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Report No.

Columbia River Fast Water Tests

Interim Report
September 1999

Prepared for:

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

N O T I C E

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Technical Report Documentation Page

1. Report No.	2. Government Accession Number	3. Recipient's Catalog No.
4. Title and Subtitle Columbia River Fast Water Tests		5. Report Date September 1999 6. Performing Organization Code Project No. 4120.12
7. Author(s) Kurt Hansen		8. Performing Organization Report No. R&DC-311-99
9. Performing Organization Name and Address U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6096		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Organization Name and Address U.S. Department of Transportation United States Coast Guard Marine Safety and Environmental Protection (G-M) and Systems (G-S) Washington, DC 20593-0001		13. Type of Report & Period Covered Interim Report 14. Sponsoring Agency Code Commandant (G-MOR)/Commandant (G-SEC) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

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16. Abstract (MAXIMUM 200 WORDS)

This is an expanded trip report that describes the evaluation of four pieces of oil spill equipment on the Columbia River in the state of Washington. The objective was to determine how well the equipment performed in fast-water conditions. Current velocities encountered ranged from one to three knots. Two of the systems, Boom Deflectors and the Boom Vane, are designed to control oil spill booms by replacing standard mooring equipment. Both worked well in steady currents. The Boom Deflectors need some additional improvements to be useful and the Boom Vane was well liked by all participants. Two skimmers were also evaluated. The results of the evaluation were inconclusive because no oil was used. Both will be evaluated at the Minerals Management Service OHMSETT facility later in 1999.

The results of this test prove that containment and cleanup in faster currents can be improved from the standard methods the Coast Guard and most of industry use. Evaluation of other methods will continue over the next year.

17. Key Words	18. Distribution Statement		
oil spill, high speed recovery, containment, skimmer, field demonstration			
19. Security Class (This Report) UNCLASSIFIED	20. Security Class (This Page) UNCLASSIFIED	21. No of Pages	22. Price

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

ACKNOWLEDGEMENTS

The work described in this report could not have been successfully completed without the efforts of the participants. Special thanks to Scott Knutson who organized and directed the tests while still participating in the New Clarissa incident and organizing the on-water demonstration by the Coast Guard at the 1999 International Oilspill Conference. Many thanks to Mr. Brent Way of Clean Rivers Cooperative and their contractor, Cowlitz Clean Sweep, who supplied facility space, equipment and personnel in the field. Mr. Tom Coe and Mr. Alan McFadyen provided copies of their pictures and videotapes**.**

TABLE OF CONTENTS

LIST OF FIGURES

1.0 INTRODUCTION

1.1 Background

Oil spills in fast moving water above one knot are difficult to control and recover due to the ease at which oil mixes with water and entrains under booms and skimmers. Fast currents also make deploying equipment and maneuvering on the water very difficult and dangerous due to the high forces exerted on boats and recovery equipment. A lack of effective fast water containment and recovery systems, mooring problems, and limited training and experience in these difficult and dangerous response conditions have hampered response efforts in currents on rivers and coastal areas. Even though 70% of the oil transported on US waterways are in currents that routinely exceed one knot, very little research and product development has been conducted on new technologies and strategies to respond to oil spills in currents from one to six knots.

The Coast Guard (CG) Research & Development Center (RDC) is performing the project Innovative Response Techniques (Fast-Water Containment). The goal of this effort is to improve the fast-water containment and recovery capabilities for both the Coast Guard and commercial response firms. The first part of the project was a review of existing technology that is documented in the report "Control of Oil Spills in Fast Water Currents, A Technology Assessment." [Coe, Gurr, 1998] Recommendations included the evaluation of several systems in field demonstrations and at the Minerals Management Service's OHMSETT Facility. This report documents the field evaluation of equipment that was identified as having the potential of increasing containment and clean-up capabilities in fast water.

1.2 Objectives

The objective of this test was to evaluate the performance of several pieces of equipment in fast currents on the Columbia River that defines the border between Oregon and Washington. The equipment includes two boom control devices and two skimmers. The boom devices are the Boom Vane (Patent Pending) manufactured by ORC of Sweden and Boom Deflectors patented and manufactured by Envirotech Nisku of Alberta, Canada. The skimmers are the Vikoma Fasflo from England and the Hydrodynamic Circus from Sweden. Performance parameters generally include usability, survivability and compatibility with other systems.

1.3 Participating Organizations

A complete list of people that attended this demonstration is given in Appendix A. The groups that participated in the tests were:

- **USCG Research and Development Center:** provided funding and overall direction for the tests.

- **USCG District 13, Office of Marine Safety (m):** provided the test director, support personnel, direction to the cleanup contractors and fast water boom.

- **Clean Rivers Cooperative (CRC):** provided personnel and equipment, including boats and a staging facility at Cowlitz Clean Sweep.

- **USCG Project Sponsors (USCG Headquarters):** the project sponsors (G-SEC and G-MOR) attended as observers and provided tension and current measurement systems through a contract with the Navy's Supervisor of Salvage.

- **Manufacturers' Representatives**; provided equipment, recommended deployment and recovery methods and on-scene support.

- **Other Participants/Observers:** Other participants included representatives from the CG Pacific Strike Team, CG District One (m), MSO, Portland and other Oil Spill Cleanup Cooperatives.

2.0 GENERAL DESCRIPTION OF ACTIVITIES

Monday, March 15:
Several potential sites were visited and the current measured at each.
Unpacked boom deflectors, hydrodynamic circus and boom vane.

