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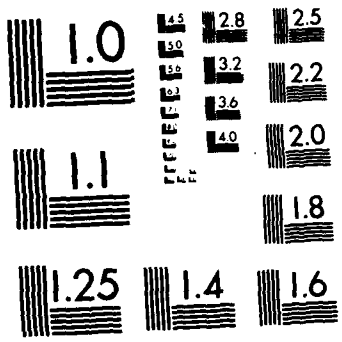

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In response to the need for low cost, rapidly deployed, deep ocean, instrumented data platforms, a program was sponsored by the Office of Naval Research to develop an Air Deployed Oceanographic Mooring (ADOM). This mooring consists of a subsurface buoy, taut moored by a cable with in line sensors, and contains a computer for data acquisition and processing. A surface float housing a satellite transmitter and antenna is tethered to the subsurface buoy by a compliant data line. The design evolved from a feasibility study, theoretical

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analyses, and testing in the laboratory, dockside, and at sea.

The program included a series of system deployments at sea. Temperature data were acquired by ADOM and telemetered to the shore station via the USAF LES-9 satellite according to a pre-set schedule. The test program concluded with two air drops from a U.S. Marine Corps C-130 aircraft. These tests demonstrated that the Air Deployed Oceanographic Mooring is a practical method for ocean data acquisition.

AIR DEPLOYED OCEANOGRAPHIC MOORING - AB1034

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Summary

In response to the need for low cost, rapidly deployed, deep ocean, instrumented data platforms, a program was sponsored by the Office of Naval Research to develop an Air Deployed Oceanographic Mooring (ADOM). This mooring consists of a subsurface buoy, taut moored by a cable with in line sensors, and contains a computer for data acquisition and processing. A surface float housing a satellite transmitter and antenna is tethered to the subsurface buoy by a compliant data line (Figure 1). The design evolved from a feasibility study, theoretical analyses, and testing in the laboratory, dockside, and at sea.

ADOM is bolted together for launch as a single cylinder (Figure 2). The anchor shell contains the bottom finder assembly, mooring line, mooring lock-up mechanism, and sensor array. The computer controller is housed in the subsurface buoy. The parachute deploys from one end.

The parachute is deployed in stages by explosive line cutters. It is released and the mooring deployed by explosive bolts fired in sequence using batteries activated by seawater.

A one-year active life is attained by using low power "CMOS" for the processor, memory, and sensor circuits. A unique scheme was devised to address the sensors. An array of temperature sensors has been integrated into a single conductor armored cable.

The program included a series of system deployments at sea. Temperature data were acquired by ADOM and telemetered to the shore station via the USAF LES-9 satellite according to a pre-set schedule. The test program concluded with two air drops from a U.S. Marine Corps C-130 aircraft. These tests demonstrated that the Air Deployed Oceanographic Mooring is a practical method for ocean data acquisition.

Introduction

Objective

The objective of this program was to develop an air deployed deep sea mooring which could make oceanographic measurements, then telemeter this data via

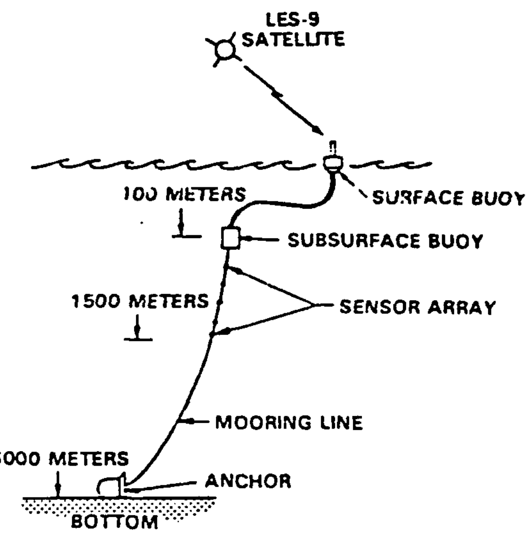

Figure 1. Air Deployed Oceanographic Mooring

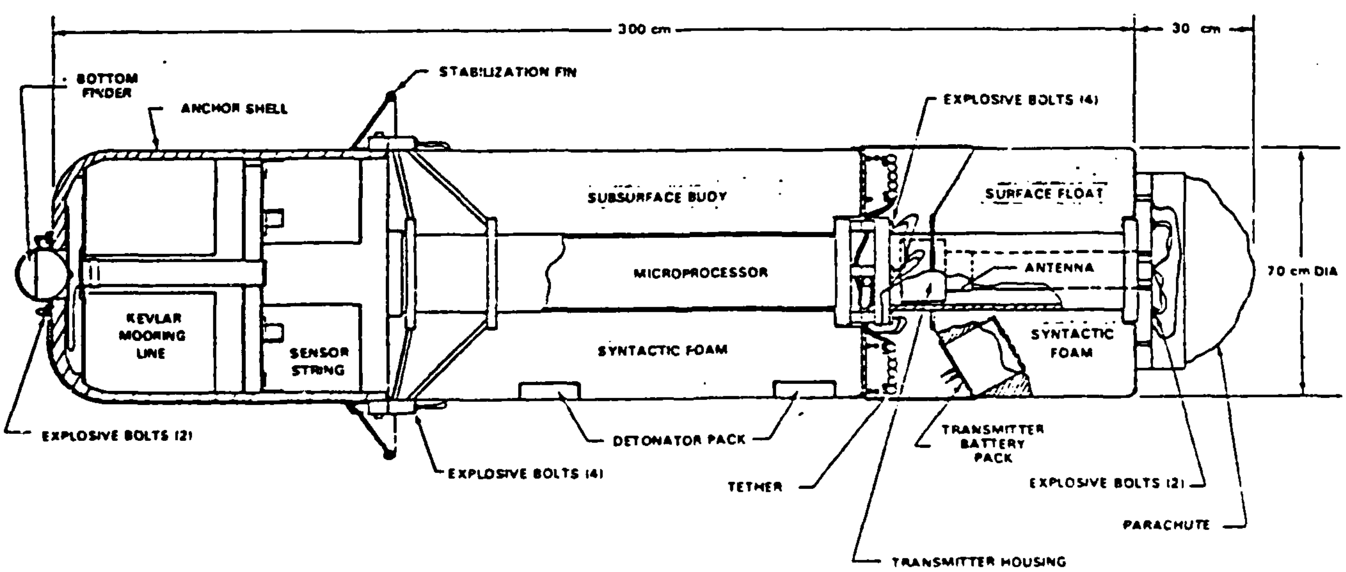

Figure 2. ADOM Assembled for Deployment

This paper was presented at the MTS Conference "Oceans '83", San Francisco, CA, August 29, 1983.
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satellite to a shore station. Desired measurements were from the upper 1500 m (4900 ft) of the water column. This would be in any deep ocean location, except the major current systems and deep trenches. Some of the parameters to be measured include pressure, temperature, conductivity, and current speed and direction. State-of-the-art sensors were available for measuring pressure and temperature, and could be incorporated into the prototype designs. The advantages of using long range aircraft were to be exploited in the delivery of moored instrument platforms. One of the expected benefits from this approach included lower final data cost, in comparison to the costs of operating oceanographic research vessels. The speed advantages of aircraft over surface vessels provide scientists with the ability to obtain synoptic data. Their quick-response capability allows data from rapidly developing phenomena to be obtained in a timely manner. Finally, long range aircraft can access remote areas of the oceans, (particularly the Arctic, Antarctic, and southern oceans) which are inaccessible to surface vessels.

Within the past decade, progress in oceanographic instruments, electronics, satellite communications, and moorings has enabled the design of reliable, light weight, moored instrument platforms. The objectives of this program could be met by a mooring system, deliverable to an intended mooring location by long range aircraft, then parachuted to the ocean surface to automatically deploy and anchor. A processing and storage unit, with a surface buoy containing a telemetry transmitter for satellite communication, would complete the system.

Organization

The ADOM project was organized in 1977, and funded by the United States Navy, Office of Naval Research, Ocean Science and Technology Division. The technological research team was made up of members from EG&G Washington Analytical Services Center, Inc. (Hydrodynamics); Naval Air Development Center (Aeromechanics); Ocean Electronic Applications, Inc. (Electronics); and the Woods Hole Oceanographic Institution (Mooring Mechanics). The University of Miami provided shore support facilities for several at-sea tests.

The scientific requirements for the ADOM were formulated by an advisory committee composed of Drs. D. Paskausky of ONR, K. Hunkins of Lamont-Doherty Geophysical Laboratory, T. Sanford of WHOI, and L. Johnson of ONR.

Project Chronology

Following is a brief outline chronology of the ADOM project:

1976 - Requirements Definition

1977 - Feasibility Study; Selection of Strawmen; Deployment Concepts

1978 - Feasibility Report Issued; Hydrodynamic Analyses; Candidate Selection; Component Design and Fabrication; Component Tests

1979 - Tank Tests; Mathematical Modeling; Anchor Drop Tests (surface vessel); A r Drops (mass model)

1980 - Tether Line Mooring Test; Sea Tests of Automatic Deployment; Separation and Payout Tests

1981 - Sea Tests (complete); Anchor Scale Model Tests (tank); Bottom Finder Sphere Tests (tank); Anchor Drop Tests (surface vessel)

1982 - Telemetry Tests; Automatic Deployment (surface vessel); Air Drops

1983 - Final Report

Requirements

The scientific requirements formulated by the advisory committee for ADOM were defined in four broad areas of scientific interest.

