Swift Current Oil Boom Experiment (S.C.O.B.E.)

Technical Report

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Also, special thanks must be given to several key individuals without whom the SCOBE project would never have realized its full potential. First, to Dr. M.R. Swift for his ever-present direction, leadership and advice throughout the duration of the SCOBE project, to Phil Coyne for all of his technical knowledge and support, to Paul Lavoie for his assistance and technical advice on dealing with the Ocean Engineering facility and equipment, and to John Scott for his assistance with the project finances.

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ABSTRACT

The SCOBE containment system was developed to contain oil spills in locations of high-current velocities where the deployment of conventional oil boom is subject to failure by leakage. The design configuration of the SCOBE system utilizes an inclined submergence plane which guides the oil into a containment region where the oil is retained and sheltered from the effects of the external high velocity current. The SCOBE design allows for the system to be towed and utilized as a skimmer or fixed in position at locations of high-current velocity and used in conjunction with conventional oil boom to funnel the oil slick into the containment system. The SCOBE system was designed as a research tool and therefore has several variable components which can be adjusted in order to determine an optimal design configuration under varying conditions.

I. INTRODUCTION

CONVENTIONAL CONTAINMENT PROBLEM:

Since the beginning of man's use of oil and the transportation of this vital fuel via the world's waterways, the causes and effects of major oil spills have been an ever increasing topic of frustration and concern. The concern is based on the incredibly devastating effect these spills have on the planet's delicate ecosystem, not to mention the enormous amounts of revenue that federal, state, and local governments spend on trying to research and prevent these disasters from happening and then cleaning and disposing of them when they do. The frustration is based mainly on society's inability to design and develop an oil containment system that performs all of the necessary functions required to control an oil spill no matter what the prevailing conditions in the water may be.

To date, the use of horizontally positioned oil booms placed perpendicular to the current has been an extremely important tool in the containment and recovery of spilled oil. However, this system is severely limited by the speed of the current in which it is deployed. In calm or slow-moving water, the system functions very well. Unfortunately, serious problems begin to appear as soon as the perpendicular component of the current velocity reaches a critical point. At this critical point, small segments of oil begin to separate from the head of the contained oil and become entrained in the water flow and are carried beneath of and away from the oil boom. Earlier research has determined this critical value to be 0.6 - 1.0 knots depending on specific oil properties, (Tsocalis et al. 1994).

This current velocity limitation is severely restricting in that many of the rivers and harbors through which the oil is transported contain current velocities that well exceed this critical value. For this reason, conventional oil boom deployment has been found to be very inefficient to use in a fixed boom system or as part of oil boom skimming operations under these conditions. As current velocity increases, entrainment becomes more and more of a factor and the containment of the oil boom is compromised.

Due to these restrictions, alternate methods of deploying conventional oil boom have been studied, designed, and performed to some degree of success. As opposed to deploying the oil boom horizontally and perpendicular to the current in an attempt to contain the spilled oil in a pocket, the oil boom is deployed at an angle to the on-coming current and the oil is then funneled to a specific recovery point. This diversion boom method reduces the magnitude of the critical perpendicular component of the current velocity which causes entrainment and boom failure. There are, however, limitations to this approach as well. Achieving a sufficient angle with the oil boom, especially in locations of high current velocity, to reduce the perpendicular component of the current velocity below the critical value requires a large length of oil boom and extremely tedious work in positioning and securing the boom in place (Swift et al. 1992).

Due to these limitations imposed on the currently used methods of oil containment relying solely on the use of conventional oil boom materials, new design concepts are desperately needed. These designs should be analyzed and studied in order to produce an oil containment system that will handle current velocities of at least two times the critical velocities of conventional booms. This would provide an oil containment system that could be effectively and reliably deployed in many of the river, harbor, and estuary environments containing high current velocities and significantly increase the ability to recover and contain spilled oil in emergency situations. One approach to accomplishing this goal is presented here in the form of an oil retention system that is based on a more elaborate rigid structure composed of multiple components that may be used in conjunction with conventional oil boom in order to achieve the desired containment results. The project name is S.C.O.B.E., an acronym for Swift Current Oil Boom Experiment.

DEVELOPMENT OF CONTAINMENT SYSTEM:

The study presented here is a continuation of previous work done by Swift et al. (1995,96) and Coyne (1995). The major objectives of this work were to develop an oil barrier design that offers superior rapid current performance and to obtain an understanding of the fluid dynamic processes associated with the design configuration. The starting point for this analysis was the cross-section shown in Fig 1-1, which employs the use of a submergence plane and containment region.

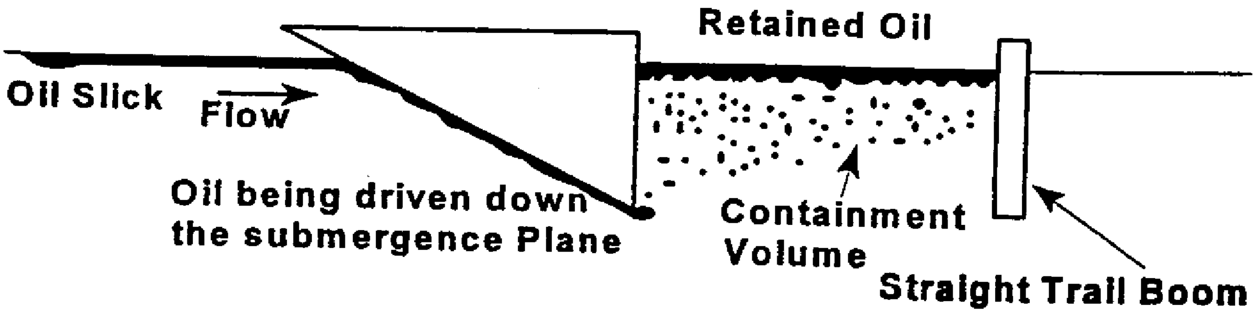

Figure 1-1. Initial submergence plane/containment volume concept

The submergence plane faces the current and forces the on-coming oil down the inclined plane and into the containment region where the oil is collected and the effects of the high velocity current are significantly reduced. Once inside the containment region, entrainment of the oil due to rapid current is eliminated. Detailed two-dimensional laboratory experiments were performed for the analysis of this configuration in order to evaluate and improve the design in an attempt to achieve an optimal design concept. Theoretical as well as experimental analysis was also performed with respect to the dynamic fluid processes that are involved with the design. Related non-dimensional parameters were studied and a fluid velocity field generated by the two-dimensional model was developed. The optimized 2-dimensional design configuration developed by Coyne is shown below in Fig 1-2.

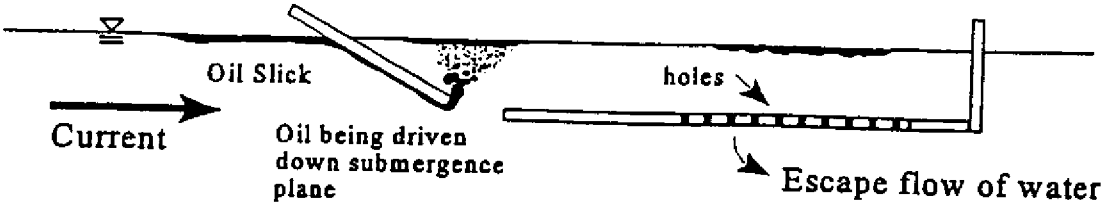

Figure 1-2. Optimized two dimensional design.

OBJECTIVES/GOALS:

The specific goals for the SCOBE project were to:

- Design, analyze and construct a rigid 3-dimensional prototype.
- Incorporate variable parameters into the design to allow for future testing and analysis.
- Test the containment system in laboratory experiments as well as conduct testing in field conditions.

The major issue that needed to be addressed for this project was moving from a small-scale fixed 2-dimensional model to a full-scale 3-dimensional floating model with adjustable components. Emphasis was placed on the construction, testing and analysis of a smaller-scaled 3-dimensional model to evaluate its performance in order to optimize the design of the full-scale prototype.

II. MATERIAL SELECTION

GENERAL MATERIAL REQUIREMENTS:

The material selection process is always an extremely important aspect in the development phase of any project, whether it is large or small In many cases the efficient use of the budget depends on the material selection process. There were several key components in determining the most effective material for the SCOBE project; strength, rigidity, weight, corrosion resistance, and cost.

The preliminary design of the oil boom consisted primarily of sheeting material and angle framing material. Two different sizes of angle framing material were considered; 2x2x1/4 in. and 3x3x1 in.. Since it is not feasible to purchase wood in angle stock the dimensions of the wood considered was standard 2x4 in. framing stock. These choices represented what were thought to be reasonable sizes for the applications in mind. Sheeting material thickness ranged from 1/8" to 1/2" and the individual sheet areas were standard 4x8 ft. or 4x12 ft.. When calculating for strength and deflection these dimensions were used.

From an infinitely large group of materials to select from it was necessary to determine the most likely candidates before time consuming calculations were done to find the best material. The following materials were chosen for their apparent strength and history of ocean engineering uses:

- Polypropylene
- High density Polyethylene
- Polyvinyl-chloride(PVC)
- Aluminum
- Steel*
- Wood(pine)
- Fiberglass

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* This material was only considered as framing material and was not considered as a possible sheeting material.

