WHOI-92-08

Copy 2

Woods Hole Oceanographic Institution

Self Deployable Deep Sea Moorings

by

H.O. Berteaux, S.M. Kery, R.G. Walden

January 1992

Technical Report

Funding was provided by the Office of Naval Technology under
Contract No. N00014-90-C-0098.

WHOI-92-08

Self Deployable Deep Sea Moorings

by

H.O. Berteaux, S.M. Kery, R.G. Walden

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

January 1992

Technical Report

Funding was provided by the Office of Naval Technology under Contract No. N00014-90-C-0098.

Reproduction in whole or in part is permitted for any purpose of the United States Government. This report should be cited as Woods Hole Oceanog. Inst. Tech. Rept., WHOI-92-08.

Approved for public release; distribution unlimited.

Approved for Distribution:

Robert D. Ballard, Interim Chairman
Department of Applied Ocean Physics & Engineering

ABSTRACT

As part of a development effort in the field of moored arrays sponsored by the Office of Naval Technology, the Ocean Structures and Moorings Laboratory (OSM&L), Applied Ocean Physics and Engineering Department (AOP&E), Woods Hole Oceanographic Institution (WHOI) conducted a study in 1991 to assess the feasibility and the merits of several self-deployable mooring designs. This study included a brief review of the state of the art, the performance of lab tests to evaluate different mooring line payout concepts, and the preliminary design of a typical candidate mooring. The results of this study are presented in this report.

The report first reviews three types of single point moored arrays which are amenable to self-deployment: subsurface, subsurface with surface expression, and surface with bottom inverted catenary. It then describes the features common to all self-deploying moorings: techniques for line and instrument storage, means for controlled payout, bottom finders and lock up mechanisms, and it also outlines desirable specifications for sensor sizes, cables and connectors.

Next the report reviews typical deployment scenarios from the bottom up or from the surface down as they apply to the three types of moorings retained.

In its final section, the report presents the conceptual design of a 6000 meters depth capability, bottom up deployment, candidate mooring. This configuration should be of strong interest when contemplating the deployment of a large number of identical subsurface moorings, inter-connected by a bottom cable, and in "close" proximity to one another. The case study outlines the design objectives and the current profiles, specifies the main components, evaluates their performance with the help of a standard computer program, and presents packaging and payout control details. Finally, a plan is proposed for the controlled, in-situ evaluation of a prototype.

ACKNOWLEDGEMENTS

The input of C. Eck, Research Engineer, in formulating mooring performance monitoring instrumentation schemes and sensor specifications is greatly appreciated.

The authors want to thank Patrick O'Malley, Senior Engineering Assistant, for his valuable contribution in preparing and conducting the line payout tests described in the report.

The help of Betsey Doherty, Graphics Illustrator and of Wendy Liberatore, Staff Assistant, in preparing the figures and the text of the report is greatly appreciated.

This project was sponsored by the Office of Naval Technology under Contract Number N000-14-90-C-0098.

TABLE OF CONTENTS

1. **ABSTRACT**

2. **ACKNOWLEDGEMENTS**

3. **BACKGROUND**

4. **TYPES OF SELF DEPLOYABLE MOORINGS**

5. **COMMON FEATURES**

   Packaging Techniques
      Flat Pack
      Spinning Reel

   Inserted Instrumentation
   Sensor Specifications
   Cables and Connectors
   Payout Controls

      Bottom Finder
      Cable Counter

   Lock up Mechanisms

6. **DEPLOYMENT SCENARIOS**

   Subsurface Mooring
      Bottom Up
      Top Down

   Subsurface Mooring with Surface Expression
      Bottom Up
      Top Down

   Inverse Catenary Surface Mooring
      Top Down
      Bottom Up

7. **LIMITS AND PRACTICAL CONSIDERATIONS**

8. **CASE STUDY**

   Environmental Specifications
   Mooring Specifications
   Parametric Analysis
   Components Design
      Buoy
      Packaging Concept One
      Packaging Concept Two

Experimental Model and Proof of Concept
    Objectives
    Preliminary Testing on Land
    Sea Tests
        Test Specifications
        Test Schedule
        Monitoring Instrumentation
        Deployment and Recovery Scenario

9. CONCLUSIONS

10. REFERENCES

BACKGROUND

Deep sea moorings have been used by the oceanographic and military communities for nearly four decades to obtain Eulerian data from the ocean environment. Instruments and sensors have been developed to measure and record variables such as currents, temperature, conductivity, sound velocity and biomass within the water column. Meteorological instruments located on a moored surface buoy have extended the range of measurements available to researchers and forecasters.

Early efforts were punctuated by frequent failures, which lead to intensive engineering programs to better understand the environmental forces affecting these moorings and to determine the best materials and techniques to permit reliable large-scale deployments. Early on, efforts were made to design mooring systems which could be deployed in a manner to reduce increasingly expensive ship time. The military program RDSS (Rapid Deployment Surveillance System) is an example of a largely successful effort to provide a self-deployed mooring system, requiring minimal ship time for deployment. Other developments followed, including the ADOM (Air Deployed Oceanographic Mooring), [1], developed by the Woods Hole Oceanographic Institution, which was a pre-packaged mooring that could be launched from an aircraft or surface vessel and would automatically deploy sensors and a surface telemetry buoy anchoring itself in any water depth.

These and other developments have demonstrated the feasibility of the concept of automatic or self-deployment and the benefits leading to lower cost and covertness.

New developments in compact, light weight, instrumentation and inductively coupled and acoustic telemetry capabilities are paving the way for the development of expendable oceanographic moorings [2], [3], [4], [5], [6], [7] and [8]. These moorings could be assembled from prepackaged modular units and deployed by passing ships of opportunity.

Large numbers of moorings, interconnected by a bottom cable, in close proximity to one another, (HIGH GAIN ARRAY) can be juxtaposed by this deployment method with greatly reduced chance of entanglement [9].

Instrumented moorings could be dropped in the path of Hurricanes, Oil Spills, or other rapidly developing environmental phenomenon to aid in the understanding and tracking of them as they occur.

TYPES OF SELF-DEPLOYABLE MOORINGS

Self deployment technology is applicable to three basic types of single point moorings (Figure 1).

1. Subsurface moorings, either independent or interconnected by a bottom cable could be deployed in this manner. Deployment can proceed in either a top down or bottom up scenario. Interconnected moorings could be streamed like a lobster pot trawl and strung out on the bottom in the required configuration. Each mooring could then be commanded to deploy in turn. This technique may be the only viable way of deploying a large, closely spaced array without entanglement. More than one mooring could be allowed to deploy at one time if they were staggered in some pattern within the array to discourage entanglement.

2. A subsurface mooring with a slack tether connecting it to a small, wave decoupled, telemetering, surface expression can be deployed by this method. This type of mooring can be adapted to hardwire, inductively coupled or acoustic telemetry methods from arrays of small new generation single point instrumentation such as current meters and CTD's. This style can also be deployed from the top down or from the bottom up. The surface buoy can be pulled under during periods of strong currents but it is designed to return to the surface when the currents decrease.

3. Surface moorings that incorporate an inverse catenary in the lowest part of the water column are ideal for surface down deployment. The mooring line is designed to be on the order of 25 percent longer than the water depth [10] and [11]. This mooring will perform well as long as the water depth is within 10 percent of the design depth. This type of mooring can withstand much stronger currents than type two without sinking the surface buoy or dragging the anchor.

New light weight instrumentation will allow the use of small surface buoys, cable sizes and anchor weights in environmental conditions that are presently only accessible with large expensive moorings.

Hard wire attachment or inductive coupling of sensors to the mooring line may be used in the upper two thirds of this mooring type. The compliant portion of the mooring below this, (polypropylene and/or nylon), precludes the use of copper conductors or optical fibers due to the stretch characteristics of this element. However, acoustic telemetry can be used to extend the depth range of observations.

The self deploying surface mooring technique is well suited to Fish Aggregation Device, (FAD) moorings which could be prepackaged in modular units and shipped to remote sites [12]. The ability of this style of mooring to function in a wide range of water depths and current regimes allows for deployment without sophisticated marine electronics or highly trained deck crews.

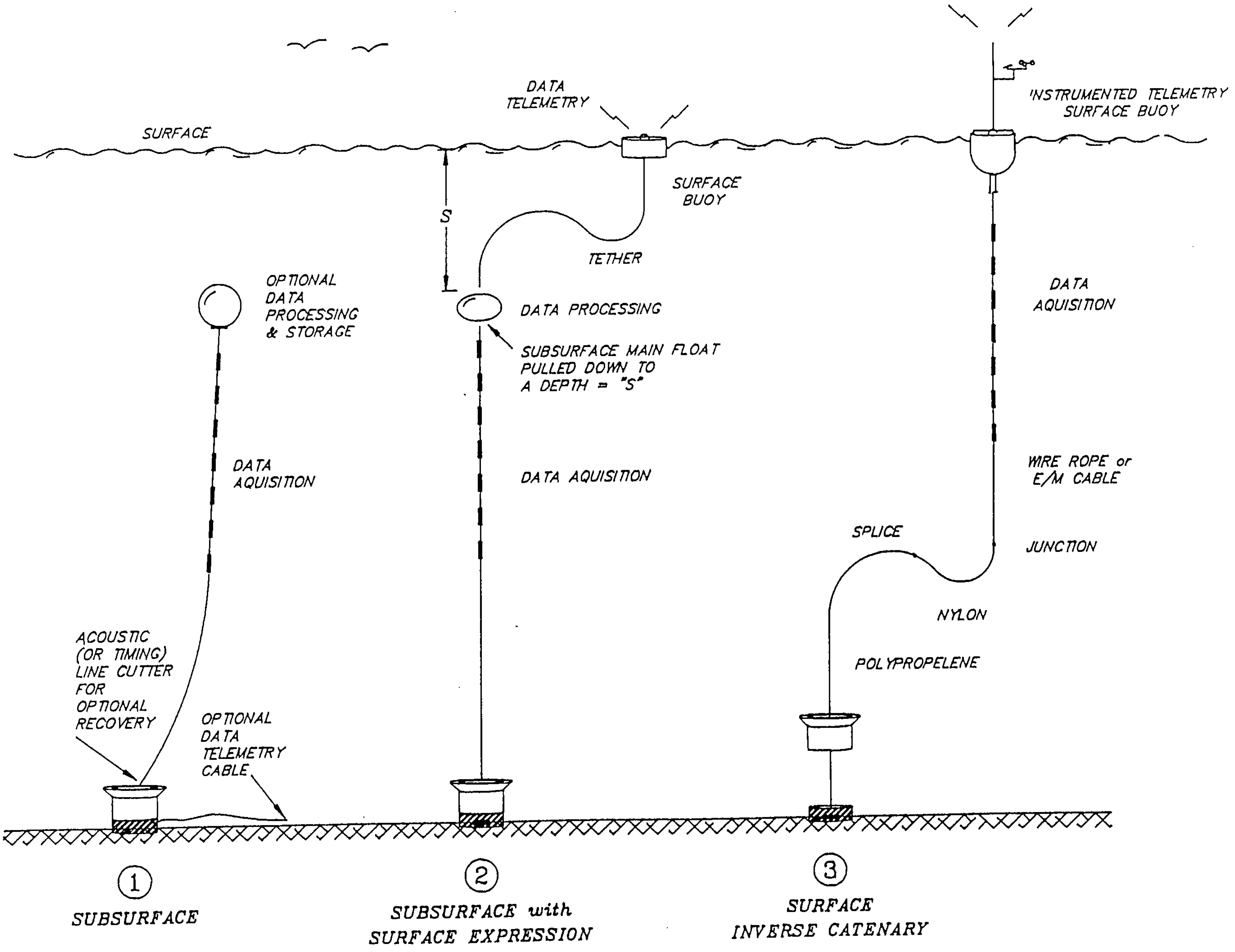

Figure 1 Applicable Mooring Types

COMMON FEATURES

PACKAGING TECHINQUES These three types of mooring require a number of similar components. They all require a packaging technique whereby long lengths of various types of cable or rope with or without inserted instrumentation will automatically pay out of a package. The formation of kinks or knots must be avoided during the pay out procedure. The sharp localized bend associated with a kink or knot can significantly reduce the cable strength and cause premature failure of the mooring system. A number of packaging schemes have been tested for feasibility. Detailed descriptions of the two most promising follow.

