Report No. CG-D-12-98

Test and Evaluation of Six Fire Resistant Booms at Ohmsett

David DeVitis
Susan Cunneff
James Nash

MAR, Incorporated
Ohmsett Facility
NWS Earle
Leonardo, NJ 07737

FINAL REPORT
December 1997

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

Prepared for:

U.S. Department of Transportation
United States Coast Guard
Marine Safety and Environmental
Protection, (G-M)
Washington, DC 20593-0001

and

United States Coast Guard
Research and Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

U.S. Department of the Interior
Minerals Management Service
381 Elden Street
Herndon, VA 20170-4817

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

The contents of this report reflect the views of the Coast Guard Research & Development Center. This report does not constitute a standard, specification, or regulation.

Marc B. Mandler
Technical Director
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

Technical Report Documentation Page

1. Report No. CG-D-12-98	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Test and Evaluation of Six Fire Resistant Booms at Ohmsett		5. Report Date December 1997
		6. Performing Organization Code Project No. 4120.5.1
7. Author(s) David DeVitis, Susan Cunneff, and James Nash		8. Performing Organization Report No. R&DC 38/96
9. Performing Organization Name and Address MAR, Inc. - Ohmsett Facility NWS Earle - Waterfront, Rte. 36 Leonardo, NJ 07737		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. 14-35-0001-30544
12. Sponsoring Agency Name and Address U.S. Department of Transportation United States Coast Guard Marine Safety and Environmental Protection (G-M) Washington, DC 20593-0001	United States Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6096	13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code Commandant (G-MOR) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

The R&D Center's point of contact is Mr. Kenneth Bitting, 860-441-2733.

16. Abstract

Six oil spill booms produced by five manufacturers for use as fire booms were tested at the Minerals Management Service's Ohmsett Facility, NWS-Earle, Leonardo, NJ. The tests were conducted between July 16, 1996 and October 4, 1996. The 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. However, this boom was at the lower edge of the range for first loss tow speed. A prototype boom, with a unique paddle-wheel operating principle, was the sixth boom included in the study. This boom was found to need further development.

17. Key Words		18. Distribution Statement
oil tow speed critical tow speed	oil loss rate first loss tow speed gross loss tow speed	This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

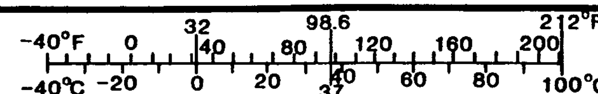

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Between July 15 and October 3, 1996 six fire resistant oil containment booms were tested at Ohmsett, the National Oil Spill Response Test Facility, Leonardo, New Jersey. The tests were sponsored by the U.S. Department of Transportation, G-M, and U.S. Coast Guard R&D Center. The six booms were the:

- American Fire Boom, American Marine, Inc.
- Dome Boom
- PyroBoom, Applied Fabric Technologies
- PaddleWheel Boom, Oil Stop, Inc.
- Spill-Tain Fireproof Oil Spill Containment Boom - Offshore Version
- Inflatable Auto Boom Fire Boom, Oil Stop, Inc.

Five of the six booms were tested for oil holding capabilities as reported in the following tests: Pre-load, First and Gross Loss Tow Speed, Oil Loss Rate, and Critical Tow Speed (measure of mechanical stability). The prototype PaddleWheel boom was found to need further development. Booms were towed in the Ohmsett Test Basin at speeds up to their maximum safe tow speeds without oil, and up to 1.3 knots with oil. Water surface conditions were either calm or one of three waves produced by the Ohmsett wave generator. One wave was a short harbor chop. The other two wave conditions were 10-inch to 14-inch high regular waves. Four of the booms performed as well as commercial non-Fire booms have performed in past tests.

1. INTRODUCTION

a. Background

At-sea incineration (*in-situ* burning) of marine oil spills is an effective response technique and has been approved for spill response use in coastal waters off Alaska and in the Gulf of Mexico. During the 1993 Newfoundland Offshore Burn Experiment (NOBE) sponsored by Environment Canada (EC), Minerals Management Service (MMS), Canadian Coast Guard (CCG), and the U.S. Coast Guard (USCG), measurements were made to collect environmental data necessary to investigate and demonstrate burning of contained oil as an oil spill response tool. One operational research need identified at NOBE was:

> "New test standards, to include dynamic testing of a heat stressed, fire-resistant booms, are necessary to evaluate fire booms for effectiveness, and set a benchmark for product improvement. Standards must be developed and validated."

The U.S. Coast Guard Research and Development Center (USCG R&DC), MMS, and CCG are currently participating in a joint project to investigate commercially available, fire-resistant, offshore containment booms for use in multiple *in-situ* burns. Under the sponsorship of the USCG R&DC, this first phase of the project evaluates the oil containment and seakeeping abilities of selected fire-resistant booms in dynamic conditions at Ohmsett - The National Oil Spill Response Test Facility in Leonardo, NJ. Various *in-situ* burn trials (with fire) will be conducted at other test tanks.

In-situ burning is beginning to appear as a response tool in area contingency plans; however, there is not much technical information that indicates to responders how fire booms will perform as oil containment booms. This information will assist responders in their planning.

The results of these tests could also help to advance the technology of fire resistant booms. Boom improvements can be made through design modifications based on observations from these tests. The opportunity to observe underwater how their boom performs provides invaluable insight to the manufacturers.

The American Society for Testing and Material (ASTM) Committee F-20 on Hazardous Substances and Oil Spill Response is developing consensus standards for testing fire resistant booms as oil containment booms as well as fire booms. The Test Plan used in these tests and the results will be evaluated by ASTM in their effort to compose a standard test for fire booms.

b. Test Objectives

The objective of these tests is to quantify: (1) the oil collection performance, and (2) the seakeeping of selected fire booms under tank towing conditions.

c. Test Scope

The purpose of this test is to characterize the oil collection performance of selected fire booms by measuring the tow speed at which the boom begins to lose oil and the rate of oil loss. These tests are conducted at a combination of tow speeds, in calm water and three wave conditions. Boom tow forces are measured at various speeds to assess drag. The test fluid is blended oil with a nominal viscosity of 2000 centipoise (cPs) and specific gravity of .94-.96. Each boom is approximately 100 feet long and is rigged with a 2:1 length-to-gap ratio.

d. Description of Fire Booms

Descriptions of the booms are presented in the order that the booms were tested. The descriptions are based on information provided by each vendor. Table 1 is a summary of the boom dimensions, materials, and buoyancy-to-weight ratios.

Table 1 Boom Characteristics

	American Marine	Dome Boom	Applied Fabrics PyroBoom	Spill-Tain	Oil Stop Inflatable
Draft (in)	21.0	44.0	16.0	26.0	25.0
Freeboard (in)	9.0	26.0	14.0	21.0	18.0
Wt/LF (lbs/lf)	8.5	30.5	8.0	19.4	9.0
No of sections	2	11	1	3	2
Length (ft)	100	100	105	90	100
Buoyancy:Wt	3.8:1	3.5:1	8:1	2.75:1	9.5:1
Predominant Fire Resistant Material	Ceramic Flotation / Refractory Fabric /SS Mesh	Stainless Steel	Glass Foam Floatation/ Refractory Fabric	Stainless Steel	Refractory Fabric / Stainless Steel
Tension Member	Stainless Steel	Stainless Steel	½" Galvanized Chain	Stainless Steel	½" Galvanized Chain

(1) American Marine, Inc. American Fire Boom

Each 50-foot boom section is 12 inches in diameter, 30 inches in height, weighs approximately 425 lbs. and has seven segments. Each 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 temperature-resistant textile 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 internal 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. Two sections were joined and used for this evaluation. See Figure 1.

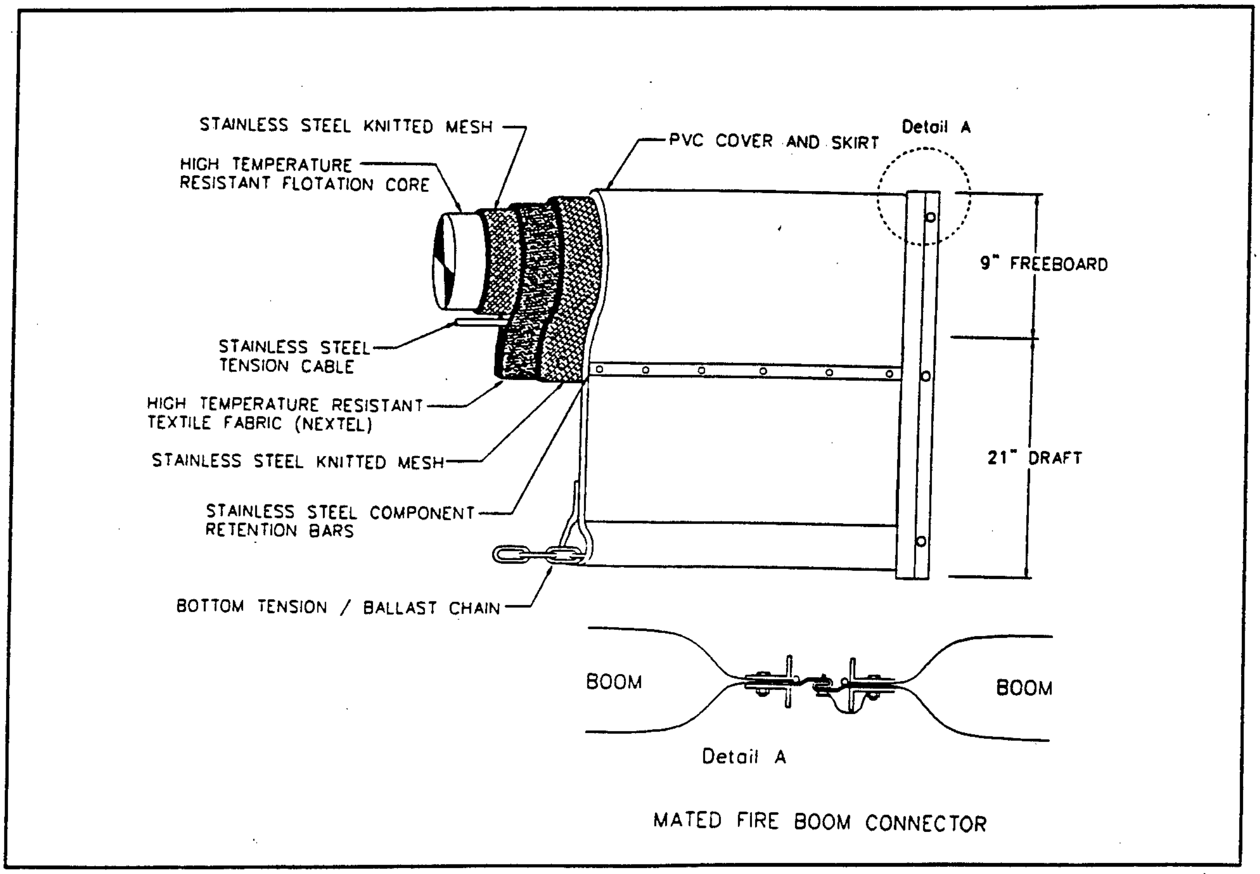

Figure 1 Details of the American Marine, Inc. American Fire Boom

(2) Dome Boom

The Dome Boom was developed during a three-year program. Beginning with a search for the most suitable materials of construction, an initial boom design was developed. A prototype boom was fabricated and tested for static flotation and under catenary and straight line towing up to five knots. Based on the test results, towing paravanes were added to the operational model. Fireproof fabric/mesh connectors were replaced with 0.4 millimeter thick, type 321 stainless steel flexible panels. The resulting boom, shown below in Figure 2, was then tested in trial burns in 1980 at Port Melon, B.C. The following year towing tests and burn tests were conducted at Ohmsett. Eleven boom sections and towing paravanes were assembled for testing. Each section weighs 275 lbs. and has a buoyancy-to-weight ratio of 3.5 : 1.

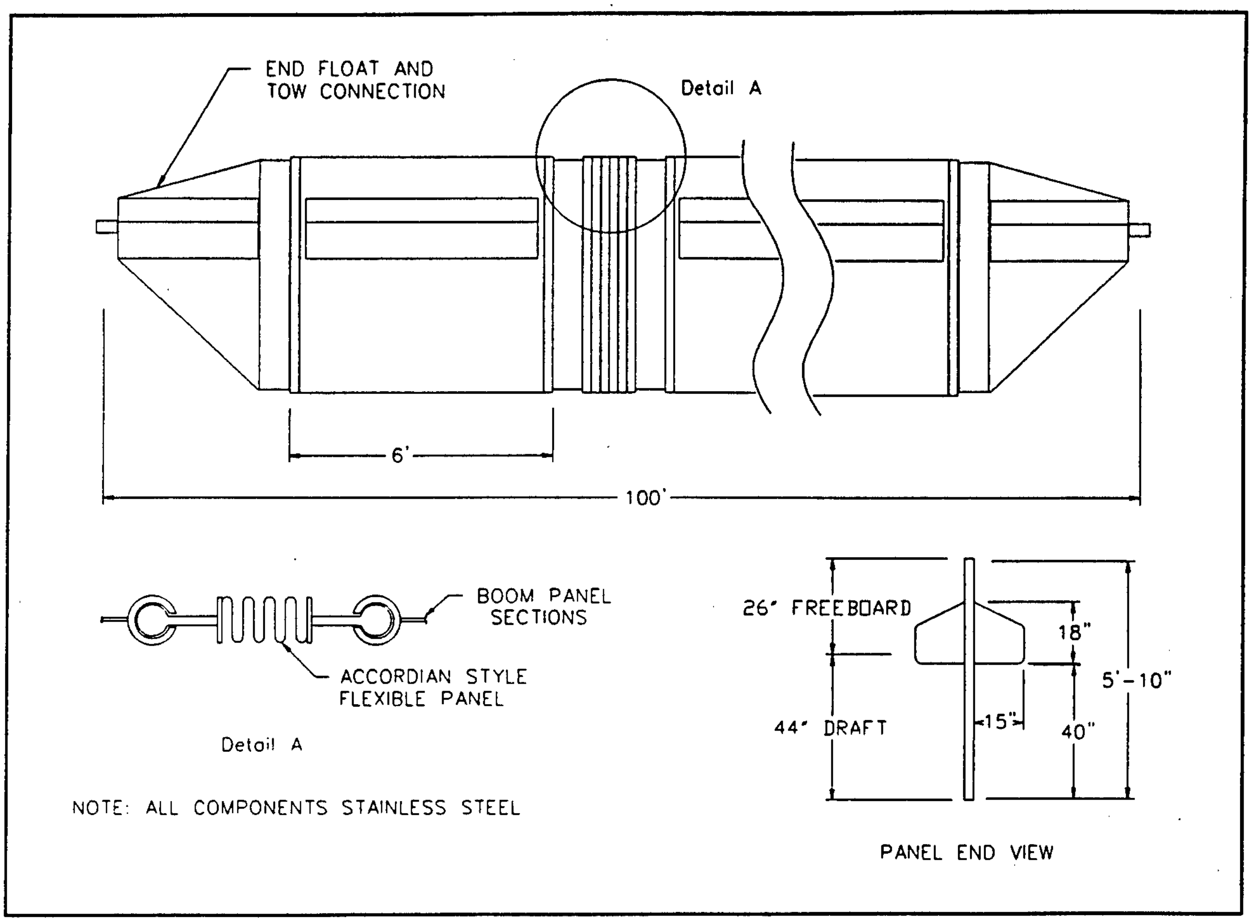

Figure 2 Details of the Dome Boom

(3) Applied Fabric Technologies PyroBoom®

PyroBoom® is a solid flotation barrier that combines wire reinforced refractory fabric for the above surface barrier with conventional GlobeBoom® fabric for the skirt. The glass, foam filled, steel hemispheres are mechanically attached to the barrier. Their modular construction allows for salvage, maintenance, and repair in the field. The boom has a 16-inch draft and a 14-inch freeboard. The boom is 105 feet long. There are galvanized shackles above each flotation hemisphere for lifting. PyroBoom® behaves like GlobeBoom® and no special handling equipment is necessary. Figure 3 illustrates the boom tested. A complete kit consists of: a boom, a U-configuration sweep assembly with wire cross bridles, and a steel storage kit with retrieval windlass.

