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**Field Experiments at the Ohmsett Facility,  
For a Newly Designed Boom System**

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## **1. Introduction**

As a major industrial nation, the United States produces, distributes, and consumes large quantities of oil. Petroleum-based oil is used as a major power source to fuel our factories and various modes of transportation, and in many everyday products. On average, the U.S. uses over 250 billion gallons of crude oil and other petroleum products (Doerffer, 1992). At every point in the oil production, distribution, and consumption process, oil is invariably stored in storage tanks. With billions of gallons of oil being stored throughout the country and being transported around, the potential for an oil spill is significant, and the effects of spilled oil can pose serious threats to the environment.

The most common equipment used for controlling oil spill is the oil boom. Booms are used to contain the oil and to keep it from spreading. Specially designed, fire resistant containment booms can be used to contain burning oil, if in-situ burning is approved. Following containment, three distinct approaches can be taken to physically remove the oil from the water. These are the use of mechanical skimmers, the use of sorbent material, and manual removal by the cleanup work force. Dispersants are also sometimes used.

The objective of this research is to design and test a boom arrangement that have a collection efficiency which is better than that of simple booms. Some designs have showed high efficiencies in our laboratory experiments. Then experiments are desired to test the possibility of translating the successful laboratory-scale design to a prototype design.

## **2. Laboratory Study**

As a first step in the design procedure, the designed boom configuration was tested with the aid of the hydrogen bubble flow visualization equipment (Wong and Wolek, 1996). This was done to obtain a preliminary look at how the boom arrangement affected the flow. The hydrogen bubble experiment showed that the designed boom configuration was very promising.

Testing with actual oil was then carried out in the open channel apparatus (Wong and Guerrero, 1995). The open channel system used consisted of two reservoirs connected with a channel of rectangular cross section. A pump was placed in one of the reservoirs and was used to create a flow around the system. A honeycomb structure made up of 20.6mm inside diameter PVC pipes was also introduced at the up-stream section of the channel to counteract the excessive turbulence created by the pumping mechanism. For all experiments, regular automotive oil type 20W40 was used in conjunction with fresh water. The viscosity and density of this oil are given as 95cs and 0.87g / cc ( ASTM 445, 40<sup>o</sup> C ) respectively.

A design arrangement consisting of a ramp at an angle to the water level and a set of four simple booms (Wong and Kusijanovic, 1998) was tested in laboratory. The ramp boom greatly changes the flow pattern in the oil collection zone. This design could achieve about 98% collection efficiency even at a current velocity of 1.3ft/s. It was also concluded that three booms in the cascade portion of the arrangement were enough, and not all four simple booms were required.

### 3. The New Design

A good prototype should produce a favorable flow field for entrapping oil, as well as it should be feasible practically. It should be easy to transport and install. With this in mind, our design is a set of three simple booms, the first two with the same skirt-lengths, and the last one with one-and-a-half times the skirt-length , Fig 1.

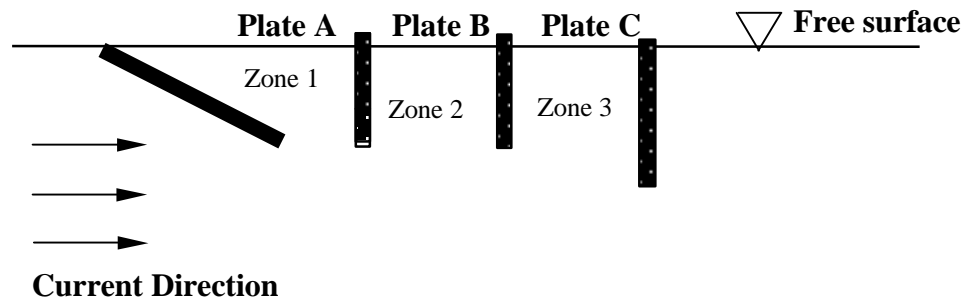


Figure 1 Side view of the boom arrangement.