Tuesday, March 16:
The equipment was deployed off the beach near Longview using Versatec 6x6 (6"float/6" curtain) boom in four-foot sections. Six boom deflectors and 350 feet of boom were initially deployed from a piling at the end of a breakwater in both closed and open modes. Tension was recorded for both conditions. This deflector/boom arrangement was later moved to an anchor further out in the current.
The Boom vane was deployed from the beach using 400 feet of Versatec boom.

Wednesday, March 17:
The deflectors were deployed with 400 feet of Kepner SeaCurtain 20 inch (8" float/12" skirt) in 10-foot sections off an anchor.
The boom vane was deployed off the beach with 400 feet of the small boom at a location about 400 yards upstream from the previous day. Tension meters were attached to the mooring line and at the boom attachment point.
Later in the day, the boom with the deflectors closed was connected to the boom vane with the end of boom attached to the beach. The deflectors were opened and boom released from the beach for the final deployment.
In the afternoon, the hydrodynamic circus was deployed at the dock site and attached to 32-foot response vessel near the end of the day.

Thursday, March 18:
The Vikoma FASFLO was deployed at the dock site. One lead boom was attached to a piling and the other was held in place by a small skiff.

3.0 TEST SITES

Longview, Washington was chosen as the deployment area because Cowlitz Clean Sweep offered their facility and several potential sites were identified that could be used. The Columbia River is influenced by tidal effects up to Portland, Oregon, which is about 30 miles upstream from Longview. It was hoped to observe currents over four knots so the tidal cycles made it crucial to select the appropriate test times. The spring snow melt that usually increases river flow had not yet started so that currents measured on the first day were mostly below 1.5 knots. Both sites selected were easily accessible by truck and had the potential for fast currents during the testing period.

3.1 Site 1

This site was located at a state park about six miles west of Longview. The beach (see Figure 1) had a gentle slope. The depth of water did not reach 3 feet until about 10 yards offshore (see Figure 2).

Figure 1. Test Site #1

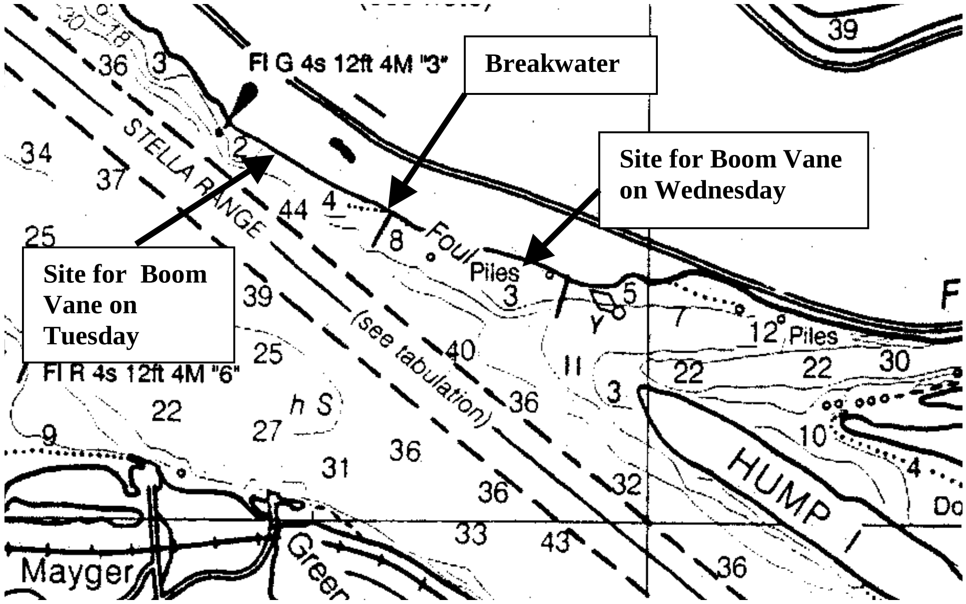

Figure 2. Map of Site #1

3.2 Site 2

The second test site was the Weyerhaeuser Dock on the Columbia River in Longview, WA, about two miles west of the center of town. The site is a pier with a floating dock, eight feet wide with an adjacent boat launch ramp (see Figure 3). Depth at the dock is about 30 feet and the river is approximately 200 yards wide at this point (see Figure 4).