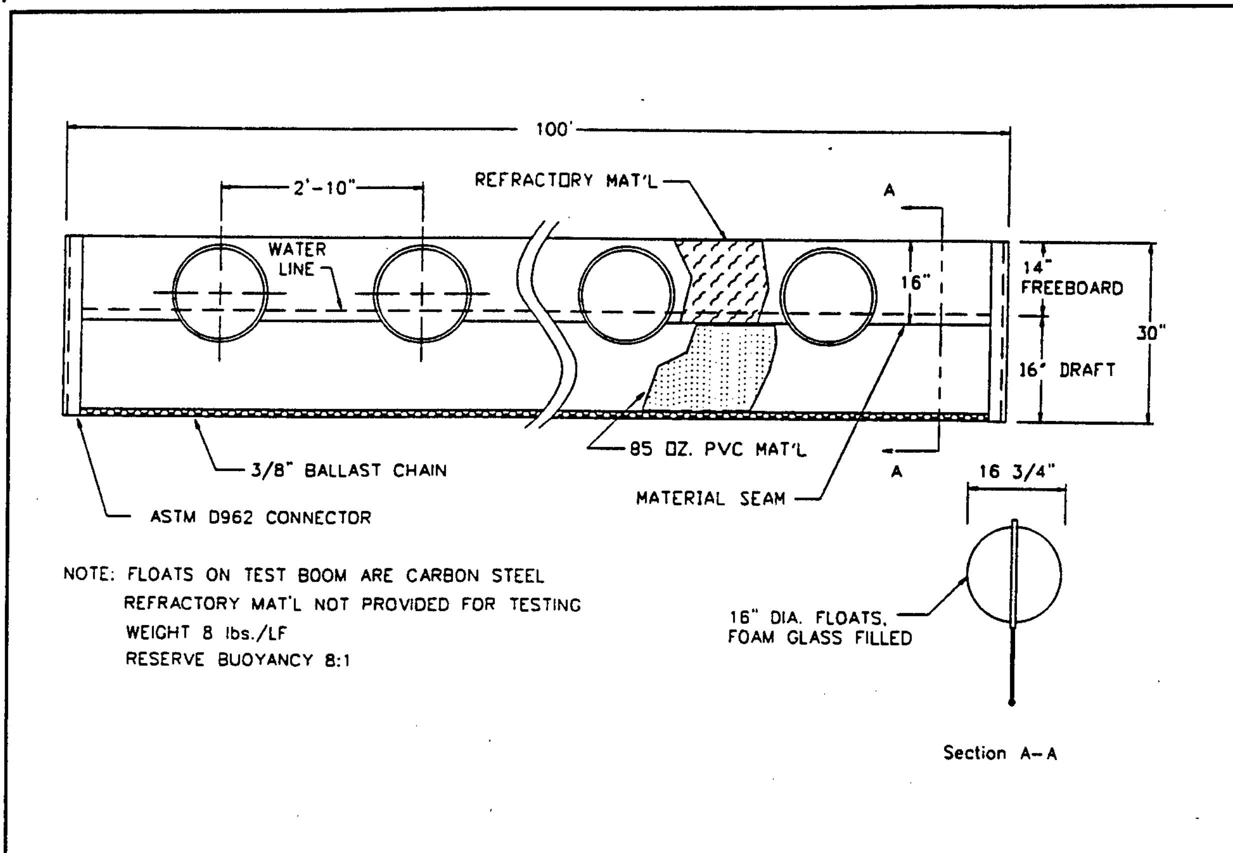

Figure 3 Details of Applied Fabric Technologies PyroBoom®

(4) Oil Stop's PaddleWheel Boom®

The PaddleWheel Boom® is a dynamic oil containment recovery device designed to contain oil in high currents. The boom system consists of a diesel engine, hydraulic motor, and a series of shaft-driven paddle-wheels that create a surface current that is counter to the local current. The oil is therefore held away from actual contact with the boom. Because oil is held away from the boom and the boom is cooled by passing water, the PaddleWheel Boom® can be used as a fire boom. See Figure 4.

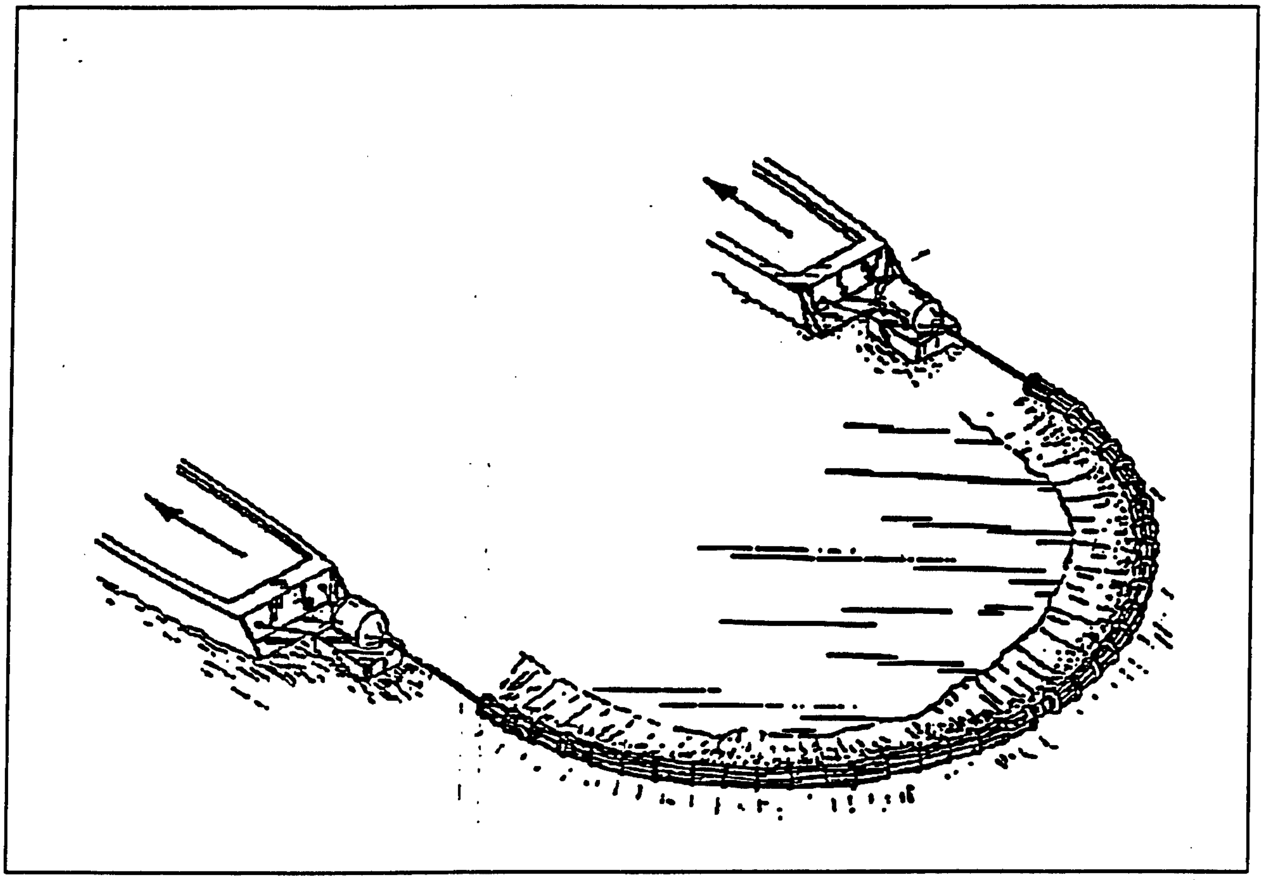

Figure 4 Artists Concept of Oil Stop's PaddleWheel Boom® in Use

(5) Spill-Tain™ Fireproof Oil Spill Containment Boom - Offshore Version

Spill-Tain™ is an external tension line boom with most of the boom material consisting of thin, type 316L stainless steel sheet metal, closed cell foam glass flotation, and stainless steel cable. The boom can follow wave action due to a patented, segmented panel design. Deployed boom segments are composed of alternating stainless steel parallelograms and rectangles, separated by trapezoids. Boom panels are supported perpendicular to the water by alternating attached outrigger floats. Adjacent boom panels are attached to each other by integrally formed piano hinges. The tension cable is affixed to the bottom outer edge of the outrigger floats. Connecting plates with five thumb screws and accompanying nut plates join the 30-foot sections to one another, with shackles connecting cable eyes at each section end (see Figure 5). Three sections were joined to form a 90-foot section for testing. Each section weighs 583 lbs., with a buoyancy-to-weight ratio of 2.75 : 1.

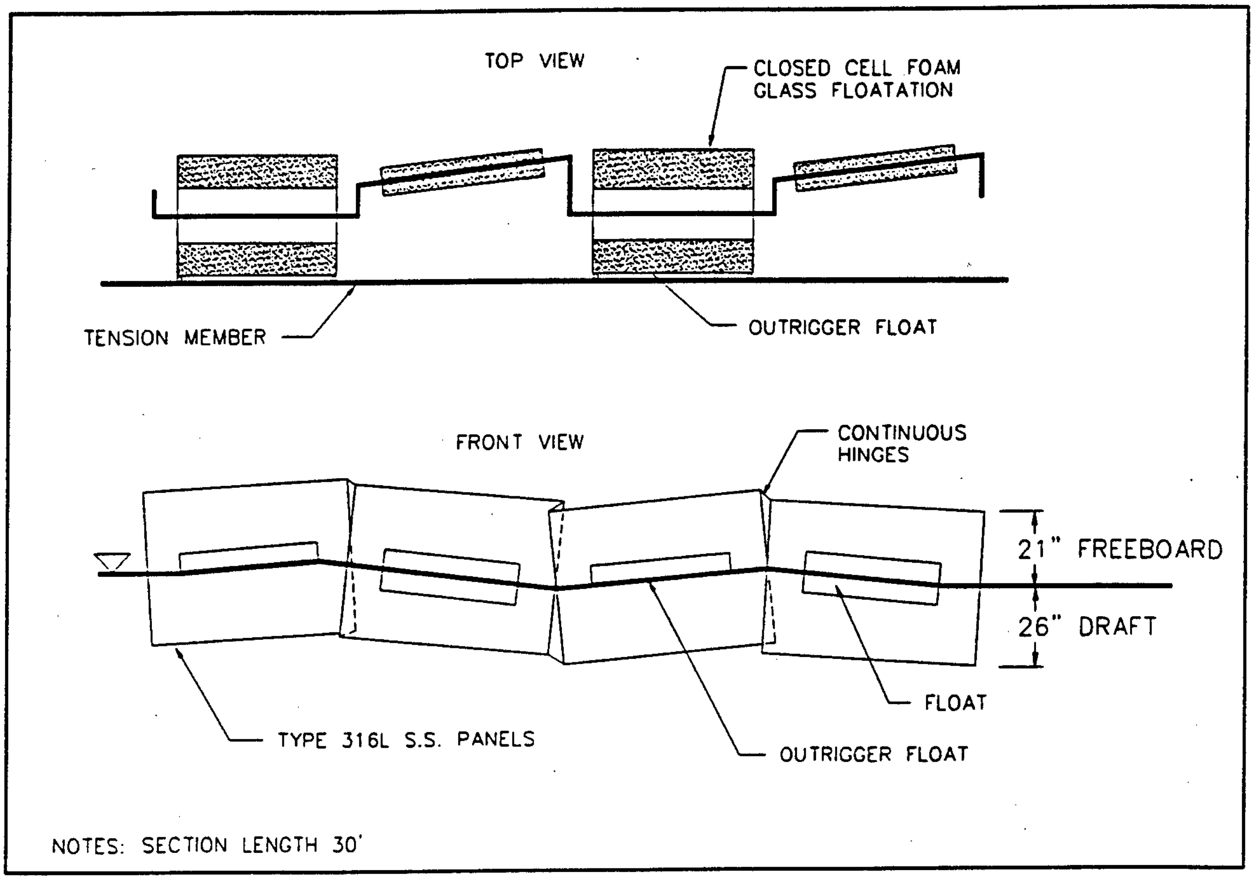

Figure 5 Details of Spill-Tain™ Fire Boom Offshore Version

(6) Oil Stop's Inflatable Auto Boom™ Fire Boom (Model is the Bay Boom)

This inflatable fire boom has a 14-inch float diameter and 22-inch skirt. It is equipped with universal end connectors. The boom is inflated using a patented single-point inflation design. Once inflated, the boom automatically sectionalizes the air chambers into separate compartments, so that individual air chambers stay inflated even if adjacent chambers are damaged or deflated. There are three layers beneath the boom's polyurethane exterior. They are: a stainless steel screen, a ceramic insulation blanket, and a high temperature inflatable membrane (see Figure 6). The tension member/ballast is a ½-inch galvanized chain contained in the hem of the boom skirt. Two 50-foot boom sections were joined for this evaluation.