Flat Pack The cable coming from the buoy is coiled in a flat spiral from the outside of the packaging cylinder winding inwards to some specified minimum diameter. Additional cable is then coiled in the next flat layer in an expanding spiral. The direction of winding alternates from clockwise to counterclockwise between adjacent layers so that any rotation or torsion of the cable that is induced by packaging is canceled out.

The lower cable end leads out of the flat pack cylinder to the top of the instrument which is clamped to the inside of the outer shell of the package. The cable attached to the bottom end of the instrument is lead back into the next spiral layer.

The cable in the spiral layers must be bonded together by some potting compound to hold it in place and prevent tangling. This compound must be carefully applied to insure that several whole layers don't pull off at once. When this has happened in tests, the layers have tumbled after pealing off and tied a long length of cable into a knot. Tests have shown Thermal Plastic Rubber, (TPR), to be better than the several types of wax and contact adhesives that were tried. Further research is necessary in this area to optimize compound selection and insure consistent quality during packaging. The concept of placing sheets of paper between the layers to facilitate payout was the subject of several lab tests. The paper tended to tear out in large portions of a sheet, often taking several turns of cable that had not unwound with it. The bundle tended to tumble which kinked and knotted the cable. The paper also tended to jam the fairlead block which implies that it would also jam the counter or lockup mechanism.

When this method works properly it allows for a very dense packaging of long lengths of cable with and without inserted instrumentation.

Spinning Reel As shown in Figure 2, the cable is wound onto a reel over a specially shaped end flange in the same manner that a fishing line goes onto a spinning type fishing reel. Expendable bathythermographs, (XBT's) are wound for self deployment in this manner. A typical XBT contains two reels wound with a continuous length of wire. One reel stays attached to the launch tube and unwinds clockwise. The other reel is inside the XBT freefall body and unwinds counterclockwise. The counter-rotation results in zero net twisting of the two conductor wire. The XBT body has fins that cause the body to rotate clockwise as it falls both for flight stability and to help the cable feed out with minimum resistance.

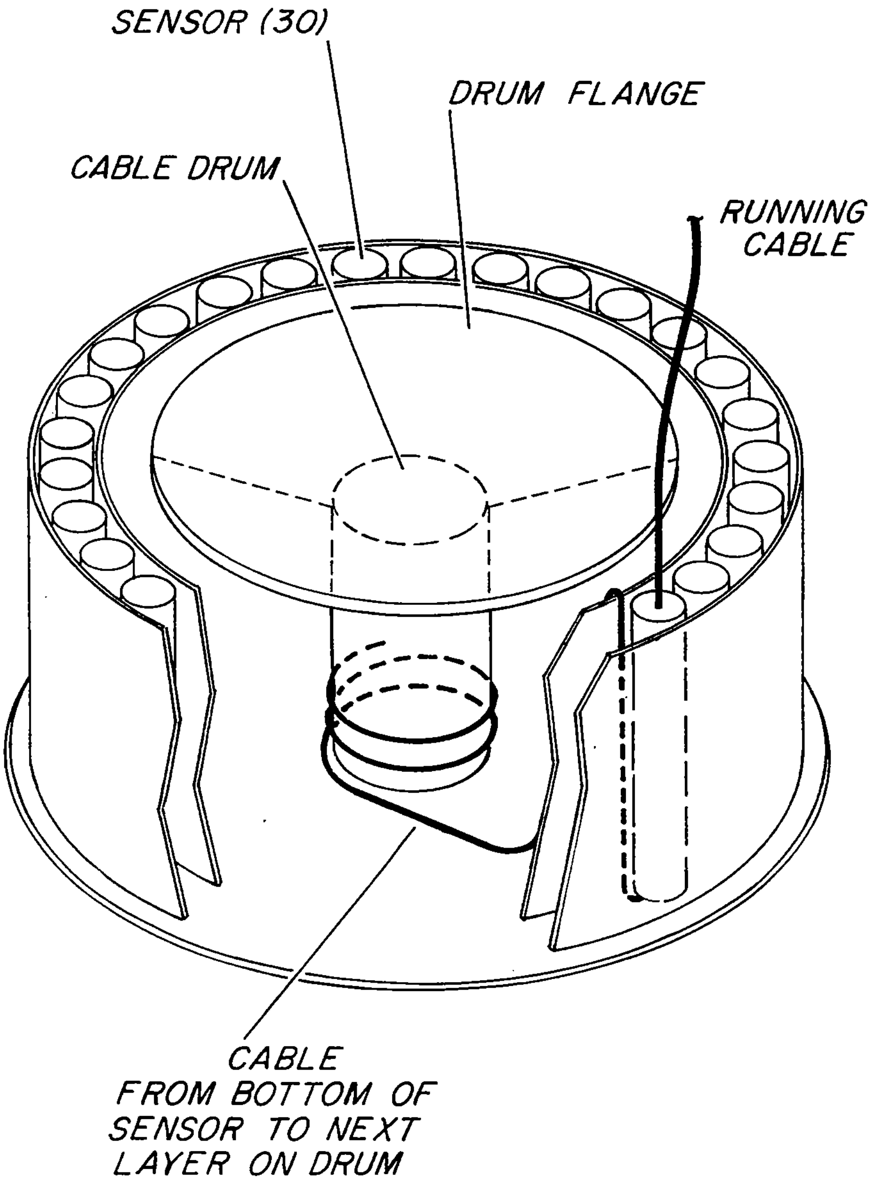

Figure 2: Spinning Reel Style Packaging with Instruments

In the proposed configuration, the instrumented portion of the mooring line would be wound clockwise over the bottom flange of a reel attached to the buoy. The top end of each segment would be lead out to the bottom of its instrument which is clamped to the inside wall of the packaging container. The segment attached to the top of each instrument would lead back in to the next windings on the same reel. The uninstrumented lower part of the mooring would be wound counterclockwise on a second reel attached to the anchoring system that would pay out over its top flange.

The traveling body should not be encouraged to rotate as it pays out as the XBT does. Some small rotational fins may be necessary to counteract the tendency of the bodies to spin due to the rotary friction of the cable against the pay out flange.

This method of cable winding is volumetrically less efficient than the flat pack method resulting in a slightly larger package.

INSERTED INSTRUMENTATION The instrument packages can be held to the inside wall of the package with breakaway plastic clamps or with VELCRO tear away fabric tape.

The instrument package size should be light weight, streamlined and compact. Transient loads resulting from the sudden acceleration of the instruments as the line pulls them out of the package can be reduced by minimizing the weight and entrained water mass of the instrumentation. A low hydrodynamic mass will minimize stress and snap loading on the cable and its attachment points.

Large instruments such as Acoustic Doppler Current Profilers could be incorporated into the subsurface buoy or possibly the anchoring system if required. Conventional current meters such as VACM's, VMCM's, or AANDERAA types would cause unacceptably high acceleration transients. These early instruments are also too large to package efficiently.

A continuous mooring cable without electrical or mechanical in line junctions is desirable to prevent hangups and kink formation by eliminating bending stiffness discontinuities and minimizing possible catch points. The sensor cable reliability would be increased and cost and complexity decreased, if the instruments could be attached without terminating the cable as in an inductively coupled or acoustic telemetry system.

SENSOR SPECIFICATIONS

Length: 8 to 12 inches
Diameter: 2 to 3 inches
Immersed weight: less than 5 Lbs
Pressure test rating: 10000 psi

In order to minimize or eliminate the connector problem, each instrument would be self powered, functioning independently on its own microprocessor, and multiplexing its data onto a common bus structure using the inductive coupling technique now under development. This technique would eliminate all of the vulnerable hardwired junctions except one at the top and allow for customized application oriented spacing of attachment points during manufacturing. A common receiver in the sub-surface buoy would gather data, inductively coupled to the tether by each of the instruments, as well as control and status information from the payout package itself. The data could be acoustically telemetered to a nearby surface vessel or uplinked from a surface buoy to a satellite.

These instruments could be constructed in a modular fashion. A single design power supply, measurement circuitry, data modulator and mechanical housing could be coupled to a number of different, independent interchangeable sensor heads. Depending on the packaging design of the payout module, and the accessibility of the instruments when loaded, individual sensor heads could be replaced prior to launch to change the sensor function, sensitivity or range.

CABLES AND CONNECTORS The basic payout technologies need to be proven on inexpensive mechanical only cables first. Ultimately telemetry from moorings deployed in this manner is a desired result. Satellite communications are data thru-put limited to a level that does not support the development of high data rate fiber optic cables and connectors. Moorings that are interconnected by hardwired bottom-layed cables could conceivably utilize fiber optic technology.

Cables with individual conductors or conductive armors can be used for hard wire or inductively coupled telemetry.

Synthetic armored cables such as Kevlar or Vectran offer the best flexibility for ease of packaging but offer little or no protection against fishbite unless encased in a protective jacket (Figure 3). A tight Kevlar braid loaded in tension has shown promise for surviving fishbite [13], [14] and [15].

Steel armored cables lack the flexibility of synthetic cables but are much more resistant to fishbite damage. Steel armors are much heavier in sea water than synthetic cables and therefore require much more buoyancy which drives the size and cost of the overall package up significantly. Steel armored cables suffer corrosive attack which does not affect synthetic fiber ropes.