Figure 3. Site #2, Weyerhouser Dock

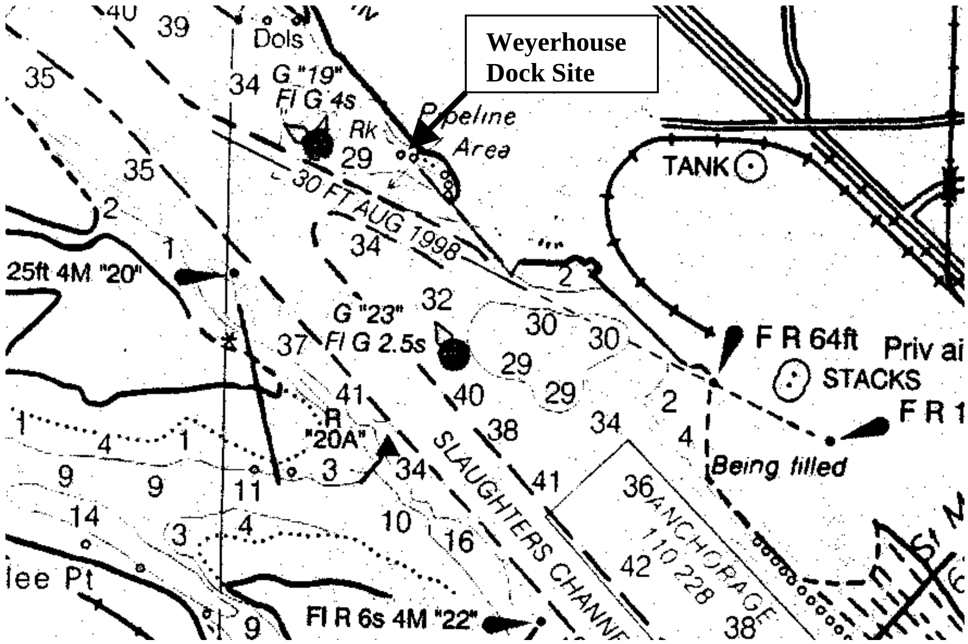

Figure 4. Map of Site #2

3.3 Tidal Cycles

The Columbia River at Longview is greatly influenced by tidal cycles. The variation in currents is from 1 to 6 knots depending on the location, tidal cycle and the amount of rain or melted snow runoff. The tidal heights for the Longview area for the week of the tests are shown in (Figure 5) [GPC Trip Report]. On the first day (Monday) the current measurements were taken during a relatively weak tide so none exceeded 1.3 knots. In order to have the maximum currents for the tests, the deployments were scheduled for the flood tide when the tide and river current flow in the same direction. This occurred early in the morning so that the deployment of equipment began at 0700 on Tuesday and Wednesday.

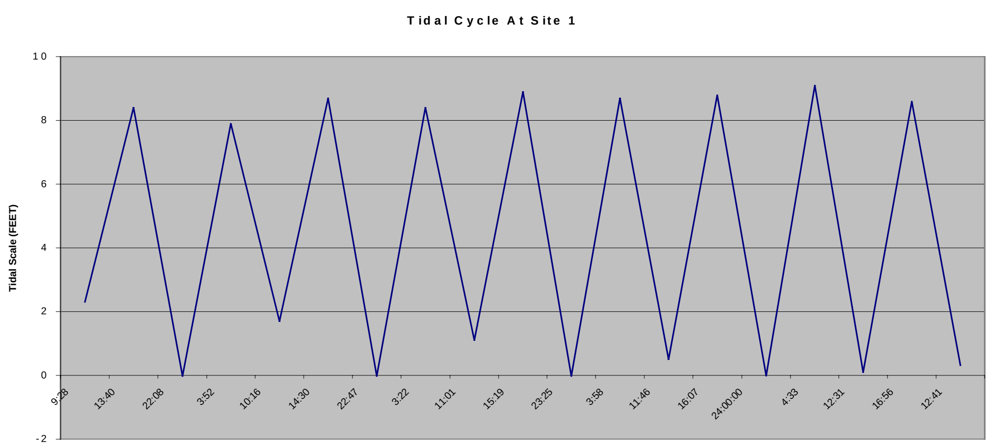

Figure 5. Tidal Cycle MON 3/15/99 – FRI 3/19/99

4.0 EQUIPMENT TESTS

4.1 Available Equipment

4.1.1 Clean River Cooperative (CRC) supplied boats and rigging equipment and was responsible for their operation. Other participants assisted in moving equipment and recording data. A general list of equipment supplied included the 20-inch boom, a 32-foot Kvichak Marine response vessel with twin 380 HP engines, a skiff with an outboard motor, lines, anchors, assorted rigging equipment and a Hydraulic Power Pack.

4.1.2 USCG Headquarters supplied the following equipment through a contract with the Supervisor of Salvage and Diving:

- A General Oceanics Flowmeter with a range of 0-10 knots. It weighs about four pounds. This meter was usually deployed from the skiff that was stationary in the water.

- An Omega tension type inline dynamometer with a range up to 10,000 pounds. It has 8 1/2 Ton SWL shackles at each end and weighs about 8 pounds dry. Tensions measurements were taken at the breakwater for the boom deflector deployment and of the mooring line for the Boom Vane.

- A submersible load cell was sent by ESSM, Williamsburg on Wednesday and was used to measure the tension created by the booms at the attachment point to the Boom Vane.

- Omega data logger

All of these units were calibrated before the tests.

4.1.3 The R&D Center supplied a video camera and digital camera for documenting the tests.

4.1.4 CG District 13 supplied the Versatec river boom.

4.2 Equipment Evaluations

4.2.1 Boom Deflectors

4.2.1.1 Equipment Description

The Boom Deflectors are made from aluminum and are 80 inches long and 16 inches high (see Figure 6) with a wing that is 60 inches long and 12 inches high. Two people using the handles built in at the top can easily move a deflector. The Petroleum Association did the initial research on this item in the 1970's for Conservation of the Canadian Environment [Brodsky, L. et.al., 1977]. These systems were fabricated from plywood and chain so it can be seen that the newer versions are an improvement. This is still a prototype system and the manufacturer is still looking for input from industry on the usefulness of these devices.

Figure 6. Boom Deflector

4.2.1.2 Equipment Evaluation

The first test of the deflectors was a deployment from the end of a breakwater at the beach site (see Figure 7). The boom with the deflectors attached was easily deployed and towed to the deployment site. With the deflectors closed, the tension measured was 30 pounds. The current measured just upstream from the pilings was 1.9 knots and just downstream it was about 1.5 knots. In order to understand the forces involved, calculations were done to determine what theoretical values could be expected. The details of the calculations are contained in Appendix B. Using a tangential drag coefficient of .029, the calculated drag is about 32 pounds at 1.4 knots. The drag coefficient selected is based on research at the University of New Hampshire and by S.L. Ross Environmental Research, Ltd. of Ontario, Canada. The calculated tension is in general agreement with the measured value.