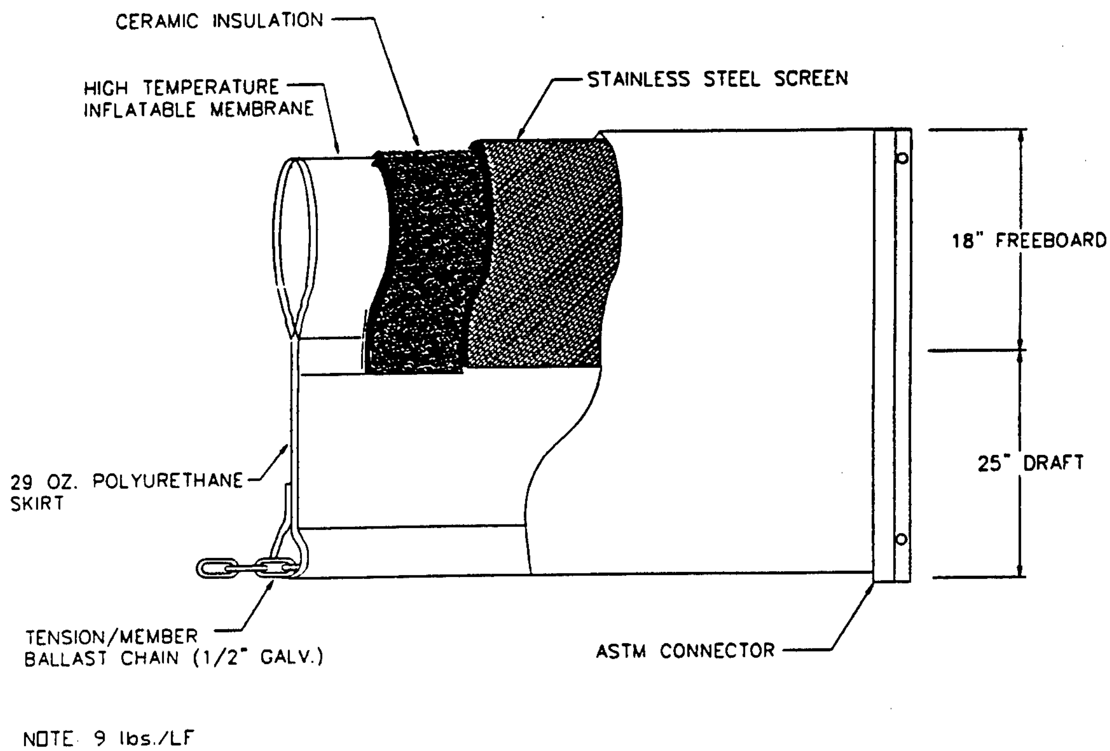

Figure 6 Oil Stop's Inflatable AutoBoom™ Fire Boom

2. TEST DESCRIPTIONS

a. Typical Test Configuration and Instrumentation

The test setup is illustrated in Figure 7 and each of the electronic meters mentioned in this section are described fully in Appendix A. The boom is rigged with a 2:1 boom length-to-gap ratio. In-line load cells are attached at each tow bridle, between the bridle and the Main Bridge tow points. Except for the load cell on the west side of the boom, all data cables are fastened to the east side of the boom. Pre-load oil is pumped directly into the boom apex using the hose suspended from the messenger cable. When encountering oil, the oil is distributed from the Main Bridge distribution manifold. Recovered fluids are pumped to the Auxiliary Bridge recovery tanks where volume measurements are recorded and fluid samples are taken using a stratified sampling thief or grab sampler.

A single underwater camera is suspended from the Auxiliary Bridge and is focused on the apex of the boom. With this camera, test personnel observe the oil loss from the boom, and mark the event electronically with the event marker. A second underwater camera is mounted on the Main Bridge and is focused on the apex from the boom mouth. A topside camera mounted on the Main Bridge tower records an overall view of the test while a portable camera, not shown in Figure 7, is used to record the testing from various perspectives.

Waves are generated at the South end of the Test Basin and controlled by the Bridge Operator in the Control Tower at the North end. A local readout of the wave generator cycles per minute is on the control console. The waves are recorded using a Datasonics ultrasonic distance meter shown in Figure 7 as "Sonic Wave Sensor." The signal from the wave meter is recorded and analyzed after testing to confirm the wave characteristics.

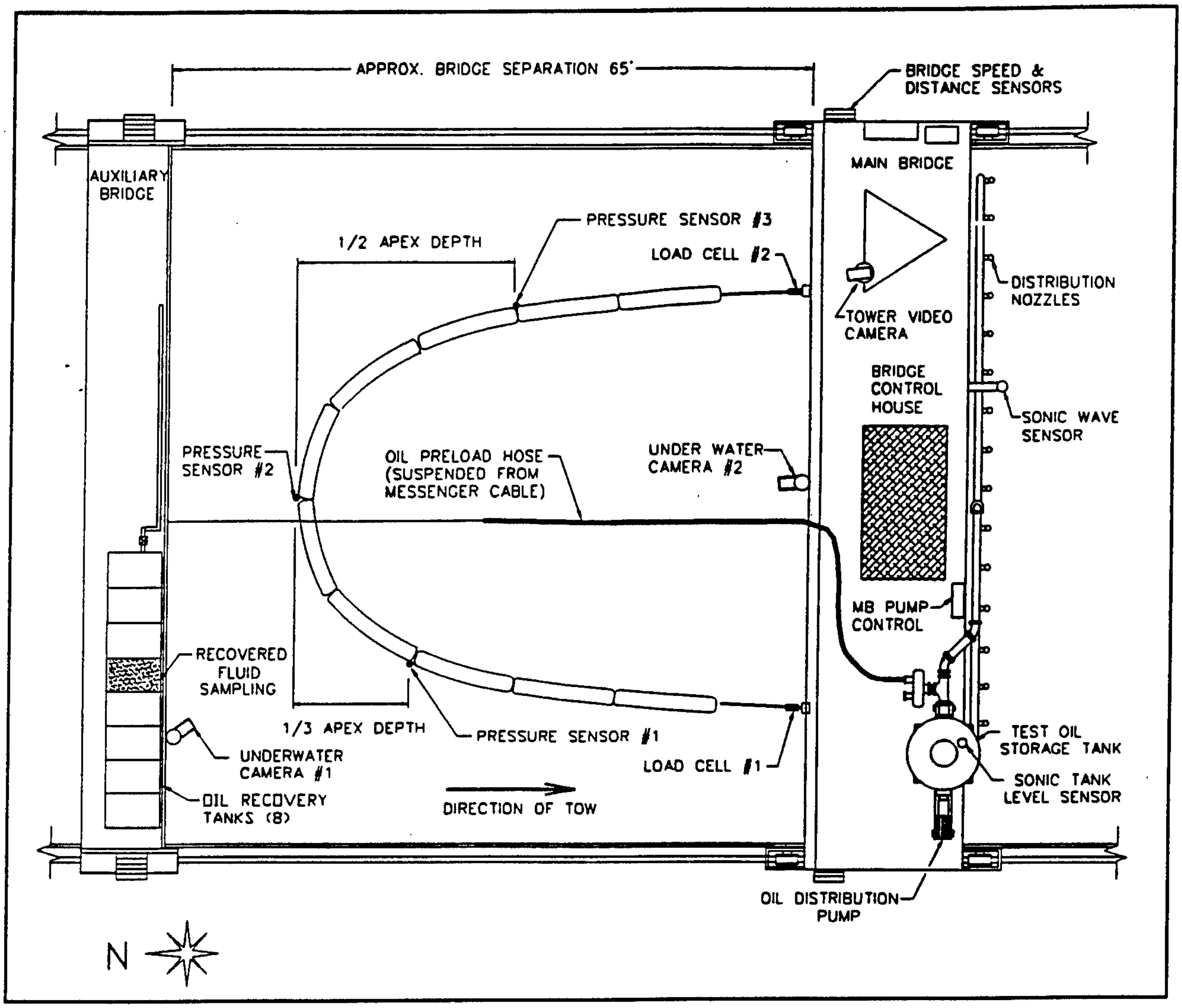

Figure 7 General Test Basin Set-up for Fire Boom Tests

b. Test Methods - Data Collection and Analysis

Pre-load Tests - This is a series of First Loss Tow Speed tests using increasing amounts of oil. This test determines the volume of oil a boom holds until the addition of more oil has a "minimal" effect on the First Loss Tow Speed. Beginning with a nominal pre-load volume, the First Loss Tow Speed is obtained. The process is repeated with increased pre-load volumes until the addition of oil to the pre-load has minimal or no effect on the First Loss Tow Speed. A graph of First Loss Tow Speed vs. Pre-load Volume is created to visually determine the pre-load necessary for the Oil Loss, and Oil Loss Rate Tests.

Oil Loss Tests - The tow speed that a boom first begins to lose oil is called "First Loss Tow Speed." At a slightly higher tow speed, oil is lost at a significantly greater rate, called Gross Loss. Both of these conditions are determined by observation using an underwater video camera image. These speed values in calm water are determined as part of the Pre-load Tests described above. Additional tests in waves are run with the same pre-load as in calm water.

Oil Loss Rate Tests - Boom loss rates are obtained by towing the boom with its pre-load volume of oil (determined during the Pre-load Tests) at First Loss Tow Speed plus 0.1 knots and 0.3 knots. The tow speed is constant for the length of the Test Basin with oil distributed at 26 G.P.M. or 105 G.P.M. respectively. In order to quantify the oil loss from the fire booms, the lost oil is skimmed and collected at the conclusion of each loss rate test run. This is accomplished by using the Auxiliary Bridge skimming boom to skim lost oil to the north end of the Ohmsett Test Basin. The oil is then removed from the water surface with an Elastec oil skimmer and pumped to the Ohmsett recovery tanks. Once free water is drained from the recovery tanks, depth measurements are made for each recovery tank holding emulsion ($\mathbf{d_i}$). Samples are then taken for analysis to determine the percent oil content; the results of these sample analyses are shown in Appendix B. Oil remaining in the boom after each test is used as the pre-load for the next test. The Oil Loss Rate (**OLR**) is then calculated:

$$\mathbf{OLR} = \sum \mathbf{d_i} * \mathbf{k_i} * \mathbf{c_i} / \mathbf{t}$$

where: $\mathbf{k_i}$ is the depth-to-volume factor for recovery tank **i**, $\mathbf{c_i}$ is the percent oil determined by analysis; and **t** is the lapsed time in minutes that the loss occurred. For the +0.3 kt loss test the results are corrected to account for loss that occurs prior to reaching the test speed. The correction involves calculating the **OLR** twice. The first +0.3 **OLR** is averaged with the +0.1 **OLR** and multiplied times the lapsed time between the +0.1 and +0.3 speeds. This can be done by examining the computer data files. The resulting calculated volume of oil is subtracted from the sigma portion of the above equation and a new **OLR** calculated.

Critical Tow Speed - This is the maximum speed the system can be towed through the water before it loses freeboard or draft. Towing speed typically begins at 1.0 knot and is incremented by 0.25 knots until the failure mode is observed. The end point is made by observation when the boom submerges or comes out of the water. The test is run in calm water and without oil. It is run last because of the potential for mechanical failure of the boom.

Tow Force - Two load cells are used to continuously measure the tension forces in each of the boom tow lines. The data are recorded on the Ohmsett data collection computer and available for post test analysis.

c. Wave Conditions

Four different surface conditions were employed during this test series. Each (except for calm) has been assigned a wave number. A wave analysis was performed for each test and is reported by test number in Appendix C.

The following wave parameters are target values for this test series. Actual wave conditions for each test appear in Appendix C. For general identification the waves are specified as:

- Calm - no waves generated.
- Wave #1 - is a regular sinusoidal wave with an $H^{1/3}$ (significant wave height, which is defined as the average of the highest 1/3 of the measured waves) of 12.0", wavelength of 14.0 feet, and an average apparent period of 1.7 seconds. Wave dampening beaches are employed during the generation of this wave condition.
- Wave #2 - is a regular sinusoidal wave with a $H^{1/3}$ of 16.5", wavelength of 42.0 feet, and an average apparent period of 2.9 seconds. Wave dampening beaches are employed during the generation of this wave condition.
- Wave #3 - is defined as a harbor chop condition with an average $H^{1/3}$ of 15.0" and an average apparent period of 2.0 seconds. For this wave, reflective waves are allowed to develop for 15 minutes prior to a given test. No wavelength is calculated for this condition.

d. Test Matrix

The matrix for the Fire Resistant Boom Test Series is listed in Table 2.

Table 2 Fire Boom Test Matrix

		WAVE DATA*					
TEST	SPEED	TYPE	$H^{1/3}$ (in)	L (ft)	T (sec)	PRE-LOAD	DIST.
PRE-LOAD	VAR	Calm	N/A	N/A	N/A	VAR	N/A
LOSS RATE	(1st loss)+.1	Calm	N/A	N/A	N/A	TBD	TBD
	(1st loss)+.3	Calm	N/A	N/A	N/A	TBD	TBD
OIL LOSS	VAR	#2	16.5	42.0	2.9	TBD	N/A
	VAR	#1	12.0	14.0	1.7	TBD	N/A
	VAR	#3	15.0	N/A	2.0	TBD	N/A
CRITICAL	VAR	Calm	N/A	N/A	N/A	NONE	N/A

* Note: Wave data are average values from previous Ohmsett tests

$H^{1/3}$ = significant wave height = the average of the highest 1/3 of the measured waves (in inches).
L = wavelength = the distance (in feet) on a sine wave from trough to trough (or peak to peak)
T = average apparent wave period = the time (in seconds) it takes to travel one wavelength.

3. TEST RESULTS AND OBSERVATIONS

a. Summary Results of All Tests

Of the six fire booms, five were tested according to the matrix listed in Table 2. The sixth boom is a unique prototype paddle-wheel boom that requires further development before it is ready for testing. A master data table shown in Appendix D lists the results for all tests performed. An assessment of the Fire Boom Test Quality for all tests performed is found in Appendix E.

b. Pre-load Determination Results

An oil pre-load volume was obtained for each of the fire booms based on the volume at which First Loss Tow Speed became independent of Tow Speed. The booms tested were similar in length and therefore the boom length-to-gap ratios (2 to 1) were constant. Variation of boom type and skirt depths were left as parameters influencing the oil containing capacity of each. The pre-load volumes for each boom tested are listed in Table 3.

Table 3 Pre-load Determination Results

Boom	Pre-load Volume (gal)
American Fireboom	360
Dome Boom	500
PyroBoom	600
Spill-Tain	350
Oil Stop Inflatable	500

Figure 8 illustrates results of each of the pre-load tests performed on each boom. A minimum of four tests were performed for each. The resulting First Loss Tow Speeds varied from .85 to 1.0 knots, a range of .15 knot.

c. Oil Loss Speed Tests

The oil containing capability of each boom was determined while experiencing four different surface conditions when loaded with the previously determined volume of oil. The tow speed at which the first oil loss condition occurred was obtained. Each test run was duplicated and the two resulting speeds averaged and plotted as Figure 8 with the supporting data in Table 4.