1. Seasonal heat exchange and current systems.
2. Weekly to annual mesoscale eddies.
3. Daily mixed layer fronts and atmospheric forcing.
4. Internal waves and rapid fluctuations.

The committee also stated:

"The various environmental processes which occur in the oceans are interdependent and so too are the scientific programs which address them. The end goal of all these programs is the prediction of real time ocean variability. Therefore, these models need to be derived from data sampling which is rapid enough to avoid aliasing, and of sufficient duration to measure the larger time scales, as in heat exchange work."

Scientific requirements for three types of studies are shown in Table 1.

Based on the scientific requirements, general guidelines (Table 2) were defined for design of the system. Operational and survival current profiles (Figure 3) were defined for the mooring design.

A P-3 aircraft was selected as a launch vehicle for determining the size and weight limitations of ADOM. The device could be stored beneath the aircraft wings or in the bomb bay. Dimensions were limited to 330 cm (130 in.) in length, 71 cm (28 in.) in diameter, and 1100 kg (2450 lb) maximum weight.

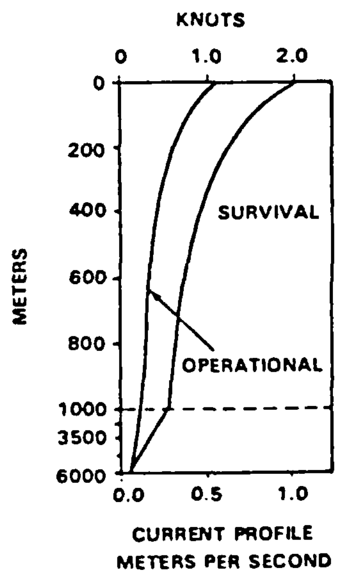

Figure 3. Design Current Profiles

TABLE 1. ADOM SCIENTIFIC REQUIREMENTS

	Heat Exchange	Mesoscale Eddies	Mixed Layer
Temperature (°C)	.001 - .01	.001 - .01	.001 - .01
Conductivity (mmho/cm)	±.01	±.01	±.01
Depth Accuracy (m)	±1	±1	±1
Currents (cm/s)	±1 (useful)	±1 (important)	±1 (vital)
Wind Speed or Sea State	—	useful	vital
Geographical Position Accuracy (km)	±10	±2 - 5	±1
Known Location (km)	±1	±1	±1
Grid Spacing (km)	500	50	.5 - 500
Depth Sensing:			
Depth Range			
0 - 200 m	every 20 m	every 50 m	20 (non-uniform distribution)
200 - 1000 m	every 100 m	every 100 m	10
below 1000 m	useful	every 200 m	100
Number of Moorings	2000 global	50 - 100	100
Frequency of Data Transmission*	monthly	weekly	weekly
Duration (years)	1 - 2	1 - 2	1

*Assumes that near real time use of the data is required for models or failure detection.

TABLE 2. GENERAL GUIDELINES

Sea State:	
Operational	4
Survival	6
Water Depth (m)	6000
Measurement Depth (m)	100 - 1500
Sensor known depth accuracy (m)	±1
Number of sensors addressable	240
Sensor Spacing (m)	20 to 200*
Temperature Accuracy	±.01°C
Sampling Rate (minutes)	10 to 60*
Frequency of Data Transmission (weeks)	1 to 4
Operational Life	Longer than 6 months

*Adjustable prior to packaging

Aeromechanical Design

Aeromechanical Concept Formulation

The ADOM aeromechanical requirements were that the buoy be compatible with the P-3 aircraft for carriage and launch; that ADOM air descent be slowed and stabilized prior to water impact; and that all air descent system components separate from ADOM after water impact.

In its present configuration, up to six ADOMs might be carried under the wings of a P-3. So far ADOM has only been deployed from C-130 aircraft which can launch large items from within the fuselage. This provides convenient access to the buoy prior to launch. This aircraft was readily available for ADOM tests.

The buoy is launched as illustrated by Figure 4. Strapped to a pallet resting on rollers set in the aircraft deck, it rolls out the back of the aircraft when the plane begins to climb and accelerate. The pallet is released from the buoy during air descent. A parachute system slows the descent and stabilizes ADOM for water entry. The parachute and attachment hardware are jettisoned when sea water activates an electronic circuit, firing explosive bolts connecting the parachute to the surface float.

Aeromechanical Analysis

A hydroballistic analysis determined that an ADOM impacting the water at 23 m/sec (76 ft/sec) in a near-vertical attitude would experience a 100 g peak shock .004 seconds after water contact. This represents the impact expected using a 8.5 m (28 ft) diameter ringslot parachute. The PCU-8/A parachute system was selected from available parachutes of similar size and type. It consists of a .9 m (3 ft) pilot parachute and a two-stage, 10 m (34 ft) diameter conical ringslot main parachute. This results in a 20 m/sec (64 ft/sec) terminal velocity with a water impact of 66 g's for a 1100 kg (2450 lb) ADOM.

Analyses of aircraft separation, flight trajectory, and parachute deceleration loads were performed. The parachute attachment assembly was designed to withstand the opening shock and drag loads of each parachute stage. A parachute jettison system was also developed to release the parachute and attachment structure at water impact.

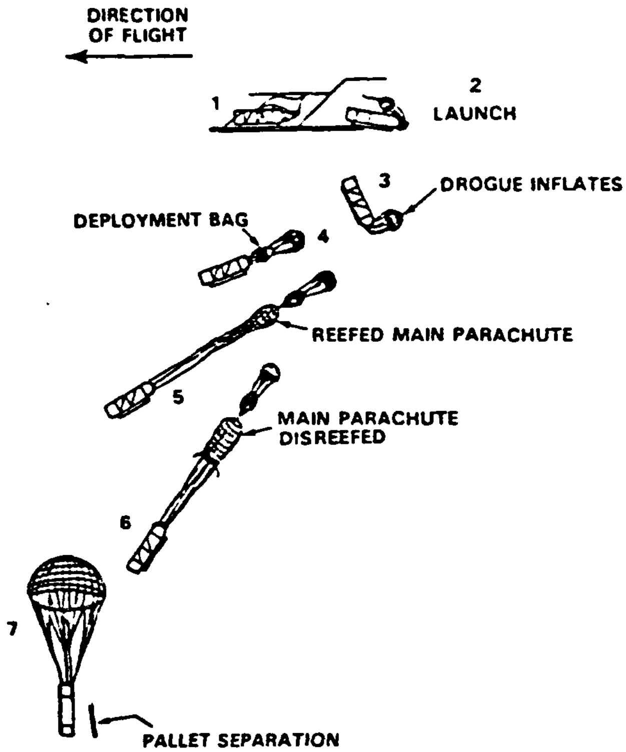

Figure 4. Air Deployment Sequence

Air Launch Hardware

The PCU-8/A parachute system is fastened to a cross-member on top of ADOM. Each parachute riser line is attached to one of the four arms. The cross is then attached to the surface float with two explosive bolts. The bolt firing circuitry is contained in a box mounted between the cross arms. ADOM's parachutes are deployed in sequence using static lines and explosive cutters.

Figure 4 shows several states of the ADOM deployment from the C-130 aircraft. In Step 1, ADOM, inside the C-130, is tied down for transport with the aircraft static lines attached. The buoy is strapped in a parachute-first/anchor-last position, on a reinforced wood pallet resting on the C-130 cargo rollers. Shortly before launch, the heavy restraints are removed and ADOM is restrained by a single quick-release strap. When the strap is released, ADOM rolls out of the aircraft as the plane climbs. In Step 2, a static line attached to the aicraft releases the pilot parachute and arms the explosive cutters that release the main parachute. The buoy descends under the pilot chute (Step 3) while the cutters delay firing for 1.5 seconds. In Step 4, the cutters release the main parachute. The pilot parachute pulls the main canopy from the deployment bag while simultaneously arming three cutters on the pallet attachment line. The mouth of the main parachute is first constricted by a reefing line (Step 5). After two seconds, two explosive reefing line cutters allow the main canopy to open fully (Steps 6 and 7). Approximately three seconds later, the pallet is released and falls away from the buoy. Upon water impact, explosive bolts fire releasing the parachute from ADOM.

Aeromechanical Subsystem Testing

Tensile tests were performed on a prototype of the parachute attachment assembly. Loads for reefed and unreefed main parachute openings were simulated. The explosive bolt firing circuit was designed with redundant circuits for reliability. Switches activated by parachute deployment to prevent accidental firings in the aircraft. The circuit was successfully tested in the prototype assembly.