No reliable, compact, cost effective, off the shelf, electro-mechanical cable connectors exist at this time for small diameter synthetic fiber cables. Development in this area will focus on adapting existing technology to fit the cable and packaging particulars in a cost effective manner.

The use of inductively coupled modems, reduces, but does not eliminate the need for E/M cable terminations. The manner in which the inductive modem is attached to the outside of the cable must be designed to eliminated stress and fatigue concentration points.

Electromechanical or electro-optical-mechanical mooring cables will require special consideration in the pay out system design to avoid damaging the signal carrying members or their terminations. Fiber optic cables are especially susceptible to breakage of the glass fibers when bent over a

CONDUCTORS: #20 AWG 19/32 TINNED COPPER

INSULATION: NOMINAL .015" THICKNESS, 105° PVC
COLOR CODED IN 3 SOLID COLORS

CONSTRUCTION: 3 CONDUCTORS CABLED TOGETHER
WITH A LEFT HAND LAY 8 TO 16 TIMES THE
CABLE CORE DIAMETER, (APPROX. DIA. = .150")

INNER JACKET: NOMINAL .250" DIAMETER
PRESSURE EXTRUDED CLEAR POLYURETHANE

STRENGTH MEMBER: 5000lb MINIMUM BREAK STRENGTH
KEVLAR BRAID TYPE 29,
2 LAYERS MYLAR TAPE BETWEEN LAYERS

JACKET: NOMINAL .050" THICKNESS, PRESSURE EXTRUDED
POLYURETHANE (APPROX. DIA. = .446")

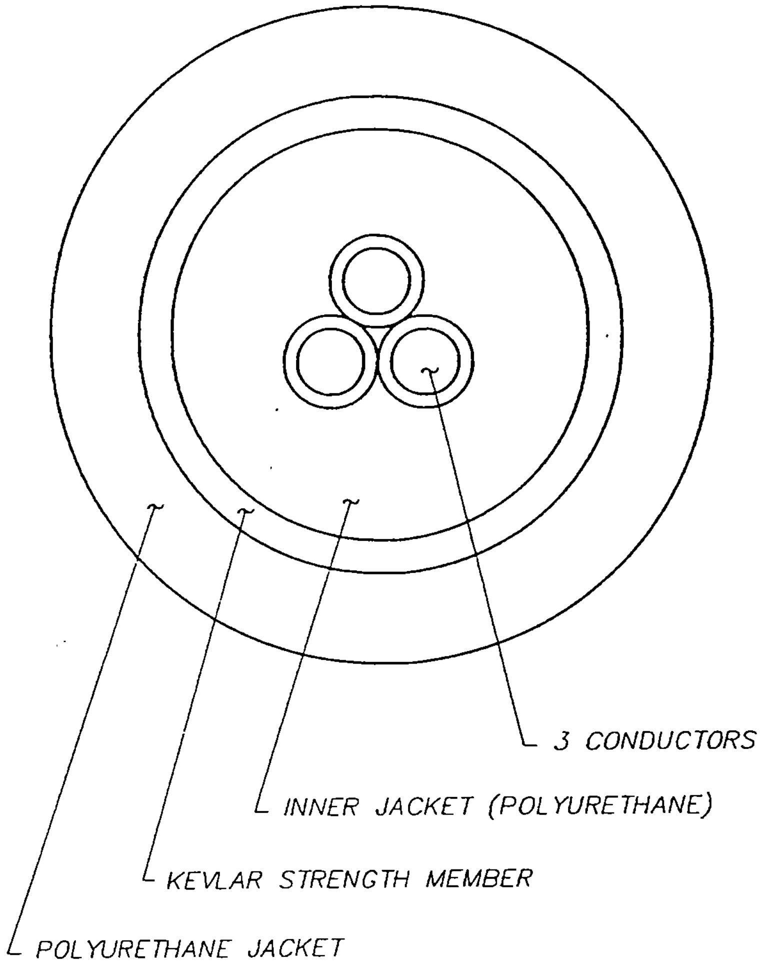

Figure 3 Typical Kevlar Armored Electromechanical Cable

small radius.

These cables are likely to be significantly larger than purely mechanical cables because they must be designed with sufficient additional strength such that the signal carrying members do not become load bearing when the cable elongates under tension.

PAYOUT CONTROLS Subsurface Moorings, (Type 1), and Subsurface Moorings with Surface Expressions, (Type 2), require some means of precisely measuring and controlling the amount of cable payed out to reach their proper depth. A number of methods have been suggested to accomplish this objective.

Bottom Finder: A mechanical or acoustic bottom or surface finder is used to cause a lockup of the pay out mechanism when the falling anchor or rising buoy reaches a preset distance from its objective. The major drawback of this method is that strong shear currents can cause more line to pay out than the distance between the buoy and the anchor.

Thus a Bottom up deployed, subsurface mooring, that locked up when it sensed it was 100 meters from the surface may actually overshoot and be on the surface when the buoy pulls the excess slack out of the line under low current conditions.

Cable Counter: An alternative method is to measure the amount of line payed out by leading the line through a cable length counter as it pays out. When it reaches a specified length, the lockup mechanism is engaged. The entire upper instrumented length is payed out in this case and it is only necessary to count the lower portion of the mooring line. The major drawback of this system is that the cable must pass through the length counter as it pays out. Traditional cable counters pass the cable over wheels and count the rotation induced in the wheels.

A cable that is covered in potting compound could cause significant difficulties. The potting compound may form a build up on the counter wheels which will degrade their accuracy, and could eventually cause jamming. A cable counter that sandwiched the cable between several cogged belts would be less susceptible to slippage and gumming up at the expense of higher pay out drag.

The spinning reel cable pack needs at least one flange diameter of open space outboard of the pay out flange. The cable is accelerated outward as it passes over the flange and is pulled back in line by the cable tension.

In either case the cable would have to be lead in and out of the counter thru a series of abrasion resistant low friction guides. Commercially available silicon carbide ceramic guides may be useful in this application.

LOCKUP MECHANISMS Early models such as the ADOM project locked up the mooring by causing a pin to cross the path of the flowing line causing it to wrap around a shaft. This method is adequate for short term deployments and proof of concept trials. It is likely that the cable will fail in fatigue at the point where the free end makes contact with the lockup pin because the cable is constrained to bend over the pin diameter. This pin diameter would have to be 20 to 40 times the cable diameter for the stress concentration to be effectively eliminated. A pin of this diameter causes significant packaging problems.

A system of cones that grip the cable inside an elastomeric bending strain relief boot is an attractive alternative (Figure 4).

Slack surface moorings, (3), are designed to pay out all of their cable regardless of water depth which results in a simpler system but does require approximate prior knowledge of the water depth for packaging.

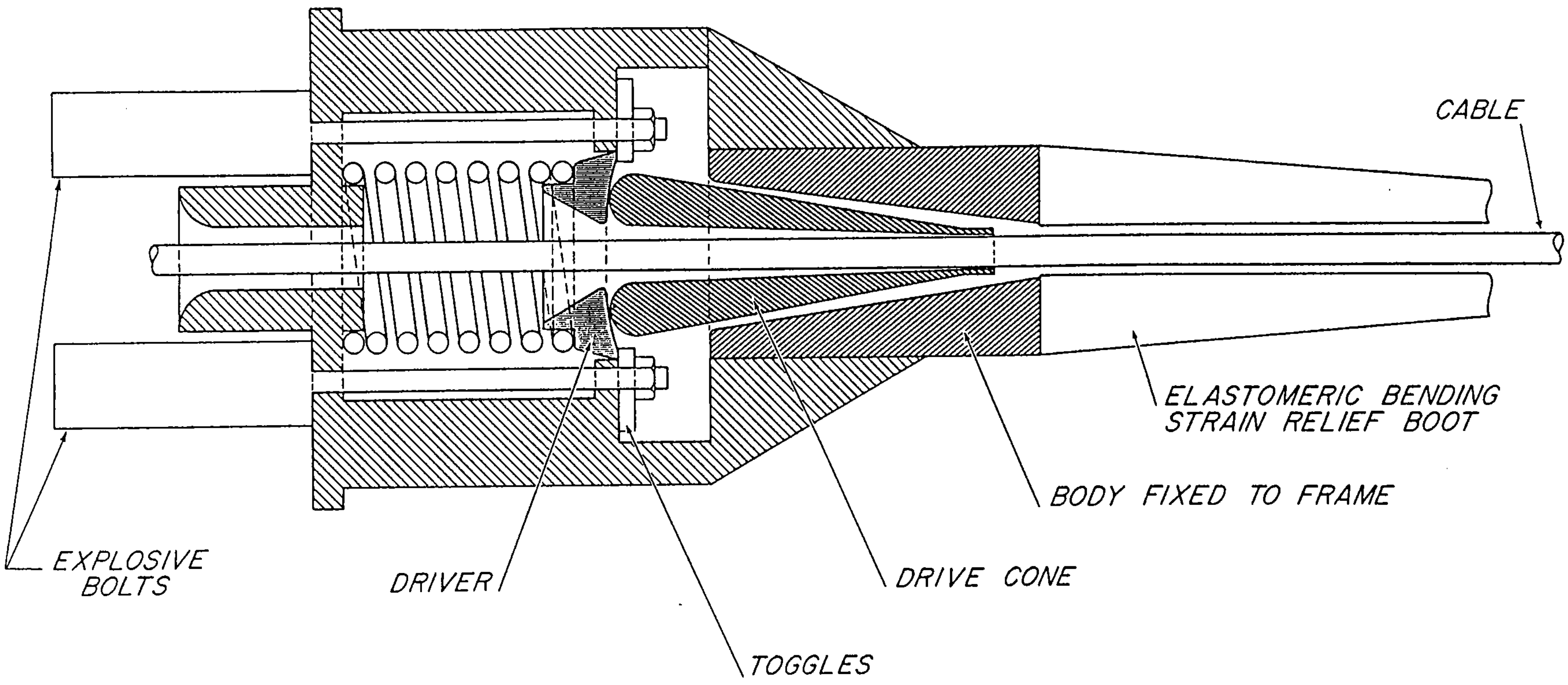

Figure 4 Dual Cone Lockup Mechanism

DEPLOYMENT SCENARIOS

SUB-SURFACE MOORING The self-deployment concept can be applied to a mooring which extends from the bottom to some depth below the surface. The concept can employ components which are designed to deploy from the bottom up, or from the surface down. Each scenario has its own advantages and disadvantages.

Bottom up - (See Figure 5). This concept employs a self-contained package, which is released from a surface vessel or submarine and sinks to the bottom in a free fall descent. The package may also be lowered to the bottom as would be the case where many interconnected packages are required to make up a horizontal array. After bottoming and upon a command from a timer or acoustically from the surface, the buoy flotation separates from the anchor and ascends, pulling out the sensors and mooring line. A line counter, located within the anchor, measures the amount of mooring line payed out and causes a mooring line lockup mechanism to activate, preventing further mooring line payout.

