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DEDICATION

I would like to dedicate this work first to my parents Pam and Bill DiProfio. You have never ceased to be the foundation that I draw from in my times of need. Without your love and support many of my educational endeavors may never have come to pass. I love you and thank you with all my heart for being there when I needed you the most, and for being the wonderful parents you have always been.

I would also like to dedicate this work to a man who embodied all the qualities I most wished to have, my grandfather, Vincent DiProfio. I wish he were here today to share in one of my greatest accomplishments, I know he would be proud. I love him and miss him dearly.

One of the individuals who had a large impact on my educational career was my third and six grade teacher Mr. James McMahon. This work is also dedicated to him. Thank you for teaching me the importance of education and instilling in me, at the most impressionable of times, the desire to learn and always strive to be the best I can.

Finally, I would like to dedicate this work to my wonderful girlfriend, Heather Janulis. Without your unwavering patience and support throughout this project I fear I may never have finished. You are more special to me than you could ever realize. Thank you for all your help.

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ABSTRACT

A FLEXIBLE, COMMERCIAL BARRIER FOR OIL CONTAINMENT IN ESTUARIES

By

William M. DiProfio

University of New Hampshire, December, 1998

The purpose of this work was to design and build a deployable, commercially viable prototype to be used at the apex of a conventional oil boom system in order to contain oil in river or tidal areas. Modifications were made to an existing flexible prototype to address buoyancy issues at both the fore and aft ends of the device. One fifth scale model tests were conducted in the UNH tow basin to determine the reaction of the device to changing deployment conditions. The physical model tests were followed by actual deployment exercises using the full-scale prototype in the Piscataqua River. Between exercises further modifications were made to the prototype's flotation in order to improve tow characteristics. The culmination of the deployment exercises was the successful physical incorporation of the prototype into the apex of a conventional oil boom system. The modified prototype was brought to the Ohmsett testing facility in New Jersey where the oil retention capabilities were tested. Heavy oil retention percentages were excellent and previous problems with washout of the fore and aft barriers were eliminated. Using the lessons learned in both the deployment exercises and the Ohmsett tests, the commercial version was designed. Stronger more durable materials were chosen, and reinforcement of key structural components was added. The construction of this prototype yielded a fully deployable, commercially viable rapid current oil containment system.

CHAPTER 1

INTRODUCTION

1.1 Overall Purpose

In the oil and fuel shipping industry today many ships and shipping terminals are inadequately prepared to prevent environmental disasters when oil spill accidents occur. These ships and shipping terminals are equipped with the industry standard in oil retention equipment. This equipment includes many varieties of conventional oil boom and some mechanized skimming devices. The equipment is well suited to handle accidents that occur in waters with negligible current, but when there is an accident in waters with significant current or wave conditions, conventional oil boom begins to fail. To date, there is no system that adequately retains an oil spill regardless of the prevailing water conditions.

The most significant condition in sheltered waters that leads to conventional oil boom failure is current. When the current perpendicular to the deployed system falls between 0.6 and 1.0 knots the oil barrier begins to fail. Conventional oil boom will take on a catenary shape when deployed in rapid current. The apex of this system is the area most vulnerable to barrier breach as shown in *Figure 1*. The purpose of this work is to design and build a deployable, commercially viable prototype to be used at the apex of a conventional boom system to contain oil in river or tidal areas.

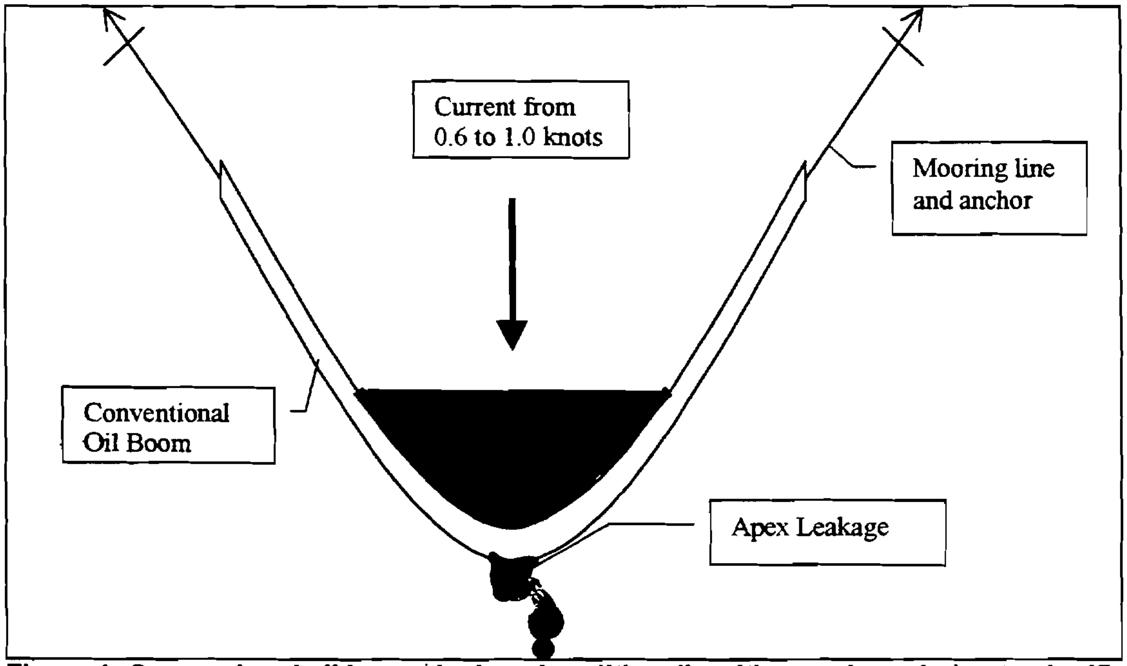

Figure 1: Conventional oil boom deployed traditionally with apex breech due to significant current.

1.2 Previous Work

Investigation of submergence plane technology, as shown in *Figure* 2, has shown that maximum oil containment speeds can be increased (Coyne,1995). The current will force the oil down the submergence plane to the gap. At the gap the oil will rise into the containment region where it will be contained while the water continues to flow out the exit holes. Research on two dimensional cross-sections revealed that the submergence plane concept was effective at collecting oil up to three times the critical values of conventional boom (Swift et al,1995,1996a, and Coyne, 1995).

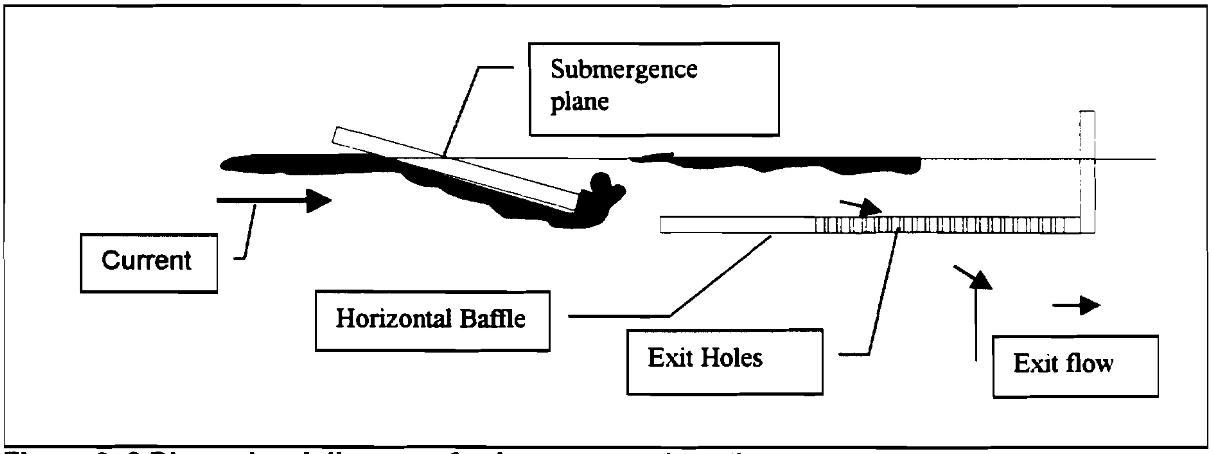

Figure 2: 2-Dimensional diagram of submergence plane theory.

The first three dimensional prototype of this configuration, constructed in 1996, was completely rigid. It had an adjustable submergence plane which allowed for varying of the gap opening as well as the submergence plane angle and vertical position relative to the horizontal baffle. Several tests were preformed with this system to determine the optimum configuration for the next prototype (Swift et al., 1996b; Steen, 1997).

A much larger prototype with a more practical design, dubbed Bay Defender, was built in 1997 (Steen, 1997; Swift et al., 1998). There were no adjustable parameters on this prototype (see *Figure 3).* It was brought to the Ohmsett testing facility in New Jersey where it under went numerous oil containment tests under various current and wave conditions. The results of those tests were very encouraging, with 98% retention of heavy oil (Sundex) at two knots (Steen, 1997; Swift et al., 1998).

Figure 3:1997 prototype in action at the Ohmsett testing facility.

The system did have some apparent limitations. Retention was not as good when using very light oil (Hydrocal). When the device was subjected to waves, there was significant washout over both the fore and aft ends. In addition when the device was towed at higher speeds, the aft end failed again due to washout. Recognition of the device's potential and it's limitations warranted continuation of the research and this thesis.

1.3 Specific Objectives

The first objective was to address the limitations of the 1997 prototype identified at the Ohmsett tests. Resolution of the "wave slop" and high speed washout issues were critical to the success of the new design.

The second was to establish a specific method with which to deploy the device in a tidal river area. Issues that needed to be addressed to achieve this objective were, assembly and deployment logistics as well as strength and buoyancy concerns.

The third objective was to re-test the modified prototype at the Ohmsett testing facility. The re-test was needed to determine if modifications made for the deployment exercises and those made based on the 97' limitations did in fact improve the oil retention capabilities of the device.

The fourth and final objective was to design and build a new commercially viable prototype. This prototype would be stronger and more durable and would also address concerns raised during the deployment study.

1.4 Approach

Existing prototype limitations were addressed first. Improvements to both the fore and aft flotation were made based on the results of the 1997 Ohmsett tests. One fifth scale model testing was conducted to determine the dynamic response of the device when subjected to certain system configurations. The information gathered during the physical model testing was critical in developing both the deployment plan and the commercial design.

The deployment phase was accomplished through a series of deployment exercises. After each full scale deployment exercise, reviews were conducted, and improvements were made for the next exercise. There were a total of four deployment exercises.

The oil retention capabilities of the modified device were tested at the Ohmsett testing facility in New Jersey. The device was deployed in the 666 ft. tow tank and subjected to various current speeds and wave conditions while collecting oil. The percent of oil recovered was calculated after each test run, and results were compiled.

The design and manufacture of the commercial version began after the deployment and validation objectives were met. This allowed for the most complete information to be used in the design. Several 1/5 scale model tests were conducted to determine the load on the device when in several different configurations. Each section of the device was redesigned, and some new materials for construction were chosen. Coordination with several commercial venders and many hours of construction resulted in a newly designed and built, commercially viable Bay Defender.

1.5 General Characteristics of Bay Defender

At this point it would be beneficial to have a general description of the key components that make up Bay Defender and their purpose. There are six primary components:

- End longitudinals
- Intermediate longitudinals
- Submergence plane
- Horizontal Baffle
- Front reserve flotation
- Rear boom

Which are shown on *Figure 4.*

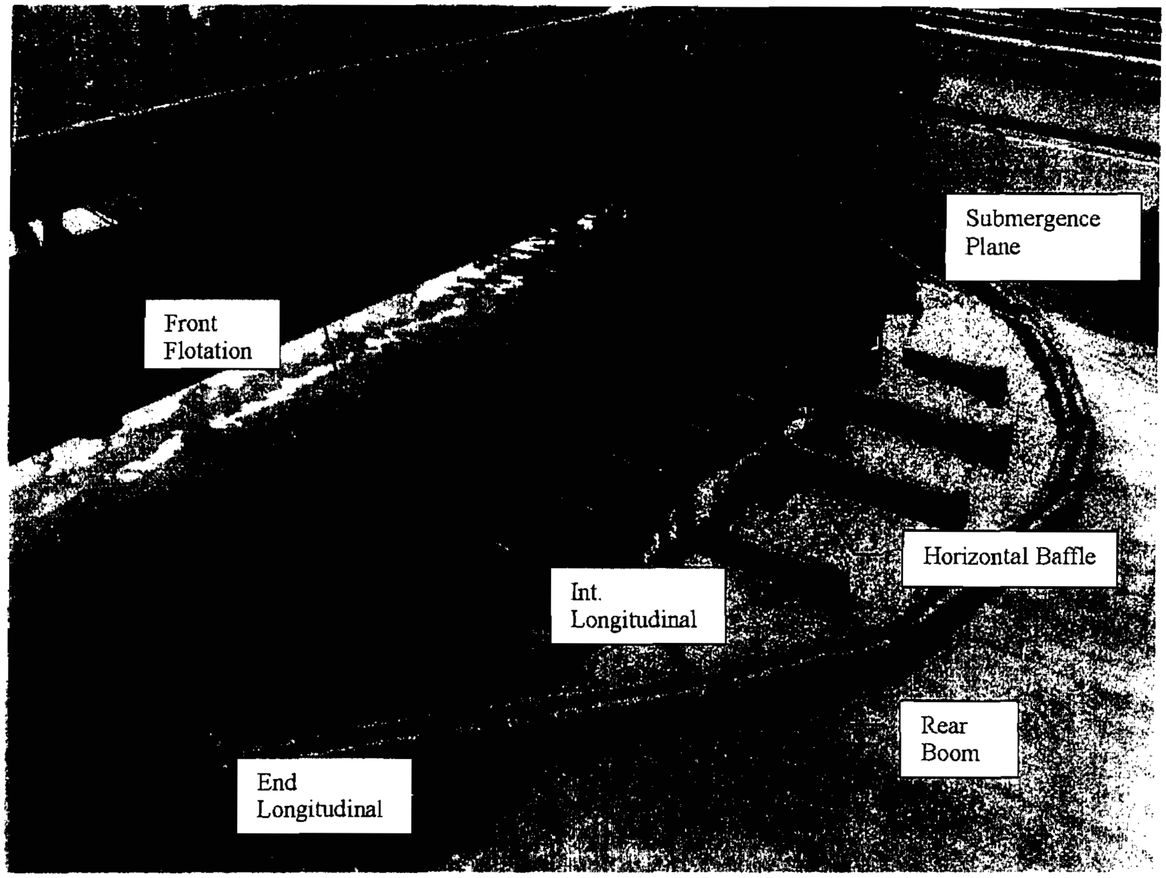

Figure 4: Labeled picture of the 1997 prototype.