Figure 7. View of Breakwater and Boom

When the deflectors were opened, the measured tension was about 130 pounds and the angle to the current was about 15 degrees. The theoretical drag on 350 feet of boom plus the deflectors is calculated to be about 231 pounds (See Appendix B) and is much larger than measured. The observed shape of the boom during this and other deployments indicate a curvature that may result in an apparent smaller angle between the current and the boom. In addition, the boom was deflected into the downstream side of the breakwater during this deployment. The vortices created by the piling and the reduced current velocity probably influenced the boom movement. Various calculations were performed for smaller angles and reduced currents. A current speed of 1.1 knots and deflection angle of 15 results in a tension value of about 134, close to the measured tension. Current measurements taken along the length of the boom might have verified this calculated value.

Later in the day, the boom arrangement was deployed further out into the current (see Figure 8). The deflection can easily be seen when a line attached a marker buoy to the leading edge of the boom. The distance between the boom and buoy is the displacement due to the sideward force of the deflectors. The current measured at the attachment point of the boom was about 1.7 knots. There were some crinkles in the boom because the section of floatation is only four feet long. Participants indicated that longer and stiffer boom sections work better in fast currents.

On Wednesday, the deflectors were attached to the larger Kepner boom and the distance to the marker buoy can be seen in (Figure 9). The speed of the current on this day was between 3.5 and 3.8 knots. The angle was estimated to be about 15 degrees by several observers. The harder floatation-filled Kepner boom appears to hold the required shape and reduce the chance of entrainment of oil better than the smaller softer boom.

Figure 8. Small boom with deflectors attached and open

Figure 9. Deflectors attached to large boom

4.2.2 Current Rudder (Boom Vane)

4.2.2.1 Equipment Description

A current rudder has been developed in Sweden based on the trawl doors that fishermen use. The original concept was by Captain Blomberg and it uses hydrodynamic forces of a passing current to push a boom into a current. It can also be used to deploy a sweep system from the side of an advancing ship without the use of cumbersome outriggers. A prototype system that weighed about 45 pounds and about 10 feet long was made of aluminum with streamlined paravanes is shown in (Figure 10).

Figure 10. Original current rudder design

The top of the frame and paravanes contain flotation that allows them to float upright with very little freeboard. Two control lines are attached to the inboard and outboard ends of the frame with bridles that connect to the top and bottom of the frame. The boom is attached to the inboard side of the frame with another bridle. The current rudder is positioned in the water so that the paravanes are parallel to the current or angled into the shore. The downstream end of the boom is moored to shore or to an inline skimmer as desired. Only a few degrees of angle toward the opposite bank are required to move the boom across the river. When vessel traffic needs to pass or large debris floats downstream, the boom cab be quickly retrieved to shore by one person by changing the paravane angle of attack to point toward the near shore. After vessel passage, the boom can be easily deployed back out into the channel in the opposite manner.

The rudder concept was refined and further developed by ORC of Sweden and the patent approval is pending. This newer system (see Figures 11 and 12) was the one evaluated during this test and is called the Boom Vane. It only weighs about 25 pounds and is about 4.5 feet long. Note that multiple curved vanes are used to increase the area that is impacted by the current. There is a stabilizing fin that can be seen in the rear view. This model has a simpler control system having either a deployed or a stalled mode. To bring the system into the shore, only one control line is needed to pull on the tail and reorient the vanes to a neutral angle that does not permit the individual vanes to exert a force. The vane can then easily be pulled in.

Figure 11. Front view of Boom Vane

Figure 12. Rear View of Boom Vane

The standard method of launching was used for this exercise. First, the entire system including the boom and mooring line is laid out along the shore. The boom was attached to the vane and its trailing edge was fastened to a tree stump on the shore. With some difficulty due to the shallow water and lack of current, the boom vane was then pushed out into the current. Once out into the current, the vane easily pulled the remaining boom off the beach. The mooring line length was adjusted to obtain a good shape of the boom.

4.2.2.2 Equipment Evaluation

On Tuesday, the deployment from the beach used 400 feet of Versatec 6X6 boom. Shallow water and lack of current near the beach made the deployment difficult. The skiff assisted in the deployment and the resulting boom shape was very good (see Figures 13, 14, 15). Deployment of this system, even with the lack of current near the shore, required less effort than that needed for a large mooring system needed for fast water. The current measured near the boom vane at this time was about 1.5 knots.

Figure 13. Boom Vane Deployment with Small Boom.

Figure 14. Boom Vane Deployment with Small Boom as seen from Shore.

Figure 15. View along Mooring Line

On Wednesday, the boom vane was easily launched with the small boom and a tension meter was installed on the mooring line. An extra length of line was attached to the boom vane in order to get it further out into the main current (see Figure 16). The tension in the mooring line was about 550 pounds at the beginning of the deployment. Readings taken 45 minutes later were three knots of current and about 580 pounds of tension. When the vane was retrieved and then released, the mooring tension increased to about 700 pounds during redeployment.

Figure 16. Boom Vane viewed from boat

The dimensions of the small boom configuration are shown in (Figure 17) as taken by range-finder binoculars. The dimension taken of the length of the mooring line appeared to be low so they are not listed. This may be because the method that the binoculars use to determine the distance between two objects is awkward. The user must take a fix on one target and then slowly rotate until the second target is viewed. The binocular measures the angles and ranges to the objects and then calculates the distance. Since the calculation of range is more straightforward, the range out to the triangle's apex and distance along the shore to the mooring line attachment will be used for all calculations.

The tension meters were used to collect data that could help determine the force that the boom vane creates so that deployment strategies can be developed. An attempt was made to determine all of the forces within the deployed system but it was not possible due to the number of unknown variables. For the configuration shown in (Figure 17), tension was not known for the boom. Using the values that ORC measured in a previous deployment, the geometry (see details in Appendix B) results in a tension load in the boom of about 1280 pounds**.** This is the combined force of the current and pull of the boom vane on the boom.