Top-Down - Self Deployed from Surface: This concept employs a self-contained package which is released from an airplane, a surface vessel or submarine. After water entry, the anchor portion separates from the buoyancy and sinks to the bottom, paying out sensors and mooring line as it falls. The buoyancy remains on the surface until lockup of the mooring line occurs. An acoustic altimeter, located in the anchor, is armed some distance from the surface and determines the anchor's distance off bottom, providing a signal to the mooring lockup mechanism at a predetermined distance from the bottom. Lockup of the mooring line causes the flotation to be pulled down a distance equal to the remaining anchor fall.

SUBSURFACE MOORING WITH SURFACE EXPRESSION When a surface expression is required for telemetry or surface measurements, a surface buoy can be employed. The buoy is attached to the subsurface buoy, using an "S" shaped tether to provide system compliance from wave induced forces. The tether should have distributed positive buoyancy near the subsurface buoy and distributed negative buoyancy below the surface buoy to minimize the risk of entanglement.

Bottom up - Self Deployed from Bottom: This deployment scenario is similar to the subsurface mooring except for deployment of the surface buoy. After the anchor has locked up and the flotation has ascended to its operating depth, the surface buoy and tether is released by a time-operated release, allowing the surface buoy to pull out the tether line as it ascends to the surface.

Top Down - Self Deployed from Surface: (See Figure 6). This scenario is similar to the self-deployed from the bottom scenario, except that the surface buoy and tether is released by a pressure operated release when the flotation has been pulled down to its operating depth. The surface buoy pulls out the tether line as it ascends.

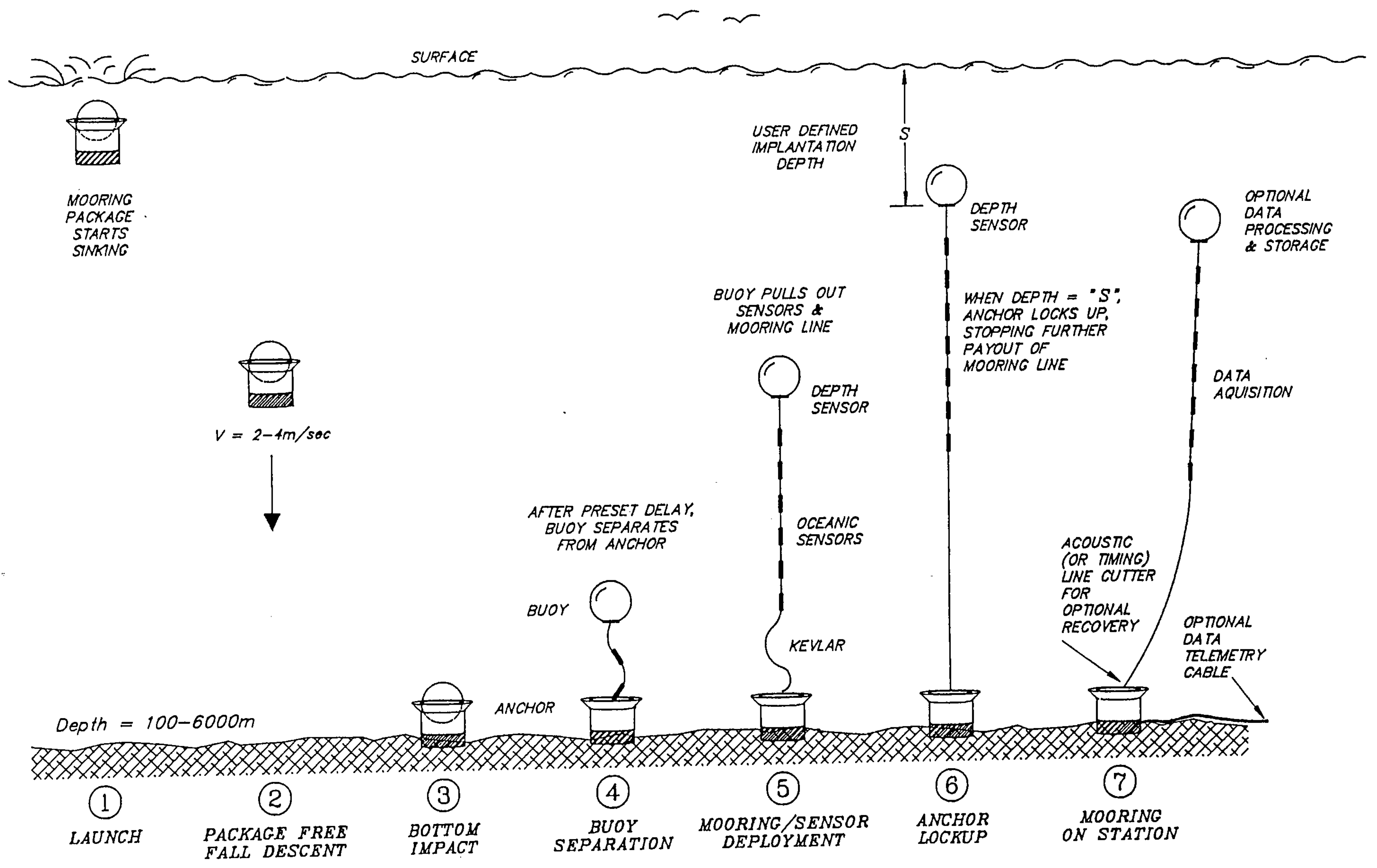

Figure 5 *SUBSURFACE MOORING – SELF DEPLOYED FROM BOTTOM CONCEPT*

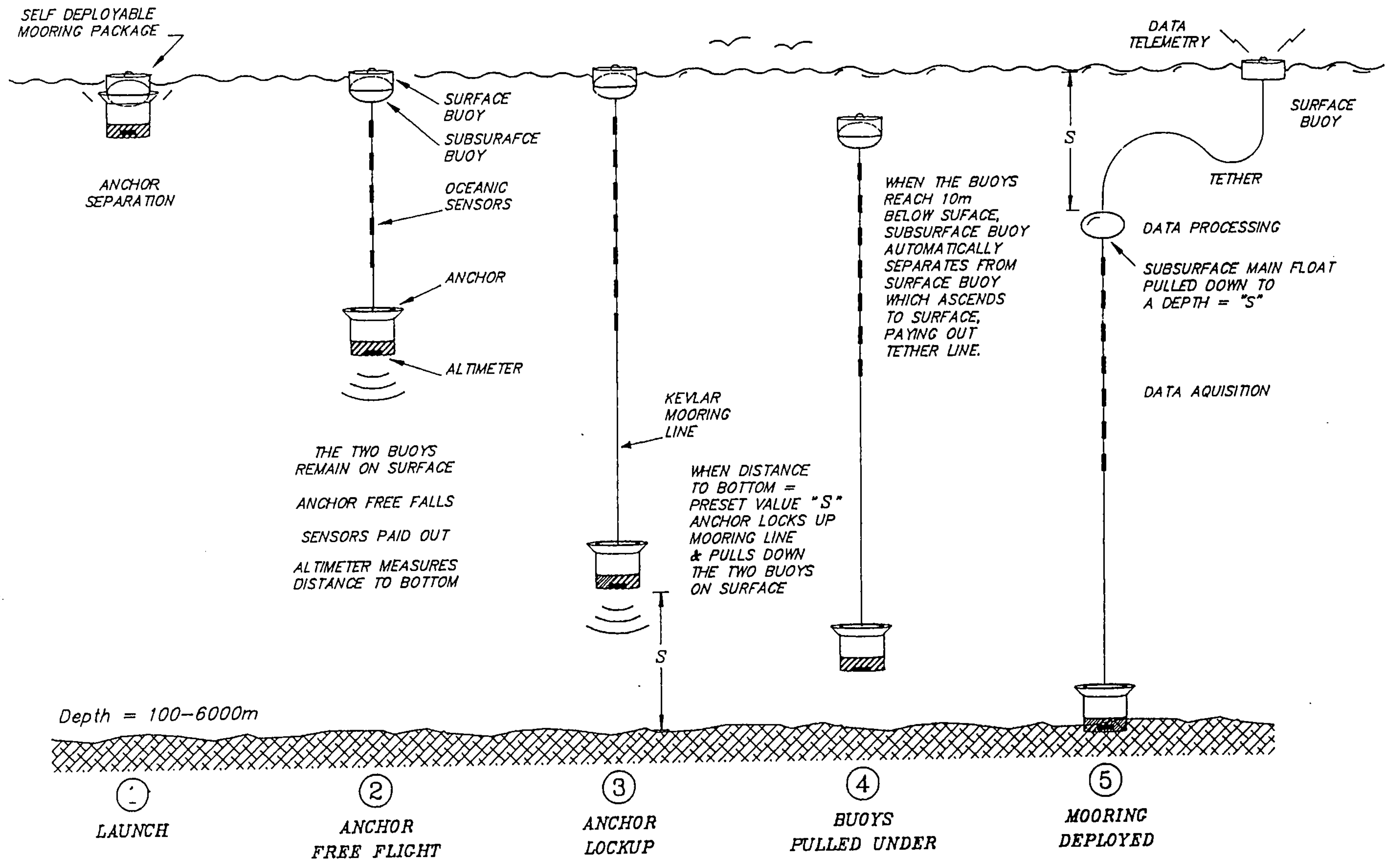

Figure 6 *MOORING – SELF DEPLOYED FROM SURFACE CONCEPT*

INVERSE CATENARY SURFACE MOORING (Figure 7)

Top Down - Self Deployed from Surface: The Mooring line is approximately 25% longer than the water depth. There is very little tension in this type of mooring under slack current conditions to pull the instrumented line out of the buoy. If all of the line does not pay out there is a chance that all of the instrumentation will not be deployed for some time after the mooring has been in the water. Wind, wave and current forcing would eventually cause them to deploy, but part of the data set might be distorted. If the anchor reaches the bottom before it has payed out all of its cable there is a chance of the mooring fouling around the anchor during slack current conditions.

In order to eliminate this potential problem, the upper part of the mooring system is deployed over the side of a ship underway. The mooring starts paying out of the package attached to the bottom of the surface buoy. The mooring is stretched out parallel to the water surface by the forwards motion of the ship. After at least one third of the mooring line length is payed out, the anchor portion of the mooring is deployed and also starts paying out. The water sheave effect caused by the vertical fall of the anchor pulling on the cable that is parallel to the surface ensures that all of the mooring line is pulled out of both ends before the anchor reaches the bottom.

In recoverable versions, the final meter of cable pulling up tight at the anchor will operate a mechanical release. This release will detach the syntactic foam anchor line container from the anchor and allow it to rise to the end of 3 meters of chain attached to an acoustic release that is built into the center of the container. The syntactic foam will be designed to act as backup recovery if the mooring should fail.

