENSION	ADJUSTED WORLD CATALOG TENSION
CALM WATER	0.3/150	Slightly high at 0.5 & 1.0 kts, then extremely low at 1.5 & 2.0 kts.	Close at 0.5 & 1 kts, then extremely low at 1.5 & 2.0 kts.
	0.2/150	Slightly low for all tow speeds.	Slightly low at 0.7 kts, close at 0.5 & 1.0 kts.
	0.3/100	Close at 0.3 kts, slightly high at 0.7 then slightly low at 1.0 kts.	Close at 0.3 kts, slightly high at 0.7 kts & slightly low at 1.0 kts.
	0.5/100	Close at 0.3 kts, then slightly high at 0.8 kts and close at 1.0 kts.	Close at 0.5 kts and 1.0 kts, slightly high at 0.8 kts.
0.6 ft WAVE	0.3/150	Slightly low at 0.5 & 1.0 kts, then very low at 1.5 & 2.0 kts.	Close at 0.5 kts, then quite low at 1.0 kts and extremely low at 1.5 & 2.0 kts.
	0.2/150	Slightly high throughout.	Slightly high throughout.
	0.3/100	Close at 0.5 kts, then slightly high at 0.8 kts & slightly low at 1.0 kts.	Close at 0.5 kts, then slightly low at 0.8 and 1.0 kts.
	0.5/100	Slightly high at 0.5 & 0.7 kts, then slightly low at 1.0 kts.	Slightly high at 0.5 & 0.7 kts, then low at 1.0 kts.
1.0 ft WAVE	0.3/150	Slightly high at 0.5 kts, close at 1.0 kts, then very low at 1.5 kts and high at 2.0 kts.	Slightly high at 0.5 kts, slightly low at 1.0 kts, then extremely low at 1.5 & 2.0 kts.
	0.2/150	Slightly low at 0.5 & 0.7 kts, then slightly high at 1.0 kts.	Slightly high at 0.5 kts, close at 0.7 kts, then slightly high at 1.0 kts.
	0.3/100	Close at 0.5 kts, then slightly high at 0.7 & 1.0 kts.	Close at 0.5 kts, then slightly low at 0.8 & 1.0 kts.
	0.5/100	Slightly high at 0.5 & 0.8 kts, then low at 1.0 kts.	High at 0.5 & 1.0 kts, then low at 1.0 kts.

OVERALL EVALUATION

When fence boom is towed at 1.5 knots or more, the tension on the boom suddenly increases by a factor of 4 to even 10 times. This seems to be true in both calm water and waves. For the most part equations designed to compute tension do not follow these radical changes well. The MMS equations have been given special constants for fence booms and these constants are quite large, particularly for fence booms in waves. These special equations sometimes are successful in tracking these changes, but not always. Sometimes they overshoot appreciably at lower speeds to track tension forces at 1.5 knots and above. Since fence booms are not likely to be towed at speeds in excess of 1 kt, it would seem to be best to not change equations that match measured values well at 0.5 and 1.0 kts. For now, equations do not follow measured values well for fence booms towed at 1.5 knots and above, particularly in waves.

Comparing Calculated tension in Larger Waves

Measured values of tension in waves only include relatively small waves of 6 and 12 inches. The MMS study suggests values of K that could be used in computing tension in Protected Water (waves up to 3 feet) and Open Water (waves up to 6 feet). Table 1.15 shows the results of tension computations using the MMS and World Catalog formulas for typical booms in Protected Water and Open Water.

Table 1.18 Computed Values of Tension for Typical Booms in Protected Water and Open Water

Protected Water - 3 foot wave 36 inch Boom - Freeboard 1 ft, Draft 2 ft, Length 200 ft MMS Computation K = 4.3; WC Tension Parameter Curve No. 4				
TOW SPEED (kts)	GAP RATIO	MMS COMPUTED TENSION (lbs)	WORLD CATALOG TENSION (lbs)	ADJUSTED WC TENSION (lbs)
0.5	0.3	129	84	330
1.0		516	186	733
1.5		1161	329	1299
2.0		2064	512	2024
Open Water - 6 foot wave 52 inch Boom - Freeboard 1.3 ft, Draft 3.0 ft, Length 200 ft. MMS Computation K = 4.7; WC Tension Parameter Curve No. 5				
0.5	0.3	212	183	876
1.0		846	363	1735
1.5		1904	603	2897
2.0		3384	904	4322

Although basin measured values are not available for 3 and 6 foot waves, these computed values of tension suggest that the MMS equations under report tension in larger Protected Water and Open Water waves, especially at lower tow speeds.

1.8 Assessment of Performance of Tension Computations for All Booms Tested

Overall Assessment of Results

o CCG 18 inch curtain boom - MMS and World Catalog equations follow measured values well - general performance of both sets of equations is about the same.
o CCG 18 inch fence boom - Equations do not follow measured results as well for fence booms, particularly at higher tow speeds. In calm water, both types of equations are good up to 2 knots. In the 0.6 foot wave, World Catalog is better up to 2 knots for the longer boom and MMS is better for the shorter boom. The same is true in the 1 foot wave. In computing tension values for fence booms, it is probably better to develop a new set of MMS constants or World Catalog tension parameters when towing at higher speeds.
o CCG 24 inch curtain boom - Measured and computed data are close throughout. Either computation system is satisfactory for this boom in the described environments.
o CCG Oil-Stop 47 inch curtain boom - Measured and computed data are close throughout. Either computation system is satisfactory for this boom in the described environments.
o US Navy 52 inch curtain boom - Computed values for this larger boom are not quite as close to measured results as for the smaller booms, but they are close enough for most purposes. Either system of computation would be satisfactory for this boom in the described environments.
o CCG 78.5 inch Ro-Boom curtain boom - Measured data on this large boom is much more irregular than on the smaller booms, and as a result, equations are much less likely to follow the measured data as well. Even though tow speeds were closer together, (there were no trials at 2 kts.) measured values were highly variable. In spite of there differences, both equations were able to compute the forces on the booms well enough to be useful in all tests reported.
o CCG 36 inch fence boom - For reasons that are not well understood, measured tension on fence booms is highly irregular and therefore difficult to simulate with equations. In all environments, both systems of equations do well up to 1.5 knots, then they fall well below measured values. Since fence booms are less likely to be towed at 1.5 knots and above, it would seem to be wise to leave the

equations as they are. Anyone who needs detailed information on tension on fence booms at 1.5 knots and above should develop a special set of constants for that particular application.
o Computed values of tension in large waves - Although basin measured values are not available for 3 and 6 foot waves, computed values of tension using both systems of equations suggest that the MMS equations under report tension in larger Protected Water and Open Water waves.

The measured test results assessed here suggest that either the MMS equations or the World Catalog equations could be used for computing forces on booms in most situations. There are situations in which one system or the other is slightly better - the user can be the judge. Computations show that in the larger protected water and open water waves that cannot be generated in a test tank, the World Catalog equations may be better.

The MMS equations are certainly easier to use since they involve fewer terms; however, if constants are gathered together and a system of computation is established, the adjusted World Catalog equations are fairly easy to use. In addition, those with good computer skills report that they are able to set up the World Catalog equations in a spread sheet format and the equations are solved in the computer. Based on the analysis of this study, it seems clear that both systems of equations have a secure place as tools to compute tension of towed containment booms.

2.0 ENVIRONMENT CANADA TESTS 1980 (5) (E-1)

Six oil spill containment booms were tested offshore of St. John's, Newfoundland in March and April of 1980. Testing was conducted about 3 nautical miles south of St. John's Harbor in Blackhead Bight. This area, sheltered by cliffs to the west and a peninsula to the south, is at the eastern extremity of the North American continent, with water temperatures, ice conditions and sea states typical of the Grand Banks oil exploration areas. Currents in the area are 1/4 knot or less and tides average 5 feet (1.5 m). One of the booms tested, the Zooom boom, was later shipped to New Jersey and tested at OHMSETT. The general results of these tests are reported separately in Section 2.2 of Chapter 4 of the main text.

The principal criteria used to evaluate the booms were oil retention characteristics, durability, and towing loads. Although it was intended to deposit a barrel of oil ahead of the towed booms, this was not done in every case because of adverse weather conditions. Data describing towing loads are reported in some detail.