Two mass models with the same outer shape, weight, and moment of inertia as the ADOM system were manufactured and assembled for air deployment tests in the Atlantic Ocean off Key West, Florida. Aircraft support was provided by the 2nd Marine Corps Air Wing. The ADOM mass models were deployed on November 6, 1979, recovered, refurbished, and dropped again on November 8. All four drops were at 610 m (2000 ft) altitude and 125 kts indicated air speed. Anchor-first and parachute-first launch orientations were tested. The parachute-first launch exhibited much better pitch stability than the anchor-first launch. In all cases, the gravity launch method worked well. The main parachute deployed and unreefed correctly in all tests. The mass model descent was very stable under the main canopy, impacting the water at the desired velocity. In each test the pallet separation occurred correctly with no damage to the buoy or parachute. The parachute system was jettisoned promptly at water impact.

Hydromechanical Design

Hydromechanical Concept Formulation

After parachute delivery to the sea surface, the ADOM package should deploy itself as a deep sea mooring. A two-stage mooring was selected to minimize the forces imparted to the mooring from ocean waves. In the absence of current, the main mooring flotation will be about 100 m (330 ft) below the surface. The surface float containing the telemetry transmitter is designed to be small and light, minimizing wave forces on the buoy. To further reduce the action of these forces on the subsurface buoy, the tether cable has a large scope and contains a compliant element.

The deployment is shown in Figure 5. After the parachute is jettisoned, the anchor portion separates from the two buoys and descends to the bottom, paying out a sensor string followed by the mooring line. When the anchor separates, a small weight is released and falls ahead of the anchor, pulling out a 100 m (330 ft) line. The mooring line deploys freely as long as tension remains in this bottom finder line. When the weight contacts bottom, 100 m below the anchor, release of tension in the bottom finder line clamps the mooring line, preventing further payout. The surface and subsurface buoys, still together on the surface are pulled down about 100 m as the anchor completes its descent, providing a taut mooring. The surface telemetry buoy is finally released and comes to the surface.

Hydromechanical Analysis

Parametric studies of mooring response to various oceanic currents were also conducted. Critical events of the ADOM mooring deployment sequence were studied. These included the impact transient at water contact, the underwater trajectory before the anchor is released, bottom finder launching transient, peak loads in the mooring line after anchor lock-up, and excess payout induced by shear currents. Following is a brief review of these studies.

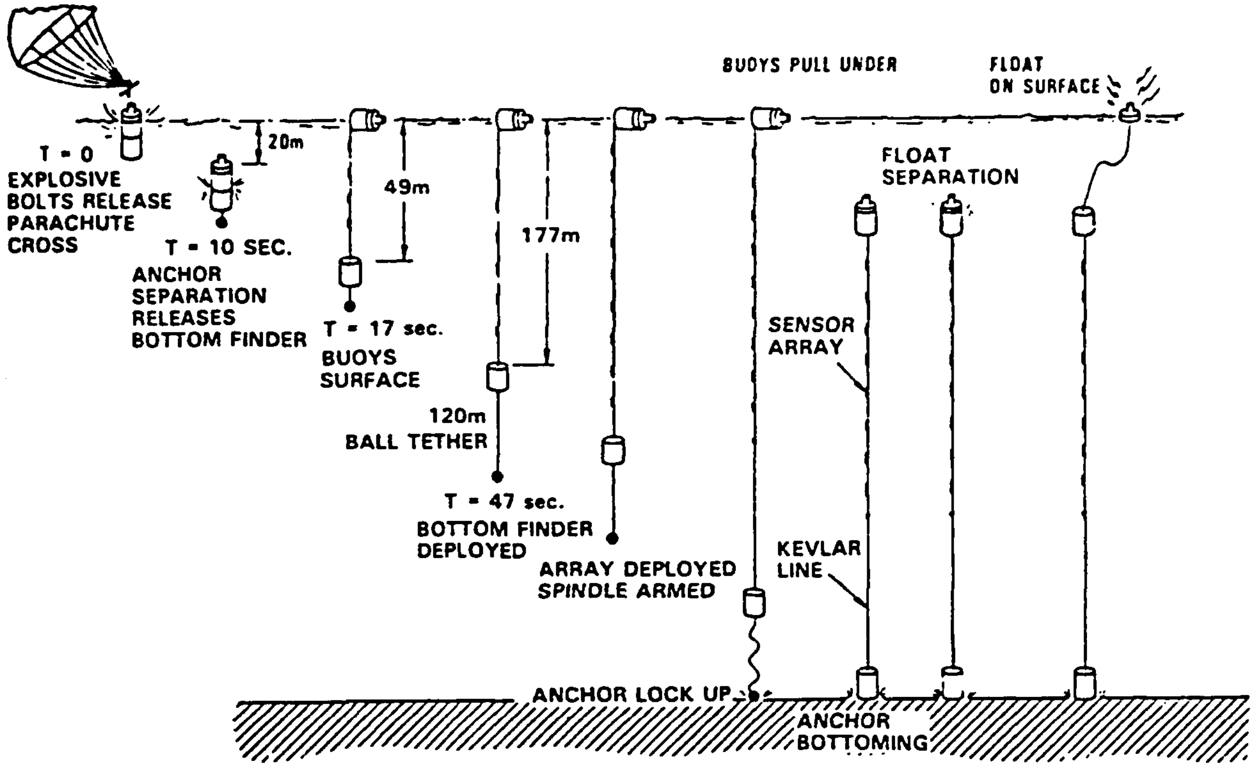

Figure 5. In-Water Deployment Sequence

Bottom Finder Launching Transient. The bottom finder consists of a stabilized lead sphere and a prescribed length of tether line. A compromise, based on tests and computations, had to be devised between the weight of the sphere and the size and strength of its tether line.

The computer program FIXADOM was used to help in determining the line tension necessary to restrain an object falling in water. By successive time integration of the object's acceleration and speed, the program computes the line elongation after impact. Tension in the line is established from a variety of material stress/strain functions. A typical tension curve obtained by this integration technique is shown in Figure 6.

High modulus of elasticity, large free falling speeds, and short tether length, create large tension peaks which may break the tether, or lead to complete relaxation resulting in premature lock-up.

As the lead sphere and anchor travel to the bottom at constant terminal velocity, the tension at the lower end of the tether line equals the immersed weight of the ball, less its water drag. At the upper end, the tension is slightly increased by the tether immersed weight, but it is drastically decreased by water drag along the tether line. Graphs of tension at the ends of a typical tether as a function of anchor terminal velocity are shown in Figure 7.

Lock-up Analysis. Payout of the mooring line stops immediately after lock-up. The lower end of the line is forced to move downwards with the anchor. The

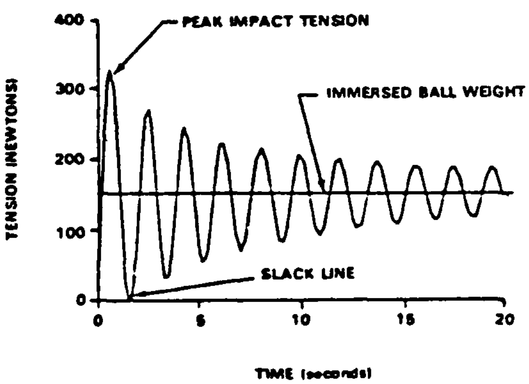

Figure 6. Predicted Bottom Finder Impact Tension

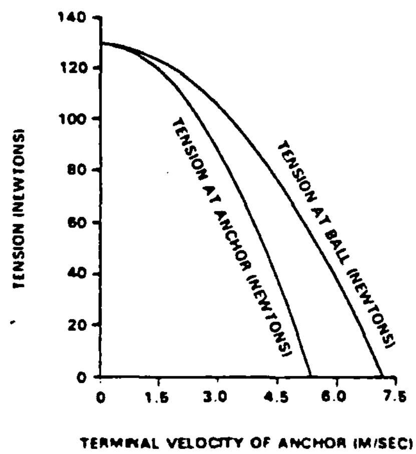

Figure 7. Predicted Bottom Finder Equilibrium Tension

upper end, a few kilometers above, is attached to the buoys still floating on the surface (Figure 5). As the line elongates, the tension builds up, slowing the anchor, and pulling on the buoys. Eventually the pull sinks the buoys, and the entire ADOM descends. The analysis of this lock-up sequence was made with the help of the computer program PULLADOM, an extension of the technique used in *FIXADOM*. *PULLADOM* computes the anchor position and tension buildup until the buoys are pulled under. It then determines the speeds and displacements of the anchor and the buoys, and the tension in the line as the whole system sinks. The computation continues until the system reaches equilibrium. Typical graphs of deployment transients are shown in Figure 8.

PULLADOM was used to assess loading under different conditions of premature lock-up and full mooring deployment. These studies indicated that the electro-mechanical (EM) cable would break should lockup occur with only a few hundred meters of cable out. To prevent this, the lock-up mechanism is not armed until the entire sensor array has been deployed.