Similarly the last several meters of cable pulling out of the surface buoy will release 3 to 5 meters of chain. The chain acts to decouple the roll of the surface buoy from bending the mooring cable.

A depth recorder survey before launch, is necessary to be sure that the water depth is within a predetermined error margin for the amount of cable in the package.

A telemetry mooring would have the conductor cable spiral wound around the chain. The whole chain assembly would then be encapsulated in an elastomeric material to protect the electrical pigtail. This method has proven to be effective on a number of WHOI surface telemetry moorings.

Bottom Up - Self Deployed from bottom: There are no advantages to a bottom up deployment for this type of mooring.

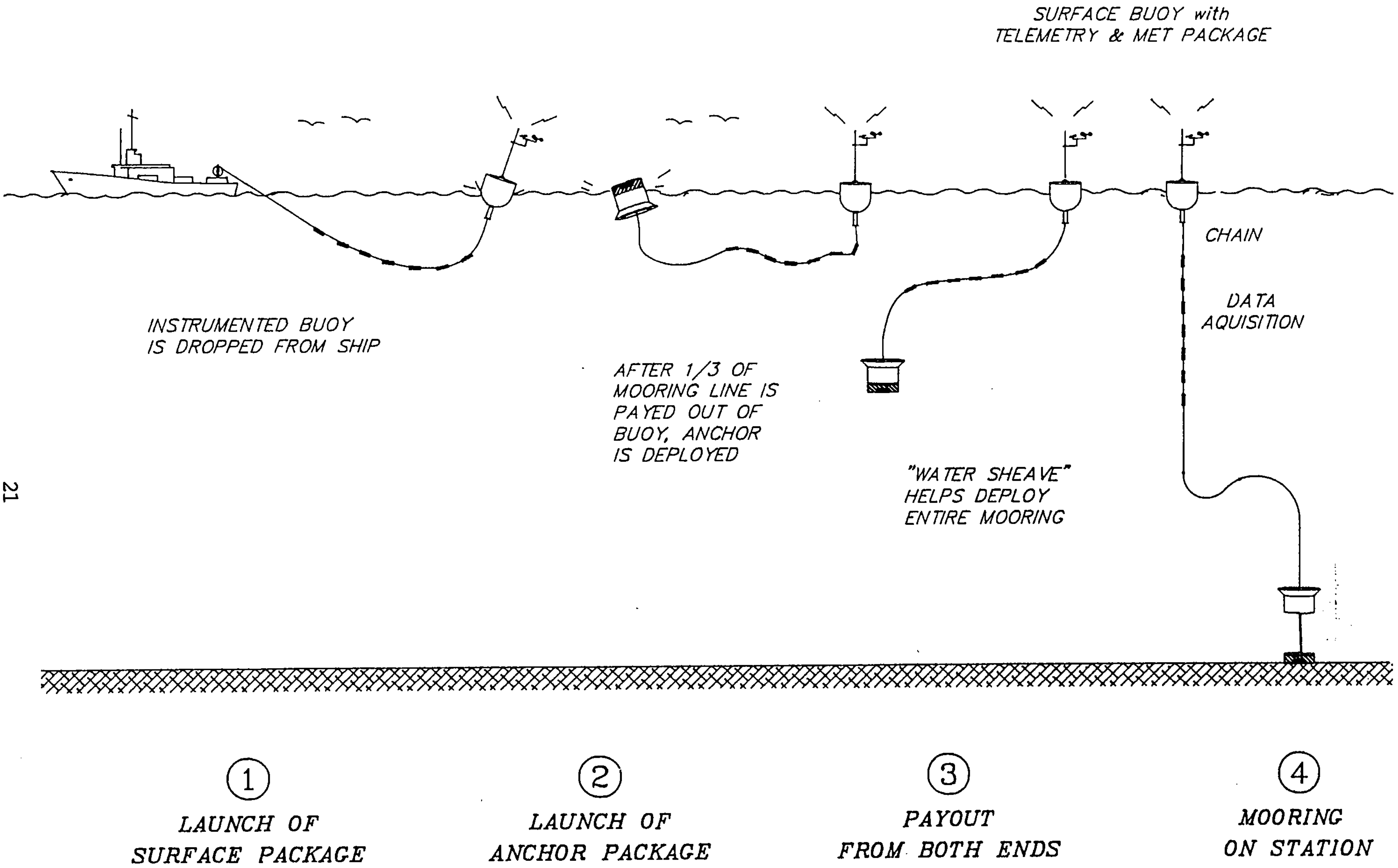

Figure 7 Inverse Catenary Mooring Deployment Concept

LIMITS AND PRACTICAL CONSIDERATIONS

Previous attempts at developing self deployed moorings (ADOM), were constrained in size and shape to accommodate a military specification. These specifications do not apply to oceanographic moorings and would eliminate several otherwise attractive packaging schemes that require a slightly larger size. After the fundamental design problems have been solved and proven by repeatable full scale testing, the feasibility of repackaging for a specific size parameter can be evaluated.

Bottom up deployment methods require that every mooring component must be able to withstand the pressure encountered at the full deployment depth. Deep water flotation foams are significantly more costly and volumetrically less efficient than their shallow water counterparts.

Surface down deployment methods require that only the bottom most components are capable of withstanding high hydrostatic pressures and so have the potential to be more cost effective.

The free rising or falling body must travel in a relatively straight line without tumbling or kiting.

For bottom up deployments, (types 1 or 2), there are actually two stability problems. The first as the complete package is descending to the sea floor and the second as the float module is rising up during self deployment.

If the complete package has any tendency to depart from a vertical flight path at terminal velocity, the mooring may deploy as much as several kilometers off station by the time it reaches the bottom in 5000 meters of water. If for any reason the package does not land upright, orderly payout may be impaired or prevented. The package must be designed to be statically and dynamically stable in the upright position.

After separation, the syntactic foam buoy must fly straight enough so as not to impair orderly payout. In the case of closely spaced interconnected moorings, any departure from vertical may result in the mooring fouling on its neighbor, which would result in the two cables chafing one another and one or both failing prematurely.

Adding a drag skirt to the afterbody of the package has been shown to increase flight stability [1]. Any departure from symmetry about the central axis, either from appendages or surface irregularities or due to the center of gravity or buoyancy being off center must be avoided.

On surface inverse catenary moorings that are to be placed where there is a steeply sloping bottom, any kiting off of the anchor could cause the anchor to reach bottom outside the design depth window. This could result in the mooring tangling or not paying out completely if the depth is too shallow. If the actual anchor depth is too deep, the mooring could become taut or at the limit run out of cable before the anchor reached bottom.

A trade off exists in terms of what the desired terminal velocity should be. A faster terminal velocity is beneficial because it gives the current less time to drift the mooring off of its intended station as the anchor or mooring package free falls to the bottom. This effect can be minimized by accounting for the set and drift and releasing the package at an appropriate offset distance.

The magnitude of disturbance required to cause flight instability decreases quickly as terminal velocity increases. Less than full scale model tests have proven unreliable as indicators of the magnitude of this instability because of the effects of scaling.

Each proposed packaging design requires full scale free fall flight stability testing as an integral part of its development effort.

The range of attainable terminal velocities varies from less than one to more than 5 meters per second.

CASE STUDY

A subsurface, Bottom up deployment mooring that utilizes a cable counter to signal the lockup device was chosen for this case study because of a perceived need for this technology within the Navy and Oceanographic community. A description of the mooring and a breakdown of the required development effort follow:

ENVIRONMENTAL SPECIFICATIONS:	
Maximum water Depth	6000 meters
Service Life	6 months to 2 years
Current Profiles	See Figure 9

MOORING SPECIFICATIONS:	
Maximum cable packaged	6000 meters
Mooring line Safety Factor	2.5
Instrumentation Load	Up to 30 instruments
Max. Instrument inclination	15 degrees re vertical
Max. weight per Instrument	-5 pounds
Approximate inst. dimensions including terminations.	2.5" Dia. by 12" long
Instrumented Length	3000 meters
Estimated buoyancy of subsurface float.	1000 pounds
Estimated immersed weight of anchor	-1500 pounds
Cable diameter	0.35 inches
Cable breaking strength	5000 pounds
Cable weight per meter	-0.0134 pounds

PARAMETRIC ANALYSIS The proposed mooring, (Figure 8), was studies using a finite element computer program. The typical oceanic current profiles, shown in Figure 9, were used to evaluate the performance of a mooring with the above specifications.