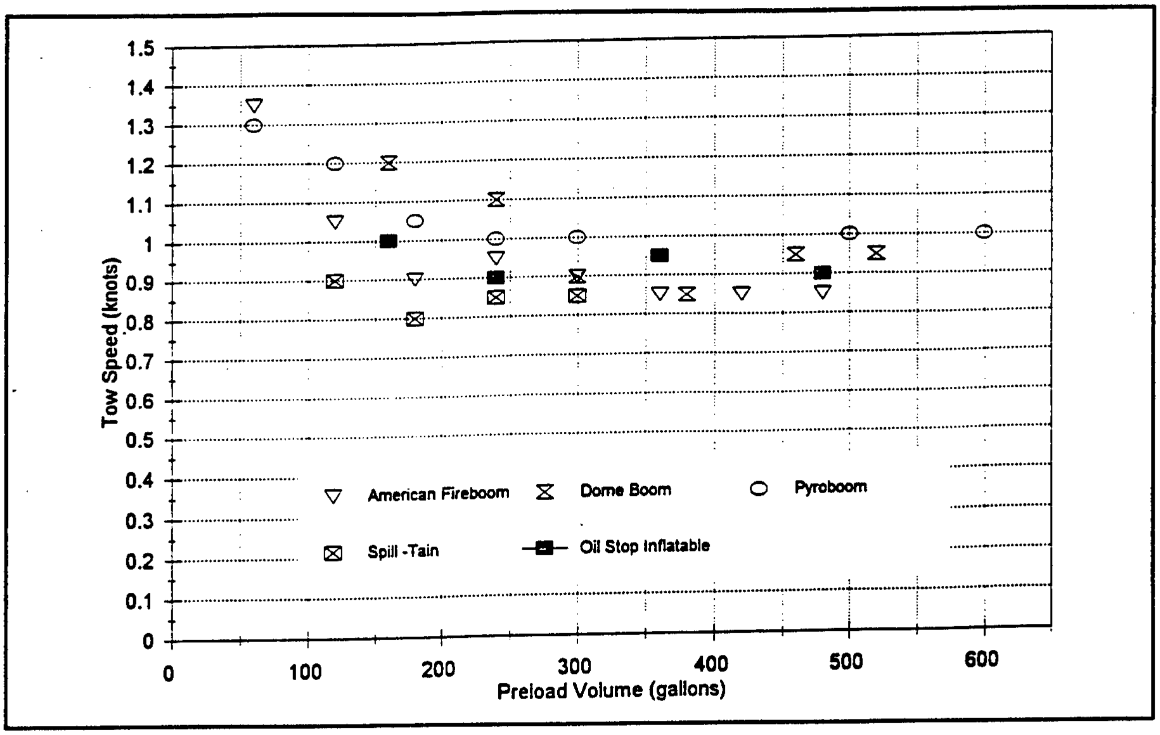

Figure 8 First Loss Tow Speed vs. Pre-load Volume

Table 4 First Loss Tow Speeds at Pre-load Volumes

Pre-load Vol. (gal)	First Loss Tow Speeds (in knots) for:				
	American Fireboom	Dome Boom	PyroBoom	Spill-Tain	Oil Stop Inflatable
60	1.35		1.30		
120	1.05		1.20	0.90	
160		1.20			1.00
180	0.90		1.05	0.80	
240	0.95	1.10	1.00	0.85	0.90
300	0.90	0.90	1.00	0.85	
360	0.85				0.95
380		0.85			
420	0.85				
460		0.95			
480	0.85				0.90
500			1.00		
520		0.95			
600			1.00		

As shown in Figure 9, the range of First Loss Tow Speeds for calm surface conditions was .15 knot. Applied Fabrics PyroBoom achieved the highest First Loss Tow Speed of 1.0 knot with the largest pre-load volume of 600 gallons; the others ranged from .85 - .95 knots. The American Fireboom, PyroBoom and Oil Stop boom oil containing capabilities in regular wave #2 increased from the calm surface conditions. This may be attributed to the wave action causing the pre-load oil to stack further into the apex along with the leading edge where losses typically occur. The performance of the Dome boom and Spill-Tain boom were unchanged.

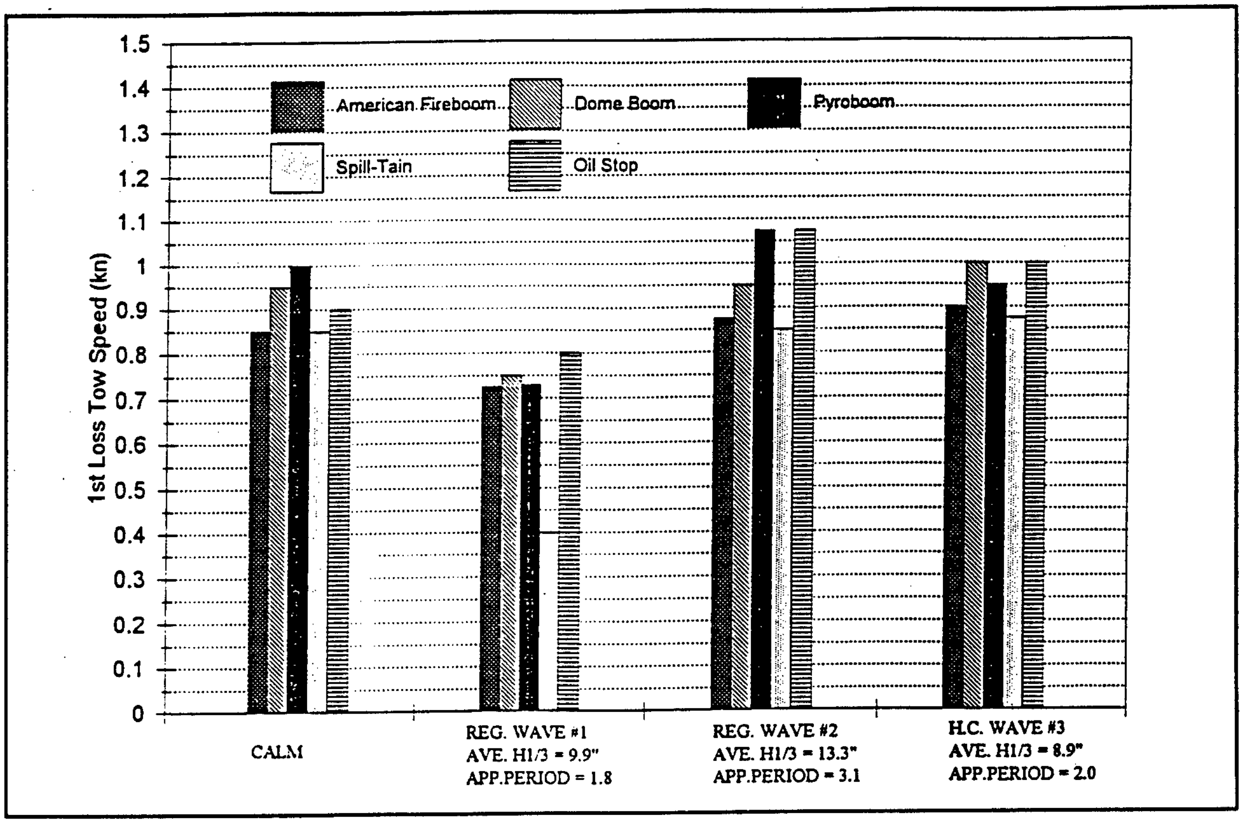

Figure 9 First Loss Tow Speeds vs. Wave Condition

During the regular wave #1 condition, four booms (excluding the Spill-Tain boom) performed comparably with First Loss Tow Speed results between .72 and .8 knots (see Figure 9). The Spill-Tain boom, with a First Loss Tow Speed of .4 knots, experienced losses from the oil front leading edge. This wave condition caused the Spill-Tain boom to exhibit a pulsating action that followed the wave motion, and with each pulse oil was lost under the apex. The Spill-Tain boom also utilized the smallest pre-load volume of 350 gallons. Overall, wave #1 had a negative effect on the oil containing ability of each boom.

During wave #2 conditions the First Loss Tow Speeds varied from 0.85 to 1.08 knots, a range of 0.23 knots (see Figure 9). The harbor chop condition, wave #3, increased the First Loss Tow Speed of each boom over the baseline calm surface condition, except for the PyroBoom.
Gross Loss Tow Speeds reported in Table 5 are consistently .2 knots higher than the First Loss Tow Speeds with the exception of the Dome boom, which has a value for calm water of .4 knots higher and wave #1 which is .3 knots higher.

Table 5 Gross Loss Tow Speeds (knots)

	American Fireboom	Dome Boom	PyroBoom	Spill-Tain	Oil Stop Inflatable
Calm	1.10	1.32	1.20	1.05	1.22
Wave #1	0.90	1.05	0.93	0.60	NA
Wave #2	1.15	1.20	1.30	1.05	NA
Wave #3	1.15	1.25	1.10	1.07	NA

d. Oil Loss Rate Tests

The amount of oil lost from the test booms has been quantified by means of the Oil Loss Rate Test. Each of the test booms were pre-loaded with the prescribed volume of oil and encountered 26 G.P.M. or 105 G.P.M., while being towed at First Loss Tow Speed +0.1 and +0.3 knots, respectively. The results of this test are plotted in Figure 10. Each test was performed twice. The PyroBoom loss rate average was 141 G.P.M., approximately double the loss rate of any other booms. By examining the results by boom type, it is clear that the solid skirt booms (Dome Boom and Spill-Tain) had the lowest loss rates. The inflatable type booms (American Fireboom and Oil Stop) performed comparably, losing an average of 19 G.P.M. at First Loss +0.1 knots and an average of 78 G.P.M. at First Loss +0.3 knots.

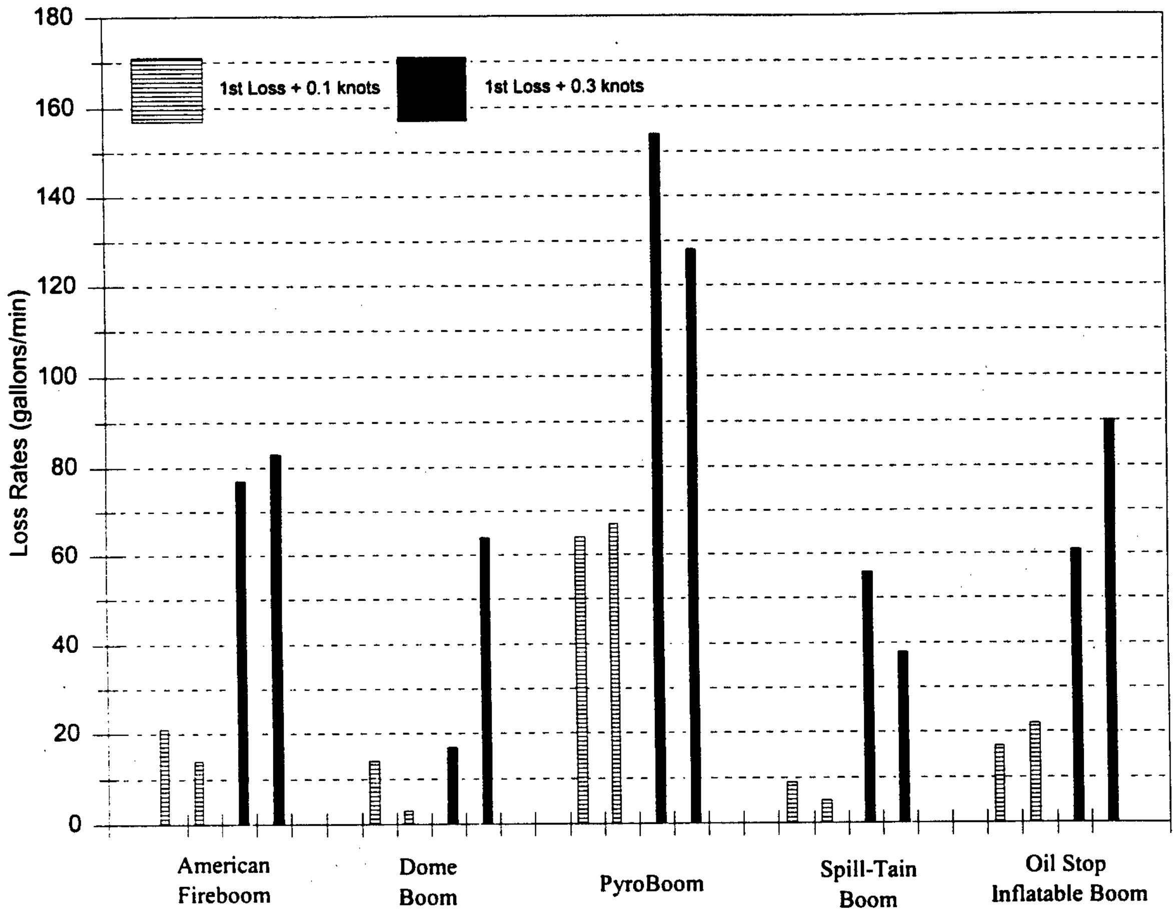

Figure 10 Oil Loss Rates at First Loss Tow Speed Plus 0.1 and 0.3 Knots

e. Critical Tow Speed and Tow Force Testing

The Critical Tow Speed of each boom was determined for calm surface conditions and repeated for data confidence. Table 6 contains the Critical Tow Speeds obtained along with the mode of failure.

Table 6 Critical Tow Speed Values for Five Fire Booms

Test Boom	Critical Tow Speed (knots)	Mode of Failure
American Fireboom	2.25	Submerged
Dome Boom	2.0	Planing
PyroBoom	2.75	Submerged
Spill-Tain	> 6.0	No Failure
Oil Stop	3.5	Submerged

The American Fireboom gradually lost freeboard until total loss of freeboard occurred at 2.25 knots around the apex. The Dome Boom skirt began planing at 2.0 knots and was towed up to 3.25 knots without causing damage. The PyroBoom exhibited planing of the boom catenary legs beginning at 2.0 knots and total loss of apex freeboard at 2.75 knots. Highest Critical Tow Speeds of 6 knots were achieved by the Spill-Tain boom, which is the maximum speed of the Ohmsett bridge towing system; the boom appeared stable throughout the test runs. During tows of the Oil Stop boom, gradual loss of freeboard occurred most severely around the apex. Once total submergence of a boom section occurred, the complete apex submerged and began oscillating violently. This behavior caused significant increases in tow forces, from the stable tow force value of 3000 lbs. to 8000 lbs. during the oscillation. Force vs Tow Speed, Figures 18 & 19, (Tow Force graphs of Test No.111 & No.112) illustrate the forces experienced at the load cells. The towing forces were obtained during each of the Critical Tow Tests and plotted as Force vs Tow Speed in Figures 11 through 19.