Figure 1 is a sketch of the boom arrangement in operation. Zones 1 to 3 are oil collection zones. Since our open channel apparatus cannot provide a side view of the flow, we resorted to a Computational Fluid Dynamics (CFD) method to study the flow fields. The computational domain is simplified into a 2-D geometry. Two papers are attached which reports on the work and conclusions reached about the computational modeling. These are Appendices A and B.

## **4. Project Activities**

Project activities included the engineering design of the prototype boom system. The major component of the engineering design was in the ramp boom, because the cascade of booms which were used, came from off-the-shelf products. The design calculations for the ramp boom are in Appendix C. Attached are the autocad drawings of the ramp boom, as well as the statement of work for the manufacture of the boom system. These constitute Appendix D.

The ramp boom involved some assembly on site. Hence, detailed analysis was performed to account for the on-site assembly modifications. In addition, there was a need to calculate the steady-state equilibrium positions of the ramp boom being towed in water as assembled on site. These calculations are provided in Appendix E. These calculations also provided the information that precipitated the step to reduce the ramp angle to fifteen degrees in the final tests. Appendix F is the compilation of the calculations for the ramp boom with the configuration used in the final Ohmsett tests in December 2000.

The weight of the ramp boom was rather high. An optimization study was done to minimize the weight of the ramp boom. It is shown that, if the original geometry (strap lengths and location of the ballast weight) of the prototype was altered as proposed by the optimization study, weight of the ballast could be reduced by 17 pounds per foot. This optimization study is included in Appendix G. However, the optimization was not carried out practically, because a new generation of improved booms were already in the works.

Appendix H is an excerpt of the final test data obtained at Ohmsett Testing Facility in December 2000, as provided by Mar Inc.

The final tests, results, analysis, discussion and conclusion are then provided to round out this report. The boom system tested at Ohmsett Testing Facility are shown in Photos 1 to 3. The boom system arrangement with the ramp boom in front, and the cascade of three booms in the rear are shown in Photo 1. The maximum amount of oil being collected at 1.5 knots tow speed without any waves, is shown in Photo 2. The boom arrangement at 1.5 knots tow speed with six-inch waves are shown in Photo 3.

## **5. Testing and Results**

### August 2000 Tests

In August tests the prototype ramp boom floated very well. It moved well, but we discovered that the boom arrangement should not be pushed on the way back. The arrangement should be pulled instead.

A small leak occurred in the fore pontoon after the first run and push-back of the boom arrangement. It was decided to stop the tests and repair the boom before further tests were to be carried out.



Photo 1 Ramp Boom System Arrangement



Photo 2 Tow Speed of 1.5 Knots without Waves





Photo 3 Tow Speed of 1.5 Knots and Six Inch Waves



## December 2000 Tests

Nine test runs were made in all, the first being without oil. The purpose of the first test was to observe how the boom arrangement floated and moved in the water. After the repairs on the fore and aft pontoons (since the August test), the ramp boom seemed sturdy and able to withstand further tests. So the tests with oil were carried out after these repairs.

Test 2 was carried out at 1 knot tow-speed, and 67 gals. of Calsol was used. Most of the oil collected in the front of the ramp boom. There was not enough speed (energy) to move the oil past the ramp boom. In other words, the boom was effective in keeping the oil out. Some oil flowed around the 16-foot wide arrangement, along the sides.

Test 3 was carried out at 1.5 knots tow speed, without using any oil. The motion of water under and around the boom arrangement was observed and studied.

Test 4 was carried out at 2 knots tow speed, with about 49.7 gals. of Calsol used. At this speed, the oil had enough energy to go under the ramp boom. Some of the oil was collected by the boom arrangement system, but most of it escaped. A rough estimate of the amount of oil collected by the booms ranges from a low of 7 gals. to a high of 10 gals. This would correspond to collection efficiencies of 14-20%.