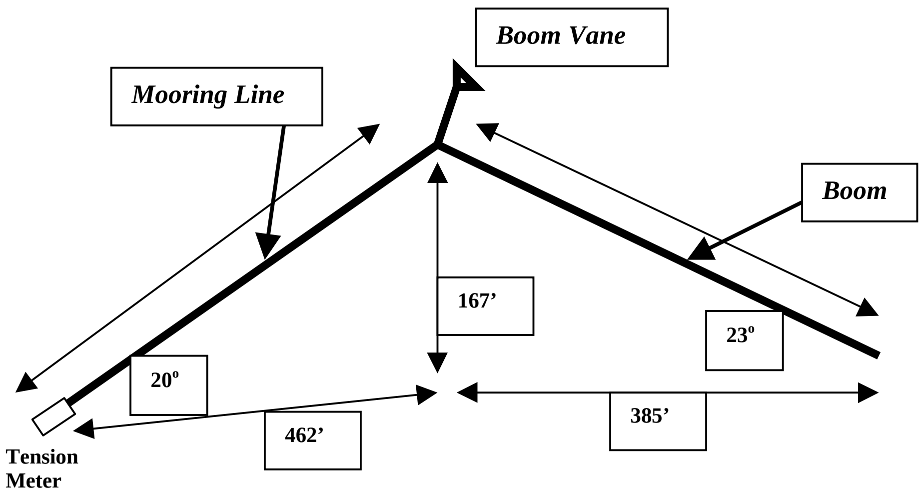

Figure 17. Boom Arrangement Dimensions with Small Boom Attached

On Wednesday afternoon, the larger boom with the deflectors attached was connected to the end of the boom vane. The deflectors were closed and the end of the boom was attached to the shore. A waterproof tension meter was installed between the boom and vane for this series of tests. With about .9 knots of current, the mooring line measured about 348 pounds with about 468 pounds at the head of the boom. (See Figure 18) for the dimensions of this configuration. The same analysis that was done before using the ORC supplied data was performed for this configuration. The results (see Appendix B) indicate a boom tension of only about 250 pounds was expected. It is not clear why these values are so far off from the expected tension forces. One possibility is the long extension line that we tied to the boom vane is not taken into account. It appears that the assumptions made in the calculations may be incorrect.

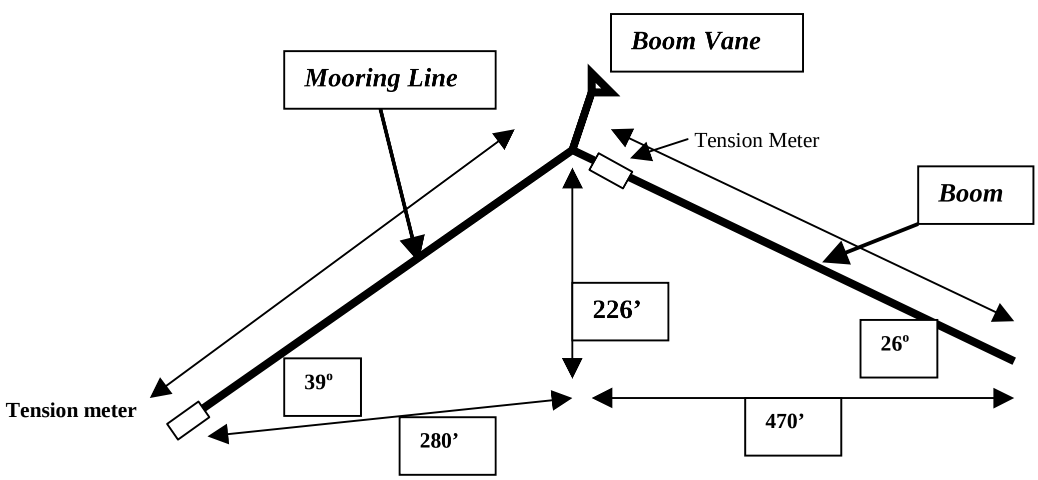

Figure 18. Boom Arrangement Dimensions with large Boom attached

Figure 19. View of Boom Vane with large Boom

The deflectors were then opened and the end of the boom released from the shore. The boom vane swept upriver before stabilizing at a sharper angle to the bank. The boom with the deflectors again created an angle of about 15 degrees with the current running just under 1 knot. The tension in the mooring line was generally unchanged (366 pounds) and the force contributed by the boom decreased to 220 pounds. The expected value of the boom tension is about 138 pounds as shown in Appendix B. This number may be the result of drag coefficients that are too low for this configuration. Using the measured values, the angle of the mooring line with respect to the shore was calculated. A calculated angle of 80 degrees appears to be consistent with the observations.

4.2.3 Hydrodynamic Circus

4.2.3.1 Equipment Description

The Hydrodynamic Circus is a device developed by Captain Blomberg of Sweden. [Blomberg, Claeson, 1997] The arrangement (seen in the staging area in the Figure 20) is designed to channel the water and oil into the circular lagoon. The two deflectors are set at about one-half the height of the device so that only surface water is funneled into the yellow section. The buoyancy of the oil keeps it on the surface while the slant of the walls and the circular flow force the water to rotate out underneath the deflectors. (see Figure 21) The size shown here is 5.6 feet long, 3.3 feet wide and about four feet high and weighs about 285 pounds. It is designed for inshore use in currents up to three knots. Larger units are available.