1.5.1 End Longitudinal/Intermediate Longitudinal

The end longitudinals are two of the major components in the strength and shape retention of the device. Each end longitudinal has attachment points for the submergence plane, the horizontal baffle and the rear boom. The primary tow points for the device are located near the middle base of each end longitudinal. These points also serve as mooring points when the device is anchored in the deployed position.

The intermediate longitudinals serve one primary function - maintaining the shape of the submergence plane with respect to the horizontal baffle. They help to ensure that the proper submergence plane angle and gap opening are maintained at all times during deployment. The intermediate longitudinals do not function as strength members.

1.5.2 Submergence Plane and Horizontal Baffle

The submergence plane and horizontal baffle provide the functionality of the device. The submergence plane forces the oil to submerge to the gap. Here, the oil enters through the gap and rises into the containment region. The horizontal baffle contains another strength member. Along the leading edge there is a chain that is connected at each end to an end longitudinal. This chain acts as a tension member and bears a large portion of the load when the device is deployed. The horizontal baffle also provides the exit area for the water flowing through the device.

1.5.3 Front Flotation and Rear Boom

The front reserve flotation serves two purposes. The first is as reserve buoyancy in the event that the front end should try to submerge. The second is as a front containment barrier should oil being contained encounter it. The rear boom provides a rear containment barrier and is simply a 50 ft. section of conventional oil boom.

CHAPTER 2

PISCATAQUA RIVER DEPLOYMENT STUDY

2.1 Pre-deployment Design Issues

Prior to the first deployment exercise there were numerous issues that needed to be addressed. Several of these issues were brought to light during the testing of the 1997 prototype. Issues that were addressed were as follows:

- Mooring angle effects
- Significance of the tow point location
- Proposal for dynamic tensioning
- Front end reserve flotation upgrade
- Rear boom upgrade
- Squaring off of the end longitudinals

2.1.1 Mooring Angle Effects

When the device is anchored in the deployed position, the mooring line forms an angle with a line perpendicular to the end longitudinal(see *Figure 5*). This angle is referred to as the mooring angle and occurs on each side of the device. It was not known what effect, if any, an adjustment of the mooring angle would have on the desired shape of the device in the deployed position. If the mooring line continued the catenary shape formed by the leading edge of the horizontal baffle, the device would naturally assume the correct position. This ideal mooring angle was found to be 18.6 degrees, based on the catenary equations used to determine the shape of the leading edge of the horizontal baffle. If the mooring angles were to become to large the device would no longer be able to maintain the tensioning required to hold shape, and the front would begin to collapse in upon itself.

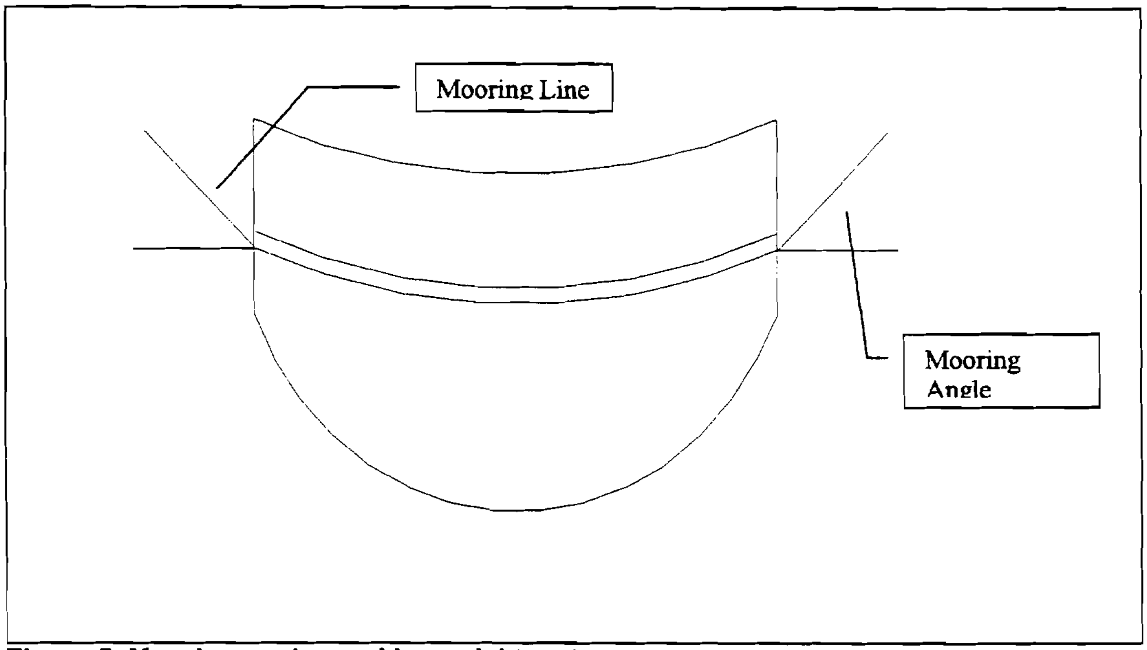

Figure 5: Mooring angle used in model tow tests.

Using a one fifth scale model of the device in the UNH tow tank, Froude scaled tests were conducted to determine the effects of mooring angle on system shape retention. The mooring angles were set to values ranging from 18 degrees to 57 degrees. The device was towed at a constant speed of two knots (full-scale) for each of the angle settings. The tests showed that as the mooring angle became larger, the device began to lose the smooth catenary shape. The leading edge of the submergence plane began to crumple, and the device no longer held the ideal shape. The device did not, however, deform to the extent that there was catastrophic failure. The device retained acceptable shape between the angles of 18 and 50 degrees. The tests showed that mooring angles, while they affected the shape of the device, did not lead to catastrophic failure and that a large region of acceptable angles existed.

2.1.2 Tow Point Location Tests

The significance of the location of the tow points was also questioned. Another series of controlled tests were performed to determine the effect the location of the tow point in conjunction with the changing mooring angle had on the shape retention of the device.

The tow point of the model was moved forward 2.75 inches which corresponded to a 13.75 inch adjustment on the full-scale prototype. The same testing procedure used in the mooring angle tests was used. The device was towed at two knots (full-scale) for mooring angles ranging from 18 to 57 degrees.

The results of these tests showed an improvement in shape retention as the mooring angles increased. The distortion of the catenary shape at the higher angles with the shifted tow points was noticeably less. By moving the tow point forward, approximately 10 degrees could be gained. Ten degrees was not a significant enough gain to warrant moving the tow point on the full-scale prototype, given the effort that would be involved in such an adjustment.

2.1.3 Suggestion for Dynamic Tensioning

Since the device was to be deployed in a dynamic environment, the question was raised as to whether the environmental conditions could be used to help maintain the proper shape and tension on the device. The idea proposed was to use a vertical wing extending from each end longitudinal, as shown in *Figure 6,* to catch the oncoming water and force the device to open into the proper shape.

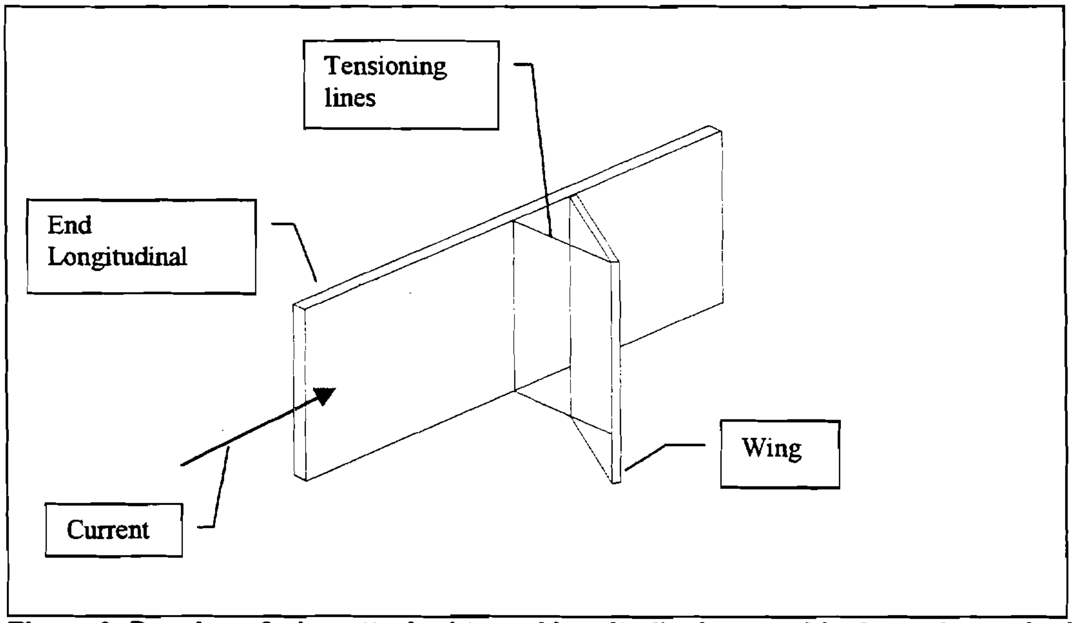

Figure 6: Drawing of wing attached to end longitudinal to provide dynamic tensioning.

The proposed wings were attached to the end longitudinals of the model, and several tests were conducted. The model was towed at speeds ranging from 1 to 2.5 knots (full-scale). In addition to tests with ideal mooring angles several tests were run with different mooring angles to see if the wings would improve the shape retention at higher angles. The tests showed that the wings lacked the ability to create enough fluid dynamic force to make any significant difference in the shape of the device. It was obvious that further investigation would prove fruitless and any viable design would be too cumbersome and fragile to be used in a field environment.

2.1.4 Front End Reserve Flotation Upgrade

The front-end flotation on the 1997 prototype consisted of small blocks of rigid, blue housing insulation foam positioned between each of the intermediate longitudinals. It was shown that this amount of flotation was not sufficient to prevent the front end from submerging when subjected to waves. In addition, if oil or contained fuel should reach the front flotation, there were openings between the blocks allowing a breach. Additional blocks of blue foam were added between the existing blocks using small flaps of fabric and zip ties to secure them. This nearly doubled the available reserve buoyancy and provided a much better barrier to front end breach.

2.1.5 Rear Boom Upgrade

The rear boom used in the 1997 prototype consisted of two 50-ft. sections of six-in. diameter conventional oil boom. The problem with this arrangement became evident during tests performed in 1997, which resulted in spill over the rear barrier. The solution was to double the volume of flotation and double the existing freeboard. A new rear boom was purchased which had a 12-inch diameter flotation member and did not cause any effect on the deployed shape of the device. Through both the front flotation and rear boom upgrades, the significant limitations recognized in 1997 were addressed.

2.1.6 Front End Re-design

One of the future hopes for deployment was the possibility that conventional boom may be attached directly to the device making it essentially one continuous system. The front edge of the end longitudinals was identified as the obvious choice of attachment points. The 1997 prototype end longitudinals did not support this type of attachment. As shown in *Figure 7,* the front was angled leaving no area to make any attachment. The new design would square off the front end providing a vertical member which is suited for attachment to conventional boom. The 1997 prototype was modified, and an attachment point provided.

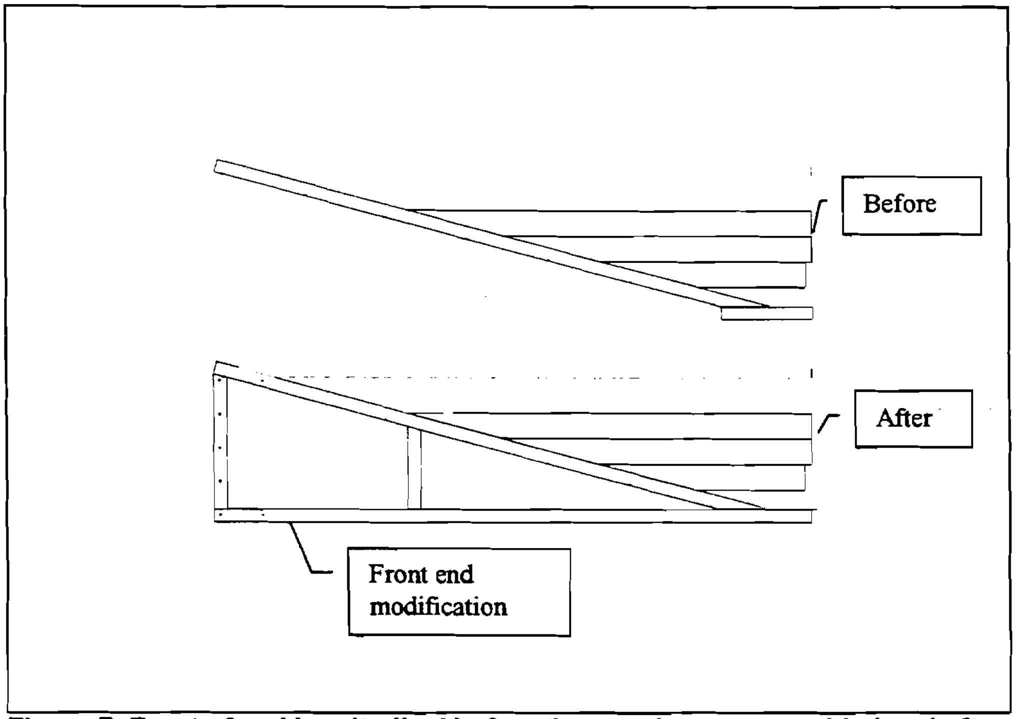

Figure 7: Front of end longitudinal before the attachment was added and after.

2.2 First Deployment Exercise

2.2.1 General

The first river deployment exercise was held on April 27,1998 at the Sprague Newington shipping terminal located on the tidal Piscataqua River. This area of the river has measured currents ranging from 1 to 3 knots during the tidal cycle. The deployment team consisted of an assembly group and boat crews. The boats and pilots were associated with the Piscataqua River Cooperative. The two boats used in the exercise were the Great Bay Responder and the Portsmouth Towing Whaler.

2.2.2 Purpose

The purpose of the first exercise was to answer the most immediate questions involving practical deployment of the device. These were:

- How difficult is the device to assemble?
- Is the device easily maneuvered off the beach?
- Once off the beach is the device easily moved into position?
- How difficult is the mooring process?