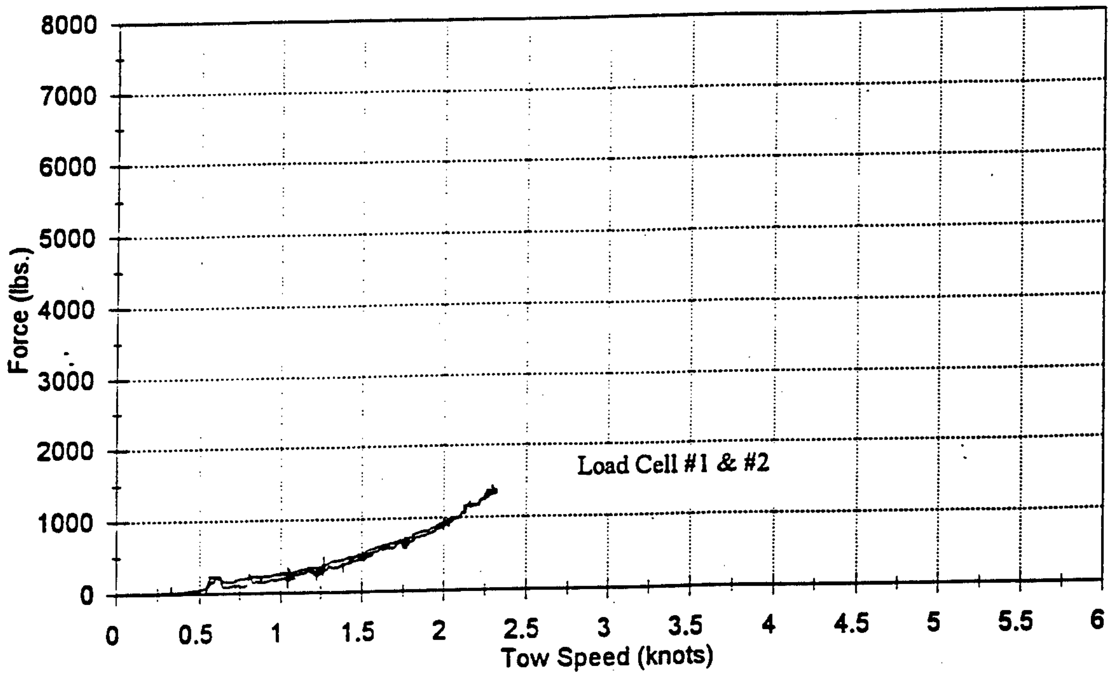

Figure 11 Tow Force vs. Tow Speed, American Fireboom (Test #20)

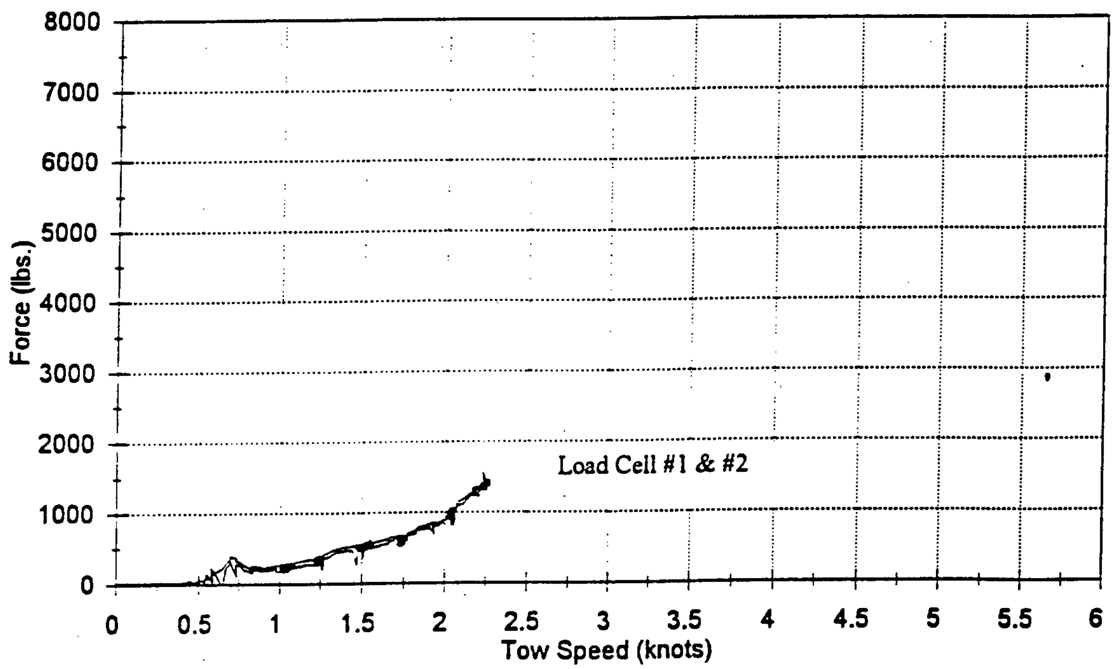

Figure 12 Tow Force vs. Tow Speed, American Fireboom (Test #21)

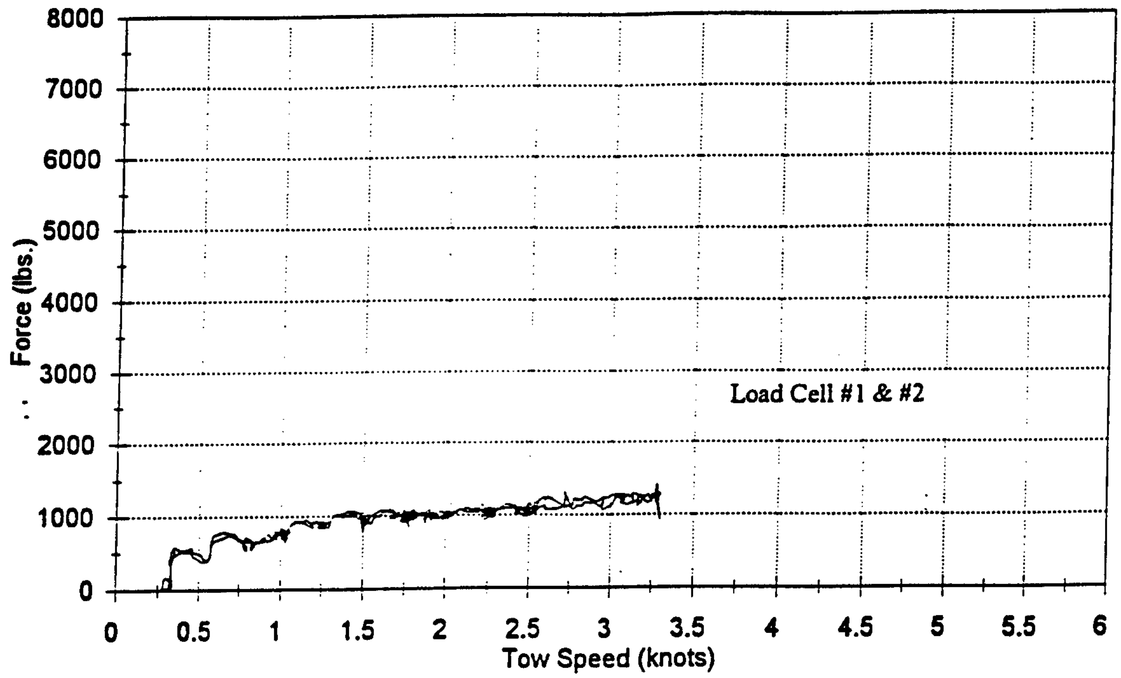

Figure 13 Tow Force vs. Tow Speed, Dome Boom (Test #40)

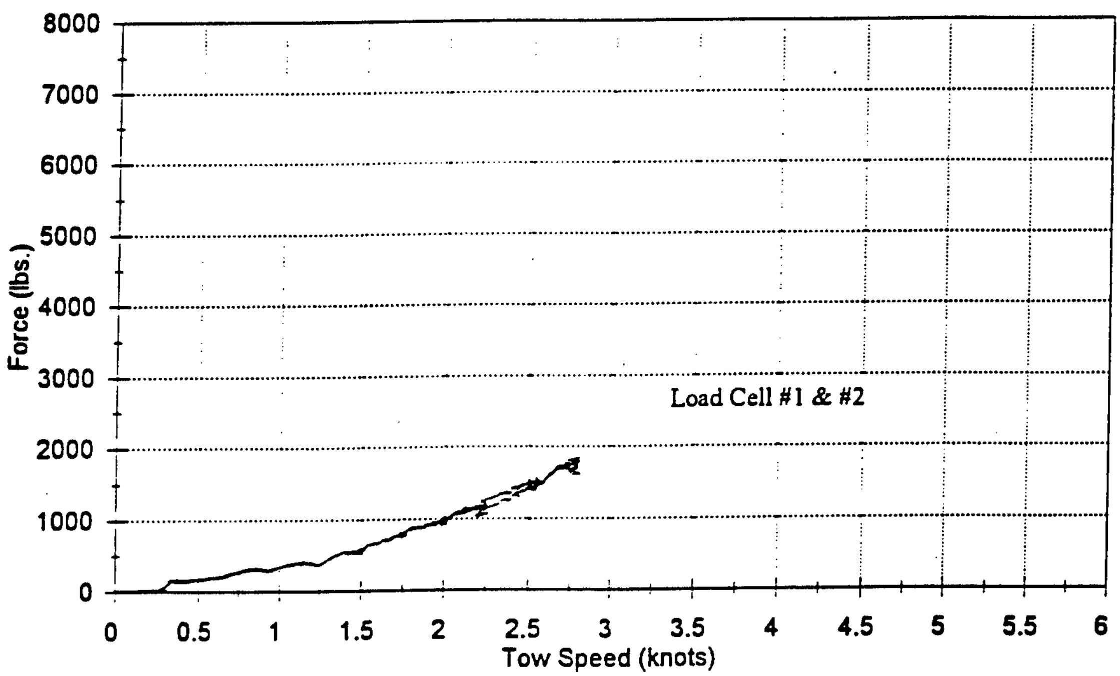

Figure 14 Tow Force vs. Tow Speed, PyroBoom (Test #61)

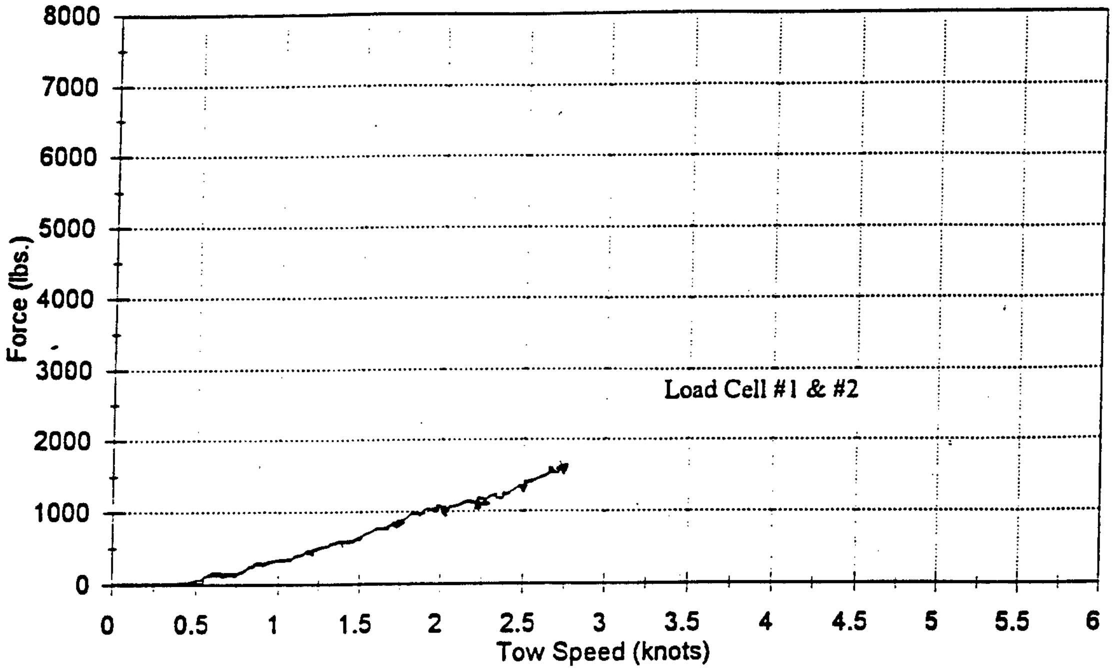

Figure 15 Tow Force vs. Tow Speed, PyroBoom (Test #62)

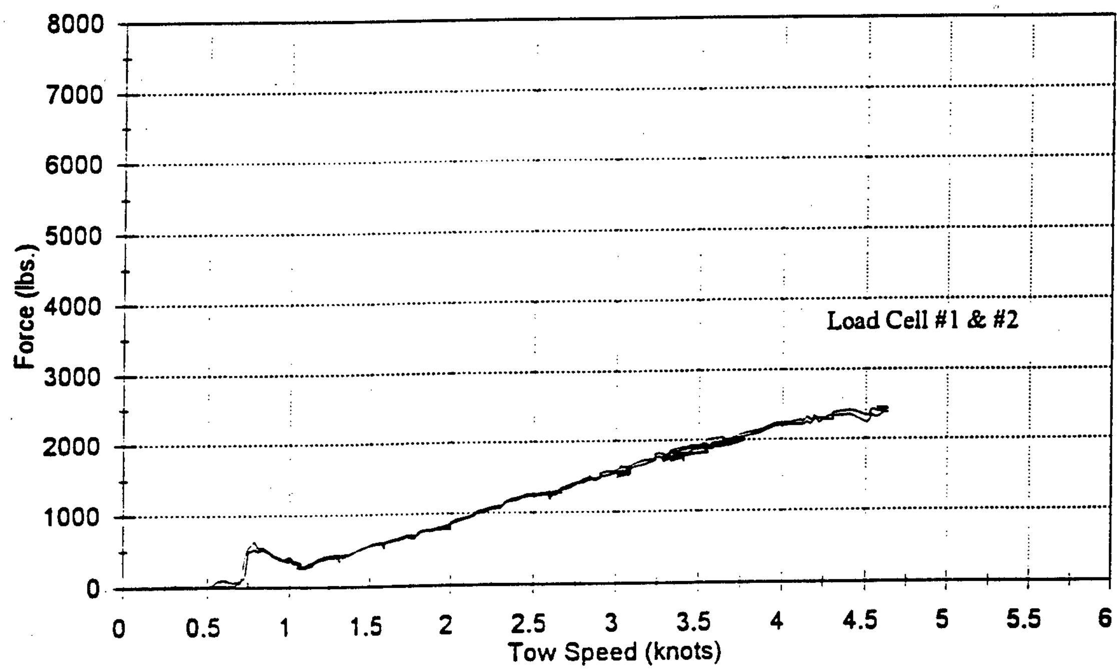

Figure 16 Tow Force vs. Tow Speed, Spill-Tain (Test #95)