2.1 Test Description

The boom was towed in a catenary configuration by two vessels. The distance across the boom opening was measured with an optical range finder. All tows were made into the wind. Sections of the AMOP and Zooom booms were towed individually to confirm that their drag was identical. The two booms were then connected to a skimmer with the intention of containing and deflecting two barrels of oil that had been spilled upwind. Forces on booms were to the nearest 10 Newtons (2 pounds of force)

2.2 Boom Description

Table 2.1 Environment Canada Test of Booms Offshore (5)

BOOM	FREEBOARD (feet)	DRAFT (feet)
AMOP/ZOOM self-inflatable curtain boom	2.2	1.3
*Albany fence boom	2	2
U.S. Coast Guard pressure inflatable boom	1.2	1.5
Troilboom external tension boom	1.3	2.3
Vikoma pressure inflatable boom	2.25	1.4

*A later version of this boom is presently produced by Applied Fabrics Technology.

2.3 Test Variables

The offshore test included many variables, but those reported included wind and wave conditions, boom length, towing gap, and tow speed.

2.4 Test Results

The tables that follow compare measured field results with computations using the MMS formulas and the World Catalog formula.

Table 2.2 Zoom Boom Towed Offshore, Newfoundland (5)

CALM WATER - FREEBOARD 2.2 ft, DRAFT 1.3 ft, LENGTH 600 ft MMS Computation K = 2.0; WC Tension Parameter Curve No. 2					
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lbs)	MMS COMPUTED TENSION (lbs)	WC TENSION (lbs)	ADJUSTED WC TENSION (lbs)
0.6	0.5	500	281	142	226
0.7	0.5	865	382	194	308
1.2	0.2	650	449	142	333
1.2	0.5	1076	1123	569	953
1.5	0.3	1110	1053	356	819
2.0	0.2	1025	1248	395	926
3.5 ft WAVES, 10 kts WIND - FREEBOARD 2.2 ft., DRAFT 1.3 ft., LENGTH 1201 ft. MMS Computation K = 3.5; WC Tension Parameter Curve No. 2					
1.3	0.4	825	3694	1801	3512
1.6	0.2	900	2798	959	2213
10 ft WAVES, 30 kts WIND - FREEBOARD 2.2 ft., DRAFT 1.3 ft, LENGTH 299 ft. MMS Computation K = 3.5; WC Tension Parameter Curve No. 2					
0.6	0.2	325	98	207	599 (311)*
0.7	0.2	300	133	222	644 (335)
1.2	0.3	400	587	504	1210 (629)
1.2	0.3	525	587	504	1210 (629)
1.7	0.2	300	786	433	1254 (652)
1.8	0.2	600	881	459	1331 (692)
2.2	0.2	750	1316	457	1668 (867)

* Approximate tension discounting the affect of the wind.

<u>OVERALL EVALUATION</u>

<u>Calm Water</u> - At tow speeds up to 1.2 knots, and 1.2 knots with a gap ratio of 0.2, both the MMS and World Catalog computed tension values are much too low, then both come fairly close at higher tow speeds. In these tests, gap ratio was measured in tow vessels using an optical range finder. The recorded gap ratio could have been in error, which could cause a large difference in recorded tension. In addition, measurement of tow speed at the very low speeds may not have been accurate, which could also have an important affect on measured tension.

<u>3.5 FOOT WAVES</u> - Computed tension values using MMS and World Catalog equations are very close, but both are much higher than measured values. Computed values are large because the boom is long and tow speeds are high. In these conditions one would have expected higher measured values of tension, but they did not occur. Wave conditions are only reported as sea state 2 - 3, which is now being interpreted as a 3.5 foot wave and 10 knots of wind. This is an average condition taken from a sea state table. Wave conditions may not have been that severe. The MMS equations do not account for the effect of wind, but the WC formulas do. In this case, the computed effect of the wind increases tension by about 3%.

10 FOOT WAVES - These wave conditions are described in the report as sea state 4 - 6. These are very severe conditions and are interpreted from the sea state table as 10 foot waves and 30 knots of wind. Since both wind and waves are considered in the World Catalog equations, computed values of tension are large. With a high freeboard and 30 knots of wind, the effect of wind nearly doubles the tension on the boom. Since the velocity of the wind is only deduced from the reported sea state, the wind may not have been nearly that strong, so the WC computed values of tension may be much too high. Table 2.2 shows , in parentheses, the approximate tension that would have been computed neglecting the wind. These values are much closer to the measured results. The MMS equations do not consider wind, and only waves up to 1 foot. Using the largest constants for this size boom, computed values are fairly close to measured values in the mid-range of tow speeds.

Table 2.3 Four Booms Towed Offshore, Newfoundland (5)

Albany Oil Fence Boom CALM WATER - FREEBOARD 2 ft, DRAFT 2 ft, LENGTH 400 ft. MMS Computation K = 3.2; WC Tension Parameter Curve No. 4					
TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lbs)	MMS COMPUTED TENSION (lbs)	WC TENSION (lbs)	ADJUSTED WC TENSION (lbs)
1.3 1.5 1.5	0.25	750 800 1000	1082 1440 1440	274 365 365	975 1477 1477
U.S. Coast Guard Pressure-Inflatable Boom 1.5 ft WAVE, WIND 7 kts, FREEBOARD 1.2 ft, DRAFT 1.5 ft, LENGTH 800 ft. MMS Computation K = 3.5; WC Tension Parameter Curve No. 2					
0.3 0.4 1.2 1.3	0.5 0.4 0.4 0.2	675 650 700 800	189 269 2419 1420	296 239 947 427	503 478 1893 1238
Troilboom External Tension Boom 1.5 ft WAVE, WIND 7 kts, FREEBOARD 1.3 ft, DRAFT 2.3 ft, LENGTH 250 ft. MMS Computation K = 7.0; WC Tension Parameter Curve No. 4					
0.3 0.3 0.6 0.6 0.6 0.6 0.6 0.7 0.8	0.4 0.5 0.2 0.3 0.4 0.4 0.5 0.6 0.5	275 350 450 475 400 500 600 675 505	145 181 290 435 638 638 725 1183 1288	86 138 70 112 175 175 280 495 404	281 362 374 444 572 572 728 1076 1050
VIKOMA Pressure-Inflatable Boom 1.5 ft WAVE, WIND 7 kts - FREEBOARD 2.25 ft, DRAFT 1.4 ft, LENGTH 1600 ft. MMS Computation K = 3.5; WC Tension Parameter Curve No. 2					
0.5	0.1 0.3 0.4 0.6	250 250 250 500	196 588 784 1176	238 381 596 1390	238 870 1186 1819

OVERALL EVALUATION

Albany Oil Fence, Calm Water - MMS and World Catalog computed values are close together and both somewhat higher than measured values. Computations could be considered a good match to measurements. U.S. Coast Guard Pressure-Inflatable Boom in 1.5 foot Wave - Measured values seem quite high at 0.3 and 0.4 knots. In these cases, MMS computed values are quite low, World Catalog computed values are closer, but remain low. At tow speeds of 1.2 and 1.3 knots, MMS computed values are much too high, and World Catalog values are somewhat lower but still much higher than measured values. In this test, measured values

seem to be both high for lower tow speeds and low for higher tow speeds. This could be the result of inaccurate speed and gap width measurements.
Troilboom External Tension Boom in 1.5 foot Wave - At tow speeds of 0.3 and 0.6 knots, gap ratios of 0.4, 0.5, and 0.2, World Catalog computed values follow measured values while MMS computations are slightly low. At 0.6 knots and gap ratio of 0.3, WC and MMS computations are both close to measured. At a tow speed of 0.6 knots and gap ratios of 0.4 through 0.6, both computations are much higher than measured.
VIKOMA Pressure Inflatable Boom in 1.5 foot Waves - MMS and WC computations are fairly close for the 0.1 gap ratio but then values become high. Measured values of tension seem to be quite low for all gap ratios except 0.1 for a boom of this length.

OVERALL ASSESSMENT OF TESTS OFFSHORE NEWFOUNDLAND

Environmental professionals have always been interested in obtaining real at-sea data on spill response equipment in offshore conditions. This is a good idea, but it is a double edged sword. As real conditions become more severe, it is difficult to obtain good measurements of performance. This seems to be the case in the offshore Newfoundland tests. These tests were to observe boom performance in containing released oil, but in many cases the oil was not released because of severe sea conditions. Measurements of tension on the booms were taken, however, since only single values are given, it is presumed that these are average values and continuous measurements were not made. Since both the MMS and World Catalog Computations are designed to predict performance at the 95th percentile, or two standard deviations more than the mean, this may explain why computed values are often higher than measured values.