It was determined at this point that the tow speed of 1.5 knots was probably optimum for the boom arrangement as tested, where the angle of inclination of the ramp boom was designed and fixed at about 15°.

So, test 5 was carried out at 1.5 knots tow speed and about 49.3 gals. of Calsol was spilled. The estimate of oil collected ranged from a low of 28 gals. to a high of 35 gals. The collection efficiency is calculated as ranging from 55%-71%.

Since the water temperature was about 34°F, the Calsol was too viscous to be pumped into the measuring tanks at Ohmsett. Thus, the experienced eye of the Ohmsett Test Engineer was used in the estimate of the oil collected. In order to obtain more accurate data using the measuring tanks, it is decided to go with a lighter oil, that is, Hydrocal 300. The last four tests were thus done with Hydrocal 300.

Test 6 was carried out at 2.0 knots tow speed and about 44.5 gals. of Hydrocal 300 was spilled. About 16 gals. of the oil was collected. The collection efficiency is thus 36%.

Test 7 was carried out at 1.5 knots tow speed and about 55.9 gals. of Hydrocal 300 was spilled. The collection efficiency was evaluated as 86.5%.

Test 8 was carried out again at 1.5 knots tow speed and about 68.8 gals. of Hydrocal 300 was spilled. The collection efficiency was evaluated as 52%. Probably, too much oil was spilled, and a lot of it flowed to the sides of the boom arrangement system. These end-effects were expected, but sometimes could not be controlled.

Test 9 was carried out at 1.5 knots tow speed with about 6-inch waves created in the test tank. About 72 gals. of Hydrocal 300 was spilled. The collection efficiency was evaluated as 27%. As it was in test 8, too much oil was used and the end effects contributed negatively to the collection efficiency. The ramp boom arrangement had very good wave-following characteristics.

## 6. Analysis

The water temperature during the test day was 34.6 °F. The properties of water, Calsol 8240 and Hydrocal 300 at the specified temperature are as follows :

$$\begin{aligned}\tilde{n}_{\text{water}} &= 1000 \text{ kg/m}^3 \\ \tilde{n}_{\text{calsol}} &= 930 \text{ kg/m}^3 \\ \tilde{n}_{\text{hydrocal}} &= 880 \text{ kg/m}^3 \\ \dot{\lambda}_{\text{water}} &= 1.71 \cdot 10^{-3} \text{ N.s/m}^2 \\ \dot{\lambda}_{\text{calsol}} &= 18.92 \text{ N.s/m}^2 \\ \dot{\lambda}_{\text{hydrocal}} &= 0.88 \text{ N.s/m}^2\end{aligned}$$

Therefore the oil relative viscosities of Calsol and Hydrocal are :

$$\begin{aligned}S_{m,\text{hydrocal}} &= \frac{\mathbf{m}_{\text{hydrocal}}}{\mathbf{m}_{\text{water}}} = \frac{0.88}{1.71 \cdot 10^{-3}} = 514.6 \\ S_{m,\text{calsol}} &= \frac{\mathbf{m}_{\text{calsol}}}{\mathbf{m}_{\text{water}}} = \frac{18.92}{1.71 \cdot 10^{-3}} = 11064.3\end{aligned}$$

And the Froude number is defined as :

$$Fr_d = \frac{U_o}{\sqrt{gd}} = 0.374U_o$$

where  $g = 9.81 \text{ m/s}^2$  (gravitational acceleration),  $d = 0.73\text{m}$  (draft of the conventional boom),  $U_o = \text{tow speed}$ .

At tow speed of 1.5 knots : (1.5 knots=0.772 m/s)

$$Fr_d = 0.288$$

At tow speed of 2 knots : (2 knots=1.03 m/s)

$$Fr_d = 0.385$$

The necessary parameters related to the prototype have been obtained. The paper “Instability study of the oil slicks contained by a boom system” (Fang and Wong, 2000)

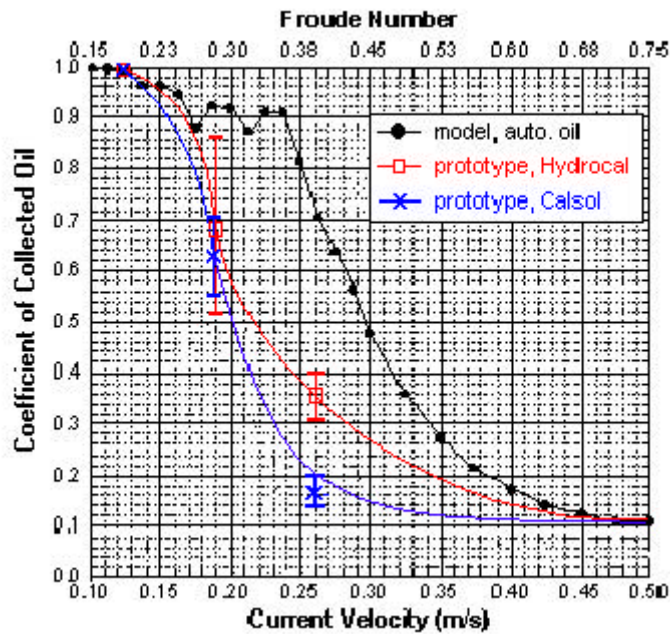
is referenced for the determination of the corresponding model parameters. In that study, automotive oil was used as the test oil. The properties of the automotive oil are :

$$\begin{aligned} \tilde{n}_{oil} &= 870 \text{ kg/m}^3 \\ \tilde{\lambda}_{oil} &= 9.5 \text{ E-2 N.s/m}^2 \\ S_i &= 79 \end{aligned}$$

The Froude number, with  $d = 4.5 \text{ cm}$  draft of model boom is :  
 $Fr_m = 1.49U_o$

Hence the model current speeds corresponding to 1.5 knots and 2 knots prototype tow speeds are 0.19 m/s and 0.26 m/s, respectively.

The prototype test data and the model test data are plotted in Figure 2.



**Figure 2 Coefficient of Collected Oil vs. Current Velocity**

Figure 2 has been adapted from a figure in “Optimization of an Oil Boom Arrangement,” (Fang and Wong, 2001). The figure is a plot of the coefficient of collected oil versus the current velocity, and the corresponding Froude number. The computational model simulated the boom arrangement system that was tested at Ohmsett. In the figure, the coefficient of collected oil is the collection efficiency for the system.

According to the test results, where both Hydrocal 300 and Calsol were used as test oils, the collection efficiency of the boom system is almost 100% at a tow speed of 1 knot. Obviously the collection efficiency is 100% when the tow speed is zero. Therefore the logical deduction is that the collection efficiency of the oil boom system is 100% for

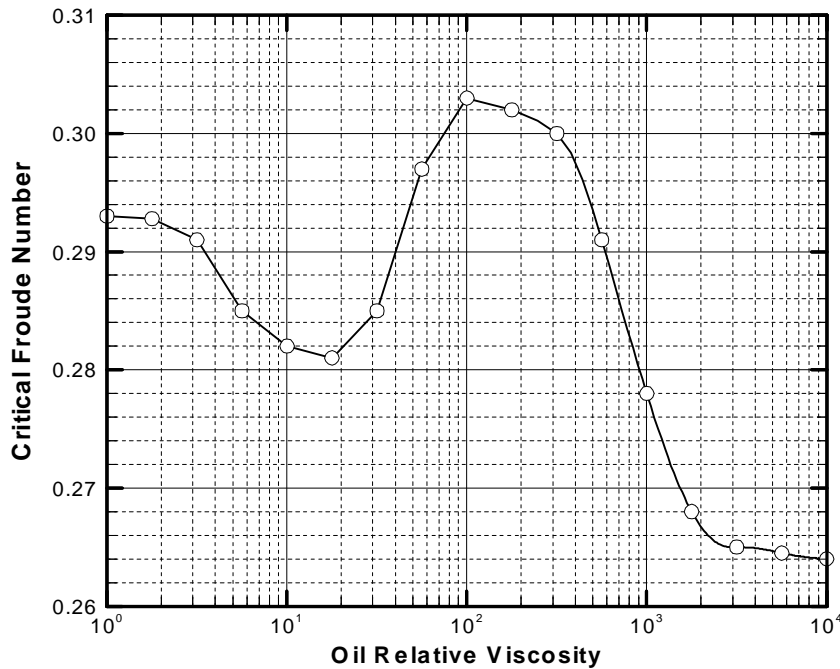
tow speeds between zero and 1 knot. For the two different test oils (Calsol and Hydrocal 300), there was an observed range of collection efficiencies corresponding to 1.5 and 2 knots of tow speeds. Two available test points for Hydrocal 300 are plotted on the graph. The first point (upper point on the red curve, Fig 2) is the arithmetic mean of collection efficiencies that are observed in test 7 and 8 (tow speed 1.5 knots). The second point corresponds to the mean of observed range of collection efficiency at test 6 (tow speed 2 knots). The error bars are also included in order to indicate the interval of uncertainties. The two available test points for Calsol 8240 are plotted in a similar way (blue curve, Fig 2), together with the error bars associated with the observed ranges of collection efficiencies.

The following observations can be made from the plot :

1. The optimum tow speed is 0.19 m/s for the model which corresponds to 1.5 knots for the prototype.
2. The critical tow speed is 0.24 m/s for the model (at tow speeds higher than this value, the collection efficiency decreases rapidly) which corresponds to 1.89 knots for the prototype.
3. The general behavior is correct since the curves obtained for the model and the prototype have similar characteristics.
4. There seems to be a critical Froude number beyond which the collection efficiency drops significantly. This was very evident during the prototype testing at Ohmsett in December 2000. The change in collection efficiency was so drastic that it appeared that an optimum velocity existed for the boom system. In effect, it was changed from almost 100% collection efficiency at one knot to very low collection efficiency at 2 knots. This is not so much a “surprise” as it is a critical Froude number that lies between 1.5 knots and 2 knots.

The critical Froude numbers of the model and the prototype appear to be different. The reason can be obtained from Figure 3. This figure is a plot of the critical Froude number versus the oil relative viscosity. The oil relative viscosity for the model test is 79, which corresponds to a higher critical Froude number than both Hydrocal 300 ( $s_1 = 514.6$ ) and Calsol ( $s_1 = 11,064.3$ ). The more viscous oils that are used to test the prototype causes the critical Froude numbers to be lowered. For this reason, the critical Froude number of the more viscous oil Calsol 8240 appears to be less than that of Hydrocal 300 (See Fig 2); both of them are more viscous than the motor oil used in the computational model that produced Fig.2. So with the computed curve, shifted to the left because of the smaller Froude number for Calsol 8240 and Hydrocal 300, we will obtain the experimental curves for the Calsol and the Hydrocal.

It is hard to make any statements with one test-point for the boom system under six-inch wave conditions, so this will not be done.



**Figure 3 Oil relative viscosity vs. the critical Froude number**

## 7. Discussions and Conclusion

The results from the final tests at Ohmsett Testing Facility, seem to validate the theoretical predictions of the computational model by Fang and Wong(2001). The model predicted a critical velocity of 1.89 knots, after which the collection efficiency drops off significantly. It was found that the ramp boom system collected very well at 1.5 knots, and its efficiency dropped off at 2 knots.

The prototype testing of the ramp boom system at Ohmsett Testing Facility was a success. It showed that the ramp boom system is in fact a useful arrangement that improves oil collection efficiency over and beyond the regular conventional boom. A high of 86.5% collection efficiency was achieved at a tow speed of 1.5 knots, where all conventional booms have failed. The next logical step is to research into the next generation of booms that will be more easily deployed, and makes use of the findings of the current work.

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