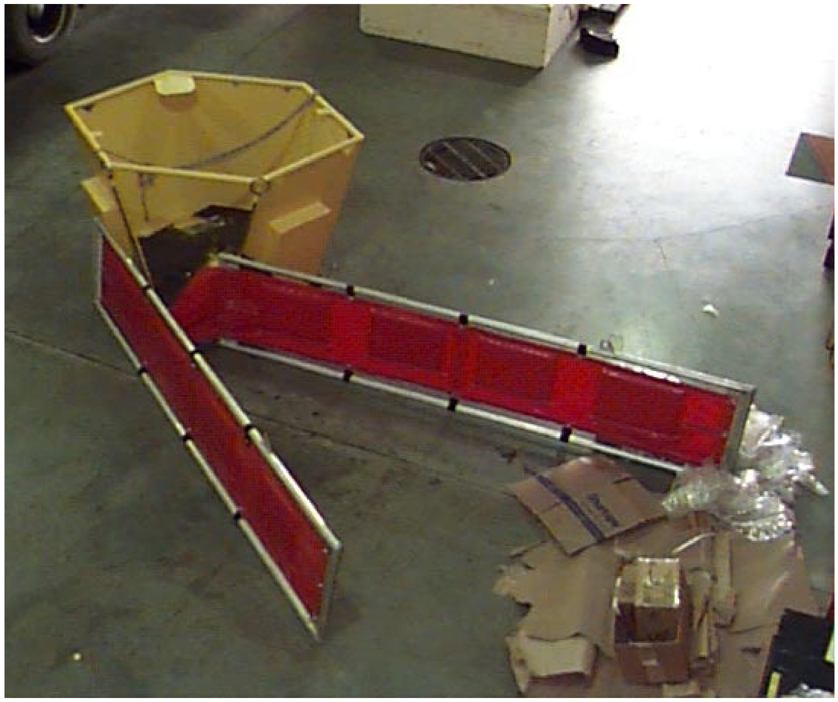

Figure 20. Hydrodynamic Circus in staging area

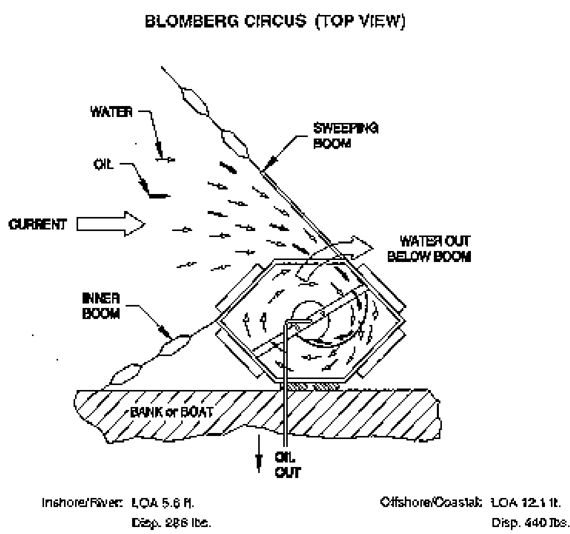

Figure 21. Circulation Scheme of Circus

For evaluation, the Circus was attached to the side of the response boat. (see Figure 22) This was done to ensure a current in order to demonstrate the physics of this equipment. A picture looking down into the device is shown in (Figure 23). It was noted that floating pieces of wood and trash remained in the lagoon while the water left the unit underneath the barrier. The attachment arrangement was not optimal, as the device tended to ride up the hull, especially when the boat slowed down for a turn. Dye was pouring into the opening but the mixing did not permit the exact flow mechanisms from being determined.

Figure 22. Hydrodynamic Circus deployed on Response Vessel

Figure 23. A View into the top of the Circus

4.2.4 FASFLO

4.2.4.1 Equipment Description

The final device that was demonstrated was the Vikoma Fasflo. The skimmer as seen in (Figure 24), is 13 feet long, 7.25 feet wide and about 3 feet high and weighs 770 pounds. The system uses two deflection booms to channel the oil into a narrow opening (Figure 25). The next section opens up allowing the velocity to decrease providing a quiet zone and allowing for gravity separation. Water escapes through bottom of the device while oil is collected past the self-adjusting weir (See Figure 26) and pumped out.

Figure 24. FASFLO Skinner from Vikoma

Figure 25. Lead Opening and Deflection Booms on Fasflo Skimmer

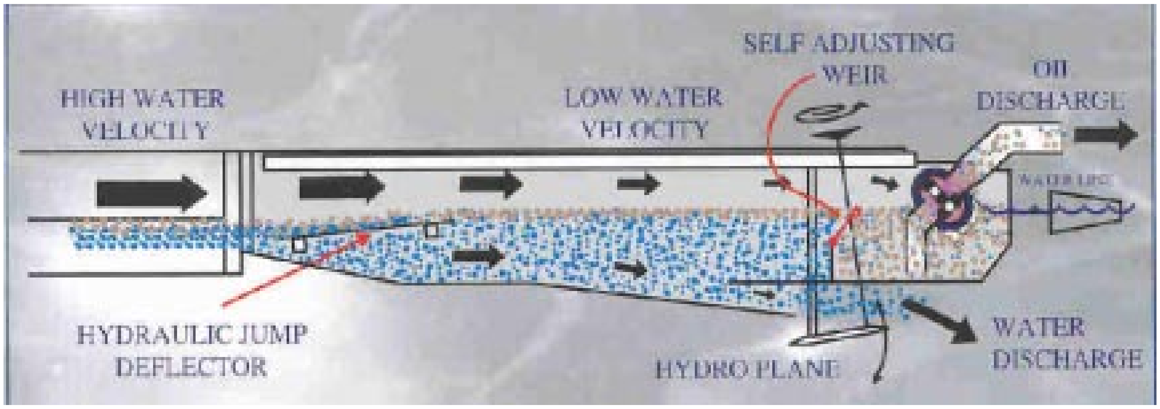

Figure 26. Cross Section of Fasflo Skimmer

4.2.4.2 Equipment Evaluation

The Fasflo skimmer was deployed by attaching it to the Weyerhauser dock with the opening in the direction of the current. One deflection boom was attached to a piling and another was held out using a skiff with an outboard motor. (see Figure 27) While this was not the optimal arrangement, it gave participants the chance to understand the principles of the skimmer and view deployment issues. Dye and popcorn was poured into the opening to demonstrate the water flow and pumping capability. Cowlitz Clean Sweep supplied the hydraulic pump to operate the system.