Critical values for these materials were accumulated through research and phone conferences with industry sources. Material properties include; density, Young's modulus (modulus of elasticity), tensile strength and yield strength. Tables containing these values can be found in *appendix A*.

STRENGTH AND DEFLECTION CALCULATIONS:

In order for a more definitive comparison it was necessary to calculate each materials reaction to similar constraints. The two constraints that were considered were strength and deflection.

It was decided that the most appropriate way in which to determine the strength of a material was to calculate the maximum load possible for a fixed length beam or angle beam of that material. A beam of length 4 meters pinned at one end was subjected to a point load F at the midpoint. *Figure 2-1* shows a graphical representation of this. Using the yield strength it is possible to calculate the maximum attainable load for this system. Yield strength is defined as

$$\sigma_y = \frac{Mc}{I} \ . \qquad (2\text{-}1)$$

Where σ_y is yield strength, M is the moment produced by the load, c is the position of the neutral axis and I is the area moment of inertia or second moment of area. Some sources define a ratio between I and c. This ratio is called the elastic section modulus defined by

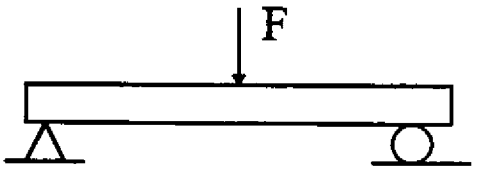

Figure 2-1: Maximum load calculation scenario. Fixed length beam subjected to a point load at the midpoint.

$$S = \frac{I}{c} \ . \qquad (2\text{-}2)$$

This term was used in several calculations of the maximum load. Since the yield strength, I and c are known, the maximum allowable moment can be found. Now knowing the distance from the pinned point to the point load, the maximum allowable load can be determined. *(See Appendix A. for sample calculations)* Maximum loads were calculated for each of the different framing materials.

The second comparison constraint was maximum deflection. Calculations for maximum deflections were made based on the following scenario. A fixed load applied at the midpoint of a fixed length beam produces some maximum deflections depending on the material used. *Figure 2-2* is a graphical representation of this situation.

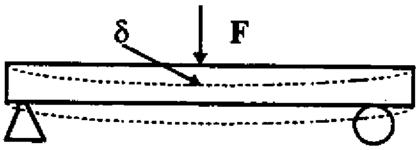

Figure 2-2: Maximum deflection scenario. A fixed length beam is subjected to a fixed load at the midpoint and the maximum deflection is calculated.

The equation for maximum deflection due to a fixed load was given as

$$\delta = \frac{Fl^3}{48EI} \quad . \qquad \text{(2-3)}$$

Where δ is the maximum deflection, F is the applied force(100 lbs.), l is the length of the beam(10 ft)* , E is the modulus of elasticity and I is the moment of inertia. Calculations for the maximum deflection of a 10 ft beam due to a 100 lb. load were done for each material.*(See Appendix A for sample calculations)*

Weight and cost were the last two considerations in the material selection process. The amount of framing material needed for the final prototype was estimated at 280 linear ft and the amount of sheeting material was estimated at 350 square ft. Approximate costs based on these estimates were gathered from catalogs and industry sources. Also using these estimates and the densities of the various materials, the approximate weights of the framing and sheeting materials were calculated.

With the completed material selection criteria it was possible to determine the most likely candidates for the framing and sheeting materials. Tables 2-1 and 2-2 show the comparative considerations that were found.

* These calculations were independent of the maximum load calculations and units were chosen arbitrarily.

Table 2-1: Cost and weight values obtained for sheeting materials.

SHEETING MATERIAL

Material	Cost	Weight (lbs)
Polypropylene	$750	409 1/4"
Polyethylene	$1320 1/2" $726 1/4"	436.7 1/4"
PVC	$1430 1/2" $770 1/4"	636 1/4"
Aluminum	$2476	614.4 1/8"
Steel	--------	--------
Fiberglass	$3300 1/4"	819 1/4"
Wood	$594 1/2" $561 3/8"	336.8 1/2"

Table 2-2: Framing material cost and performance.

FRAMING MATERIAL

Material	Cost	Weight (lbs)	Max. Load (lbs)* 3x3x1/4"	Max. Deflection(ft)* 100 LB load
Polypro.	$840	108	18.29 - 38.06	13.19 - 18.14
Polyethylene	--------	--------	21.12 - 32.16	--------
PVC	$700	168.2	46.7 - 50.96	4.83 - 9.67
Aluminum	$2476	324.5	37.15 - 530	.29
Steel	$280	937	265.4	.1
Fiberglass	$1106	216.3	--------	.23 - .276
Wood (2x4)	$770	223.8	225.6 - 338.42	Flat: 3.23 Edge:.61

*There are two values for some material representing the maximum and minimum ranges of material properties i.e. modulus of elasticity.

Wood 2x4s were chosen as the most effective framing material given the application. It's strength when on edge is comparable to that of steel yet it does not have the weight and density shortcomings of steel. The wood would in fact lend a natural buoyant force allowing the oil boom to float unaided. The cost was well within budget constraints and it was also an easily worked material, not requiring any machining or special skill. The only real drawback for wood was its lack of water resistance and its potential for rot in marine environments. This would be an obstacle easily overcome with some form of sealant or paint. In addition the SCOBE system was not intended for extended periods of field testing. This would reduce the opportunity for rot or water saturation. Originally it was thought that some form of fiberglass would be the best material to use for framing due to its low density and high strength, however, the cost of fiberglass framing could not be fit into the budget.

The sheeting material that was chosen was 1/4" PVC. PVC, while remaining at a low cost, provides solid rigidity to the frame. Based on the deflection calculations of the other materials for the framing it could be seen that PVC was by far the most rigid while still having enough "give" not to be brittle. PVC is also very corrosive resistant when used in a marine environment. As with wood PVC is also easy to worked and can be cut or drilled without any specialized training.

These material selections represented the best combinations of cost, weight, strength and rigidity for the group of materials investigated. These materials were used on both the model and the prototype at different scales to provide for convenience of design.

III. CONCEPT DEVELOPMENT

ORIGINAL DESIGN DESCRIPTION:

The initial design for the 3-dimensional oil containment system is shown in Fig. 3-1. It can be seen here that the submergence plane is attached to two side panels that run the entire length of the containment unit. These side panels are connected at the end of the unit by the back plane, and a bottom plane called the baffle encloses the containment region. The gap between the end of the inclined submergence plane and the beginning of the baffle where the oil and water flow into the containment region is shown here. The original dimensions for the SCOBE containment system were developed with specific testing requirements in mind. It was hoped that the prototype design could be tested in the new wave tank that was being constructed in the Ocean Engineering facility, so the prototype had to fit within the 12 foot width of the wave tank. It was also decided that in order to maintain realistic design dimensions and structural integrity, the depth dimension of the design was limited to 1.5 ft. As a result, the desired freeboard level of the design was determined to be 6 in.

Previous work by Swift et al. (1995) had determined that oil retention is improved as the distance from the submergence plane to the end of the containment region increases. The length of the containment system was ultimately determined by trying to increase the length of the containment region as much as possible while still maintaining structural integrity of the overall design. It was finally decided that a length of 18 ft would be used which would allow for over a 9 foot distance from the very end of the submergence plane to the back plane at the end of the containment region.

It can also be seen from this figure that the containment system has been split vertically down the middle into two individual sections. This was done with transportation of the completed oil boom system in mind. Moving a structure 18 feet long and 12 feet wide is certainly a significant problem that needed to be addressed. It was decided that