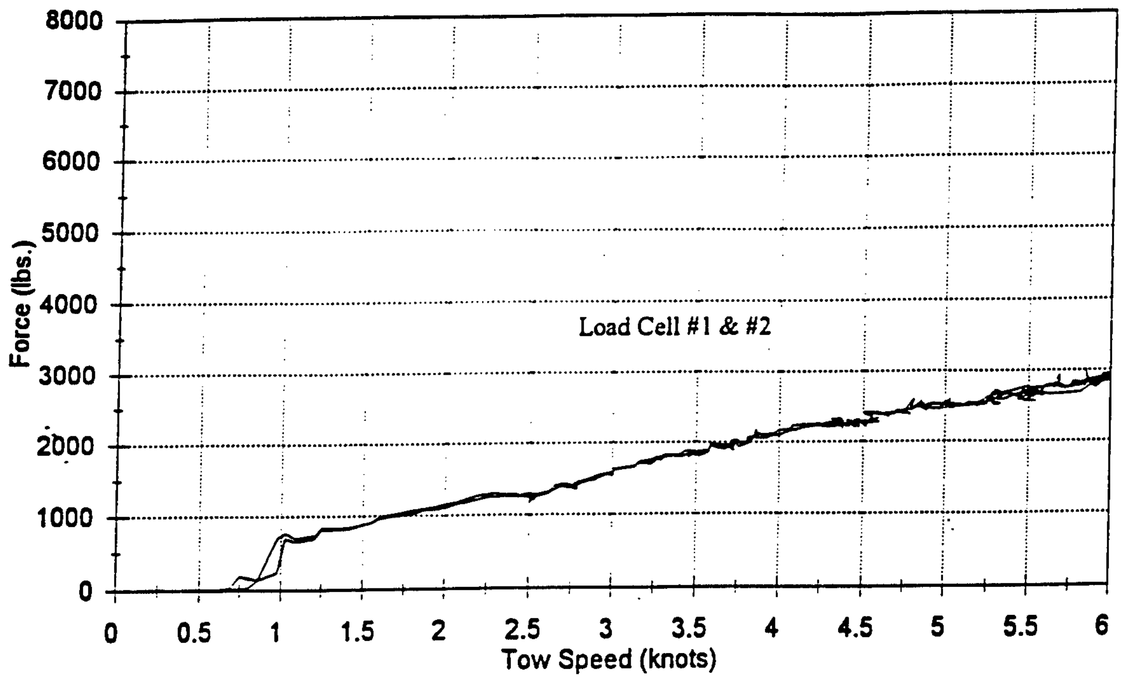

Figure 17 Tow Force vs. Tow Speed, Spill-Tain (Test # 96)

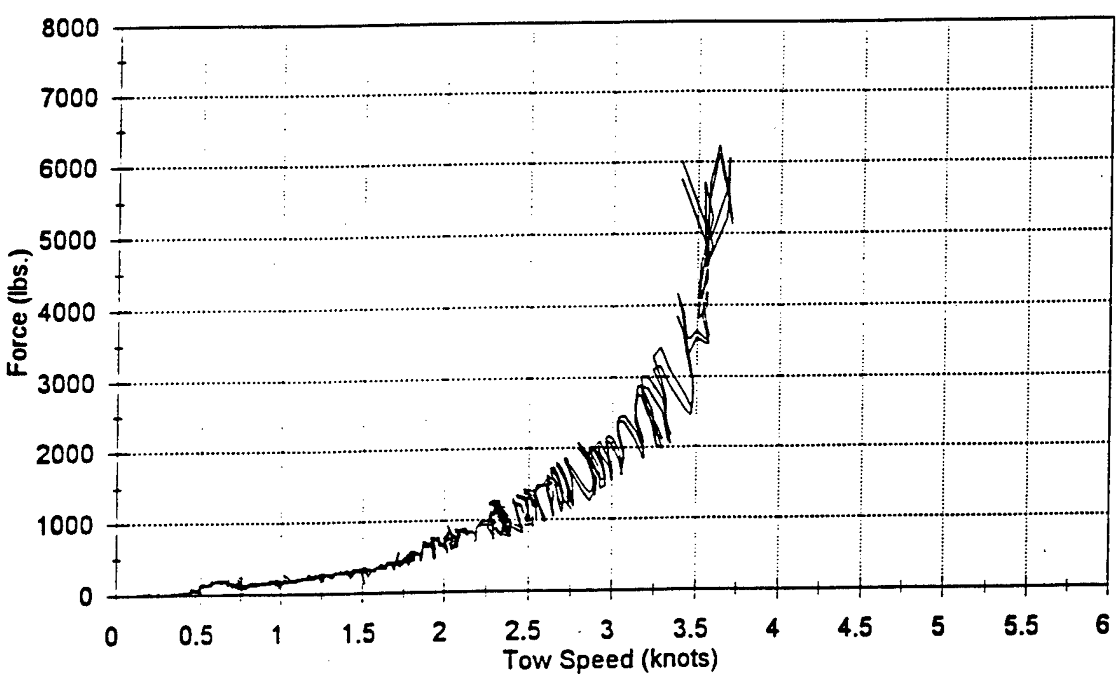

Figure 18 Tow Force vs. Tow Speed, Oil Stop Inflatable (Test # 111)

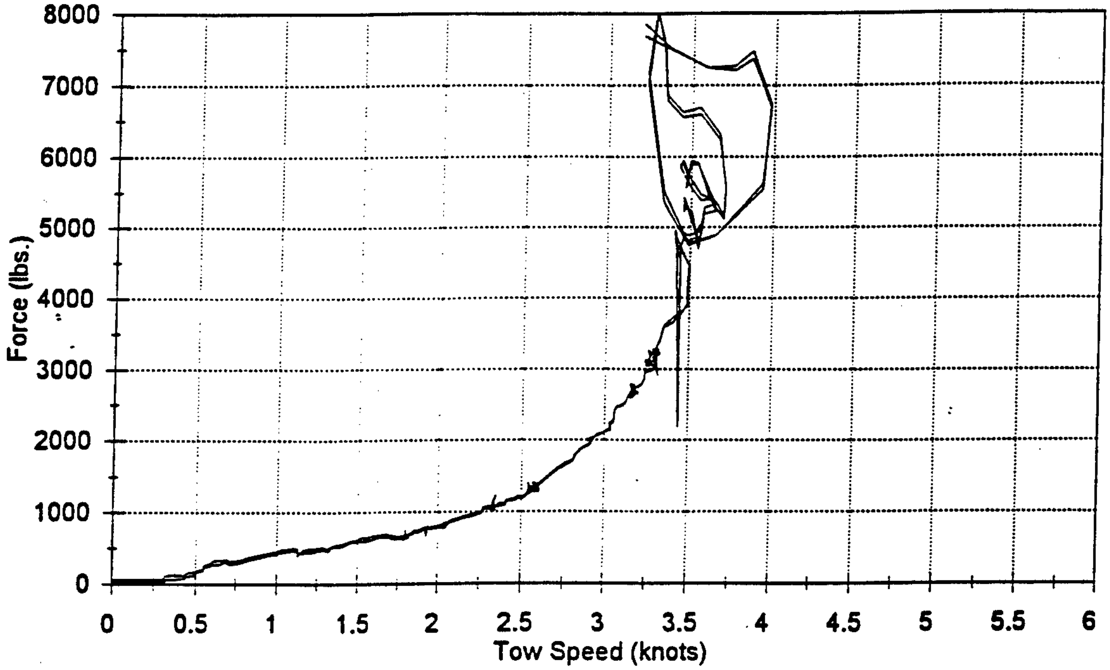

Figure 19 Tow Force vs. Tow Speed, Oil Stop Inflatable (Test # 112)

4. SYSTEMS COMPARISON

Summary data are presented in Table 7. The First Loss Tow Speeds are averages of two tests. The Gross Loss Tow Speed values are based on a single test. It is interesting to note that the Spill-Tain boom, with the best Critical Tow Speed performed below some of the other booms in the First and Gross Loss Tests. The Oil Loss Rate tests show that the First and Gross Loss values are not necessarily good indicators of loss rate. Although the Spill-Tain boom showed losses at lower speeds, when the losses were quantified, the loss rates were lower than the losses for three other booms at similar speeds. If plotted as in Figure 20, the skirt-type booms (PyroBoom, American Marine, and Oil Stop) appear to have higher loss rates than the fence booms (Spill-Tain and Dome).

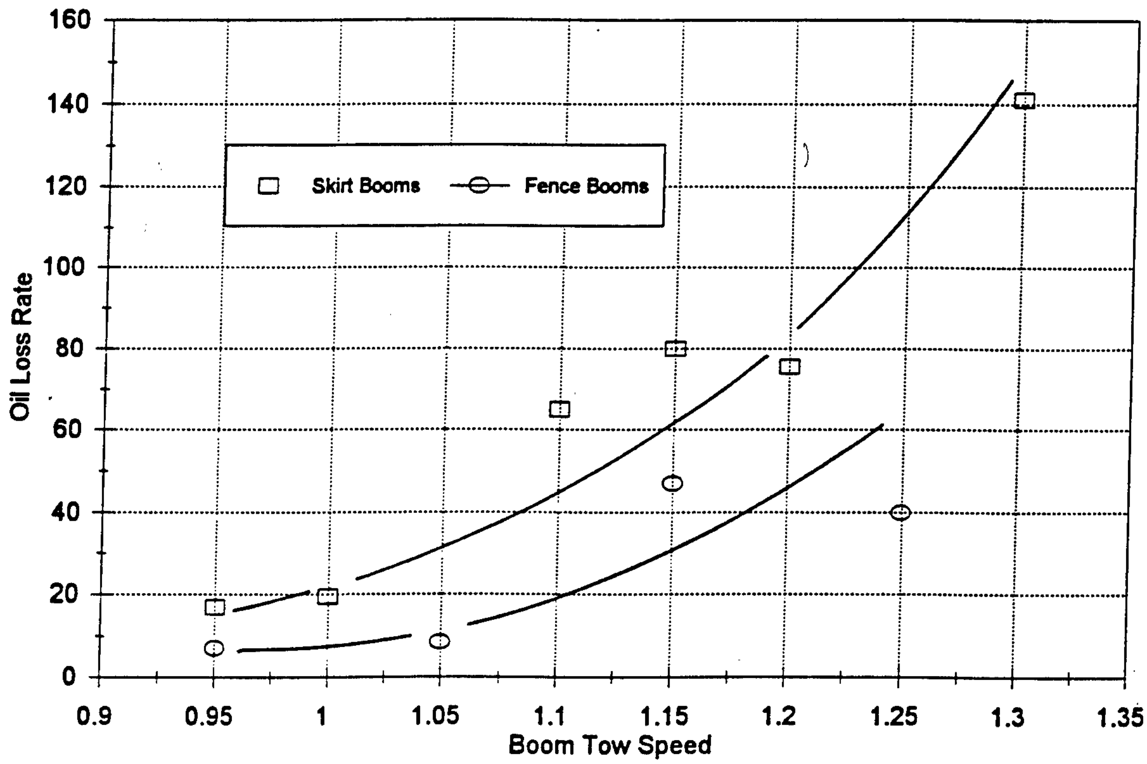

Figure 20 Oil Loss Rate vs. Tow Speed for Skirt and Fence Type Booms

Table 7 Compiled Boom Performance Data

BOOM NAME		First & Gross Loss Tow Speed (knots)				Loss Rate Test (gallons per min @ knots)		Critical Tow Speed (Knots)	Tow Force (lbs) @ 2 Kts	Maximum Tow Force (lbs)
		Wave Condition				1st Loss + 0.1	1st Loss + 0.3			
		C	1	2	3					
PyroBoom:	First Loss	1.00	0.72	1.07	0.95	65 @ 1.10	141 @ 1.30	2.75	2,050	3,500
	Gross Loss	1.20	0.93	1.30	1.10					
Spill-Tain:	First Loss	0.85	0.40	0.85	0.88	7 @ 0.95	47 @ 1.15	> 6.00	2,000	5,800
	Gross Loss	1.05	0.60	1.05	1.07					
American Marine:	First Loss	0.85	0.72	0.87	0.90	17 @ 0.95	80 @ 1.15	2.25	1,800	2,800
	Gross Loss	1.10	0.90	1.15	1.15					
Dome Boom:	First Loss	0.95	0.75	0.95	1.00	8.5 @ 1.05	40 @ 1.25	2.00	2,000	2,500
	Gross Loss	1.32	1.05	1.20	1.25					
Oil Stop:	First Loss	0.90	0.80	1.07	1.00	19.5 @ 1.00	75.5 @ 1.20	3.50	1,500	8,000*
	Gross Loss	1.22	- -	- -	- -					

* Note: Tow Force spike of 11,000 lbs. was recorded while in oscillating mode during failure

Actual Measured Wave Conditions: C =Calm: no waves generated
1 = Wave #1: regular sinusoidal wave: H = 9.9", L = 16.2', T = 1.8 sec.
2 = Wave #2: regular sinusoidal wave: H = 13.3", L = 42.1', T = 3.1 sec.
3 = Wave #3: harbor chop: H = 8.9", no L or T calculated.

5. CONCLUSIONS

a. Mechanical Stability

Of the fire booms tested in this series that produced recovered oil results, all yielded comparable results with non-fire booms; specifically, all booms were able to contain their pre-load volumes at .85 knots and above in calm water.

1. The six-knot Critical Tow Speed of the Spill-Tain boom was well above the normal range of two to three knots for the other booms.

2. The critical tow forces of each boom resulted in steadily increasing loads except for the Oil Stop Inflatable boom which went into an oscillating mode. The cause of this behavior is unknown and did also occur during the repeat run.

3. In terms of Critical Tow Speed, the PyroBoom experienced two modes of failure, planing along the catenary legs and loss of freeboard at the apex.

b. Oil Holding

The five booms performed similarly in calm and harbor chop surface conditions. For calm surface conditions, the five booms resulted in oil loss speeds ranging from .85 to 1.0 knots. For wave condition #1, each boom performed comparably, within a 0.1 knot range, except for Spill-Tain. For wave condition #2, PyroBoom and Oil Stop First Loss Tow Speeds increased above calm surface loss speed to 1.05 knots. Each boom performed comparably when experiencing wave #3. The short period wave condition, wave #1, reduced the oil holding capability of each boom. It is interesting to note that the Spill-Tain boom has the best stability as measured by Critical Tow Speed, and demonstrated low Oil Loss Rates, but lost oil at a very low speed when towed in wave condition #1. This finding is counter to the idea that good mechanical stability is indicative of good oil holding characteristics.

In both cases, First Loss + .1 knots and First Loss + .3 knots, the Spill Tain and Dome booms (fence-type booms) resulted in approximately half the oil loss rates of the skirt-type booms while containing their appropriate pre-load volumes.

c. General

The PaddleWheel Boom is a prototype boom that was tested along with the other five booms in this test series. Since virtually no oil was recovered with this boom, the results of those tests do not appear in any of the data tables in this report.

APPENDIX A FIRE BOOM INSTRUMENTATION

1. Carriage Speed and Distance

Carriage speed is measured by a pulse-type tachometer sensor that monitors the motion of a wheel of the Main Bridge that runs on the Test Basin deck. The output is recorded by the data collection system during tests, and is displayed in the Main Bridge house and on the data collection console on the third floor of the Control Tower. The speed is recorded and displayed in knots.

Carriage Speed Sensor: Airpax Magnetic Pickup for Carriage Speed
Model # 70087-3040-012

Carriage distance is measured by a position encoder that records the revolutions of the same wheel used for measuring carriage speed. The output is recorded by the data collection system during tests, and is displayed on the Main Bridge control console and the data collection console in the Control Tower during the tests. Carriage distance (position) is measured in feet.

Carriage Distance Sensor: Miter Gear Boxes - 48 pitch for outputting carriage distance information into a Computer Conversions Corp Encoder Unit (Model # HTMDS90-128-PHA) which has a -10 to +10 VDC output.

2. Wind Speed, Wind Direction, and Air Temperature

These meteorological instruments are located on the west side of the Ohmsett Test Basin, at approximately mid-length. The instruments are located on a tower approximately 10 ft above the Test Basin deck. The output of all three instruments is available to the data collection system for recording during tests, and is also displayed on panel meters on the data collection console in the Control Tower.