Figure 27. FASFLO Skimmer attached to Weyerhauser Dock

5.0 CONCLUSIONS AND RECOMMENDATIONS

The field demonstration of four pieces of oil spill equipment was completed. Two out of the four systems are still considered to be in the developmental stage but the demonstration provided the participants the opportunity to see the equipment, interact with the manufacturers and exchange ideas. The conclusions are based on the data collected and comments provided.

Boom Deflectors - These devices appear to be relatively easy to handle and did deflect boom. They will probably work best with rigid foam filled boom and in a steady high-speed current. It would be useful if the flotation section was reduced in size and the deflector placed deeper in the water. A lighter design would make them easier to handle and not as likely to dig into sand when deployed from a beach. Calibration of the deflectors is needed so users can determine how many are needed based on the current and river width. They should be evaluated for use in controlling boom in systems deployed off vessels.

Boom Vane - The most enthusiasm was shown for this equipment. It was easy to deploy and held the collecting boom steady and in a good shape for oil collection. This also works better with rigid boom. It is most easily deployed where the water is deep enough right near the shore and sufficient current exists. Calibration is needed for this system so that users know the size and amount of mooring line and the amount of boom needed for a deployment. One concern is how it handles large debris. It should be tested with vessels as it has the potential of reducing the size or eliminating the standoff structure needed for vessel of opportunity systems. A lifting eye would be useful in handling the vane.

Skimmers - Less was learned about the two skimmers because oil was not used. Their efficiency and methods of their use will be explored at tests at OHMSETT during the summer. Both the Hydrodynamic Circus and the Fasflo have some handling problems due to their unique requirements. Both appear to be dependent upon the operators making correct judgements concerning their deployment and pumping the oil out of the collection section.

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Appendix A: Columbia River Demonstration Attendees

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APPENDIX B Calculations

I. Background

The calculations are performed in English units because the tension meters were calibrated to pounds of force. The current was measured in knots (nautical miles per hour) and converted to feet per second. The conversion is: V (knots) x 1.689 = V feet/second.

Drag is calculated by the formula below:

$$\textbf{Drag} = \mathbf{1/2\ \rho\ A\ C_{DN}\ V^2 + 1/2\ \rho\ A\ C_{DT}\ V^2}$$

Where: ρ = density (1.935 slugs/ft^3)
A = cross section area of the boom below the waterline (ft^2)
C_D = drag coefficient (C_{DN} = 1.5 normal forces and C_{DT} = .029 for tangential forces for booms)
V = velocity (ft/sec)

The other parameters used for the booms and deflectors are:

Small Versatec Boom - Length = 350 feet, skirt = 6 inches

Large Kepner Boom - Length = 400 feet (with deflectors)

Deflectors - Area in water = 5 feet x 8 inches (.667 feet)
Drag Coefficient = 1.5 and .029

II. Deflector Deployment off Breakwater (Section 4.2.1.2)

a) Deflectors Closed - the areas of the boom and the deflectors are included
Area of one deflector when closed = 6.667' x .667' = 4.45 $feet^2$
Area of boom = 350'x0.5'
V = 2.36 feet/sec (1.4 knots)

$$\text{Drag} = 1/2\ \rho\ A\ C_{DN}\ V^2 + 1/2\ \rho\ A\ C_{DT}\ V^2$$

$$\begin{aligned}\text{Drag} &= 0 + 1/2\ (1.935)\ (350'\text{x}0.5' + 6(4.45\text{ft}^2))\ .029\ (2.36)^2 \\ &= 31.6 \text{ pounds}\end{aligned}$$

b) Deflectors Open - the areas of the boom and the deflectors are included

Area of one deflector = 6.667' x .667' = 4.45 $feet^2$

Area of boom = 350'x0.5'

V = 2.52 feet/sec (1.5 knots)

Drag of boom = $1/2\ (1.935)\ (350'\text{x}0.5')\ 1.5\ (2.52 \sin 15°)^2 +$
$1/2\ (1.935)\ (350'\text{x}0.5')\ (.029)\ (2.52 \cos 15°)^2$
= 108.04 + 29.09 = 137.1 pounds

Drag of deflectors = $1/2\ (1.935)\ (30'\text{x}0.667')\ 1.5\ (2.52 \sin 45°)^2 +$
$1/2\ (1.935)\ (30'\text{x}0.667')\ (.029)\ (2.52 \cos 45°)^2$
= 92.2 + 1.78 = 94 pounds

Total Drag = 137.1+ 94 = 231.1 pounds

Trying a more appropriate value for current closer to the shoreline:

V = 1.86 feet/sec (1.1 knots)

Drag of boom = $1/2\ (1.935)\ (350'\text{x}0.5')\ 1.5\ (1.86 \sin 15°)^2 +$
$1/2\ (1.935)\ (350'\text{x}0.5')\ (.029)\ (1.86 \cos 15°)^2$
= 58.85 + 15.84 = 74.7 pounds

Drag of deflectors = $1/2\ (1.935)\ (30'\text{x}0.667')\ 1.5\ (1.86 \sin 45°)^2 +$
$1/2\ (1.935)\ (30'\text{x}0.667')\ (.029)\ (1.86 \cos 45°)^2$
= 58.9 + 0.67 = 59.57 pounds