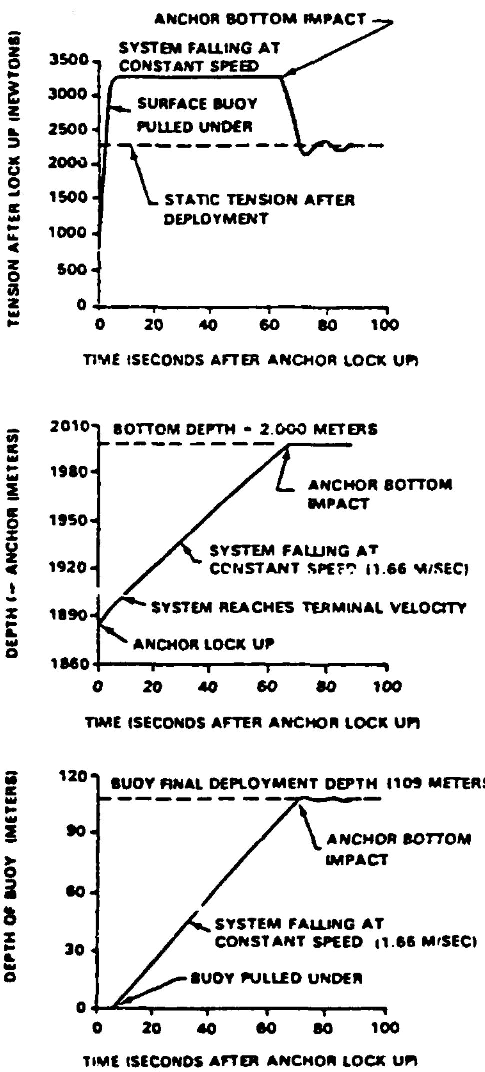

Figure 8. Predicted Anchor Lock-up Transient

Excess Payout Analysis. If the ocean current speed varies with depth, the anchor does not fall vertically. The cable drifts relative to the anchor so that its length could exceed the water depth at time of lock-up. In that case, correct deployment could not be achieved.

The excess payout problem was investigated with the help of the computer program FALLADOM. This program calculates the anchor trajectory, configuration of the mooring line, and drift of the buoy on the surface, over specified time steps (Figure 9).

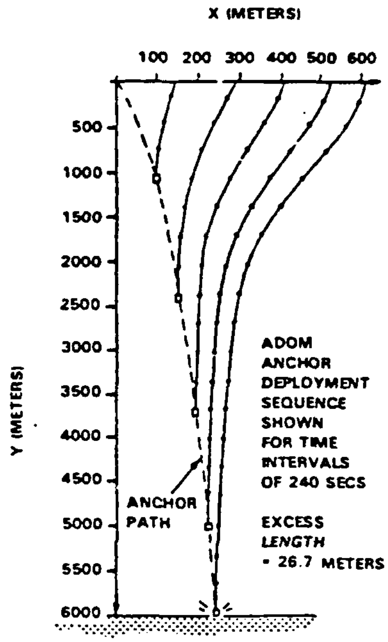

Figure 9. Predicted Mooring Shape During Deployment

FALLADOM assumes that the buoy and anchor are initially at rest. Gravity and hydrodynamic forces accelerate the buoy and anchor. Anchor and buoy move apart for a short time (approximately 0.01 seconds). Forces are subsequently updated and new accelerations obtained. The process is repeated until the end of the first time step is reached. The length of mooring line payed out is then assumed to equal the distance between anchor and buoy positions. This cable length is modeled as a point mass, connected to the anchor and buoy by weightless, linear springs. Forces acting on the buoy, the first node, and the anchor, are evaluated. New accelerations are thus obtained, integrated, updated, and integrated again until the next time step is exhausted. The additional length of cable payed out is then equal to the distance between the anchor and the position of the first cable node. A new node is created and a third computation step started. The process is repeated until the anchor reaches lock-up depth.

FALLADOM was used to estimate the excess of cable payed out as a function of current shear, mooring line material, force required to pull the mooring line out of the anchor, anchor terminal velocity, and depth. This sensitivity study indicated that:

- Excess cable deployment increases with the vertical current gradient (shear).

- Heavier mooring lines (i.e., steel as opposed to Kevlar) will reduce excess payout.

- Stronger pull-out forces will also result in less excess payout.

- Slow anchor descent increases excess payouts.

- Excess payout increases with water depth.

Results obtained for the actual ADOM prototype, when deployed in the "survival" design profile (Figure 3) are listed in Table 3. These values show that a deployment could be safely made in such a shear.

TABLE 3. SUMMARY OF FALLADOM RESULTS

	DEPTH (m/ft)		
	1524/5000	3048/10,000	6096/20,000
Buoy Excursion	266/874	466/1530	811/2660
Anchor Excursion	155/508	242/794	337/1105
Excess Payout	5/16.3	12.6/41.3	35/114.8

Buoys. The surface float was analyzed to evaluate its metacentric parameters -- weight, buoyancy, stability, and natural motions. Water impact stresses in both the *surface and subsurface* floats were considered, with special emphasis on the bolted joints. In addition, their safe working depth was estimated.

Tether. The primary functions of the tether are to moor the surface float to the subsurface buoy and conduct data from the processor in the subsurface buoy to the transmitter in the surface float. However, the tether also performs several less obvious functions.

The tether line allows ADOM to accommodate a range of environmental variations, while protecting it from damage by environmental extremes. The tether allows the surface float to ride 3 m (10 ft) waves in the operational current profile, while protecting the delicate electrical conductor from wave damage. When the current exceeds the operational profile speed, the tether submerges the surface float to a safe depth. Equally, when the current approaches still water, the tether must not foul.

The tether also accommodates small errors in the deployed length of the mooring line. A 1% error in the length of the mooring line may result in a 50% error in the subsurface buoy depth. The tether must provide its essential functions while accommodating these anchor errors. Finally, the volume of the tether itself must fit within the space available in the ADOM deployment package, and deploy smoothly from it. Tether parameters are summarized in Table 4.

Figure 10 shows the shape of the tether in three currents -- 10%, 50%, and 100% of the operational profile -- both when the anchor is terminated normally, and when an extra 50 m (160 ft) are deployed in a 6000 m (20,000 ft) water depth.

TABLE 4. TETHER DESCRIPTION

Type	Length (m/ft)	Diameter (mm/in.)	
Natsyn	15/50 53/175	19/.75 3.6/.14	- Rubber with jacket EM
Jacket EM	12/400	2.8/.11 3.6/.14	- Double armor with solid polyethylene
Foamed EM	12/400	3.6/.14 12/.46	- Jacket EM with foamed polyethylene

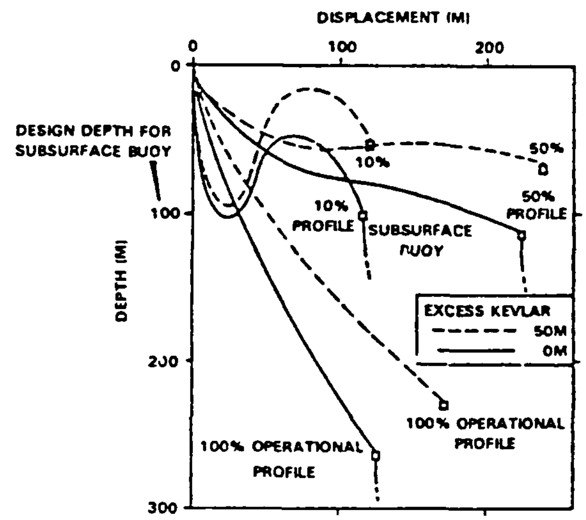

Figure 10. Predicted Surface Tether Shapes

In-Water Hardware

The final ADOM design consists of a cylinder 70 cm (28 in.) in diameter and 300 cm (120 in.) in length. The cylinder is made up of three main components fastened together in line with explosive bolts. The nose, or bottom end, is the anchor -- a hollow casting containing the mooring line and sensor string. The subsurface buoy forms the center section of the ADOM cylinder. The surface buoy is at the top and bolts to the subsurface buoy with the surface tether packaged between the two. The parachute attaches to the top of the surface buoy. A description of each major component and sub-assemblies follows.

Surface Float. The surface float supports the antenna, transmitter, and batteries. The float uses an aluminum tube for basic structure, surrounded by buoyant syntactic foam, and covered with a fiberglass skin (Figure 11). The antenna is shown extended for transmission. As built, the float has the following characteristics:

Weight in Air	115 Kg (225 lb)
Freeboard	20 cm (8 in.)
Reserve Buoyancy	78 Kg (170 lb)
Natural Heave Period	1-1.3 seconds
Natural Roll Period	3 seconds
Depth Capacity	600 m (1900 ft)

The syntactic foam for both the surface float and subsuface buoy was manufactured from 7.5 cm (3 in.) diameter epoxy balls, .6 to 1.0 cm (1/4 to 3/8 in.)