The temperature sensor is a Model 41350 by R.M. Young, Inc. It is located in a Gill Multi-Plate radiation shield (protected and naturally ventilated to prevent direct sunlight from hitting the thermal sensor and giving a false temperature reading).

The wind speed and direction sensor is a Model 5103, also manufactured by R.M. Young, Inc. It is an outdoor, high performance, rugged, four-blade, helicoid propeller wind speed sensor.

The signals from these sensors feed a Model 26302 by R.M. Young, Inc. anemometer. A wind and temperature translation unit in the data collection console feed data to the data collection system during tests.

3. Basin Water Temperature

The water temperature is monitored continuously by a temperature dependent resistor probe. The output is displayed as °F on a meter on the data collection console and recorded during tests by the data collection system.

Water Temperature Sensor: Omega RTD Probe, Model # PR-11-2-100-1/4-6E.

4. Wave Height Meter

The wave height meter is a Datasonics Sonar Air Altimeter, 27 kHz, Model PSA 900-A, S/N 335. The wave height is measured by an acoustic altimeter specifically designed for use in air. It is mounted on a support structure extending from the south side of the Main Bridge at a nominal height of 3.05 M (121 inches) above the mean basin water surface level. The output of the sensor is available to the data collection system during tests and is also displayed during tests runs on the data collection system screen. The output readout is in inches.

5. Oil Tank Level

The Main Bridge oil tank level is measured by an ultrasonic level/monitor at the top of the Main Bridge oil storage tank. The readout, in inches, is available during tests in the Main Bridge house, west data cabinet, and is recorded during tests, in gallons, on the data collection system. "The (sonic) Probe" is manufactured by Milltronics, Model PL-396, S/N 005827.

6. Tension Load Links

The two tension load links made by Metrox, M/D Totco, Model RGA 2052-5K, outputs 1.6862 mV/V and has an excitation voltage of 10 VDC. Their outputs are conditioned to a 0-5,000 lb., 4-20 mA loop outputs to the data collection system in the Control Tower. The outputs are recorded for each test.

7. Remote Marker Button

This is a portable button that will be used to mark events on any data run. This button puts a DC voltage level on a data collection system input to mark an event during a test. This is an Ohmsett design unit and outputs a DC voltage of between .75 VDC to 1.0 VDC (when pressed).

APPENDIX B FLUIDS TESTING

The measurements made in the chemistry laboratory at the Ohmsett Facility are as follows:

1. VISCOSITY (ASTM D2983)

Viscosity is measured using a Brookfield Engineering Model LV Viscometer. The samples are collected in 600 ml beakers, the contents are cooled to 50°F (10°C), then the temperature is raised to 140°F (60°C) using a Brookfield Constant Temperature Bath. Viscosity measurements are made every 50°F (10°C), yielding a Temperature vs. Viscosity curve for each sample collected. This is done to find the viscosity at variable test temperatures as is found in the test tank.

2. SURFACE & INTERFACIAL TENSION (ASTM D971)

Surface and interfacial tensions are measured with a Fisher Scientific Tensiomat. Approximately 50 mls of oil is needed to determine both surface and interfacial tensions. Measurements are made under standardized nonequilibrium conditions in which the measurement is completed one minute after formation of the interface.

3. SPECIFIC GRAVITY (ASTM D1298)

This analysis is performed using the hydrometer method. The oil sample is transferred to a 500 ml cylinder, the appropriate hydrometer is lowered into the sample and allowed to settle. The hydrometer scale is read and the temperature is recorded.

4. WATER AND SEDIMENT IN PETROLEUM (ASTM D1796)

A recovered oil sample of approximately 100 mls is mixed with an appropriate solvent (toluene), heated to 140°F (60°C) if necessary to assure sample uniformity, and rotated at 2,000 rpms in a centrifuge for 15 minutes. The amount of water and sediment is measured and the percentages calculated from the amount of sample used.

5. OIL AND GREASE IN WATER, TOTAL RECOVERABLE, INFRARED (ASTM 3921 MODIFIED)

A 500 - 1000 ml water/oil sample is acidified to a pH less than 2.0 and the oil is extracted with carbon tetrachloride. The oil and grease concentration is determined by comparison of the infrared absorbance of the sample extract with a known-oil reference standard, using a Shimadzu IR-435 Spectrophotometer.

WO-19 FIRE BOOM OIL ANALYSIS LOG

TEST INFO		TEST OIL @ 25° C						RECOVERED FLUID		
TEST NO.	DATE	SAMPLE	SPECIFIC GRAVITY	S.T. (dynes/cm)	I.F.T. (dyne/cm)	VISC (cPs)	BS&W (%)	SAMPLE	BS&W (%)	% OIL
BOOM #1: AMERICAN MARINE										
9	07-16-96	7-16-1400	0.952	33.0	28.5	5,100	23.0			
10	07-17-96	7-17-1130	0.956	32.0	27.0	3,200	40.0	T10-1G	42.3	57.7
11								T11-2G	65.5	34.5
12								T12-3G	62.4	37.6
13-15								T13-4	67.2	32.8
								T13-5	72.2	27.8
16-21	7-18-96	7-18-0830	0.942	31.9	24.3	1,475	49.2			
BOOM #2: CANADIAN COAST GUARD										
22-28	7-23-96	7-23-1140	0.939	33.0	26.0	2,740	11.5			
		7-23-1140D	0.940	32.7	26.4	2,600	10.0			
29								29	82.5	17.5
								29	98.5	1.5
								29	80.3	19.7
30								T30-1	58.3	41.7
								T30-1D	51.2	48.8
31/32	7-24-96	7-24-1000	0.975	32.9	28.7	2,940	10.5	T31/32-2	60.3	39.7
33								T33-3	32.3	67.7
34-41										
BOOM #3: APPLIED FABRICS										
42-48	7-30-96									
49		7-30-1035	0.938	32.7	27.0	2,480	8.5	T49-1	38.3	61.7
50								T50-3	23.3	76.7
51-54										
55-58	7-31-96	7-31-0915	0.941	32.4	25.2	2,680	10.1			
59								T59-4	42.3	57.7
								T59-5	49.2	50.8
								T59-6	51.2	48.8
60	08-01-06	08-01-0830 (T60)	0.949	31.7	25.8	3,280	9.5	T60-1	30.2	69.8
		08-01 Purge	0.937	32.2	25.0	2,840	10.1	T60-1D	30.2	69.8
								T60-2	38.0	62.0
61-62										

TEST INFO		TEST OIL @ 25° C						RECOVERED FLUID		
TEST NO.	DATE	SAMPLE	SPECIFIC GRAVITY	S.T. (dynes/cm)	I.F.T. (dyne/cm)	VISC (cPs)	BS&W (%)	SAMPLE	BS&W (%)	% OIL
BOOM #4: OIL STOP										
63-66	08-06-96	08-06-0700	0.933	33.6	25.8	1,600	5.0			
67		08-06-1445	0.933	34.2	25.5	1,500	5.1	T67-1	27.3	72.7
68	08-07-96							T68-3	27.2	72.8
								T68-3D	24.2	75.8
69-72										
73-77	08-08-96	08-08-T78 (MB)	0.935	33.9	26.0	2,240	4.3			
78										
79										
BOOM #5: SPILL-TAIN										
80	08-14-96									
81-83		08-14-0810 (T81)	0.935	33.5	26.8	2,080	4.1			
84								T84-0	49.3	50.7
								T84-1G	24.2	75.8
85		08-14-1100 (T85)	0.935	33.9	26.0	2,160	3.7	T85-3	25.2	74.8
86								T86-2G	33.2	66.8
87								T87-4	39.3	60.7
								T87-4D	36.2	63.8
88-96	08-15-96	08-15-1500	0.935	33.6	26.8	2,040	4.0			
OIL STOP II										
97	10-02-96	10-02-0840 (T97)	0.928	33.8	28.7	1,050	2.3			
		10-02--0840 (T97) D	0.927	34.0	28.0	1,100	2.3			
98-100										
101								T101-1G	2.6	97.4
102								T102-2	35.2	64.8
								T102-2D	30.4	69.6
103								T103-3	46.3	53.7
104								T104-4	39.0	61.0
								T104-5	35.0	65.0
105	10-03-96	10-03-0902 (T105)	0.934	34.1	27.5	2,175	2.0			

D = Duplicate sample
MT = Mixing tank sample
MB = Main bridge sample

WO19 FIRE BOOM BASIN WATER ANALYSIS LOG

Sample ID	Temperature (^{o}C)	Salinity (ppt)	pH	Turbidity (NTU)	Oil/Water (mg/l)
7-15	27.0	15.2	7.99	0.27	2.3
7-22	26.0	15.3	7.96	0.33	4.1
7-29	26.0	15.0	7.89	0.45	6.1
8-5	27.5	15.0	7.87	0.57	6.1
8-14	25.0	14.8	8.05	0.38	12.4
8-14D	25.0	14.8	8.07	0.47	9.0

APPENDIX C FIRE BOOM WAVE ANALYSIS

Boom Type	Test No.	Wave Type	Gen Settings	$H^{1/3}$ (in)	$H^{1/3}$ (in)	$H^{1/3}$ (HC)	Apparent Period	Apparent Period	Wavelength (ft)	Wavelength (ft)
American Marine	14	Reg	3"-35	10.70				1.73	15.28	
	15	Reg	3"-35	9.70				1.87	17.78	
	16	Reg	6"-19		12.18		3.12			41.60
	17	Reg	6"-19		10.62		3.15			42.29
	18	Harbor Chop	3"-30			7.12				
	19	Harbor Chop	3"-30			10.99				
Dome Boom	34	Reg	3"-35	10.52				1.76	15.74	
	35	Reg	3"-35	9.46				1.78	16.09	
	36	Reg	6"-19		10.96		3.11			41.45
	37	Reg	6"-19		11.42		3.13			41.82
	38	Harbor Chop	3"-30			10.06				
	39	Harbor Chop	3"-30			8.06				
Applied Fabrics	51	Reg	3"-35	9.69				1.83	16.98	
	52	Reg	3"-35	9.82				1.78	16.13	
	53	Reg	6"-19		15.52		3.13			41.80
	54	Reg	6"-19		17.02		3.17			42.53
	55	Reg	3"-35	9.30				1.79	16.41	
	56	Harbor Chop	3"-30			8.42				
	57	Harbor Chop	3"-30			8.24				
Spill-Tain	88	Reg	6"-19		12.81		3.11			41.49
	89	Reg	6"-19		17.14		3.17			42.54
	90	Reg	3"-35	9.47				1.78	16.18	
	91	Reg	3"-35	10.53				1.81	16.63	
	92	Harbor Chop	3"-30			6.09				
	93	Harbor Chop	3"-30			9.00				
Oil Stop	105	Reg	3"-35	10.44				1.78	16.17	
	106	Reg	3"-35	9.49				1.72	15.06	
	107	Harbor Chop	3"-30			9.39				
	108	Harbor Chop	3"-30			11.36				
	109	Reg	6"-19		15.81		3.17			42.59
	110	Reg	6"-19		9.65		3.16			42.49
			AVG	9.92	13.31	8.87	3.14	1.78	16.22	42.06
			STD	0.50	2.66	1.56	0.02	0.04	0.72	0.45

[BLANK]

APPENDIX D MASTER DATA TABLE

Test No.	Test Type	Surface Condition	Pre-load Vol (gal)	1st Loss Speed (knots)	Gross Loss Speed (knots)	Oil Loss Rate (gpm)	Dist. Rate (gpm)	Tow Speed (knots)	Comments
AMERICAN MARINE: AMERICAN FIRE BOOM									
1	Pre-load	Calm	60	1.35	---	---	---	---	---
2	Pre-load	Calm	120	1.05	---	---	---	---	---
3	Pre-load	Calm	180	0.90	---	---	---	---	---
4	Pre-load	Calm	240	0.95	---	---	---	---	---
5	Pre-load	Calm	300	0.90	---	---	---	---	---
6	Pre-load	Calm	360	0.85	---	---	---	---	---
7	Pre-load	Calm	420	0.85	---	---	---	---	---
8	Pre-load	Calm	480	0.85	---	---	---	---	---
9	Oil Loss	Calm	480	0.85	1.10	---	---	---	---
10	Oil Loss Rate	Calm	360	---	---	21	26	1.00	---
11	Oil Loss Rate	Calm	405	---	---	14	26	1.00	---
12	Oil Loss Rate	Calm	380	---	---	77	105	1.20	---
13	Oil Loss	Calm	362	---	---	83	105	1.20	---
14	Oil Loss	Reg Wave #1	360	0.70	0.90	---	---	---	---
15	Oil Loss	Reg Wave #1	370	0.75	0.90	---	---	---	---
16	Oil Loss	Reg Wave #2	360	0.85	1.10	---	---	---	---
17	Oil Loss	Reg Wave #2	360	0.90	1.20	---	---	---	---
18	Oil Loss	Harbor Chop #3	360	0.90	1.15	---	---	---	---
19	Oil Loss	Harbor Chop #3	360	0.90	1.15	---	---	---	---
20	Critical Tow Spd	Calm	0	---	---	---	---	2.25	---
21	Critical Tow Spd	Calm	0	---	---	---	---	2.25	---

Test No.	Test Type	Surface Condition	Pre-load Vol (gal)	1st Loss Speed (knots)	Gross Loss Speed (knots)	Oil Loss Rate (gpm)	Dist. Rate (gpm)	Tow Speed (knots)	Comments
DOME BOOM									
22	Pre-load	Calm	160	1.20	---	---	---	---	---
23	Pre-load	Calm	220	0.50	---	---	---	---	Heavy rain/H_2O in
24	Pre-load	Calm	240	1.10	---	---	---	---	---
25	Pre-load	Calm	300	0.90	---	---	---	---	---
26	Pre-load	Calm	380	0.85	---	---	---	---	---
27	Pre-load	Calm	460	0.95	---	---	---	---	---
28	Oil Loss	Calm	520	0.95	1.30	---	---	---	---
29	Oil Loss Rate	Calm	500	---	---	14	26	1.10	---
30	Oil Loss Rate	Calm	500	---	---	17	105	1.30	---
31	Oil Loss Rate	Calm	500	---	---	---	---	1.10	No oil
32	Oil Loss Rate	Calm	500	---	---	3	26	1.10	---
33	Oil Loss Rate	Calm	500	---	---	64	105	1.30	---
34	Oil Loss	Reg Wave #1	500	0.70	1.05	---	---	---	---
35	Oil Loss	Reg Wave #1	500	0.80	1.00	---	---	---	---
36	Oil Loss	Reg Wave #2	500	0.90	1.10	---	---	---	---
37	Oil Loss	Reg Wave #2	500	1.00	1.30	---	---	---	---
38	Oil Loss	Harbor Chop #3	500	1.00	1.20	---	---	---	---
39	Oil Loss	Harbor Chop #3	500	1.00	1.30	---	---	---	---
40	Critical Tow Spd	Calm	---	---	---	---	---	3.25	---
41	Critical Tow Spd	Calm	---	---	---	---	---	3.25	---