Wind and wave conditions were described as being in the range of two sea states. Sea state definitions are broad so citing a range of two states is even more general. Exact wave and current measurements are not given, but some comments in the report give the reader an idea of what was going on. In the Albany oil fence tests the comment was that the boom bridged between wave crests in sea states 3 to 4. In the U.S. Coast Guard boom test it was noted that a barrel of oil released for the test was lost under the boom in about 10 minutes. Further, that although no current measurements were made, it was allowed that there could have been a wind induced current of about 0.5 knots. The Troilboom tests were made in a 2 meter (6 foot) long swell. The Vikoma tests were conducted in harbor chop waves 4 to 6 inches high superimposed on a 6 foot swell.

Problems in taking measurements in these conditions are obvious. Gap ratio was determined using an optical range finder and only one gap is reported per run. Towing speed must have been very difficult to measure, particularly at the lower tow speeds. As the boats operated in the swell, it must have been difficult to determine if the progress was 0.3 knots ahead or 0.2 knots astern. This possibly explains why measured tension seemed to be high at very low tow speeds. The waves probably caused a considerable tension on the booms at all tow speeds.

This makes an evaluation of the accuracy of computed values of tension difficult. In some cases computed values of tension follow measured values very well. In some cases, measured values of tension seemed to be quite high at lower tow speeds, and this could have been caused by wave action. Overall, computed values in tension seem to be helpful and at least not dangerous because they tend to be on the high side. Although the World Catalog formulas do not predict performance much better than the MMS equations, they may be somewhat better to use in these conditions because to the opportunity to enter a wide variety of wind and wave conditions.

Equations in general do not represent waves very well because they do not account for the steepness of waves, which is a major factor in determining how booms react. A very long wave, even though it may have a considerable height, would have almost no effect on a boom because the boom just gradually rises and falls and performs in nearly the same was as it would in calm water. Clearly steps should be taken to determine how a boom performs based on the steepness of waves.

3.0 OHMSETT TESTS 1992 (6)

NOFI Vee-Sweep 600 and 600S booms were tested at OHMSETT between August and October 1992 to determine if skimming could be performed at speeds higher than 0.75 knots. Test objectives included measurement of:

- o Critical Tow Speed without oil; that is, the speed at which failure occurs by submergence, planing, splash over, or mechanical (physical) failure
- o First Loss and Gross Loss tow speeds in oil
- o Boom wave conformance
- o Oil Loss rate at various speeds above the First Loss Tow Speed

A complete description of these tests is contained in section 2.1 of the main body of this report.

3.1 Test Description

The 60 meter (197 foot) length of the sweep was doubled over to form a V and held in this shape by cross netting at the bottom of the skirt. The bottom netting was intended to stabilize the oil in the sweep. The sweep was towed with a 27.6 inch (700 mm) depth and a mouth opening (gap) of 16 meters (52 feet). The gap was reduced from the designed 19.8 meters (65 feet) to fit in the tow basin's width without causing excessive blockage. (The Vee-Sweep would normally be used with a 39 inch [1,000 mm] skirt depth but this would result with bottom effects in the tow tank.)

3.2 Boom Description - NOFI Vee-Sweep

The Vee-Sweep is a boom for use with a skimmer at the apex of the V-shaped configuration. Oil is funneled back to the skimmer by the converging sides of the V. The 60 meter (197 foot) length of the sweep is doubled over to form the V and held in this shape by cross netting at the bottom of the skirt. The bottom netting is intended to help stabilize the oil in the sweep.

<u>NOFI Vee-Sweep 600 Boom</u>

The test report does not describe the boom's physical characteristics or show a sketch. The table below shows data published in the 1999-2000 edition of the World Catalog of Oil Spill Response Products.

<u>Freeboard</u>	24 inches (600 mm)
<u>Draft</u>	39 inches (1,000 mm) This is the normal draft. Because of the depth of the test tank, a draft of 27.6 inches (700 mm) was used.
<u>Boom Height</u>	63 inches (1,600 mm) normal; boom height for the tests was 51.6 inches (1,300 mm)
<u>End Connectors</u>	NOFI DEC. - G-hooks with flexible fabric sealing
<u>Skirt Material</u>	PVC/polyester
<u>Flotation</u>	pressure inflatable sections 10 feet (3 m) long
<u>Weight</u>	6.2 lbs/ft (9.3 kg/m)
<u>Reserve Buoyancy</u>	157 lbs/ft (236 kg/m)
<u>Reserve B/W Ratio</u>	25:1 (Bitting [A-3] shows B/W of 15:1)
<u>Ballast</u>	galvanized chain
<u>Tension Member</u>	Two chains and a cable

3.3 Test Variables

- o Test oil type
- o Tow speed
- o Wave patterns

3.4 Test Results

Table 3.1 shows measured test results compared with MMS and World Catalog computations. The report lists tow forces on both sides of the boom, which is taken to be total tension. This table shows measured tension as ½ that amount. Tension in waves was generally the same as, and sometimes less than, in calm water, therefore values for calm water are shown here.

Table 3.1 Measured and Computed Tension of the 52 inch NOFI VEE SWEEP BOOM (6)
MMS Computation K = 2.0; WC Tension Parameter Curve No. 5

TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lbs)	MMS COMPUTED TENSION (lbs)	ADJUSTED WC TENSION (lbs)
2.5	0.26	2230	1473	1441
3.0		2910	2121	2075
3.5		4270	2886	2825

OVERALL EVALUATION

These results show that MMS and World Catalog computations are relatively close together and both are fairly low. The test report, however, concedes that measured tow forces for this large boom are likely to be higher than what would be expected at sea. This caveat, quoted in part suggests that ". . . . the measured tow force is probably higher than would be expected in the open ocean for the reduced mouth opening due to the bottom blockage effects. This may partially or totally compensate for the extra force expected on a sweep towed with the designed mouth opening."

4.0 MSRC, Coast Guard, Navy, and MMS Phase I Tests Offshore 1994 (7)

In May 1994 the Marine Spill Response Corporation (MSRC), the U.S. Coast Guard, U.S. Navy, and Minerals Management Service (MMS) conducted a joint test of oil containment booms in Lower New York Bay and in the Atlantic Ocean east of Sandy Hook, New Jersey. These tests were performed to collect data on boom performance, including tow forces, skirt draft, and boom freeboard, as a function to tow speed and environmental forces caused by currents, wind, and waves. Four booms were tested:

- o 3M Fire Boom (Presently the Elastec/American Marine Fireboom)
- o Barrier Boom
- o USCG/Oil Stop Inflatable Boom
- o U.S. Navy USS-42 Boom

Use of these booms permitted collection of data over a range of buoyancy to weight ratios of 5:1 to 52:1, skirt drafts from 610 mm to 1,500 mm (24 top 60 inches), and free boards from 350 mm to 1,190 mm (14 to 47 inches). Data collected were also used to compare calculated boom loads (force) and measured loads.

4.1 Test Description

In most tests booms were towed in tandem. The Oil Spill Response Vessel (OSRV) *New Jersey Responder,* the center vessel, towed two booms and acted as the command vessel. The USCG vessels *Penobscot Bay* and *Point Francis* towed the outer ends of the booms. The sweep width for one boom was held constant at approximately 300 feet (91.5 m).

4.2 Boom Description

Table 4.1 MSRC Phase I Offshore Tests (7)

BOOM	FREEBOARD (feet)	DRAFT (feet)
U.S. COAST GUARD OIL STOP Pressure inflatable curtain boom	1.5	2.0
NORLENSE BARRIER Boom, Self-inflatable curtain boom	3.9	4.9
U.S. NAVY 3M Fireboom, internal foam flotation curtain boom	1.2	2.3

The U.S. Navy USS-42 boom was also tested but boom length was not reported, therefore tension computations could not be made. Boom freeboard and draft varied with tow speed in tests and they are reported on the boom tension data sheet.

4.3 Test Results

The table that follows compares measured field results with computations using the MMS formulas and the World Catalog formula.

Table 4.2 MSRC PHASE I TESTS - SANDY HOOK, N.J. (7)
Calm Water - Variable Freeboard and Draft - Gap Ratio = 0.46

TOW SPEED (kts)	FREEBOARD/ DRAFT (ft)	MEASURED TENSION (lbs)	MMS COMPUTED TENSION (lbs)	ADJUSTED WC TENSION (lbs)
U.S. COAST GUARD OIL STOP BOOM - LENGTH 656 feet MMS Computation K = 2.0; WC Tension Parameter Curve No. 2				
0.5	0.9/1.6	513	240	200
1.0	0.75/1.8	1059	1079	901
1.5	0.6/2.1	1970	2834	2366
BARRIER BOOM - LENGTH 1312 feet MMS Computation K = 4.8; WC Tension Parameter Curve No. 6				
0.5	4.2/5.5	1,791	3,983	3,519
1.0	3.9/5.5	4,668	15,933	14,076
1.5	3.7/5.6	8,237	35,849	31,670
U.S. NAVY 3M BOOM - LENGTH 650 feet MMS Computation K = 2.0; WC Tension Parameter Curve No. 3				
0.5	0.6/2.8	70	389	463
1.0	0.36/2.5	438	1,555	1,645
1.5	0.1/2.6			

OVERALL EVALUATION

U.S. Coast Guard Oil Stop Boom - MMS and World Catalog computations are close together and follow measured tension fairly well; somewhat low at 0.5 knots, close at 1.0 knots, and somewhat high at 1.5 knots.
Barrier Boom - Measured tension is the highest of all tests performed, but although MMS and World Catalog computations are fairly close, they are many times higher than measured values. These high computed values for tension result from the great length of the boom and deep draft. Computations have been carefully checked many times and appear to be correct for the data given, but the reason for the large differences in computed and measured values is not apparent.
U.S. Navy 3M Boom - As with the barrier boom, MMS and World Catalog computations are fairly close together but computed values are considerably larger than measured tension.