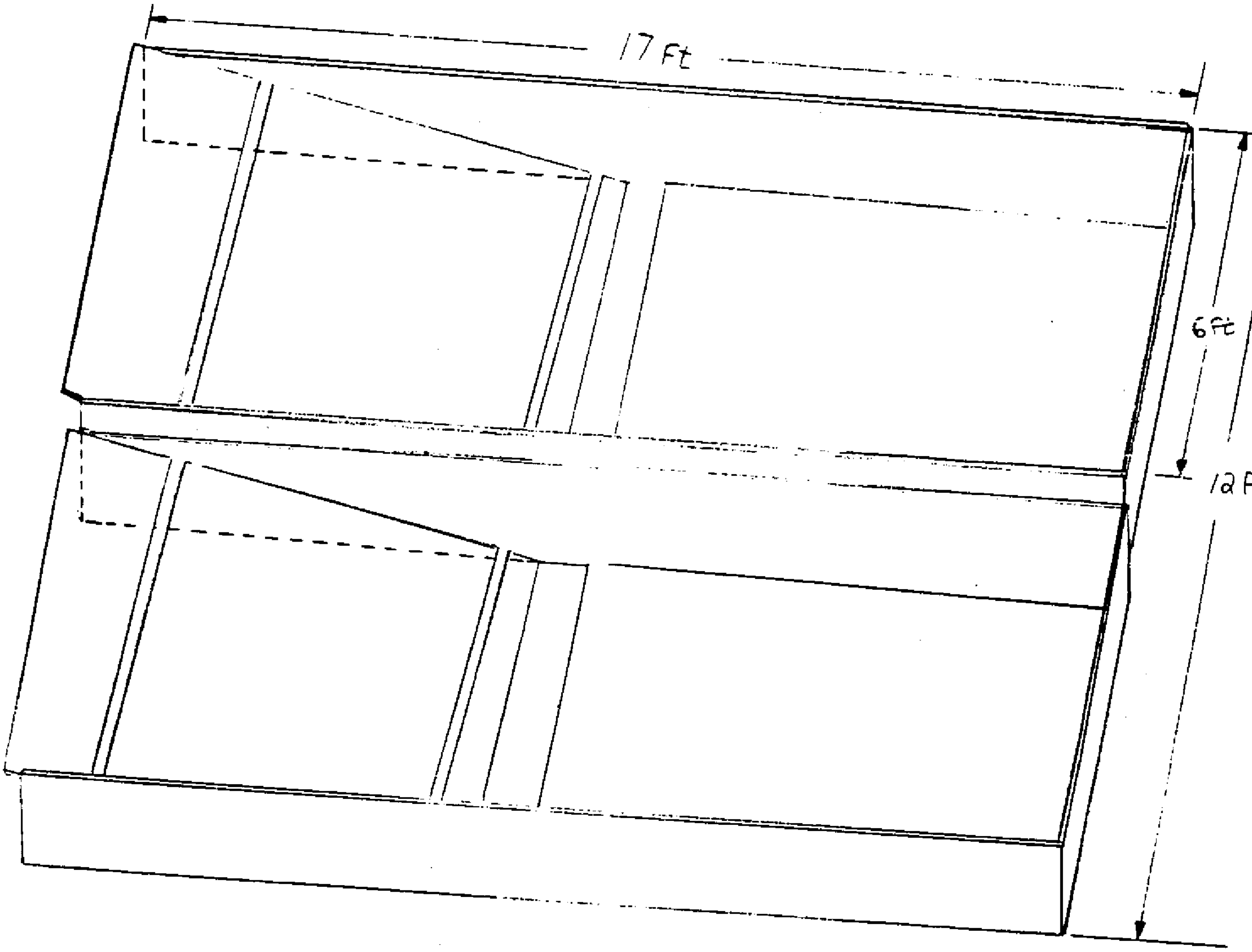

Figure 3-1. Initial design for 3-dimensional oil containment system.

separating the system into two components that could be stacked one on top of the other during transportation was the most feasible design configuration. This design criteria required that a system for connecting and disconnecting the two individual sections relatively quickly and easily be developed, and this will be discussed in a later section.

VARIABLE PARAMETERS:

Due to the fact that the SCOBE project was designed for and will be used as a research tool for future work and further development, it was desired that several of the design parameters for the 3-dimensional prototype should be adjustable in order to determine the optimum design configuration under various operating conditions. One of the major components of the SCOBE design that needed to be adjustable was the angle of the submergence plane. In order for the submergence plane angle to be continuously adjustable while also allowing for control of the gap distance from the end of the submergence plane to the beginning of the baffle, three degrees of freedom were required. These were the vertical position, horizontal position and angle with respect to the horizontal. The adjustable submergence plane and its various components will be covered in greater detail in a later section on the prototype construction.

Two other components of the SCOBE design which were desired to be adjustable were the baffle configuration and the draft. As can be seen in later figures of the final design configuration, the baffle is lined with rows of 2 1/8 in. holes cut through the PVC to allow for the outflow of water traveling through the containment region. The baffles on each section of the oil boom are removable and can be replaced with different hole configurations in order to determine the optimal design pattern. Although a plan was developed for the adjustability of the draft to allow for varying water line depths, this plan was not implemented in the final design due to the lack of available time for adapting and perfecting the system for use. The plan called for buoyancy to be placed along the outside of the oil boom and attached to a tracking system which could be raised and lowered to adjust the water-line depth accordingly. This concept may still be implemented for future use if the adjustability of this parameter is considered essential.

IV. PHYSICAL MODEL

MODEL DESIGN AND CONSTRUCTION:

The solutions to many engineering problems are achieved through the use of a combination of theoretical analysis and experimental data. In order to fully understand the dynamic fluid processes involved in high current velocity situations and their effects on the SCOBE design, it was decided that a scale model would be constructed for use in laboratory testing. With the successful development of a valid model, it is possible to predict the behavior of the prototype under various sets of conditions. For the SCOBE model it was desired to have a high degree of similitude between the model and the prototype and for this reason all of the materials used to construct the model were exactly the same as the materials that were used for the construction of the final prototype.

There are often many variables that need to be considered when dealing with fluid dynamic processes. For the purposes of dimensional analysis and model scaling, many of these variables have been collected into groups of nondimensional parameters. These dimensionless parameters are the foundation for model testing and for applying the results of these model tests accurately to the later design and development of the prototype. One difficulty that frequently arises when dealing with these parameters is the development of a model in which the experimental data is distorted because the similarity requirements made through equating nondimensional terms are not satisfied. This may occur in the study of open channel or free surface flows where the Reynolds number, Froude number, and Weber number all contribute to the final analysis. The Reynolds number $\left(\frac{\rho V \ell}{\mu}\right)$ relates inertial forces and viscous forces on a fluid element. The Froude number $\left(\frac{V}{\sqrt{g\ell}}\right)$ contains the acceleration due to gravity and is therefore an important parameter when the fluid weight and surface wave motion are under consideration. The Weber number $\left(\frac{\rho V^2 \ell}{\sigma}\right)$ takes into account surface tension and is an important consideration when there is an interface between two fluids. Fortunately, in many problems involving free-surface flows, including the analysis for the SCOBE project, both surface tension and viscous effects are considered small and inconsequential when compared to the effects of gravitational forces. For this reason, all model scaling performed for the SCOBE project was made utilizing the Froude number where dynamic similarity between the model and the prototype was achieved by equating their respective Froude numbers:

$$\frac{V_m}{\sqrt{g_m \ell_m}} = \frac{V_p}{\sqrt{g_p \ell_p}} \qquad \textbf{(4-1)}$$

where $g_p = g_m$ and therefore $\frac{V_m}{V_p} = \sqrt{\frac{\ell_m}{\ell_p}}$ **(4-2)**

It was decided that the SCOBE model would be a 1/3 scale model representation of the prototype. As stated before, the materials selected for the prototype were used for the construction of the model, which at this scale had dimensions of 6 ft. long by 4 ft. wide. The wood framing used for the external frame of the design had dimensions of 1.167 in. by 0.5 in. while the PVC sheeting used was .0625 in. thick. This PVC thickness for the model was slightly smaller than exactly 1/3 the thickness of the .25 in. PVC that was used for the prototype due to the fact that only standard size PVC sheeting could be purchased. In order to ensure that the wood framing was waterproof, a polyester resin was used in which the resin mixture was combined with a hardening agent and then applied by paint rollers onto every surface of the wood framing pieces. A yellow coloring agent was also added to the resin mixture to give the oil boom an easily identifiable color. Once dried, the resin provided a solid waterproof barrier around the wood pieces.

It was decided at the beginning of the model construction phase that the model would be used primarily to determine the effects of static and hydrodynamic loading as well as the buoyancy and overall effectiveness of the general prototype design. For this reason, the variable parameters discussed in the previous section were not incorporated into the model design. The submergence plane was securely attached using two lengths of metal tubing to the side panels of the containment system at an angle of 10 degrees and this fixed angle was used for all of the model testing. However, to maintain structural similarity with the prototype, the model was constructed in two separate sections which were then connected together using 4 bolts evenly spaced down the length of the oil boom. Pictures of the completed model design are shown here in Figures 4-1, 4-2, & 4-3.

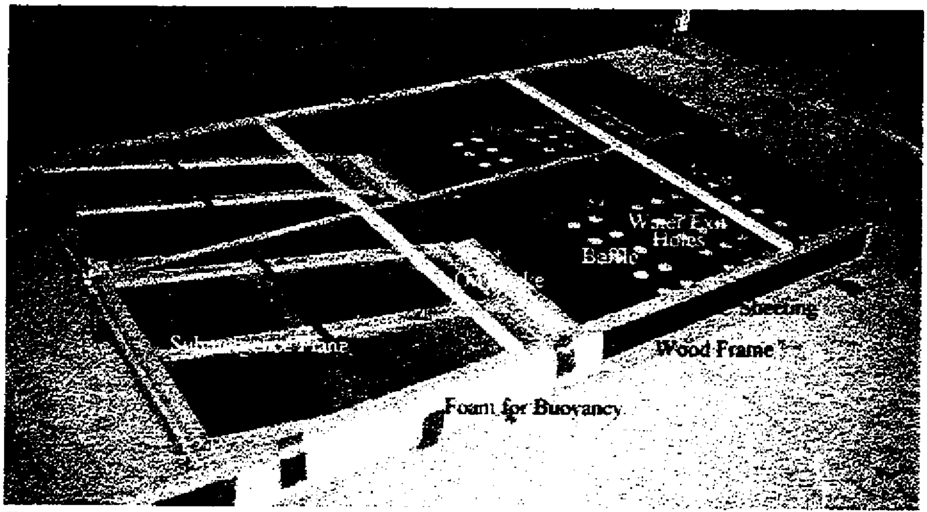

Figure 4-1. Photo of Oil Boom Model. Major components are labeled. Photo taken after model testing.

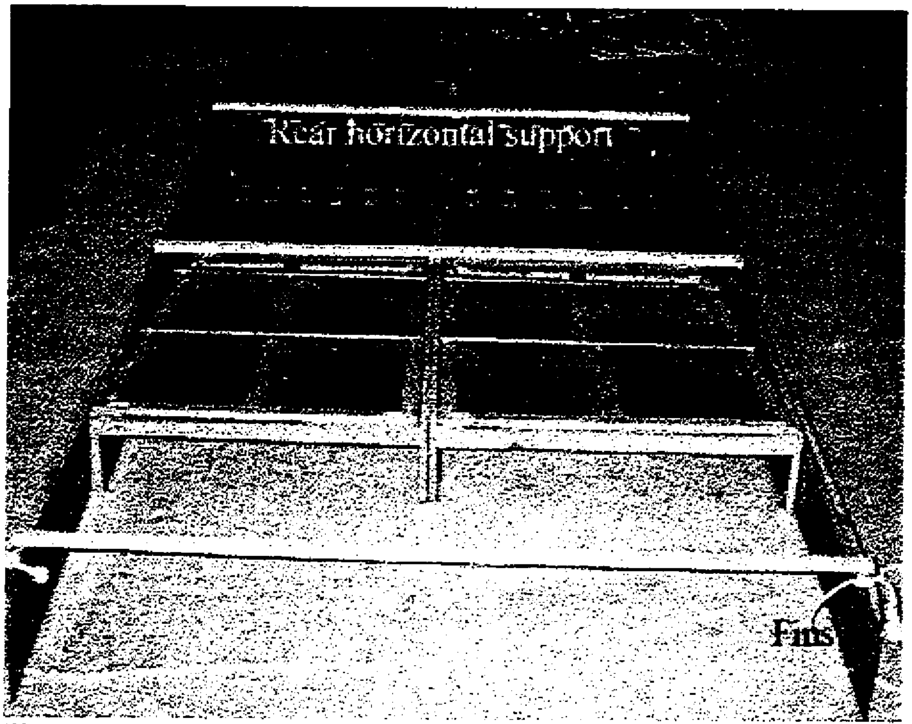

Figure 4-2. Photo of front of Oil Boom Model. Front fins (labeled) help to trap the simulated oil beads. Rear horizontal support members proved to help with the structural integrity. Photo taken during the model testing.

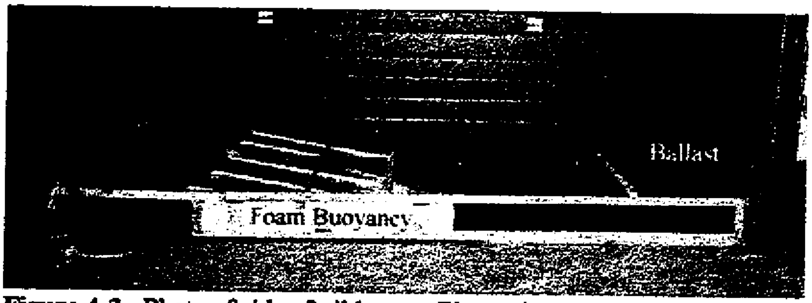

Figure 4-3. Photo of side of oil boom. Photo shows positioning of Foam and Ballast added during the model testing phase. Photo taken after model testing.

As can be seen in these figures there are 7 rows of 6 holes on the baffle of each section of the SCOBE design. These holes are necessary for the exit flow of the water that has entered the containment region through the gap between the submergence plane and the baffle. The area of the entrance gap was calculated to be 141.375 in^2 while the total exit area of the holes was determined to be 148.4 in^2. It was desired that the exit area be at least the same as if not greater than the entrance area in order to ensure that the velocity of the water exiting the containment region was equal to or slightly less than the velocity of water entering the containment region. Also shown in these figures are the "fins" that were attached to the front end of the model design. These fins were attached for testing reasons and will be described in the next section.

MODEL TESTING AND RESULTS:

After the construction of the model was completed, various sets of tests were conducted to see how the model responded to various situations. First, static testing was conducted to determine the structural integrity of the model. The model was supported at each end to determine linear rigidity and then supported at alternate corners to determine torsional rigidity. As expected, the model was extremely strong in the linear direction due to the framing configuration but was much more prone to twisting due to the torsional load. In an attempt to alleviate the twisting moment, a linear cross member was attached horizontally across the width of both sections of the oil boom as can be seen in Figure 4-2.

Although this cross member was an improvement, it still did not supply the desired structural support. It was determined that support members attached at the two end corners and then criss-crossed over the middle of the two sections in an "X" pattern would supply enough rigid support to alleviate the problem.

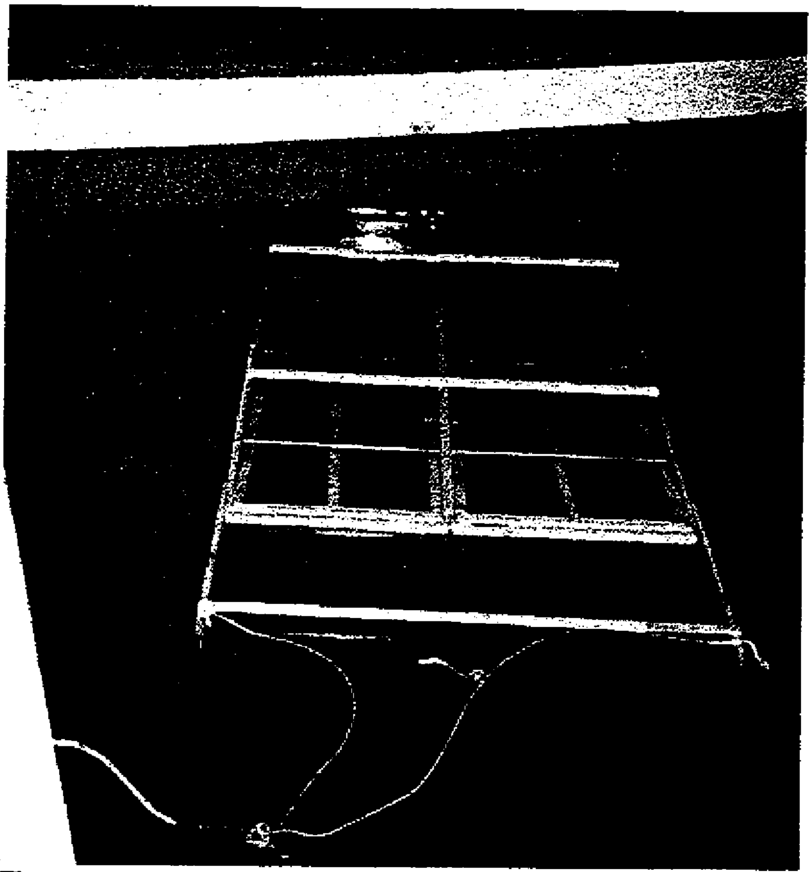

Figure 4-4. Photo of physical model floating in OE building pool. Model proved to do extremely well during the brief testing phase. Photo taken during model testing.

The next test was a buoyancy test to determine how the model floated and how much buoyancy and/or ballast would need to be applied in order for the model to float evenly at the desired level, which called for a 2 in. water line (see Fig. 4-4). The buoyancy of the model alone without adding any additional buoyancy or ballast was surprisingly close to the desired level. However, due to the design configuration, the front end of the model with the submergence plane was slightly heavier and therefore slightly less buoyant than the back end of the model. To overcome this, ballast in the form of a metal plate was added to the back of the model while foam insulation was added to the side panels in the front of the model to increase the buoyancy of the front end. This addition of buoyancy and ballast proved to be effective for maintaining the correct water-line level.

The last tests conducted on the model were bead recovery tests in which small plastic beads were used as oil substitutes since it was desired that actual oil not be used in the laboratory testing equipment. These tests would be used to evaluate the effectiveness of the SCOBE design. It was hoped that these tests could be conducted in the recirculating flume that was being constructed at the Ocean Engineering facility, although the construction was not completed in time to do so. As an alternative, the model was placed in the 40x60x20 ft. engineering tank. Instead of creating a water current that would pass by the stationary oil boom, a method needed to be developed for towing the oil boom through the stationary water. This proved to be a non-trivial problem as the only available means for towing the oil boom was a single speed motor that operated at a much lower velocity than was required to simulate high-velocity current conditions. The desired operating velocity for the prototype was determined to be 3 knots, and applying Froude scaling to this yields a model velocity requirement of 1.73 knots. A two block pulley configuration was assembled and attached to the crane motor in an attempt to increase the towing velocity. With the two block system the velocity of the model was increased to .577 knots (.974 ft/sec) yielding a scale velocity of 1 knot for the prototype. This velocity is the critical value for conventional oil booms and was considered too low for use as a testing velocity. Two additional blocks were then added to the pulley configuration which in turn raised the model velocity to .862 knots (1.455 ft/sec) and the corresponding scaled prototype velocity to 1.5 knots. Due to the lack of a better testing method, the bead tests were conducted at this velocity. Although this value was considered as the low end of an acceptable testing velocity, the bead tests were conducted at this velocity due to time considerations and the need to complete the model testing and begin the development and construction of the prototype.

The beads used for the tests were 1/2 in. diameter white beads with a specific gravity of .862 tested in water with a density of 62.4 lb/ft^3, which yielded the bead density as 53.8 lb/ft^3. For the tests, the beads were dropped in a line down one side of the large water tank and the SCOBE system collected the beads as it was towed past them. Although the buoyancy of the model was relatively stable in still water conditions, an interesting problem occurred during the bead testing. As the model was towed across the tank, the attitude of SCOBE was affected as the front of the model rose up and the back was forced down. This attitude problem was an issue that needed to be addressed in the design of the prototype. Despite these buoyancy difficulties, the model performed exceptionally well in these preliminary tests, collecting and retaining 100% of the beads that were in its path. As the water and beads entered the containment region, the beads quickly rose to the surface and were caught in back eddies keeping them near the front of the containment region as the water flowed out through the exit holes in the baffle, again showing encouraging results of the oil boom design. As stated before, time considerations and the extremely promising results of the preliminary model testing prompted the SCOBE group to move forward to the prototype phase of development and construction.

V. PROTOTYPE DESIGN AND CONSTRUCTION

EXTERNAL FRAMING:

During the testing of the model it was found that the wood framing and PVC sheeting complemented each other well in order to give the oil boom its high structural integrity. The first point that must be noted is that the framing was purposely positioned on the outside surface of the model. This was done in order for the submergence plane to lie flush with the inner side wall (see figure 5-1).

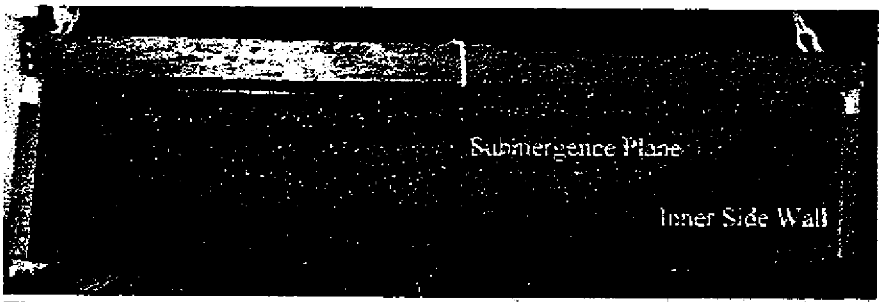

Figure 5-1. Photo of Front of Oil Boom. The submergence plane is clearly flush with the inner side walls of the oil boom. Photo taken as boom is hoisted out of OE Building Pool after first float test.

For the prototype, the frame itself is made of 2"x4" kiln dried spruce. As seen in figure 5-2, the frame was assembled using common wood working methods - angled cuts, nails, steel angles and tee's, and exterior screws. The ¼" PVC sheets were pre - drilled before they were nailed to the wood frame. Appendix B contains additional figures of the frame and PVC structure.

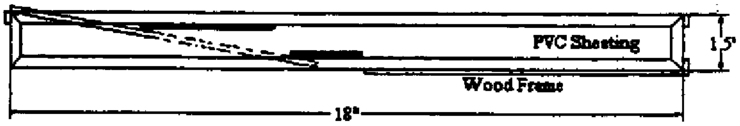

Figure 5-2. Schematic Diagram of side of oil boom. The wood frame was attached using common methods - angled cuts, nails, steel angles, and exterior screws.

As seen in the photograph of the prototype in figure 5-3, the basic structure of the framing is relatively simple. The wood used in the prototype is exactly 3/1 scale to the model. It was noted during testing of the model that there is a twist in the model along the diagonal. This did not disturb the operation of SCOBE. However, it was feared that this problem would be magnified in the prototype scale. Various bracing methods were discussed and tested. The decision was made to add diagonal wood cross pieces along the top of the prototype. These will not be able to go along the full length of the prototype as they would interfere with the submergence plane operation.

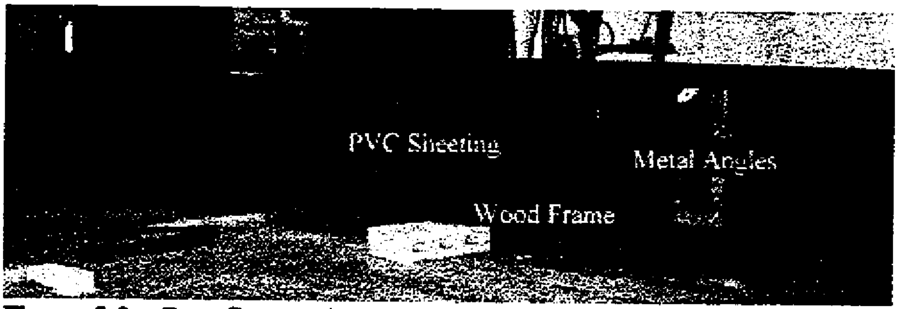

Figure 5-3. Rear-Corner view of the oil boom prototype. Key features of construction are labeled. Photo taken during construction.

It is well known that wood is not a very water resistant material. In the construction of the model a polyester resin was used to seal the wood from the environment. This process proved to be very time consuming. For the prototype oil based exterior paint replaced the polyester resin. While the oil based paint is a less effective sealant, it was determined to be more efficient than the complicated and messy polyester resin application process. In addition it was found that the dried resin was extremely brittle and was easily chipped and scratched. In the interest of expediting the project only one coat of paint was applied. It is recommended that later coats be applied as the oil boom is utilized. This will give the oil boom a longer life expectancy. Proper treatment of the oil boom will ensure years of usage.

BAFFLE DESIGN:

The baffle, or bottom plane, is the plane that lies to the rear of the boom, below the water line. Figure 5-4 shows the top view of the baffle. The numerous exit flow holes are very apparent. As previously stated the exit flow holes allow for the water that flows through the inlet area to exit the baffle area. The maximum inlet dimensions with the submergence plane in the 10 degree position is approximately 9 in. x 67.5 in. or 607.5 in^2. Using a 2 1/8 in. diameter hole cutting bit, 191 holes were cut in each section of the oil boom (see Figure 5-5). This produces an exit area of approximately 677.3 in^2. The current ratio of inlet area to exit area is 1:1.1. It has been proven that a larger exit area provides for a smoother transition of flow from inlet to exit (Swift et al., 1995). If the inlet area is adjusted above 677.3 in^2, adjustment of the baffle will be necessary. The baffle configuration was designed so that the existing baffle could be easily removed and replaced by alternative baffles with different hole patterns. Future researchers have the option of adjusting these areas.

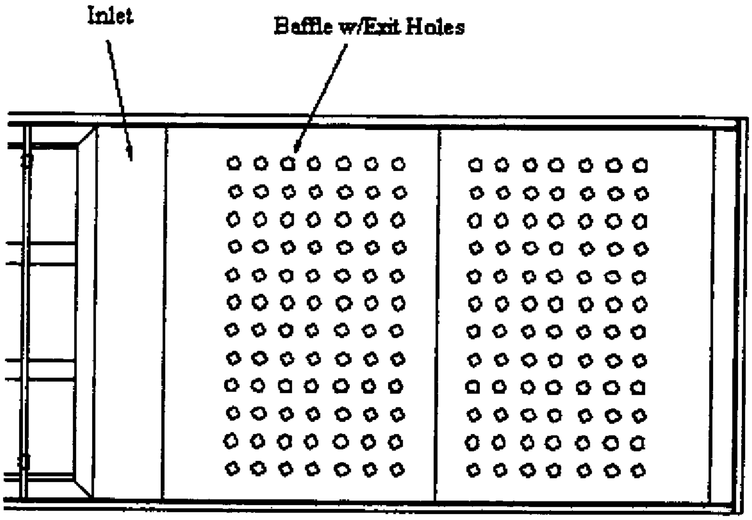

Figure 5-4. Schematic drawing of rear of oil boom. Baffle with Exit Holes and Inlet are labeled.

SUBMERGENCE PLANE DEVELOPMENT:

Finding the angle that the submergence plane makes with the water line that allows for optimum operation of the oil boom is a critical parameter that will be studied by future researchers. Designing the adjustability of the submergence plane angle while maintaining the structural integrity of the oil boom was a key issue. Construction and design of this system proved to be one of the most difficult tasks faced by SCOBE.