Test No.	Test Type	Surface Condition	Pre-load Vol (gal)	1st Loss Speed (knots)	Gross Loss Speed (knots)	Oil Loss Rate (gpm)	Dist. Rate (gpm)	Tow Speed (knots)	Comments
APPLIED FABRIC TECHNOLOGIES: PYROBOOM									
42	Pre-load	Calm	60	1.30	---	---	---	---	---
43	Pre-load	Calm	120	1.20	---	---	---	---	---
44	Pre-load	Calm	180	1.05	---	---	---	---	---
45	Pre-load	Calm	240	1.03	---	---	---	---	---
46	Pre-load	Calm	300	1.05	---	---	---	---	---
47	Pre-load	Calm	500	1.02	---	---	---	---	---
48	Oil Loss	Calm	600	1.02	1.30e	---	---	---	---
49	Oil Loss Rate	Calm	600	---	---	64	26	1.15	---
50	Oil Loss Rate	Calm	600	---	---	67	26	1.15	---
51	Oil Loss	Reg Wave #1	600	0.80	1.20	---	---	---	Splash-over
52	Oil Loss	Reg Wave #1	600e	0.60	0.80	---	---	---	Splash-over
53	Oil Loss	Reg Wave #2	600e	1.05	1.30	---	---	---	---
54	Oil Loss	Reg Wave #2	600e	1.10	1.35	---	---	---	---
55	Oil Loss	Reg Wave #1	600	0.60	0.80	---	---	---	---
56	Oil Loss	Harbor Chop #3	600e	0.90	1.15	---	---	---	---
57	Oil Loss	Harbor Chop #3	600	1.00	1.20	---	---	---	---
58	Oil Loss Rate	Calm	600	---	---	---	---	---	Aborted / No
59	Oil Loss Rate	Calm	600	---	---	154	105	1.30	---
60	Oil Loss Rate	Calm	600	---	---	128	105	1.30	---
61	Critical Tow Spd	Calm	0	---	---	---	---	2.75	Catenary legs planed @ 2.0 kn
62	Critical Tow	Calm	0	---	---	---	---	2.75	

Test No.	Test Type	Surface Condition	Pre-load Vol (gal)	1st Loss Speed (knots)	Gross Loss Speed (knots)	Oil Loss Rate (gpm)	Dist. Rate (gpm)	Tow Speed (knots)	Comments
OIL STOP: PADDLE BOOM									
63	Pre-load	Calm	60	0.50	---	---	---	---	Oil dispersed in water column. Severe turbulence pulled oil down.
64	Pre-load	Calm	60	0.50	---	---	---	---	
65	Pre-load	Calm	60	0.60	---	---	---	---	
66	Pre-load	Calm	100	0.60	---	---	---	---	
67	Oil Loss Rate	Calm	120	---	---	---	26	0.75	Lost all the oil
68	Oil Loss Rate	Calm	120	---	---	---	26	0.75	
69	Oil Loss	Reg Wave #1	120	---	---	---	---	---	Lost Pre-load
70	Oil Loss	Calm	120	0.40	---	---	---	---	---
71	Oil Loss	Calm	50-120	0.50	---	---	---	---	---
72	Oil Loss	Calm	50-120	0.40	---	---	---	---	---
73	Oil Loss	Calm	50	Variable < .5	---	---	---	---	Cable broke
74	Oil Loss	Calm	50	Variable < .5	---	---	---	---	Oil pushed out
75	Oil Loss	Calm	125	Variable < .5	---	---	---	---	Oil pushed out
76	Oil Loss	Calm	50	Variable < .5	---	---	---	---	Universal bad
77	Oil Loss	Calm	200	0.25	1.00	---	---	---	---
78	Oil Loss	Calm	30	0.40	0.60	---	---	---	---
79	Oil Loss	Calm	50	Variable < .5	---	---	---	---	---

Test No.	Test Type	Surface Condition	Pre-load Vol (gal)	1st Loss Speed (knots)	Gross Loss Speed (knots)	Oil Loss Rate (gpm)	Dist. Rate (gpm)	Tow Speed (knots)	Comments
SPILL-TAIN: FIREPROOF OIL SPILL CONTAINMENT BOOM									
80	Pre-load	Calm	120	0.85	--	---	---	---	---
81	Pre-load	Calm	180	0.70	---	---	---	---	---
82	Pre-load	Calm	240	0.85	---	---	---	---	---
83	Pre-load	Calm	300	0.85	---	---	---	---	---
84	Oil Loss Rate	Calm	300	---	---	9	26	0.95	---
85	Oil Loss Rate	Calm	350	---	---	56	80	1.15	---
86	Oil Loss Rate	Calm	300	---	---	5	26	0.95	---
87	Oil Loss Rate	Calm	350	---	---	38	80	1.15	---
88	Oil Loss	Reg Wave #2	350	0.80	1.00	---	---	---	---
89	Oil Loss	Reg Wave #2	350	0.90	1.10	---	---	---	---
90	Oil Loss	Reg Wave #1	350	0.40	0.60	---	---	---	---
91	Oil Loss	Reg Wave #1	350	0.40	0.60	---	---	---	---
92	Oil Loss	Harbor Chop #3	350	0.85	1.00	---	---	---	---
93	Oil Loss	Harbor Chop #3	350	0.90	1.15	---	---	---	---
94	Critical Tow Spd	Calm	0	---	---	---	---	2.35	Didn't reach critical tow speed
95	Critical Tow	Calm	0	---	---	---	---	4.50	
96	Critical Tow Spd	Calm	0	---	---	---	---	6.00	Boom did not fail. Bridges max tow spd.

Test No.	Test Type	Surface Condition	Pre-load Vol (gal)	1st Loss Speed (knots)	Gross Loss Speed (knots)	Oil Loss Rate (gpm)	Dist. Rate (gpm)	Tow Speed (knots)	Comments
OIL STOP: INFLATABLE FIRE BOOM									
97	Pre-load	Calm	160	1.00	- - -	- - -	- - -	- - -	- - -
98	Pre-load	Calm	240	0.90	- - -	- - -	- - -	- - -	- - -
99	Pre-load	Calm	360	0.95	- - -	- - -	- - -	- - -	- - -
100	Pre-load	Calm	480	0.90	- - -	- - -	- - -	- - -	- - -
101	Oil Loss Rate	Calm	500	- - -	- - -	17	26	1.00	- - -
102	Oil Loss Rate	Calm	534	- - -	- - -	22	26	1.00	- - -
103	Oil Loss Rate	Calm	504	- - -	- - -	61	105	1.20	- - -
104	Oil Loss Rate	Calm	509	- - -	- - -	90	105	1.20	- - -
105	Oil Loss	Reg Wave #1	500	0.80	- - -	- - -	- - -	- - -	- - -
106	Oil Loss	Reg Wave #1	500	0.80	- - -	- - -	- - -	- - -	- - -
107	Oil Loss	Harbor Chop #3	500	1.00	- - -	- - -	- - -	- - -	- - -
108	Oil Loss	Harbor Chop #3	500	1.00	- - -	- - -	- - -	- - -	- - -
109	Oil Loss	Reg Wave #2	500	1.10	- - -	- - -	- - -	- - -	- - -
110	Oil Loss	Reg Wave #2	500	1.05	- - -	- - -	- - -	- - -	- - -
111	Critical Tow	Calm	0	- - -	- - -	- - -	- - -	3.50	- - -
112	Critical Tow	Calm	0	- - -	- - -	- - -	- - -	3.50	- - -

APPENDIX E ASSESSMENT OF FIRE BOOM TEST QUALITY

General

The Fire Boom Program was performed in accordance with the "Fire Boom Ohmsett Test and Evaluation Test Plan," June 1996 (except as noted otherwise); the "General Quality and Procedures and Documentation Plan" Manual, February 1993; and the "Operating Manual for Ohmsett Laboratory Including Laboratory Procedures", April 1993. The following is an assessment of the various quality elements of the Fire Boom Test Program as it relates to the accuracy, precision and validity of the data presented in this test report.

Initial Calibration Data

All instrumentation utilized during these tests was calibrated and verified to be within the acceptable calibration limits for the test period by the Ohmsett Quality Control Engineer.

Pre and Post Checks and Conditions

Prior to testing, the instrumentation used to collect data for the automated data collection system was checked by the Ohmsett Instrumentation Technician to assure proper operation. Similarly, this instrumentation was also checked upon completion of testing. Both pre- and post-checks were made each test day to provide assurance that the instrumentation was functioning normally during the test period. Any anomalies were brought to the attention of the Ohmsett Test Director for appropriate action and are so noted in the appropriate section of this report. Weather was observed and recorded continuously during testing by the automated data collection system. This instrumentation was also included in the pre- and post-checks performed by the Ohmsett Instrument Technician.

In addition to the above, independent, random observations were made and recorded by the Ohmsett QC Engineer and on the Quality Checklists for pre- and post-test conditions. These observations of pre- and post-test conditions were randomly compared to other data to assure data accuracy.

Test Checks and Conditions

Test data are continuously recorded by the automatic data collection system and by manual methods during testing. Random over-checks were used to observe and record data independently of both the automated data collection system and manual methods. This data was recorded on the Quality Checklist by the Ohmsett QC Engineer. For this test series, approximately 900 independent over-checks were performed. These independent over-checks were then compared on a random basis to both automatically and manually collected data. No discrepancies which would have compromised the data quality were noted.

Sampling

Sampling for the Fire Boom Test Program included the following areas: basin water analysis, test oil analysis, and recovered fluid analysis. The Fire Boom Test Plan required that a minimum of 10% duplicate samples be obtained. For basin water analysis, 20% was achieved; for test oil, 12.5% was achieved; and for recovered fluid analysis, 16.1% was achieved. The analyses for these samples as well as for duplicate samples are shown in Appendix B. In addition, repetitive test series were performed. These will be addressed later in this assessment.

Significant Occurances/Variations

Any significant occurrences/variations which may have affected any of the test results presented in this test report are reported and discussed in the appropriate section of this report. The Applied Fabrics PyroBoom tested was not the actual PyroBoom which would be used at a burn. The boom tested was manufactured with a 100 oz. urethane above the lateral seam and an 85 oz. PVC fabric below the seam. The actual PyroBoom is equipped with Applied Fabric's Refractory fabric above the lateral seam and the 85 oz. PVC material below.

Data Reduction and Validation

Data reduction, as well as discussions regarding the treatment of outliers, are discussed in the appropriate sections of this report. Data validation is discussed elsewhere in this report as appropriate.

Data Accuracy and Precision

Data accuracy was achieved through the use of calibrated and verified instrumentation and through cross-checks between collected data (both automated and manual) and the independent observations made and recorded on the Quality Checklists.

Data precision is accomplished by measuring variances between and among redundant sampling and repetitive testing. In order to assess the precision (reliability) of the data presented in this report, the following is offered:

Basin Water Analysis

The data presented in Appendix B regarding basin water analysis performed during the Fire Boom Test Program were reviewed and analyzed for over-all variations and for variations between original and duplicate samples. Particular attention was paid to the oil-in-water content of Sample No. 8-14 because its value was considered to be significant when compared to other values achieved during the test program. Initial reaction was that it might be considered an outlier. However, given that this value occurred during the latter portion of this phase of the test series (where oil-in-water content increases over time) and that its duplicate sample (8-14D) had a value of 9.0%, the value of Sample

No. 8-14 is considered to be statistically insignificant when compared to its duplicate (well within statistical limits). Therefore, basin water data were considered to be satisfactory to the accuracy and precision requirements of the Test Program.

Test Oil Analysis

The analysis of test oils utilized during the test program was reviewed and analyzed for over-all variations and for variations between original and duplicate samples. During the analysis, particular attention was given to the Bottom Solids &Water (BS&W) content of Sample Numbers 7-16-1400 and 7-18-0830 because of their unusually high values (40.0% and 49.2%, respectively). If valid, what is the effect on the test data? Assuming a "worst-case" scenario, e.g. BS&W values of 40.0% and 49.2%, it was considered that Sample No. 7-18-0830 had a minimal or no effect on the test data because it was used for Test Numbers 16 thru 21 which were First and Gross Loss Tests and Critical Tow Speed Tests. Because recovered fluid samples were associated with Sample No. 7-17-1130 (Test Numbers 10-13), the oil loss rates were recalculated to determine what effect the high BS&W value may have had, and the results of these recalculations indicated that the effect was insignificant. It should be noted that on occasion in the past, abnormally high BS&W values have been attributed to an occasional "water slug" obtained while sampling the test oils. Aside from the discussion above, test oil data is considered to be within the precision requirements of the Test Plan.

The recovered fluid analysis in Appendix B was used to calculate the oil loss rates presented in Figure 10. In order to assess the validity/reliability of that data, recovered fluid analysis was required and analyzed for variations for both within-test samples (where more than one sample was analyzed per test) and between assigned and duplicate samples.

The test samples analyzed for within-test variance were T13-4 and 5; T29-1 and 2; T59-4,4 and 6; T60-1 and 2; T84-0 and 16; and T104-4 and 5. The variances for the with-in test samples listed above were statistically insignificant and therefore met the precision requirements of the Test Program. Five sets of original and duplicate samples were also statistically analyzed. In all instances, the variances were statistically insignificant. Therefore, the original vs duplicate recovered fluid analysis satisfies the precision requirements of the Test Program.

Repetitive Test Runs

In order to assess the precision of the testing performed, 29 sets of repetitive tests were statistically analyzed for variances regarding Oil Loss Rates, First and Gross Loss and Critical Tow Speeds. The repetitive test data can be found in Appendix B. For the convenience of the reader, the repetitive test sets are listed below by test type and boom manufacturer:

LIST OF REPETITIVE TESTS

TEST TYPE	MANUFACTURER	TEST SET NOS.
Oil Loss Rate	American Marine	10-11,12-13
--	Dome Boom	29-31/32,30-33
--	Applied Fabrics	49-50, 59-60
--	Spill-Tain	84-86, 85-87
--	Oil Stop	101-102, 103-104
1st/Gross Loss	American Marine	14-15, 16-17, 18-19
--	Dome Boom	34-35,36-37, 38-39
--	Applied Fabrics	51-52-55; 56-57, 59-60
--	Spill-Tain	88-89, 90-91, 92-93
--	Oil Stop	105-106,107-108,109-110
Critical Tow Speed	American Marine	20-21
--	Dome Boom	40-41
--	Applied Fabrics	61-62
--	Spill-Tain	94-96
--	Oil Stop	111-112

The statistical variance between the repetitive test sets was found to be insignificant. Therefore, based on the precision of these test sets, all testing for Oil Loss Rate, First and Gross Loss and Critical Tow Speeds is considered to be within the precision requirements of the Test Program. Based on the discussion above on basin water analysis, test oil analysis, recovered fluid analysis, and repetitive test runs, the data presented in this test report are considered to be accurate, precise and valid within the prescribed requirements of the Test Program.

Documentation of Tests

All analytical laboratory testing results, calibration data, pre and post checks, test checks and conditions, quality checklist, test run data, automated and manually recorded data, as well as above-water and below-water visual documentation used to prepare this Test Report are on file at the Ohmsett Facility.