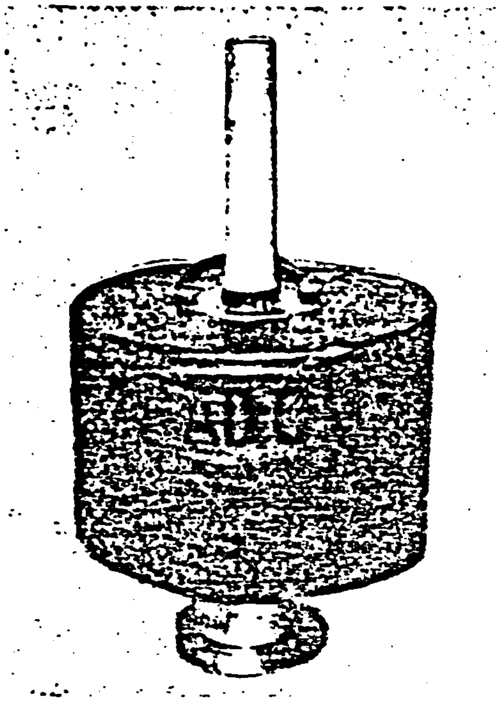

Figure 11. ADOM Surface Float

diameter epoxy peas, and epoxy resin binder extended with glass "micro-balloons." This composition achieved a .32 g/cm^3 (20 lb/ft^3) density. The balls alone will sustain 2 MPa (300 psi) continuously, and 5 MPa (700 psi) for short durations. The resin, micro-balloon binder, and fiberglass skin roughly double the pressure capacity of the balls.

Tether. The length of compliant rubber keeps the tension in the tether nearly constant as waves buffet the float. The parallel EM cable is 3.5 times as long as the unstretched length of the rubber section. It carries the data signal to the transmitter in the float and provides a redundant member if the rubber fails.

The elastic tension of the rubber will immerse the float before the EM cable becomes taut. The unfoamed cable segment and its foamed pair form an S-shaped arc that avoids tangling in low current conditions. The lengths and buoyancy have been chosen so the apex of the buoyant segment remains submerged even in still water with the anchor cable 50 m (164 ft) too long.

The foamed and jacketed sections of the tether are wound in a tray, using a one-over/one-under technique, similar to one used by long-line fishermen. The tether loops are secured to the tray with a high melting point wax. The rubber section is wound similarly. The clamps joining the rubber and EM cable are secured to the tray using fine wire. The lower end of the rubber is coupled to a grip epoxied to the EM cable. Figure 12 shows the surface float attachment.

Subsurface Buoy. A central aluminum tube provides structural support and houses the microprocessor. Syntactic foam provides buoyancy, and a fiberglass skin protects the buoy from damage in handling. The buoy is joined to the surface float and anchor during storage, delivery, and air deployment, by four explosive bolts at each junction. The subsurface buoy weighs 240 kg (525 lb) and has a displacement of 525 kg (1150 lb) in water, yielding a net buoyancy of 285 kg (625 lb). The subsurface buoy is capable of withstanding hydrostatic pressures of 600 m (1900 ft). A conical fin, similar to the anchor stabilizer, is attached at the bottom end of the subsurface buoy. It retards the ascent of the buoy and its surface float in the moments after the anchor is released.

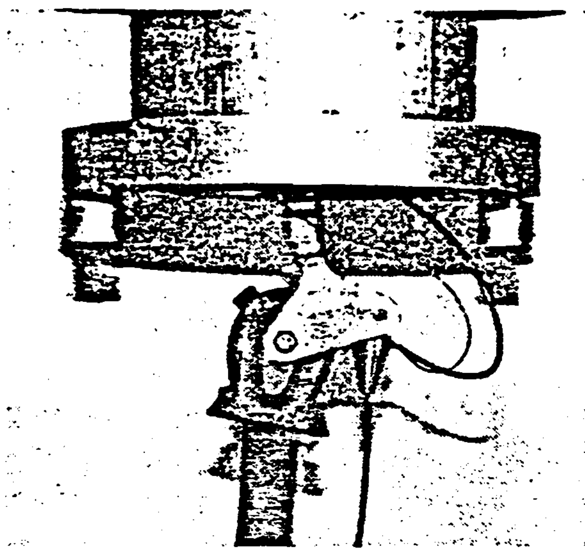

Figure 12. Tether Attachment at Surface Float

Anchor. The anchor assembly (Figure 13) contains the sensor string, mooring line, and bottom sensing line latch. The anchor is a hollow cylindrical steel casting 94 cm (37 in.) long, weighing 431 kg (950 lb).

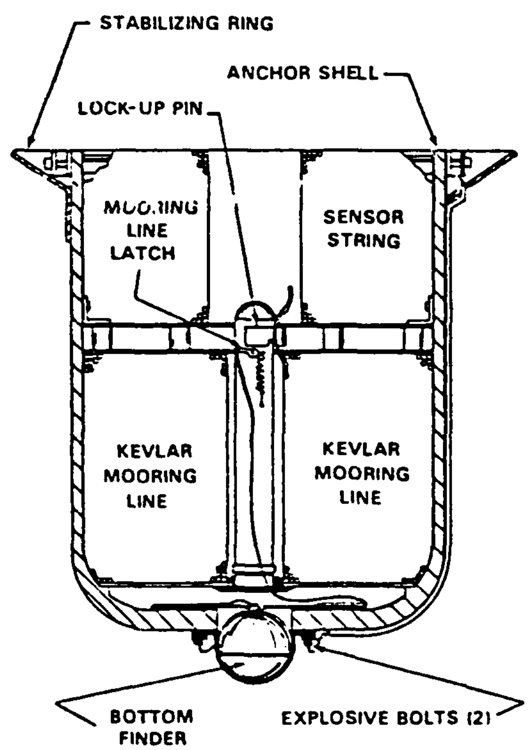

Figure 13. ADOM Anchor Assembly

The solid lower end is 3.8 cm (1.5 in.) thick and the walls are 2.2 cm (7/8 in.) thick. The butt and walls are faired together with a 1/4 diameter ogive to reduce the stresses during water impact. There is a cutout in the center of the nose to contain the bottom finder sphere. The total weight, including mooring line, sensor string, and bottom finding hardware, is 635 kg (1400 lb). A conical stabilizing ring is attached to the upper portion of the casting to provide afterbody drag during descent through the water column. This provides a stabilizing moment, and also reduces the terminal velocity from 5.5 m to 4.3 m (18 ft to 14 ft) per second. The stabilizer is constructed of .64 cm (1/4 in.) fiberglass, inclined back 120 degrees and extending 11 cm (4.5 in.) out from the anchor. A series of 2.5 cm (1 in.) holes are drilled in its surface to induce turbulent flow.

The inside of the anchor is divided by two partitions into three chambers. The smallest chamber, at the nose of the shell, holds the 100 meter bottom finder line in a flat coil. The mooring line is spooled in the central chamber, with the latching post extending up through the center. A double partition separates the Kevlar chamber from the sensor array space in the top of the anchor. The latch pin fits between the surfaces of the partition. A smooth fiberglass ring is installed inside the top edge of the casting, and another around the top of the spool housing. These protect the Kevlar line from abrasion and reduce its bending radius when under tension and moored. Four attachments for the explosive bolts that fasten the anchor to the subsurface buoy are placed around the top of the anchor.

<u>Mooring Line</u>. The Kevlar mooring line is contained in the bottom section of the anchor. The line is a rope construction consisting of two contrahelically wound layers of Kevlar. There are six strands in the inner layer consisting of five yarns (150 denier), and 12 two-yarn strands in the outer layer. A polyester jacket is braided around the Kevlar member giving an outside diameter of .56 cm (.22 in.). The rated breaking strength is 1400 kg (3170 lb). 4500 m (15,000 ft) of line is wound in a special spool that fits within the casting and pays out from the center. The spool is specially wound with a turn put into the line for each turn on the spool to provide a deployed line free of turns.

An adhesive is applied to the line as it is wound to bind together the turns and layers of the spool. This provides a slight back tension, 89 N (20 lb), to the line during payout and also prevents multiple turns from pulling out. Several materials were used during the development including latex rubber and special waxes. Depolymerized rubber gave excellent performance.

<u>Sensor String</u>. The inner end of the Kevlar spool is attached to the sensor string which is flaked into to the upper section of the anchor using a one-over/one-under turn to provide torsion-free payout. 1200 m (3900 ft) of sensor cable can be stored in this manner, depending upon the number of sensors required. A double-caged armor torque-balanced electromechanical cable, with a single 18 AWG electrical conductor is used. The cable is sheathed with .038 cm (.015 in.) wall thickness of black Surlyn , to an outside diameter of .54 cm (.21 in.). The cable breaking strength is 8900 N (2000 lb). Sensors are attached in-line with special epoxy-filled fittings.

<u>Mooring Line Lock-Up Mechanism</u>. Several methods were considered for braking and holding the mooring line after anchor descent. The method chosen is a modification of the T-bar system (Swenson, R. C., personal communication) shown in Figure 13. A spindle, attached to the bottom of the anchor, extends through the core of the Kevlar spool above the two plates holding the spool in place. The spring-loaded lock-up pin is shown in the lock-up position, protruding into the space between the two plates. This pin is retracted during mooring line payout, its end conforming to the smooth surface of the spindle. In this configuration, the Kevlar turns slip off the end of the spindle. When the pin is unlatched, as shown in the figure, turns of Kevlar build up around the spindle. As many turns as are necessary to completely stop payout will accumulate.