2.2.3 Procedure

The exercise was accomplished in 3 phases: assembly, movement into position and deployment. The assembly was to take place on the bank of the river during low water, which would provide the most beachfront to lay out and assemble the device. One of the boats would be piloted close to shore where a line would be attached to one of the eyebolt tow points on an end longitudinal. The device would then be walked off the beach as it was being towed into the river until it was floating on its own. The device would be towed to the deployment position where the second boat would attach a line to the opposite tow point and pull the device perpendicular to the oncoming current. Anchors would be attached and the device would be anchored one side at a time, the second side being used to make minor tension and position adjustment.

2.2.4 Results

The complete assembly took one hour and thirty minutes. This was longer than expected and would be unacceptable in an emergency situation. The attachment of the submergence plane and horizontal baffle were particularly difficult. Attachment of the horizontal baffle required two people, one to lift the end longitudinal and another to attach the fabric to the base. The most time consuming procedure was the attachment of the front reserve buoyancy. Each block of foam had to be positioned individually and zip tied securely. There were 26 blocks of foam each requiring 4 zip ties to attach them. The mud from the beach also presented problems, making it difficult to attach nuts without first rinsing the bolts with water.

Movement off of the beach went smoothly with the Great Bay Responder coming close to shore where both the tow line and mooring line were attached. The attachment eye was through bolted to the steel bracket termination for the chain tension member. This was by far the strongest point in the end longitudinal and allowed the system to be towed endwise as shown in *Figure 8.* Problems with towing the device became immediately evident when the lead end longitudinal submerged as the towboat began to accelerate. The device was towed to the deployment position with nearly 1/3 of it's full length submerged. The second boat then attached the opposite mooring line and brought the device perpendicular to the oncoming current. The first anchor was released, and after the device was put in tension by the opposite mooring line, the second anchor was released. After the second anchor settled the device was fully deployed. It held shape well and appeared to be adequately tensioned. As the device sat, it collected seaweed and other debris that strayed into it's path. This was very encouraging and indicated that functionality in the deployed state had not been sacrificed. Though there were several evident design changes needed, the first deployment exercise was viewed as a success by both the UNH team and the Piscataqua River Cooperative participants.

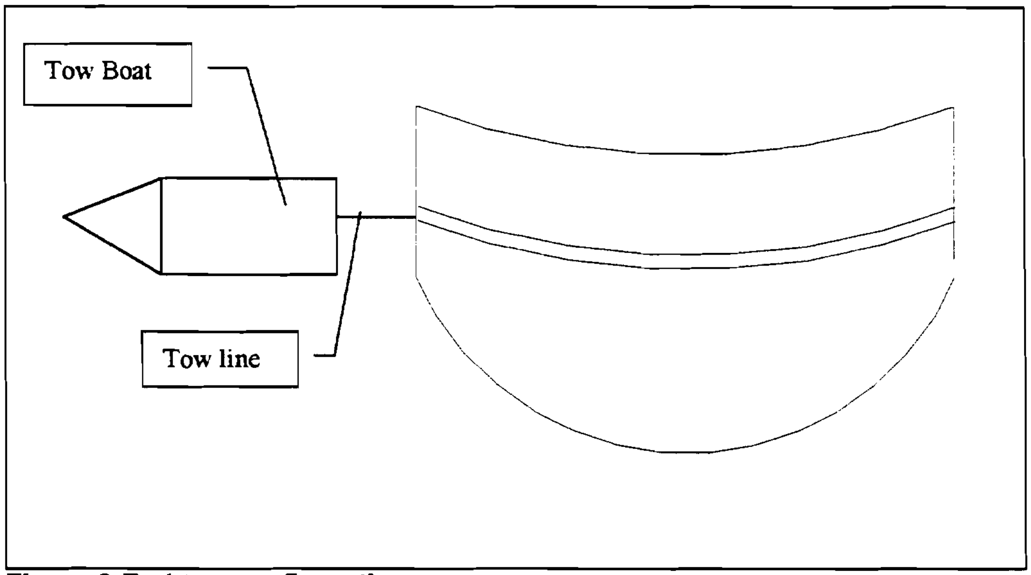

Figure 8:End tow configuration

2.3 Modifications for Second deployment exercise

The most critical issue noticed in the first deployment exercise was the submergence of the first 1/3 of the device during tow. A meeting was held between the UNH team and Steve Root, the lead pilot for the Cooperative. Several potential solutions were discussed, and two promising ideas were chosen for further investigation. The first proposal was to attach a bridle to the lead end longitudinal which would angle it much like the bow of a boat in hopes that this would force it to stay on the surface. The second proposal was to add large amounts of reserve buoyancy to counteract the force driving the device under.

The one-fifth scale model was again tested in the UNH tow tank. Before testing could begin, it was necessary to ensure that the model emulated the device when subjected to similar conditions. To this end the model was connected to a vertical tow post extending below the carriage. The tow line was secured to the post near water line thereby simulating the tow boat. The model was towed at speeds ranging from .5 knots to 2 knots (full-scale). As expected the model's performance mirrored that of the full-scale prototype with one third of it's length submerging at higher speeds.

The testing of the bridle proposal was conducted first. Two separate bridle configurations were used as shown in *Figure 9*. The model was towed at speeds ranging from one to three knots (full-scale). It was connected to the tow carriage in the same manner as in the emulation tests.

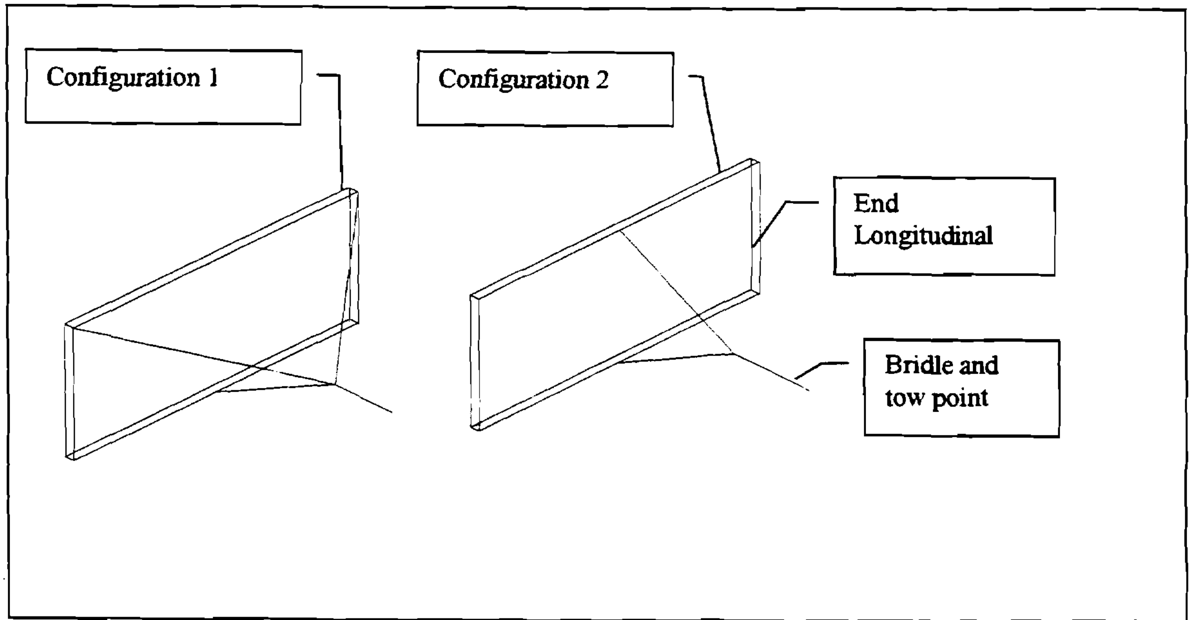

Figure 9: The two bridle configurations used during the model tests.

The results of these tests showed that the device could be forced to stay on the surface by means of a bridle attachment. Both configurations showed very similar results. When the model was towed at two knots (full-scale), there was significant water flow over the longitudinal. At three knots there was more overflow of the longitudinal and there was significant bending in upper support. The upper support was not designed as a load bearing member, and bending was undesirable.

The next series of tests involved attaching a proportionally large flotation member to the upper part of the end longitudinal. The first test was performed with a flotation member having a triangular cross section. This was used, to reduce drag and help the model cut through the water. The single tow point was used and the model was attached to the carriage in the same manner as the previous two tests. It was towed again at speeds ranging from one to three knots.

The results of these tests were very promising. The flotation member proved to be more than adequate in keeping the model on the surface. There was no submergence, and there was no overflow of the longitudinal. With no bridle attached to the upper support there were apparently no undesirable loads being placed on the model.

Because the triangular cross-section might have proven to be difficult to manufacture, a simpler square cross-sectional member was used in its place in the next series of tests. While also being simple to manufacture, the square cross-sectional member provided more volume and, therefore, more reserve buoyancy. The same test parameters were used. The results were identical to the previous test.

The reserve flotation member proposal was implemented. The challenge was finding a foam member that met the specification needed for the flotation. After many days of searching, a supplier of closed cell industrial insulation was found. Large blue foam members were purchased from Northeast Building Supplies located in South Berwick, Maine. Typically these members were used as flotation for lake side docks and rafts. An individual member measured 22 inches wide, 10.5 thick and 8 feet long. By splitting a member longitudinally the desired cross-section was achieved. Finally the reserve flotation was attached to the prototype end longitudinals using long threaded rods. After these modifications and a day of minor repairs the device was ready for the second Piscataqua River field exercise.

2.4 Second Deployment Exercise

2.4.1 Purpose

One purpose of the second deployment exercise was to validate the end longitudinal flotation modification, secondly, incorporation of conventional oil boom into the system was also desired. The desired effect was an integrated oil containment system to replace the standard containment configuration shown in *Figure 1*. Conventional oil boom would serve as lead-ins to the device in the apex position.

2.4.2 Procedure

Prior to the exercise a meeting to formulate a plan was held between the UNH team and Steve Root. The plan of attack was to deploy a pair of 100 ft., six in. diameter conventional boom segments in a catenary shape with the apex of the catenary left open as shown in *Figure 10*. The Bay Defender would then be positioned at the apex perpendicular to the on coming current.

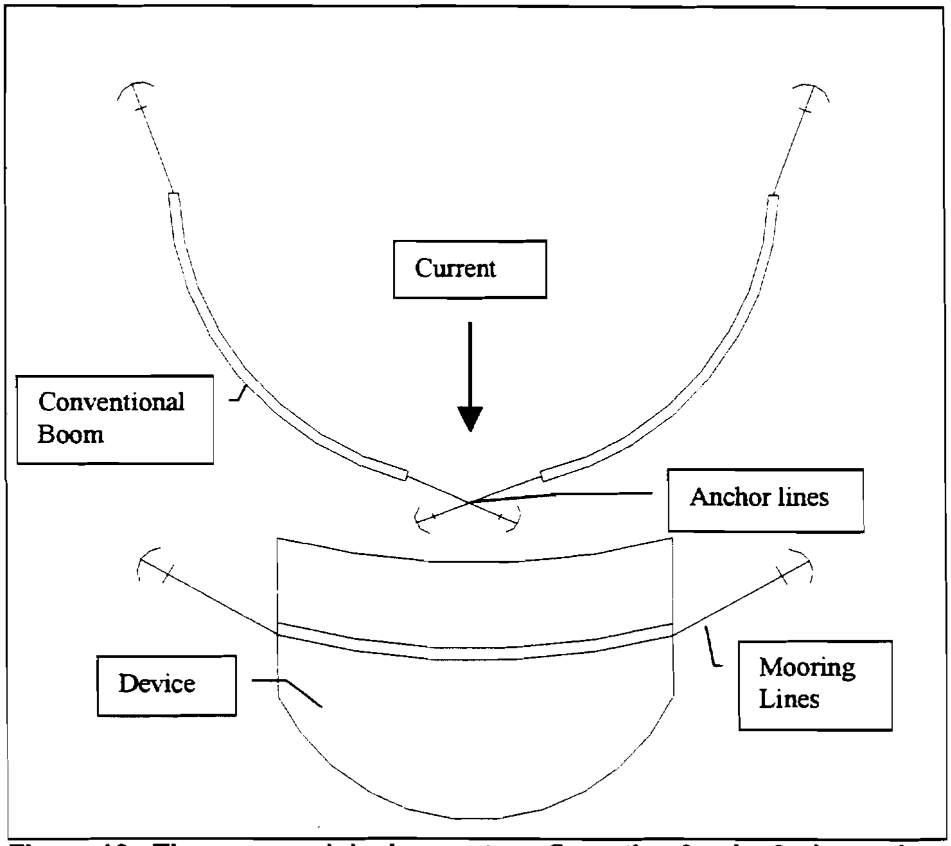

Figure 10: The proposed deployment configuration for the 2nd exercise

2.4.3 Results

The assembly again took approximately one hour and thirty minutes. During the assembly, the Great Bay Responder and the Portsmouth Towing whaler positioned the conventional boom. Positioning of each 100-ft. section proved to be a more cumbersome task than first anticipated. There was significant difficulty in positioning the apex in the correct location. It was only through superior piloting skill that the boom was finally positioned.

The GB Responder then pulled the device, with assistance from the team members on shore, off the beach and into the river. The device was towed to the deployment position at the apex of the conventional boom with no difficulty. The modified flotation on the end longitudinals prevented the device from submerging while towing, which in turn allowed for greater tow speeds. Once in position the whaler picked up the tow line on the opposite side and brought the device perpendicular to the current and in front of the apex. The GB Responder released anchor first. The device drifted a small amount and then stabilized. The whaler then released anchor, and it's side of the device drifted significantly. Bay Defender came to rest canted at approximately a 45 degree angle to the current and no longer covered the apex of the conventional boom.

The problem was that the anchor was sailing considerably with the current before it would grab the bottom of the river. A second attempt was made by the whaler, this time moving past the perpendicular position in hopes of compensating for the drift. To move past the perpendicular the tow line and the device had to be brought almost over one leg of the apex. At one point the end longitudinal tow point and the connector on the conventional boom became entangled, and it took nearly thirty minutes to release the device. Finally on the third attempt the device was positioned in a less then perfect, but adequate position.

There were two obvious problems that needed to be addressed prior to the third deployment exercise. The first was the problem of positioning the conventional boom. The second was the sailing anchor issue which caused the device to stray from the correct position.

2.5 Third Deployment Exercise

2.5.1 Purpose

The purpose of the third deployment exercise was to achieve an easily executed deployment that did not depend on very skilled pilots and that was not at the mercy of the current.