5.0 MSRC, Coast Guard, Navy, & MMS Offshore Tests 1994, Phase II (8)

A series of at sea towing tests on fire resistant oil containment boom was performed by the Marine Spill Response Corporation (MSRC), the Texas General Land Office, Minerals Management Service (MMS), and various boom manufacturers at a site offshore of Galveston, Texas in August 1994. These tests were to assist MSRC Region III in evaluating fire resistant booms for future acquisition, to continue data collection for further development of ASTM guidelines on selection of booms, and to compare offshore results with test tank data. Fourteen tests were performed in sea state 1 on three booms: Applied Fabric Pyroboom™, Oil Stop Auto Boom™ Fire Model, and a SeaCurtain™ Fire Guard. The Navy 3M Fire Boom test results for Phase 1 testing in New Jersey were also included to compare with this set of fire boom results. Tow speed, tow tension, skirt depth, and skirt angle were recorded both electronically and manually and weather parameters were recorded using wind and wave sensors. Comparisons were made between the tow speed and the following parameters: tow tension, skirt draft, skirt tilt, and freeboard.

5.1 Test Description

Two booms were towed in tandem for most of the tests. The *Gulf Coast Responder* and the *Texas Responders's* Munson Boat each towed an end of the boom, with the *Texas Responder* in the center towing the other end of both booms. The sweep width between the towing vessels was held constant at approximately 91m (300 feet) using radar. This distance was varied for the Applied Fabric boom, which was towed in a "U" configuration with a distance of 46 m (150 feet) between vessels. Video cameras recorded each test run from four positions: the *Texas Responder*, the *Gulf Coast Responder*, and the two support boats. The two support boats were placed behind the apexes of the booms being towed, with video cameras focusing on the apex. Scales attached on the booms allowed the freeboard, both forward and aft, to be documented by video camera.

Test runs began with tow vessels lining up in the desired direction to the wind or swell at very slow speeds. Pre-measured rope lines between the vessels were used to maintain a constant sweep width between the vessels. The tow vessels accelerated to 0.5 knots, and when the speed was confirmed to be steady, the data for the run were recorded for approximately 10 minutes. Then the speed was increased to 1.0 knot and 1.5 knots, following the same procedure. The entire procedure was repeated for the opposite tow direction, after which the booms were recovered. A functional test was also performed to obtain the speed at which submergence or planing failure at the apex of the boom occurred in calm water conditions. On the first day of testing, wave conditions were reported to be 0.8 to 1.1 feet; on the second day they were 1.0 to 1.3 feet. A 1 foot wave was assumed for all computations.

5.2 Boom Description

Table 5.1 MSRC Phase II Offshore Tests (8)

BOOM	FREEBOARD (ft)	DRAFT (ft)
SeaCurtain Firegard, self-inflatable curtain boom	0.75	2.25
Applied Fabric Pyrboom, fence boom	1.125	2.0
Oil Stop Auto Boom Fire Model, pressure-inflatable curtain boom	1.25	2.25
Navy 3M Fire Boom, internal foam flotation curtain boom	1.2	2.3

5.3 Test Results

The table that follows compares measured field results with computations using the MMS formulas the World Catalog formula. Data for the Applied Fabric Technologies Pyroboom are not shown because only 146 feet of boom were available for testing. As a result, the boom was towed at the end of long lines and gap ratio could not be determined accurately.

Table 5.2 MSRC Phase II Offshore Tests

TOW SPEED (kts)	GAP RATIO	MEASURED TENSION (lbs)	MMS COMPUTED TENSION (lbs)	WC TENSION (lbs)	ADJUSTED WC TENSION (lbs)
Seacurtain Firegard 1 foot WAVE - FREEBOARD 0.75 ft., DRAFT 2.25 ft., LENGTH 500 ft. Gap 300 ft, Gap ratio = 0.6 MMS Computation K = 2.9; WC Tension Parameter Curve No. 3					
0.48	0.6	288	451	501	861
1.0		1002	1958	1397	2404
1.54		704	4643	2803	4825
Oil Stop Auto Boom Fire Model 1 foot WAVE - FREEBOARD 1.25 ft., DRAFT 2.25 ft., LENGTH 656 ft. Gap 300 ft, Gap ratio = 0.46 MMS Computation K = 2.9; WC Tension Parameter Curve No. 3					
Against Current (1)					
0.48	0.46	358 (2)	453	363	904
1.0		917	1969	1068	2523
1.6		1718	5040	2286	5395
With Current					
1.5		1168	4430	2051	4840
2.0		2369	7876	3352	7910
2.5		3696	12306	4970	11729
Navy 3M Fire Boom 1 foot WAVE - FREEBOARD 1.2 ft., DRAFT 2.3 ft., LENGTH 653 ft. Gap 300 ft, Gap ratio = 0.46 MMS Computation K = 2.9; WC Tension Parameter Curve No. 3					
0.5	0.46	270 (3)	501	390	796
1.0		1124	2004	1261	2567
1.5		2653	4508	2181	4449

Notes: (1) Measured tension values are identified as being with the current and against the current, but the current is not reported.
(2) Measured tension was reported at each end of the boom. These values are the average of the two tension numbers reported.
(3) Measured tension for the 3M Fireboom was not reported on a data sheet. Measured tension values were taken from a graph with a large scale and therefore are not very accurate.

OVERALL EVALUATION

Seacurtain Firegard - MMS and World Catalog values for computed tension are fairly close together but much larger than measured tension. Measured tension actually decreases between 1.0 and 1.5 knots. This unexpected result was possibly caused by things that were happening in the real offshore environment that could not be accounted for in equations. For example, the Seacurtain boom lost all freeboard at 0.7 knots. Further, a skirt tilt of 23° was reported at 1 knot and 14° at 1.5 knots, showing that the boom was not vertical in the water. This could result in a reduction of force. Also note that the gap ratio for this test was 0.6, which resulted in high values for computed tension. If the gap had been mis-represented and was closer to 0.46 as in the other tests, then computed values would have been much lower. Finally, computed values of tension are not extremely high for this size boom. If these computation were made for planning purposes, the would be satisfactory in that they show how the tension increases with tow speed and provide a safety factor that would ensure that a strong boom would be procured to do the job.
Oil Stop Auto Boom Fire Model - Data for these tests are recorded as with the current and against the current, but the velocity of the current is not identified. MMS and World Catalog computed values of tension are fairly close together but much higher than measured values. Computed tension for the higher tow speeds recorded with the current is substantially higher than measured tension; however, the effective tow speed may be much lower than reported because of the boom being towed with the current. Lower tow speeds would have resulted in much lower computed values of tension.
U.S. Navy 3M Fire Boom - As before, MMS and World Catalog computed values of tension are fairly close together but much higher than measured values. This could also be considered as satisfactory result in that planners would have a built in safety factor.

6.0 MSRC, Coast Guard, Navy, & MMS Offshore Tests 1994, Phase III (9)

A series of at sea towing tests were conducted in lower New York Harbor Bay and east of Sandy Hook, New Jersey in December 1994. These tests collected data on boom performance at sea in higher sea states and developed boom selection criteria based on typical modes of boom failure. Recommendations were made to improve the ASTM guidelines for boom selection. Data were collected to show how irregular tow speeds affect tow force; tow force as a function of tow speed; comparison of buoyancy to weight ratio to tow speed of submergence; and boom freeboard and draft as a function of tow speed. Four booms were tested in a four day test series:

- o *Norlense A/S Barrier Boom Model No.-1370-R* - self inflatable curtain boom
- o *USCG Inflatable Oil Containment Boom* - pressure inflatable curtain boom manufactured by Oil Stop Inc.
- o *US Navy Model USS-42 Boom* - pressure inflatable curtain boom
- o *MSRC Sea Sentry II Boom (Engineered Fabrics)* - pressure inflatable curtain boom

6.1 Test Description

The *M/V Seahorse* towed two booms in tandem for most tests. During the first day of testing, the USCG vessels *Penobscot Bay* and *Red Beech*, towed the outside ends of the booms along side the *M/V Seahorse*. For the second day of testing, only one boom was towed at a time by the *M/V Seahorse* and the *Penobscot Bay*. For the third and fourth test days, three vessels again formed the tandem configuration with the *M/V Seahorse* as the center vessel and the *Penobscot Bay* and the *Itco XII* as the outside towing vessels. For each boom, the vessels held the sweep width between them constant at about 91.5 meters (300 feet), except for one test in which the Barrier Boom was towed in a U configuration with a sweep width of 183 meters (600 feet).