The lock-up pin diameter has a significant effect on the useful strength of the line. The sharpest bend in the mooring line occurs there, and Kevlar, being a very high modulus material, is sensitive to this. The final pin diameter of 3.8 cm (1.5 in.) resulted in a breaking value of 9800 N (2200 lb). This was judged satisfactory for the application.

<u>Bottom Finder</u>. A lead [illegible]here is connected to the lock-up pin latch by a fine [illegible]ar line. Tension of 20 N (4 lb) or more on this [illegible]e will keep the lock-up pin extended. Upon contact [illegible]h the bottom, the tension due to the sphere is re[illegible]d, extending the lock-up pin and preventing furt[illegible]payout of the mooring line. The 14 cm (5.5 in.) [illegible]re weighs 13.6 kg (30 lb) in air. The sphere mai[illegible] 50 N (12 lb) tension at the latch with 100 m (3[illegible] of tether. A .32 cm (1/8 in.) groove is machine[illegible]to the surface of the sphere 30 deg below the equator. The groove induces turbulent flow for maximum terminal velocity. Ribbon fairing is attached 30 deg above the equator to stabilize its flight path. 100 m (328 ft) of .12 cm (3/64 in.) diameter Kevlar line connects the sphere and the lock-up pin, providing a strong, 100 N (225 lb test, lightweight line. This line is coiled within the nose of the anchor in a Flemish winding and held in place by a special wax. The sphere is held in the anchor nose by a strap which is fastened to the anchor with two explosive bolts. Upon water entry, the explosive bolts fire, allowing the sphere to fall away. During the 45 second interval when the sphere is paying out the bottom finder line, there is no tension on the latch. A safety pin prevents the lock-up pin from coming out during this time. This pin is attached to the sensor string/mooring line junction with a small wire lanyard which is pulled out after all the sensor string is deployed, assuring that all bottom finder cable has been payed out.

<u>Hydromechanical Testing</u>

Extensive testing of the ADOM subsystems was necessary to determine concept feasibility and to obtain design confidence. Over 100 documented tests on anchor components were conducted in the laboratory, test tanks, shallow water, and at sea.

<u>Surface Tether</u>. Measurements of stress/strain were made on both the EM cable and the Natsyn rubber section. Buoyancy loss of the foamed section as a function of hydrostatic pressure was determined through tests in a pressure tank. Buoyancy loss of 2.2% was observed at a pressure equivalent to 100 m (328 ft) and 7% loss at 400 m (1312 ft).

<u>Sensor Cable</u>. The mechanical characteristics of the sensor cable were determined and various methods of deploying it investigated. Inside payout, from a spool assembly similar to the mooring line, was not possible because of the in-line sensors and cable rigidity. A figure-8 system, using deploymerized

rubber (DPR) and polyurethane clips to hold the loops in position, worked well; however, only 500 m (1641 ft) of the 1200 m (3937 ft) required, could be stored in the anchor. A packaging technique permitting greater storage was tested, wherein the cable was flaked into the top of the anchor with alternating turns: one-over/one-under. DPR was used as an adhesive. An at-sea test using 500 m of this cable stowed with this technique was successful. Tests performed on the sensor EM cable included tensile, stress/strain, torque, and termination effectiveness.

Mooring Line. Extensive tests were made on the Kevlar mooring line. Various packaging techniques and binder materials were tried to obtain an orderly payout, free from multiple turns, wuzzles, or kinks. Laboratory tests, including stress/strain, ultimate tensile, elastic characteristics, creep, and torque were conducted. Sea tests were also performed to confirm orderly payout of long lengths of Kevlar line. Spooling with a light application of depolymerized rubber (DPR) prooved to deploy best. Chinese finger terminations were tested and found to exhibit full breaking strength of the rope. A mooring was set near Bermuda for two months using the ADOM mooring line. Upon recovery, the line was showed no degradation under test.

Anchor Lock-Up. Tests conducted on the lock-up mechanism confirmed its ability to brake the mooring line payout upon actuation. They showed that complete lock-up took place within 1 m to 2 m (3.3 ft to 6.6 ft) after the latch pin extended. Anchor drops from the dock and from a vessel at sea confirmed proper operation of the mechanism.

Bottom Finder Sphere. The performance of the bottom finder subsystem, from the time of lead ball release to time of bottom impact, had to be fully evaluated and demonstrated.

Tests to observe the flight pattern of free falling spheres and measure the peak tension in tether lines were conducted in the 30 m (100 ft) deep tank at the Naval Surface Weapons Center (NSWC), White Oak, Maryland. These tests revealed that smooth spheres, no matter how perfect their sphericity, had a strong tendency to kite off the vertical. Cutting a groove 2.2 cm (1/8 in.) deep 30 deg below the equator greatly improved their flight path. Inserting flexible plastic ribbons approximately three sphere-diameters long in a groove 30 deg above the equator, corrected the kiting problem entirely. Typically, a 14 cm (5.5 in.) diameter sphere, weighing 14 kg (30 lb) in water and equipped with ribbons, would fall in a straight vertical path at 6.7 m/sec (22 ft/sec). Tension measurements confirmed the model prediction both in amplitude and shape (Figure 6). Complete line relaxation, which would cause premature lock-up, was observed.

Proper release of the sphere from the anchor nose by firing either one or both retaining explosive bolts was confirmed by tests performed off the dock at Woods Hole Oceanographic Institution. A series of tests was also conducted off the shore of Florida to record the descent velocity of typical lead spheres as a function of tether line length.

The performance of the entire bottom finder subsystem was assessed in a series of seven free fall drops of full size ADOM anchors performed in the Tongue of the Ocean (October 1981). The anchors were instrumented to provide confirmation of the depth at which lock-up would occur. Grooved spheres yielded erratic results. Two lock-ups occurred on bottom impact, and two occurred 120 m (400 ft) off the bottom as they they should. All tests performed with ribbon-equipped spheres produced perfect lock-up.

Anchor. Early in the project, drop tests of scale models and full-size anchors were conducted in shallow waters and in the NSWC tank. The purpose of these tests was to determine the anchor terminal velocity and assess its stability during free fall. Conical flaps added to the after edge were shown to provide excellent anchor flight stability. Anchors equipped with these flaps reached a terminal velocity of 4.3 m/sec (14 ft/sec).

Electronic Design

The electronic components for ADOM consist of a processor for acquisition of data from sensors in the mooring, and a satellite telemetry system to transmit the data from the buoy to a shore based computer. In addition, lithium battery packs in specially designed cannisters power the processor and telemetry, and circuits trigger the explosive bolts used for staging of the buoy hardware.

Data Acquisition Processor

A feasibility study determined the following characteristics for the data processor:

1. One year operating capability;
2. Programmable operation for variable sampling algorithms;
3. Rugged to survive launch and operating conditions; and,
4. Data acquisition from a large number of sensors incorporated into a single conductor, armored upper mooring cable of 1500 m (4900 ft) in length.

The first two requirements were met by development of an all CMOS microcomputer with unique sensor addressing capability. When the study was initiated, two CMOS microprocessors existed — the RCA 1802 and the Intersil 6100. The 6100 was chosen because the 12 bit data word allows data storage and manipulation, and the simple but elegant instruction set allows quick program development. The use of static CMOS allows the use of variable microprocessor clocks and the achievement of very low power consumption.

The processor is constructed in following modules: CPU, program memory, real time and system clocks and interfaces for data acquisition, telemetry, a terminal, and data memory. The boards are supported on three sides in a strong aluminum frame. By eliminating shock sensitive parts and supporting the frame in a cylinder inside the subsurface float, the system is designed and tested for 300g shock loads lasting 5 milliseconds. No damage to the electronics has occurred during sea and air launch tests.

The program is stored in CMOS PROMs (Programmable Read-Only Memory); 3K words of program are used with 1K of program RAM. This can be expanded easily but has not been necessary. The PROM memory can be replaced by a RAM board for program development. With this change, programs are written on a modified PDP-8 computer and direct memory access used to transfer data into and out of the ADOM processor. This allows rapid program development and assists in debugging new circuitry and software. A 1K program can be written, debugged, and firmed into PROMs in about four hours. The computer also allows immediate documentation of the programs.

The clock board provides an accurate real time clock and a microprocessor-controlled system clock. The real time clock uses a temperature compensated low frequency (32.768 KHz) reference oscillator with an accuracy of ten seconds per year. The time records are kept in a single chip clock circuit (OKI). The reference oscillator is multiplied by a controlled factor to provide the variable system clock.

Each ADOM has unique values for its sensor string and individual schedules for data acquisition, telemetry, and mooring release (for system recovery). To enable this, a universal program for all ADOMs is used, and a customizing PROM, unique to each ADOM, is incorporated into the terminal interface board. Thus, redeployment or reconfiguration can be achieved rapidly by changing one PROM.

In normal operation, the processor is usually in a quiesent state. Its system clock is stopped and supply voltage reduced. At the beginning of each minute, the processor starts and reads the clock to its schedule. If no activity is scheduled, the processor returns to the quiesent state. If data acquisition is scheduled, it is performed immediately, taking 500 microseconds (msec) per sensor. Data telemetry will depend on the capacity of the data memory. Usually all data in memory is transmitted every telemetry cycle.

In the quiesent state, current consumption is approximately 100 mA. The system clock for the other modes is chosen to be the minimum practical. During data acquisition, the current consumption will depend on the sensors, and is about 30 mA for a ten sensor array. During telemetry, the processor consumes 15 mA. For operation with data every six minutes and telemetry twice a week, the average processor current is 1-2 mA. This easily allows operation of the system with 12 lithium D cell batteries.

The method of acquisition is demonstrated in Figure 14. The sensor cable carries power and signals from the processor. After enabling the sensor power (nominally five volts at the top of the array), a series of single audio tones is applied. Eight possible tones are used, varying from 350 to 800 Hz. Initially, the highest frequency is transmitted and used by each sensor to establish a reference oscillator. A sequence of three to eight tones follows. The number of tones is set when the sensors are assembled, depending on the number of sensor addresses needed.

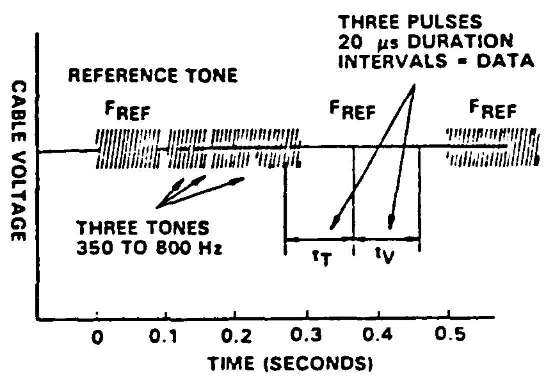

Figure 14. Sensor Interrogation Sequence

In practice, three tones will be used, giving 512 unique sensor addresses. Power limits the actual number of sensors to about 180 in a 1500 m (4900 ft) cable.

The sensors compare each tone sequence to their assigned sequence. The sensor which matches responds with three 20 msec negative pulses. The interval between the first two is a direct measure of the supply voltage at the sensor and the second interval is directly proportional to the data measurement. So far, temperature has been the primary measurement of the sensors.

The second pulse interval from a sensor gives temperature to an accuracy of 0.1C. If correction is made for the supply voltage variation, the accuracy increases to 0.1C. This correlation could be made in the ADOM processor, but it is more economical to let the shore station computers do it.

A limited frequency band is used in the sensor array. This allows the addition of frequency modulated continuous data in the same sensor array. An array of frequency modulated hydrophones has been designed and evaluated. ADOM could combine ten hydrophones with 20 temperature sensors in a single mooring.

Figure 15 shows the sensor packaging. The diameter is 33 mm (1.3 in.) and length is 178 mm (7 in.). The housing is fabricated from hard anodized aluminum and carries the mooring tension. A window allows measurement of the external temperature.

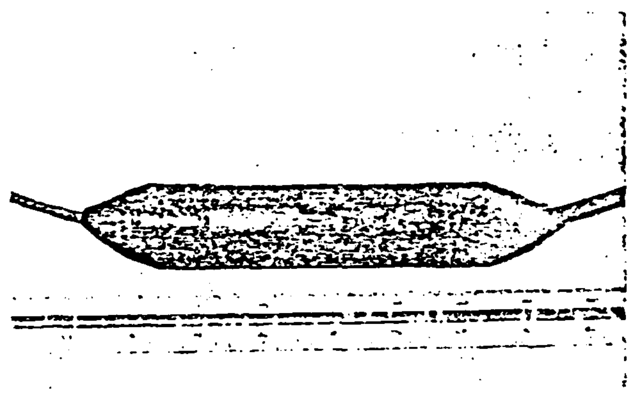

Figure 15. In-line Temperature Sensor

The ADOM sensor array coupled to the Kevlar mooring line through a release link. The link has upper and lower sections connected by a small explosive bolt. The upper section is shaped like a data sensor but the lower section ends in a stainless steel eye. The device contains a circuit to explode the bolt on command from the processor. The bolt is contained in a flexible shield inside the two sections so the link can be handled safely.

Data is stored in a CMOS RAM memory array. A flexible design is used so that higher density can be incorporated at will. 1K devices have been replaced with 4K devices. 16K and 64K boards have already been designed. Since the memory access is handled both directly and through input/output commands, addressing the extension of the memory is easily accomplished. Memories of 256K x 12 have been used, although 1M word memories are quite practical. These memories require very little hardware overhead, and the data is retained by three volts at very low current.

The processor fetches data for the telemetry from the memory and formats it into 20 word frames. The first two words provide synchronization and identification. Sixteen words of data follow. Two clock words are used as terminators. This sequence is repeated until all data is telemetered. The overhead of this sequence is 25%, but the data synchronization can be established if a frame is interrupted. Formatting is performed in the processor's telemetry interface and transmitted up the surface tether by a conventional open collector drive. The source voltage is supplied by the radio transmitter and is used to indicate that transmission is possible. If the source voltage drops, the processor terminates the telemetry attempt.

Telemetry Radio Transmitter

The telemetry of data from the buoy was also the subject of a study where several approaches were reviewed:

1. Low power telemetry to an aircraft;
2. Orbiting satellite; and,
3. Geosynchroneous satellite LES-9.

The latter, a USAF satellite operated by Lincoln Laboratories, has a high data rate and was available at no charge, so it naturally formed the basis for a detailed analysis.

A primary concern is that the satellite is operated on a priority basis. Therefore, use by ADOM could be denied at any time. Inopportune ADOM transmissions would intefere with other satellite users. Since there exists no practical mechanical method to turn off the ADOM telemetry, two possibilities for control have been considered. The first is to transmit commands from the LES-9 to enable/disable the buoy telemetry. Since the surface buoy is very active in a seaway, its antenna gain cannot exceed 3 dB. With this factor, the buoy command receiver sensitivity must be better than -128 dB for 0 dB signal to noise. The cost of such a receiver is excessive.

The second approach is to operate the telemetry so that the satellite can ignore unwanted ADOM transmissions. This is possible since LES-9 has several operating modes. Normally, the satellite uses a wide band mode where several narrow band sources can share the available satellite transmitter power, or where frequency hopping can be employed. Medium and narrow band modes with selectable center frequencies can also be chosen under ground control. Link calculations were made for both narrow and medium band operation. Initially, the narrow band was selected. The resulting telemetry characteristics were 20W transmitter, 1200 baud, FM / 2.5KHz deviation, and S/N (Signal-to-Noise Ratio) of 6dB at downlink receiver. FM modulation was selected since an existing receiver was available, and a suitable differential phase modulation receiver was not. The only item needed for the telemetry was a transmitter.

Further transmitter requirements included an immersion capability to 300 m (984 ft), being packagable without increasing the system length, and external connections to processor and power only. From these requirements, a transmitter was developed which consists of a totally enclosed electronic assembly integrated with the antenna, and with inputs of modulation and power only. This assembly is housed inside the surface float before launch and held in place by the launch parachute attachment. On release of the parachute on water entry, the transmitter is propelled by a spring to its operating position. Since the standing wave ratio (SWR) becomes excessively high in the enclosed position or when the antenna is under water, a method for the transmitter to signal this to the processor is necessary. The transmitter measures the SWR during transmission, and when necessary, signals the processor to cancel telemetry.

Figure 16 shows the transmitter assembly. The upper cylinder houses a helical antenna tuned to 300 MHz. Two antenna lengths are possible depending on the antenna pattern. The shorter length gives a mushroom shape pattern with a single lobe and approximately 3 dB gain directly overhead. Since the surface buoy attitude can vary considerably, this flattish pattern is quite good for most locations.

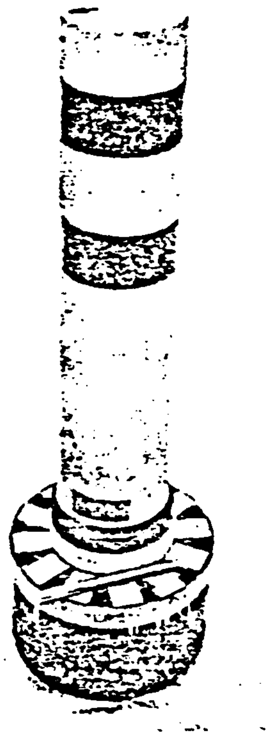

Figure 16. ADOM Telemetry Transmitter/Antenna

The transmitter was tested and the effective isotropically radiated power (EIRP) measured. It was within 0.5 dB of the expected value. Satellite telemetry tests were then performed with the transmitter both on a roof, and position monitored in a surface float in calm water. Both positions had disappointing S/N of less than 0 dB, and excessively high (10^{-2}) error rates.

A special data decoder was added to improve the link. This decoder uses probability techniques to improve decoding at low S/N. Laboratory tests showed error rates less than 10^{-5} for S/N down to -4 dB. When incorporated into the satellite link the error rates were about 10^{-4}. These errors came in clusters and were probably due to a transient noise source.

The remainder of the shore station consisted of two computers. Since short satellite windows were available, the first computer was essentially an ADOM copy. It stored data from all buoys transmitting within the window. It also converted the data from binary form to fixed-point decimal. Processing time for 32K words of binary data was about one hour.

The second computer peformed final conversions, including the conversion of the time data and calculations of the temperature data to the final accuracy. All sensor constants were input at this point. An example of the telemetered data is shown in Figure 14. This data was obtained during a ship-launched ADOM test.

A final component of the ADOM electronics is the firing circuit for the large explosive bolts that clamp the surface float and anchor to the subsurface buoy before deployment. For this purpose, the circuits are powered by saltwater batteries and can only fire the bolts after complete immersion in saltwater. Each battery can fire only one bolt at a time; therefore, a sequential firing system is used where the four bolts for each location are fired at 200 msec intervals. This technique is used to drop anchor ten seconds after water entry, and release the surface float 800 seconds after water entry. It has been completely successful.

System Test

Two fully assembled ADOM systems were deployed over-the-side of the M/V VENTURE. The first deployment was in June 1981, the second in February 1982. Both deployments were made in the Tongue of the Ocean in 2000 m (6600 ft) deep water. The purpose of these over-the-side drops was to evaluate the automatic deployment and telemetry systems. Launching was accomplished by suspending the ADOM over the side from its parachute cross, using the vessel cargo boom. The unit was released by firing the explosive bolts attaching the ADOM to the cross. The 1981 deployment was only partially successful. Considerable tangling occurred in the sensor EM cable during the anchor free fall, and lock-up did not occur. A series of changes, component tests, and improvements were implemented for the 1982 test. The 1982 deployment was a complete success. The launch sequence was perfect, all explosive bolts firing with proper delay. Sensors and Kevlar cables payed out without problems. Deployment events occurred as shown in Figure 5.

On December 6, 1982, the first air deployment of two fully-operational ADOM buoys was conducted in the Atlantic Ocean north of the Bahama Islands. Excellent aicraft support was provided by the 2nd Marine Corps Air Wing. Shoreside support facilities and the research vessel CAPE FLORIDA were provided by the Rosenstell School of Marine and Atmospheric Science, University of Miami. Both ADOM buoys were deployed from 610 m (2000 ft) altitude and 125 knots. The air deployment and parachute staging were successful in both cases, impacting the water about 40 seconds after launch.

The parachutes jettisoned properly after impact. The anchors separated, and the sensors and Kevlar mooring line appeared to payout in an orderly manner. In both cases, the surface and subsurface buoys remained on the surface and anchored. The surface buoys separted and pulled the tether line out properly. Lock-up of the mooring line did not occur on the first drop, allowing all of the Kevlar to pull out before fetching up. On the second drop, the subsurface buoy was nearly submerged. Subsequent retrieval of the Kevlar indicated proper lock-up. However, measurement of the line length confirmed that 75 m (246 ft) of excessive line had been paid out. The motion picture records of the ADOM descent show what appears to be a piece of the pallet lodged in the anchor fin. At impact, the chunk may have either wedged more tightly or broken the fin. The resulting asymmetry prevented a vertical anchor drop, and explains the excess payout.

The full electronics system was included in both over-the-side and air drop system tests. Total system operation was only partially successful. During the over-the-side tests, full operation was achieved with data telemetered through the satellite to the shore station of Key Biscayne, Florida. Data was telemetered over a three day period. The data is demonstrated in Figure 17.

During the air drop tests the electronics system was partially successful. The processor, array, and transmitter all worked completely. In one ADOM, the cable that connects the battery packs to the transmitter was jarred loose by the impact of water entry

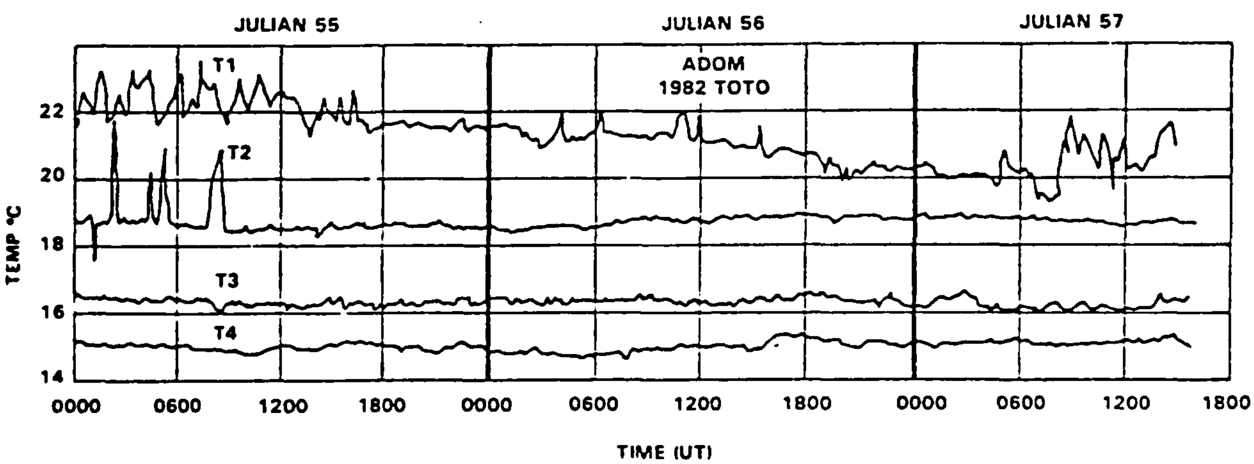

Figure 17. Telemetered Temperature Data Received at Key Biscayne Shore Station During Second Over-the-Side Deployment in the Tongue of the Ocean During February, 1982

and lay against an explosive bolt. The detonation of the bolt damaged the cable.

The internal coaxial cable carrying the modulation signal to the transmitter, failed in fatigue in the early test. It was replaced by a polyethylene based cable for later tests.

Two original processors, although subject to much modification, are still operating after four years of tests, and use in the air test. The original three sensor arrays have been used repeatedly.

The lithium batteries have performed well and without problem. A total of 120 D cells have now been used.

Conclusions

The development and at-sea testing of ADOM demonstrated that the deployment of oceanographic moorings from aircraft into depths as great as 6000 m (20,000 ft) is both feasible and practical. Useful measurements have been made by these devices and telemetered to shore stations by satellite relay.

The expansion of the ADOM system to the air deployment of an oceanographic buoy network for defense/industrial/academic use is a practical goal.

The ADOM aeromechanical system worked well throughout subsystem and integrated system testing. The C-130 launch technique was simple and safe. The PCU-8/A parachute provided ADOM with a reliable, controlled, and stable air descent. Proper jettison and separation of the pallet and parachute occurred in all tests.

The ADOM mooring uses a variety of materials with unusual mechanical properties. The success of the deployments confirmed that current computer models can accommodate these new materials with good accuracy. For example, the length of the bottom finder cable includes an adjustment for the stretch of the mooring. An error of 0.17 in the mooring strain could leave the subsurface float on the surface.

The anchor fell vertically in test tank drops, and the deployment models attributed all horizontal drift to ocean currents. The at-sea tests gave some evidence that the anchor trajectory may be slightly off the vertical. A compact "underwater flight recorder" is needed in order to gather test data from anchor drops in the deep ocean.

The use of explosive bolts fired from seawater-activated batteries under electronic control has proved highly reliable Rapidly firing the 4-bolt patterns in sequence effectively reduces the current capacity required from the batteries.

Handling long lengths of cable at low tension without reels and sheaves is practical using DPR to control the pullout. Clamping the line in accumulating turns around a fixed post is a simple, effective brake.

The all-CMOS computer has been demonstrated to be an effective tool for low power, long life signal processing in a buoy at sea. The use of addressable sensors has been demonstrated. The number of sensors can exceed 300 in a single ADOM mooring. ADOM data has been successfully telemetered via satellite. Operation of the link at maximum range has been proven. The design demonstrates the safe operation of high energy lithium batteries and explosive bolts.

While our confidence in ADOM is high, the ultimate judgment will require long term deep ocean deployment trials. ADOM is comparable in cost to conventional deep sea moorings. ADOM has the edge for deployment in remote waters, where the cost of ship time is prohibitive; for synoptic measurements, where multiple ships would be required to set many moorings over a large area; and for observing short-lived events, which ships cannot reach quickly.

An increasing variety of small, low power in-line sensors is expected from normal development of oceanographic instrumentation.

Finally, ADOM represents a successful coordination of the goals and efforts of a multi-disciplinary team assembled from industry, academia, and government agencies. The deployment of oceanographic moorings from aircraft into ocean depths of 6000 m (20,000 ft) is a practical way to gather data for telemetry ashore by satellite relay.

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