2.5.2 Procedure

Another meeting was held, and deployment strategies were again discussed. Two modifications were suggested. The first was to deploy the conventional boom as a single unit by connecting the apex with a line and a single anchor. The second was to run lines from the lead edge of the conventional boom to the tow points on the device to hold it in position. The theory was that the new stabilizer lines would prevent the device from drifting and the side mooring lines could be used primarily for tensioning as shown in *Figure 11.*

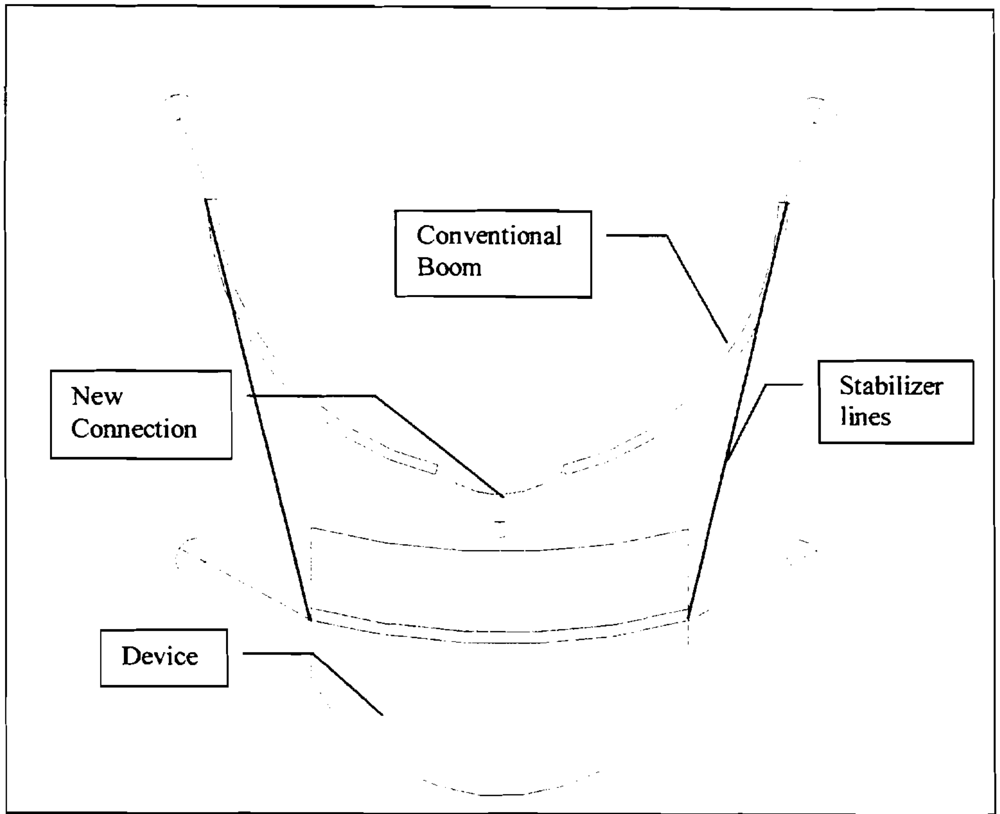

Figure 11: Improved deployment configuration for the 3rd exercise.

Each of these modifications was made. The deployment procedure was the same as the previous second exercise. The conventional boom would be set first, and the device would be moved into position and attached to the conventional system then tensioned with the mooring lines.

2.5.3 Results

In this exercise the assembly took only one hour. This improvement was attributed to practice. The conventional boom was attached as proposed and brought out for deployment. Each boat took one leg of the attached boom and set the lead ends. The apex anchor was then attached at the center of the apex line and released. Once the boom settled there was significant J'ing at the apex, which means that instead of forming a gradual curve each leg formed a shape similar to a J. It was apparent that the tension on the apex anchor was not sufficient, and several attempts were made to improve the shape. The shape finally obtained did not remove the J'ing completely but was adequate.

The device was towed to position without event. With each boat towing a tag line from each end longitudinal, the stability lines from the conventional boom were attached to the device simultaneously. The device did not hold shape when it was release to the stability lines. There was not adequate tension to straighten out the submergence plane. The anchors were attached, and the first anchor set attempted. The anchors continued to sail with the current similar to the last exercise. The pilots were unable to deploy the device in the correct position. There were several setbacks during the exercise including one anchor line being cut because of entanglement and one crown line caught in the prop of the Responder. A heavier anchor was attached to one side of the device in an attempt to reduce drift. This attempt was also an improvement but since the tidal current was diminishing to slack water the exercise was concluded without a successful deployment. The closest attempt had the device deployed canted and off center of the apex.

It was apparent that a new approach was needed. By deploying the conventional boom and the device separately, there were too many variables and the skill required by the boat pilots was too great. A new method had to be found that incorporated the conventional boom into the device so that they could both be deployed simultaneously.

2.6 Fourth Deployment Exercise

2.6.1 Purpose

In the fourth deployment exercise the primary objective was to execute a new deployment plan that allowed for simultaneous deployment of both the conventional boom and the device. The plan needed to be simple in execution and not rely on skilled boat pilots for implementation.

2.6.2 Procedure

The course of action chosen was one that had been anticipated from the beginning of the project. The conventional boom would be attached to the front of each end longitudinal as shown on *Figure 12*. This measure had not been taken before because it was feared that there might be some catastrophic failure of the end longitudinals or the submergence plane due to the forces applied when the 100-ft sections were attached.

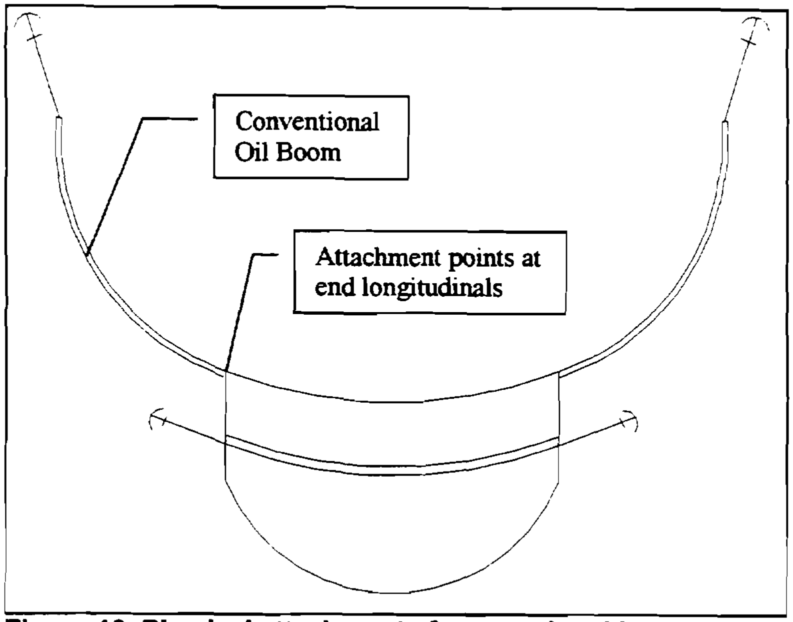

Figure 12: Physical attachment of conventional boom with the device.

To guard against the submergence plane failing in tension, webbing was added to the sides and corners to strengthen the material. The attachment mechanism would be a piece of fabric approximately one and a half feet in length bolted to the end longitudinal at one end and connected to the conventional boom with an ASTM Z-connector at the other. (see *Figure 13*)

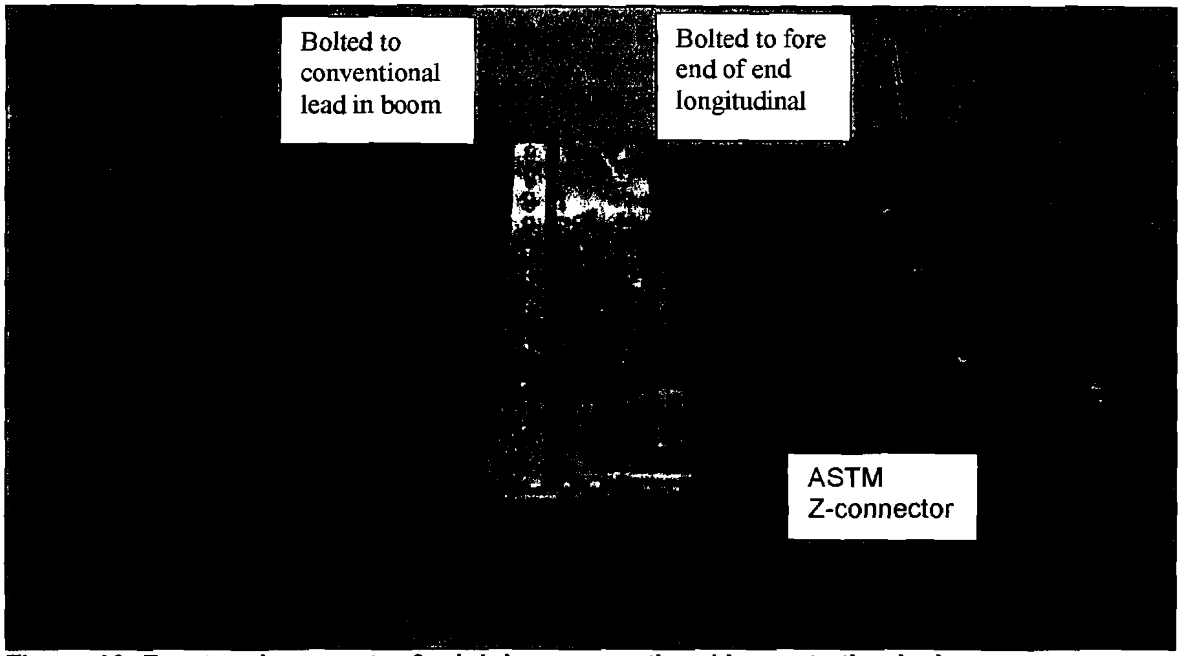

Figure 13: Front end connector for joining conventional boom to the device.

The conventional boom was to be attached while the device was just off the beach and from there be towed to the deployment position. At that point the second boat would retrieve the end of one of the boom sections and anchor it. While the first boat still held the device with the tow line the second boat would take the second leg of boom and bring the device perpendicular to the current and set the anchor. At this point the device would be held by the lead in boom and the device could be tensioned with the mooring lines. The major concern with this plan was the tensioning. It was unclear whether the device would collapse in on itself. Preparations were made to provide additional tensioning to the mooring lines using a 2 ton come-along and a specially modified mooring line with loops to hook onto. In case the device required greater tension a come-along on each side could be used to bring the device to the proper shape.

2.6.3 Results

Assembly of the device (during rain) was not timed in this exercise. Once the device was assembled and floating, the Great Bay Responder brought over the two 100 ft. sections of conventional boom. They were attached to the device with the Z-connectors, and the device was towed off shore. The device was towed to the deployment position, where the second boat retrieved and set one of the 100ft sections of boom. With the whaler still holding the device with the tow line, the Responder retrieved the second length of boom and brought the device perpendicular to the current and set the anchor. As the device was being brought around the whaler slacked off the tow line until the full drag force on the device was being held by the conventional boom lengths. The tension that the J'ing of the boom applied to the device proved sufficient enough to open it to the deployed position. The device was essentially deployed without the use of the mooring lines. The mooring lines were then set to provide more tensioning bringing the device to a near perfect position for oil containment. *Figure 14* shows the device in its fully deployed position with the conventional boom incorporated.


Figure 14: Fully deployed Bay Defender with conventional boom integrated.

2.7 Deployment Conclusions

It was the overall objective of the deployment study to find a simple, rapid means to deploy the Bay Defender prototype. With the fourth exercise that means was found. When the boom is attached to the front of the device the handling and positioning becomes very simple. Maneuvering in this configuration does not require expert pilots, unlike the skill level needed to maneuver in the first three exercises.

There was one other key issue that arose during the exercises. The assembly of the device needed to be significantly simplified if the device was ever going to realistically be used in an emergency. Several key areas that needed improvement were: the attachment of the front flotation, attachment of the submergence plane and horizontal baffle and the use of zip-ties for securing the rear boom and front flotation. The time and manpower required to attach these components was unacceptable. The front flotation was composed of 26 different fabric and foam pieces. The attachment of this component alone took over 25 minutes. Simplicity should be the key to any future assembly and is essential if time is to be kept to a minimum.

The deployment study was looked on as a success by both the UNH team and the Piscataqua River Cooperative participants. The desired incorporation of the prototype with conventional boom into one system was achieved. The study essentially proves that the Bay Defender has tremendous merit as an emergency response system in a rapid current tidal area.

CHAPTER 3

OHMSETT OIL RETENTION TESTS

3.1 Purpose

The third objective of this study was to test the oil containment capability of the newly modified device. To do this the device must be subjected to conditions that would best represent actual oil collection conditions. It was important to find out if the modifications made to the 1997 prototype during the deployment exercises decreased or enhanced the performance characteristics of the device. The UNH tow tank could not support the Bay Defender prototype and is not equipped to utilize real oil. For this reason the outdoor tow tank located at Ohmsett in New Jersey was used. The Ohmsett tank has both the capacity and oil use capability to accommodate the Bay Defender.

3.2 Ohmsett Organization

The Ohmsett tow tank is operated by the Minerals Management Service (MMS) through a contract with MAR inc.. The tank is located on the northern coast of New Jersey and is an outdoor facility. *Figure 15* shows a top down diagram of the Ohmsett facility (Steen, 1997). The tank is 666 feet long, 65 feet wide, 11 feet deep and holds 9.84 million gallons of brackish water. The facility is equipped to handle actual oil studies and is utilized by many commercial oil barrier manufacturers for prototype testing. There are three narrow tow carriages, referred to as bridges, positioned along the length of the tank. They are connected to a cable drive system that runs along both sides of the tank. Each bridge can be independently positioned. The cable drive system is capable of tow speeds ranging between zero and six and a half knots. The tank is also equipped with wave making capabilities.