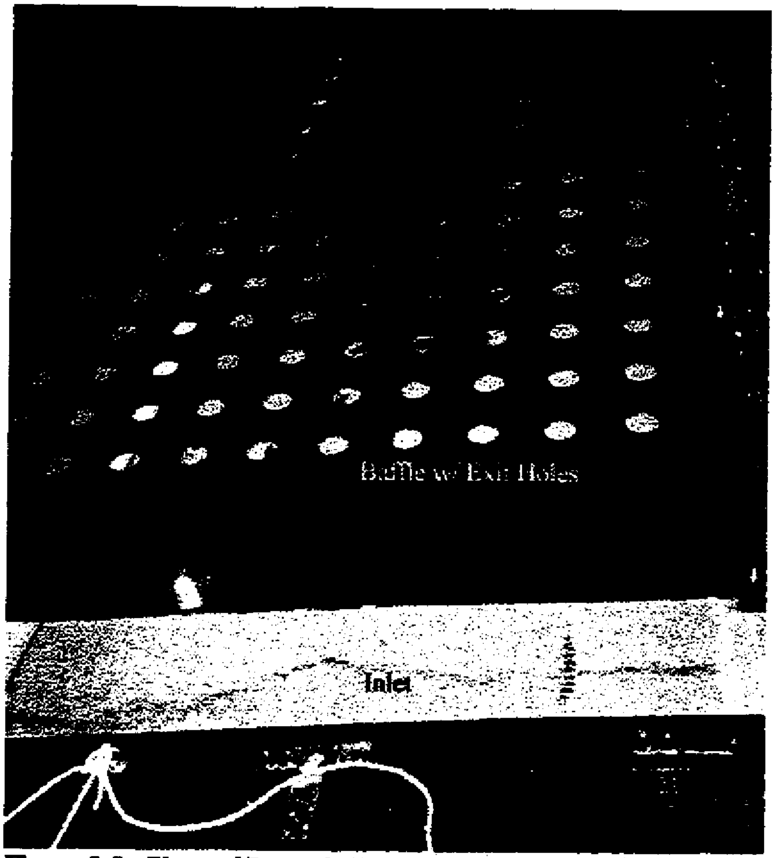

Figure 5-5. Photo of Rear of oil boom. Baffle and Inlet are labeled. 191 holes were cut in each section of oil boom to allow for exit of water. Photo taken during construction.

The submergence plane system has 3 degrees of freedom; angular, horizontal and vertical. The first degree of freedom is the adjustability of the submergence plane angle. Horizontal slots were cut in the PVC sheeting on the sides and are fitted with hollow steel rods that can slide easily in both directions. The submergence plane is suspended on a rolling track system. The rods can be adjusted in the slots to produce submergence plane angles ranging from 10 to 30 degrees. A graphical representation of this can be seen in figure 5-6.

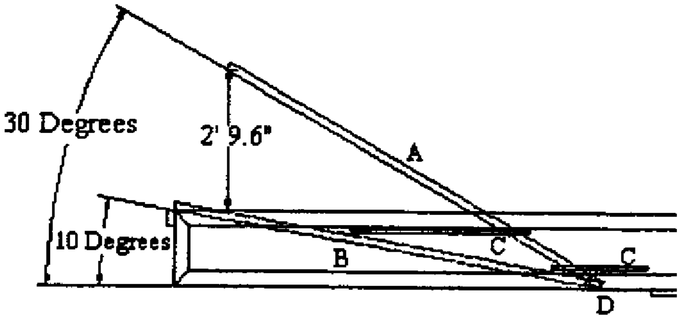

Figure 5-6 Side view of front of SCOBE system. Picture shows range of angles over which the submergence plane must operate. Submergence plane must rotate from position B (10deg.) to position A (30deg.) while keeping rotation point D fixed. This is done by cutting slits, C, in the side PVC in order for the track to slide into these positions.

The second degree of freedom is in the horizontal direction. The horizontal slots allow for the submergence plane to be moved in either direction without disturbing the plane angle. By altering the horizontal position the inlet area is varied. When the submergence plane is positioned for 10 degrees the maximum distance from the plane to the baffle is 9 in. This is exactly 3 times the 10 deg. distance of the model. If additional inlet area is required the slots can be elongated. Adjustments in the slot lengths are not recommended because of their permanent nature and possible structural integrity changes that may occur. The horizontal slots are depicted in figure 5-6.

The third degree of freedom is in the vertical direction. The submergence plane is suspended from a roller/track assembly. The plane can be moved along the line of the angle that is chosen. Moving the submergence plane down changes the position of the bottom edge relative to the front edge of the baffle. It should be noted that an adjustment in the vertical positioning of the plane will cause a change in the inlet distance as well. Therefore, in order to maintain a constant inlet distance a horizontal adjustment is also required.

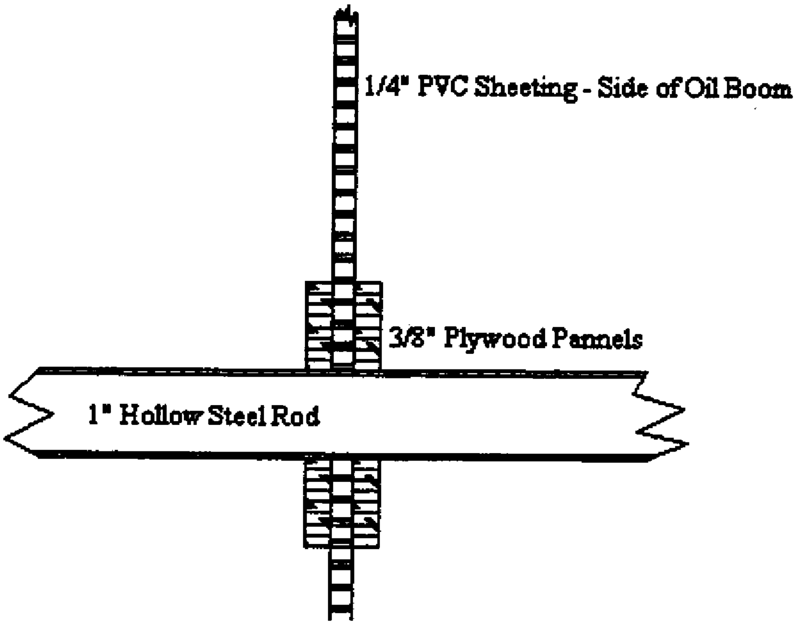

Figure 5-7a. Cut view of Rod mounts along the center axis of rod. Plywood plates are bolted together and tightened until the rod can no longer slide through slits.

It would now be prudent to describe the tracking and hardware system. The rods are 1 inch diameter hollow rods made of 16 gauge steel that slide along slots cut in the side panels of SCOBE. The horizontal locking system consists of two 3/8 in.

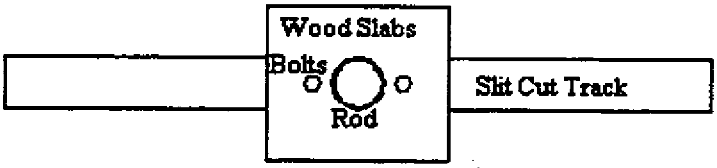

Figure 5-7b. Side view of mounts used to keep steel rods in place.

plywood plates placed on either side of the PVC wall and bolted through the slot with a ¼ in. bolt assembly. Figures 5-7a and 5-7b show side and front views of the horizontal locking system. When the bolts are tightened sufficiently the submergence plane rods are rendered immobile. There are locking plates at each of the 4 PVC intersections on each oil boom section. This system should withstand the force produced by the current that will be directed against the submergence plane. A photo of this assembly is seen in figure 5-8.

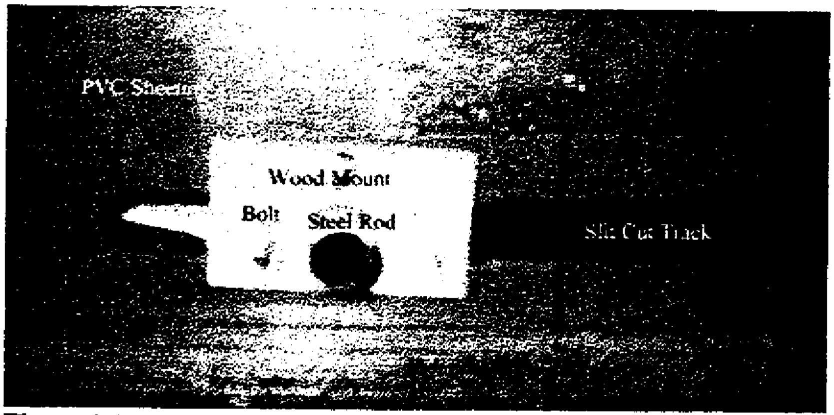

Figure 5-8. Photo of Mounting Plate and Rod on the side of oil boom. The wood slabs were cut to a shape that ensures full motion of the submergence plane. Photo taken during construction. Plywood plates are not painted in photo in order clearly distinguish them.

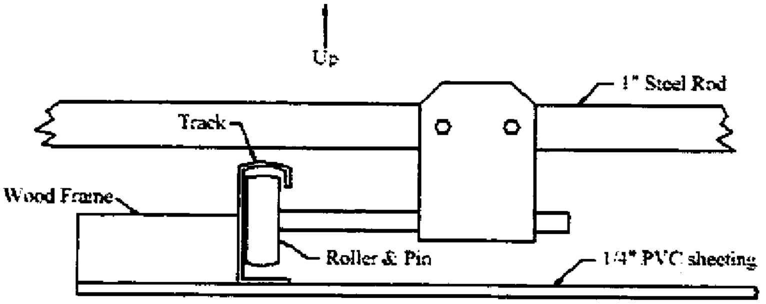

Figure 5-9. Track & Roller Assembly. Garage door track and roller hardware was modified in order for the submergence plane to 'hang' from the hanging rod - attached to the side walls. During operation most of the force will actually be in the upward direction - due to the current pushing on submergence plane.