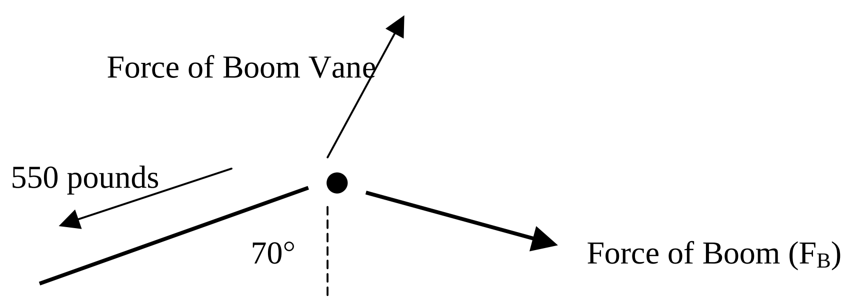
Total Drag = 74.7 + 59.57 = 134.27 pounds

<u>II. Boom Vane Deployment</u>

a) Initial Deployment with small boom on Wednesday:

Using boom forces measured by ORC, AB:

At 3 knots, total force = 5750 Newtons = 1293 pounds at an angle of 33 degrees



Σ **F$_x$ = -**550 sin 70° + 1293sin33° -F_{BX} = -516.8 + 704.2 - F_{BX}

F_{BX} = -187.37 pounds

Σ **F$_y$ =** 550 cos 70° + 1293cos33° - F_{BY} = -188.1 + 1084 - F_{BY}

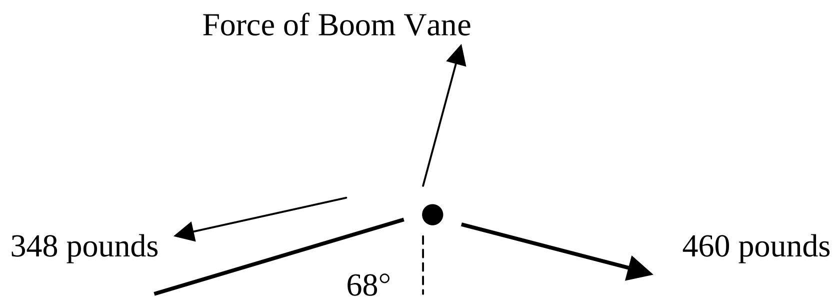
F_{BY} = - 895.9 pounds

Total = SQRT ($F_{BX}^2 + F_{BY}^2$) = 1280.8 pounds tension in the boom at 3 knots

b) Deployment with large boom: the deflectors are closed.

Area of boom = 400'x 1' + 26.67'x1' for deflectors

Force of Boom Vane = 140 pounds (625 Newtons) @ 33 degrees



ΣF$_x$ = -348 sin 68° + 140sin33° + F_{BX} = -322.66 + 76 + F_{BX}

F_{BX} = 246 pounds

ΣF$_y$ = -348 cos 68° + 140 cos33° - F_{BY} = -127.37 + 117.41 - F_{BY}

F_{BY} = 10 pounds

Total = SQRT ($F_x^2 + F_y^2$) = 246 pounds at 1 knot

c) Last Deployment with deflectors: the deflectors are open.

Area of deflectors = 26.67’ x .667’

Area of boom = 400’x 1’

$V = V_{measured} =$ 0.9 knots = 1.52 feet/sec

Angle = approximately 55°

$$\text{Drag} = 1/2\, \rho\, A\, C_{DN}\, V^2 + 1/2\, \rho\, A\, C_{DT}\, V^2$$

$$\text{Drag of boom} = 1/2\,(1.935)\,(400'\text{x}1.0')\,1.5\,(1.52 \sin 15°)^2 + 1/2\,(1.935)\,(400'\text{x}1.0')\,(.029)\,(1.52 \cos 15°)^2$$

TOTAL = 89.84 + 16.47 = 106.41 pounds

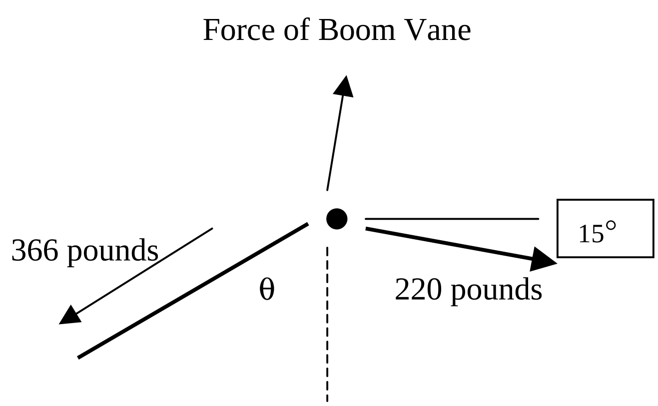
$$\text{Drag of deflectors} = 1/2\,(1.935)\,(26.67'\text{x}0.667')\,1.5\,(1.52 \sin 45°)^2 + 1/2\,(1.935)\,(26.67'\text{x}0.667')\,(.029)\,(1.52 \cos 45°)^2$$

= 30.38 + 0.46 = 30.84 pounds

Total = 106.41+ 30.84= 137.25 pounds

This is much lower that the 220 pounds measured although a current of 1 knot only increases the tension to about 178 pounds.

Calculation of Mooring Line Angle with Respect to the Shore.



using the vane forces from ORC at one knot to calculate angle:

$$\Sigma\, F_y = 0 = -366 \cos\theta + 140 \cos 33° - 220\,(\sin 15°)$$

$$\cos\theta = 60.48/366$$

$$\theta = 80°$$