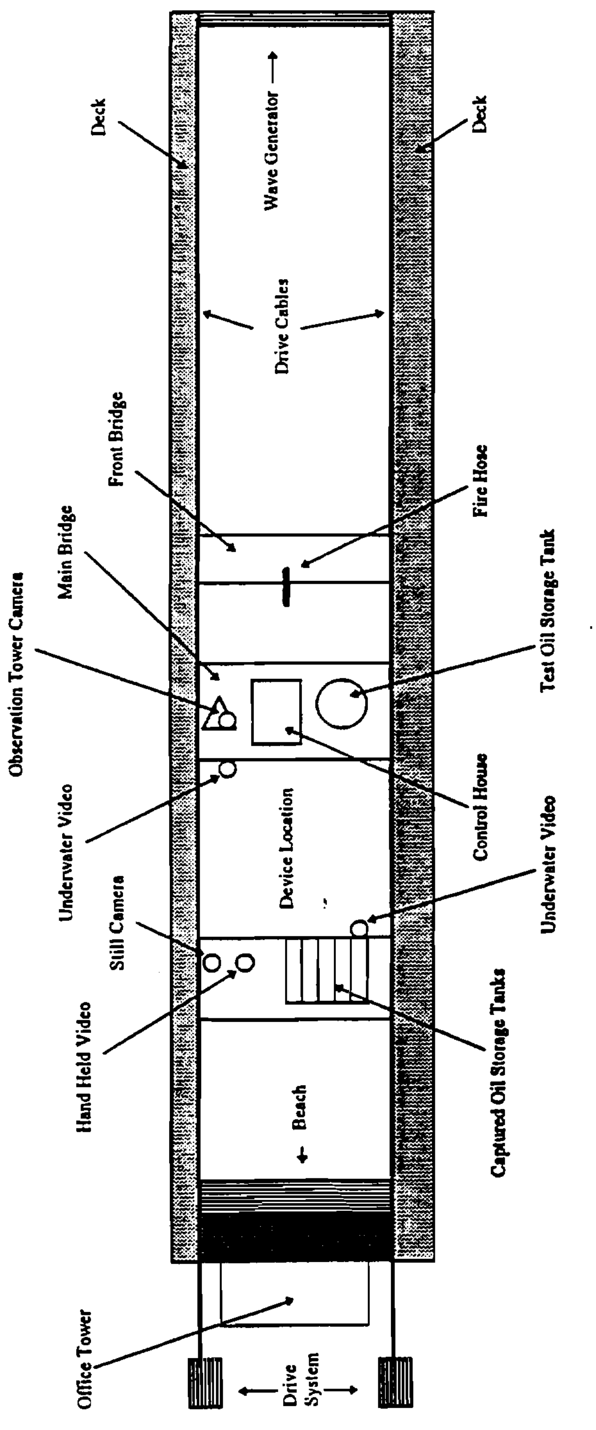

Figure 15: Ohmsett configuration, not to scale (Steen, 1997).

Measurement of oil recovered is conducted using recovery tanks and chemical analysis. The oil contained within the device at the conclusion of a run is pumped into a recovery tank where it is allowed to sit. Once the majority of water has separated from the oil, it is decanted off the bottom of the tank. A sample of the oil is taken for chemical analysis to determine the percentage of water and other material still present in the recovered oil. Using this analysis the amount of oil recovered is determined. Once the amount of oil recovered is known, it is recorded as a retention percentage by dividing by the amount of oil introduced during the run and multiplying by 100 (Steen, 1997; Swift et al., 1998).

Properties of the are two oils commonly used in testing at Ohmsett, are given in to Table 1.

Table 1: Characteristics of common oils used at the Ohmsett testing facility.

Oils	Kinematic Viscosity (centistokes)@ 20 C	Specific Gravity	Interfacial Tension (dyne/cm)	Surface Tension (dyne/cm)
Sundex	10,000.0	0.955	34.4	35.5
Hydrocal	190.0	0.897	25.9	33.6

Tests are administered by the test director and a team of Ohmsett employees. Each run is video taped and logged. At the conclusion of testing Ohmsett assembles a packet and sends video and oil recovery data to the tested organization.

3.3 1998 Ohmsett Tests

The issues that were brought to light in the 1997 Ohmsett tests were the catalyst for the first work done during the preparations for the deployment study. The front reserve flotation and rear boom upgrades were direct results of the observations made. As was stated before, the gaps that existed in the front flotation were filled with additional foam members, and the rear boom buoyancy and freeboard were doubled. These were the two major design differences that were seen as having a direct effect on the outcome of the tests. The addition of the side flotation members and the squaring of the end longitudinals were also in place for the Ohmsett tests, but were not expected to impact the results in any way.

There were three specific objectives that were sought after during this series of tests. The first was to ensure that the modifications made during the deployment study did not detract from the performance of the device. The second was to show that the front and rear flotation upgrades limited washout during wave testing. The third was to shift the maximum oil retention speed up to between 2.5 and 3 knots with the new rear boom upgrade. The third was to prevent oil from escaping through the front with the additional foam blocks.

The 1998 prototype was brought to Ohmsett July 13 for experiments conducted over a five day period from Monday through Friday. The system was first assembled on the side of the tank and slowly lowered in with the help of the Ohmsett team. Ohmsett had replaced the tow posts used in 1997 with newer posts. This caused some initial concern since it was unsure if the same test condition could be obtained. The device was tensioned between the new posts in the same manner as the 1997 tests (see *Figure 16)*. The same test protocol was observed, and the same oil retention measurement procedures were used. The tests were conducted over a five day period from Monday to Friday and weather conditions were not a factor in any of the tests.

Figure 16: 1998 Bay Defender prototype with upgrades positioned for testing at Ohmsett.

There were 23 runs made with tow speeds ranging from 1 to 2.5 knots. Wave tests were conducted with a wave height of 0.5 feet and a period of 2.61 seconds. The first three test runs and the very last run were hydrodynamic observation runs and were not oil retention tests. Each oil containment test was repeated at least once in order to provide some form of test redundancy. Each oil retention test consisted of a run at constant speed with oil deployment to the water surface in front of the device. Once the device was brought to a halt at the end of a run, the recovered oil was removed to the bridge recovery tanks where the samples were taken and volumes measured.

3.4 1998 Test Results

The 1998 test results were also very encouraging with some oil retention percentages just slightly higher than 1997 and some slightly lower. The maximum tow velocity with little or no over flow over the rear boom was found to be 2.25 knots with complete failure between 2.4 and 2.5 knots. See Table 2 for tabulated average oil retention percentages.

Table 2 : Oil retention results for 1998 Ohmsett tests.

Test #	Oil Type	Tow Speed(knts)	Waves	Ave. Retention Percentages
4,5	Sundex	1	No	82.40
6,7	Sundex	1.5	No	87.15
8,9	Sundex	2	No	87.79
10,11	Sundex	1.5	Yes	90.61
12,13	Hydrocal	1	No	90.735
14,15,22	Hydrocal	1.5	No	81.23
16,17,20,21	Hydrocal	2	No	46.95
18,19	Hydrocal	1.5	Yes	77.30

There was significant improvement in the wave handling characteristics. There was no noticeable "wave slop" over either the fore or aft barriers during any of the wave runs. While retention of heavy oil (Sundex) remained excellent, containment of light oil (Hydrocal) at two knots was disappointing.

3.5 Ohmsett Test Conclusions

The test results while encouraging were not as exceptional as were hoped for. One interesting result in the oil retention data was the low values obtained for Hydrocal at two knots. In the previous year these low values were attributed to possible human error. In 1998, however, there was an experienced individual taking samples and decanting the recovered oil. This makes it apparent that the poor performance in 1998 must have been due to some other aspect of the test, variation in oil properties or the device itself.

Because of the poor results in the initial two Hydrocal runs at two knots, there were two additional runs made. During the initial tests, it became apparent that the device might not have been sitting as low in the water as the 1997 prototype. After reviewing the video of the 1997 tests, this concern was validated. Extensions were manufactured and attached to the posts to lower the device to the level of the previous year. The second two runs of Hydrocal were at this lower level. The results were still lower than expected. The submergence plane appeared to be planing up causing water to rush into the device at higher speeds than were expected. These higher speeds then affected the horizontal baffle area where the contained oil was caught in vortices that formed at the rear boom and exited out the back of the device. One possibility was that there was not adequate exit area which caused the vortices to form and the oil to escape. Another explanation might have been in the condition of the oil itself. When the oil was introduced to the water it did not remain as an adhesive slick, but instead it broke into clouds of droplets which reduced its ability to rise in the containment area.

The second interesting result was the maximum effective tow speed of only 2.25 knots. The rear boom upgrade was intended to boost the maximum tow speed to as high as three knots. Since this did not happen, another explanation needed to be found for why the rear boom was being washed over between 2.4 and 2.5 knots.

After discussion with the UNH team the problem appeared to be one of continuity. The flow into the system did not seem to match the flow out of the system. This was causing the water to gather at the rear boom and eventually overwhelm it. The exit holes in the horizontal baffle, however, provide more than two times the area of the entrance gap. This meant that the holes to the front of the baffle were not being utilized by the exit flow. One solution would then be to increase the exit area at the extreme rear of the containment area.

The increase of both the fore and aft flotation did effectively eliminate the problem of "wave slop". These were features that would definitely be incorporated into the new commercial prototype.

CHAPTER 4

Commercial Prototype Design and Manufacture

4.1 Design Criteria

The next logical step in the evolution of the Bay Defender study was to design the first commercially viable system using the results of both the deployment study and the tests at Ohmsett to define the design criteria. The key criteria which were decided on were:

Deeper draft from 12 inches to 15 inches

Adjustability of gap opening and rear apex area

Continuous front flotation

Improvement of side flotation members

Use of more durable materials

The maximum oil retention speed of 2.25 knots from the Ohmsett tests was disappointing. The solution had been to increase the rear boom buoyancy and freeboard in an attempt to discourage rear wash out. With only the small gain in speed, it was shown that by merely increasing freeboard and buoyancy could not solve the problem. As mentioned before the problem then became one of continuity. The exit holes in the horizontal baffle were not providing enough exit area, and the water was seeking alternate routes of exit, primarily over the rear boom. The proposed solution for the commercial device was to have an adjustable apex area. If the device was going to be subjected to speeds of greater than 2.25 knots, then the rear apex could be opened to provide a larger exit area.

Another proposed adjustable feature for the commercial device would be the gap opening. In the previous year's tests, video taken of the gap opening during test runs showed significant amount of oil missing the gap altogether and eventually rising at the front exit holes in the horizontal baffle. By adjusting the gap opening, specifically the vertical distance from the base of the submergence plane to the leading edge of the baffle (or the bite), the hope is that the device will capture that oil which was previously bypassing the gap entirely.

The time needed to assemble the front flotation during the deployment exercises was unacceptable. The proposed solution for the commercial device was the design of a continuous front flotation member. Thus reducing the need to assemble 26 individual flotation components. If the front barrier was continuous there would be no worry of oil escaping during Ohmsett test deceleration and no need for the fire hoses to contain it.

The side flotation for the 1998 prototype was effective, but was not very durable. The foam used was standard blue insulation foam and had a tendency to soak up limited amounts of oil. This was undesirable, and more appropriate foam, as well as a more aesthetic appearance, was requested.

Over the two years of testing, the prototype took a tremendous amount of abuse. The effects were readily apparent in the dilapidated appearance of the end longitudinals and intermediates. The commercial device would need to be constructed from much more durable, as well as stronger materials, primarily the end longitudinals and intermediates. The submergence plane and horizontal baffle would need to be reinforced to prevent tearing at tension points.

4.2 Design and Construction

Design of the commercial system primarily involved improving on the existing system using new stronger materials and using components that were not expendable after a single use. Each major component was either replaced entirely or modified to fit the new design.

The end longitudinal is one of the major structural components of the Bay Defender system. For this reason strength and durability were a primary concern in their design. The material chosen for the new end longitudinal was 6061-T6 aluminum. Aluminum was chosen specifically for its strength and propensity to be used in the marine and river environments. It was also chosen over other materials, such as wood or fiberglass, based on cost, strength and manufacturing issues. The primary structural members were rectangular beams 2 inches by 3 inches with 1/8-inch thick walls. The new longitudinals are slightly longer than the previous design to incorporate the new 15 inch draft. Each end longitudinal uses aluminum chambers built in for it's flotation. The longitudinals were made independently stable with the use of these chambers and lead ballast. The tow point is a steel eyebolt bolted at the point adjacent to the leading edge of the horizontal baffle.

The primary difference between the new and old end longitudinals (besides the material) is the attachment points for the submergence plane and the horizontal baffle. Aluminum angle stock welded to the side of the longitudinal serve as the attachment point base. This removes the need for the longitudinal to be picked up for attachment of the fabric. The bolts used to attach the components are left in place and do not have to be removed during attachment. This saves time and prevents the bolts from being dropped in the mud and becoming difficult to handle. *Figure 17* shows the end longitudinal during construction. See Appendix A for technical drawings.

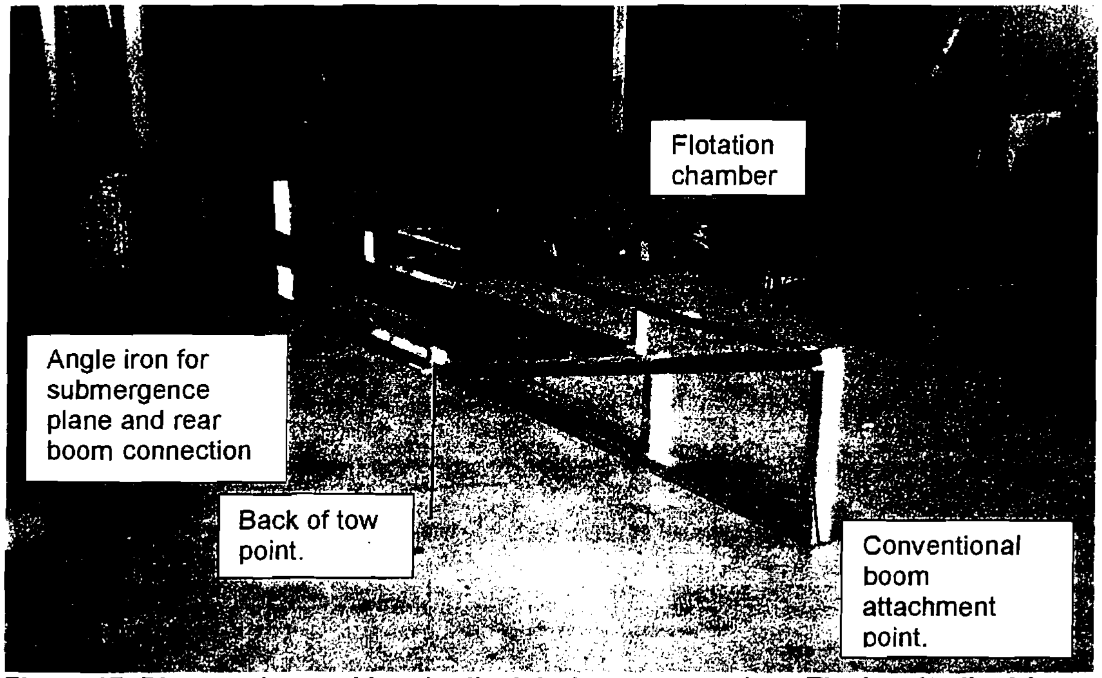

Figure 17: Picture of an end longitudinal during construction. The longitudinal frames were built by Custom Welding and Fabrication located in Northwood, NH.

The intermediate longitudinals also went through a complete redesign. Again aluminum was used for durability and corrosion resistance. The desire was to remove all foam flotation from the longitudinals to increase the durability and lower maintenance time. Unfortunately in the case of the intermediate, it was not cost effective to design and build aluminum flotation chambers for each one. Instead new foam was chosen to replace the existing foam. The previous foam was thin blue house insulation foam, and was attached using standard wood glue. The wood glue did not hold the foam in place very well when the foam was subjected to any force (i.e., fire hoses used in the Ohmsett tests). In addition this foam had a tendency to be too rigid and would break when force was applied. The new foam is not rigid and is held on both with an epoxy compound and long thin rods bolted at each end to prevent the foam from breaking away should the epoxy fail.

The adjustability of the bite (vertical distance from the rear edge of the submergence plane to the leading edge of the baffle) was incorporated into the intermediates. A telescoping tube/pin arrangement, as shown in *Figure 18,* allows for the leading edge of the horizontal baffle to be lowered increasing the bite.

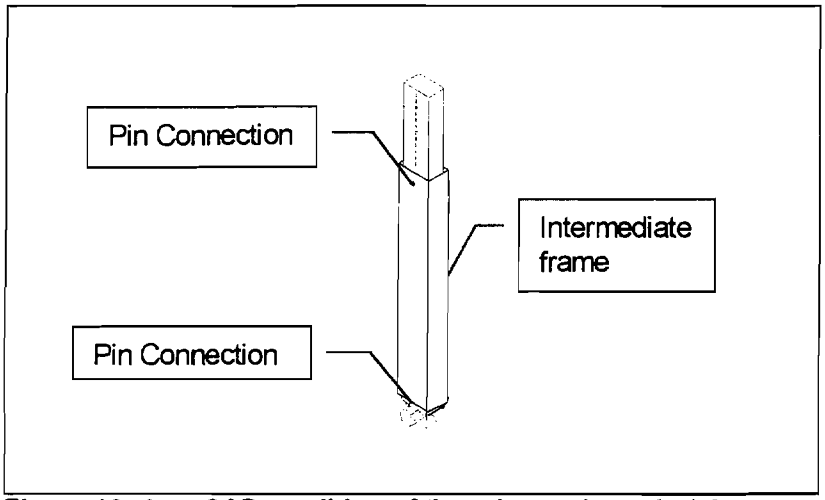

Figure 18: AutoCAD rendition of the telescoping tube/pin arrangement.

Attachment of the intermediate to the rest of the device is accomplished with two standard bolts and pin at the leading edge of the horizontal baffle (see *Figure 19).*

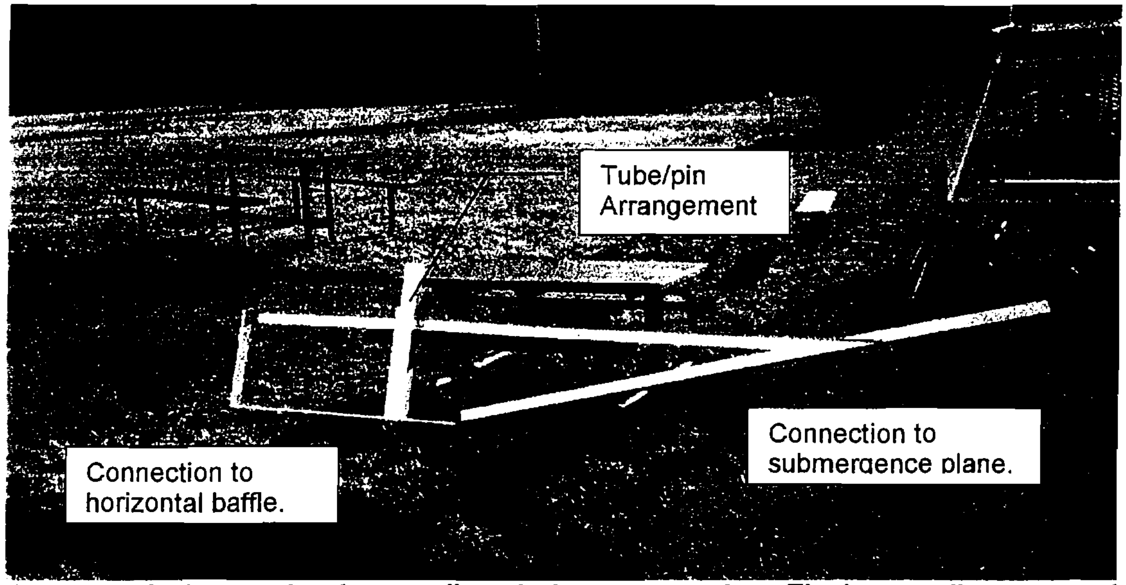

Figure 19: A picture of an intermediate during construction. The intermediates were also built by Custom Welding and Fabrication.

The front flotation was the most drastically changed of all the components. The foam members and fabric flaps were completely omitted. A four-inch diameter inflatable tube providing 234 lbs. of reserve buoyancy replaced the foam. The flotation is encased in a pocket that is a continuation of the submergence plane. The pocket is secured using stainless steel snaps. This new flotation is continuous and should eliminate any leakage from the front of the barrier. The omitted of the individual fabric flaps, the 26 foam pieces and the need to use zip ties will drastically improve the assembly time of the device.

The side flotation was merely bolted to the side of the earlier prototype, and the foam was subjected to significant wear during the deployment exercises. Many attempts were made to find a substitute for the existing foam with no luck. Since the existing foam would have to be used, it would need to be protected. The new side panels for the longitudinals would be designed to incorporate the foam into them. The foam would be encased in the fabric protecting the foam from both wear and oil.

A new submergence plane and new horizontal baffle were cut from large pieces of fabric provide by JPS/OILTROL, Inc. Webbing was also used to strengthen the submergence plane at its critical points. Steel grommets were used as connection points to the end longitudinals. The fixed exit area in the horizontal baffle remained twice that of the inlet area at the gap.

The existing rear boom was modified to accommodate the deeper draft by adding three inches to the skirt length. The adjustability of the apex exit area was designed into the rear boom. An adjustable rope lacing configuration was used as shown in *Figure 20*. The rope can be loosened at the top of the boom and the apex will open according to how much slack is permitted in the line. The boom can also be fixed in place using standard steel quicklinks, which are used in the non-adjustable portion of the boom. The quicklinks were used to replace the zip ties in the previous design.

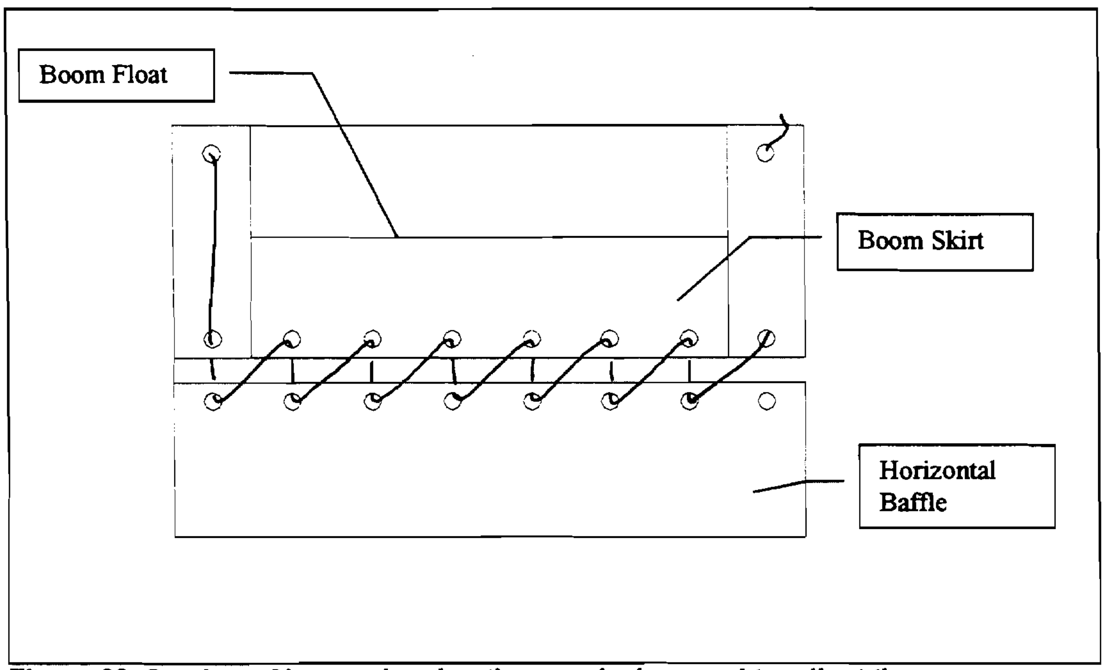

Figure 20: Section of boom showing the rope lacing used to adjust the apex.

One other modification was made to the old design. The end longitudinals and the intermediates in the previous design were angled inward and stayed perpendicular to the catenary curve of the submergence plane and horizontal baffle. In the commercial prototype they were positioned parallel to the current. This was done to make design, construction and assembly easier.

4.3 Dynamic Loading Tests

The materials chosen and the design used for the commercial prototype were seen as more than adequate to handle expected loads. However, for completeness sake some simplified strength calculations were performed. To perform these calculations it was important to understand what loads the new device would be subjected to. This question prompted several dynamic loading tests. The tests were performed on the 1/5 scale model in the UNH tow tank.

There were two configurations of the device identified during the deployment study that would subject the device to it's greatest loads. The first is when the device is being towed from the tow point on the end longitudinal. The second is when the device is towed by one of the 100ft. lengths of boom attached to the fore end of one of the end longitudinals.

During the tow tests it became apparent that the physical model would not withstand the full range of speeds that were required to determine the loads wanted. In addition the loadcell available had a maximum load of 10 lbs. to determine the loads desired several runs were made with speeds ranging from .5 to 2 knots (full-scale), and loads were measured using the loadcell. Theory was then used to extrapolate within the range of interest.

The drag force on an object is defined by

$$D_f = \frac{1}{2}\rho C_D A U^2.$$

In this equation, D_f is the drag force, C_D is the coefficient of drag, U is the speed of the tow, A is the area seen by the fluid, and ρ is the density of the fluid medium.

If the Area is considered to be constant throughout the tests, then the drag coefficient and the area can be combined into one term S. Using the drag forces obtained from the loadcell during the test it is possible to obtain a value for S. Then using the average value of S it is possible now to determine the drag force produced by any speed desired. A maximum speed of 6 knots was chosen. This value represents the device being towed, for example, at three knots through a three-knot current.

Maximum loads on the end longitudinals could then be calculated. At a speed of 6 knots the tow point on the longitudinal was found to be subject to a load of approximately 3000 lbs. If towed from the corner of the end longitudinal by the 100 ft. length of boom, the applied load was determined to be approximately 10,000 lbs.

The areas of concern for the tow load of 3,000 lbs. are the eyebolt which will be in direct tension and the end longitudinal structure which will be put in bending as the tow load is applied. The eyebolt selected is rated for a working load of 5,200 lbs. which provides a factor of safety of about 1.7 (In addition to the manufacturer's factor of safety).

To simplify calculation of the bending stress produced in the end longitudinal, it was necessary to make several assumptions. The first assumption was that the submergence plane and horizontal baffle act as a distributed load along the longitudinal putting it in static equilibrium with the tow load. A shear force and bending moment analysis was then done, and the maximum bending moment was found. From this maximum bending moment it was possible to calculate the resultant bending stress and compare that to the yield stress of the material. A cross-section of the entire structural longitudinal at the location of the highest moment was used in the calculation of the resultant bending stress. The bending stress was found to be 13,700 psi. The yield stress of aluminum is between 38 and 40 ksi. A detailed derivation of this analysis can be found in Appendix B.

Two factors should be taken into account when considering the last analysis. First the chosen tow speed of 6 knots is fairly large in relation to the expected tow speed of between 2 and 3 knots. The second is that while it shows that the longitudinal as a whole will withstand the load, there may be some localized stress issues. If the base beam itself is assumed to withstand the entire load the resultant bending stress nears the yield stress of the material. For this reason it is recommended that a small reinforcing bar of approximately 1/4-inch aluminum be welded beneath the tow point. Due to time constraints this modification was not applied during this thesis.

The critical components of the corner configuration, subject to the 10,000 lb. tow load, are the fabric of the submergence plane, the conventional oil boom and the ASTM Z-connector used to attach the boom to the device. The submergence plane fabric is reinforced by 2-inch nylon webbing, which is rated to 12,000 lbs. in tension. The oil boom fabric is rated to 500 lbs/in. The webbing reinforces over 20 inches of oil boom fabric, which alone can withstand the corner load. Failure of the submergence plane or oil boom fabric are not critical concerns.

The Z-connector would be subjected to two possible modes of failure, failure in tension and failure in shear. When subjected to the 10,000 lbs. load, the normal stress produced in the connector is approximately 2.5 ksi. When the shear component is calculated, the shear stress is found to be approximately 1.3 ksi. There is no concern of the Z-connector failing.

The results of this analysis show that the commercial prototype was designed to handle the expected loads. The 1997, 1998 prototype underwent the deployment exercises with no failures due to excessive loading, and the new commercial prototype is built with stronger more durable materials. Failure of the device due to excessive loading is not expected.

4.4 Costs

As with any endeavor that uses the word commercial, the question of cost arises at some point. The Bay Defender study is no different. While it is difficult to project manufacturing costs because of the differences in possible manufacturing procedures, it is possible to give the cost of materials and fabrication of the prototype.

Steps taken to reduce the cost of the prototype included avoiding the use of custom made material components, (instead, using standard dimensions of aluminum tubing) and the use of commonly found fasteners. Another step was to avoid using external paid labor in fabrication; what could be done at home was. Once the components were received from the vendors it took approximately 54 man hours to complete construction. Table 3 shows the break down of components their cost and their supplier, as well as the total cost of the prototype.

Table 3 : Break down of cost and suppliers of individual components.

Item	Supplier	Cost
End Longitudinal	Custom Fabrication and Welding	$1500
Intermediate Longitudinal	Custom Fabrication and Welding	$2110
Horizontal Baffle and Submergence Plane	JPS/OILTROL Inc.	$1000
Rear Boom	American Boom and Barrier Corp.	$600
Front Flotation	Slickbar Inc.	$230
Side Flotation	Northeast Building Supplies	$162
Intermediate Flotation	UFP Technologies	$248
Miscellaneous (fasteners etc..)	-------	$300
Total		**$6150**

CHAPTER 5

CONCLUSION

The evolution of the Bay Defender project is continually progressing. This work has been the next logical step in that evolution. The submergence plane theory that is the root of this study has been proven year after year. The Bay Defender design vastly out performs conventional systems. This was first shown in 1997 and was again validated during this work at Ohmsett in 1998.