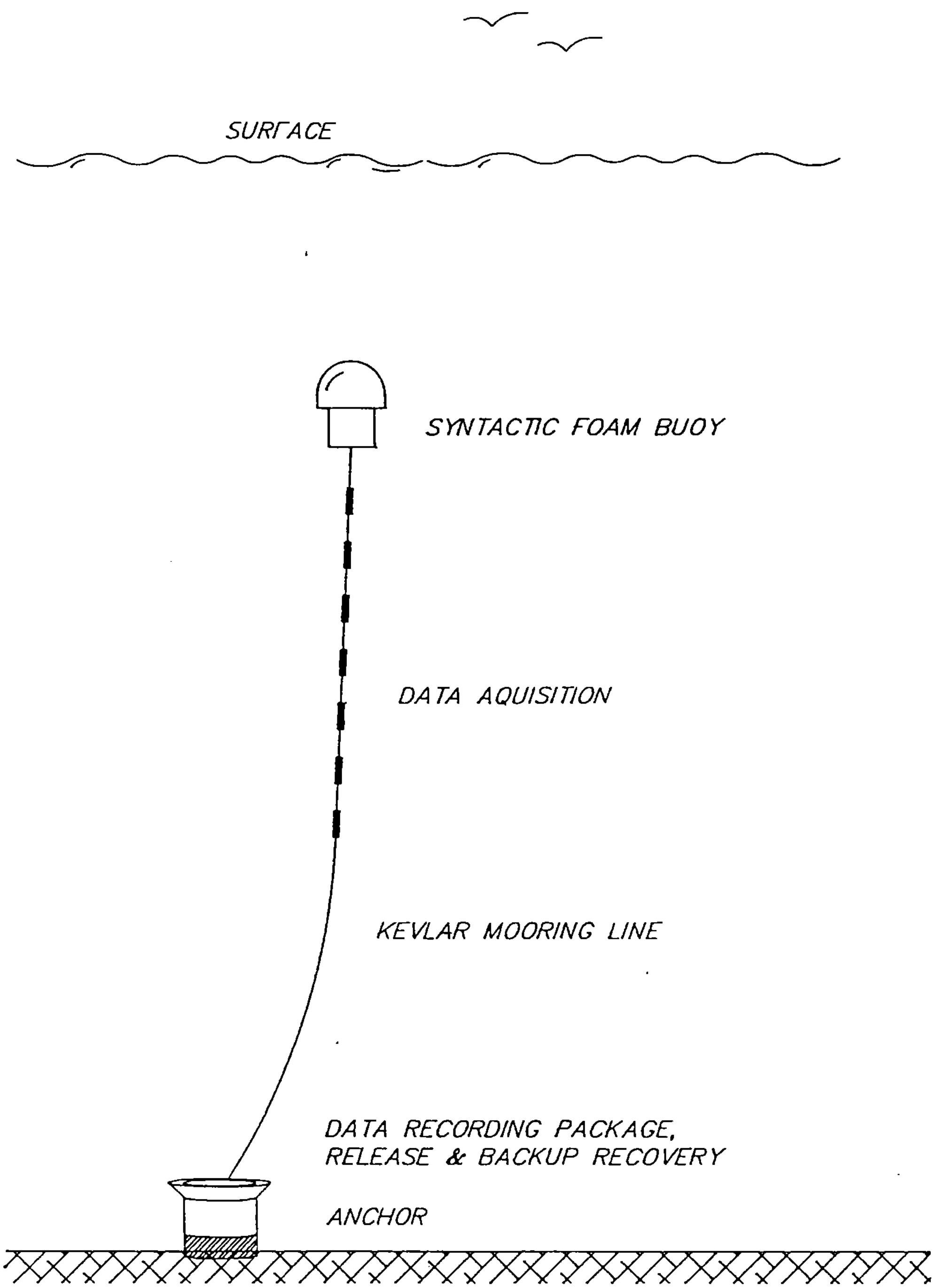

Figure 8 Subsurface Mooring Example

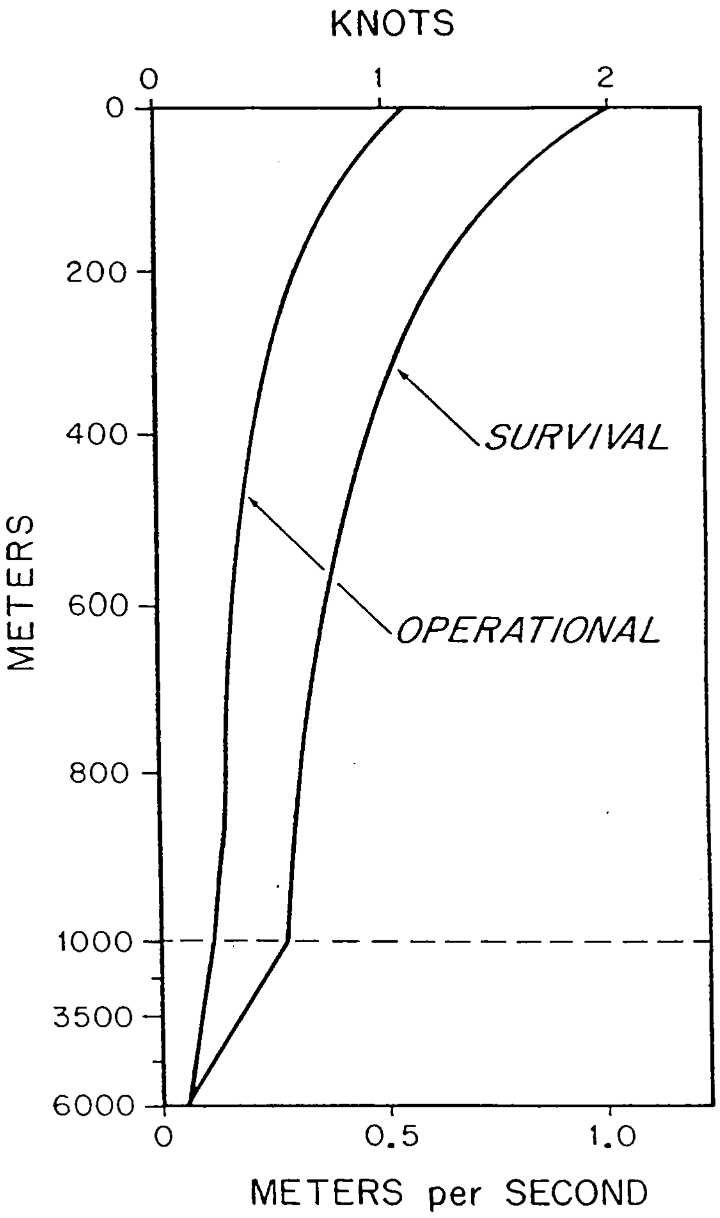

Figure 9 Current Profiles

Results of a parametric analysis appear in the following table:

Parameter	Zero Current	Design Current	Survival Current
Buoy depth (m)	800	805	889
Maximum Inst. Inclination (Deg.)	0	2	12
Watch circle radius @ buoy (m)	0	162	905
Anchor tension (pounds)	896	896	897
Min. Safety factor in cable	5.0	5.0	5.0

COMPONENTS DESIGN:

Buoy: A subsurface buoy with 1000 pounds of buoyancy satisfies typical depth excursion and instrument inclination criteria. The bottom up deployment method requires that the syntactic foam buoyancy modules for the subsurface buoy and the packaging container/backup recovery module, be rated for 6000 meters working depth. Several alternatives exist in the commercial sector for foams with this depth rating. Pour in place foam at 40 pounds per cubic foot can be precisely molded to the exact shape required. The density may be reduced slightly by placing 10, 12, 13, or 17 inch glass balls inside the shape. Sympathetic implosions between the glass spheres is possible at depth which could destroy the buoyancy module.

The second alternative is 32 pound per cubic foot density foam that is cast into blocks in a special pressure chamber. The bricks would have to be laminated together and then shaped. This would result in a somewhat more compact buoy but the cost would be much higher due to the many hours of labor involved and the hazardous working conditions involved in machining glass filled epoxy.

Packaging Concept One, Flat Pack Cable Stowage: The anchor module shell provides the packaging container for all of the mooring components (Figure 10). The syntactic foam buoy caps the shell and helps to stabilize the package during descent to the sea floor. An axisymetric flange protrudes from the outside of the package near the top, to provide some stabilizing afterbody drag force. The instrumented portion of the mooring line is packaged in flat spirally wound layers with the instruments clipped or Velcroed to the outside wall of the container.

A space containing the cable counting, fairleading and lockup mechanism is below the upper cable bay. The balance of the mooring line is stored on a spool with a universal winding located at the bottom of the packaging shell cavity. A central hub of this cable pack contains the control, data recording and release electronics packages. In recoverable versions, the packaging shell above the anchor is cast in syntactic foam which separates from the anchor when the release is fired and brings the bottom of the mooring to the surface. This packaging system is very similar to the ADOM design developed at WHOI.

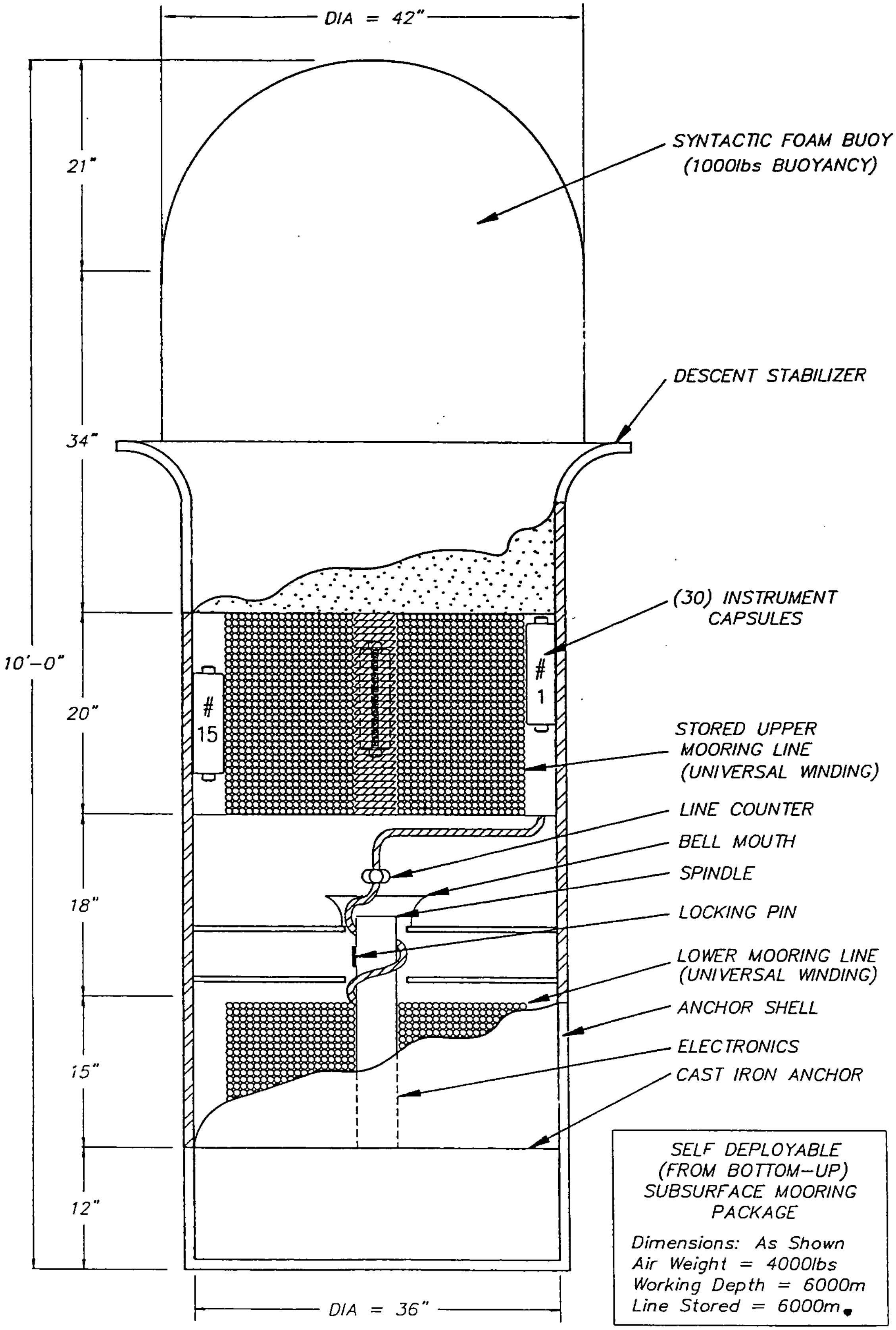

Figure 10 Self Deployment Package with Universal Winding

The syntactic foam is held to the top of the packaging container by explosive bolts which are fired to allow the mooring to deploy.

Packaging Concept Two, Spin Pack Cable Stowage: This packaging system is similar in appearance to the one previously described (Figure 11). The outside diameter has increased to approximately 48 inches at the stabilizing flange. The instrumented upper portion of the mooring line is wound on a spinning reel type spool that is molded as an integral part of the syntactic foam buoy. The pay out flange is covered with an ultra high molecular weight polyethylene skin for abrasion resistance. Instruments are attached to the skirt portion of the buoy with Velcro tape.