6.2 Boom Description

Table 6.1 MSRC Phase III Offshore Tests (9)

BOOM	FREEBOARD (ft)	DRAFT (ft)
U.S. Coast Guard pressure inflatable curtain boom	1.5	2.25
U.S. Navy USS-42 pressure inflatable curtain boom	1.3	2.3
Norlense self-inflatable curtain (barrier) boom	4.0	5.0
MSRC Sea Sentry II pressure inflatable curtain boom	1.9	3.7

Only 330 feet of the Navy USS-42 were available for testing, so an older boom was attached to get a sweep width of 300 feet. As a result, the actual gap of the USS-42 boom could not be measured accurately and therefore computations of boom tension could not be made.

6.3 Test Results

The table that follows compares measured field results with computations using the MMS formulae and the World Catalog formula. For the first time in this test series, the standard deviation of measured tension was determined and used. It was found that the standard deviation in measured tension was high when towing in waves. In some cases, one standard deviation was as large as and even larger than the mean. The MMS and World Catalog equations were established in tank tests to be at the 95th percentile of measured values, or about two standard deviations above the mean. These computations are therefore likely to be, and should be, much higher than an average taken without a measure of deviation, in either calm water or waves. The larger computed value is therefore expected and desired. In the table that follows, all computed values of tension are compared to measured values plus two standard deviations.

Table 6.2 MSRC Phase III Offshore Tests (9)

TOW SPEED (kts)	AV. MEASURED TENSION (lbs)	AV. MEASURED TENSION + 2 SD (lbs)(1)	MMS COMPUTED TENSION (lbs)	WC TENSION (lbs)	ADJUSTED WC TENSION (lbs)
US COAST GUARD PRESSURE INFLATABLE BOOM (OILSTOP) FREEBOARD 1.5 ft., DRAFT 2.2 ft., LENGTH 656 ft., GAP 300 ft., GAP RATIO 0.46 WAVES 1.3 ft., WIND 8 kts MMS Computation K = 2.9, WC Tension Parameter Curve No. 3					
0.6	373	879	705	592	1397
0.9	829	2147	1586	985	2325
1.42	1856	3198	3954	1997	4713
1.6	1797	3227	5011	2402	5711
2.0	2806	4781	7830	3430	8095
2.5	5071	7537	12234	5152	12159
NORLENSE SELF-INFLATABLE CURTAIN BARRIER BOOM FREEBOARD 4.0 ft., DRAFT 5.0 ft., LENGTH 1312 ft., GAP 600 ft., GAP RATIO 0.46 WAVES 2 ft., WIND 10 kts. MMS Computation K = 6.6, WC Tension Parameter Curve No. 6					
1.0	3684	Not Reported	22572	6538	29400
1.46	4845(2)	6729	42174	10248	46116
	8581(3)	17830			
1.87	6857	7949	69300	15076	67842
2.0	8445	11353	79200	16805	75623
2.4	9580	Not Reported	114048	22724	102258
MSRC SEA SENTRY II PRESSURE INFLATABLE CURTAIN BOOM FREEBOARD 1.9 ft., DRAFT 3.7 ft., BOOM LENGTH 660 ft., GAP 300 ft., GAP RATIO 0.46 MMS Computation K = 6.6, WC Tension Parameter Curve No. 6					
0.63	796	3850	2930	1027	4622
0.9	2795	8341	5934	1653	7439
1.1	1768	6822	8864	2216	9972
1.41	3213	8611	14565	3255	14645
1.61	5252	10596	18974	3991	17960
2.14	5631	9981	33700	6499	29243
2.47	8235	8259	44689	8333	37499

Notes:
1) Average measured tension plus two standard deviations. This is very close to the work done by MMS that based formulae on the 95th percentile.
2) This is the average of highly diverse values ranging from 1319 to 8581 pounds.
3) This shows the maximum value, which was plotted in the test report.

OVERALL EVALUATION

U.S. Coast Guard Pressure Inflatable Boom - MMS and World Catalog computed values are fairly close to measured values plus two standard deviations up to 1.6 knots tow speed then they are considerably higher.
Norlense Barrier Boom - MMS and World Catalog values are close but much larger than measured values plus two standard deviations. This is a very large boom with a deep draft towed at fairly high speeds, which makes computed values very high.
MSRC Sea Sentry II - MMS and World Catalog computed values are close to measured values up to 1.4 knots, then computed values become much higher. As tow speed increases beyond 1.6 knots, measured values of tension actually decrease, which is not an expected result. At 1.6 knots and beyond, all computed values become very large.

Note: The MSRC Phase I report compares offshore measured tension with ITOPF and World Catalog computed results and faulted the computations as being too low and not representing true values of tension adequately. These computations were made with the original formulae before they were altered to match the series of measured values of tension tabulated in controlled tests. Since the formulae have been adjusted, they now compute values that are very much larger than those measured offshore. Searching for an answer this apparent paradox has not yielded any solutions but there are possible answers. First, towing a large boom at relatively high speeds, up to 2.5 knots, is bound to show a high computed value of tension. Showing measured values to be low suggests that tow speeds were not as high as reported. Second, the effect of wind and waves on these large booms makes computed values of tension high. There is some evidence to suggest that measured tension in long waves is likely to be the same as in calm water. This is noted in the test report. "Average tow forces for each boom were approximately the same in each sea state." (Page 26) And later, "A boom experienced the same average tow force for a given tow speed, regardless of sea state." The wave length in which this is true is likely to be in the range of length to height ratio of 12:1 to 15:1 and longer. The exact ratio at which this would true should be determined in controlled tests. To check this theory, computations were performed using the World Catalog formula for the Sea Sentry II boom in calm water instead of waves. The results of these computations show values much closer to measured tension at least up to a tow speed of 1.4 knots. This result suggests that the relationship between wave length to height ratio and measured tension should be investigated.

7.0 U.S. Coast Guard Offshore Tests 1993 (11)

The Carderock Division of the Naval Surface Warfare Center, (CDNSWC) was tasked by the U.S. Coast Guard Research and Development Center to evaluate the performance of the Coast Guard Vessel of Opportunity Skimming System (VOSS), the NOFI V Sweep boom, and the Fully Integrated Oil Collection System (FIOCS). Tests were conducted off the coast of Groton, Connecticut and near Montauk Point, Long Island during the first two weeks of May 1993. The VOSS system is half-catenary supported by a jib extended over the side of the host vessel. This configuration is not covered by existing boom tension equations, and therefore this part of the test report is not analyzed. The FIOCS consists of a relatively small boom catenary towed by a single 650 foot guiding boom. This configuration is also not represented in tension equations, and therefore this is not a part of the analysis. Data on the NOFI V Sweep boom is covered in this section.

7.1 Test Description

Two booms were towed in tandem over the side of the tug/supply vessel *Trojan*. The NOFI V Sweep was deployed on the starboard side of the host vessel. The V Sweep is constrained into a V-shape by underwater netting of various strengths and grid sizes. The netting is attached to the boom skirt constraining the boom into a V shape rather than allowing the boom to take a more standard parabolic shape. The boom is typically towed by two vessels, but for these tests, the boom was attached to the outboard portion of an outrigger (jib) while the inboard section was pulled close to the host ship through a block and tackle arrangement and secured to the forward section of the ship. Boom tension was measured by a load cell on the outboard end of the outrigger and a load cell on the inboard section of the boom where it was secured to the forward section of the ship. Tow speed was measured with a knotmeter positioned in the apex of the boom. Wave height was measured with a floating wave buoy.

7.2 Boom Description

This pressure inflatable boom had a freeboard of 2 feet, a draft of 3.3 feet, and a length of 140 feet. The towing gap of 42 feet gave a gap ratio of 0.3.