The hardware that was used to secure the submergence plane to the rod is common garage door track and hardware (see Figure 5-9). The type of roller used is actually a special type used in 'Car Wash' applications and as such is typically used in a wet environment. The hardware was modified to fit the needs of the SCOBE design. This type of hardware was chosen as it is extremely strong and fairly weather proof. The only foreseen difficulty with the hardware is the corrosion of bearings within the roller due to salt water. However, this is not a major concern due the relative low-cost of the item (~$3.50/each) as well as the ease of replacement. The results of the theoretical design are seen in Figure 5-10. Four such assemblies are used on each submergence plane. During construction it was noted that this design works extremely well.

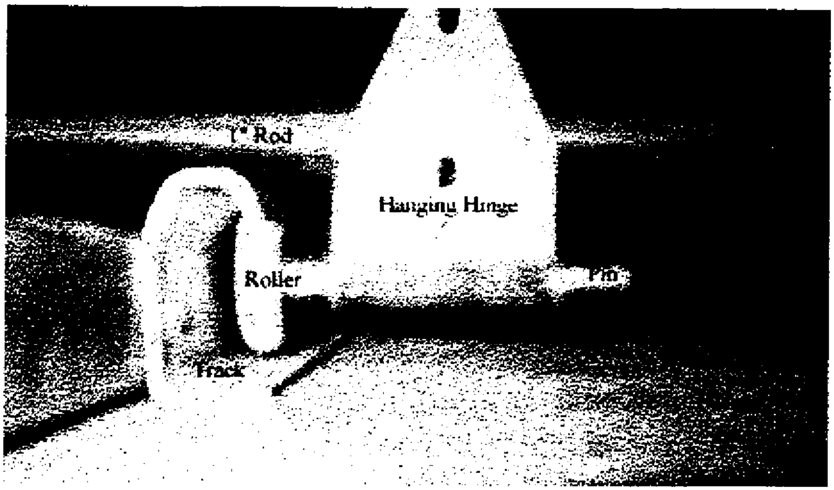

Figure 5-10. Photo of Submergence Plane Track and Assembly. Parts are as labeled. Pin gives ample free play to allow for any movement in the horizontal direction. However, not too much that it could slide out.

The submergence plane was assembled in a similar fashion as the rest of the frame and PVC sheeting (see Figure 5-11). The track was attached to the inner side of the wood frame. The hinge gives the steel rod ample room, approximately .75 in., to clear above the track. The rods are attached to the oil boom walls as discussed previously. Now that the submergence plane is free to slide along this track, it was necessary to find a method of fastening it into place. The quickest and cheapest method that was arrived at was to attach the rods with a rope to the front and rear of the submergence plane. Each rod attached in this fashion would allow for complete fastening of the submergence plane along the track axis. As discussed, the rods themselves are free to move through the slots in the side wall of the oil boom. These are held in place using the method already discussed. A secondary design for the submergence plane braking system was investigated. Unfortunately this system was not finalized in time for implementation. This secondary system consisted of clamps connected to the submergence plane rods positioned along the center frames of the plane. These center frames are apparent in figure 5-11. The clamps would be loosened to allow movement of the submergence plane and tightened again when the proper angle is chosen.

The result of the theoretical drawing shown in figure 5-11 is seen in the photograph of the actual prototype in figure 5-12. This is a photo of the working submergence plane. It has been noted that at least two people are needed in order to position the submergence plane. This should also be done prior to attaching the two sections of the oil boom.

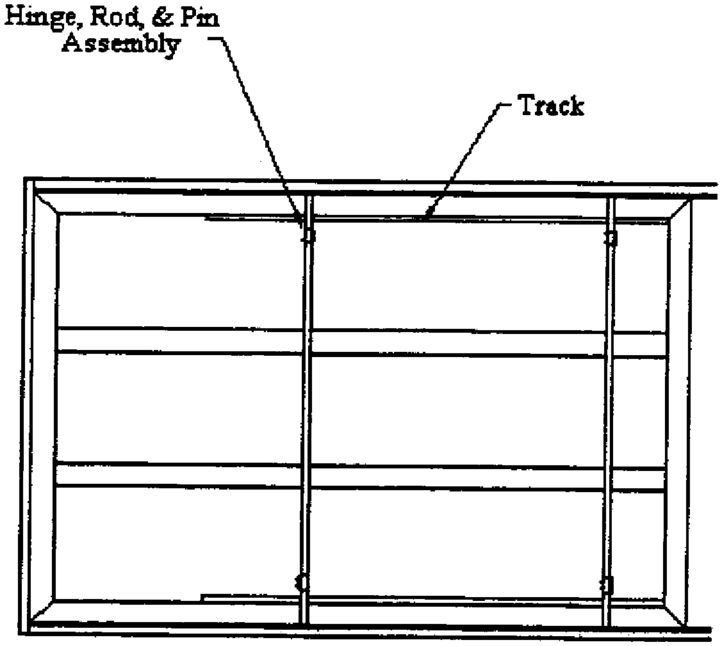

Figure 5-11. Front-top schematic drawing of oil boom. Track and Hardware are clearly labeled. Track is attached by use of 3" exterior screws to the inner side of the 2"x4" wood frame. The hinge hangs from the rod, which is attached to side walls of oil boom.

Upon concluding the discussion of the submergence plane it should be noted that the each plane is greater than 200 lbs. Therefore, when operating SCOBE at or close to the extreme angle of 30 degrees caution must be taken that the elevated weight does not create a torque arm with greater force than the hardware can support. Therefore, it is recommended that additional support be used in this situation. Another, unforeseen problem at these higher range of angles is that the additional mass outside the water will yield less buoyancy than had been planed for the front end of the SCOBE design. This can be overcome by the addition of more buoyancy which can easily be

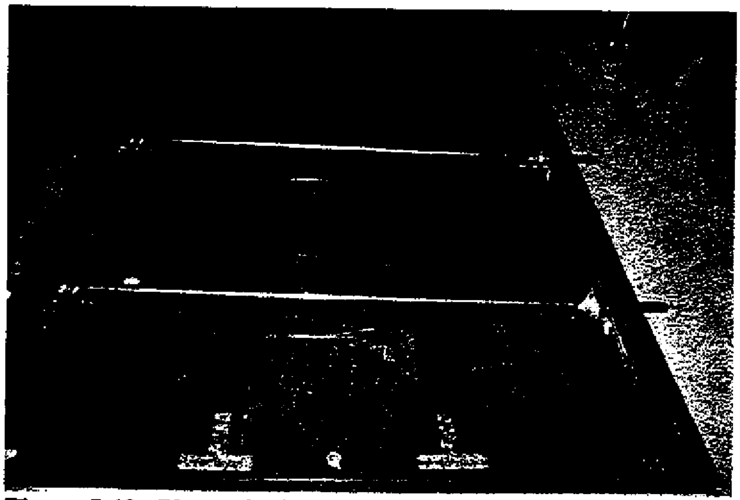

Figure 5-12. Photo of submergence plane and track assembly. Photo taken during construction.

added to the side of the oil boom. Based on previous research by Swift et al. (1995), it is unlikely that these larger angles will be found to be the optimum angle for operation. Therefore, this may turn out to be an unwarranted concern.

VI. DISCUSSION OF BUDGET

The SCOBE group was allowed a $2,500 budget with which to work. The major portion of the allowable funds was allocated to the parts and materials for the construction of both the physical model and the prototype. This included such things as the framing materials, the sheet material, and the miscellaneous hardware that would be needed to complete the construction. Approximately $1,800 was allocated for the parts and materials. Field testing of the finished prototype required the use of one of the research vessels located in the Great Bay/Little Bay river system and approximately $600 was reserved for boat rentals. The remaining $100 of the budget was set aside for clerical purposes.

The total amount spent including parts materials and clerical work was $1620.18. This was within the $1,800 allotment. With boat rentals approximated at $600 the final total will fall well within the $2,500 budget.

VII. CONCLUSION

At this point in time, the SCOBE project has not yet come to its full conclusion. All of the work done up to this point has been in anticipation of the testing of the prototype under field conditions to determine the effectiveness of the new rigid 3-dimensional oil containment system. Primary testing of the 1/3 scale model proved to be very encouraging and showed extremely promising results for the testing of the prototype. The selection of spruce 2x4's for the framing material and PVC for the sheet material has also proven to be very effective with respect to the SCOBE design specifications. Throughout the development process several modifications from the original design concept were identified and incorporated into the final prototype design in order to yield the optimal design configuration.

Construction of the full-size prototype has just been completed. The testing phase for the prototype is now the top priority for the SCOBE project. One section of the prototype has already been tested for buoyancy in the large water tank and the buoyancy question for achieving the correct water line, while also controlling the attitude change, is now being addressed. Reservations have already been made for the use of a research vessel to tow the SCOBE containment system in the field environment of the Great Bay/Little Bay river system with popcorn being utilized as the oil substitute. Tests will be conducted to determine the collection and retention percentages for the SCOBE design at current velocities equal to the design velocity of 3 knots. Tests will also be conducted to investigate the containment system's reaction to hydrodynamic forces due to towing as well as wave fields. The results of these tests will determine the overall effectiveness of the SCOBE design and will determine if the system performs to standard at the required velocities of 3 times the critical value of conventional oil booms. If so, the SCOBE design will finally provide a reliable and easily deployable containment system for high current velocity locations and help save enormous amounts of time, money and natural wildlife in the event of an accidental oil spill.