A hollow in the center of the pay out flange contains one meter of chain attached to the central strength member of the buoy and the top end of the mooring line. The chain is held inside the flange by a plastic membrane that is torn off by the force of the end of the cable fetching up on the buoy.

A void between the buoy section and the anchor section contains the caterpillar style cable counter, the fairleading system and the lockup mechanism. This system folds down flat for packaging and then extends above the anchor system on a spring loaded pipe frame to allow the cable to unwind from the lower spinning reel cable bay without slapping or abrading during deployment.

The lower spinning reel has the control, data recording and release electronics built into its hub. The reel body and container shell are made of syntactic foam and act as backup recovery for the mooring. The anchor is attached to the container by a release that activates when the anchor reaches the bottom. This allows the release and backup recovery to rise to the top of several meters of chain. The separation insures that the release and backup recovery will not get silted into the bottom. The separation will also provide a better communications path to the release.

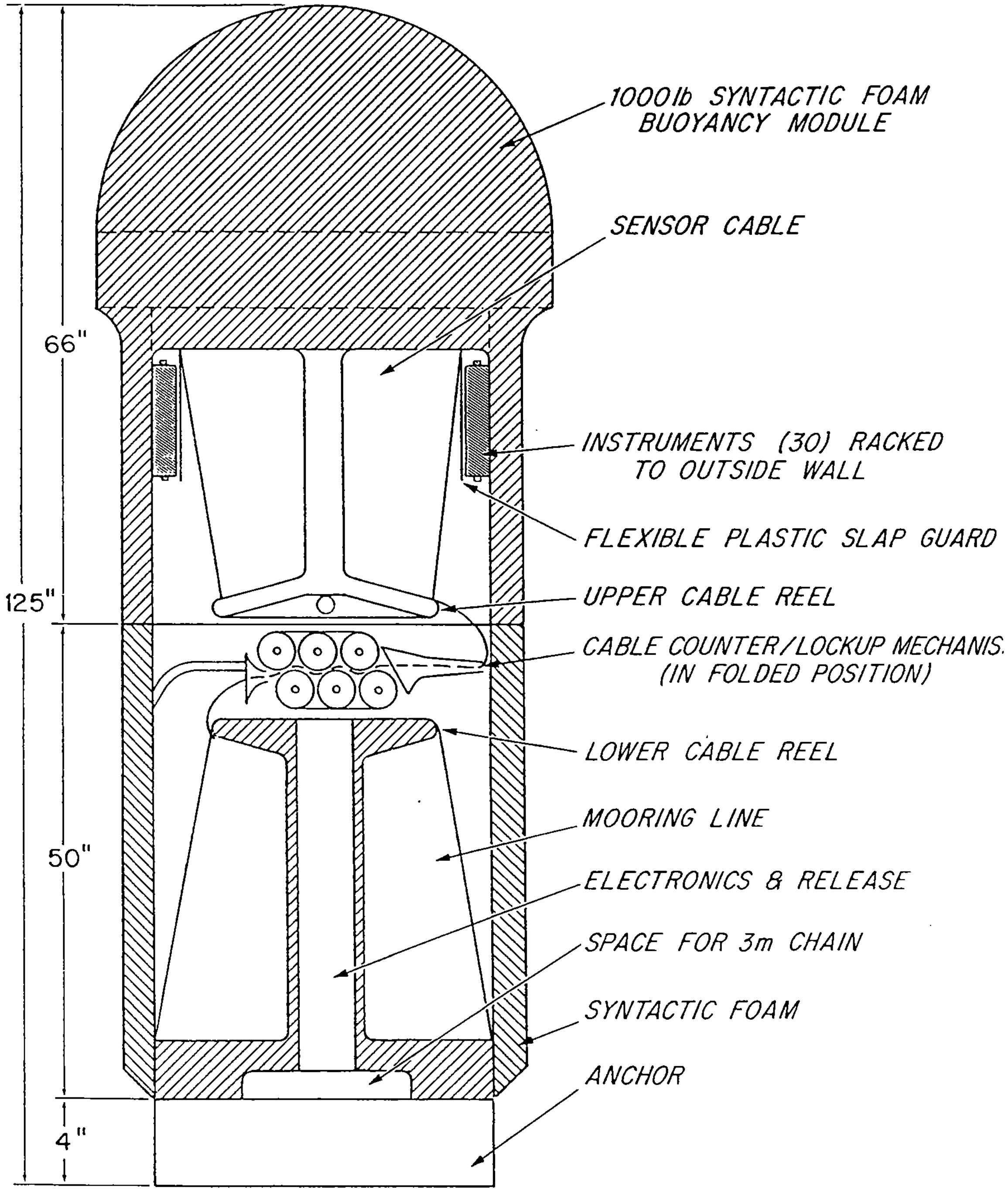

Figure 11 Self Deployment Package with Spining Reel Winding

EXPERIMENTAL MODEL & PROOF OF CONCEPT

Objectives:

Full scale field tests are necessary to develop the case study design into an operational unit. No one of the designs discussed in this paper will meet all of the needs of the Oceanographic and Navy communities. A development of any one of the possible designs will greatly simplify the development of any subsequent types due to the solution of shared common problems. Future development efforts must capitalize on the successful portions of previous work.

Areas which have been shown to be troublesome in past programs should be given priority attention.

1) Orderly pay out of mooring line including Stowage and pay out of sensor line and sensors.

2) Reliable sensing of the bottom or surface and accurate and reliable mooring line lockup mechanism.

3) Cables and connectors

4) Fishbite protection of mooring and sensor lines.

Testing of Specific Components: All of the mooring components should be designed, fabricated and thoroughly tested before attempting a full scale deployment. Tests of some of the fundamental components must precede the design of the overall package.

Preliminary Testing on Land:

Cable Packaging: A 500 meter single conductor cable sample with dummy instruments should be packaged in each of the two proposed schemes. Orderly payout can be tested at a local airfield with a simple overhead sheave and a vehicle moving at approximately the terminal velocity of the buoy. Several tests of each type should be conducted to gain an understanding of the nuances of each packaging method.

An in situ test of the cable payout including the effects of fluid damping can be made with a scale model in a water depth of up to 100 feet where correct payout can be photographed or video taped by divers.

The best candidate cable packaging system can be selected on the basis of the results of these tests. Winding methods should be optimized to yield the least number of turns in the cable as it pays out. The reversing of winding direction between the upper and lower pay out reels will help to a point. Reversing of winding direction between successive instruments in the upper section may also be advantageous. These tests will provide necessary experience in winding cable in the two candidate configurations. Data on actual packaging factors for the two different winding schemes is essential for designing the exact package size that is required.

1. Cable Packaging, Flat Pack:

The flat pack method was successfully employed on WHOI's ADOM project to coil the 100 meter bottom finder weight pennant. To test the feasibility of applying this method to longer instrumented lengths, four consecutive 100 foot lengths with instruments between were packaged in a flat pack with gummed paper between the layers. The paper caused numerous difficulties during the payout test including whole layers pulling out at one time. The layered bundle then proceeded to tumble and tied a knot in the cable. Additional testing with elastomeric potting compounds instead of paper is necessary. The universal winding method proposed for the lower section of the mooring cable was used in the lower section of the ADOM project with mixed results.

2. Cable Packaging, Spin Pack:

The spin pack method has never been attempted on this scale before at WHOI. Preliminary pay out testing on instrumented lengths of cable spooled in this manner showed promise. The crossover angle required for smooth pay out and how it effects the packaging density requires further investigation. A higher crossover angle will result in a larger required packaging volume and increased kinking of the cable at crossover points. Pay out from a lower crossover angle increases the risk of the live end burying and pulling out a wuzzle. This sometimes happens with spin type fishing reels if the line is wound with inadequate tension. Wuzzles formed on this type of fishing reel, will usually correct themselves as additional line is payed out providing that it does not get fouled in anything outboard of the flange.

Depth Control Methods: Two methods have been proposed to determine when to engage the cable lockup mechanism. The bottom or surface finder method and the cable counter method.

The mechanical bottom finder used on the ADOM project proved to have reliability problems due to flight instability of the sensor weight. Several manufacturers advertise off the shelf acoustic altimeters that should be evaluated as candidates for its replacement.

The caterpillar style cogged belt cable counter and lockup mechanism requires development and prototype testing.

Lockup Methods: The Cone grip style lockup mechanism requires development and prototype testing. The pin crossing the cable path method has been shown to work on the ADOM experiment.

Both types of lockup mechanism should be tested to optimize cable fatigue life in cyclic bending both in the lab and at sea.

Sea Tests:

Test Specifications

Water depth	5000 meters
Subsurface buoy depth	500 meters
Cable length stored in package	5000 meters
Design life	1 year
Site location	South of Bermuda
Deployment method	Bottom up
Depth control method	Cable counter
Number to be tested	Two units

Test Schedule: Two complete final units employing different variations should be tested in situ on several successive cruises. Fatigue and wear can only be evaluated from failure modes experienced after the mooring has been on station for a period of time. A time interval between cruises of several months will allow any necessary design changes identified on the first cruise to be implemented.

Monitoring Instrumentation: The reception of status information from the package is desirable so that orderly and correct deployment can be monitored. The electronics package can be designed to monitor the deployment sequence and report back the following information by acoustic telemetry.

1. Flight attitude during descent.
2. Altitude off the bottom or package depth during descent.
3. Bottom impact.
4. Package orientation after bottom impact.
5. Explosive bolt detonation and package separation controlled by the system clock or by acoustic command.
6. Depth of the ascending buoy and instrument string.
7. Engagement of lockup device.
8. The package should acoustically transpond to allow the ship to triangulate its position on the bottom.

An acoustic release modified with a microprocessor board can be programmed to perform these functions. The flight and landing attitude can be monitored with accelerometers, tilt sensors or a gyroscope. A depth sensor or altimeter located at the top of the buoy can be wired to telemeter down the cable to the electronics package located in the anchor shell to provide depth information during both ascent and descent.

The explosive bolt system can be designed to be mechanically redundant such that the successful detonation of any one of several bolts will release the package as intended. Separation can be determined by mounting a magnet on the buoy and a reed switch on the package. A similar arrangement can be incorporated into the lockup mechanism to indicate when the cone or pin has properly engaged. Magnet and reed switch systems can be used to indicate when each of the sensors are deployed, but the large number of sensors significantly increases the complexity of the electronics and wiring required.

Acoustic transponding for location is a normal function of most acoustic releases.

Deployment and Recovery Scenario

1. Deployment, Bottom up: The water depth and lockup depth are programmed into the controller software for the actual depth at the mooring site. Alternatively, the lockup depth is programmed and the package uses a pressure sensor or altimeter to measure the water depth. The package is released and allowed to free fall to the bottom. A timed or acoustic command fires an explosive bolt which allows the buoy to detach from the package and start pulling out the mooring line. The instrumented portion of the mooring pays out completely. The cable counter measures the cable length paying out of the bottom cable pack and signals the controller to activate the lockup device. The controller also fires an explosive bolt that allows the syntactic foam package to rise above the anchor on several meters of chain. Deployment is now complete: The position of the anchor and buoy can now be acoustically determined from the surface ship by triangulation.