Table 7.1 U.S. Coast Guard Tests Offshore (11)
NOFI V-SWEEP BOOM, Freeboard 2 feet, Draft 3.3 feet
Length 140 feet, Gap 42 feet, Gap Ratio 0.3

WAVE HEIGHT (ft)	TOW SPEED (kts)	MEASURED TENSION (lbs) AVERAGE	MEASURED TENSION (lbs) MAXIMUM	MMS COMPUTED TENSION (ft)	ADJUSTED WC TENSION (lbs)
MMS Computation K = 3.4; WC Tension Parameter Curve No. 5					
CALM WATER	1.13 2.13	325 1046	max. 420 av + 2 SD 361[1] max 1344 av + 2 SD 1154	603 2139	621 2207
MMS Computation K = 4.6; WC Tension Parameter Curve No. 5					
SEA STATE 1 2 ft WAVE	1.15 1.25 1.89 2.08	333 309 811 869	577 527 1212 1738	842 995 2276 2742	1199 1357 2597 3042
MMS Computation K = 4.6; WC Tension Parameter Curve No. 5					
SEA STATE 2 4 ft, WAVE	1.0 1.48 2.12 2.72 3.0	300 439 837 1403 1491	1014 1450 2363 4450 3505	638[2] 1396 2863 4718 5738	1235 2093 3583 5343 6284

Notes: 1) This value shows the average plus two standard deviations, which is close to the 95th percentile. The standard deviation was only recorded for measured values in calm water.
2) The MMS equations have a constant multiplier for calm water, 6 inch, and 1 foot waves. Since there are no additional constants for higher waves, these computed values are lower than they might have been if increasing constants had been available.

OVERALL EVALUATION

Calm Water - MMS and World Catalog computed values are close together but much higher than the maximum measured values.

2 Foot Waves - MMS and World Catalog computed values of tension are substantially higher than measured values, with the World Catalog values ranking the highest.

4 Foot Waves - MMS Computed values are less than the measured maximum at 1 knot and 1.48 knots then larger than the maximum. World Catalog computed values are higher than measured maximums throughout.

Although nearly all computed tension values for these tests are larger than measured maximums, they are not so high as to be not useful. If computed values were used in planning to use a boom of this type, they could be considered to contain an appropriate safety factor.

8.0 Stevens Institute of Technology Wave Tank Tests (12)

A series of scaled tests were performed by the Davidson Laboratory at Stevens Institute of Technology in 1994 under a grant of the U.S. Coast Guard through the New Jersey Science Consortium.

8.1 Test Description

Scaled boom models were towed in the test tank and results were reported as full scale tests. Scales of 1/8, 1/4, and 3/8 were used with a constant 24 foot length of boom giving scaled boom lengths of 192, 96, and 64 feet. Wave heights were 0.5, 1.0, and 1.5 feet giving scaled values of 4, 8, and 12 feet. The width of the test tank limited the sweep width to 8 feet which permitted a gap ratio of 3:2 for a 12 foot boom and 3:1 for a 24 foot boom. Most tests were run with a gap ratio of 3:1. Tests were performed using light weight pressure inflatable boom. Air pressure was maintained and monitored while buoyancy to weight ratio was changed by adding and deleting ballast weights. Three different buoyancy to weight (B/W) ratios were tested for each boom sample. Data were recorded a scaled tow speeds of 0.5, 1 and 2 knots. The results of tests showed no scale effects on heave response to various types of waves.

8.2 Boom Description

Boom sizes were 0.5, 1.0, and 1.5 feet giving a constant scaled boom height of 4 feet. The test boom was provided by Slickbar products Corporation of Seymour, Connecticut.

8.3 Test Results

The table that follows compares measured test tank results, reported as full scale, with computations using the MMS formulae and the World Catalog formula. Tests were performed in regular and irregular waves. The regular waves all had a length to height ratio of 12:1 and a period of 3 to 5.5 seconds. The irregular waves did not have a length to height ratio reported and a period of 5.5 to nearly 8 seconds. All results in this study were reported as total drag force, which is double the tension reported in all other tests in this report. These measured test results, therefore, are divided by two to compare with the computed results.

Table 8.1 Stevens Institute Wave Tank Tests (12)
Freeboard 1.6 feet, Draft 2.4 feet Gap Ratio = 0.3, Boom Length 192 feet
Regular Wave Length/Height Ratio 12:1 - All values 1/8 scale
MMS Computation K = 2.9, WC Tension Parameter Curve No. 3

WAVE HEIGHT (ft)	TOW SPEED (kts)	MEASURED TENSION (lbs)	MMS COMPUTED TENSION (lbs)	ADJUSTED WC TENSION (lbs)
BUOYANCY TO WEIGHT RATIO 16.2:1				
4' REGULAR WAVE	0.5	320	100	368
	1.0	657	401	782
	2.0	2001	1604	2072
8' REGULAR WAVE	0.5	473	100	553
	1.0	568	401	1041
12' REGULAR WAVE	0.5	517	100	719
	0.9	901	325	1145
4' IRREGULAR WAVE	0.5	63	100	368
	1.0	204	401	782
6' IRREGULAR WAVE	0.5	81	100	464
	1.0	534	401	919
8' IRREGULAR WAVE	0.5	207	100	553
BUOYANCY TO WEIGHT RATIO 12.5:1				
4' REGULAR WAVE	0.5	378	100	368
	1.0	665	401	782
	1.9	1692	1604	2072
8' REGULAR WAVE	0.5	390	100	553
	1.0	741	401	1041
12' REGULAR WAVE	0.5	627	100	719
	0.9	1067	401	1145

NOTES: 1) Since the MMS equations are only prepared for waves up to 1 foot in height, all values for a given tow speed in waves of 1 foot and higher are the same.
2) World Catalog formulae include provision for wave height but not wave type; therefore, all computations for a given tow speed and wave height are the same.
3) Tests with the lower buoyancy to weight ratio were intended to show that for a given tow speed, booms with the lower B/W ratio experienced higher tension. This is marginally true in some cases and not true in others.

Table 8.2 Stevens Institute Wave Tank Tests (12)
Freeboard 1.6 feet, Draft 2.4 feet Gap Ratio = 0.3, Boom Length 96 feet
Regular Wave Length/Height Ratio 12:1 - All values 1/4 scale
MMS Computation K = 2.9, WC Tension Parameter Curve No. 3

WAVE HEIGHT (ft)	TOW SPEED (kts)	MEASURED TENSION (lbs)	MMS COMPUTED TENSION (lbs)	ADJUSTED WC TENSION (lbs)
BUOYANCY TO WEIGHT RATIO 34.3:1				
2' REGULAR WAVE	0.5	114	56	130
	1.0	262	223	310
	2.0	960	891	903
4' REGULAR WAVE	0.5	103	56	185
	1.0	255	223	391
6' REGULAR WAVE	0.5	121	56	231
	1.0	310	223	459
2' IRREGULAR WAVE	0.5	47	56	130
	1.0	224	223	310
3' IRREGULAR WAVE	0.5	54	56	158
	1.0	218	223	353
4' IRREGULAR WAVE	0.5	63	56	185
5.6' IRREGULAR WAVE	0.5	88	56	223
	1.0	245	223	446

NOTES: 1) Since the MMS equations are only prepared for waves up to 1 foot in height, all values for a given tow speed in waves of 1 foot and higher are the same.
2) World Catalog formulae include provision for wave height but not wave type; therefore, all computations for a given tow speed and wave height are the same.
3) Tests with the lower buoyancy to weight ratio were intended to show that for a given tow speed, booms with the lower B/W ratio experienced higher tension. This is marginally true in some cases and not true in others.

OVERALL EVALUATION

Looking at performance using the long boom, 1/8 scale and buoyancy to weight ratio of 16.2:1, computed results for a 4 foot regular wave show MMS values low and World Catalog computations fairly close. In the 8 foot regular wave, the measured value at 1 knot seems low and not consistent with other results. The World Catalog computation is close at 0.5 knots and high 1.0 knot. In the 12 foot regular wave World Catalog values are somewhat high and MMS values remain low. In all irregular waves, measured values or tension are very low, so MMS values are fairly close and World Catalog values are quite high. Having low measured values of tension in substantial irregular waves is not an expected result.

Considering performance in regular waves at the lower buoyancy to weight ratio (12.5:1), results are similar. World Catalog computations are generally close to slightly high while MMS computations remain low except for a single isolated case, a 4 foot wave at 1.9 knots. The report presents the argument that for a given tow speed, tension increases as B/W ratio decreases. Data show that is only marginally true for this small change in B/W ratio and measured values are so close that they may fall within the range of the accuracy of the measurement.

Table 8.2 shows a similar set of tests, but with a shorter boom, a scale of 1/4 instead of 1/8, and a substantial increase of B/W ratio, to 34.3:1. Measured tension is lower than in similar tests, but since most wave conditions are different, there are not many values to compare. Since the boom length is smaller, MMS computed tension is somewhat low in regular waves but quite close in irregular waves. World Catalog computed values are fairly close in regular waves and quite high in irregular waves.

9.0 OHMSETT TESTS OF FIRE RESISTANT BOOMS 1996 (13)

Six fire resistant oil containment booms were tested at OHMSETT between July and October 1996. Tests were sponsored by the U.S. Coast Guard Research and Development Center and Minerals Management Service. Booms tested included

- o American Fire Boom, American Marine, Inc.
- o Dome Boom, Dome Petroleum
- o PyroBoom, Applied Fabric Technologies
- o Paddle Wheel Boom, Oil Stop Inc.
- o Spill-Tain™ Fireproof Oil Spill Containment Boom - Offshore Version
- o Inflatable Auto Boom™ Fire Boom, Oil Stop Inc.

Five of the six booms were tested for their oil holding capability by determining oil pre-load, first and gross loss tow speed, oil loss rate, critical tow speed, which measures mechanical stability, and tension on the booms at various tow speeds. No tests in fire were performed in this series. The Paddle Wheel Boom was found to need further development and did not go through the full series of tests.

9.1 Test Description

Pre-load Tests - A series of first loss tow speed tests using increasing amounts of oil to determine the volume of oil a boom holds until the addition of more oil has a minimal affect on first loss tow speed.
Oil Loss Tests - The tow speed at which the boom first begins to lose oil is called the first loss tow speed.
Oil Loss Rate Tests - Boom loss rates are obtained by towing the boom with its pre-load of oil at the first loss tow speed plus 0.1 knots and 0.3 knots.
Critical Tow Speed - This is the maximum speed at which the system can be towed before losing freeboard or draft. Towing speed typically begins at 1 knot and is increased in 0.25 knot increments until failure is observed. The failure occurs when the boom submerges or comes out of the water. This test is run in calm water without oil. The boom failure and type of failure are noted on data sheets and the likely affect the failure had on the tension measurement.
Tow Force - Two load cells were used to continuously measure the tension forces in each of the boom tow lines.
Wave Conditions - All measurements of boom tension were made in calm water.

9.2 Boom Description

Table 9.1 Booms used in U.S. Coast Guard OHMSETT Tests (13)

	AMERICAN MARINE - Internal foam curtain boom	DOME BOOM - fence boom	PYRO BOOM - fence boom	SPILL-TAIN - fence boom	OIL STOP - curtain, pressure inflatable boom
DRAFT (ft)	1.75	3.7	1.3	2.2	2.1
FREEBOARD (ft)	0.75	2.2	1.2	1.75	1.5
B/W RATIO	3.8:1	3.5:1	8:1	2.75:1	9.5:1

Table 9.2 Tests of Fire Resistant Booms at OHMSETT (13)
All Tests Recording Tension Were in Calm Water
Gap Ratio was 0.5 In All Cases

TOW SPEED (kts)	MEASURED TENSION (lbs)	MMS COMPUTED TENSION (lbs)	WC TENSION (lbs)	ADJUSTED WC TENSION (lbs)
AMERICAN MARINE BOOM Freeboard 0.75 ft., Draft 1.75 ft., Length 100 ft. MMS Computation K = 2.86 (interpolated for draft); WC Tension Parameter Curve No. 2				
0.5	30	63	22	37
1.0	250	251	89	151
1.5	500	563	200	340
2.0[3]	900	1001	355	604
DOME BOOM Freeboard 2.2 ft., Draft 3.7 ft., Length 100 ft. MMS Computation K = 4.8; WC Tension Parameter Curve No. 6				
0.5	500	222	47	202
1.0	800	888	188	808
1.5	1000	1998	422	1815
2.0[4]	1000	3552	750	3225
PYRO BOOM Freeboard 1.2 ft., Draft 1.3 ft., Length 105 ft. MMS Computation K = 2.24 (interpolated for draft); WC Tension Parameter Curve No. 2				
0.5	80	38	18	31
1.0	400	153	69	117
1.5	600	344	156	265
2.0	1000	612	277	471
2.5[5]	1500	956	432	734
SPILL-TAIN Freeboard 1.75 ft., Draft 2.2 ft., Length 90 ft. MMS Computation K = 3.2; WC Tension Parameter Curve No. 4				
0.5	-	79	25	65
1.0	500	317	101	263
1.5	700	713	226	588
2.0	1025	1267	401	1043
2.5	1250	1980	627	1630
3.0[6]	1550	2851	903	2348
OIL STOP Freeboard 1.5 ft., Draft 2.1 ft., Length 100 ft. MMS Computation K = 2.0; WC Tension Parameter Curve No. 3				
0.5	150	53	27	62
1.0	325	210	107	246
1.5	500	473	240	552
2.0	800	840	426	980
2.5	1525	1313	665	1530
3.0	2000	1890	958	2203

Notes:
1) All values of measured tension are an average of graphic plots using a very small (inaccurate) scale.
2) Tests were performed to determine critical tow speed, therefore boom draft was increasing as speed increased. This would have increased the computed tow tension if the change in draft was known.
3) Boom submerged at 2.25 knots.
4) Critical tow speed planing.
5) Boom submerged at 2.75 knots.
6) No failure at more than 6 knots.

OVERALL EVALUATION

American Marine Boom - MMS computed values for tension are close to measured values. World Catalog computed values are somewhat low. The boom submerged at 2.25 knots indicating that draft was increasing. The increase in draft, if known, would have resulted in larger values for computed tension.

Dome Boom - MMS and World Catalog computed values are close together, but low at 0.5 knots, close to measured value at 1 knot, and high at 1.5 and 2.0 knots. The boom failed by planing at 2 knots, which probably accounts for the low value of measured tension at 1.5 knots and no increase in tension at 2 knots.

Pyro Boom - MMS and World Catalog computed values of tension are close at 1 knot then World Catalog values are somewhat lower. The boom submerged at 2.75 knots which suggests draft was increasing with tow speed. Since the increased draft was not reported, computations of tension are necessarily low. Also, earlier tank measurements of tow tension slowed that fence booms tend to have higher measured tow tension that is not reflected in computations.

Spill-Tain - MMS computations are quite close to measured tension up to 2.0 knots, then they are significantly higher. World Catalog computations begin a bit low, are very close to the measured value at 2.0 knots, and then are somewhat higher than measured values.

Oil Stop Boom - Computed values of tension are a little low at 0.5 knots, then follow measured values closely up to 3.0 knots.

10.0 OHMSETT TESTS of Four Fire Resistant Booms 1999 (14)

Seven commercial fire booms were burn tested at the U.S. Coast Guard Fire and Safety Test Detachment in Mobile, Alabama from August to October 1998. Four of these seven booms passed the test sequence described in ASTM F20 Fireboom test protocol and were shipped to the OHMSETT facility for further testing.

The four booms selected were tested at OHMSETT between September and November 1998. Tests were sponsored by the U.S. Department of Transportation and the U.S. Coast Guard R&D Center. Booms tested include:

- o Elastec/American Marine Hydrofire
- o Spill-Tain
- o Applied Fabrics Pyroboom®
- o Applied Fabric Technologies/SL Ross Pocket Boom

The Spill-Tain boom and Applied Fabrics Pyroboom® were both tested at OHMSETT in 1996 (13). The Applied Fabrics Technologies/SL Ross Pocket Boom is a smaller version of the Dome boom previously tested. It was re-engineered by SL Ross and manufactured by Applied Fabrics Technologies. The Elastec/American Marine Hydrofire boom was a newly developed prototype that circulated water as a cooling agent.

The purpose of the test was to measure the oil collection and containment performance and sea keeping performance of the booms in a variety of towing and wave conditions. Specific test results include:

- o Individual oil pre-load required for testing
- o First and gross loss tow speeds
- o Oil loss rate
- o Critical tow speed at which the boom loses freeboard or draft
- o Tow forces on booms during tests

Tests were performed in calm water and three wave conditions. This section is only concerned with measured boom tension and all but one of these tests were performed in calm water.

10.1 Test Description

Pre-load Tests - A series of first loss tow speed tests using increasing amounts of oil to determine the volume of oil a boom holds until the addition of more oil has a minimal affect on first loss tow speed.
Oil Loss Tests - The tow speed at which the boom first begins to lose oil is called the first loss tow speed.

Oil Loss Rate Tests - Boom loss rates are obtained by towing the boom with its pre-load of oil at the first loss tow speed plus 0.1 knots and 0.3 knots.
Critical Tow Speed - This is the maximum speed at which the system can be towed before losing freeboard or draft. Towing speed typically begins at 1 knot and is increased in 0.25 knot increments until failure is observed. The failure occurs when the boom submerges or comes out of the water. This test is run in calm water without oil. The boom failure and type of failure are noted on data sheets and the likely affect the failure had on the tension measurement.
Tow Force - Two load cells were used to continuously measure the tension forces in each of the boom tow lines.
Wave Conditions - All but one of the measurements of boom tension were made in calm water.

The test booms were rigged in a catenary configuration with a gap ratio of 3:1. Each manufacturer's section of Fireboom was extended by attaching a 25 section of Applied Fabric Technologies Globe boom at each end. This provided the additional length necessary to position the test booms at the apex. Globe boom comes in at least ten sizes and unfortunately the specific boom used in this test was not identified. Although the boom size could probably be determined from the manufacturer, current equations for computing boom tension have no provision for computing tension with different kinds of boom joined together. As a result, computations were made assuming the boom was all of the same type and appropriate notations have been made.

10.2 Boom Description

Table 10.1 Booms used in U.S. Coast Guard OHMSETT Tests (14)

	ELASTEC/AMERICAN MARINE HYDRO-FIRE	SPILL-TAIN	PYROBOOM	POCKET BOOM
DRAFT (ft)	1.75	1.9	1.6	2.1
FREEBOARD (ft)	0.83	1.9	0.9	1.1
B/W RATIO	3.6:1	2.75:1	3.2:1	2.0:1

10.3 Test Results

The table that follows compares measured test tank results with computations using the MMS formulas and the World Catalog formula. All measured values are taken from graphs with a very small scale and therefore are only approximate. Also note that these are likely to be average values while both sets of equations used to compute tension are designed to compute values that fall within the 95th percentile of all values recorded or two standard deviations above the mean.

Table 10.2 Tests of Four Fire Resistant Booms at OHMSETT 1999 (14)
All Booms Were Extended by 25 feet of Globe Boom at Each End
Gap Ratio Was 3:1 In All Cases

TOW SPEED (kts)	MEASURED TENSION (lbs)	MMS COMPUTED TENSION (lbs)	WC TENSION (lbs)	ADJUSTED WC TENSION (lbs)
ELASTEC/AMERICAN MARINE HYDROFIRE Freeboard 0.8 feet, Draft 1.8 feet, Length 100 feet[1], Tests in 1.1 foot Waves MMS Computation K = 3.5; WC Tension Parameter Curve No. 2				
0.5	20	46	24	56
1.0	160	184	61	146
1.5	275	413	117	280
2.0	490	735	190	455
2.5	825	1148	280	672
3.0	1150	1654	389	932
SPILL -TAIN Freeboard 1.9 feet, Draft 1.9 feet, Length 95 feet[2],Tests in Calm Water MMS Computation K = 3.2; WC Tension Parameter Curve No. 4				
0.5	95	44	9	36
1.0	210	174	37	146
1.5	305	391	83	330
2.0	540	695	147	586
2.5	810	1086	229	914
3.0	1125	1564	329	1316
PYRO BOOM Freeboard 0.9 feet, Draft 1.6 feet, Length 100 feet[3], Tests in Calm Water MMS Computation K = 2.65 (interpolated for draft); WC Tension Parameter Curve No. 4				
0.5	20	32	8	32
1.0	250	127	33	130
1.5	510	286	73	292
2.0	790	509	130	518
2.5	1175	795	203	810
POCKET BOOM Freeboard 1.1 feet, Draft 2.1 feet, Length 104 feet[4], Tests in Calm Water MMS Computation K = 3.2; WC Tension Parameter Curve No. 4				
0.5	50	53	11	44
1.0	100	210	45	178
1.5	250	472	100	398
2.0	390	839	177	708
2.5	490	1310	277	1106
3.0	545	1887	399	1594

Notes: 1) Hydrofire boom test section was 49.3 feet.
2) Spill-Tain boom section was 45 feet.
3) Pyro Boom section was 50 feet.
4) Pocket boom section was 56.7 feet.

OVERALL EVALUATION

First it must be noted again that all of the booms were extended by tow 25 foot sections of Globe Boom of unknown dimension. Further, measured values of tension were average whereas formulae computing tension are set at the 95th percentile or two standard deviations above the mean.

Elastec American Marine Hydrofire Boom - World Catalog computations are close to measured results and at tow speeds of 2 knots and higher, somewhat below measured values. MMS values are close at the low end and somewhat high at 1.5 knots and above.

Spill-Tain Boom - Both computation methods are fairly close to measured values; MMS values are slightly high at 1.5 knots and above while World Catalog values are somewhat closer and slightly high at tow speeds above 2.5 knots.

Pyro Boom - Both computation methods are quite close together but below measured values.

Pocket Boom - Computed values remain fairly close but substantially above measured tension. This is not an expected result because measured values of tension are generally higher than computed values for fence booms.

11.0 Conclusions and Recommendations

11.1 Conclusions

1) Measured test results suggest that either the MMS equations or the World Catalog equations could be used for computing forces on booms in most situations. There are situations in which one system is better than the other - the user can be the judge based on data shown in this appendix. Computations show that the World Catalog equations may be better for computing tension in waves greater than one foot.

The MMS equations are easier to used since they involve fewer terms; however, if constants are gathered together and a system of computation is established, the World Catalog equations are also fairly easy to use. In addition, those with good computer skills report that they are able to set up the World Catalog equations in a spread sheet format and the equations are solved in the computer. Based on the analysis of this study, it seems clear that both systems of equations have a secure place as tools to compute tension on towed containment booms.

2) Neither the MMS and World Catalog equations follow measured results for fence booms very well. This is probably because large exterior buoyancy members produce hydrodynamic forces that are not represented in the equations. The user who has a continuing requirement for predicting tow forces on fence booms should probably use existing measured values of boom tension to develop a special set of constants for the MMS equations and a separate curve for tension parameter using the World Catalog formulae.

3) Comparing measured boom tension from offshore tests to computed values has mixed results. There are a great many reasons for this, only some of which are well understood.

o Average tension is generally measured in offshore tests. Current equations are designed to predict the values included in the 95th percentile, or two standard deviations above the mean. Standard deviation has rarely been recorded in offshore tests, but when it has, it is generally large, sometimes much larger than the average value itself. In most cases, computed values of tension for offshore operations are much larger than average measured values, which is good because it shows computed values are predicting numbers that may be within the 95th percentile, which provides a safety factor for boom design and use.
o Measuring tow speed offshore is difficult, particularly at lower speeds. In addition, currents sometimes occur offshore that are not being measured. Since all equations that predict boom tension have a squared term for tow speed, inaccuracies can cause a substantial change in the result. o Gap ratio has a substantial effect on boom tension. It is often difficult to maintain the desired gap ratio in offshore tests which results in a large difference between measured tension and computed tension.
o Computed tension is directly proportional to boom draft. As booms are towed at higher speeds, they sometimes tend to submerge, which may result in increased boom draft. (The bottom tension member of a curtain boom may tend to bow the boom up so that draft may not increase even though freeboard is decreasing.) In any case, a unreported increase in boom draft will make measured tension larger than computed tension.
o Wave action increases tension on booms, but not always in a way that can be predicted by an equation. Wave height is significant but it must also be linked with wave length, which is something current equations do not address. It is easy to understand how an extremely long wave will have no effect on boom performance, but short, choppy waves will change performance. Tests suggest that wave length to height ratio is the controlling factor and that the crucial point is a length to height ratio

of about 12 to 15:1. Waves longer than this are not likely to affect boom performance but shorter waves certainly will. Some offshore tests show measured values of tension in waves to be about the same or even less than those in calm water. In these cases one would immediately suspect that the wave length to height ratio was greater than 15:1.

o Some booms fail by planing in offshore tests. The resulting reduction in boom draft causes a decrease in boom tension or boom tension that does not increase with increasing tow speed.

11.2 Recommendations

1) The MMS and World Catalog equations follow basin measured data very well in most cases and offshore data is some cases. These equations should be checked and tested in future controlled tests and in offshore tests when possible and results used to improve the performance of the equations. Additional work could be done to make measured values of tension in offshore tests more accurate.

2) Test data suggest that boom tension is a function of wave length as well as height and that performance depends of the wave length to height ratio. Controlled tests should be performed to determine how wave length affects boom tension and the length to height ratio at which waves no longer increase boom tension in tow.

REFERENCES FOR APPENDIX C

Reference numbers from main text are shown in parens.

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