Now it has also been shown that this system is not only useful as a research tool for the technology, but is readily deployable as a practical solution to an emergency spill response. The Piscataqua river deployment exercises proved that the system can be used in conjunction with conventional boom in river and tidal areas. The next step may be to extend the length of the system beyond 40 ft., possibly to span over one hundred feet in an effort to virtually seal off a rapid current area during an emergency.

The commercial prototype should serve as the next tool in the design process. It should be used to build and improve on the deployment process, as well as to further study the oil retention capabilities of the system. The successes to this point of the Bay Defender system can only serve to strengthen the reasons for continuation of this research into the next phase. This system marks the next generation in oil barrier technology.

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APPENDIX A

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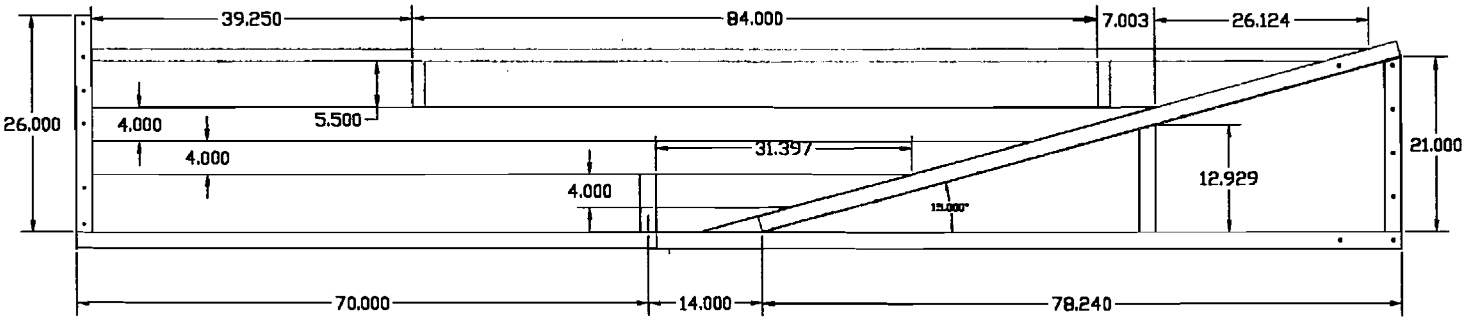

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		SPECIAL APPR.		

University of New Hampshire
Jere Chase Ocean Engineering Center
University of New Hampshire
24 Colovos Road, Durham, NH 03824

TITLE
End Longitudinal

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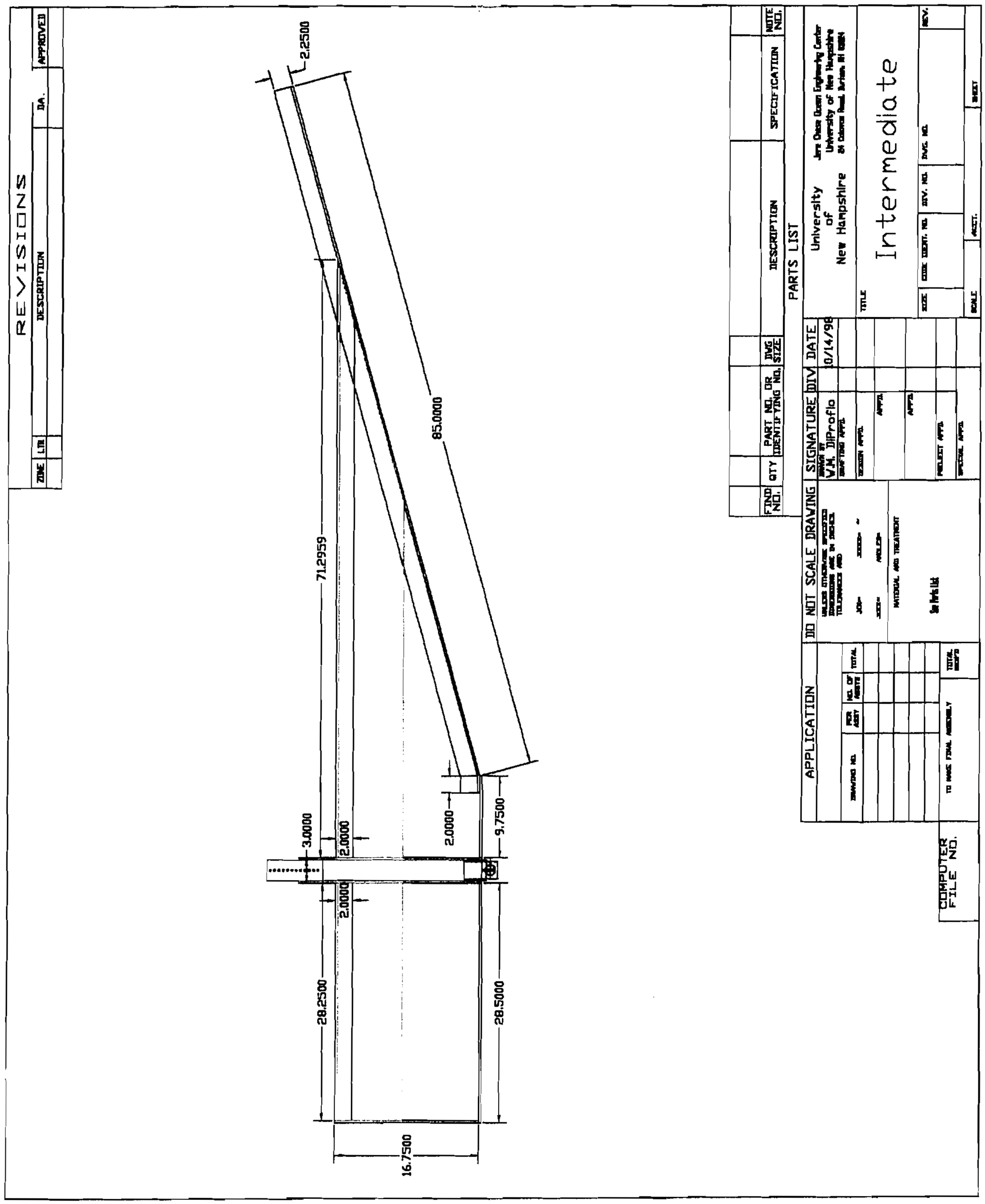
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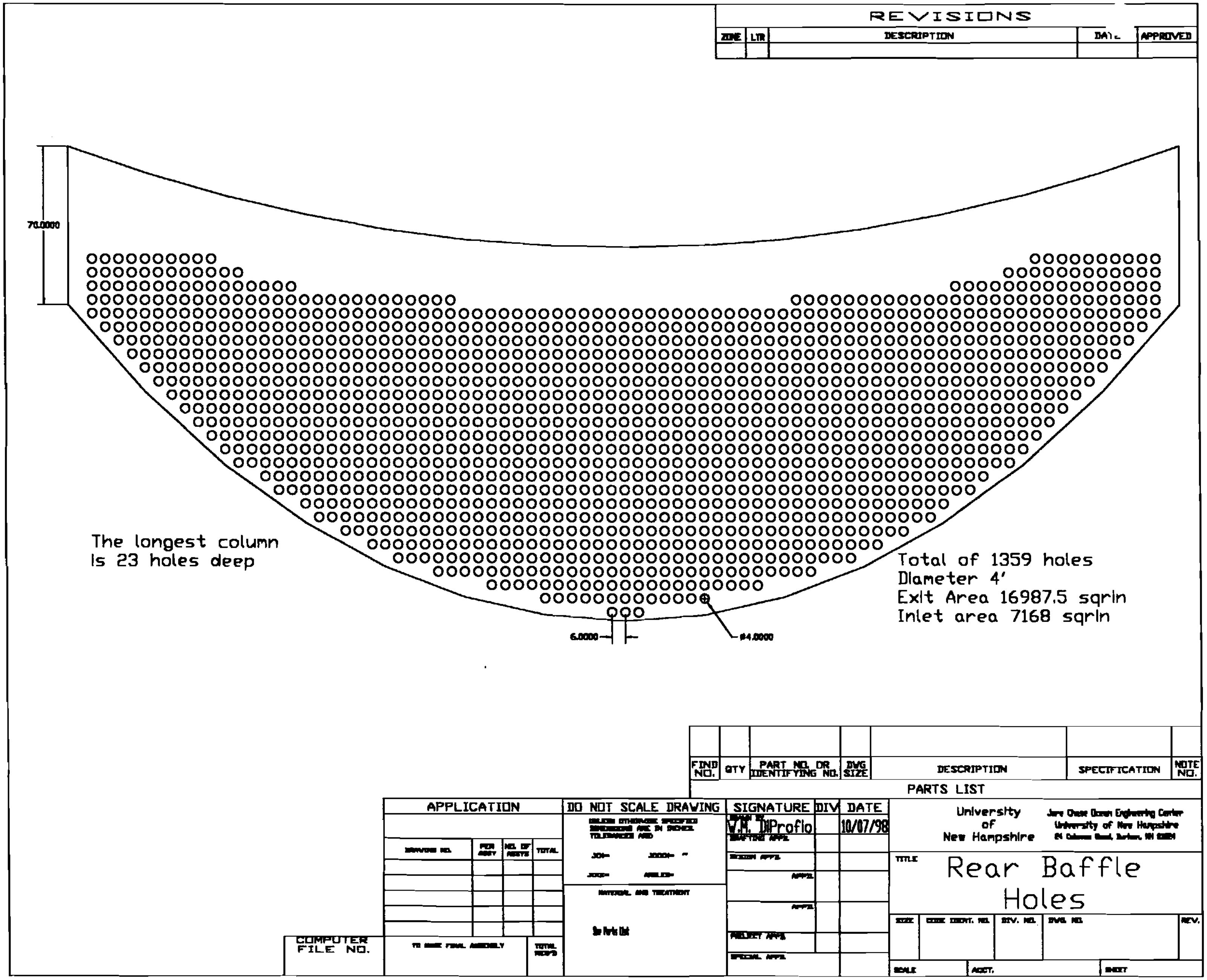
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University
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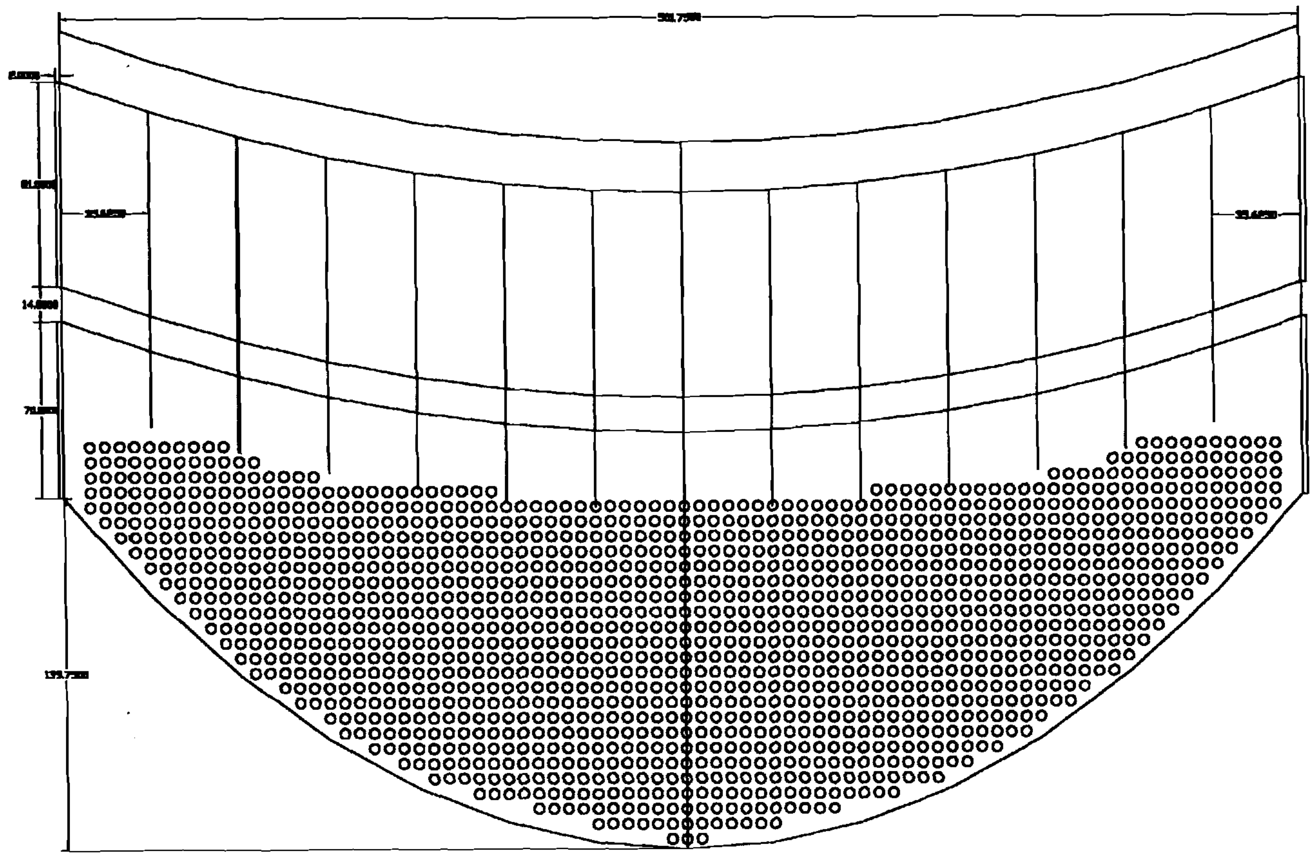

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MATERIAL AND TREATMENT

See Parts List

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V.M. DiProfio 09/30/98

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PROJECT APPR.

SPECIAL APPR.

COMPUTER FILE NO.

University of New Hampshire

Jere Chase Ocean Engineering Center
University of New Hampshire
24 Colovos Road, Durham, NH 03824

TITLE

Submergence Plane and Rear Baffle

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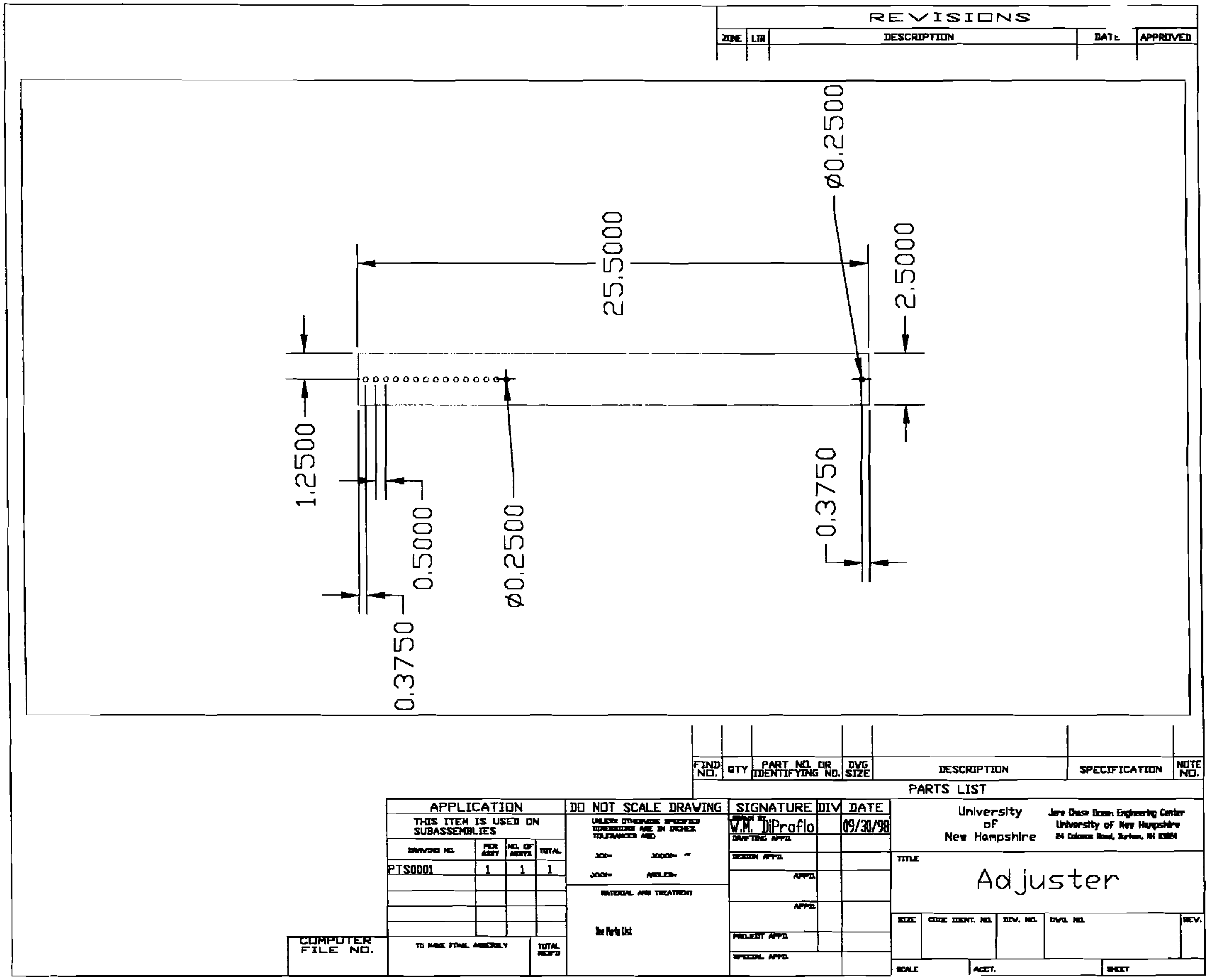

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Jere Chase Ocean Engineering Center
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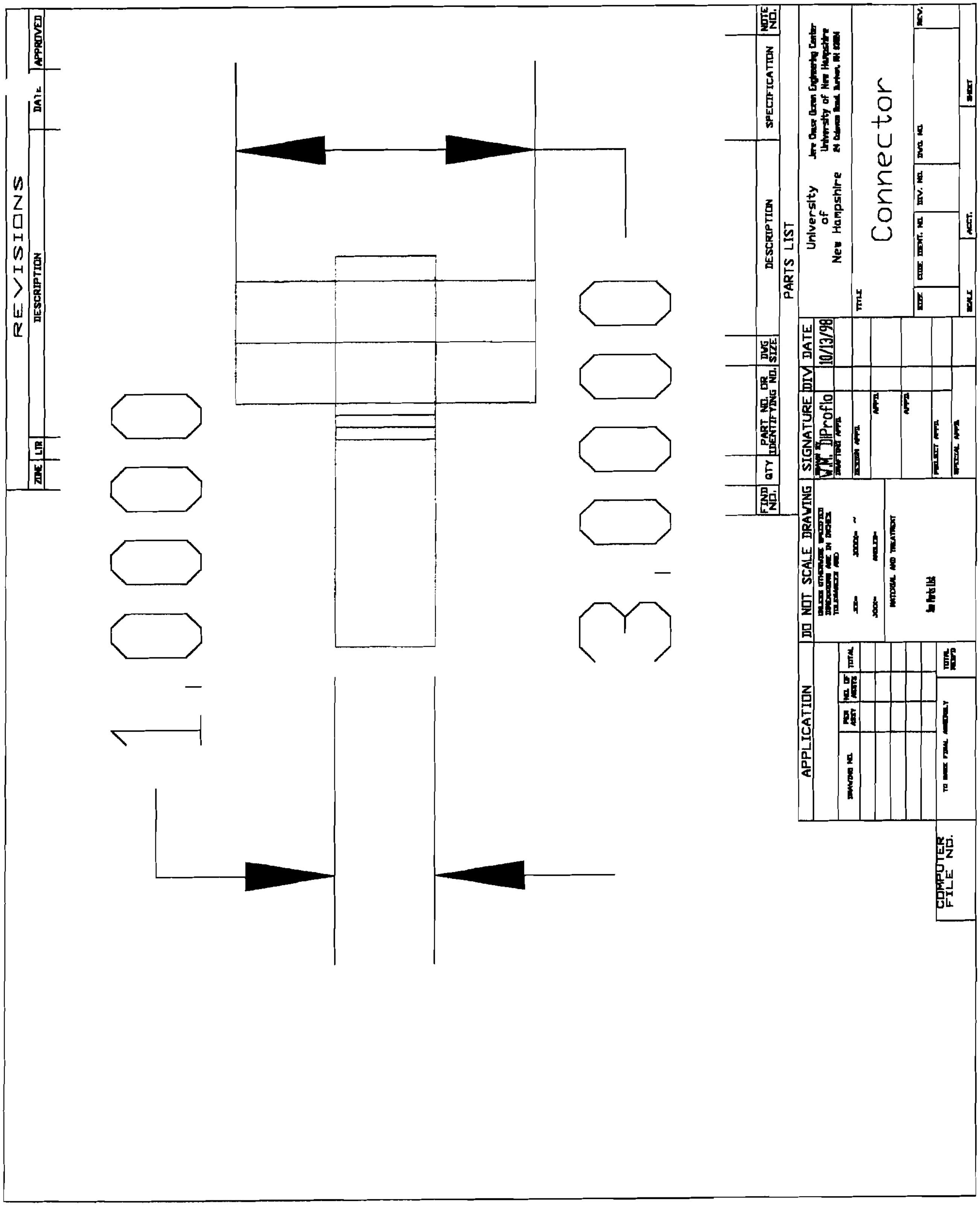
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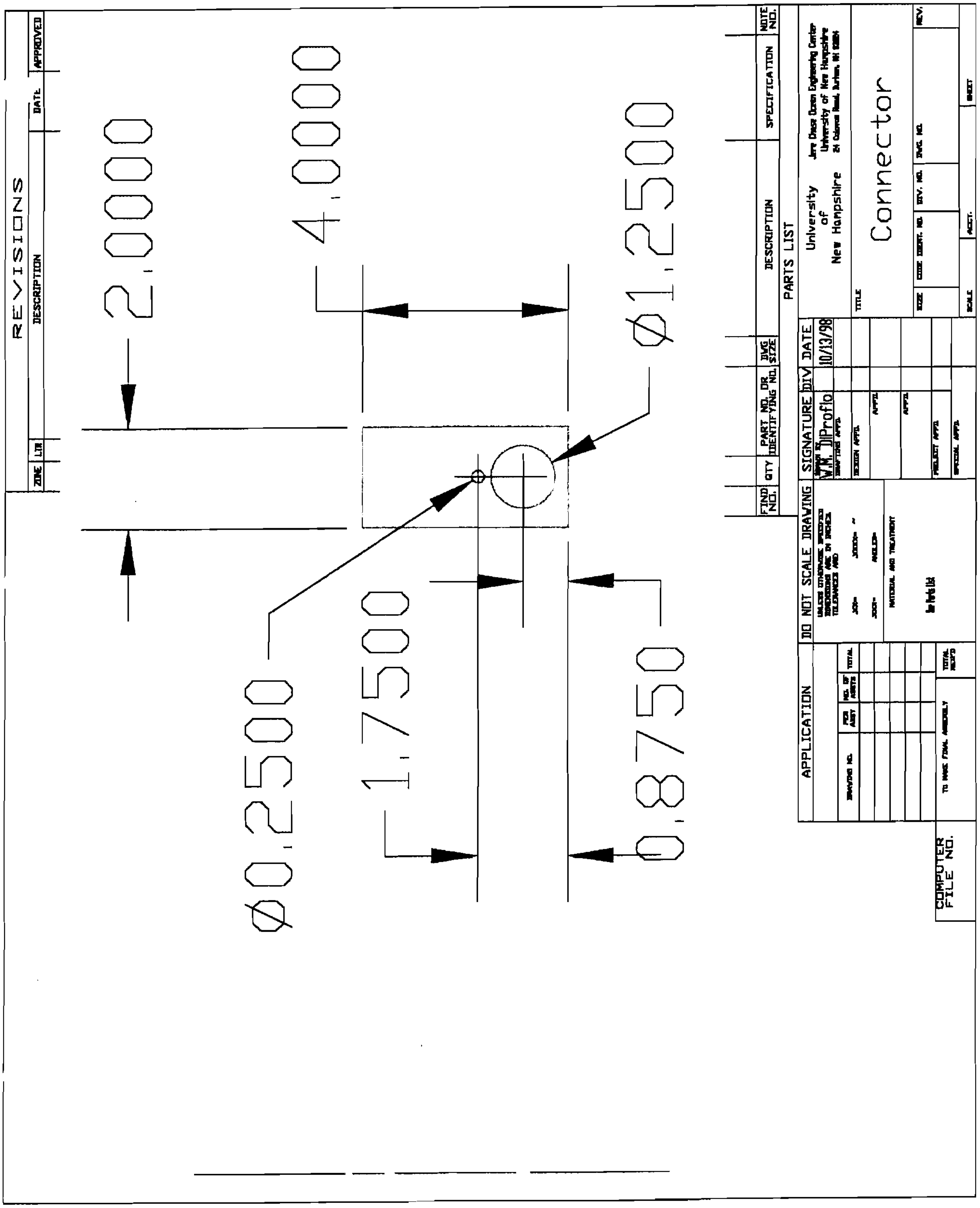
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APPENDIX B

Calculation of Shear and Normal stress in the ASTM Z-connector due to the proposed tow load of 10,000 lbs.

Normal stress is defined by:

$$\sigma = \frac{F}{A}$$

Where F is the force of the tow load and A is the cross sectional area of the material.

The cross sectional area of the Z-connector that is exposed to the normal stress is 3.93 in^2.

The calculated normal stress is then 2.5 ksi.

The shear stress is defined as

$$\tau = \frac{F}{A}$$

Where F again is the applied force and A is now the cross sectional area of the material exposed to shear.

The Area exposed to shear on the Z-connector is 7.875 in^2

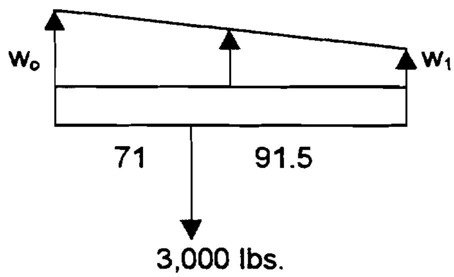
The calculated shear stress is 1.26 ksi.

Bending Stress produced in cross-section of longitudinal.

The tow force is modeled as a point load applied at the tow point.

The Submergence plane and Rear baffle act as a distributed load putting the beam in static equilibrium.

Free Body Diagram



The first part of this problem is to define w_1 and w_o. Simultaneous equations will be used to calculate these values.

Since the magnitude of the distributed load is equal and opposite to the point load it must act at the same location. This location is the centroid of the distributed load. The equation of the centroid can be found and is:

$$X_c = \frac{A_1 x_1 + A_2 x_2}{A_1 + A_2}$$

Where A_1 and A_2 are the areas of the two representative sections of the distributed load and x_1 and x_2 are the centroids of the sections.

$A_1 = 162.5\ w_o$ and $A_2=81.25(w_o-w_1)$

Simplification of this equation gives:

$$3033.33 w_1 - 1367.71 w_o = 0$$

The second equation is defined by the equation of the line of the distributed load. The integral of this line is equal to the magnitude of the distributed load which is equal to and opposite of the point load. The second equation is:

$$\left[-\frac{(w_o - w_1)}{2 \cdot 162.5} \cdot x^2 + w_o x \right] \Big|_0^{162.5} = 3000$$

Simplification of equation 2 gives:

$$81.25w_o + 81.25w_1 = 3000$$

Solving the two equation gives:

$w_1 = 11.47$
$w_o = 25.45$

With these values the Shear and Moment diagrams for the beam can be found.

The loading function of the beam is defined as:

$$q = -.0859x + 25.45 - 3000 < x - a >^{-1}$$

Where a is the distance from the edge of the beam to the point load.

The shear function is defined as the integral of the load function which was calculated to be:

$$V = -.04299x^2 + 25.45x - 3000 < x - a >^0$$

The Moment function is defined as the integral of the shear function which was calculated to be:

$$M = -.01433x^3 + 12.72x^2 - 3000 < x - a >^1$$

Now the Shear and Moment diagram can be drawn and the largest bending Moment found. The largest bending Moment will produce the largest bending stress.

The largest bending moment was found to be 59,033 lbs-in.

Bending stress is defined as:

$$\sigma = \frac{Mc}{I}$$

Where M is the bending Moment, c is the distance to the neutral axis and I is the moment of inertia for the beam.

The moment of inertia is a combination of the 2x3 by 1/8 inch base beam and the 2 4x3 by 1/8 inch beams used for flotation chambers.

$I = 6.47$

The distance to the neutral axis is simply the middle of the beam.

$c = 1.5$

The bending stress can then be calculated.

$\sigma = 13686$ psi.