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Swift, M.R., Coyne, P., Celikkol, and Coane, C. (1996). Oil Containment Performance of Submergence Plane Barriers. (in press).

Tsocalis. E.A., Kowenhoven, T.W. and perakis, A.N. (1994). A Survey of Classical and New Response Methods for Marine Oil Spill Cleanup, *Marine Technology*. **31**, (2),79-93.

APPENDIX A.

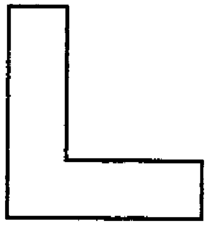
Material Properties

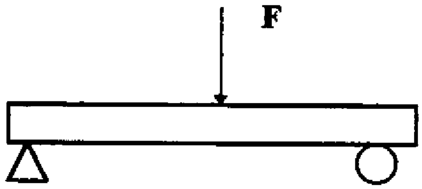
Material	Tensile strength(ksi)	Yield Strength	Youngs Modulus(psi)	Density(g/cm^3)
Wood	4 - 5	40 - 60 Mpa	1.2 - 1.5 E 6	.4
Aluminum	29	5 - 70 ksi	10.0 E 6	2.7
Polypro.	4 - 6	5.2 - 5.2 ksi	.16 - .22 E 6	.9
PVC	5 - 9	6.5 - 7.0 ksi	.3 - .6 E 6	1.4
Fiberglass	14.5 - 43.5	------------	------------	1.8
Polyethelene	3 - 5.5	2.9 - 4.4 ksi	.06 - .18 E6	.96
Steel	58	250 Mpa	28 E 6	7.8

Sample Calculations:

Maximum load for a fixed beam with a point load applied at the midpoint.

Steel Angle Iron(3x3x1/4"):





The Section modulus for 1/4" ASTM A-36 Steel angle iron : .557 in^3 : 9.449E-6 m^3
Yield strength : 250 Mpa
X, the distance from the force to the end of the beam: 2 m

$$\sigma_y = \frac{M}{S}$$

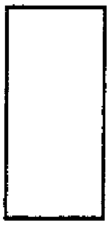
$$M = S\sigma_y = 9.449E\text{-}6 * 250E6 = 2362.1 \text{ Nm}$$

The maximum moment is given by the distance from the force to the end of the beam.

$$M = F * X \qquad F = \frac{M}{X}$$

$$F = 1181.2 \text{ N} = 265.4 \text{ lbs}$$

Wood 2x4 framing material(pine on edge)



Section modulus:3.06 in^3 : 5.02 E-2
Yield Strength σ_y : 40 - 60 Mpa
X of moment arm: 2 m

$$\sigma_y = \frac{M}{S}$$

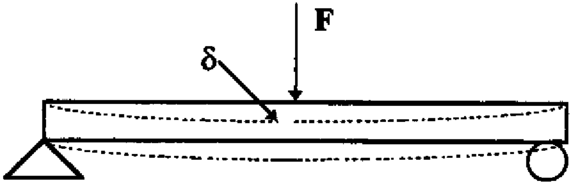
M = Sσ_y =5.02E-5*40E6 = 2007.037 Nm : σ_y= 40 Mpa
M = Sσ_y = 5.02E-5*60E6 = 3012 Nm : σ_y = 60 Mpa

$$F = \frac{M}{X}$$

σ_y = 40 Mpa F = 1003.52 N = 225.6 lbs
σ_y = 60 Mpa F = 1505 N = 338 lbs

<u>Maximum deflection of a fixed beam due to a fixed load</u>

Steel angle iron(3x3x1/4")



$$\delta = \frac{Fl^3}{48EI}$$

F the force applied : 100 lbs
l the length of the beam : 120 in
E youngs modulus: 28 E 6 psi
I moment of inertia(calculated) : .348 in^4

$$\delta = \frac{100 \cdot 120^3}{48 \cdot 28E6 \cdot .348} = .37in$$

Wood 2x4 (pine on edge):
Force and length are the same.
E youngs modulus: 1.16 psi
I moment of inertia(calculated) : 5.36

$$\delta = \frac{100 \cdot 120^3}{48 \cdot 1.1E6 \cdot 5.36} = .61in$$

Appendix B

Schematic Diagrams of Prototype - Major Views:

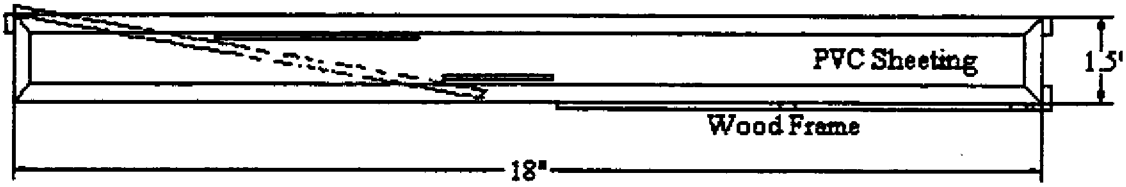


Figure B-1. Schematic side view of Prototype. Wood frame and PVC sheeting are labeled.

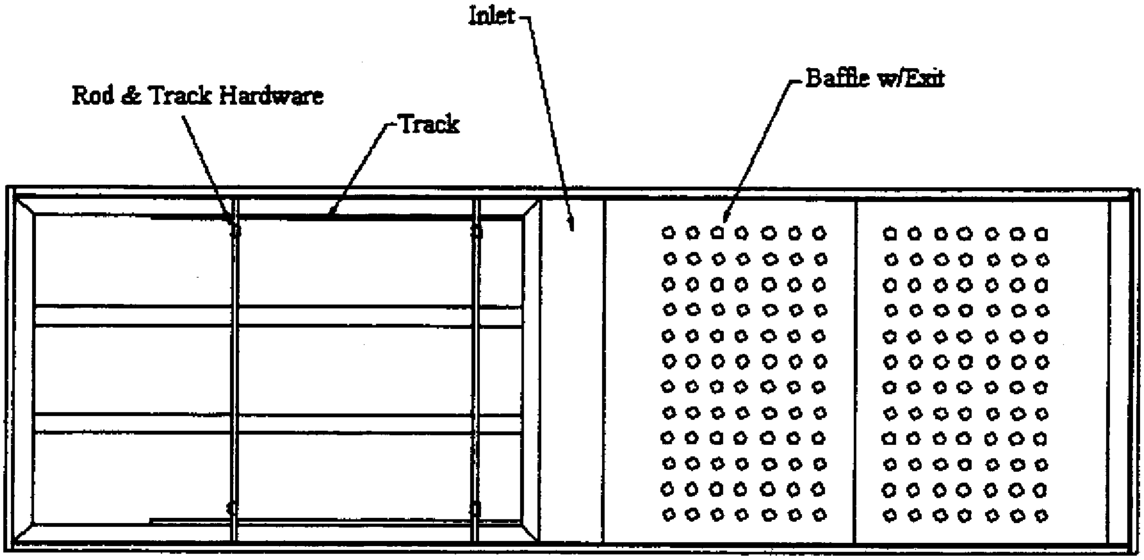


Figure B-2. Schematic top view of Prototype. Major components are labeled.

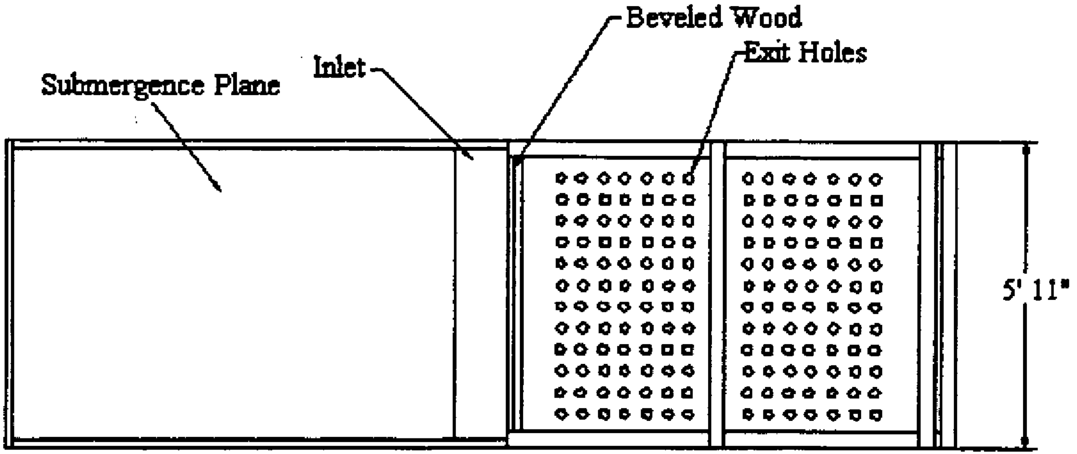


Figure B-3. Schematic bottom view of Prototype. Major components are labeled.