2. Recovery, Including Emergency backup measures: If the mooring line should fail at some time during the deployment, the buoy would rise to the surface. A self contained underwater ARGOS transmitter located in the top of the buoy would notify the users that the buoy was adrift. The buoy could be recovered with the aid of the ARGOs location message. The bottom half of the mooring line would sink to the bottom. The syntactic foam packaging container is designed to have enough buoyancy to bring up the remainder of the mooring when the release is actuated. The buoyancy of the foam should be several hundred pounds in excess of the sum of the weights of the components that it would be lifting. This insures that any portion of the mooring that has settled into the bottom mud, would be pulled free, and that the mooring could rise thru any strong current shears without being swept away.

CONCLUSIONS

Self deployment of oceanographic moorings is feasible. Increasing ship time costs and the new emphasis on long term, global coverage, environmental modeling make this technology more attractive than ever before.

It is important to note that much of the work required to develop a successful, self deploying mooring has already been completed. Each of the mooring types discussed, have been used repeatedly on full scale deep ocean deployments, when launched in a conventional, ship time, and labor intensive manner. The following tasks relative to self deployment have been successfully completed on previous programs.

A. Hydrodynamic analysis of the Self-deployment sequence.

B. Free fall flight Stability analysis and drop tests.

C. Anchor holding characteristics.

D. Hydrodynamic analysis of the deployed mooring types including wave forces on the several surface buoy options.

E. Terminal velocity calculations and verification tests.

F. Explosive bolt separation tests at depth and pressure.

G. Preliminary testing of the instrument packaging method.

H. Preliminary testing of the Flat Pack and Spin Pack cable spooling systems.

I. Advances in low power, computer-controller and sensor electronics will facilitate the real time monitoring of the deployment to a degree that was unattainable on previous attempts.

Much of the mooring work that takes place today relies on instrumentation technology that is over twenty years old. The large size, weight and drag of these instruments necessitates the use of large buoys, large diameter mooring lines and heavy anchors. The number of moorings which can be deployed on any one cruise is limited by the number of large components that will fit on deck. The ship time cost associated with deploying arrays of moorings is often a large fraction of the total project budget.

The self deploying mooring offers the benefits of reduced ship time and an increase in the number of moorings which can be carried by a given ship on a cruise. The initial price tag of new sensors is significant. The cost of maintaining older instrumentation increases every year. New instruments offer greatly increased flexibility in terms of sampling rates, on board data manipulation, data storage and telemetry capabilities in a much smaller, lighter, package.

The decrease in instrument size and weight allows for the down sizing of all other mooring components for the same mission and safety factor on a given mooring. The decrease in mooring component size can result in cost savings of as much as 50 % per mooring.

The development of self deployable oceanographic moorings is a necessary, logical evolution of technologies presently in use. The successful development and implementation of this technology opens doors for a broad spectrum of future uses with a strong potential for increase in data returned per unit cost.

REFERENCES

[1] "Air Deployed Oceanographic Mooring - AB1034, L.W.Bonde, D.B.Dillon, Washington Analytical Services Center Inc., E.J.Softley, Ocean Electronic Applications Inc., R.G.Walden, H.O.Berteaux, Woods Hole Oceanographic Institution, T. Popp, Naval Air Development Center. Proceedings Oceans 83, San Francisco Ca, August 1983

[2] "Modular Acoustic Velocity Sensor, (MAVS)", D.A.Trivett, A.J.Williams III, E.A.Terray, Proceedings; Current Measurement 90 Symposium. IEEE

[3] "Recent Developments in Ocean Data Telemetry", D.E.Frye, B.Owens, In preparation for publication in proceedings, Oceans 91, IEEE

[4] "Digital output temperature sensing module for Oceanographic & Atmospheric Measurements", Proceedings, Marine Instrumentation 90, March 90

[5] "An Acoustic Telemetry System for Deep Ocean Mooring data Acquisition and Control", J.Catipovic, M.Deffenbaugh, L.Freitag, D.E.Frye, Proceedings of Oceans 89, Sept 1989

[6] "Robust 5000 bit per second underwater communication system for remote applications", Proceedings MTS 90, Oct. 90

[7] "Surface Telemetry Engineering Mooring, STEM", H.O.Berteaux, P.R.Clay, D.E.Frye, E.C.Mellinger, Oceans / IEEE proceedings, Baltimore MD, Nov 1988

[8] "Expendable Meteorological and Oceanographic Instruments", T.R.Herrett, Planning Systems Inc. Slidell ,Louisiana, R.L.Pickett, NORDA Code 311, Published ASW Oceanographic program office, NORDA Technical Note 405, September 1988 (Limited Dist.)

[9] "Severe Environment Surface Mooring, SESMOOR", S.M.Kery, Proceedings, Oceans 89, Sept. 1989

[10] "NDBC Mooring Design Manual", D.R.May Lt. U.S.C.G., National Data Buoy Center, Feb, 1988

[11] "Design Improvements to fish aggregation device (FAD) Mooring systems in general use in Pacific Island Countries", R.L.Boy, B.R.Smith, South Pacific Commission, Handbook No.24, (1984)

[12] "Deep Sea Moorings Fishbite Handbook", H.O.Berteaux, B .Prindle, WHOI Technical Report 87-8

[13] "Preliminary Assessment of fishbite resistance of lines designed for use in Deep Sea Moorings". B. Prindle, National Data Buoy Center Reference order No. 400-QANW-6-00458:S-1, May, 1987, Woods Hole Oceanographic Institution.

[14] "Evaluation of Mooring Line Resistant to Shark Bite". D.L .Feigenbaum, Prepared for NDBC, Feb,1989, By Old Dominion University Research Foundation.

[15] "Electromechanical cable to buoy transition, The potted chain method", S. Kery, Unpublished technical memorandum. Woods Hole Oceanographic Institution, January 1991

DOCUMENT LIBRARY

March 11, 1991

Distribution List for Technical Report Exchange

Attn: Stella Sanchez-Wade
Documents Section
Scripps Institution of Oceanography
Library, Mail Code C-075C
La Jolla, CA 92093

Hancock Library of Biology &
Oceanography
Alan Hancock Laboratory
University of Southern California
University Park
Los Angeles, CA 90089-0371

Gifts & Exchanges
Library
Bedford Institute of Oceanography
P.O. Box 1006
Dartmouth, NS, B2Y 4A2, CANADA

Office of the International
Ice Patrol
c/o Coast Guard R & D Center
Avery Point
Groton, CT 06340

NOAA/EDIS Miami Library Center
4301 Rickenbacker Causeway
Miami, FL 33149

Library
Skidaway Institute of Oceanography
P.O. Box 13687
Savannah, GA 31416

Institute of Geophysics
University of Hawaii
Library Room 252
2525 Correa Road
Honolulu, HI 96822

Marine Resources Information Center
Building E38-320
MIT
Cambridge, MA 02139

Library
Lamont-Doherty Geological
Observatory
Columbia University
Palisades, NY 10964

Library
Serials Department
Oregon State University
Corvallis, OR 97331

Pell Marine Science Library
University of Rhode Island
Narragansett Bay Campus
Narragansett, RI 02882

Working Collection
Texas A&M University
Dept. of Oceanography
College Station, TX 77843

Library
Virginia Institute of Marine Science
Gloucester Point, VA 23062

Fisheries-Oceanography Library
151 Oceanography Teaching Bldg.
University of Washington
Seattle, WA 98195

Library
R.S.M.A.S.
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33149

Maury Oceanographic Library
Naval Oceanographic Office
Stennis Space Center
NSTL, MS 39522-5001

Marine Sciences Collection
Mayaguez Campus Library
University of Puerto Rico
Mayaguez, Puerto Rico 00708

Library
Institute of Oceanographic Sciences
Deacon Laboratory
Wormley, Godalming
Surrey GU8 5UB
UNITED KINGDOM

The Librarian
CSIRO Marine Laboratories
G.P.O. Box 1538
Hobart, Tasmania
AUSTRALIA 7001

Library
Proudman Oceanographic Laboratory
Bidston Observatory
Birkenhead
Merseyside L43 7 RA
UNITED KINGDOM

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. WHOI-92-08

2.

3. Recipient's Accession No.

4. Title and Subtitle
Self Deployable Deep Sea Moorings

5. Report Date
January 1992

6.

7. Author(s)
H.O. Berteaux, S.M. Kery, R.G. Walden

8. Performing Organization Rept. No.
WHOI-92-08

9. Performing Organization Name and Address

Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) N00014-90-C-0098
(G)

12. Sponsoring Organization Name and Address
Office of Naval Technology

13. Type of Report & Period Covered
Technical Report

14.

15. Supplementary Notes
This report should be cited as: Woods Hole Oceanog. Inst. Tech. Rept., WHOI-92-08.

16. Abstract (Limit: 200 words)

As part of a development effort in the field of moored arrays sponsored by the Office of Naval Technology, the Ocean Structures and Moorings Laboratory (OSM&L), Applied Ocean Physics and Engineering Department (AOP&E), Woods Hole Oceanographic Institution (WHOI) conducted a study in 1991 to assess the feasibility and the merits of several self deployable mooring designs. This study included a brief review of the state of the art, the performance of lab tests to evaluate different mooring line payout concepts, and the preliminary design of a typical candidate mooring. The results of this study are presented in this report.

The report first reviews three types of single point moored arrays which are amenable to self-deployment: subsurface, subsurface with surface expression, and surface with bottom inverted catenary. It then describes the features common to all self deploying moorings: techniques for line and instrument storage, means for controlled payout, bottom finders and lock up mechanisms, and it also outlines desirable specifications for sensor sizes, cables and connectors.

Next the report reviews typical deployment scenarios from the bottom up or from the surface down as they apply to the three types of moorings retained.

In its final section, the report presents the conceptual design of a 6000 meter depth capability, bottom up deployment, candidate mooring. This configuration should be of strong interest when contemplating the deployment of a large number of identical subsurface moorings, interconnected by a bottom cable, and in "close" proximity to one another. The case study outlines the design objectives and the current profiles, specifies the main components, evaluates their performance with the help of a standard computer program, and presents packaging and payout control details. Finally, a plan is proposed for the controlled, in-situ evaluation of a prototype.

17. Document Analysis a. Descriptors

moored arrays
self deployable moorings
expendable moorings

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement
Approved for public release; distribution unlimited.

19. Security Class (This Report)
UNCLASSIFIED

20. Security Class (This Page)

21. No. of Pages
40

22. Price

(See ANSI-Z39.18) *See Instructions on Reverse* OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce