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**Expendable Oceanographic Mooring (XMOOR)**

by

Daniel E. Frye, Donald Peters, and Richard Arthur

April 1997

**Technical Report**

Funding was provided by the Office of Naval Research through Contract Nos.  
N000-14-92-C-6028 and N000-14-95-1-0774.

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# EXPENDABLE OCEANOGRAPHIC MOORING (XMOOR)

Daniel E. Frye, Donald Peters, and Richard Arthur

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# **EXPENDABLE OCEANOGRAPHIC MOORING (XMOOR)**

**Daniel E. Frye, Donald Peters, and Richard Arthur**

## **ABSTRACT**

An expendable, self-deploying mooring (XMOOR) for shallow water applications has been developed to address Navy requirements for environmental monitoring. The project has been conducted jointly between the Woods Hole Oceanographic Institution and the Naval Research Laboratory at Stennis, MS. WHOI has taken the lead on the mechanical design of the system while NRL has developed the electronics.

Eight prototype XMOOR systems have been built. They are designed for water depths between 10 and 100m, for deployments of up to 3-months' duration, and for automatic deployment. Their sensor suite includes barometric pressure, air temperature, water temperature at up to 25 levels, and conductivity and pressure at up to 3 levels. Data telemetry is accomplished via the Argos DCS and by line-of-sight VHF radio. The radio link provides two-way communications to allow for remote configuration of the data collection program.

This report describes the XMOOR mechanical system. The data collection and telemetry systems are described separately in [1] and [2].

## **ACKNOWLEDGMENTS**

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# **1. INTRODUCTION**

## **1.1 Background**

The Expendable Oceanographic Mooring project was a multi-year technology development conducted jointly between the Woods Hole Oceanographic Institution and the Naval Research Laboratory at Stennis, MS. It was begun in FY93 with funding from the Office of Naval Technology as part of the Tactical Oceanography Program and was completed under ONR sponsorship early in 1996. The first year's program was devoted to the development of an expendable mooring for depths up to 300m with the potential to handle 3000m depths. Two prototype systems were built and successfully tested in August 1993 offshore Provincetown, MA. Based on these results, on feedback from potential Navy users of the device and on the new emphasis being placed on shallow water applications by the Navy, a modified specification was developed during the Fall of 1993 and Winter of 1994. This new specification was then used as the basis for the development of a smaller, lighter, shallow-water oriented mooring which was designed and built in FY 94 and FY95. Eight prototypes were fabricated at WHOI and seven were transferred to NRL for integration with electronics and sensors and for further testing. To date, NRL has deployed fully integrated XMOORs on two Navy research cruises [1].

## **1.2 Project Organization**

The XMOOR design and development effort was conducted jointly between WHOI and NRL. WHOI was responsible for the mechanical design, the overall mooring configuration, the automatic deployment system, and the in-line data collection pucks. NRL was the lead on the data acquisition and telemetry electronics, software development for data collection, processing and telemetry, and sensor integration. The inductive telemetry link used to transfer data from the data collection pucks to the surface controller was originally developed at WHOI on the first generation XMOOR, but was implemented on the second generation XMOOR prototypes by NRL [2] , [3], and [4].

Both NRL and WHOI were involved in at-sea tests. WHOI performed various mechanical and mooring tests in local waters near Woods Hole, while NRL performed several offshore deployments of fully integrated XMOORs on Navy cruises. This report describes the WHOI contributions to the XMOOR project with a brief description of the system electronics and sensors.

## **1.3 Design Objectives**

XMOOR specifications developed for the shallow-water environment were based on the following requirements. The system should be as small and light as possible, be completely self-deploying in depths up to 100m, be capable of operating for three months in most nearshore environments, and provide real-time data on important water

column properties. These general design objectives were developed into an initial specification for the first eight prototypes which is shown in Table 1-1. The long range goal of further miniaturizing the system so that it would be compatible with sonobuoy delivery systems, i.e., air-deployable 12cm (4 7/8 inch) diameter by 91cm (36 inches) long cylinders was delayed until the XMOOR prototypes proved successful. Since several of the design concepts were quite new and therefore high risk, it was decided that it would not be cost effective to expend substantial resources on miniaturization of high risk designs until they were proven to be reliable in a range of ocean environments.

**TABLE 1-1: XMOOR Prototype Specifications**

<b>SIZE:</b>	Length 1.67m (65.6") Diameter 17.5cm (6 7/8")
<b>WEIGHT:</b>	45.5 kg (100 lbs)
<b>OPERATIONAL RANGES:</b>	Water depth: 10-100 meters Current: 0-150 cm/sec (0-3 knots) Duration: 0-3 months
<b>SENSOR CONFIGURATION:</b>	Atmospheric: air temperature barometric pressure  Oceanographic: temperature (up to 25 depths) conductivity (up to 3 depths) pressure (up to 2 depths)
<b>TELEMETRY CAPABILITIES:</b>	Long range: Argos (256 bits per transmission) Short range: VHF (9600 bits/sec) On the mooring: Inductive (1200 bits/sec)
<b>DEPLOYMENT:</b>	Deployable by a single untrained person Data collection rates configurable prior to deployment or remotely by RF link

## 2. SYSTEM OVERVIEW

### 2.1 Technical Issues

To meet the design objectives, the development of a number of new approaches to shallow-water mooring systems was required. The underlying issues can be divided into four areas, but obviously they must all fit together as an integrated design. This section provides the rationale for the design approach taken in the XMOOR prototype.

Mooring Design: The mooring design was a key element in the overall system design. XMOOR is necessarily a surface mooring because continuous access to the RF telemetry channel is a requirement, as are meteorological sensors. The surface buoy has to be inflatable to meet the mooring payload requirement and the packaging dimensions. Successful surface moorings with small anchors (i.e., using embedment techniques rather than deadweight to moor the system) require reasonable scope and a low angle of attack at the anchor. To meet these requirements along with the packaging and weight limitations, a folding, omnidirectional, lightweight anchor was developed and packaged with 15m of chain.

The chain provides scope and compliance to absorb wave energy and minimizes the angle of attack at the anchor. Since surface moorings have high loads on their mooring lines due to wave forcing, the mooring line needs high strength, high resistance to bending loads, and general robustness. These requirements suggested wire rope or high-strength synthetic lines for the mooring strength member. The decision to use the high strength synthetic Vectran rather than wire rope was predicated on the self-deployment and packaging requirement. Wire rope (or E/M cable) could not be packaged in the small diameter XMOOR container due to its inherent stiffness. Potential high-strength synthetics including Kevlar, Spectra, and Vectran were evaluated as mooring line candidates. Vectran was chosen for its high strength (equivalent to Kevlar or Spectra), high resistance to bending degradation (a major problem with Kevlar), and low creep (Spectra's major shortcoming).

Self-deployment also required a lock-up mechanism on line payout to provide automatic scope adjustment for varying water depths. This is particularly important in shallow water situations, where too much line deployed could result in tangling, snagging on the bottom, or vulnerability to vessel traffic (if excess line was floating at the surface).

Two basic types of lock-up mechanisms were considered: continuous and discrete. The continuous technique arrests the mooring line at any point along its length. A discrete mechanism uses preselected points on the line to hold the mooring. The discrete lock-up approach was chosen for XMOOR to minimize the potential for failure at the lock-up point. The lock-up points were designed specifically to minimize bending and chafing which could lead to a failure at the stress concentration point.



The discrete lock-up points that were developed for XMOOR use a hollow braid spectra lanyard Chinese-fingered over the mooring line to transfer the mooring load from the mooring line to a short piece of stainless steel chain. The mooring line is relieved of the mooring load without being bent where it is in tension. The free end of the spectra hollow braid, which is very robust in bending and chafing situations, is terminated in an eye splice around an endless stainless steel thimble. This thimble is shackled to a short piece of stainless steel chain that terminates at a lock-up fitting.

The spectra lanyard termination was incorporated not only at the discrete lock-up points, but also at the termination of the mooring line to the surface buoy. In this location the lanyard thimble was captured in a welded bail fixed to the bottom of the instrument housing located just beneath the buoy. The free end of the mooring line was then whipped alongside this top termination lanyard and sleeved in polyester material up to the thimble at the bottom of the housing. It was then looped and electrically spliced to a pigtail ending in a connector plugged into the instrument housing endcap.

In addition, a pair of these lanyards were employed at the mid-water data collection puck location, where they transferred mooring loads from the mooring line to the top of the puck housing, and from the bottom of the puck housing back to the mooring line. This eliminated a stress concentration at the point where the mooring line passes through the puck.

The lock-up latching mechanism closes when the lower section of XMOOR (the anchor canister/line canister combination) hits the bottom. Any lock-up points passed while the canisters are still falling through the water are simply pulled out past the latch. When the canisters reach the bottom, line continues to be pulled out by the action of wind and current on the mooring, until the next lock-up point is captured in the closed latch. The lock-up system therefore always results in additional line being payed out after the system reaches the bottom, providing some, but not excessive, scope. The locations of the four lock-up points on the prototype mooring lines were chosen to give acceptable ranges of scope for the specified range of water depths.

Three-Month Life: A major feature in the XMOOR design, differentiating it from expendable sensors like sonobuoys and XBTs, is the requirement for three-month life. This lifetime is not far removed from the oceanographic standard of six to twelve months for relatively massive, manually deployed systems weighing thousands of pounds [5]. To meet this requirement the system components have been made as robust as possible within the available size and weight constraints. Particular problems that had to be solved to meet the three-month life requirement were gas leakage in the inflatable buoy and failure of the mooring line where it connects to the surface buoy, the data collection pucks, and the lock-up points.

The issue of long-term durability was a particular design driver for the mooring line and the various sensor attachment points. A design using a multiconductor

Vectran cable with breakouts for each thermistor, conductivity and pressure sensor would have been a simpler conceptual approach than the XMOOR design, but this approach would require 20 or more conductors to be subjected to the bending and tension loads of the mooring line, which would significantly increase the potential failure rate. All of the electrical breakouts would also have increased the chance for failures due to water leaks. The XMOOR design uses a single, highly helixed conductor in conjunction with several inductive modems/data collection pucks so that only one robust conductor is subjected to the full loading of the mooring. Very lightweight thermistor chains are then married to the mooring line in a way that puts no strain on the thermistor chain wiring and a single watertight connection is made to the data collection puck. The mooring line is continuous through the pucks, so no electromechanical terminations are required. A third option was also evaluated; two- or three-conductor Vectran cable with hardwired data telemetry from each puck could also have been implemented in XMOOR with some increase in the size of the Vectran. At this point in time, there is no clear answer to which of these two approaches (the single conductor or the 2 or 3 conductor approach) is best in terms of robustness, cost, and ease of use. The inductive link has led to some problems during testing. Whether these problems are significant in the long run is unclear.

Packaging: XMOOR packaging and weight constraints have also played a significant role in driving the prototype design. The surface buoy material was chosen so that it could be packed in a small volume. The requirement to use N<sub>2</sub> gas to inflate the buoy made the packaging problem difficult since eight bottles are required for inflation - each with its own seawater-activated inflation device. Maximum mooring line size was strongly influenced by the line canister dimension and maximum anchor size was also determined by the anchor canister dimensions. Anchor type (embedment) was forced by the weight constraint.

Finally, the data collection puck dimensions were driven by the canister diameter and the limited length of the line canister that contains both the line and the data collection pucks prior to deployment. Since each puck is a stand-alone CTD with inductive modem, thermistor chain electronics, and three-month battery pack, the requirement to produce a puck 15cm (6 inches) in diameter by 7.6cm (3 inches) high was a significant challenge.

Cost: An expendable mooring needs to be inexpensive. The XMOOR mechanical system could be made inexpensive to manufacture in quantity with some further investment in engineering and tooling. As with miniaturization, it was not cost effective to perform a serious engineering effort to minimize production costs until the system design was fully evaluated. The prototype XMOOR system has a parts cost of about \$15,000 which is dominated by the sensor and electronics components (2/3 of the total). The present mechanical components, which include all of the mooring components, anchor, buoy, self-deployment system, etc., cost about \$4,500. About two days of technician time are needed to assemble the system (in a lot of eight units).

## 2.2 General Description

The XMOOR prototype is shown in Figure 2-1. Figure 2-2 is a photograph of an XMOOR ready for deployment. Figure 2-3 shows the system after deployment. An inflatable surface buoy provides a platform for VHF and Argos transmitter antennas and meteorological sensors and supports the mooring over a wide range of water depths and current loads. An instrument housing positioned immediately below the buoy contains radios, data acquisition electronics, sensors and batteries for up to three months operation (Table 2-1). Beneath the instrument housing, a line canister holding up to 125 meters of mooring line packaged for automatic deployment and two data collection pucks is positioned. The data collection pucks (one at mid-depth and one at the bottom), contain conductivity, temperature, and depth sensors, inductive modems and toroids, batteries, and electronics for thermistor chains which are married to the mooring line. Finally, an embedment-type anchor with 15 meters of chain provides holding power with scope and compliance to accommodate surface wave action.

## 2.3 System Operation

This section describes the mechanical operation of the XMOOR system during the deployment sequence. Specific details of the mechanical components are covered in Section 3.

Prior to deployment, XMOOR is fully contained in a cylinder 17.5cm (6 7/8 inches) in diameter by 1.67m (66 inches) long. XMOOR is deployed by dropping it into the water anchor end first. Its orientation on hitting the water is not particularly important, but the anchor end, which is heavy, should hit the surface first. The undeployed system will sink momentarily but the buoy inflators will completely inflate the buoy within about 15 seconds. There are eight N<sub>2</sub> bottles each with an actuator. The actuators are commercially available devices in which spring loaded needles are used to penetrate the gas bottles. They are triggered by the rapid decomposition of a small tablet that reacts with seawater allowing the needles to puncture the tops of the gas bottles.

As XMOOR enters the water the actuator/lock-up drag wing opens. This pulls a retaining pin from a spring-steel mating ring which opens and allows the line canister to separate from the surface pressure housing. The drag wing also engages a retaining pin in a second mating ring holding the breakaway anchor canister together. The line canister and anchor canister then fall to the bottom. Mooring line is spooled in the line canister in two spools separated by the mid-water data collection puck. The line spools are held together with an acrylic mastic. As the canisters fall, line is unspooled and the mid-water puck is pulled out. The drag wing holds the line lock-up mechanism open until the canisters hit the bottom. When the drag wing falls down to a vertical position, it closes the lock-up mechanism and releases the mating ring connecting the line canister and the anchor canister. Current and wind are then relied upon to pull out any

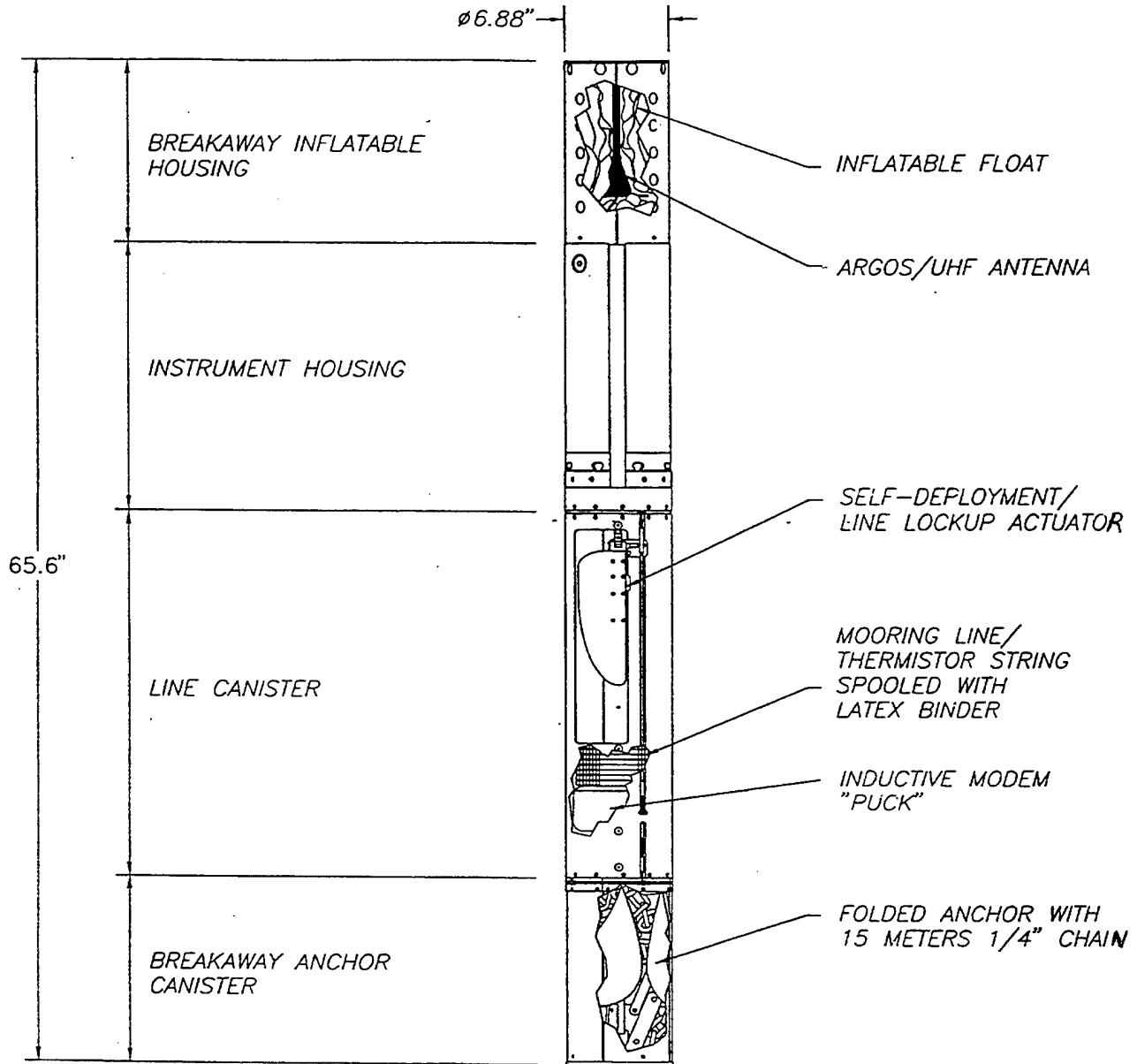


Figure 2-1: XMOOR prototype



Figure 2-2: XMOOR packaged for deployment

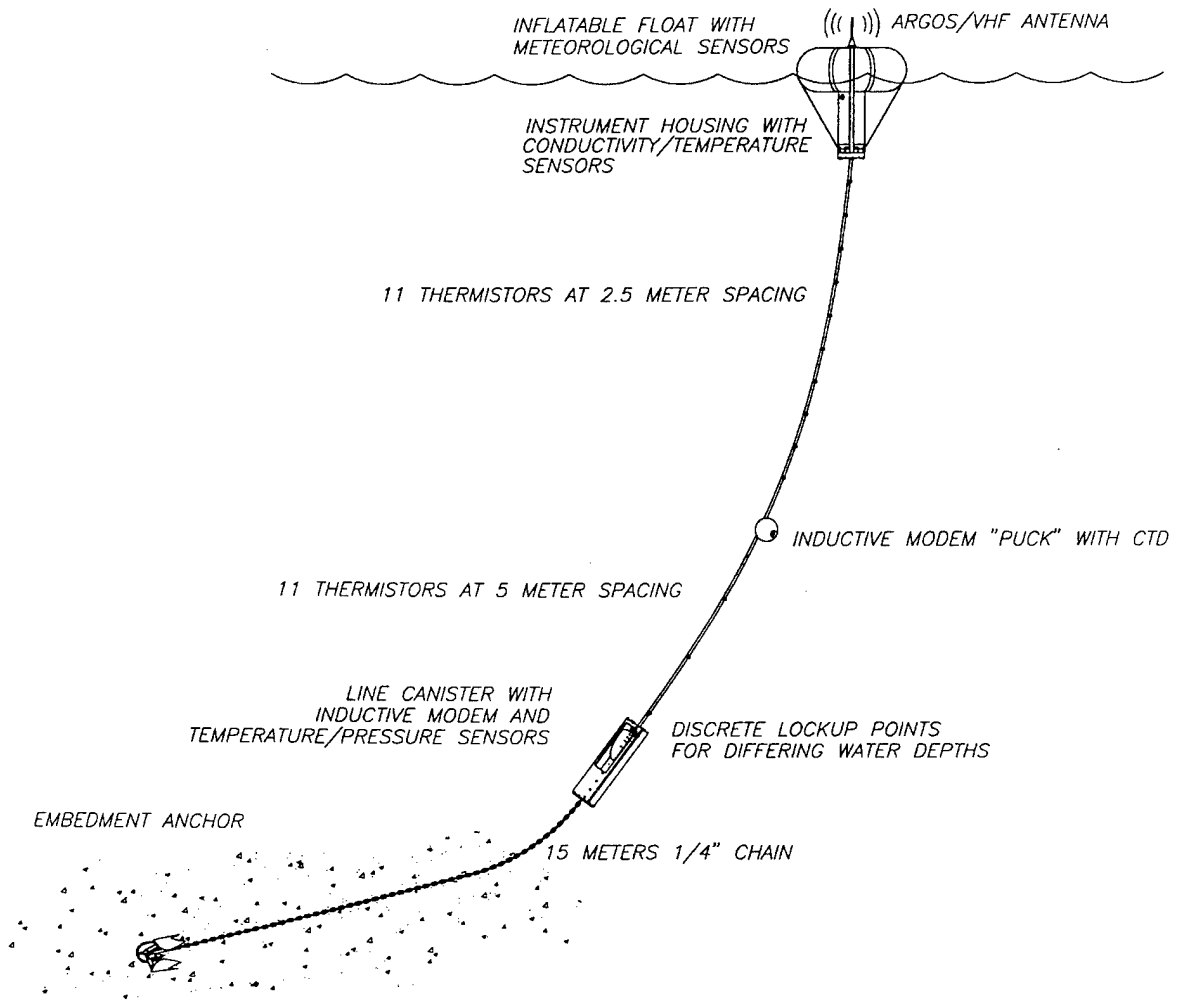


Figure 2-3: XMOOR configuration after deployment

**TABLE 2-1: XMOOR Prototype Payload**

<u>COMPONENTS</u>	<u>MANUFACTURER</u>	<u>MODEL OR DESCRIPTION</u>
Argos PTT	Seimac	SmartCat III
VHF Radios	GINA	Model 5000
Controller	Onset	Tattletale Model 5
Air Temperature Sensor	YSI	Thermistor 44108
Barometric Pressure Sensor	Motorola	MPX 4115
Water Temperature Sensor	YSI	Thermistor 44108
Thermistor Chain	Daycon	Miniature Tz
Conductivity/Pressure/ Temperature Sensor	FSI	Micro CTD
Inductive Modem	NRL	1200 b/s
Surface Buoy	Patten, Co.	Modified toroid
Buoy Inflator	Halkey-Roberts	Auto-inflator
N <sub>2</sub> Gas Bottle	Leland, Ltd	2500 psia, 77 cc's
Mooring Line	Cortland	Vectran/Hyline conductor (1275 lb RBS)
<b>Batteries</b>		
Instrument housing	Alkaline	21 D-cells
Data collection puck	Alkaline	8 AA cells

remaining line (until the next lock-up) and the anchor chain. The anchor embeds as it is dragged by the action of wind and current. In tests in 20m of water with 1.5 knot currents, the entire deployment sequence was completed in about 30 seconds. Circular tidal motions may pull the anchor out of the bottom, but its omnidirectional nature allows it to quickly re-embed. In a hard-bottom environment, sharp points on the anchor flukes are designed to snag irregularities in the bottom.

Key points in the operational scenario are:

- The mooring self-adjusts for depths between 10 and 100m using discrete lock-up points at 15, 30, 60, and 125 meters of line.
- Temperature sensors are distributed throughout the water column - at 2 ½ meter intervals in the upper layers and at 5 meter intervals in the lower layers.

- Sensor data collection and data telemetry is controlled by electronics in the housing below the surface buoy. An inductive link is used to access the subsurface data collection pucks using a single conductor in the mooring line with a seawater return. Each puck is addressed with a unique ID and sensor data are immediately transmitted.
- Salinity measurements are made using a new highly accurate and very compact CTD packaged specifically for this application.
- Data are available in real time via a two-way line-of-sight radio link, and a one-way, low baud rate satellite link with global coverage.
- Batteries in the surface pressure housing and the subsurface data collection pucks are capable of collecting and transmitting data for up to three months, depending on the duty cycle implemented.



### **3. XMOOR MECHANICAL DESIGN**

#### **3.1 Surface Buoy and Instrument Housing**

The surface buoy is shown in Figure 3-1a and Figure 3-1b. It has a volume of approximately 88 L (3ft<sup>3</sup>) and provides about 890N (200 lbs) of total buoyancy. It was designed specifically for the XMOOR prototype and is built by Patten Co. of Lakeview, FL, to our specification. Buoy material is nylon coated urethane. Nylon straps hold the pressure housing to the buoy and transfer the mooring load. The buoy is filled with N<sub>2</sub> gas supplied by eight high pressure bottles each with 77 cc's of 2500 psia gas. These bottles are purchased from Leland, Ltd, Bedminster, NJ. Each bottle has an inflator valve with seawater actuator made by Halke-Roberts, St. Petersburg, FL. The bottles are fitted to the buoy in small pockets on the outside surface of the buoy.

The instrument housing is an aluminum cylinder (3mm - 1/8 inch wall) with an endcap at the bottom. On the top end is a single coaxial connector for the Argos PTT and RF link antenna. A second feedthrough is provided for the barometric and air temperature sensors. On the bottom end cap a connector for the inductively transferred data is located next to a grounding stud used for the seawater return. A padeye for connecting the mooring line is centered on this end cap. Detailed drawings for the surface buoy, instrument housing and all other mechanical components can be found in Appendix 6.1. The instrument housing holds the Argos PTT, VHF transceiver, Tattletale controller, inductive modem, air temperature, barometric pressure and surface water temperature sensors, and battery pack.

#### **3.2 Line Canister and Lock-Up Mechanism**

The middle section of XMOOR consists of the line canister, which holds the spooled line and data collection pucks prior to deployment. The wall of the line canister houses the drag wing actuator/lock-up mechanism.

The maximum outside diameter of the line canister is limited by the 17.5cm (6 7/8 inch) system diameter constraint, while the inside diameter of 16.2cm (6 3/8 inch) is the minimum diameter found to allow free rotation and pullout of the mid-water puck. The resulting average line canister wall thickness is 6.4mm (1/4 inch). Early in the design stage a single mechanism to provide self-deployment actuation and line lockup was envisioned. Since this mechanism would only occupy space on one side of the line canister, it was decided to offset the inside bore of the line canister by 3.2mm (1/8 inch), resulting in a wall thickness of 9.6mm (3/8 inch) on the actuator side, and 3.2mm (1/8 inch) on the opposite side. The resulting increase of volume was enough to allow the actuator/lock-up mechanism to be housed within the wall of the line canister, and not encroach on either the O.D. or I.D. of the canister.

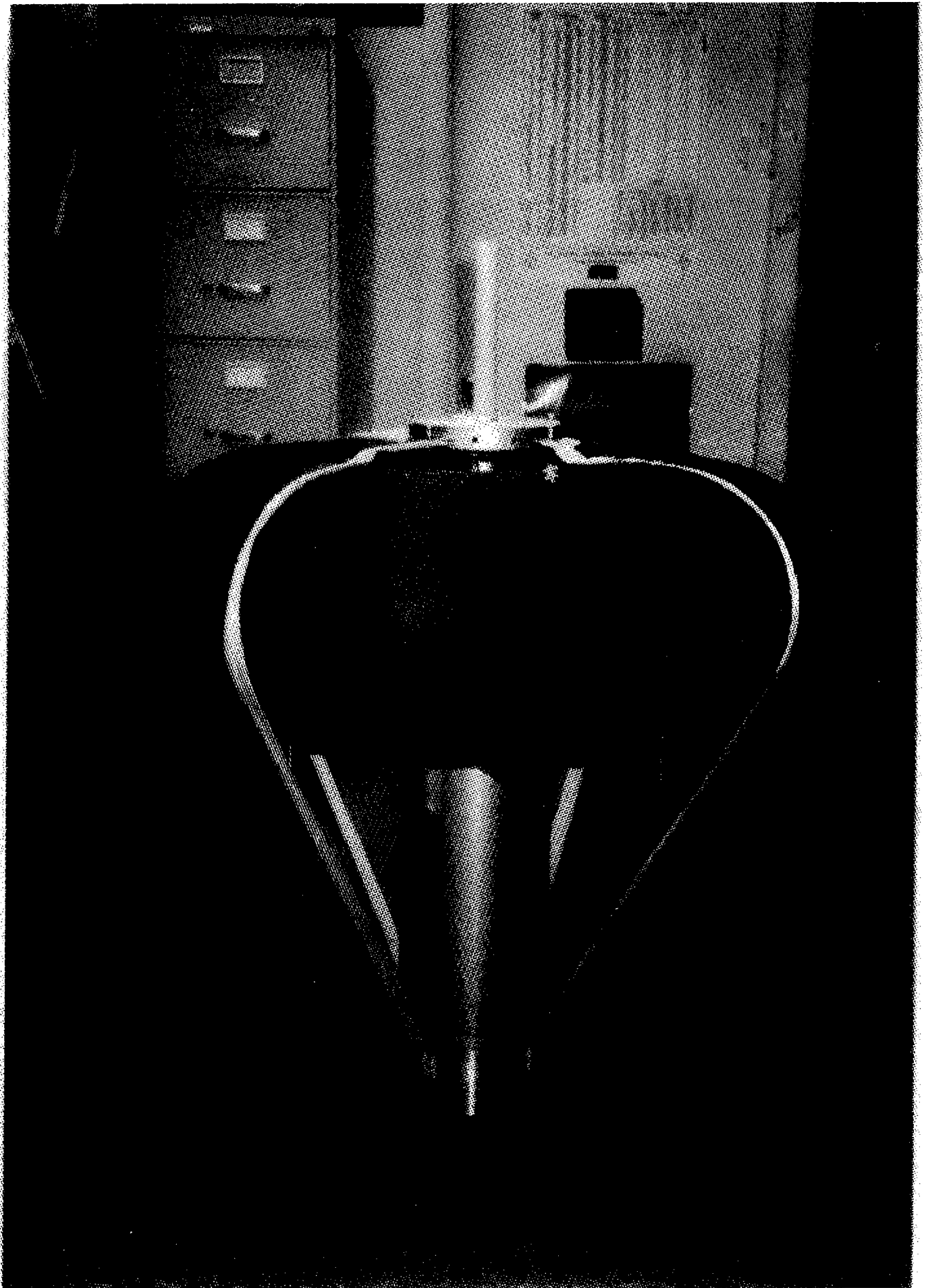


Figure 3-1a: Photograph of XMOOR surface buoy and instrument housing

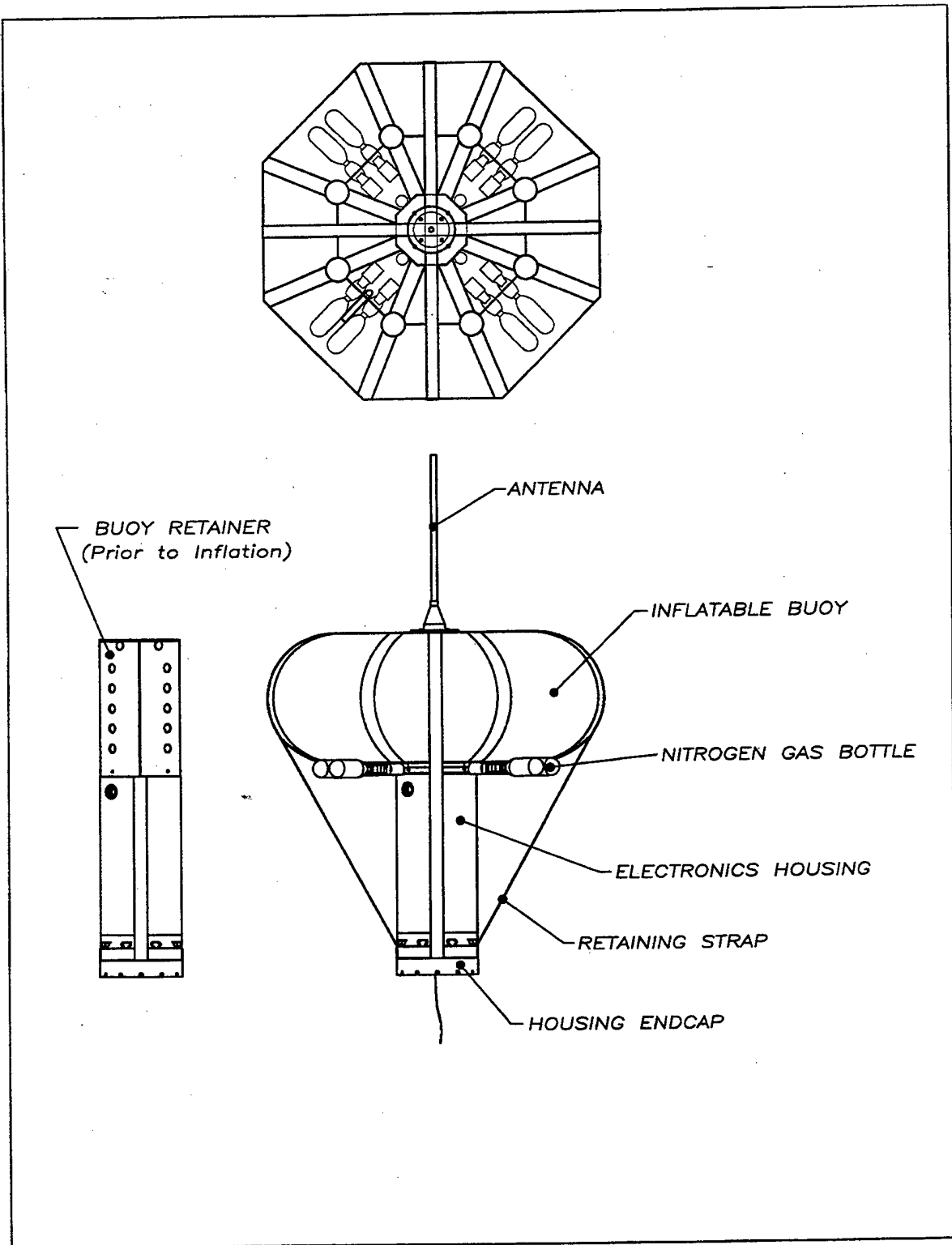


Figure 3-1b: Design of XMOOR surface buoy and instrument housing

The line canister is a nylon cylinder 17.5cm (6 7/8 inches) in diameter and 43cm (17 inches) long (Figure 3-2a). At the top is a machined ring that connects the line canister and the instrument housing. Along an interior wall is a stainless steel track which acts as both the structural strength member through which the mooring forces pass and as a guide for the individual lock-up slides. Prior to deployment all four lock-up slides are placed on and captured by the lock-up guide. As the mooring line is pulled out of the canister during deployment, the slides pull off the top of the guide and out of the canister. When the drag wing, located on the outside of the line canister returns to a vertical position, the top of the guide is closed off and the next slide to hit the top is captured. This stops further unspooling and transfers the mooring load to the guide. The wing is also locked down once a slide is captured. Any line or sensors left in the canister remain in the canister.

### 3.3 Line Packs

The line packs are constructed with 4.8mm (3/16 inch) Vectran line with a single copper conductor helixed around a small internal Vectran core. Figure 3-2 shows the line construction and specifications. The line is wound into two line packs in each XMOOR prototype. The top line pack is 30m long and attaches to the instrument housing just below the buoy at a padeye. The electrical conductor is terminated to a Mecca connector which plugs into a pin on the bottom end cap of the instrument housing. At the lower end of the upper line pack the line passes through the mid-water data collection puck and through the split toroid in the puck. Mechanical terminations for the surface buoy, lock-up points, and mid-water puck are made by slipping a hollow braid spectra lanyard over the vectran line and then back splicing the spectra lanyard over a stainless steel thimble (see Drawing No. 011-3-0106 in Appendix 6.1) The mid-water puck attaches to the line with a spectra lanyard above and below the puck. These lanyards pass the mooring line forces through the puck protecting the mooring line where it passes through the puck and split toroid (Figure 3-3).

A thin polyester sleeving holds the 11-channel thermistor chain snugly to the mooring line. The line with thermistor chain is then wound into a line pack and coated with an acrylic mastic to maintain its integrity. The line pack is wound on a mandrel and feeds from the inside out like a ball of twine (Figure 3-4).

The lower line pack is constructed in a similar manner, but is 60-95m long. [XMOOR is designed to use up to 125m of line - the eight prototypes built to date have used 90m of line so that available thermistor chains could be used without modification.] A 55m thermistor chain is married to the line beginning 5m below the mid-water puck. This chain is also an 11-channel chain, but its thermistors are spaced at 5m intervals rather than the 2 1/2m intervals in the upper chain. As stated previously, the mooring line is continuous from top to bottom, so both line packs are wound from one shot of the Vectran cable.

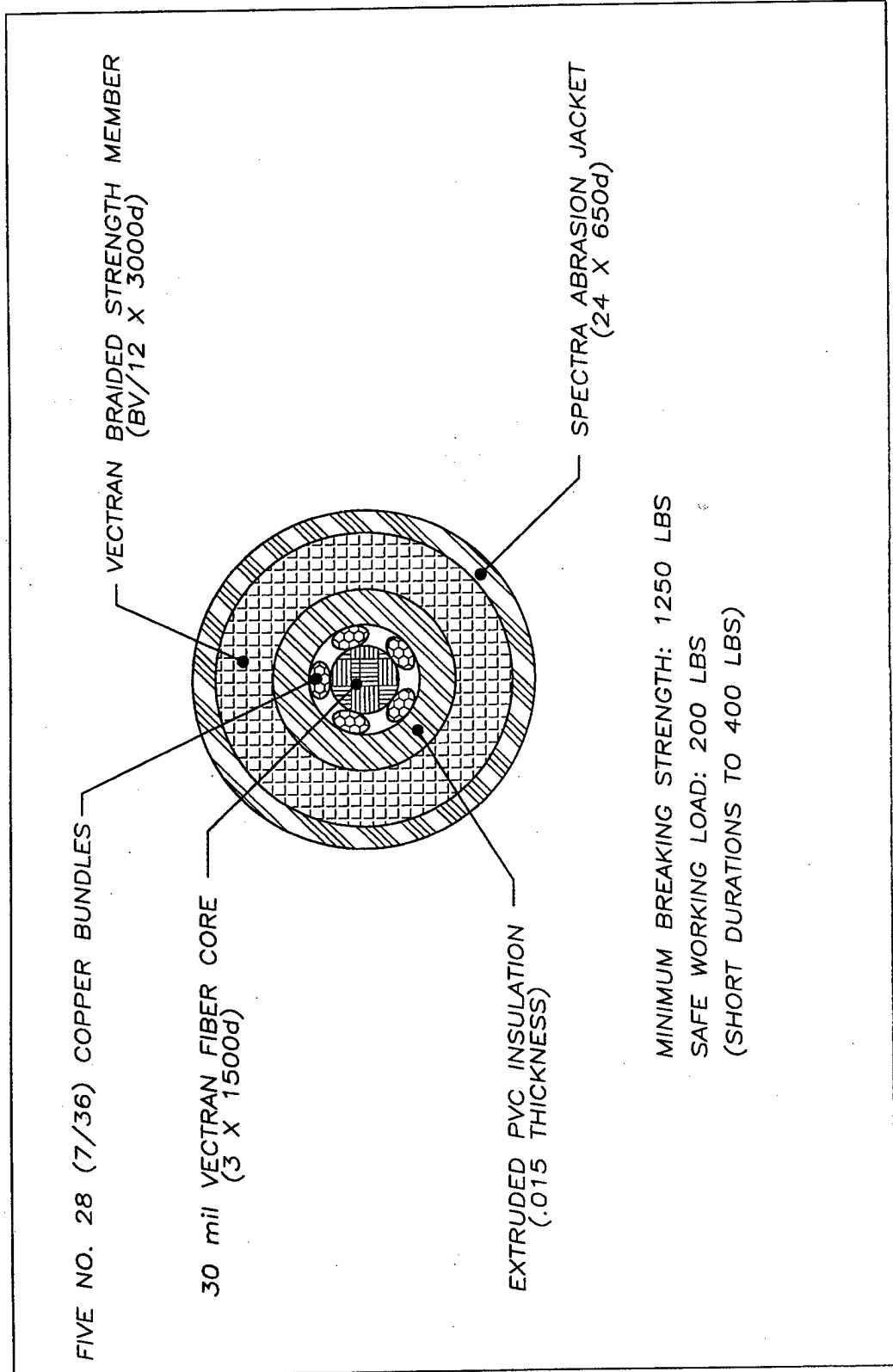


Figure 3-2: Line construction and specifications

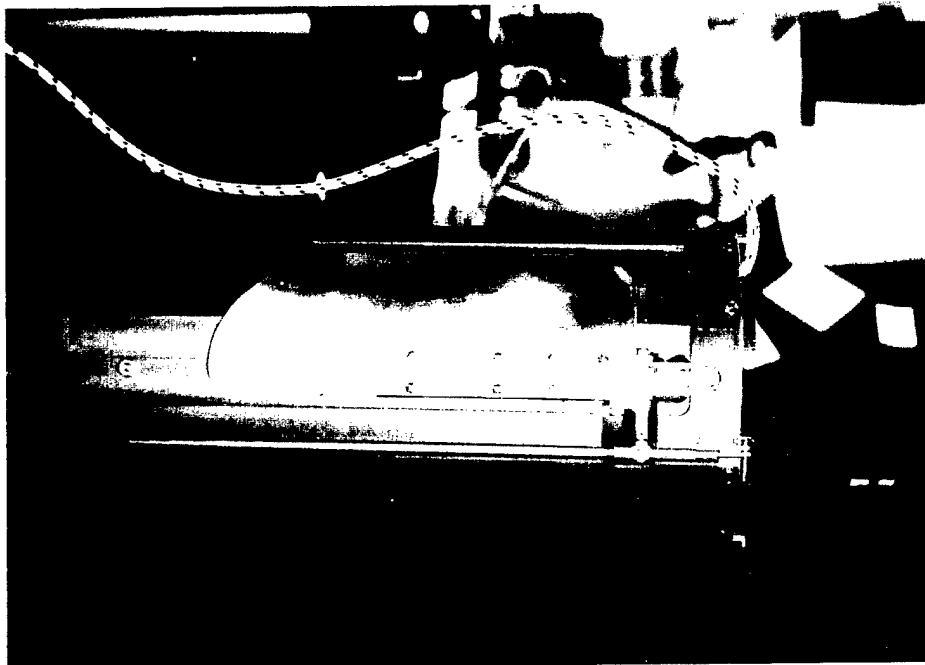
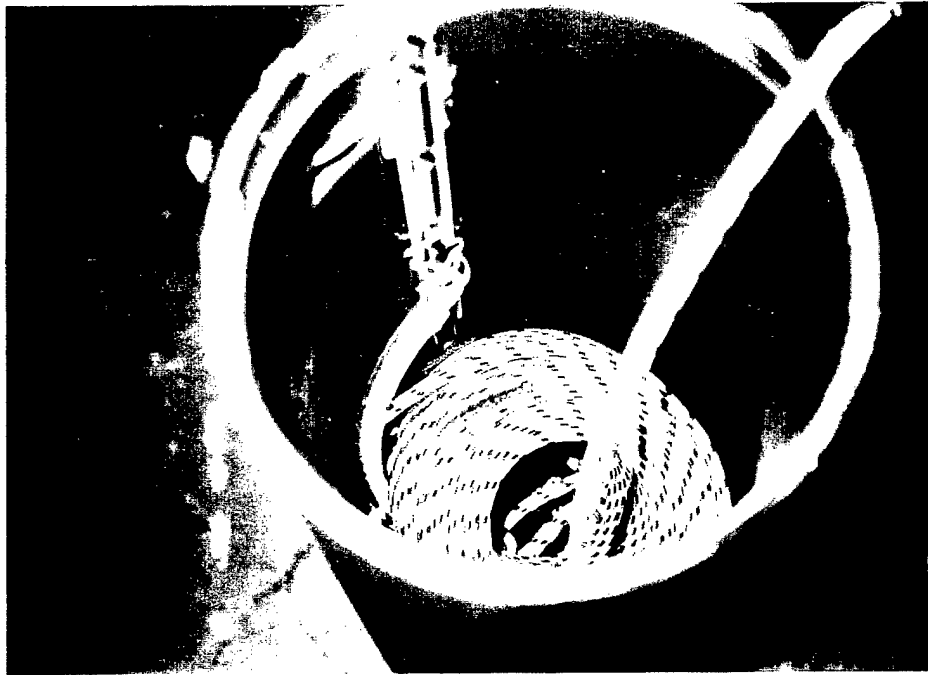


Figure 3-2a: Line canister, lock-up slide and line pack

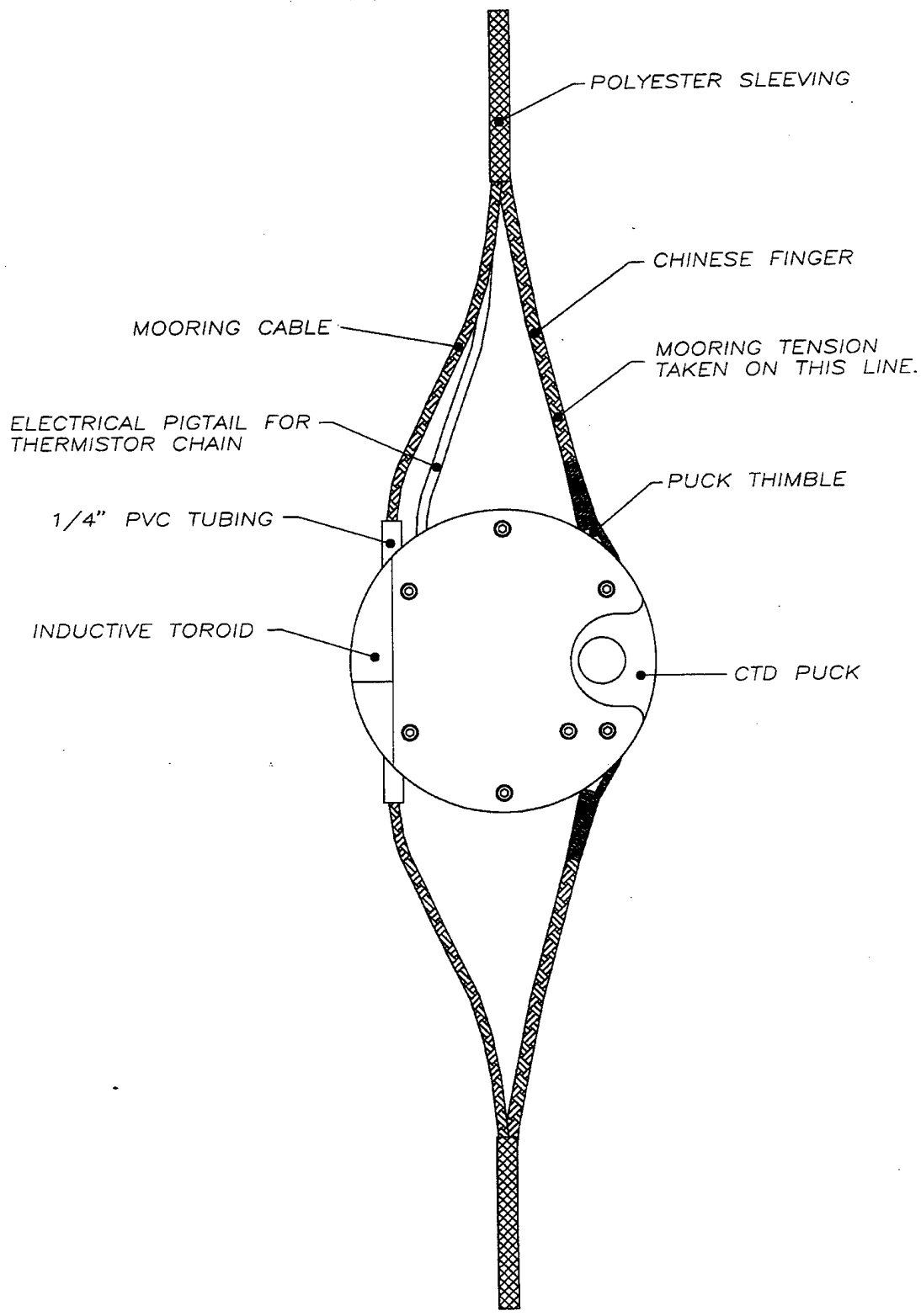


Figure 3-3: Mooring line where it passes through the puck

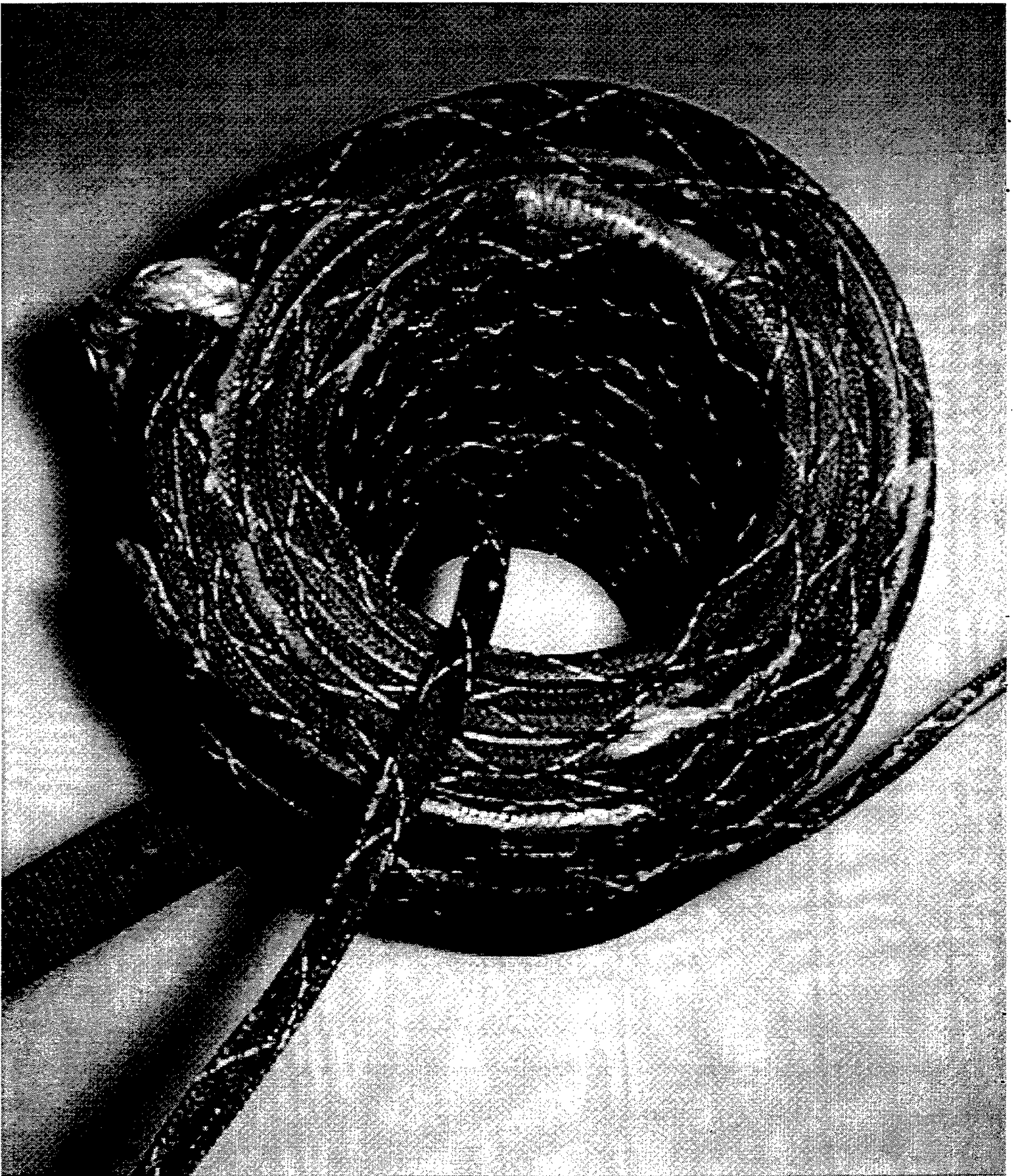


Figure 3-4: Line pack feeding from the center



Four lock-ups are spliced to the line packs at line lengths of 15, 30, 60, and 90 or 125m. These locations were chosen to provide appropriate scope for a range of water depths, to account for the location of the data collection pucks, and to facilitate assembly. The design will tolerate other choices or more lock-up points, if the requirement exists. The key design consideration for the lock-up points is to provide a strong connection through which all mooring forces pass, without putting undue stress on the mooring line. This is accomplished by splicing short lanyards to the mooring line and terminating the other end of the lanyards to the small stainless steel lock-up links.

### **3.4 Data Collection Pucks**

The data collection pucks are self-contained instruments that measure conductivity, temperature, pressure, and eleven channels of thermistor chain data. They contain inductive modems for communication with the system controller located beneath the surface buoy and have a three-month battery supply made up of eight alkaline AA cells. Puck mechanical design is shown in Figure 3-5. Figure 3-6 shows several photographs of the puck and line canisters. The pucks are 15cm (6 inches) in diameter by 7.6cm (3 inches) high. They have a split ferrite toroid which can be opened to run the mooring line through the puck. The mid-water puck has a 12-pin feedthrough for the upper thermistor chain and the bottom puck (which remains in the line canister on the bottom) has a similar feedthrough for the lower thermistor chain. The inductive conductivity cell is molded into the puck and has an associated temperature and pressure sensor exposed to the seawater.

Each puck is machined from a single piece of glass-filled delrin. Access to the electronics is available through a cover which has an O-ring seal and is attached with machine screws. The pucks weigh about one pound in water when loaded with electronics and batteries.

### **3.5 Anchor Canister**

The anchor canister is an aluminum cylinder with four side panels that are held in place by rings at the top and bottom - similar to a wooden barrel. The top ring attaches the anchor canister to the line canister above it prior to deployment. When the canisters hit the bottom, the drag wing folds down and the canisters disconnect. The sides of the anchor canister are then free to fall away (Figure 3-7).

Inside the anchor canister is 15m of 6mm (1/4 inch) galvanized chain and the three-fluke folding anchor which was developed specifically for XMOOR. The chain has a rated breaking strength of 24kN (5400 lbs) and provides mooring scope to the system. The chain also provides compliance for wave action and lowers the angle of attack to the anchor. The chain is terminated at its upper end with a shackle to the lock-up guide at the bottom of the line canister and at its lower end to the anchor stock with another shackle. The anchor and chain are deployed by the action of the wind and currents which tend to drag the mooring away from its deployment site. The anchor embeds as

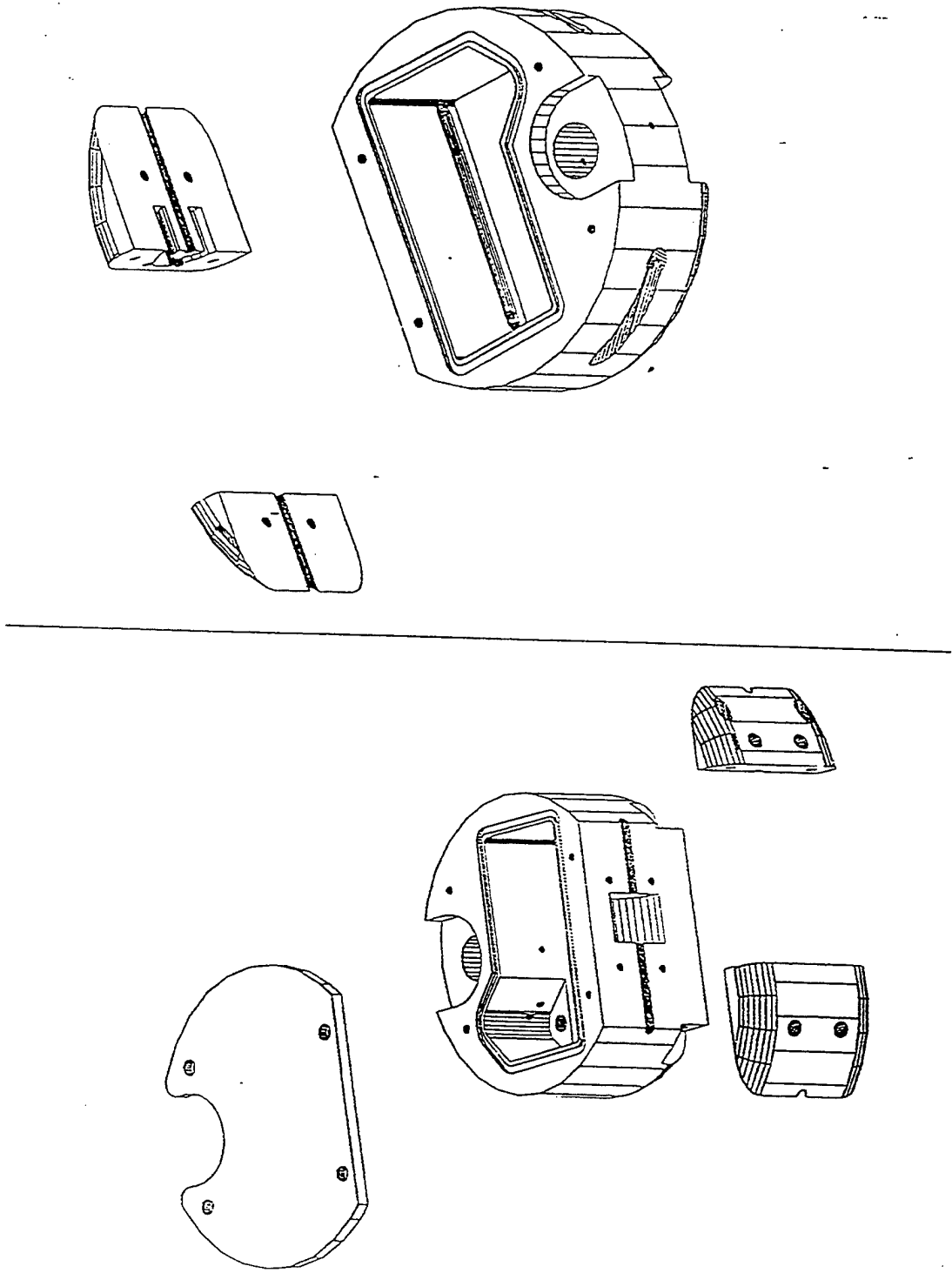


Figure 3-5: Puck mechanical design

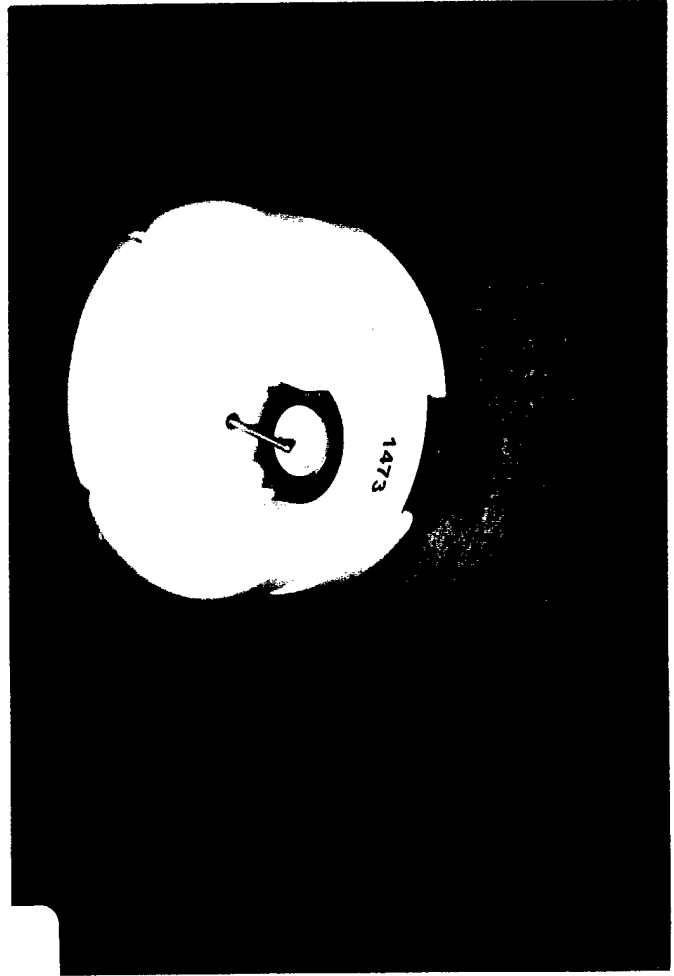
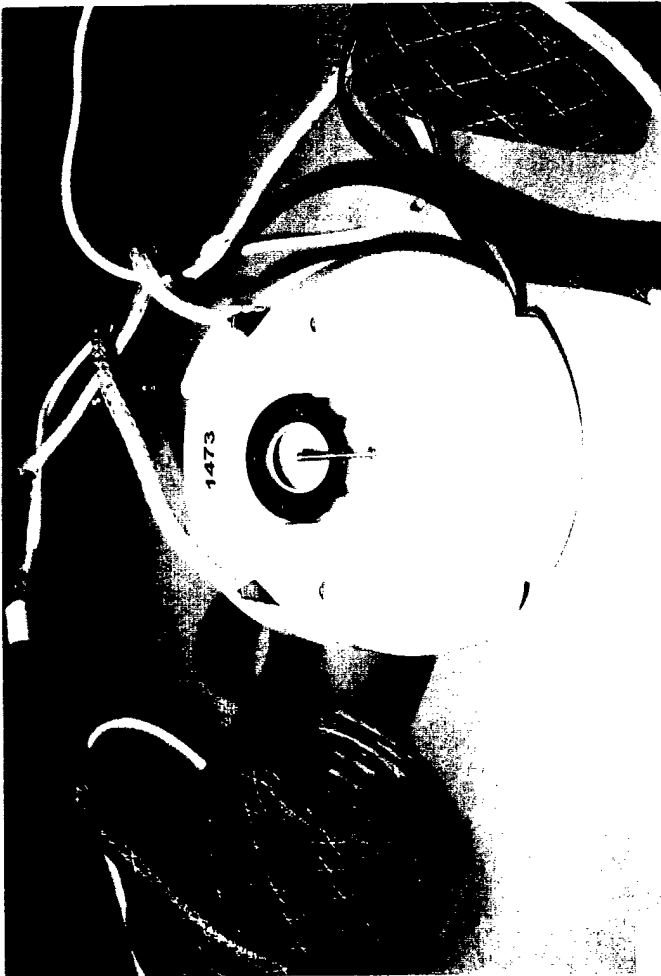
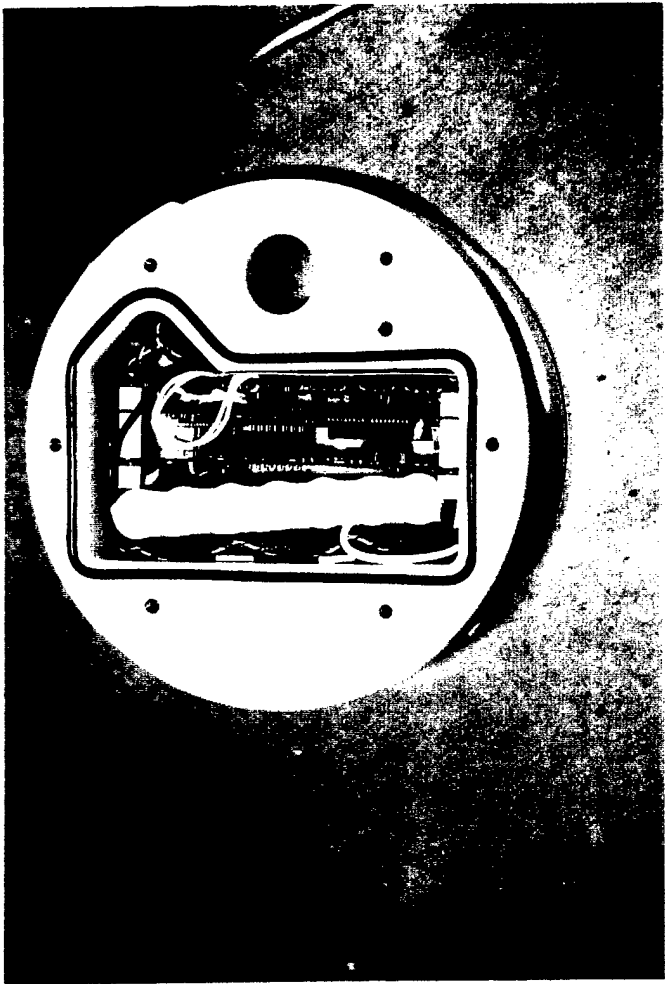


Figure 3-6: Puck and line racks

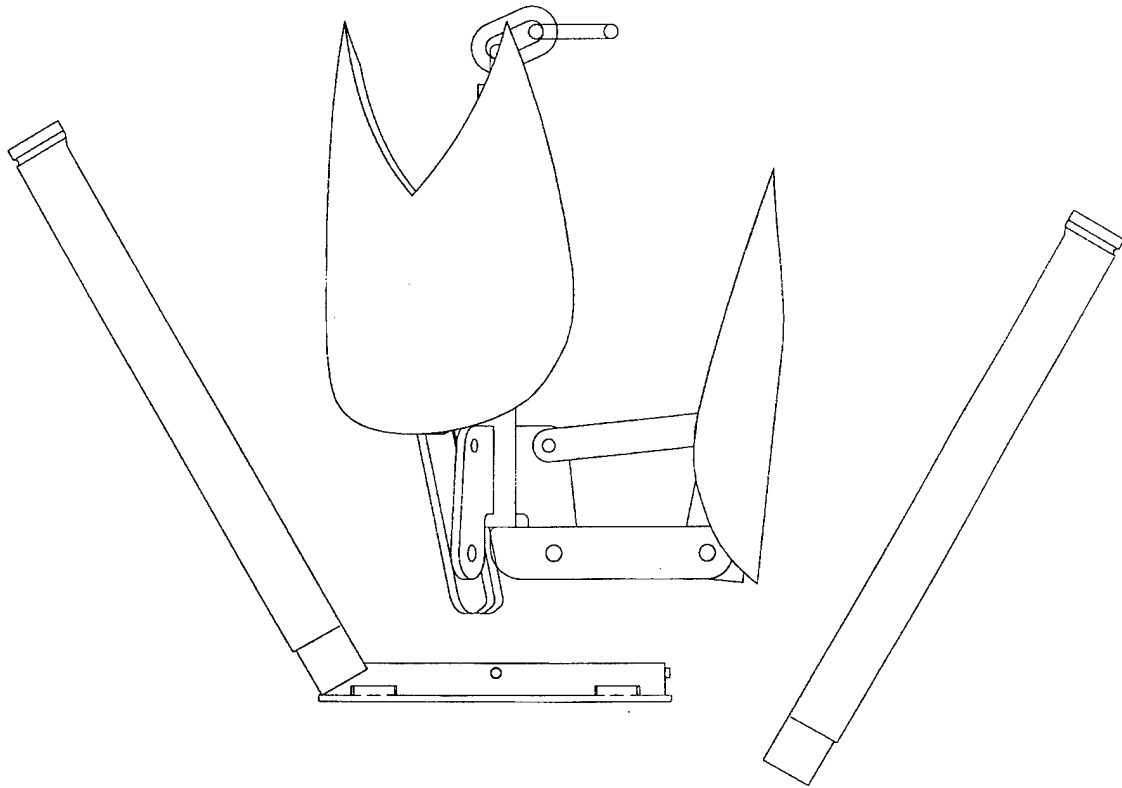


Figure 3-7: Anchor with breakaway canister (two sides shown falling away)

it is dragged. Changing current direction may cause the anchor to drag, but it quickly re-embeds as it moves along the bottom. By using three flukes, the XMOOR anchor avoids the directionality problems associated with Danforth type anchors. It is designed to respond similarly to the Bruce anchor, but provides more holding power than a Bruce anchor sized to fit the XMOOR packaging constraints. Figure 3-8 shows the anchor embedded in the sand.

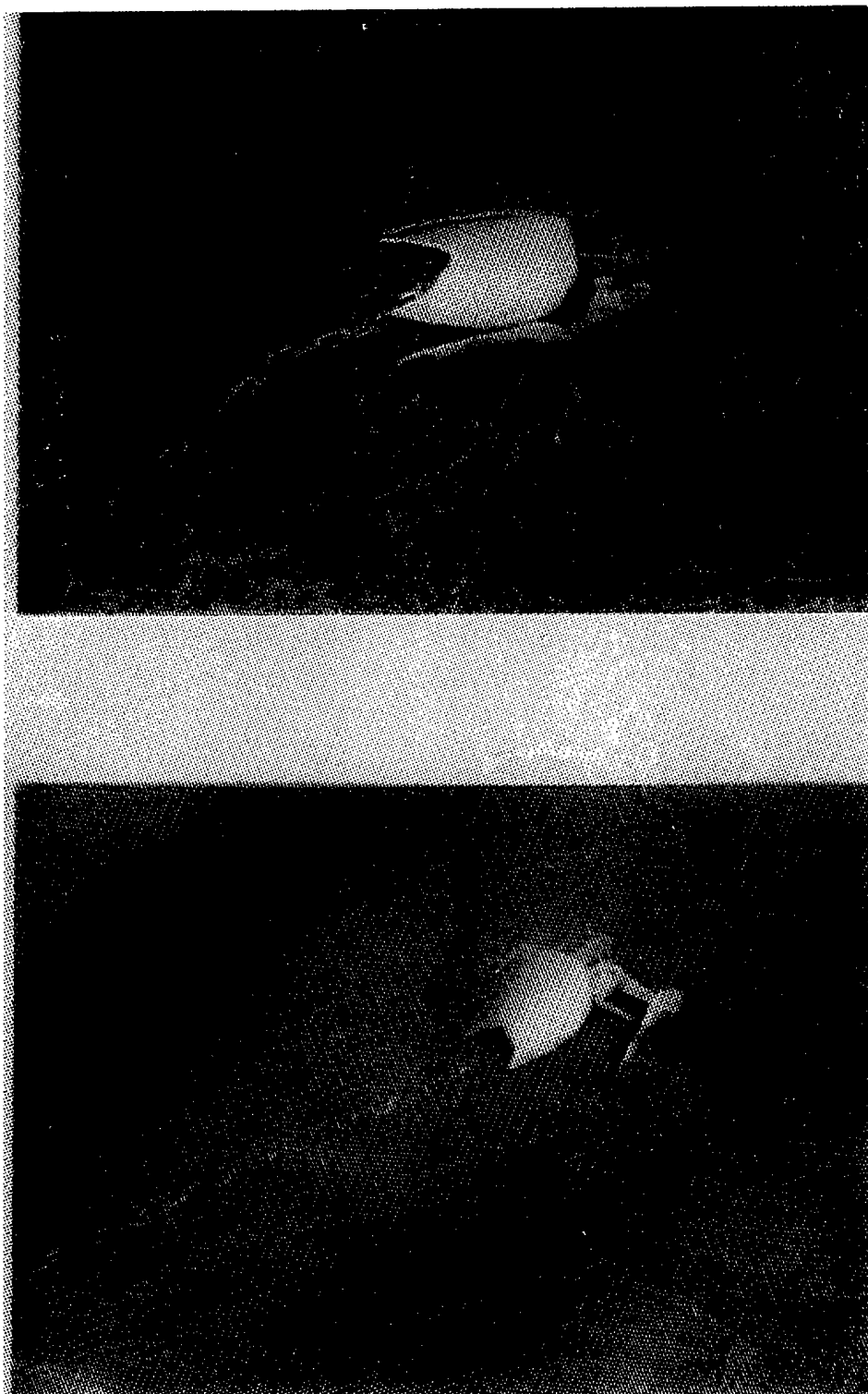


Figure 3-8: XMOOR anchor embedded in sand

## 4. DISCUSSION

The Expendable Oceanographic Mooring project was an ambitious engineering development whose goal was to design and build a prototype shallow-water, self-deploying mooring capable of making comprehensive water column measurements for several months. It follows on several earlier attempts to develop self-deploying moorings such as ADOM [6] and incorporates ideas from sonobuoys and small drifting buoys. The designs resulting from the project are sophisticated and simple and they appear to function as designed; however, long-term tests in a range of coastal environments have not yet been carried out so the reliability of several key mechanical systems is still uncertain. Small modifications to the design will likely be necessary to optimize the long-term survivability of the system.

The specific areas in the XMOOR design which involve new design concepts and technical innovations are:

1. Inductive telemetry of water column sensor data to the surface buoy: This technique uses a single conductor to transmit data up the mooring and allows polling of sensors so that multiple instruments can share the single conductor.
2. Vectran mooring line with a single, robust conductor: Vectran is a very high strength synthetic with very low stretch and better resistance to bending failure than Kevlar. The single conductor used for telemetry was constructed by wrapping it around a small Vectran core in a high angle helix. This construction provides improved reliability over typical multi-conductor synthetic lines, especially where they connect to a surface buoy.
3. Self-inflating buoy with 3-month life: Most self-inflating systems use liquid CO<sub>2</sub> as an inflation gas. CO<sub>2</sub>, however, is difficult to contain over long periods since it diffuses through most rubbers. XMOOR uses high pressure nitrogen as an inflation gas to achieve long life with a thin urethane-coated nylon buoy.
4. Lightweight embedment style anchor packaged in small diameter housing: XMOOR requires substantial holding power in strong currents with a variety of bottom types and variable scope. An anchor with folding flukes was developed that works well in most environments.
5. Automatic deployment with self-adjusting mooring scope: The purpose of this feature was to allow an untrained person to take a pre-packaged system into the field and deploy it anywhere in the near-shore region without having any special knowledge of water depth, current profile, or bottom type. No on-site configuration is required and no special deployment equipment is needed.

6. Miniature CTD with integral inductive modem and 11-sensor thermistor chain:  
This is the heart of the in-water sensor system and it was developed specifically for the XMOOR project. The thermistor chain was developed for drifting buoys under a separate NRL program and integrated into the CTD system. Falmouth Scientific, Inc., under subcontract to WHOI/NRL, developed the CTD sensor electronics. The inductive modems were originally developed at WHOI [3] and [4], but were implemented by NRL for the second generation XMOOR prototype.

As more experience is gained with the prototype systems and as specific applications are defined, modifications to the prototype sensor suite, telemetry systems, and data collection systems are anticipated. While the system can support different payloads, the packaging and self-deploying constraints may require substantial engineering modifications to accommodate substantive payload changes.

Besides the issues of size, weight, range of conditions, and lifetime, a final constraint on the XMOOR prototype is cost. Expendable systems need to be inexpensive if they are to be used in large numbers. It should be noted that some of the specifications for XMOOR are seriously at odds with the typical definition of inexpensive - particularly the requirements for CTD measurements at several depths and three-month life. In spite of these difficulties, XMOOR is reasonably inexpensive. Table 4-1 lists the component prices of the XMOOR mechanical system when ordered in small (8) quantity. Obviously, high volume production techniques have not been utilized to date. A similar list of the electronic components is shown in Table 4-2. The costs associated with mechanical assembly and test are difficult to quantify, but given some experience with the fabrication techniques, several technician days is a reasonable estimate. It remains to be seen whether or not an expendable mooring with a component cost of \$15,000 will be used as an expendable. With this in mind, XMOOR has been designed to be capable of recovery and refurbishment. Refurbishment consists of re-batterying, replacing worn-out line and chain, and replacing the buoy assembly (if necessary). The systems can then be re-packed and used for considerably less than the cost of replacement.

**Table 4.1: XMOOR Component Costs - Mechanical**

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST
Surface Buoy w/ 8 Inflators	1	\$236.00	\$236.00
Buoy Side Retainers	4	\$6.00	\$24.00
Tree Rivets	8	\$0.32	\$2.56
Nitrogen Gas Cartridges	8	\$15.12	\$120.96
Buoy Retaining Ring	1	\$34.00	\$34.00
Electronics Pressure Housing	1	\$390.00	\$390.00
Pressure Housing Endcap	1	\$312.00	\$312.00
Hex Plug on Housing	1	\$6.10	\$6.10
Seacon Bulkhead Connector XSA- BC	1	\$16.10	\$16.10
Seacon pigtail RMA-FS	1	\$15.70	\$15.70
Mooring Cable	410'	@\$0.64	\$262.40
Polyester Sleeving 84n1483 Type BXPO16	410'	@\$0.53	\$219.31
Lock-up Hardware	4	\$12.50	\$50.00
Lock-up Slide	4	\$20.00	\$80.00
6-Wire Pave Connector	1	\$175.00	\$175.00
12-Wire Pave Connector	2	\$240.00	\$480.00
Coax Epoxy Connector (antenna)	1	\$185.00	\$185.00
Ground Lug	1	\$44.00	\$44.00
Buoy Endcap	1	\$52.00	\$52.00
Buoy Strap Rating Ring	1	\$54.00	\$54.00
Anchor	1	\$300.00	\$300.00
Anchor Canister Side Top	4	\$42.00	\$168.00
Anchor Canister Rolled Side	4	\$6.00	\$24.00
Anchor Canister Bottom	1	\$98.00	\$98.00



DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST
Misc. Hardware	1	\$20.00	\$20.00
Anchor Chain	50'	@\$0.50	\$25.00
Line Canister, Bare Tube	1	\$344.00	\$344.00
Lockup Track	1	\$20.00	\$20.00
Track Bottom Tab, Welded	1	\$45.00	\$45.00
Activator Wing	1	\$25.00	\$25.00
Actuator Fixed Piece	1	\$38.10	\$38.10
Accuator Moving Piece	1	\$78.70	\$78.70
Accuator Arm	1	\$33.00	\$33.00
Accuator Lock-up Spring	1	\$87.00	\$87.00
Pushrod, Top and Bottom	1	\$15.45	\$15.45
Upper Pushrod End	1	\$15.30	\$15.30
Lower Pin Puller	1	\$16.10	\$16.10
Top Ring, to Buoy	2	\$116.00	\$232.00
Bottom Ring, to Anchor Can	1	\$155.00	\$155.00
Spring Retainer Ring	2	\$8.80	\$17.60
<b>TOTAL</b>			<b>\$4,516.38</b>

**Table 4-2: XMOOR Component Costs - Electronics/Sensors**

COMPONENT	QUANTITY	COST	TOTAL COST
Barometric pressure sensor	1	\$23.00	\$23.00
Air Temperature	1	\$39.00	\$39.00
Thermistor Chain	2	\$1500.00	\$1500.00
CTD Puck w/conductivity, temperature, pressure, modem, batteries	2	\$1,950.00	\$3,900.00
Surface Controller	1	\$1,327.00	\$1,327.00
GINA Model 5000	1	500.00	500.00
SEIMAC Smart CAT III	1	\$1,000.00	\$1,000.00
Puck Controller Board	2	\$159.00	\$318.00
Batteries	21	\$2.00	\$42.00
<b>Approximate Total Electronics/Sensors</b>			\$10,149.00
<b>Approximate Total XMOOR Prototype</b>			\$14,665.00

## 5. REFERENCES

- [1] J. Boyd, R. Burnes, B. Bricker, and D. E. Frye, "An expendable, self-deploying coastal mooring: telemetry and sensors," presented at AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February 12-16, 1996.
- [2] Frye, Daniel E. and Janice Boyd, "Expendable Oceanographic Mooring - XMOOR," *Sea Technology*, August 1996, pp 61-65.
- [3] R. Eastwood, T. Dickey, J. Kemp, and D. Frye, "Inductive telemetry for ocean moorings: operational experience," presented at AGU/ASLO Ocean Sciences Meeting, San Diego, CA, February 12-16, 1996.
- [4] Daniel Frye, Steve Merriam, Bob Eastwood, John Kemp, Neil McPhee, Steve Liberatore, Ed Hobart, Alex Bocconcelli, and Susan Tarbell, "Atlantic Long-Term Oceanographic Mooring (ALTOMOOR)," WHOI Technical Rpt. WHOI 96-02, May 1996.
- [5] Daniel Frye, "Surface telemetry mooring - two extremes," presented ONR/MTS Buoy Workshop, San Diego, CA, March 27-28, 1996.
- [6] L. W. Bonde, D. B. Dillon, E. J. Softley, R. Walden, H. Berteaux, and T. Popp, "Air Deployed Oceanographic Mooring (ADOM) - AB1034," *Proceedings, Oceans '83*, San Francisco, CA, Aug. 29 - Sept. 1, 1983.
- [7] Donald A. Moller, "A computer program for the design and static analysis of single-point subsurface mooring systems: NOYFB," WHOI Tech. Rpt. WHOI 76-59, June 1976.

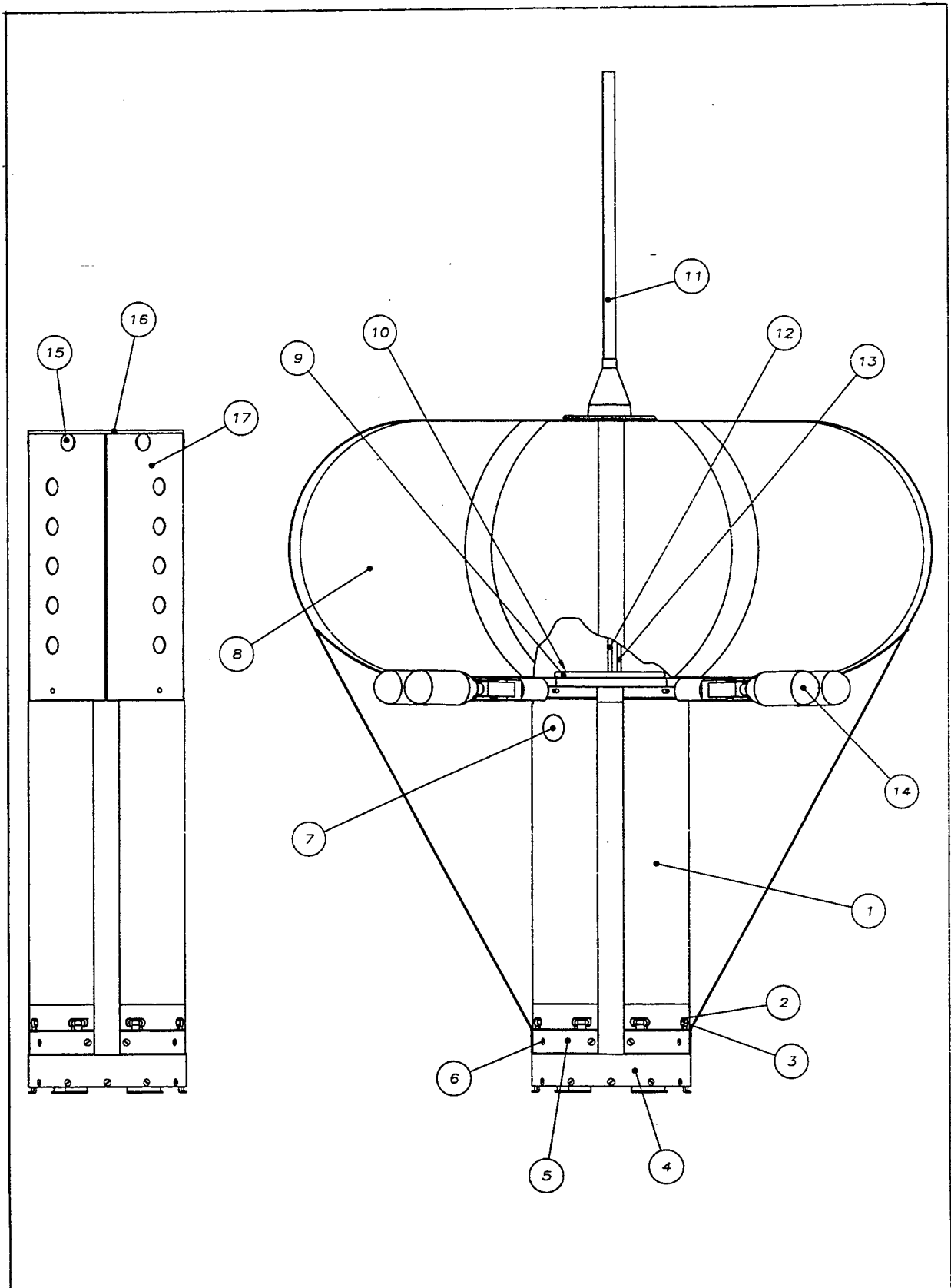
## 6. APPENDICES

This section contains three appendices which provide:

- 6.1 Mechanical Drawings
- 6.2 Selected Model Runs
- 6.3 Test Reports

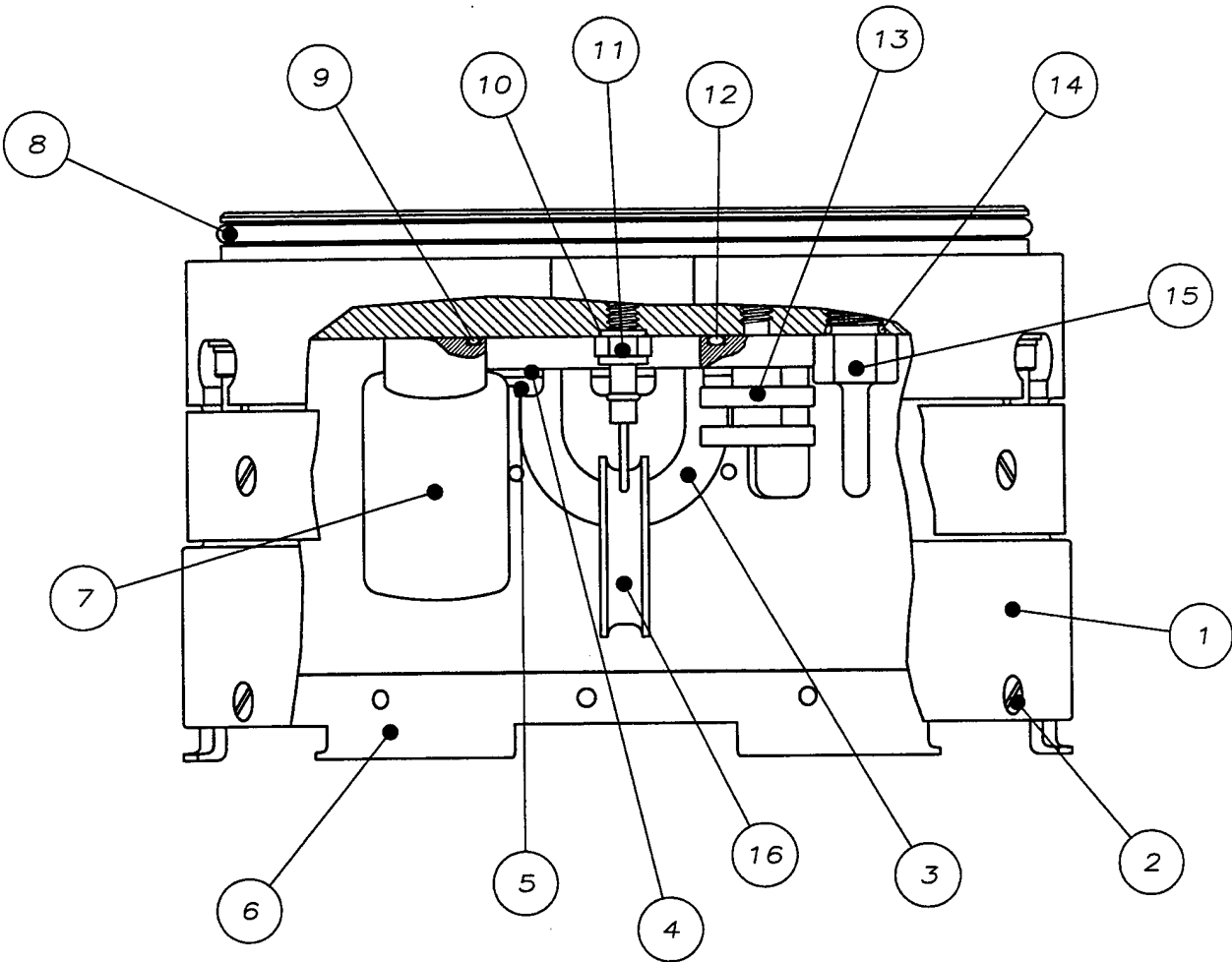
Appendix 6.2, Selected Model Runs, shows how XMOOR responds to the current drag associated with typical coastal current profiles. The model used, NOYFB [7], is a static model which computes the mooring shape based on standard values for component drag coefficients, weights, and frontal areas. Wave forcing is not considered.

# 6.1 Mechanical Drawings



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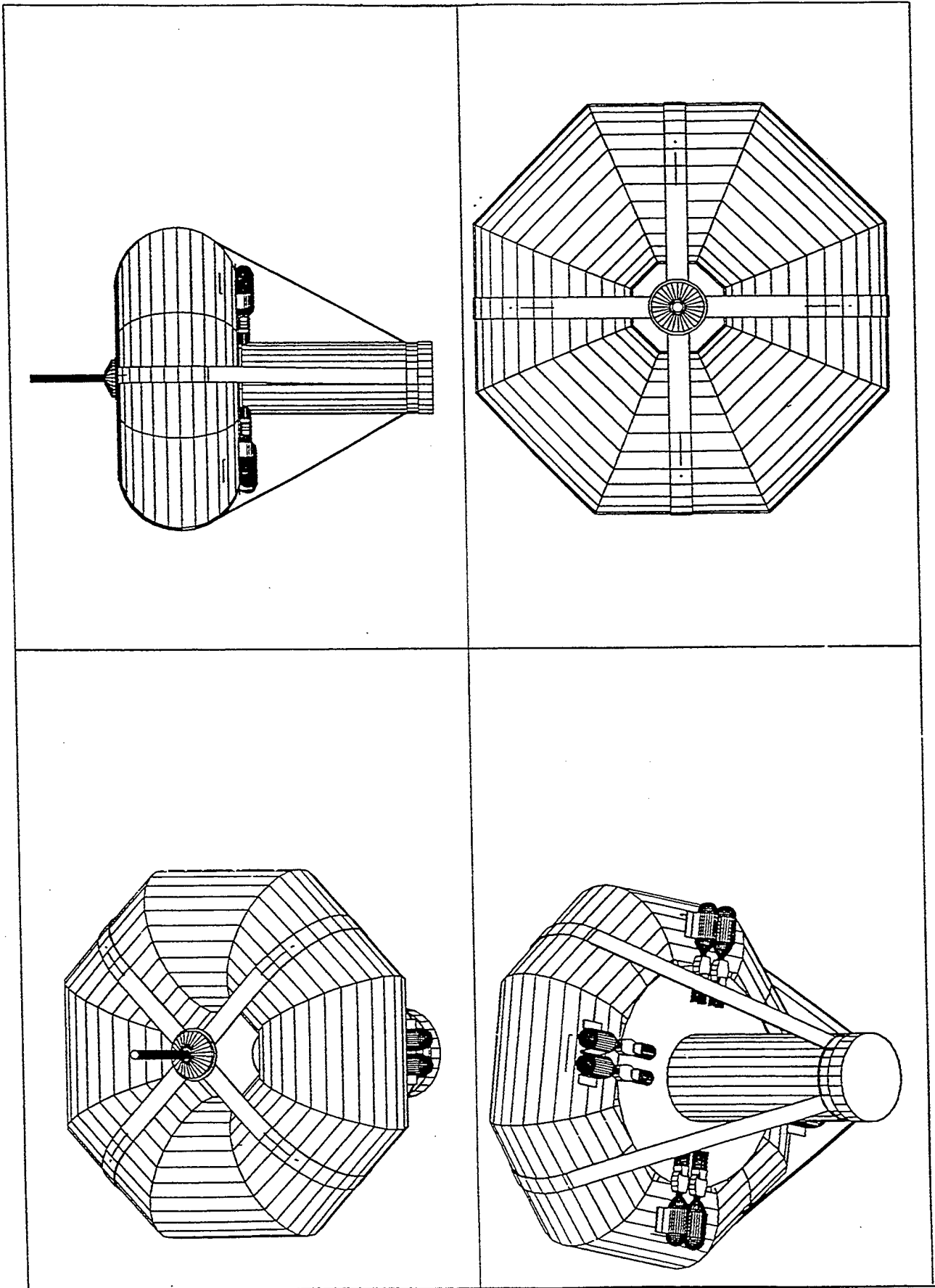




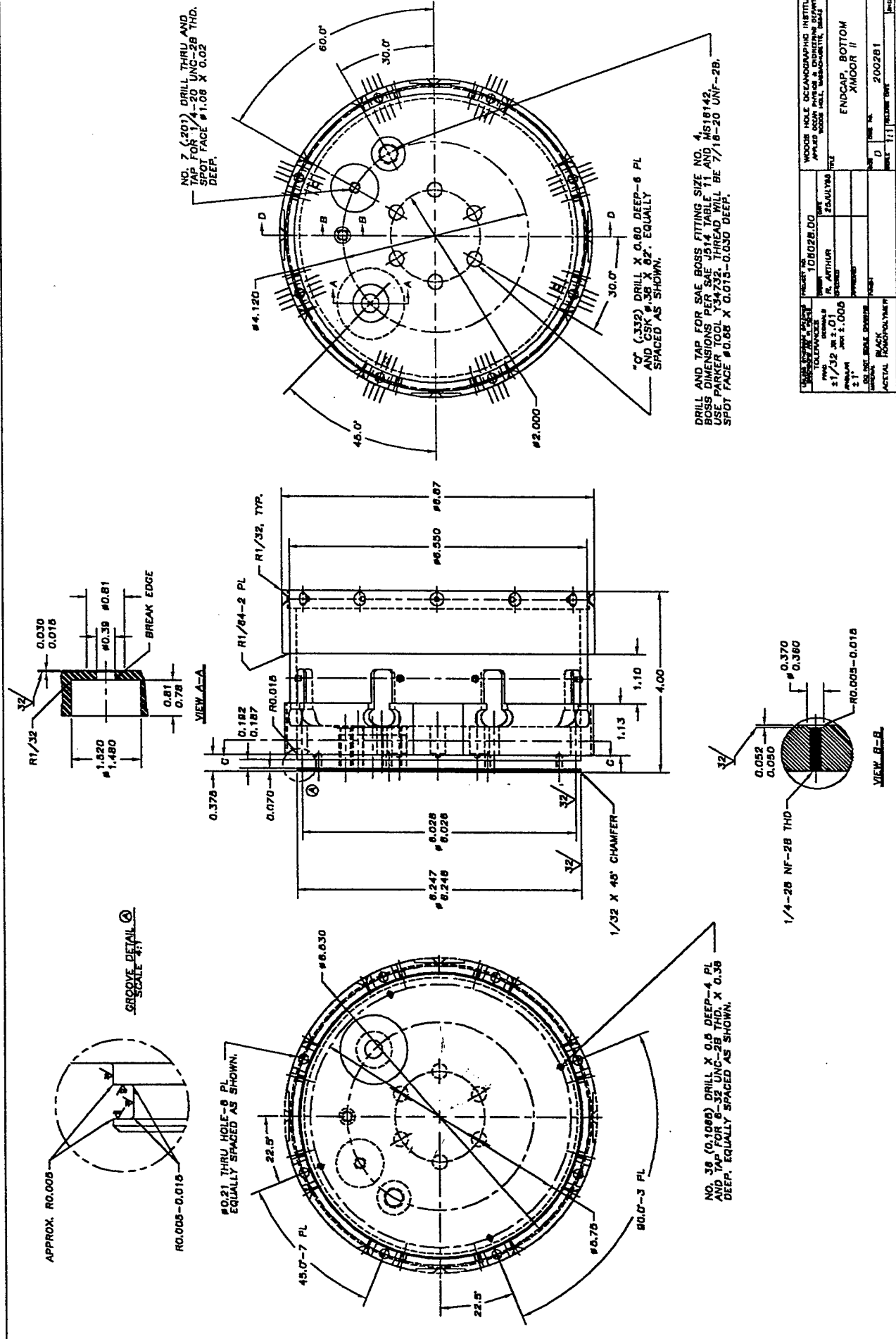
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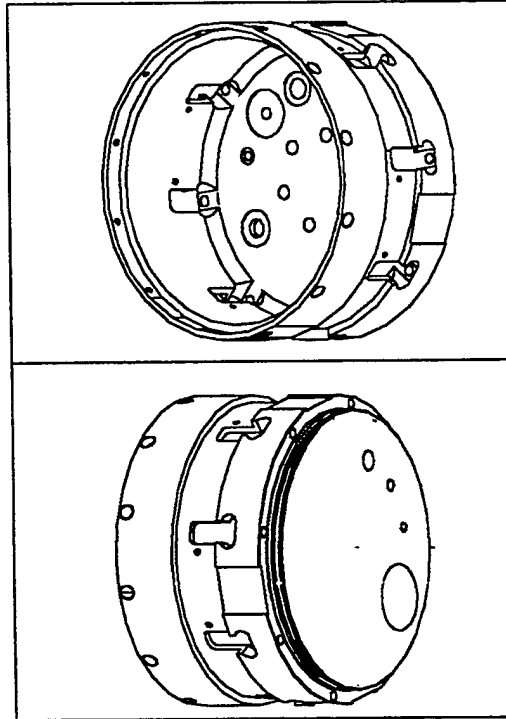
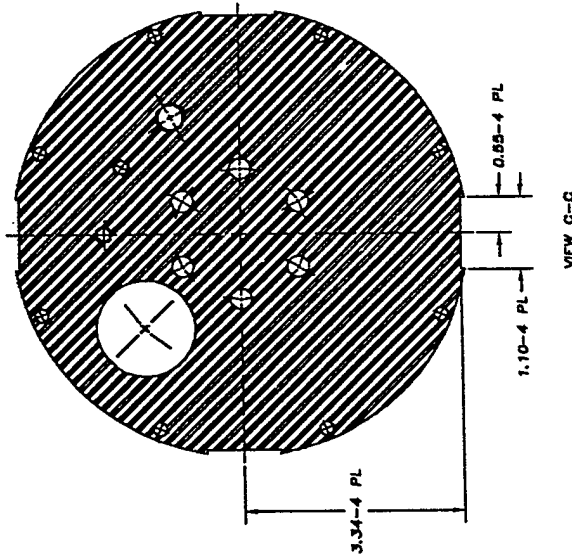
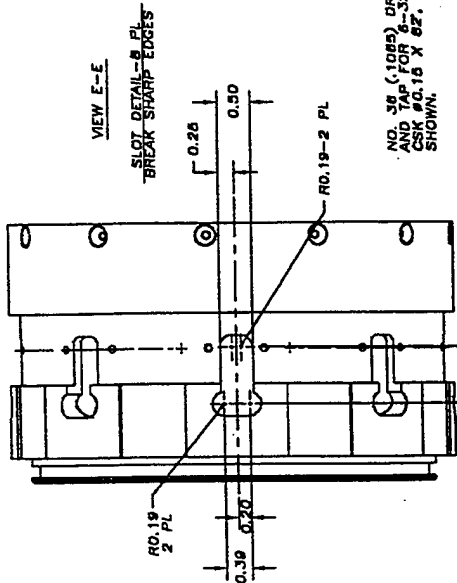
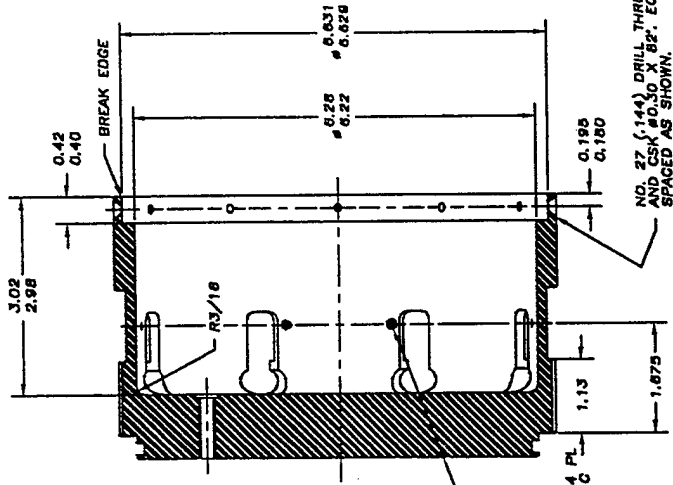
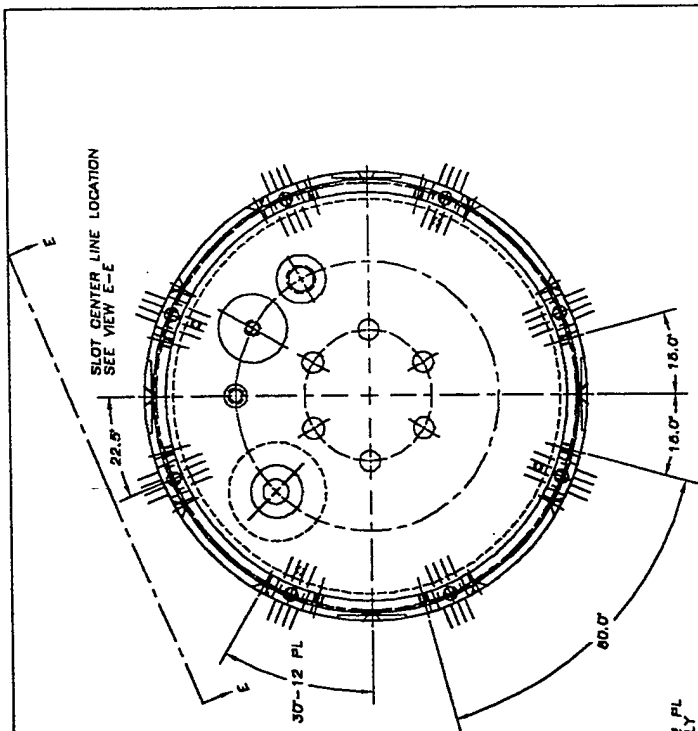


Surface buoy and instrument housing

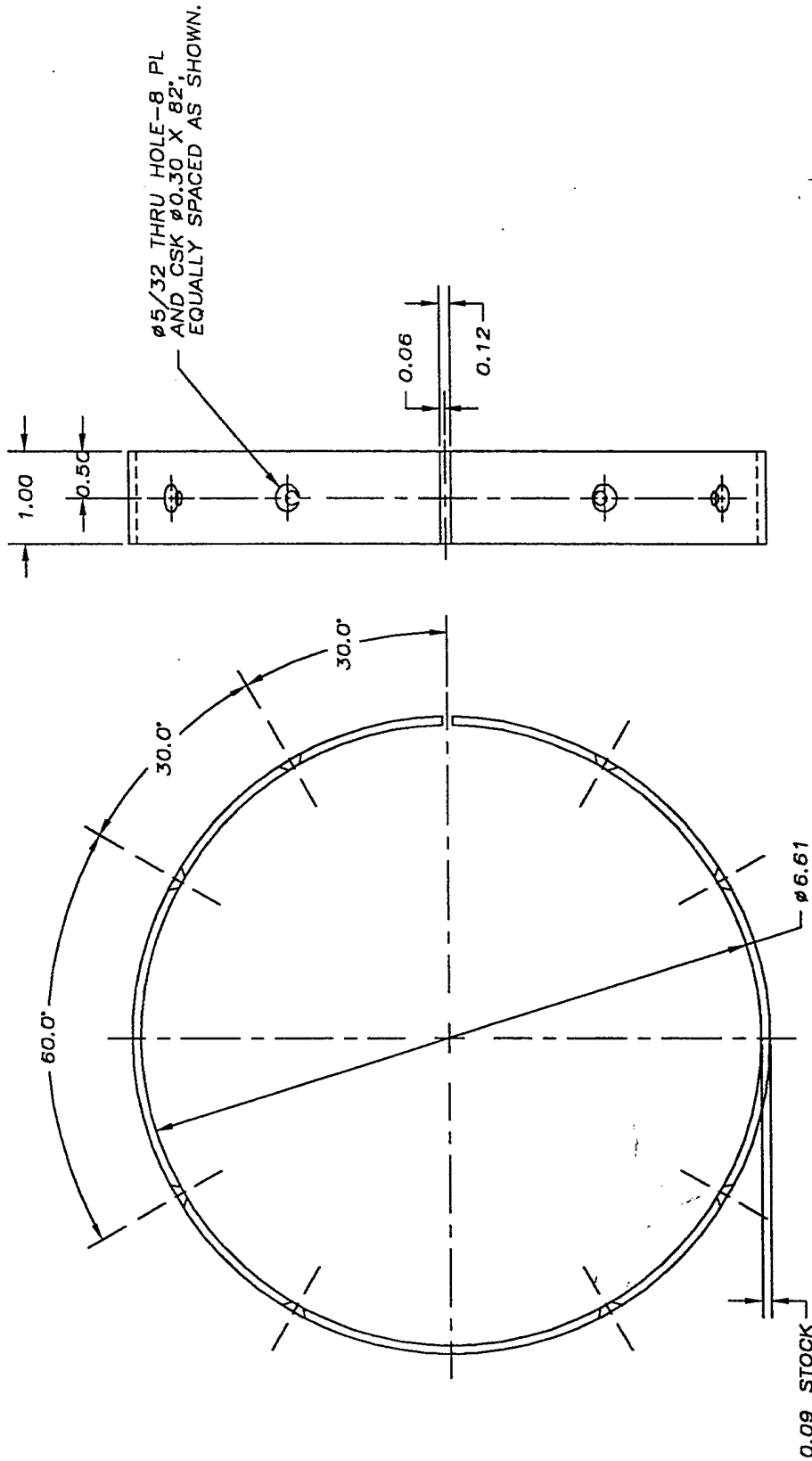


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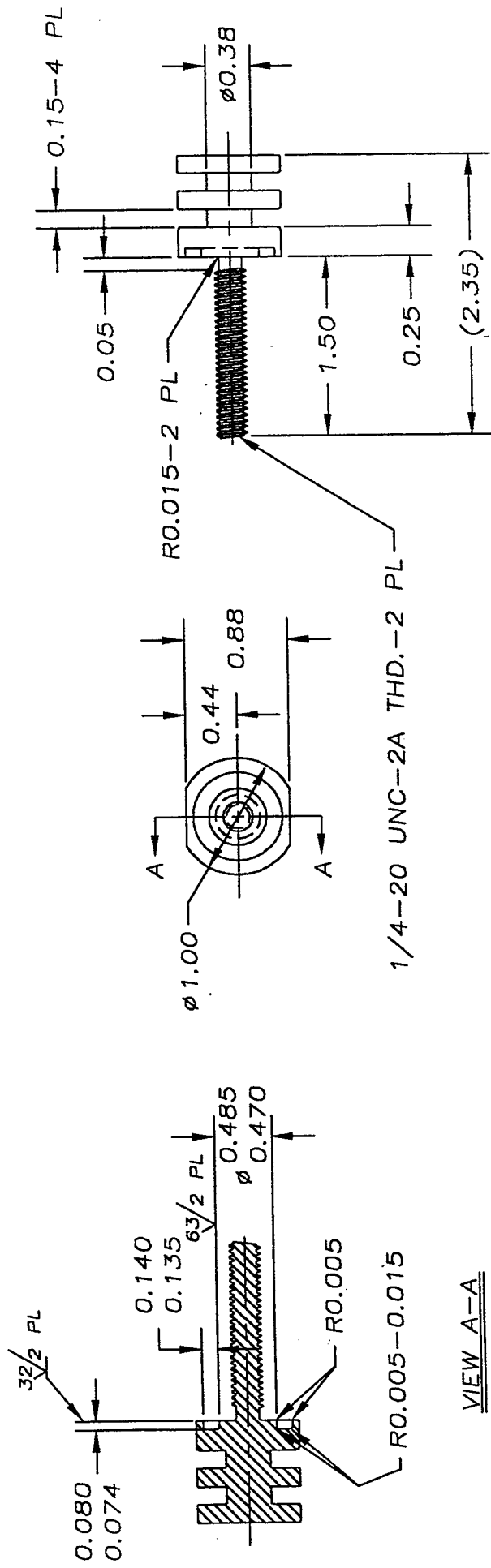
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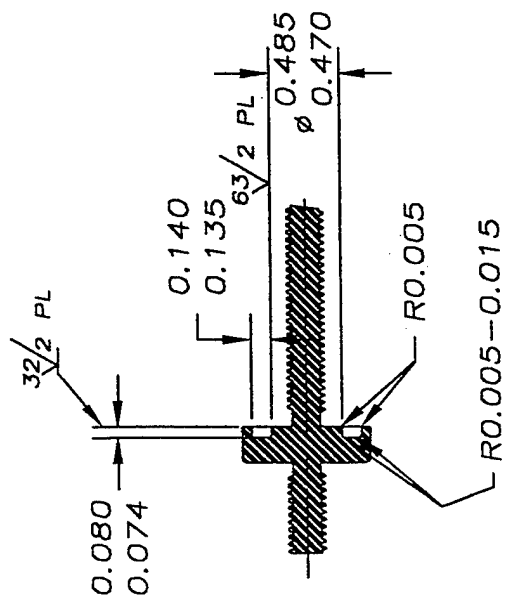


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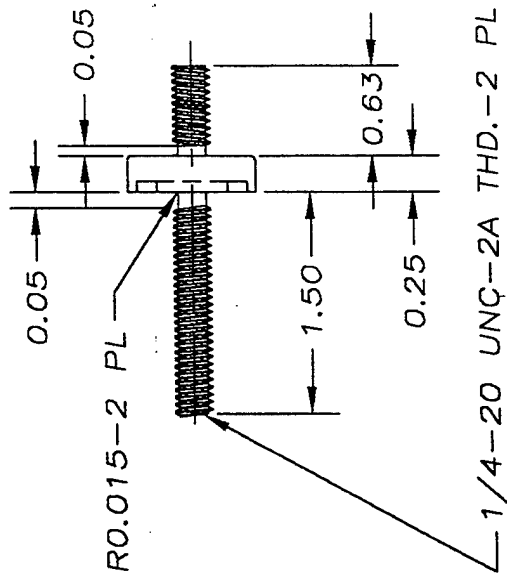
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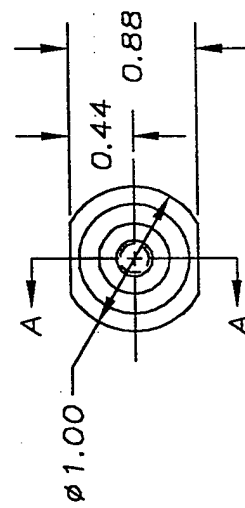
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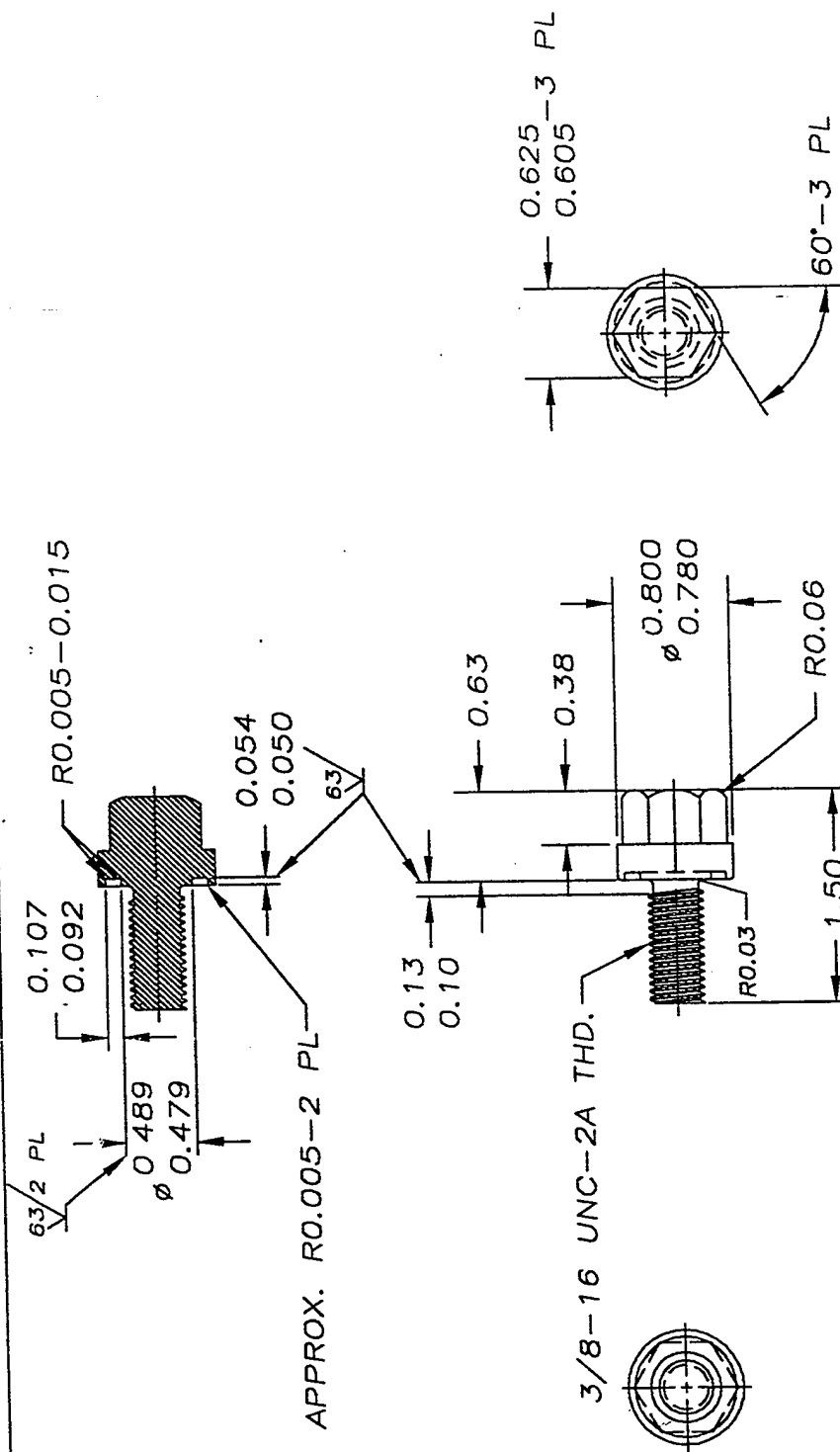


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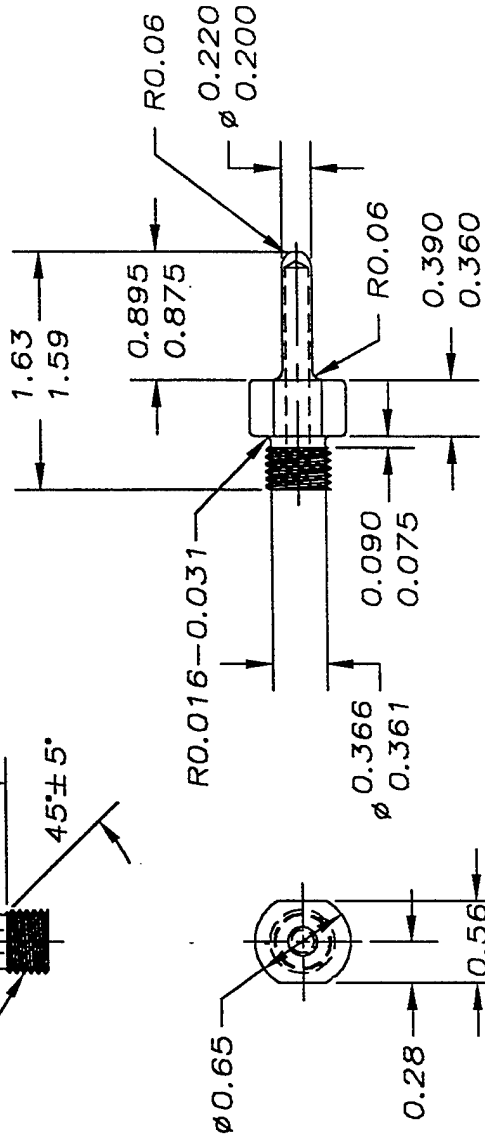
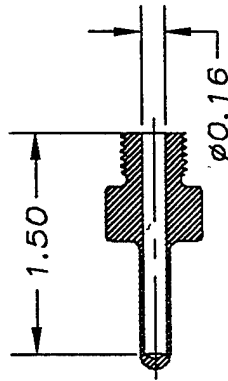
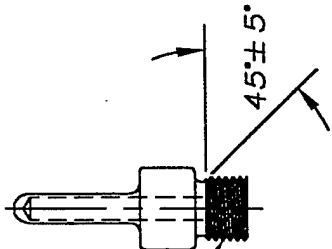


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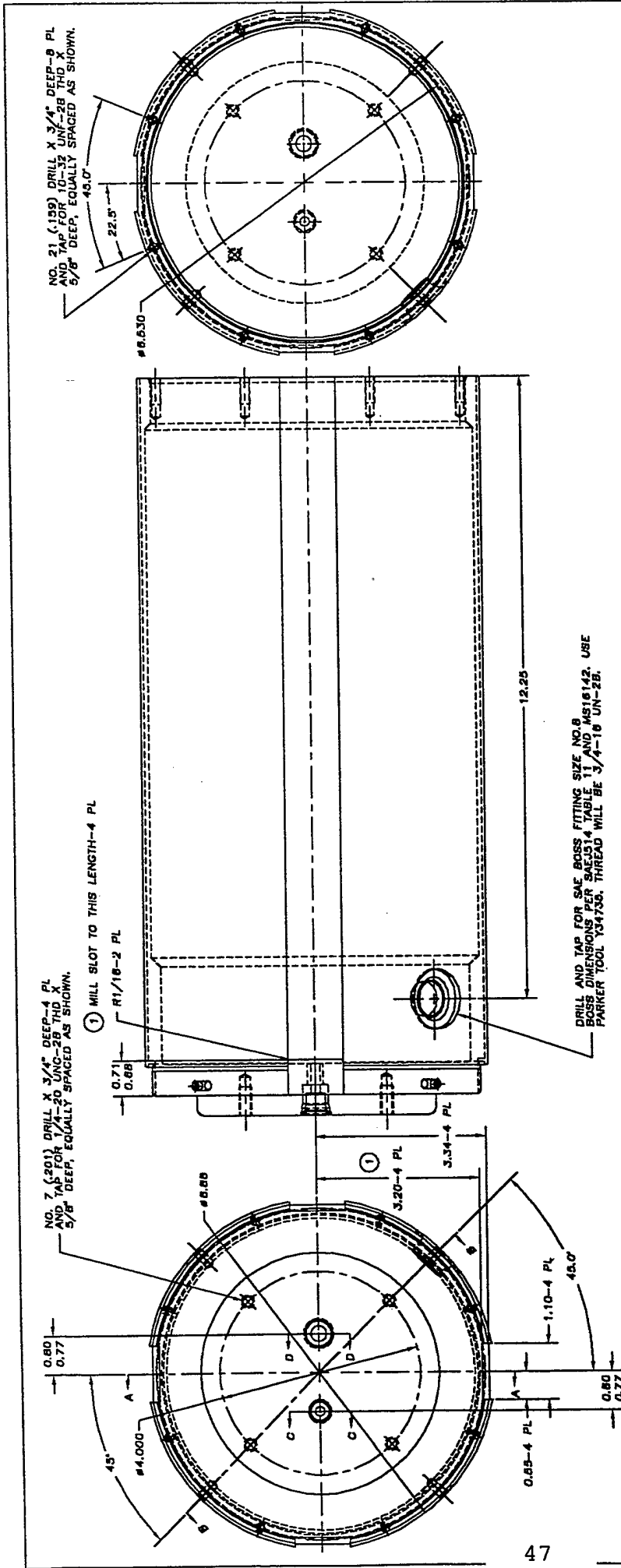


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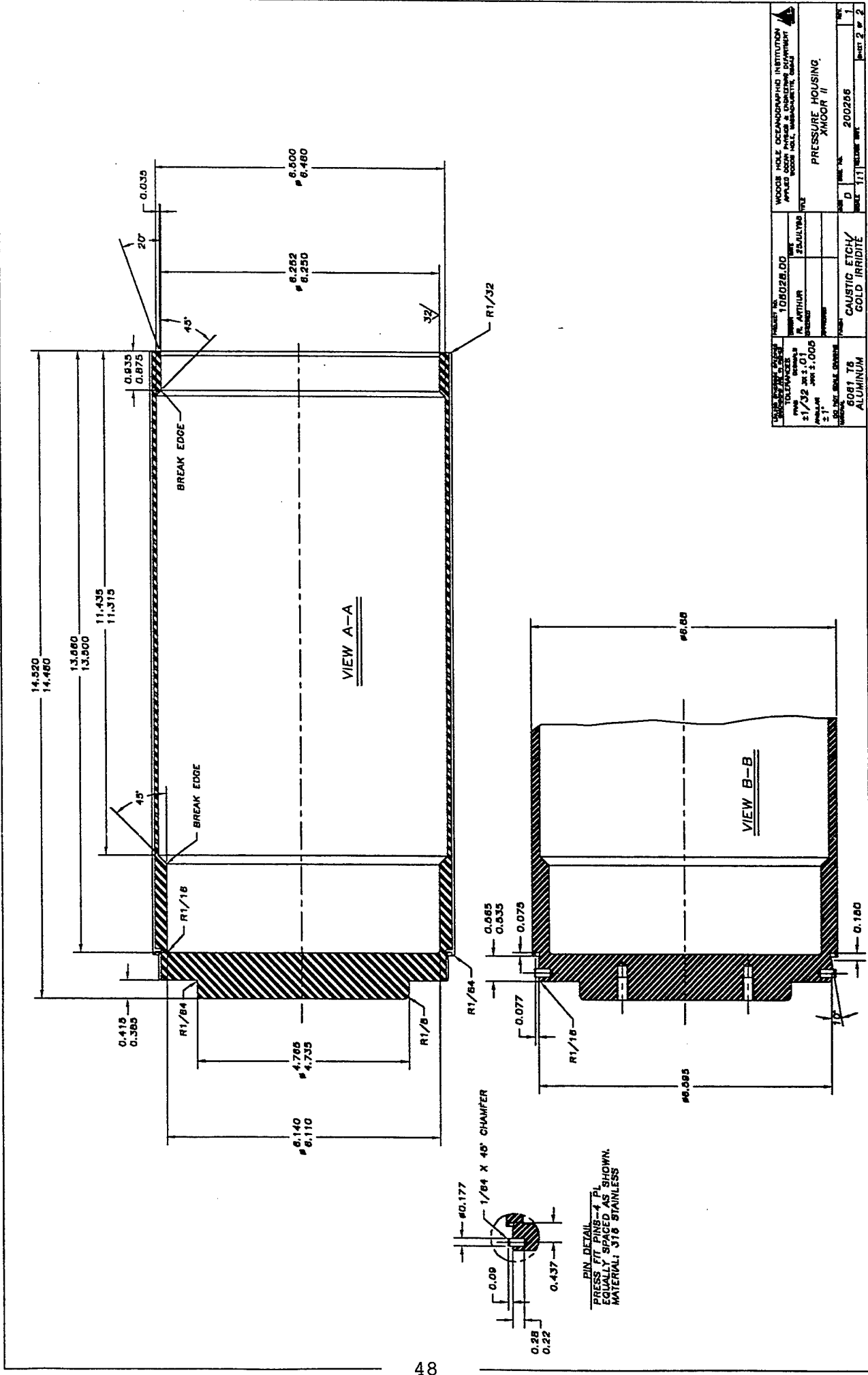
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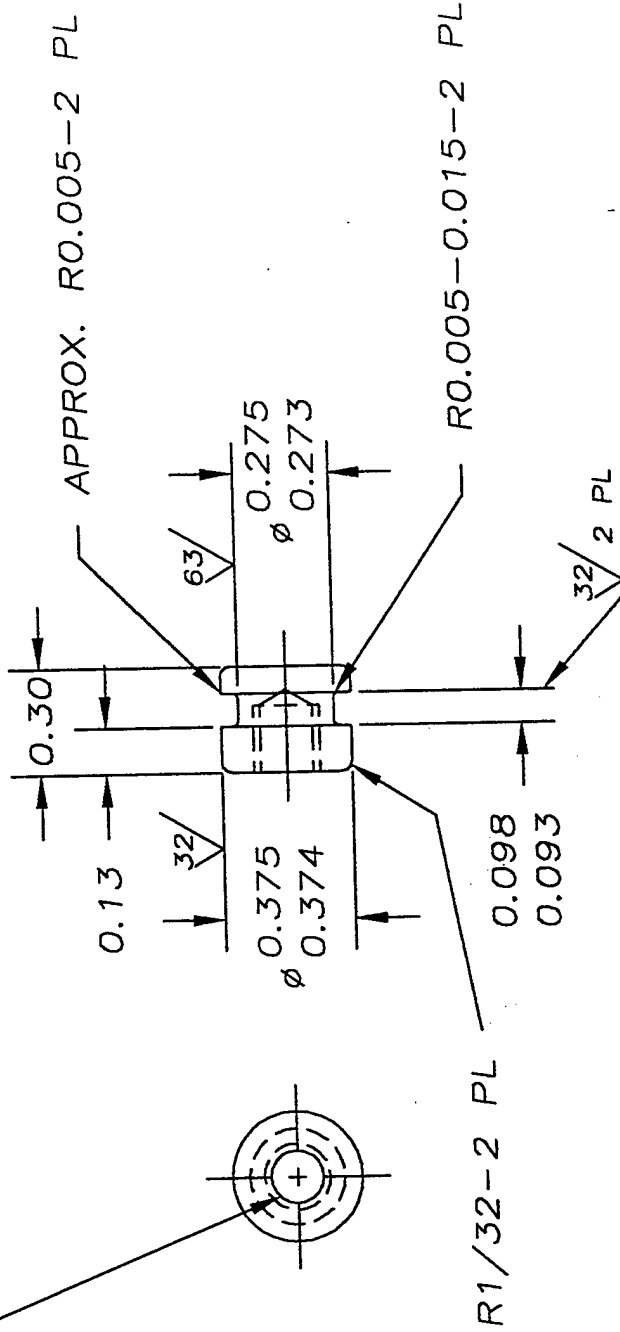
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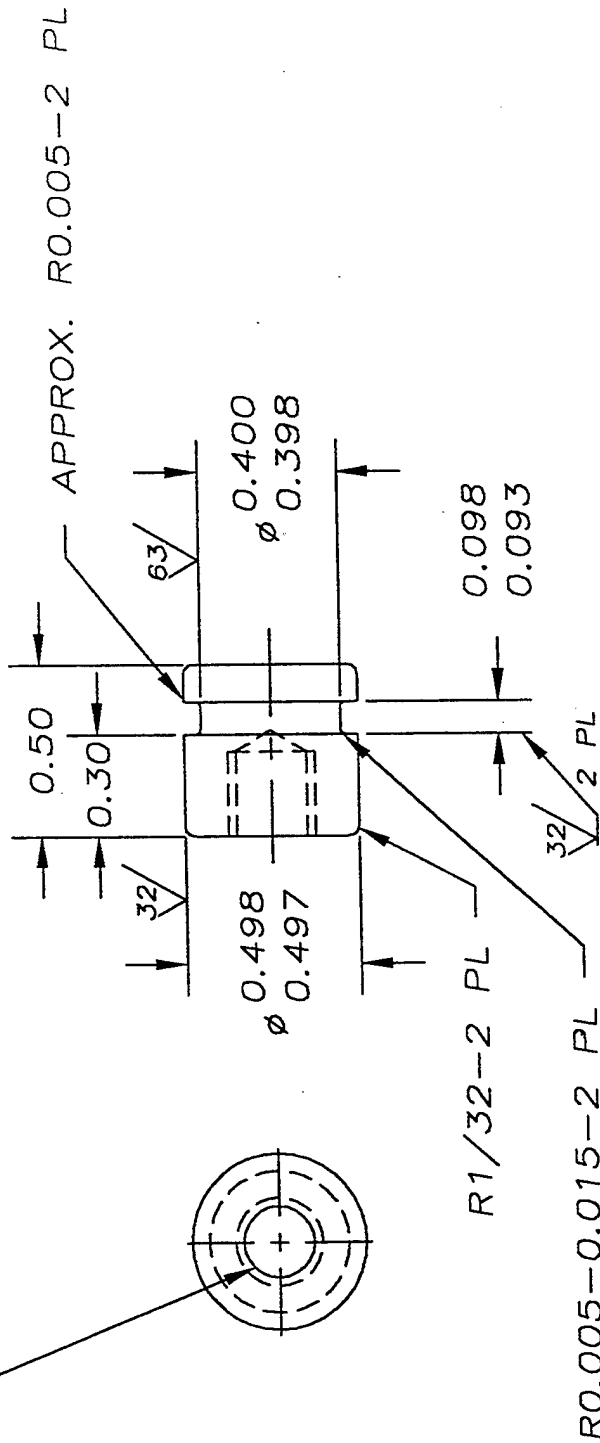
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TOLERANCES		DRAWN	DATE	TITLE	
FRAC	DECIMALS	R. ARTHUR	12DEC94	PLUG, 3/8 IN. (2-010) XMOOR II	
$\pm 1/32$	.XX $\pm .01$	CHECKED		SIZE	DWG. NO. 200248B
ANGULAR	.XXX $\pm .005$	APPROVED		SCALE	2:1 RELEASE DATE
$\pm 1^\circ$		FINISH		REV.	
DO NOT SCALE DRAWING					
MATERIAL	6061T6 ALUMINUM				

NO 7 (.201) DRILL X 1/4 DEEP  
AND BOTTOM TAP FOR 1/4-20 UNC-2B THD.

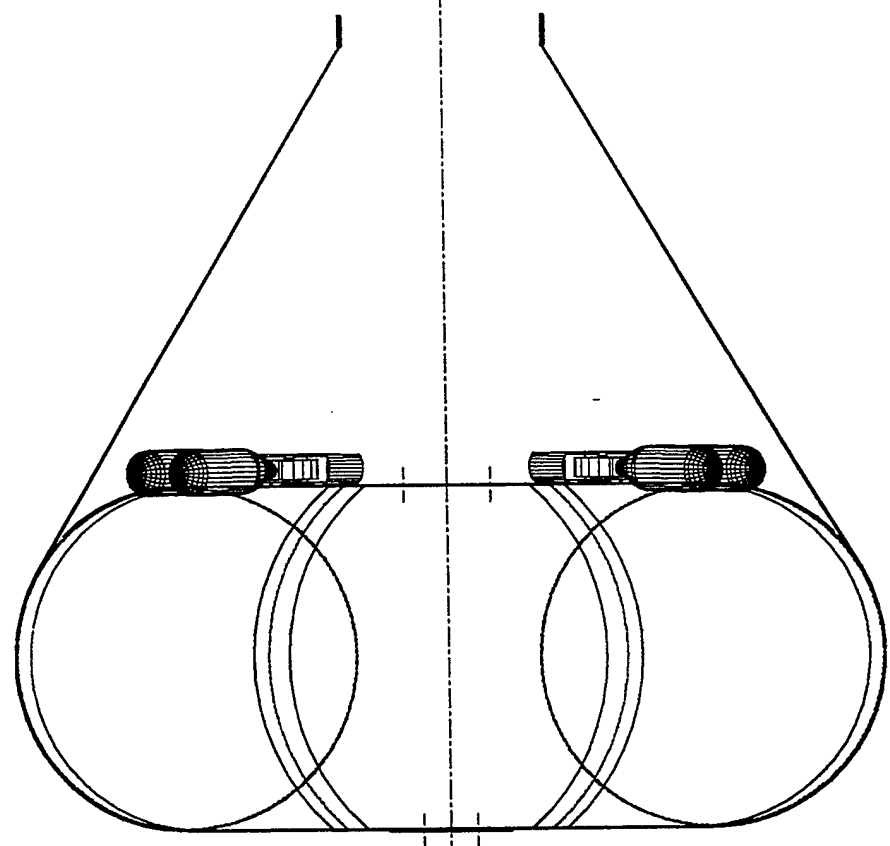
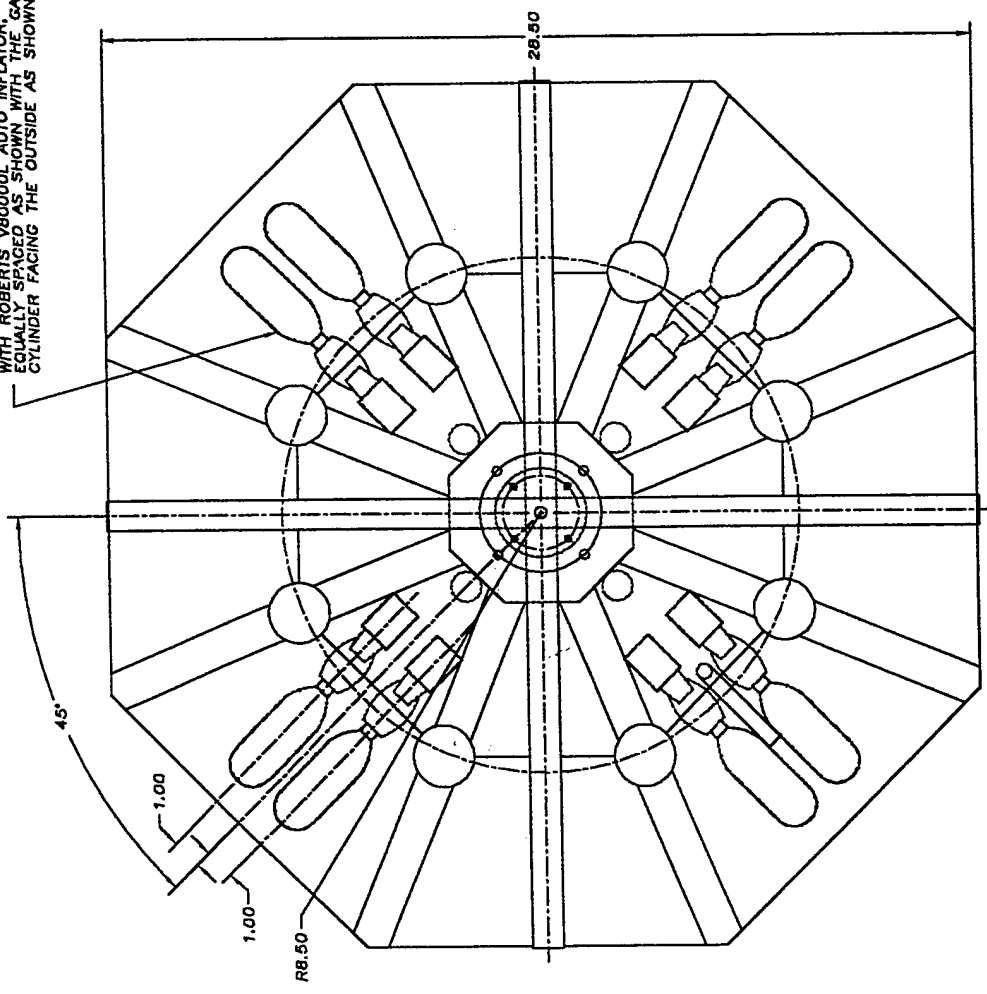


WOODS HOLE OCEANOGRAPHIC INSTITUTION  
APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT  
WOODS HOLE, MASSACHUSETTS, 02543

PROJECT NO.	106028.00
DRAWN	R. ARTHUR
CHECKED	
APPROVED	
DATE	25AUG94
TITLE	
PLUG, 1/2 IN. (2-012) XMOOR II	
SIZE	B
DWG. NO.	200248
SCALE	2:1
RELEASE DATE	
REV.	
SHEET	OF

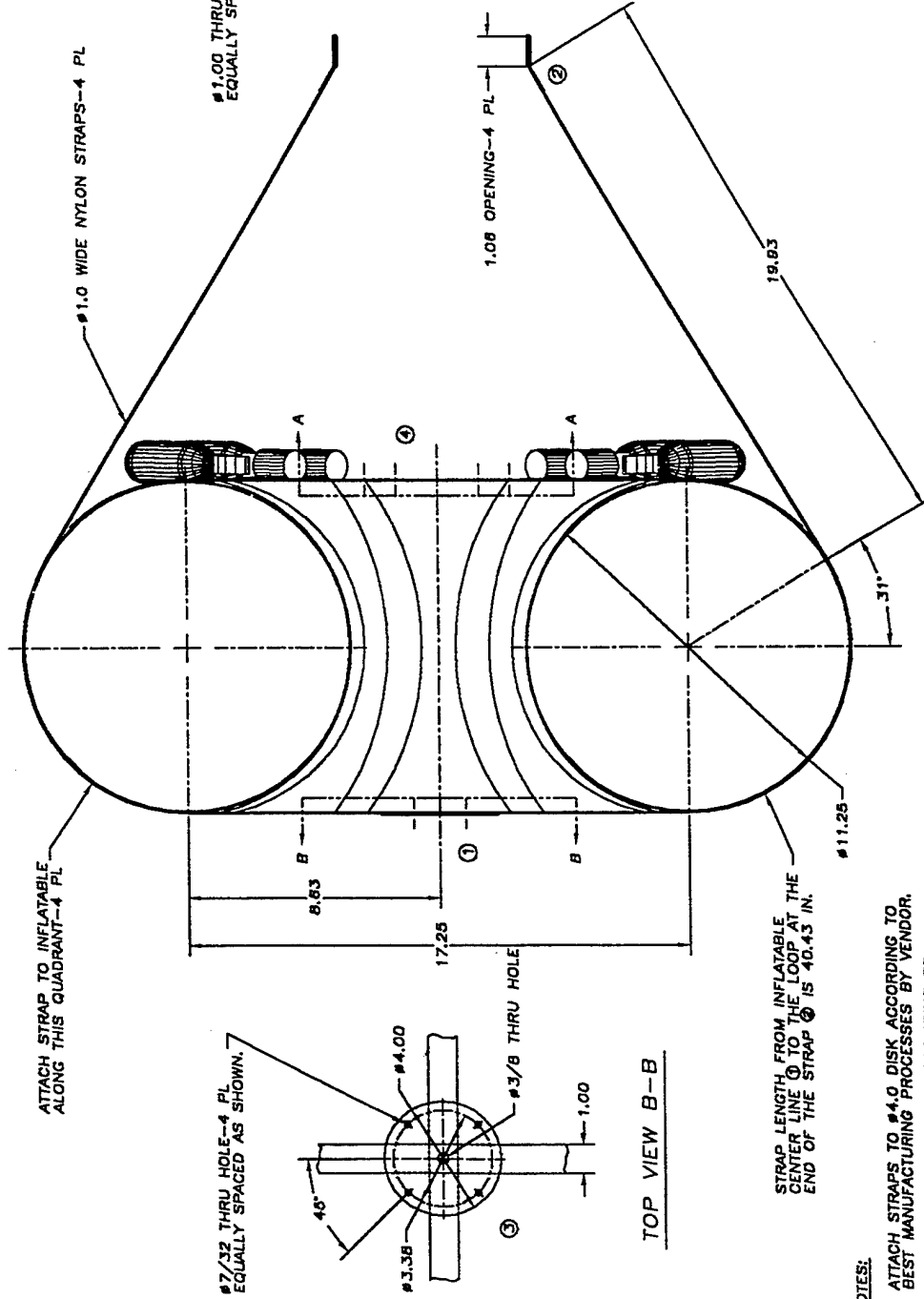
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	FRAG DECIMALS
TOLERANCES	$\pm 1/32$ .XX $\pm .01$
	.XXX $\pm .005$
	ANGULAR $\pm 1^\circ$
DO NOT SCALE DRAWING	
MATERIAL	6061T6 ALUMINUM
FINISH	

NITROGEN GAS FILLED CYLINDER-B PL WITH ROBERTS V80000L AUTO INH. GAS EQUALLY SPACED AS SHOWN WITH THE CYLINDER FACING THE OUTSIDE AS SHOWN.



PROJECT NO.	1475	DESIGNER	W. J. ARTHUR	DATE	11/28/58
SCALE	AS SHOWN	CHECKED		DATE	11/28/58
APPROVED		DATE			
WOODS HOLE OCEANOGRAPHIC INSTITUTION Woods Hole, Massachusetts					
INFLATABLE BUOY					
ANCHOR II					
D 200258					
REV. 1 OF 2					

NOTES:  
1. LOCATE VALVE FOR GAS BOTTLES AT APPROX. 2.0 IN. FROM CENTER AND APPROX. 2.0 IN. APART AS SHOWN.



TOP VIEW B-B

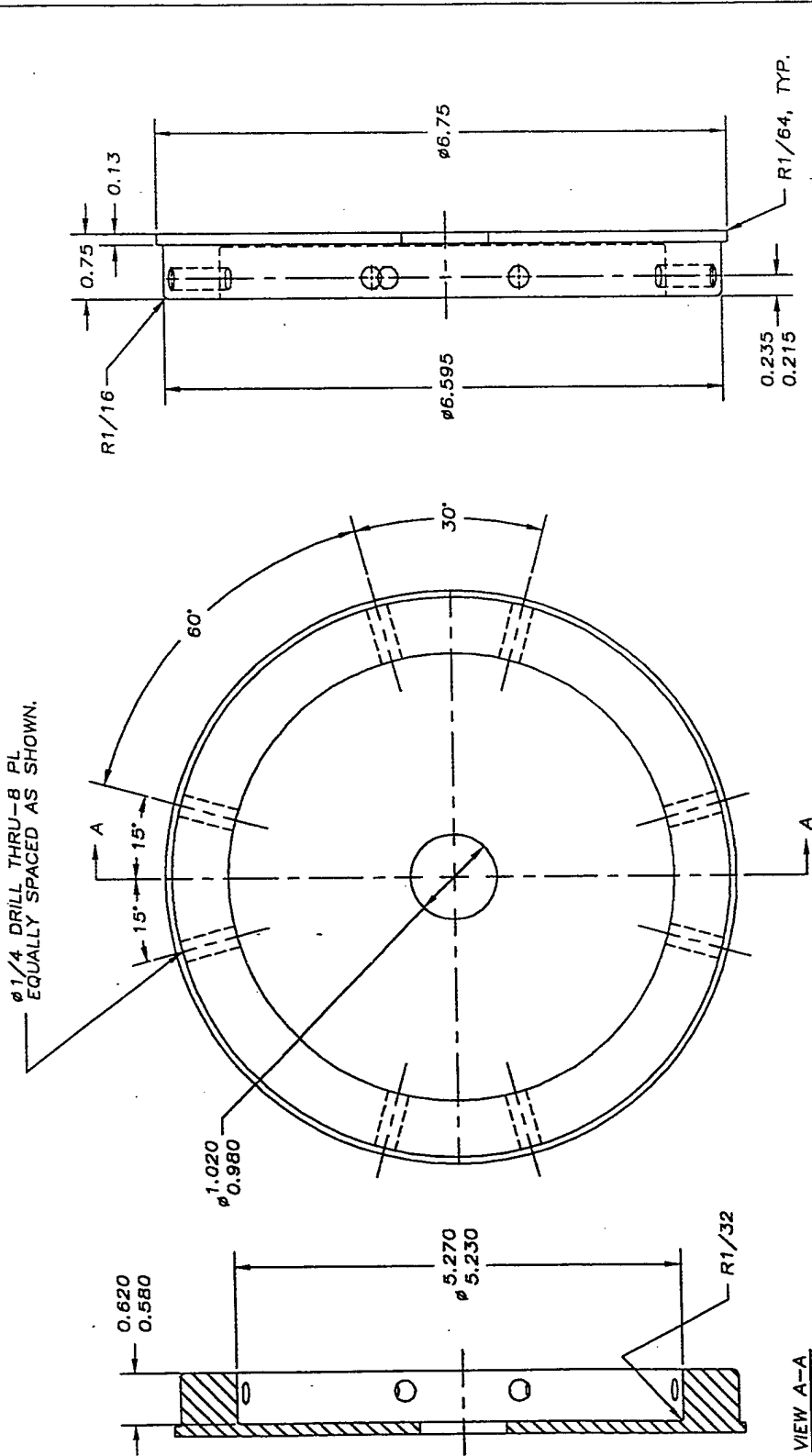
BOTTOM VIEW A-A

NOTES:

- ③ ATTACH STRAPS TO INFLATABLE TO BEST MANUFACTURING PROCESSES BY VENDOR.
- ④ ATTACH BOTTOM FLANGE ACCORDING TO BEST MANUFACTURING PROCESSES BY VENDOR.
- ⑤ THIS HOLE PATTERN IS REFERENCED 45° FROM THE BUOY STRAPS (AS IN VIEW B-B).

MATERIAL: BEST POSSIBLE MATERIAL(S) TO MAINTAIN CARBON DIOXIDE GAS AT AVERAGE PRESSURE OF 2 PSI FOR 90 DAYS.

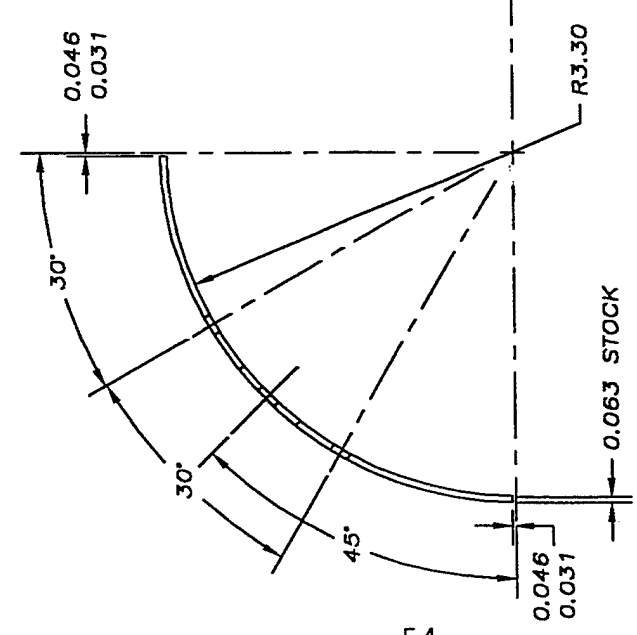
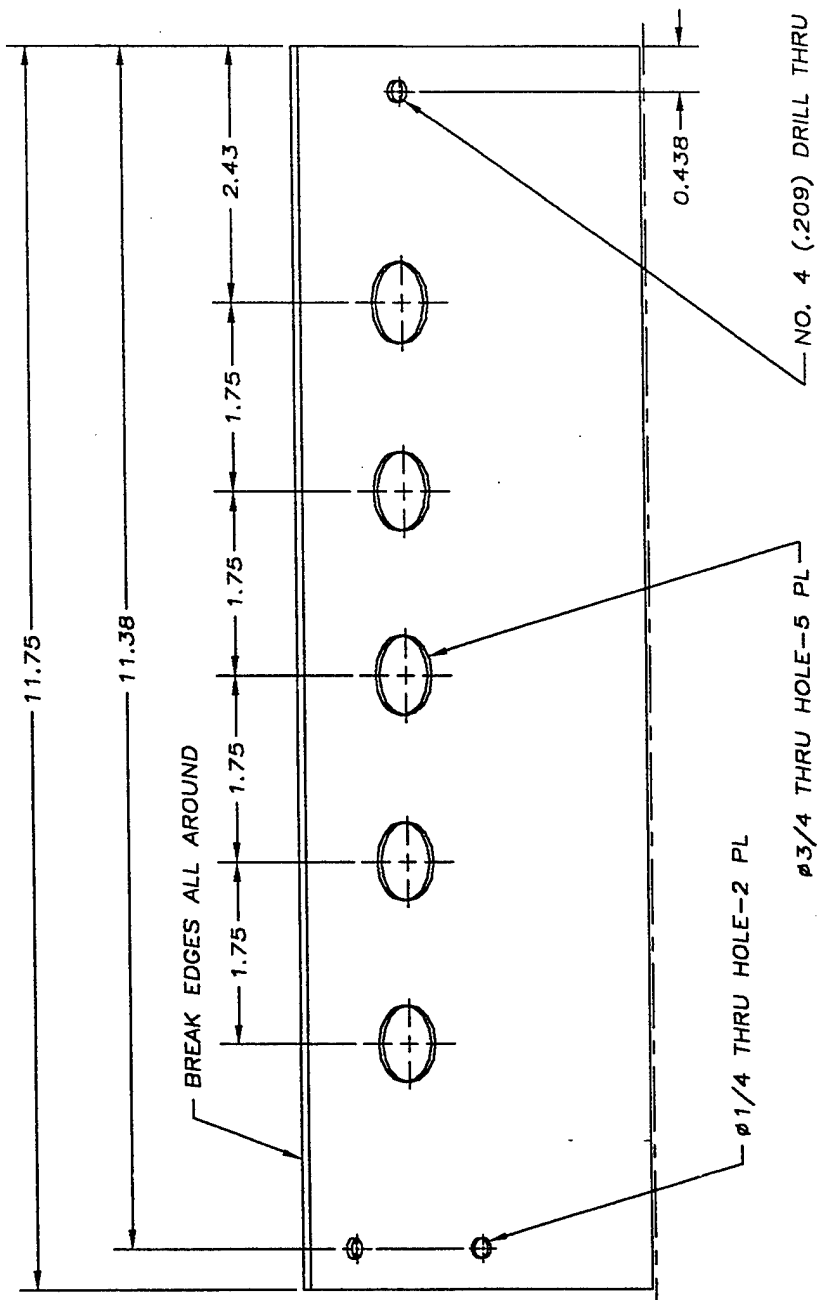
PROJECT NO.	175284	WORKS HOLE OCEANOGRAPHIC INSTITUTION
NO. OF SHEETS	2	PROJECT NO.
SHEET NO.	1	PROJECT NAME
DATE		PROJECT NO.
SCALE		PROJECT NAME
AS NOTED		PROJECT NO.
		PROJECT NAME



VIEW A-A

NOTES:  
BREAK ALL SHARP EDGES.

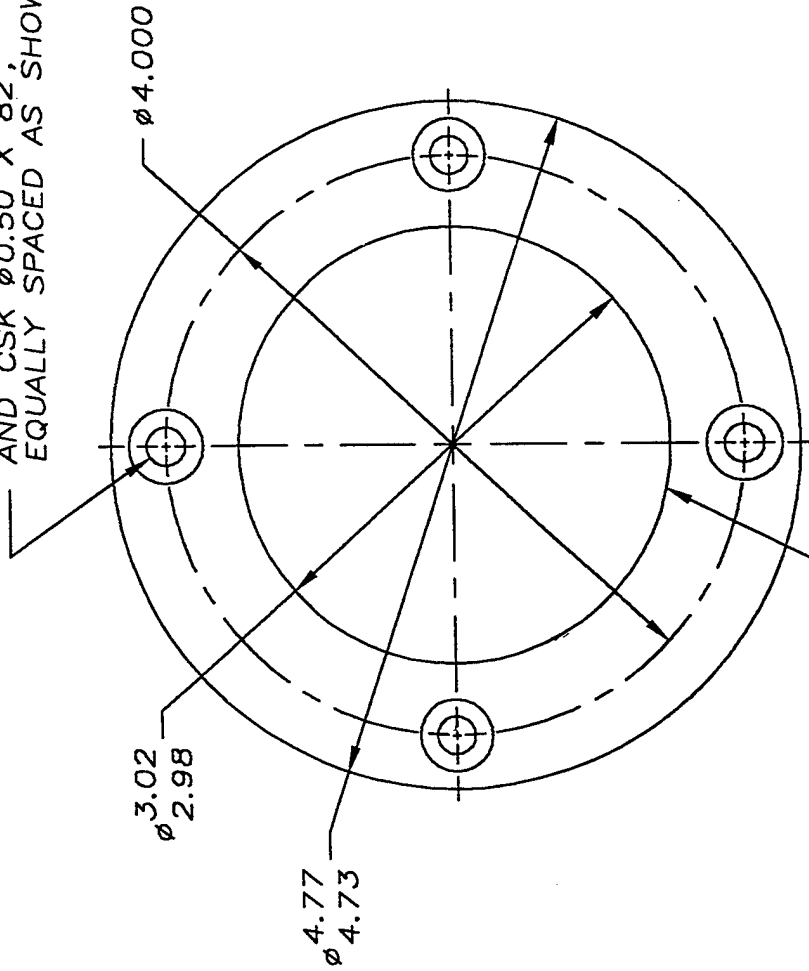
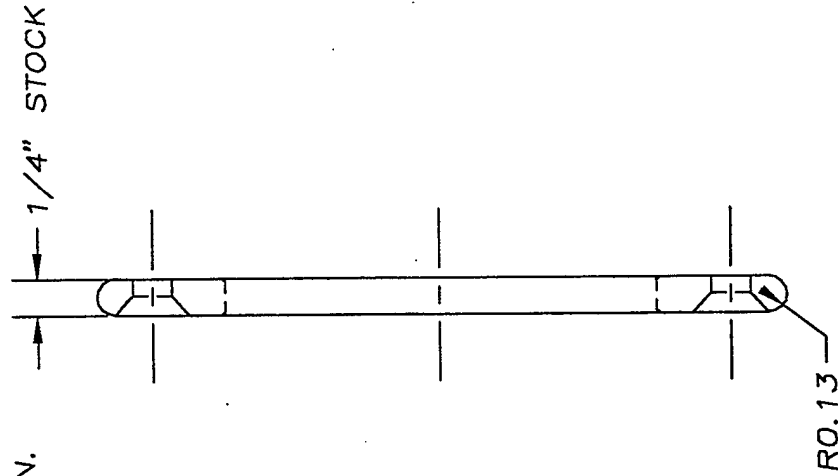
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		PROJECT NO. 106028.00	
TOLERANCES	FRAC	DECIMALS	DATE
± 1/32	± .01	± .005	28APR95
ANGULAR ± 1°	± .008		
DO NOT SCALE DRAWING MATERIAL	BLACK ACETAL HOMOPOLYMER	DRAWN BY R. ARTHUR	CHECKED BY
		APPROVED BY	
		DATE	
WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543		TITLE	
		ENDCAP, BUOY XMOOR II	
DATE	DWG. NO.	REV.	
28APR95	200284		
SCALE 1:1	PREPARED DATE	SHEET	OF



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		PROJECT NO. 106028.00		WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543	
TOLERANCES		DRAWN	DATE	TITLE	
FRACTIONAL	DECIMALS	R. ARTHUR	1 DEC 94	BUOY SIDE RETAINER XMOOR II	
$\pm 1/32$	$.001 \pm .01$	CHECKED		SIZE	REV.
ANGULAR	$.0001 \pm .005$	APPROVED		C	DWG. NO. 200287
$\pm 1^\circ$				SCALE	RELEASE DATE
DO NOT SCALE DRAWING				1:1	
MATERIAL	5052 ALUMINUM	FINISH	CAUSTIC ETCH/ GOLD IRRIDITE		

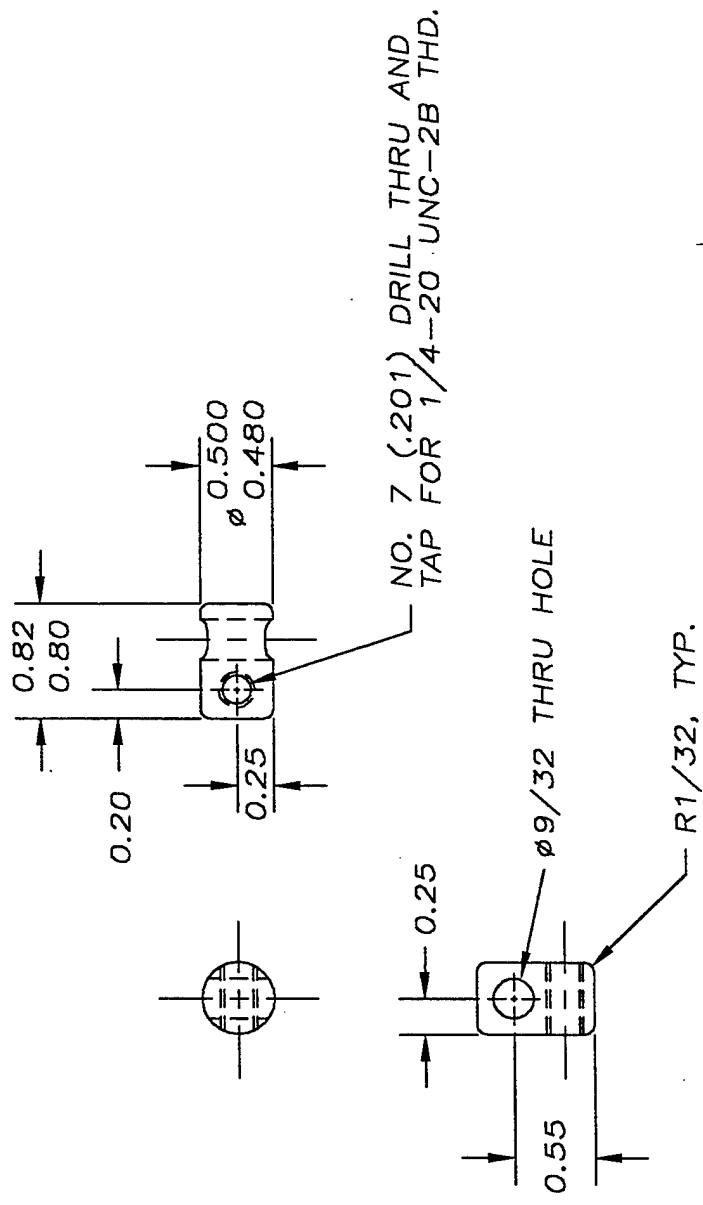


Ø 0.26 DRILL THRU-4 PL  
AND CSK Ø 0.50 X 82°  
EQUALLY SPACED AS SHOWN.



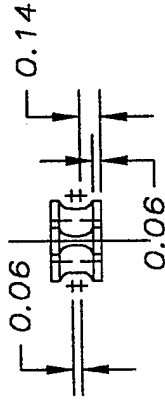
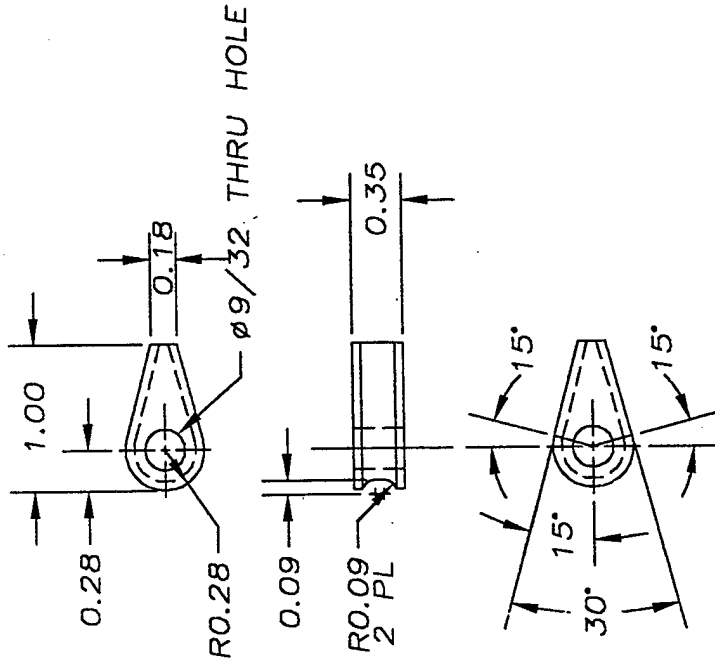
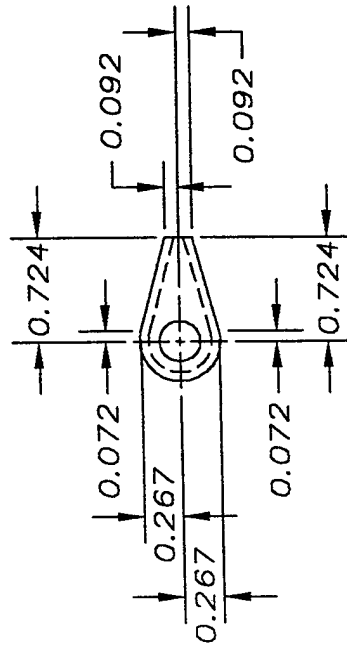
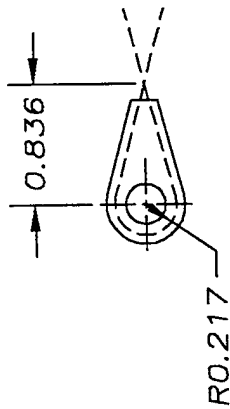
BREAK EDGE-2 PL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		PROJECT NO. 106028.00		WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543	
TOLERANCES	DECIMALS	DRAWN	DATE	TITLE	
FRACTIONAL		R. ARTHUR	28NOV94	RETAINING RING, BUOY XMOOR II	
± 1/32	.XX ± .01	DESIGNED		SIZE	B
ANGULAR	.XXX ± .005	APPROVED		DWG. NO.	200259
± 1°				SCALE	1:1
DO NOT SCALE DRAWING		FINISH		REV.	
MATERIAL	6061T6 ALUMINUM			RELEASE DATE	
					SHEET OF



NOTES:  
BREAK ALL SHARP EDGES.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		PROJECT NO. 106028.00		WOODS HOLE OCEANOGRAPHIC INSTITUTION	
TOLERANCES		DRAWN	DATE	APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT	
FRAC	DECIMALS	R. ARTHUR	04MAY95	WOODS HOLE, MASSACHUSETTS, 02543	
±1/32	.XX ±.01	CHECKED		TITLE	
ANGULAR	.XXX ±.005	APPROVED		PUCK RETAINER	
±1°				XMOOR	
DO NOT SCALE DRAWING				SIZE	DWG. NO.
MATERIAL				B	200293
300 SERIES				SCALE	RELEASE DATE
STAINLESS				1:1	
					SHEET OF

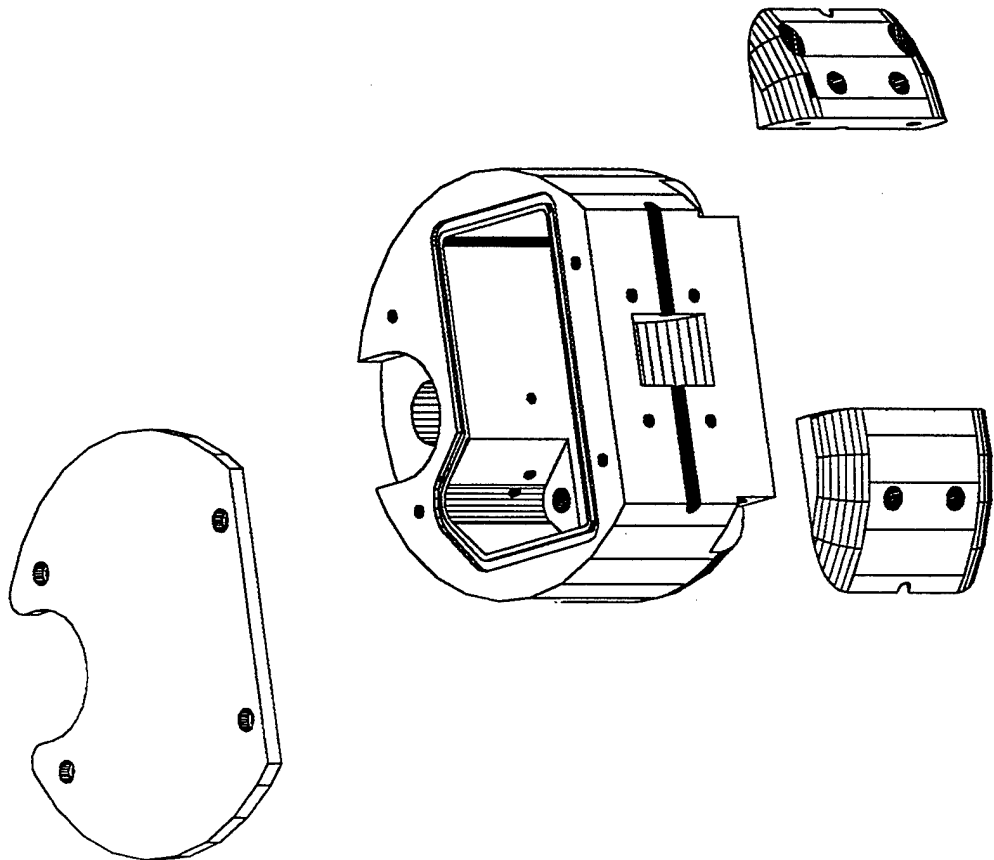
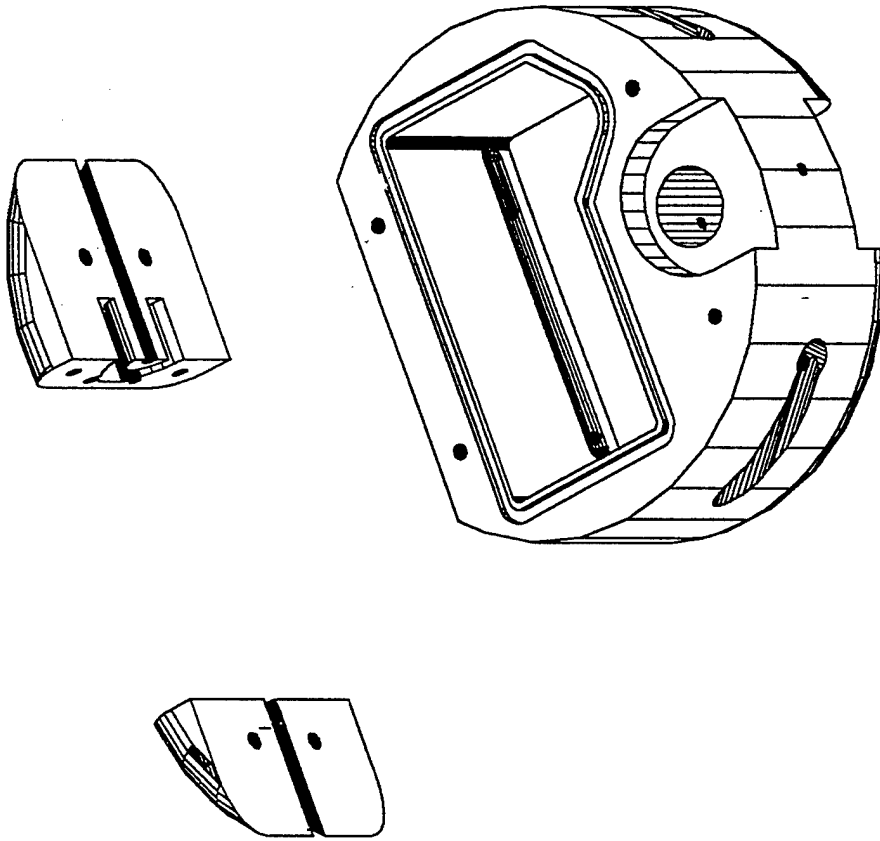


NOTES:  
BREAK ALL SHARP EDGES.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	PROJECT NO.	106028.00	
	TOLERANCES	DATE	04MAY95
FRAC	DRAWN	R. ARTHUR	
DECIMALS	CHECKED		
$\pm 1/32$	APPROVED		
$.xx \pm .01$	FINISH		
ANGULAR			
$\pm 1^\circ$			
DO NOT SCALE DRAWING			
MATERIAL			
300 SERIES			
STAINLESS			

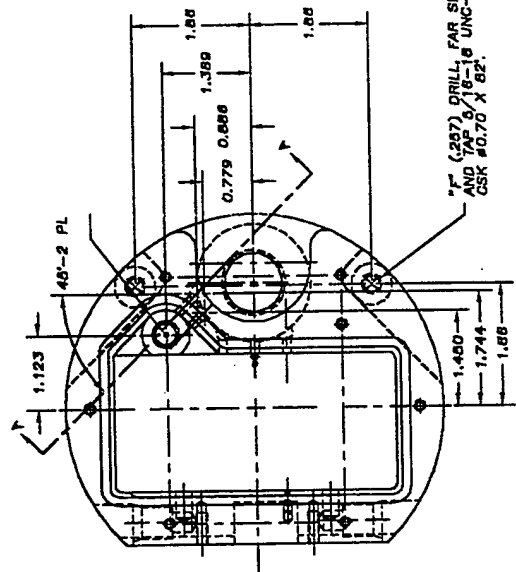
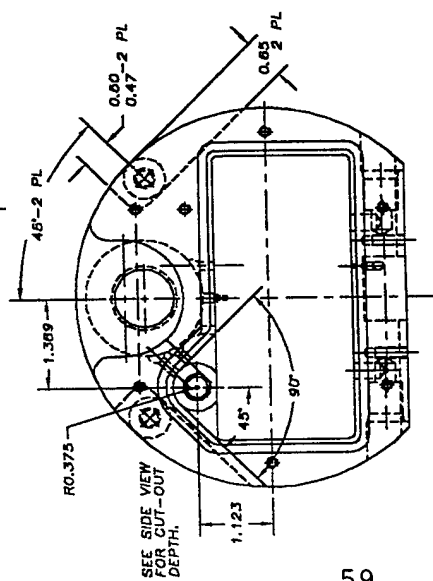
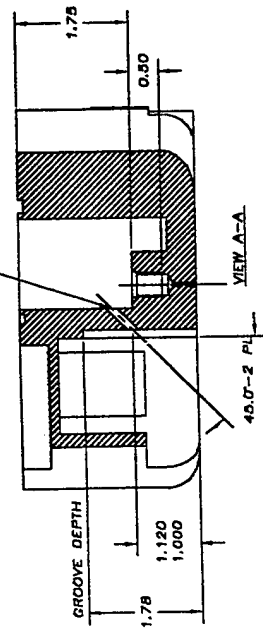
  

WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543			
TITLE PUCK THIMBLE XMOOR			
SCALE	DWG. NO.	REV.	OF
1:1	200293B		
RELEASE DATE			

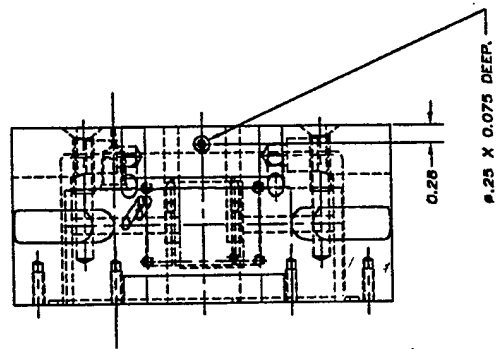
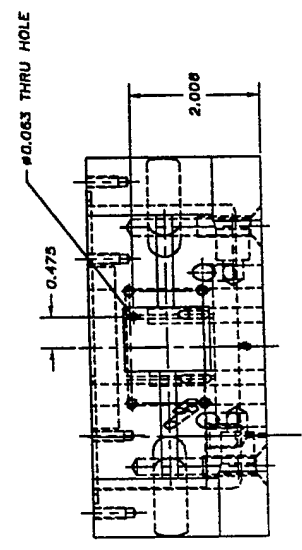
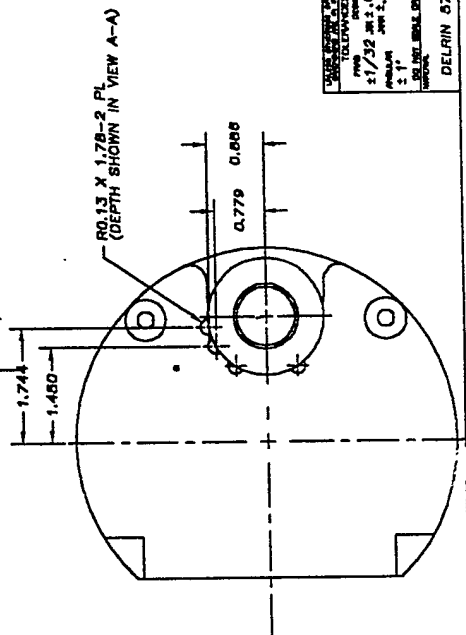
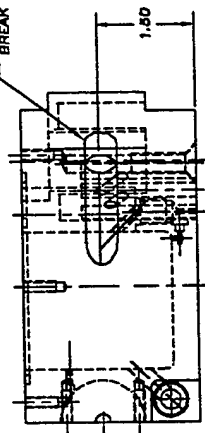


Data collection puck housing

#3/64 DRILL THRU AND TAP FOR SAE BOSS FITTING SIZE NO. 3 X 0.50 DEEP. USE DIMENSIONS PER SAE J1926 AND J1927. USE PARKER TOOL NO. T34731. THREADS WILL BE 3/8-24 UNF-2B.



USE #1/2 BALL END MILL-2 PL  
BREAK SHARP EDGES-2 PL

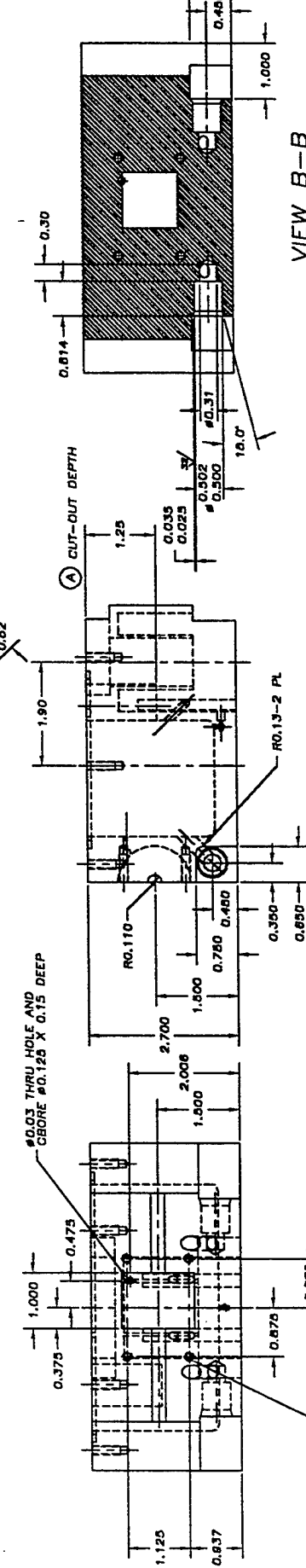
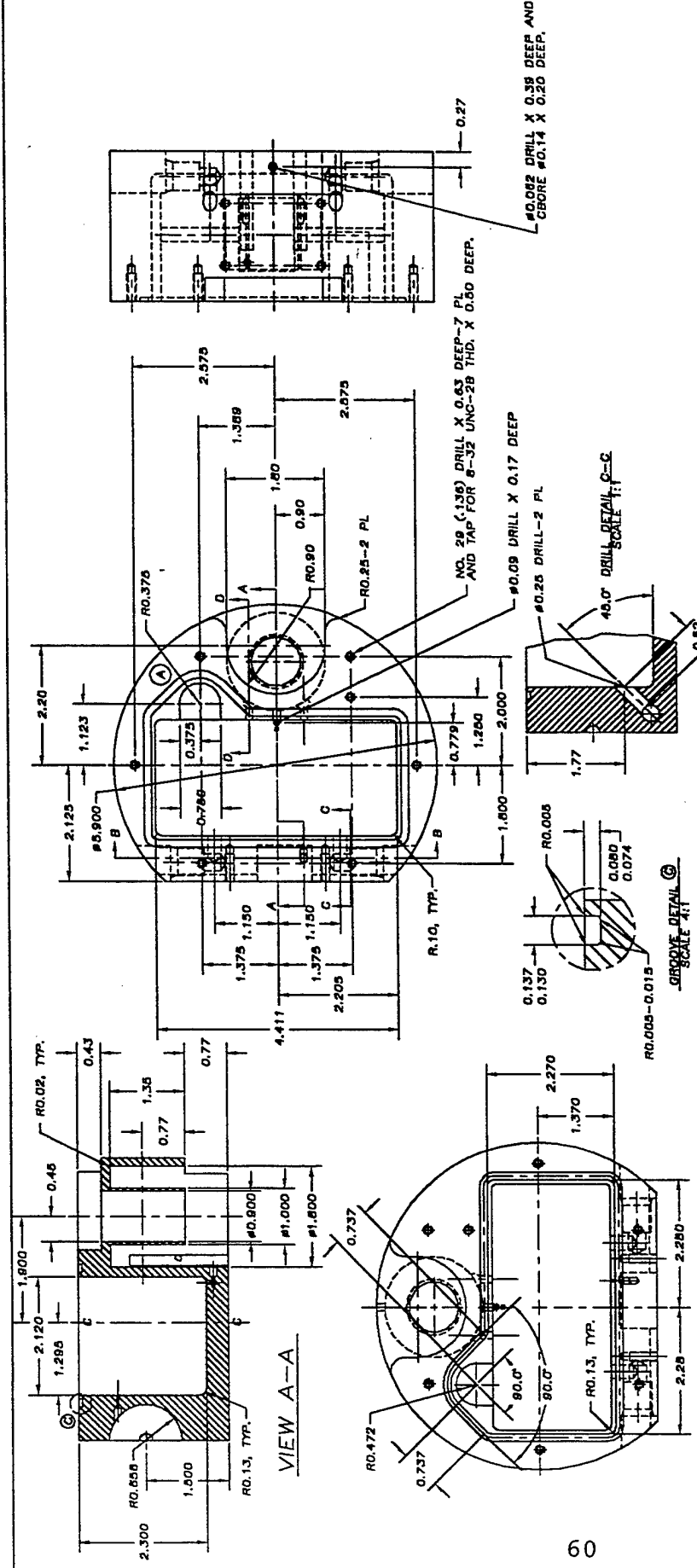


**MODIFICATIONS:**

- Drill end tap SAE port.
- Modify slot shape and depth.
- Add two holes and two grooves.
- Open thru hole up from #1/32 to #1/16.
- Add two slots in the side of puck; drill and tap from bottom.
- Add counterbore to existing hole.

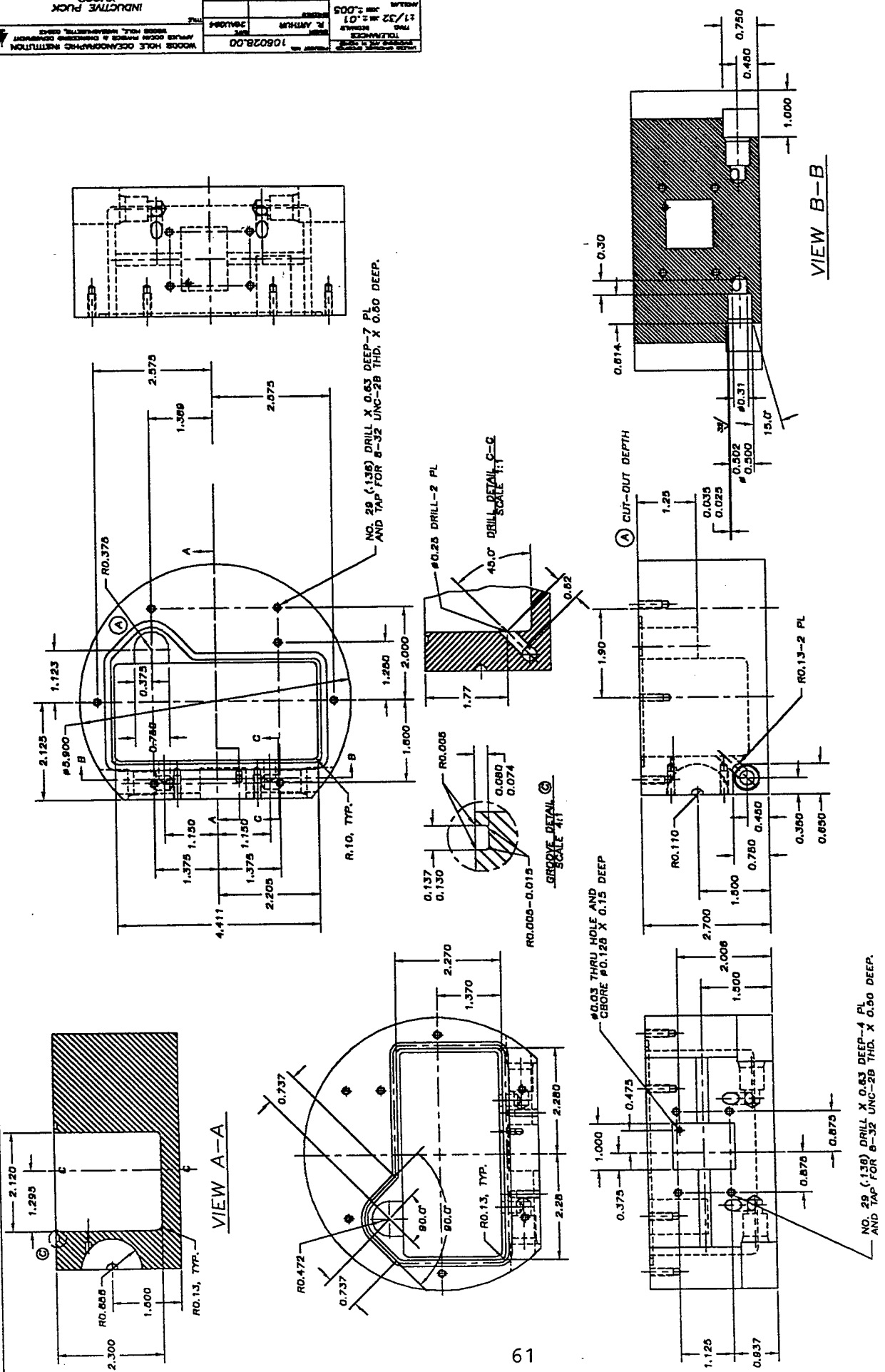
DATE OF ISSUE	1060208.00	WOODS HOLE OCEANOGRAPHIC INSTITUTION
ISSUED BY	R. ARTHUR	APPLIED SCIENCE CENTER & OBSERVATORY
DESIGNED BY	2/1/32 JMT:OT	WOODS HOLE, MASSACHUSETTS
CHECKED BY	JMT:2.005	
APPROVED BY		
DATE OF REV.		
REV.		
DELIN 870	NONE	CONDUCTIVITY PUCK
		XINGOR
		200263
		200263
		200263
		200263

106028.00	WOODS HOLE OCEANOGRAPHIC INSTITUTION	APPROVED	UNIVERSITY OF CALIFORNIA
		DATE	1971
		BY	R. ANTHONY
		SCALE	AS SHOWN
	CONDUCTIVITY PUCK	NO. 1	200233A
		REV.	3
		NOTES	DELFIN 570
			NONE
			1:1

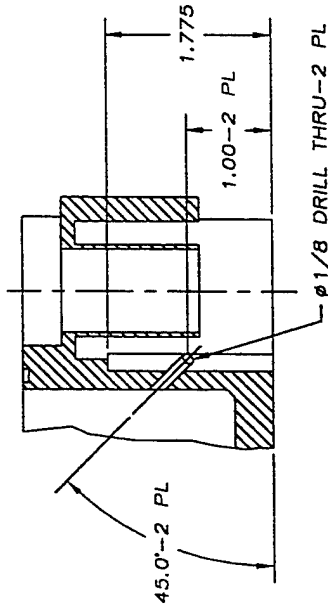
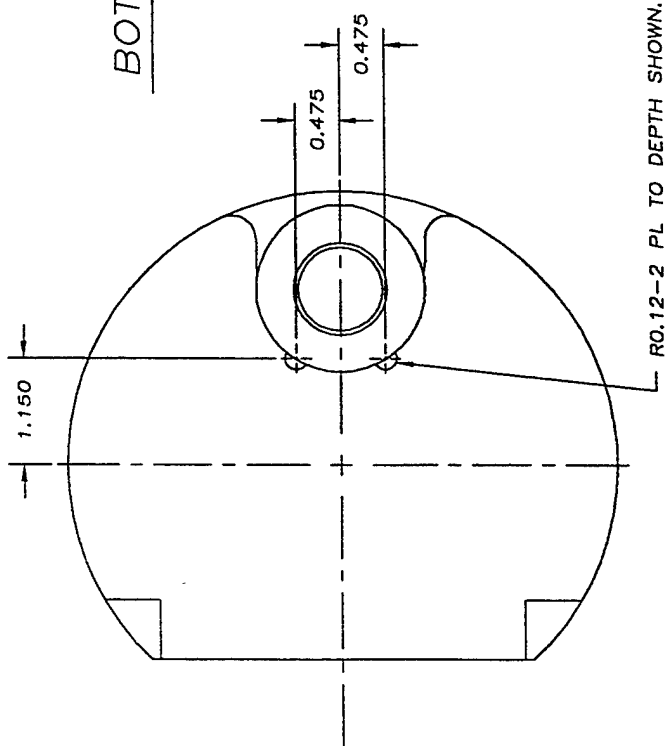


VIEW B-B

WOODS HOLE OCEANOGRAPHIC INSTITUTION WOODS HOLE, MASSACHUSETTS	108028.00	DELFIN 570
INDUCTIVE PUCK XMOOR	NONE	
2002330		



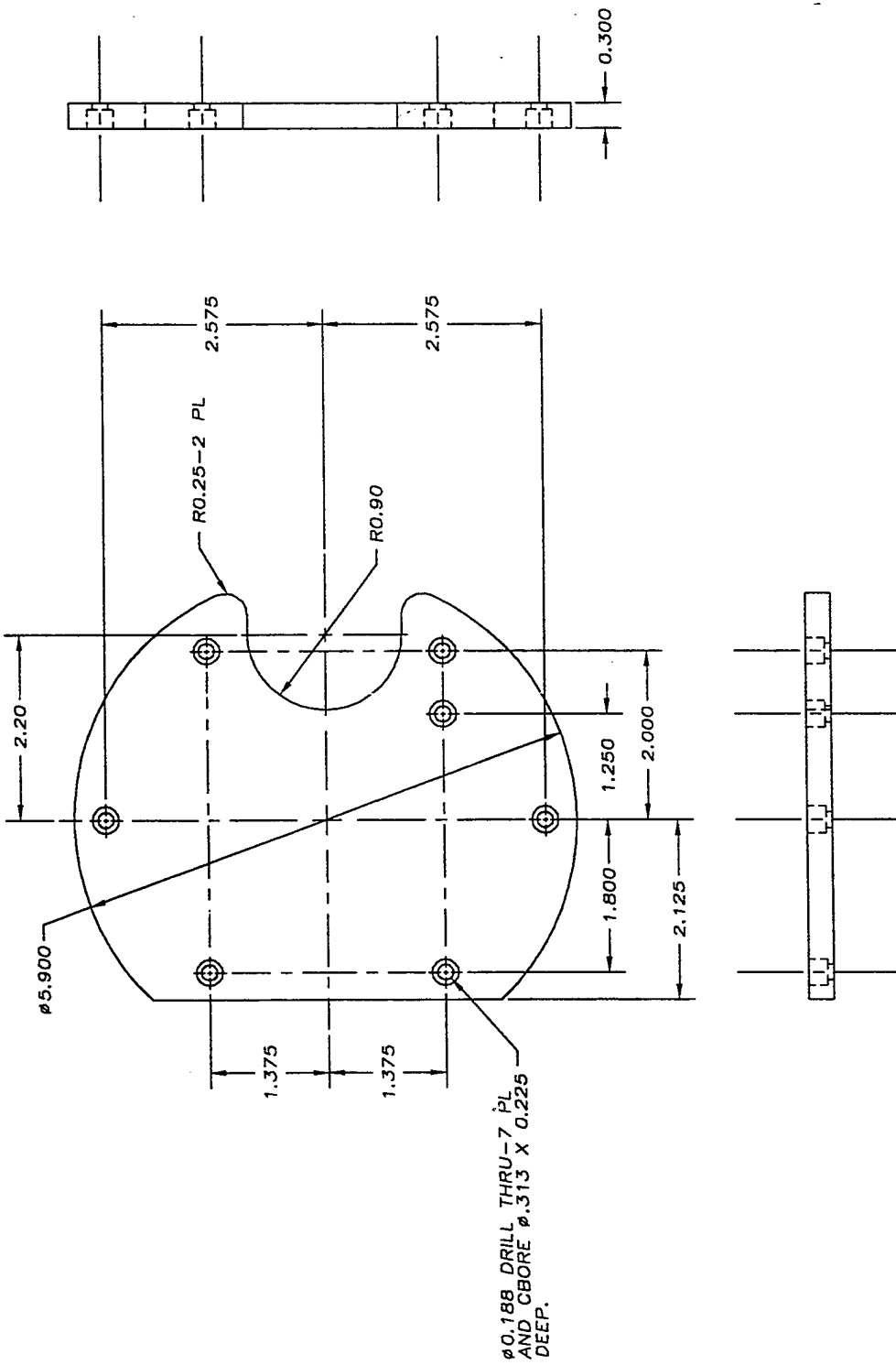
BOTTOM VIEW



VIEW D-D  
SCALE 1:1

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES FRACTIONS .005 DECIMALS ±.01 ANGULAR ± 1° DO NOT SCALE DRAWING MATERIAL DELRIN 570	PROJECT NO. 106028.00 DRAWN R. ARTHUR CHECKED APPROVED FINISH NONE	DATE 3AUG84 TITLE CONDUCTIVITY PUCK XMOOR	WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543
	SIZE C SCALE 1:1 MATERIAL DELRIN 570	DRG. NO. 200233A RELEASE DATE	REV. 2 SHEET 2 OF 2



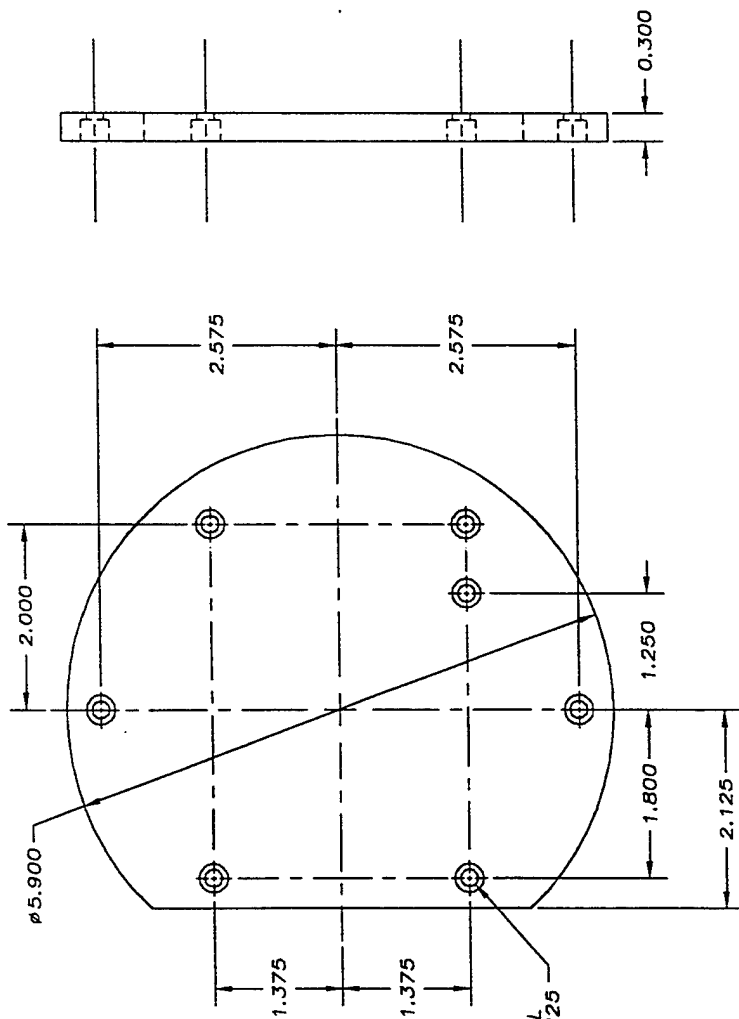


63

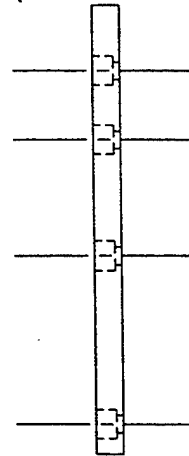
NOTES:

1. BREAK ALL SHARP EDGES.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	PROJECT NO.	10602B.00	
	DATE	4/AUG/84	
TOLERANCES	DESIGNER	R. ARTHUR	
FRACTIONAL	CHECKED		
DECIMALS	APPROVED		
$\pm 1/32$ .004 $\pm .01$	FINISH	NONE	
ANGULAR			
$\pm .005$			
$\pm 1^\circ$			
DO NOT SCALE DRAWING			
MATERIAL			
DELTRIN 570			
WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543			
TITLE COVER, CONDUCTIVITY PUCK XMOOR			
SCALE	DWG. NO.	REV.	
1:1	C	200233B	
	RELEASE DATE		
			SHEET OF



Ø0.188 DRILL THRU-7 PL  
AND CBORE Ø.313 X 0.225  
DEEP.

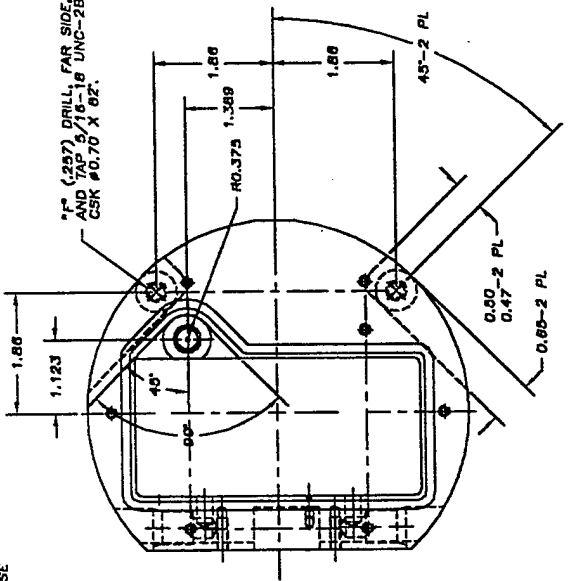


NOTES:

1. BREAK ALL SHARP EDGES.

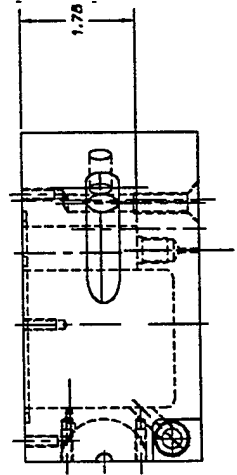
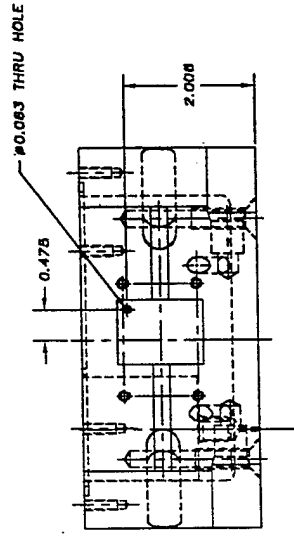
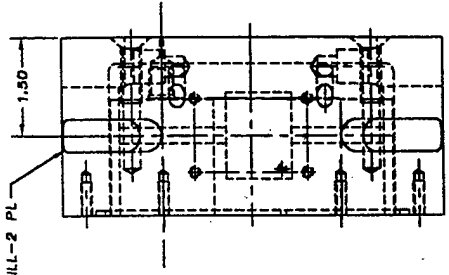
UNITED STATES GOVERNMENT SPECIFICATIONS DRAWING SHEET AND INCHES		PROJECT NO. 106028.00		WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543	
TOLERANCES FINI DECIMALS $\pm 1/32$ .XX $\pm .01$ ANGULAR $\pm 1'$ DO NOT SCALE DRAWING MATERIAL		DRAWN R. ARTHUR	DATE 4AUG64	TITLE COVER, PUCK XMOOR	DWG. NO. 200233H
DELRIN 570		CHECKED	APPROVED	SCALE 1:1	RELEASE DATE
NONE		NONE		SHEET OF	NO.

#3/64 DRILL THRU AND DRILL AND TAP FOR BOSS SET SCREWS AND TAP FOR 80 DEEP. USE MILLERS PER SAE J1928 AND MST8142. USE PARKER TOOL NO. Y34731. THREADS WILL BE 3/8-24 UNF-2B.



USE #1/2 BALL END MILL-2 PL

#F (257) DRILL, FAR SIDE, X 2.00 DEEP-2 PL AND TAP 5/16-18 UNC-2B X 1.00 DEEP. CSK #0.70 X 8Z.



MODIFICATIONS:

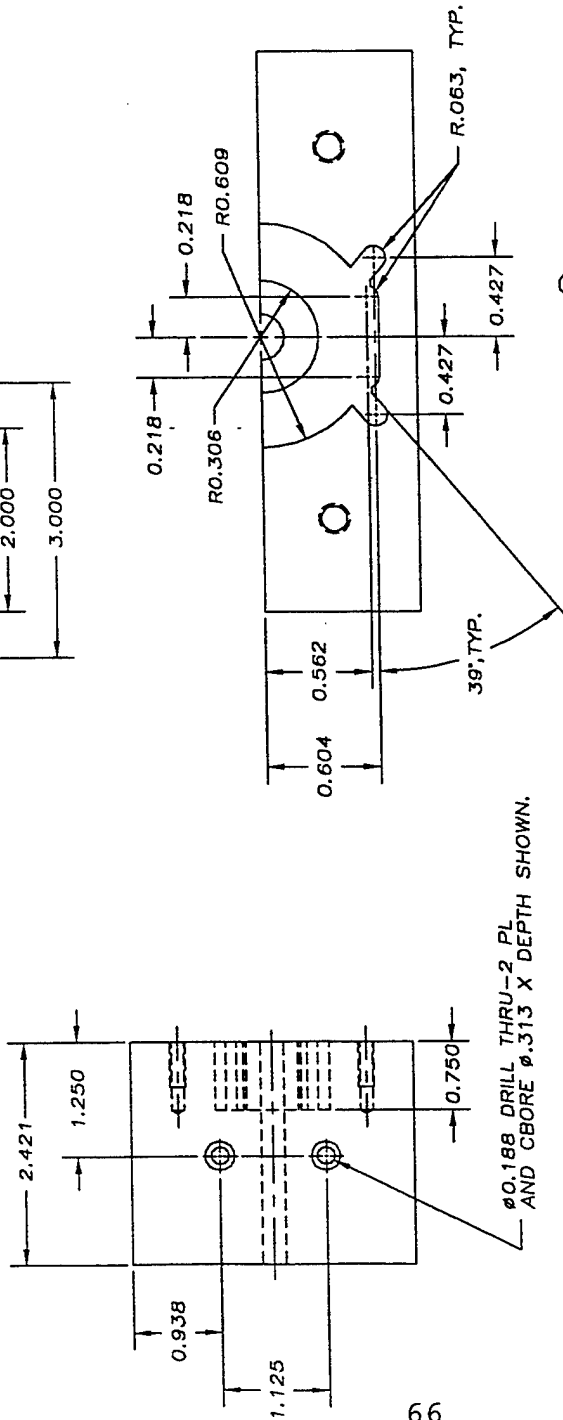
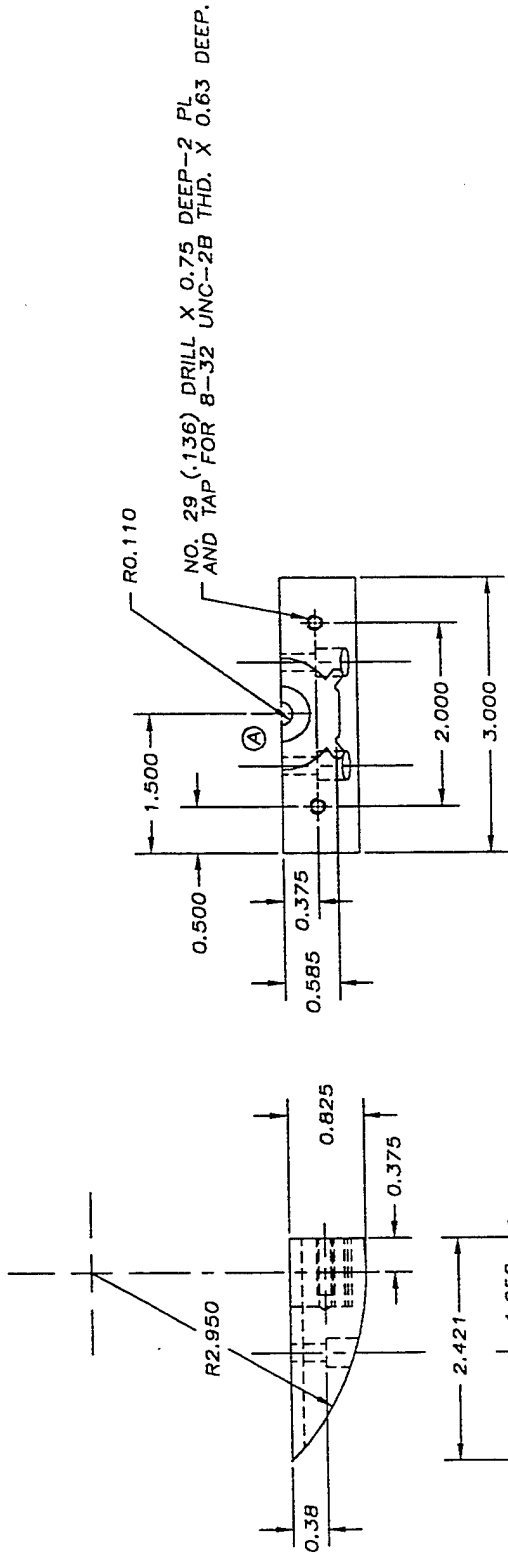
Drill and tap SAE part.

Modify slot shape and depth.

Open thru hole up from #1/32 to #1/16.

Add two holes in the side of puck drill and tap from bottom.

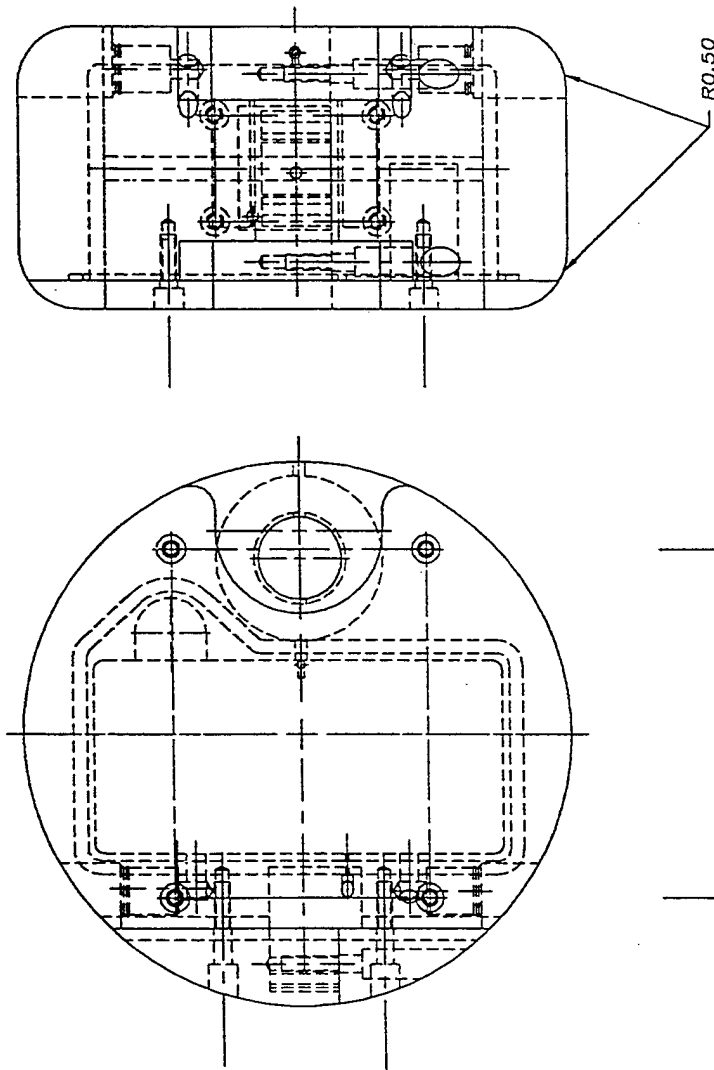
DRAWING NO. 106028.00 PART NO. 410794 MATERIAL QUANTITY UNIT		WOODS HOLE ORGANIZATION APPROVED BY DATE	
DESIGNER R. ARTHUR CHECKER DATE APR 3, 1965		INDUCTIVE PUCK XIMCOR	
DELIN 870 NONE		D 200233A 111 106028.00	
SHEET 1 OF 1		PART 1 OF 1	



66

Ø 0.188 DRILL THRU-2 PL  
AND CORE Ø .313 X DEPTH SHOWN.

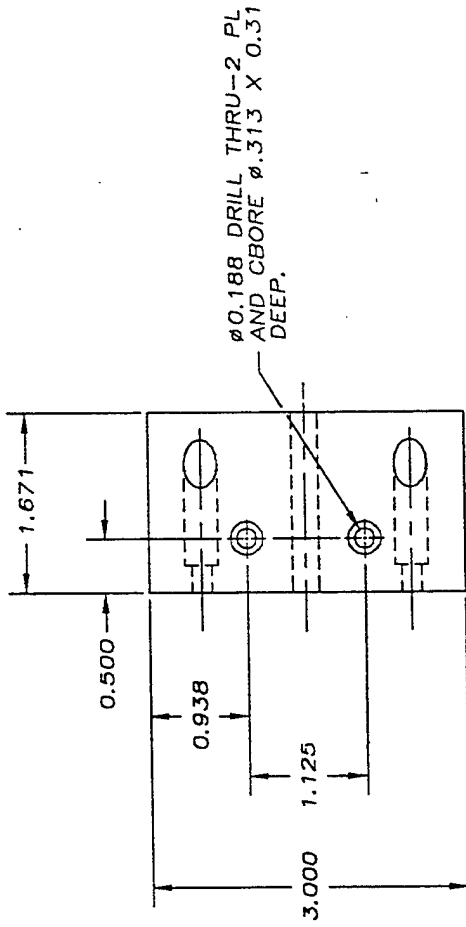
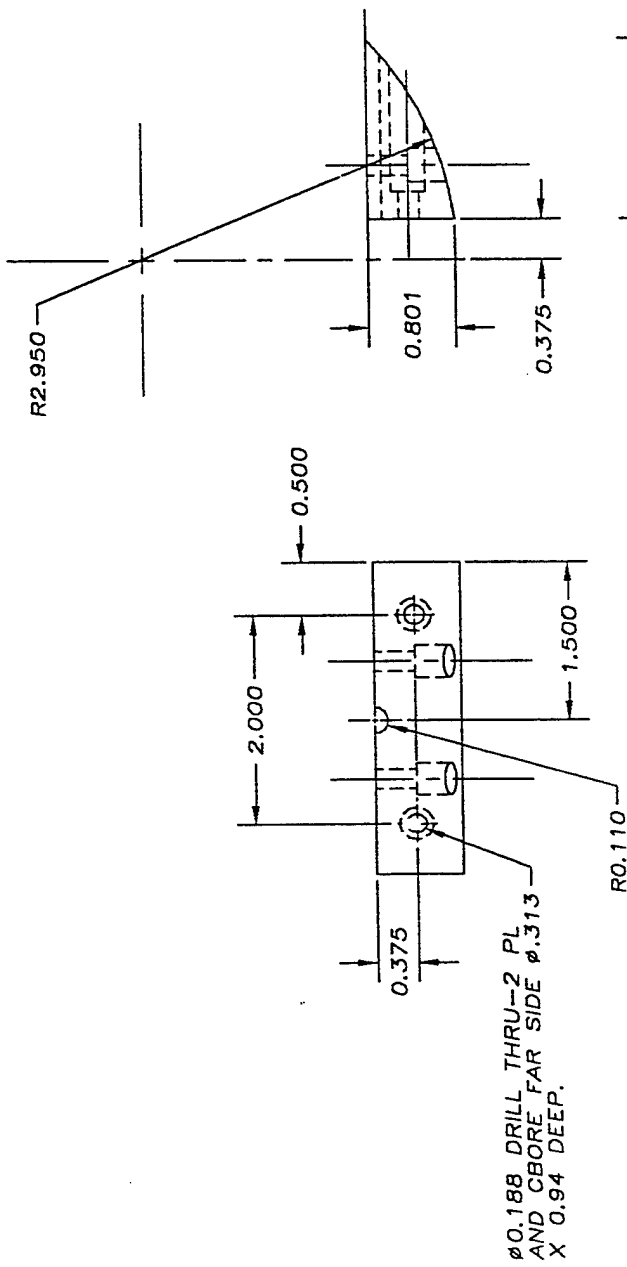
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES	PROJECT NO. 10602B.00	WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543
FRAC DECIMAL ± 1/32 FOR ± .01	DATE 2AUG84	TITLE CLAMP BLOCK, TOROID CONDUCTIVITY PUCK XMOOR
ANGULAR ± 1°	DRAWN R. ARTHUR	SIZE C
DO NOT SCALE DRAWING	CHECKED	DWG. NO. 200233D
MATERIAL DELRIN 570	APPROVED	SCALE 1:1
	FINISH	RELEASE DATE
	NONE	REV. OF



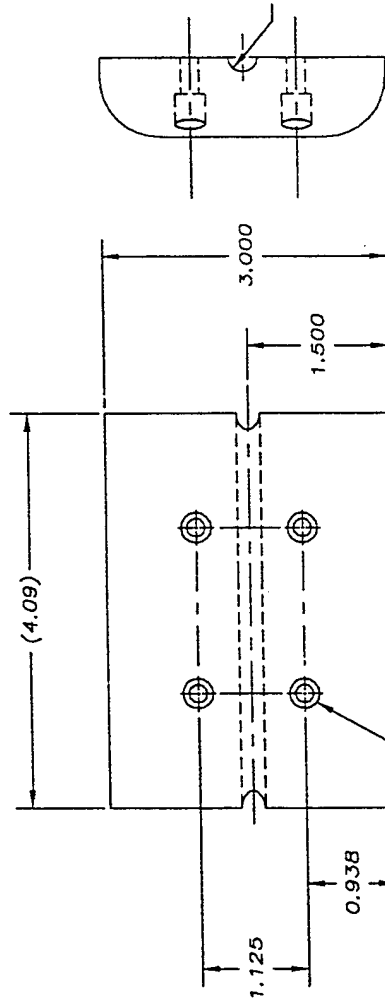
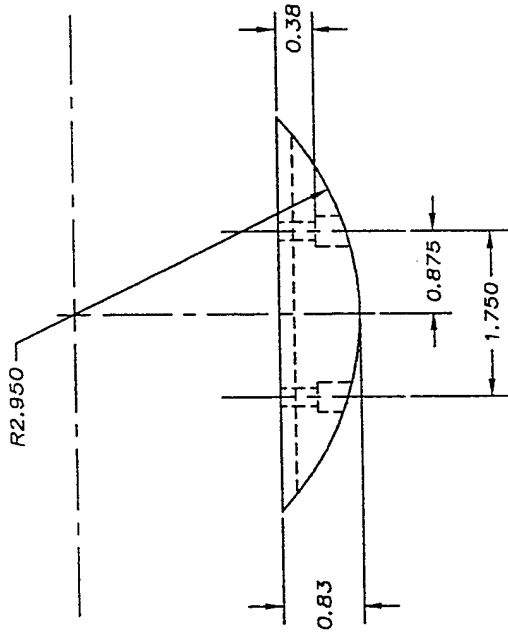
NOTES:

ASSEMBLED ALL PARTS AND RADIUS EDGES AS SHOWN.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES FRACTIONS DECIMALS ± 1/32 .001 ± .01 ANGULAR ± 1° DO NOT SCALE DRAWING NATIONAL	PROJECT NO.	106028.00	DATE	29 JUNE 64	WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543		
	DRAWN	R. ARTHUR	ENTERED	APPROVED	CONDUCTIVITY PUCK XMOOR		
DELTRIN 570	NONE		SCALE	1:1	RELEASE DATE	2002.3.3E	
						SHEET	OF

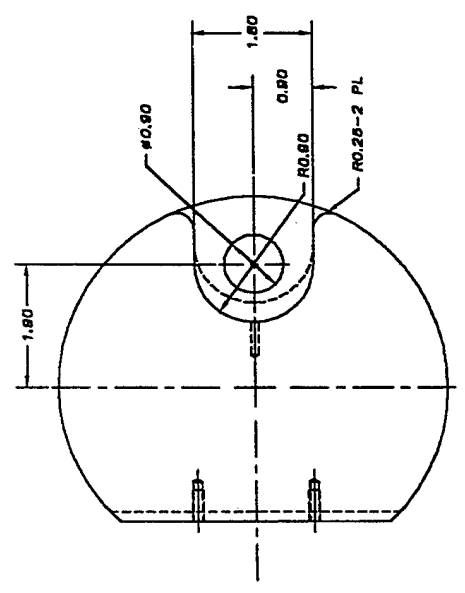
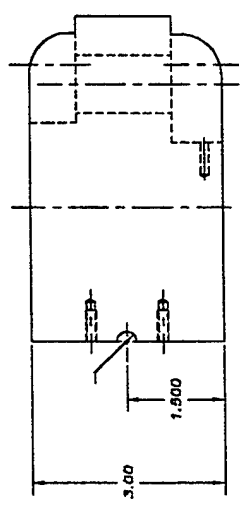
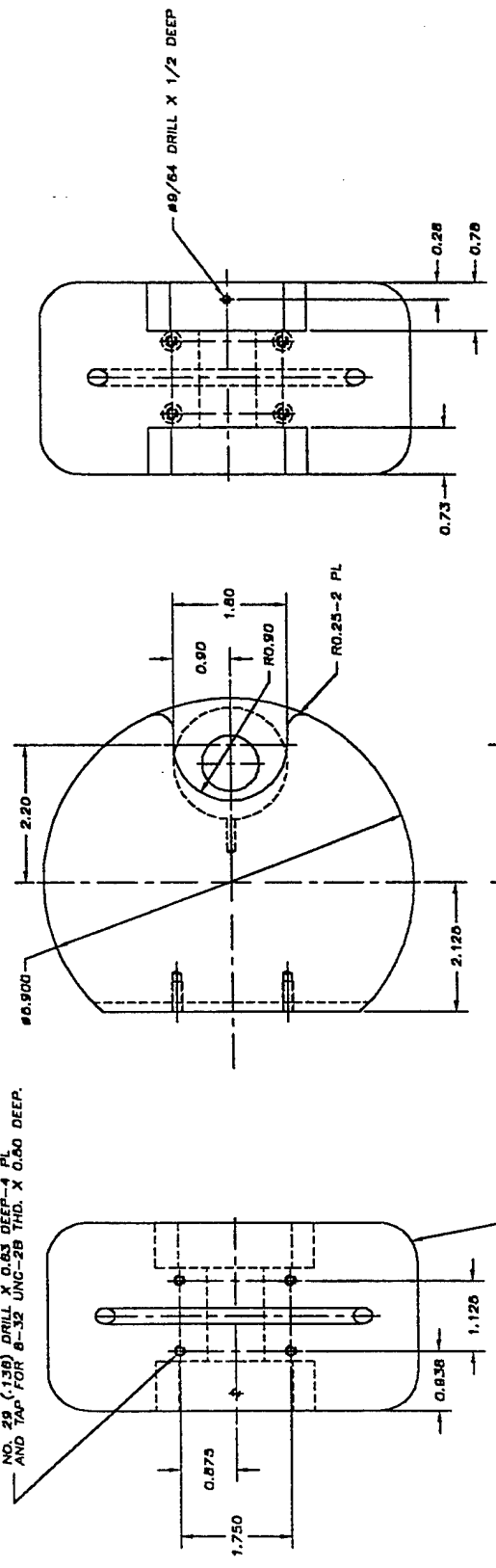


UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		PROJECT NO. 106028.00	
TOLERANCES		DRAWN	DATE
FRACTIONS .005 ± .005		R. ARTHUR	16 JUNE 94
DECIMALS ± 1/32 .004 ± .01		ENTERED	
ANGULAR ± 1°		APPROVED	
DO NOT SCALE DRAWING		FINISH NONE	
MATERIAL DELRIN 570		SCALE 1:1	
		SIZE C	REV.
		DWG. NO. 200233C	RELEASE DATE
		WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543	
		TITLE RETAINER, TOROID CONDUCTIVITY PUCK XMOOR	
		SHEET OF	



WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING DEPARTMENT WOODS HOLE, MASSACHUSETTS, 02543		PROJECT NO. 106028.00	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES		DRAWN R. ARTHUR	DATE 16JUNES94
TOLERANCES FINISHERS $\pm 1/32$ FOR $\pm .01$ ANGULAR $\pm 1^\circ$		CHECKED APPROVED	TITLE CLAMP BLOCK, MOCK PUCK XMOOR
DO NOT SCALE DRAWING MATERIAL PVC		FINISH NONE	SIZE G
		DWG. NO. 200233M2	REV. OF
		SCALE 1:1	RELEASE DATE SHEET OF

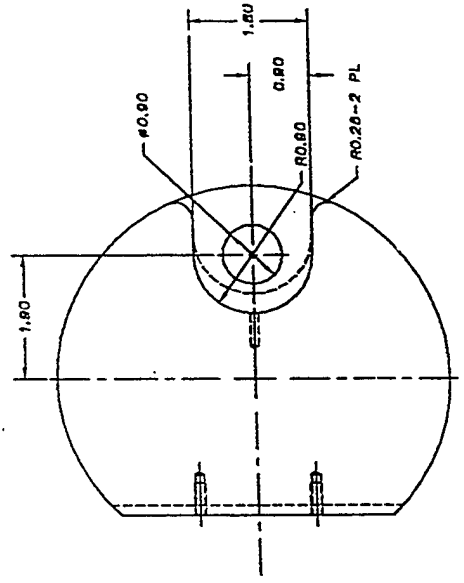
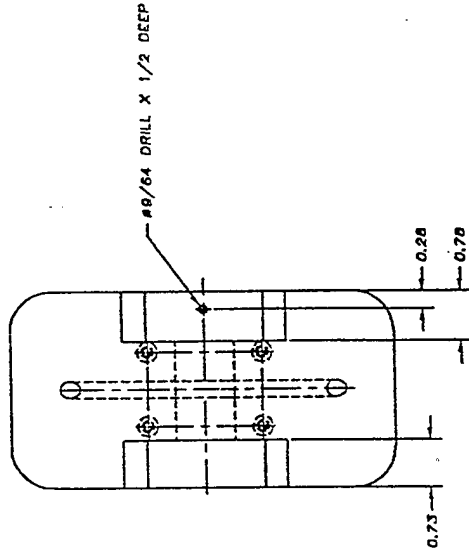
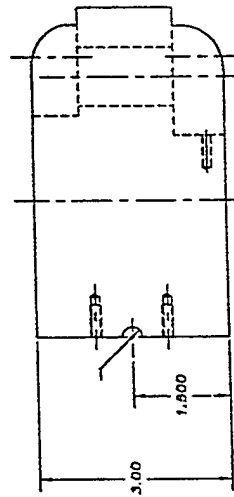
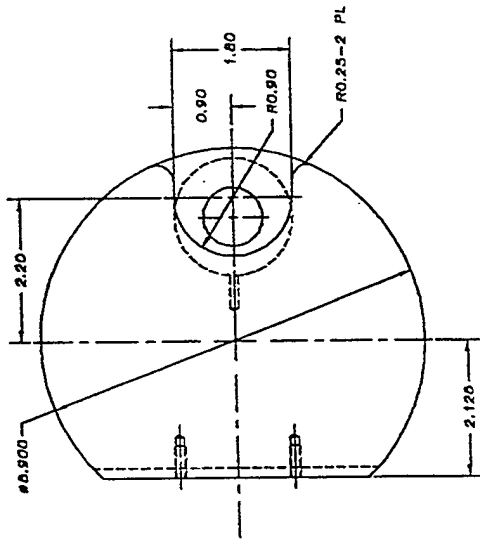
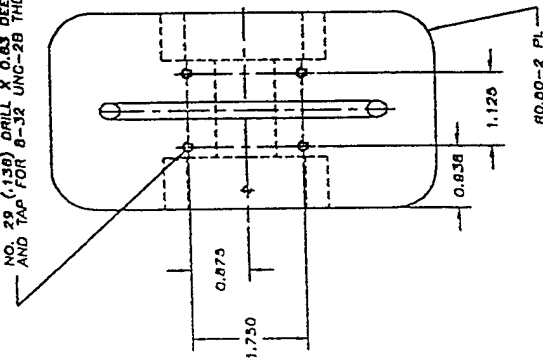
NO. 28 (.138) DRILL X 0.83 DEEP - 4 PL  
AND TAP FOR 8-32 UNC-2B THID. X 0.80 DEEP.



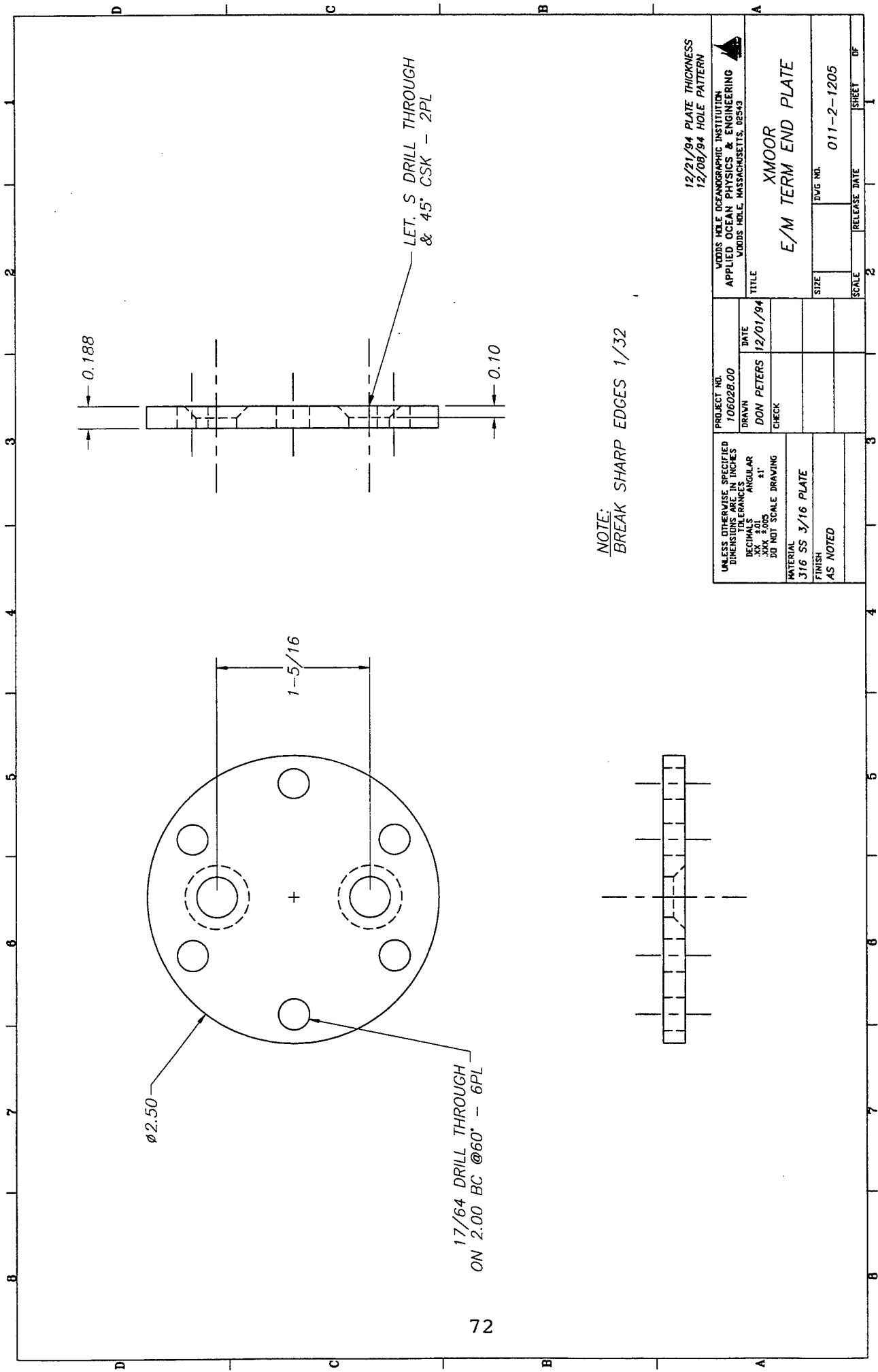
QUANTITY 108026.00 PART NO. 441024 NAME MOCK INDUCTIVE PUCK MATERIAL PVC FINISH NONE QUANTITY 108026.00 PART NO. 441024 NAME MOCK INDUCTIVE PUCK MATERIAL PVC FINISH NONE		QUANTITY 108026.00 PART NO. 441024 NAME MOCK INDUCTIVE PUCK MATERIAL PVC FINISH NONE	QUANTITY 108026.00 PART NO. 441024 NAME MOCK INDUCTIVE PUCK MATERIAL PVC FINISH NONE
--	--	--	--



NO. 29 (.138) DRILL X 0.83 DEEP-4 PL  
AND 1/16" FOR 8-32 UNC-2B THD. X 0.80 DEEP.



PROJECT NO.	108029.00	DATE	11/23/54
BY	W. J. HARRIS	DESIGNED BY	W. J. HARRIS
CHECKED BY	J. L. HARRIS	APPROVED BY	J. L. HARRIS
SCALE	3/4" = 1"	QUANTITY	1000
DATE	11/23/54	PRICE	1.00
DESCRIPTION	MOCK INDUCTIVE PUSH		
WORK CENTER	MOCK INDUCTIVE PUSH		
OPERATOR	NONE		
INSPECTOR	NONE		
DATE	11/23/54		
PRICE	1.00		
QUANTITY	1000		
TOTAL	1000		
REVISIONS	NONE		
APPROVED	W. J. HARRIS		
DATE	11/23/54		

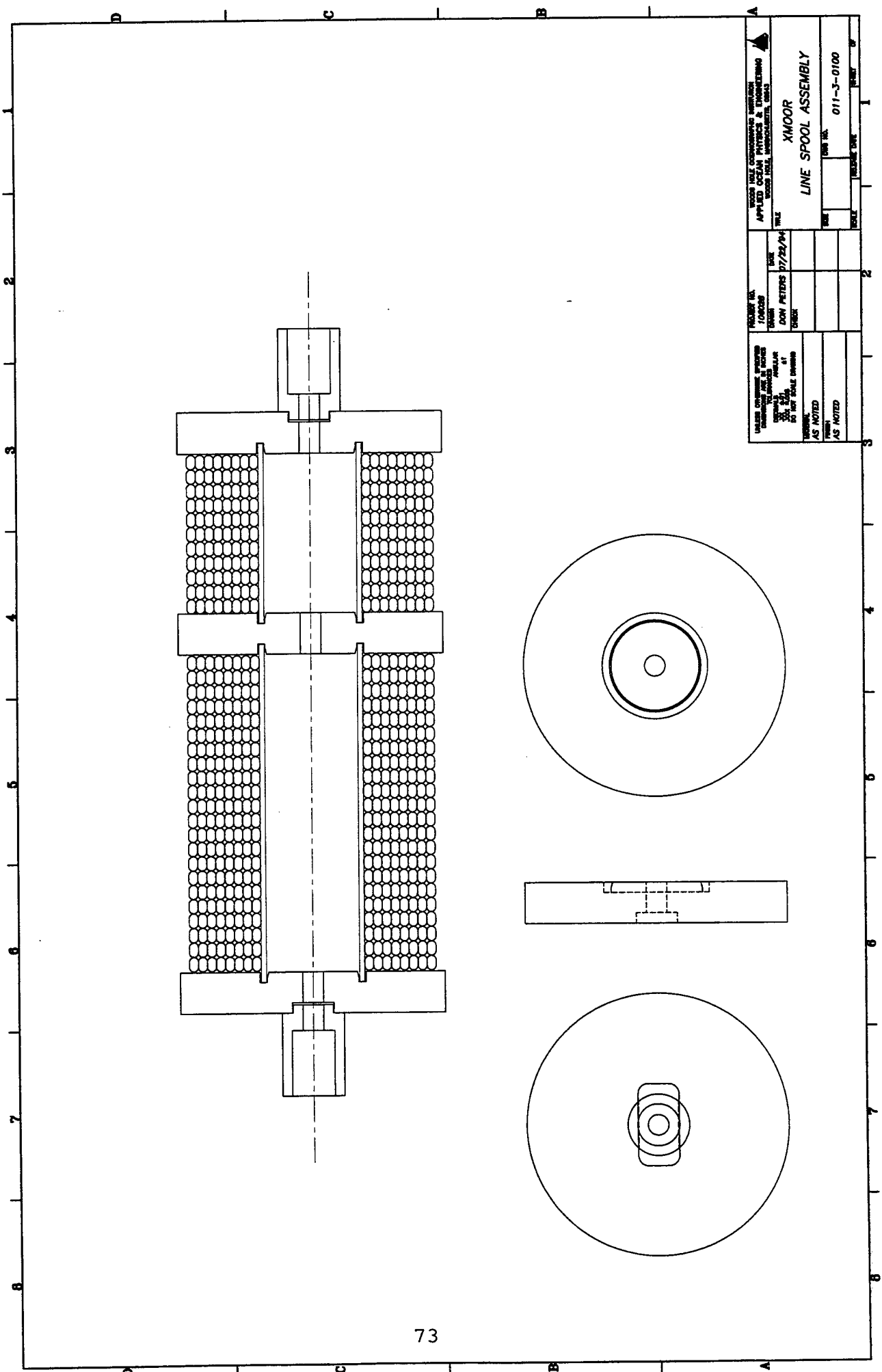


17/64 DRILL THROUGH  
ON 2.00 BC @60° - 6PL

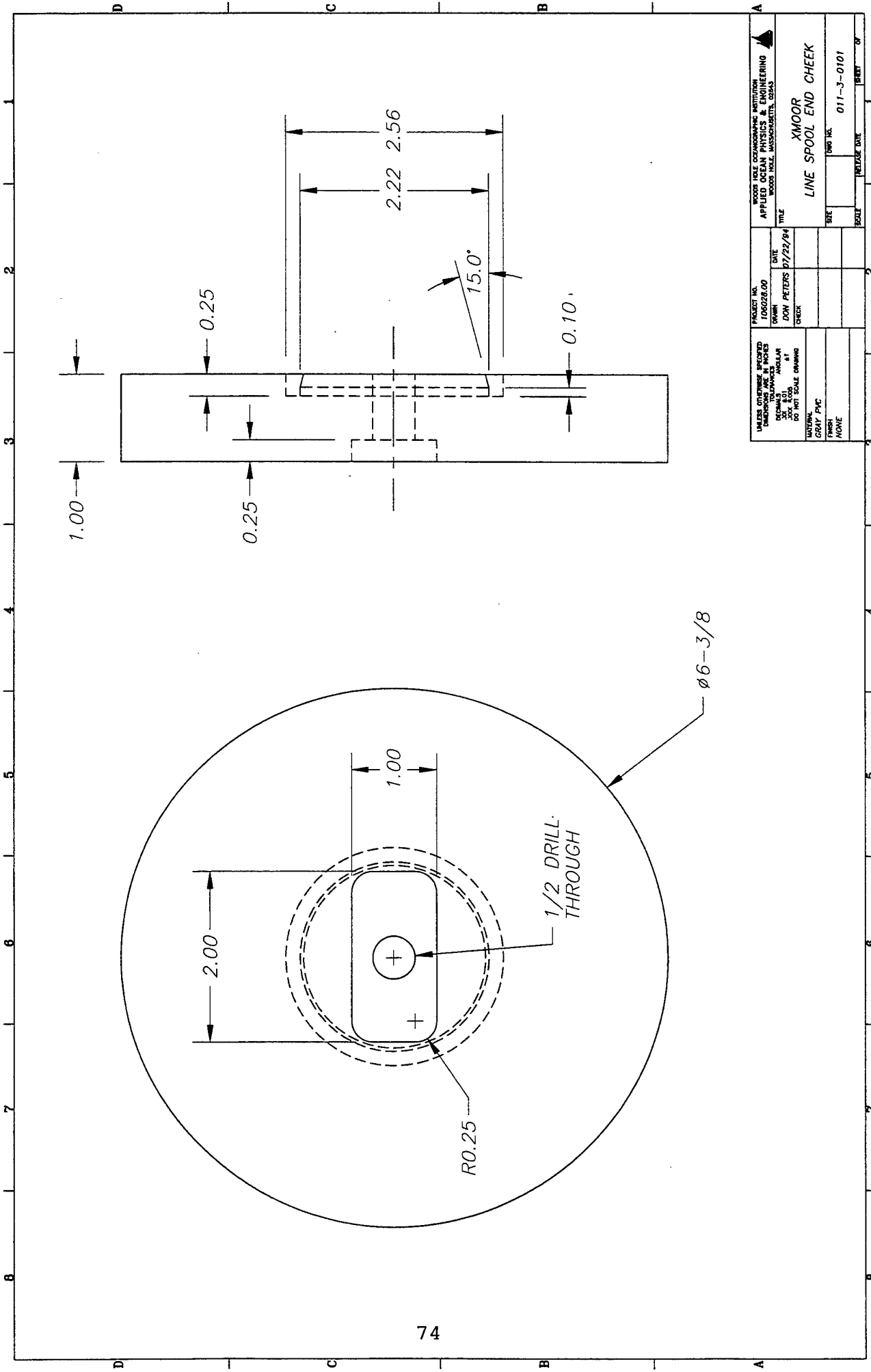
NOTE:  
BREAK SHARP EDGES 1/32

12/21/94 PLATE THICKNESS  
12/08/94 HOLE PATTERN

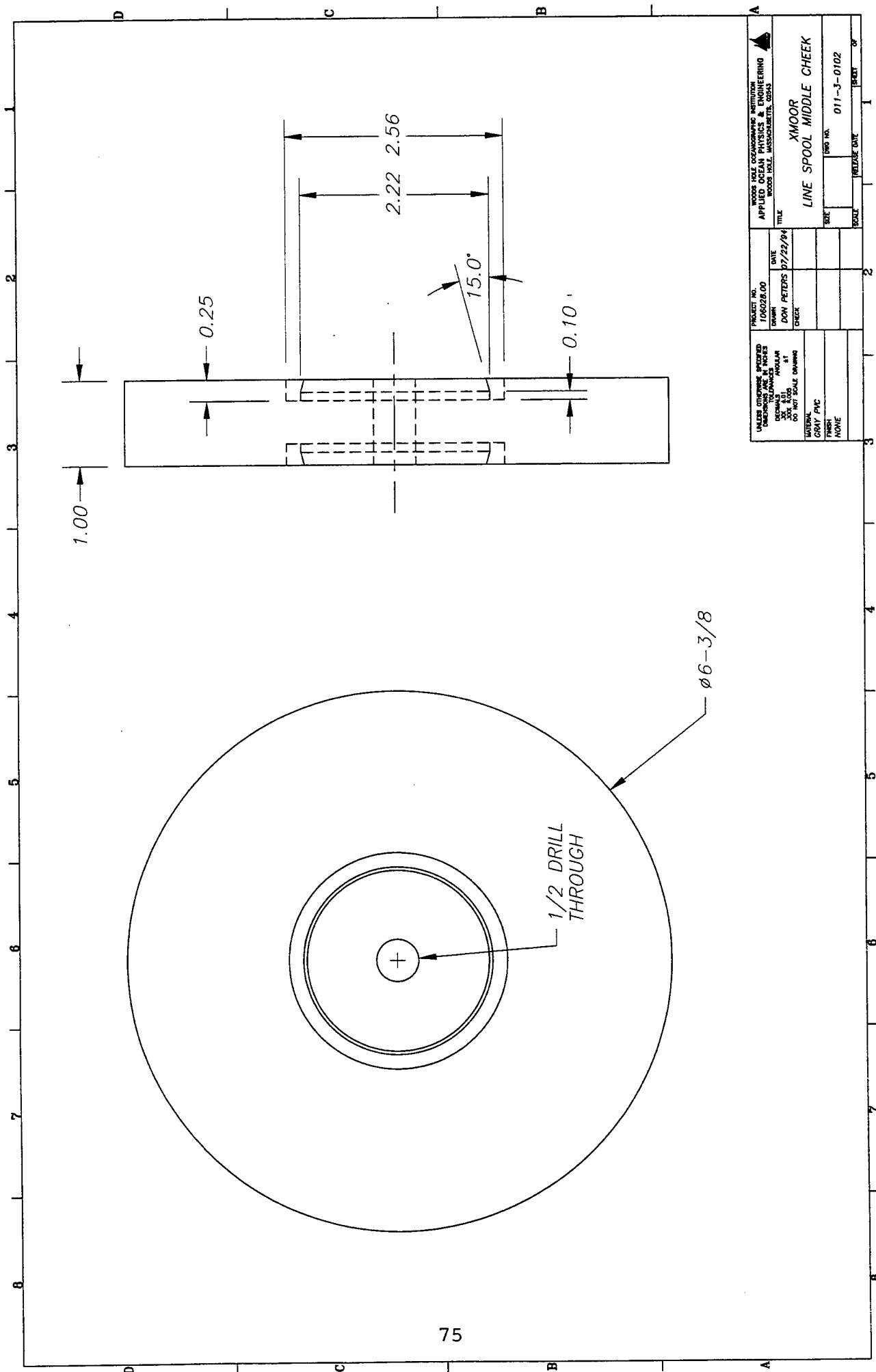
UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES TOLERANCES DECIMALS .005 ANGULAR ±1° XXX FOR DO NOT SCALE DRAWING		PROJECT NO. 106028.00	DATE 12/01/94	12/21/94 PLATE THICKNESS 12/08/94 HOLE PATTERN	
MATERIAL 316 SS 3/16 PLATE		DRAWN DON PETERS	CHECK	VODDS HALE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING VODDS HOLE, MASSACHUSETTS, 02543	
FINISH AS NOTED		TITLE E/M TERM END PLATE		XMOOR	
AS NOTED		SIZE		DVG NO. 011-2-1205	
AS NOTED		SCALE		RELEASE DATE	
AS NOTED		SCALE		SHEET OF	



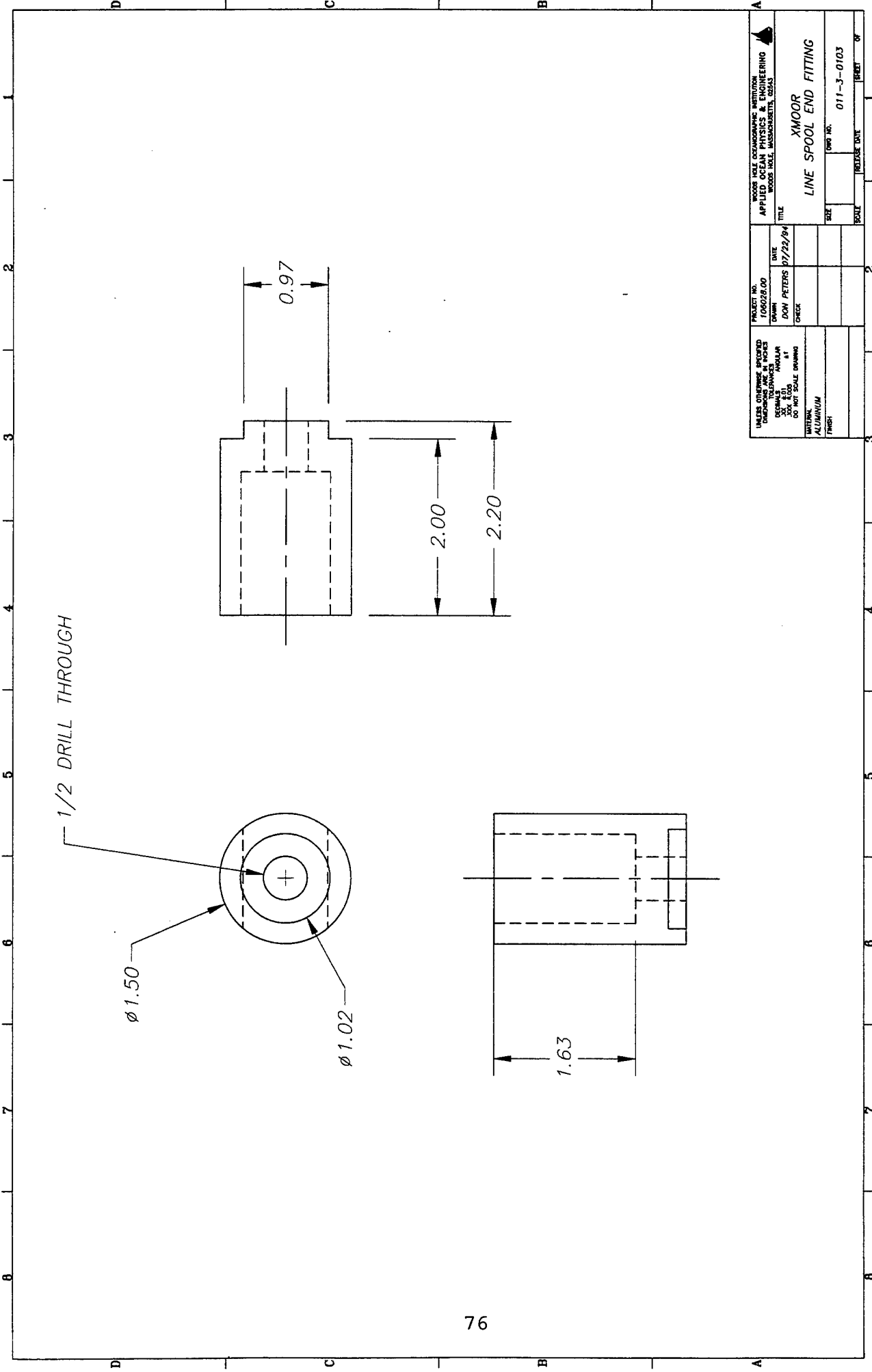
DESIGN NO. 100000		DATE 07/22/04		DRAWN BY DON PETERS		CHECKED BY [Blank]		PROJECT NO. 011-3-0100	
TITLE LINE SPOOL ASSEMBLY		SCALE [Blank]		SHEET NO. 1		TOTAL SHEETS 1		REVISIONS [Blank]	
DESIGNER APPLIED OCEAN PHYSICS & ENGINEERING 100000, WASHINGTON, DC 20004		DATE 07/22/04		DRAWN BY DON PETERS		CHECKED BY [Blank]		PROJECT NO. 011-3-0100	
TOLERANCES UNLESS SPECIFIED FRACTIONS TO DECIMALS DECIMALS TO THIRDS ANGLES TO NEAREST 5 MINUTES UNLESS NOTED OTHERWISE		TOLERANCES AS NOTED		FINISH AS NOTED		MATERIALS AS NOTED		WEIGHTS AS NOTED	



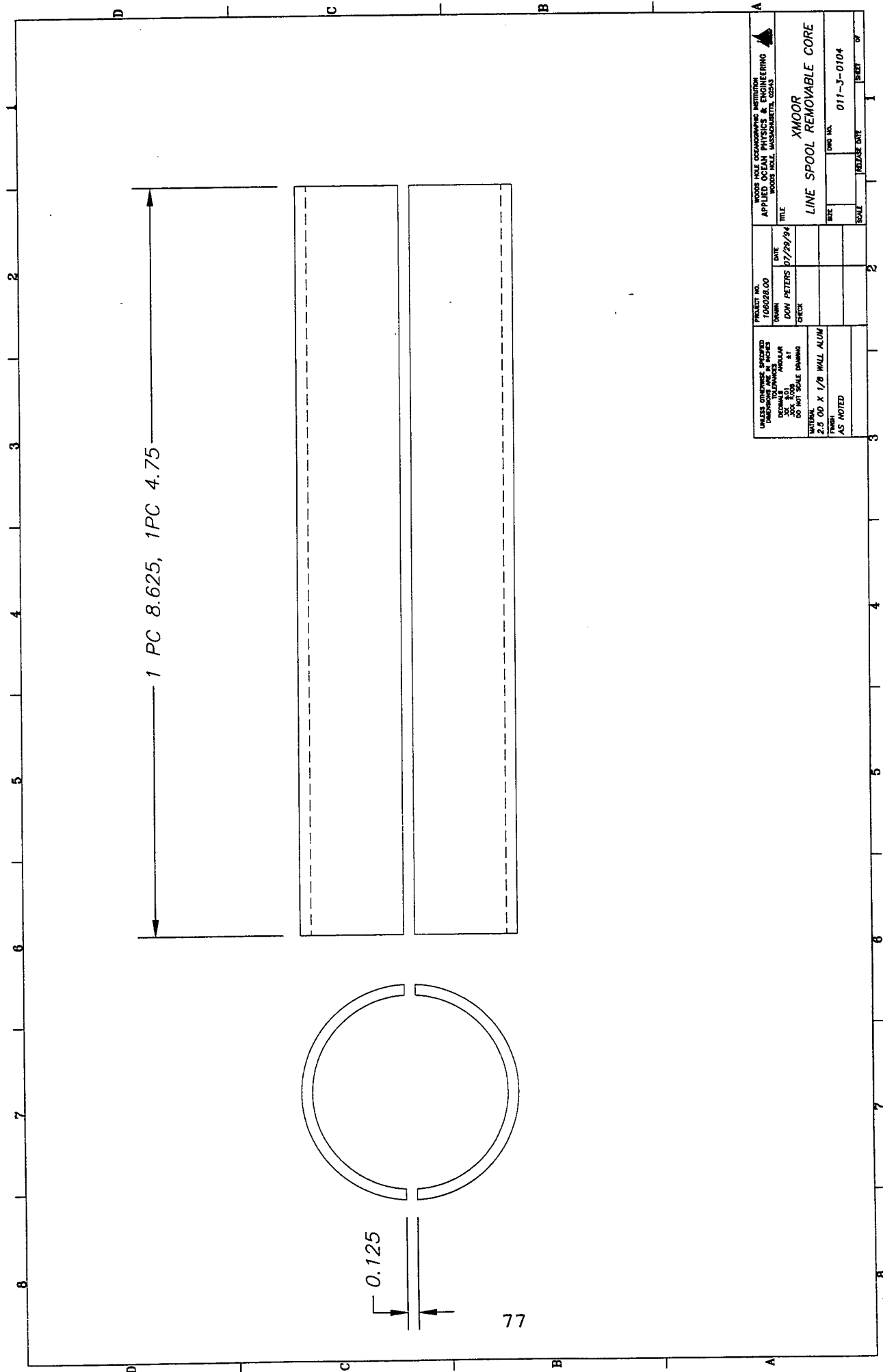
WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, USA		PROJECT NO. 106028.00		DATE 07/22/94	
DRAWN DON PETERS		CHECK DON PETERS		TITLE LINE SPOOL END CHEEK	
MATERIAL GRAY PVC		FINISH NONE		SHEET NO. 011-3-0101	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE AS FOLLOWS: DIMENSIONS IN PARENTAL PARENTAL DIMENSIONS DIMENSIONS IN PARENTAL DIMENSIONS IN PARENTAL DIMENSIONS IN PARENTAL		SCALE AS SHOWN		DATE 07/22/94	
DRAWN DON PETERS		CHECK DON PETERS		DATE 07/22/94	
MATERIAL GRAY PVC		FINISH NONE		SHEET NO. 011-3-0101	



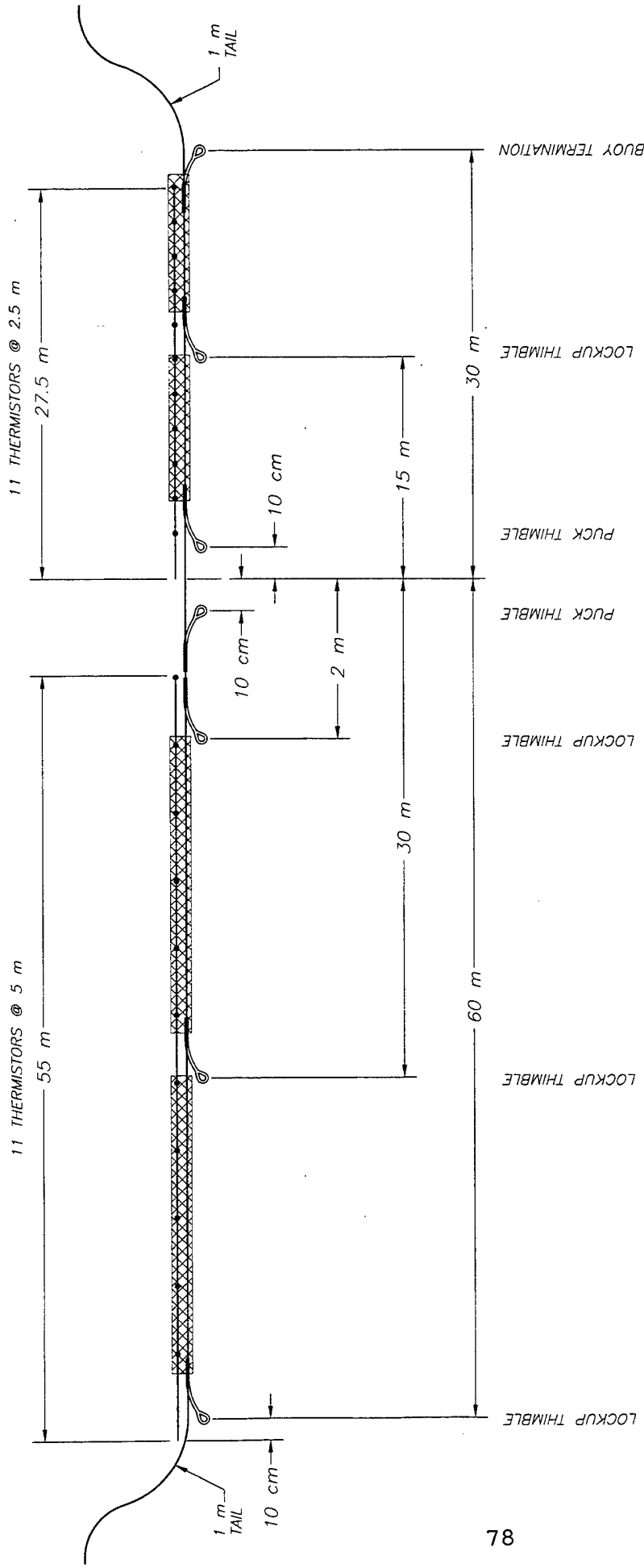
WOODS HOLE TECHNOLOGICAL INSTITUTION APPLIED MECHANICAL PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, 02543		PROJECT NO. TUSOZ8.00		DATE 07/22/94	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS AND FRACTIONS SHALL BE TO THE NEAREST 0.001 UNLESS SPECIFIED OTHERWISE		DRAWN BY DON PETERS		CHECKED BY DON PETERS	
MATERIAL CRYSTAL PVC		TITLE LINE SPOOL MIDDLE CHEEK		SCALE 1:1	
DESIGNED BY NONE		DATE 01-3-0102		RELEASE DATE 01-3-0102	



WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, U.S.A.		PROJECT NO. 106028.00		DATE 07/22/94		TITLE LINE SPOOL END FITTING	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE TO BE 300 ± 0.05 DO NOT SCALE DRAWING		DRAWN DON PETERS		CHECK		SIZE 011-3-0103	
MATERIAL ALUMINUM FINISH		SCALE		RELEASE DATE		SHEET OF	



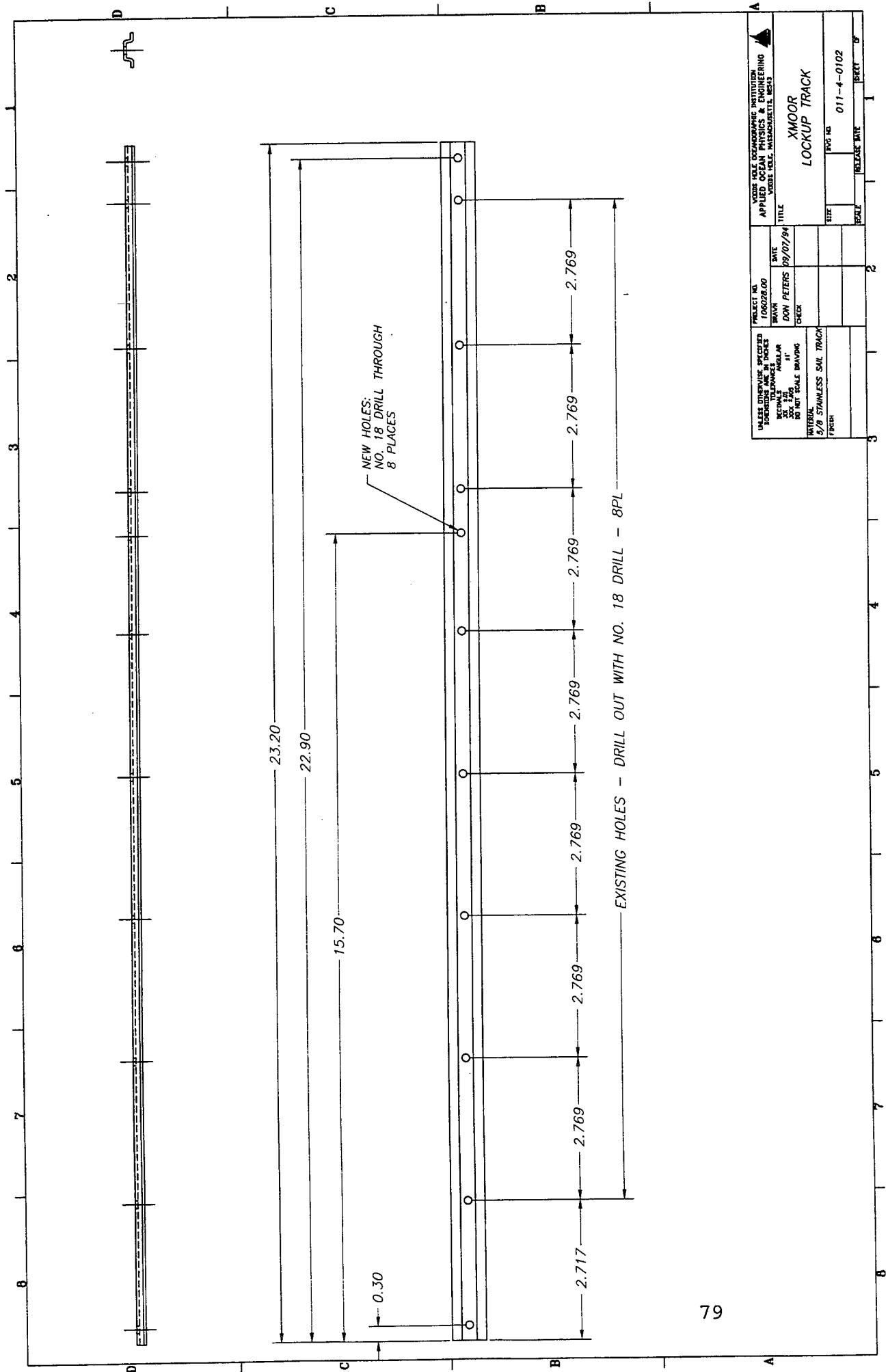
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS TO 0.01 FRACTIONS IN 16ths HOLE SIZES DO NOT SCALE DRAWING		PROJECT NO. 106028.00	DATE 07/29/94	WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, USNS
DRAWN DON PETERS		CHECK DON PETERS	TITLE LINE SPOOL REMOVABLE CORE	SHEET NO. 011-3-0104
MATERIAL 2.5 00 X 1/8 WALL ALUM		FINISH AS NOTED		SCALE RELEASE DATE
AS NOTED		2		1



- MATERIALS:**
- 1 BUOY TERMINATION, DWG 011-2-1200
  - 3 ENDLESS 1/4" THIMBLE, SS
  - 2 PUCK THIMBLE, DWG 200293B
  - 9 m, 5 mm SPECTRA HOLLOW BRAID
  - 90 m, 6 mm POLYESTER SLEEVING
  - 92 m, E/M LINE

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN MILLIMETERS DECIMALS IN INCHES DO NOT SCALE DRAWING MATERIAL AS NOTED FINISH AS NOTED		PROJECT NO. 000000.00	WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS 02543	
DRAWN DOON PETERS	DATE 05/20/95	TITLE XMOOR MOORING LINE ASSEMBLY		
CHECK		SIZE DWG NO. 011-3-0106	SCALE	SHEET OF

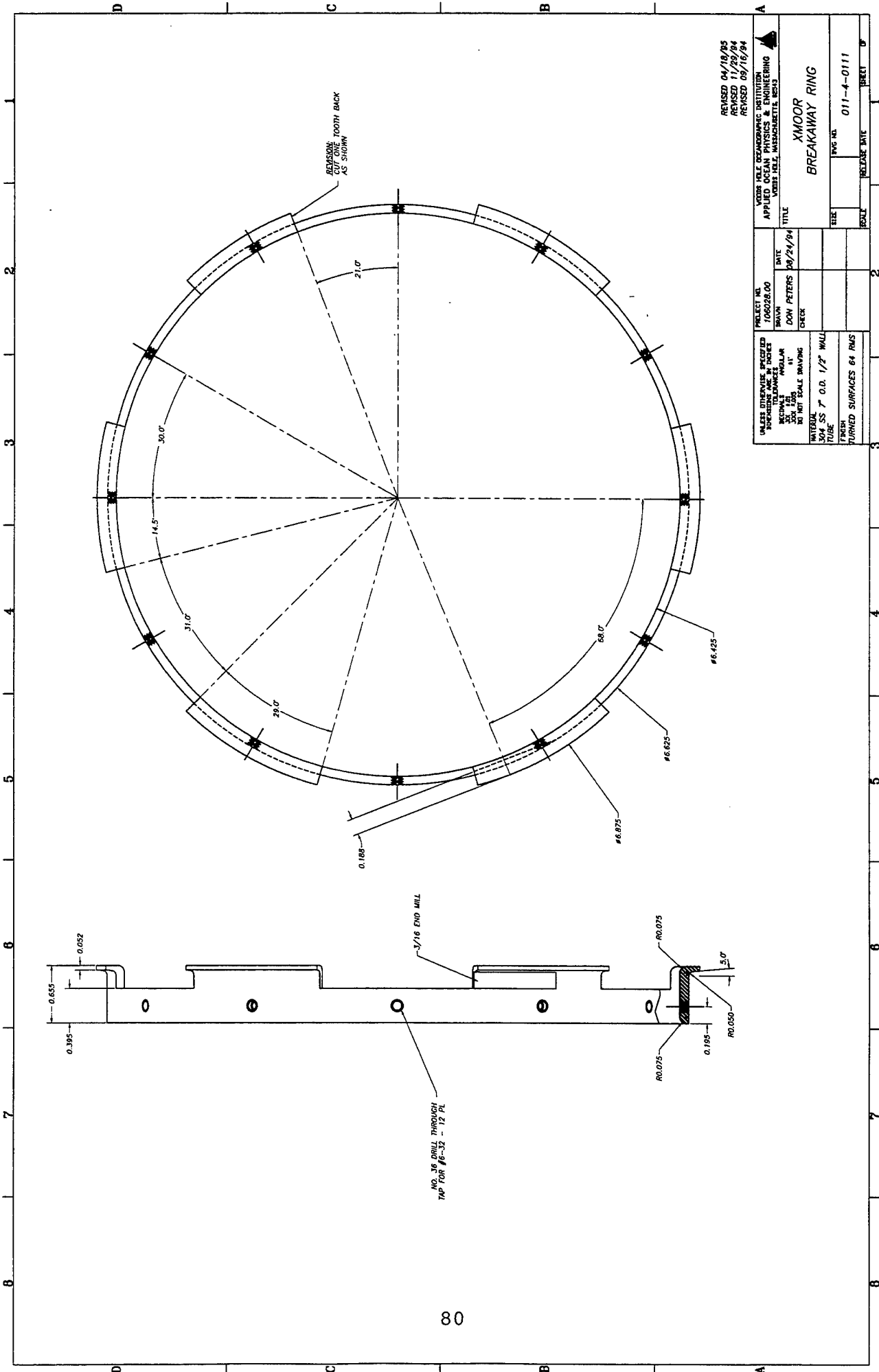


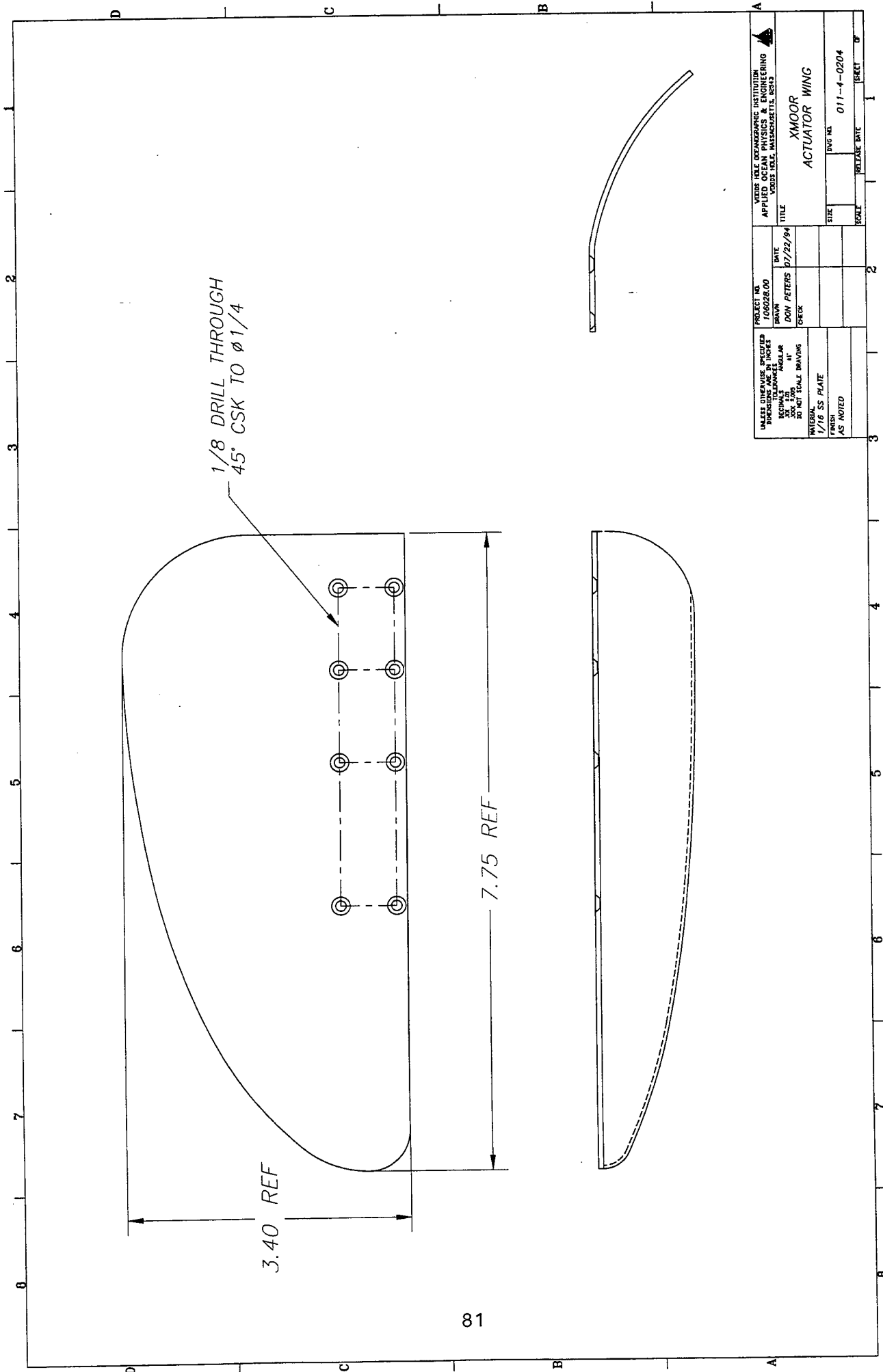


NEW HOLES:  
NO. 18 DRILL THROUGH  
8 PLACES

EXISTING HOLES - DRILL OUT WITH NO. 18 DRILL - 8PL

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES FRACTIONS TO BE IN 16ths		PROJECT NO. 10002800		DATE 09/07/04	
MATERIAL 3/8 STAINLESS SAIL TRACK FRAMING		CHECKED DON PETERS		TITLE XMOOR LOCKUP TRACK	
APPROVED BY APPLIED OCEAN PHYSICS & ENGINEERING WOBURN, MASSACHUSETTS, USA		DRAWN BY DON PETERS		SCALE 1" = 1'-0"	
SHEET NO. 011-4-0102		SHEET 1		OF 1	



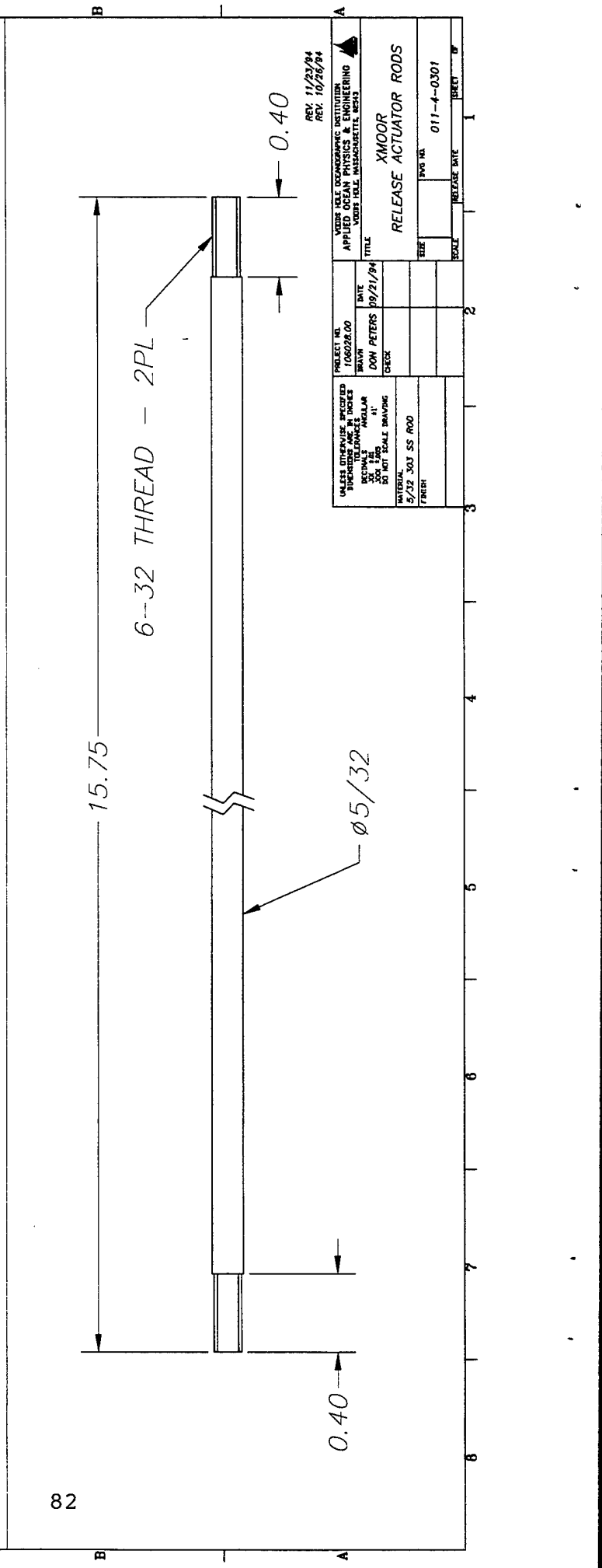
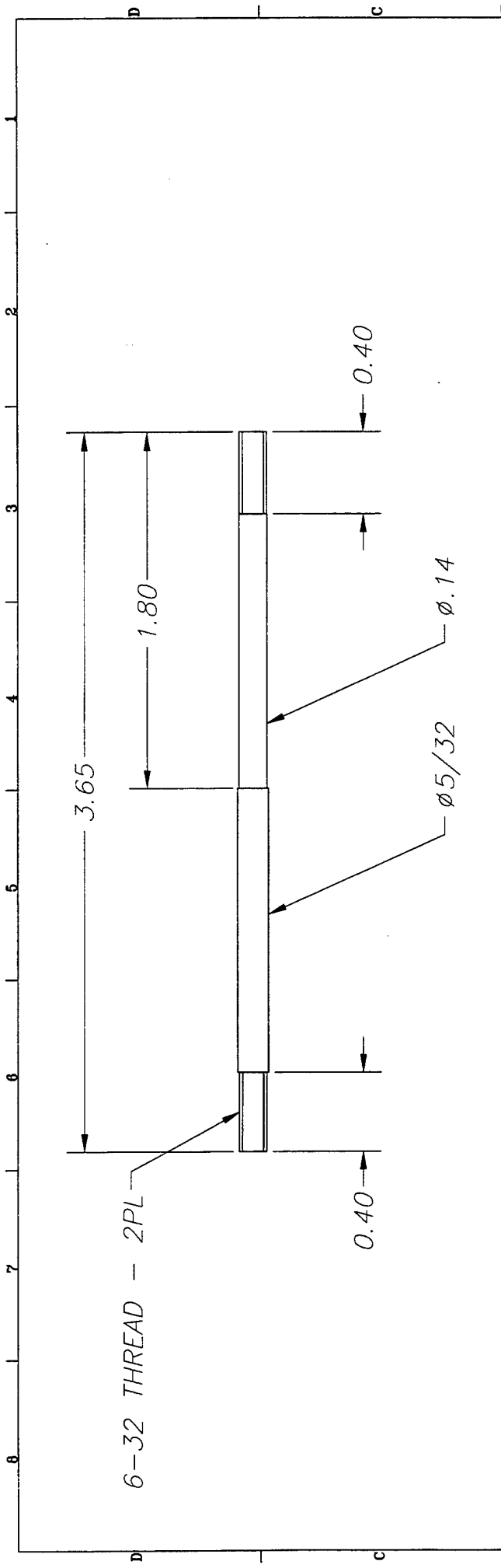


1/8 DRILL THROUGH  
45° CSK TO Ø1/4

3.40 REF

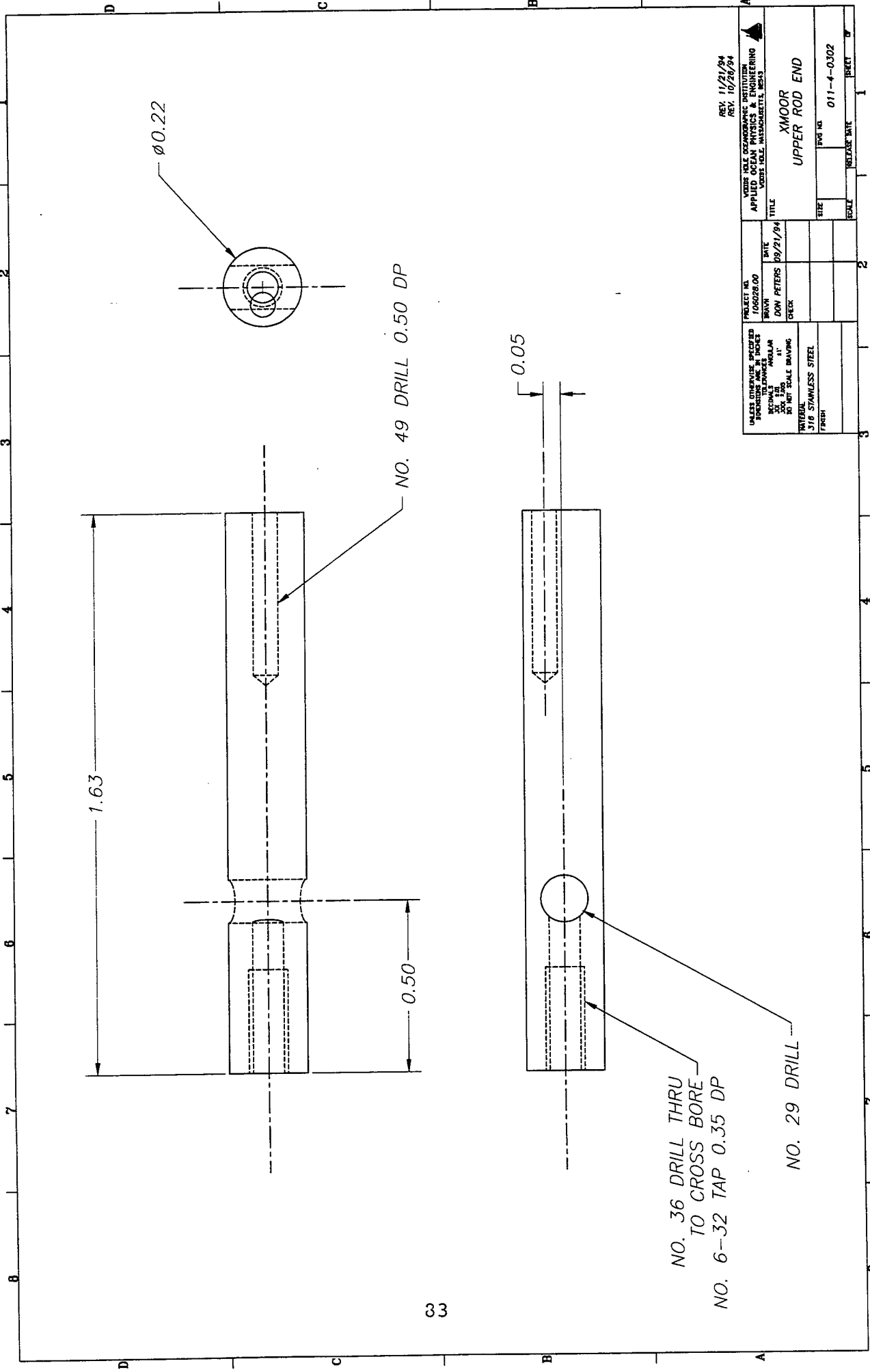
7.75 REF

VIKING HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING 1060228.00 VDDIS TOLL, MASSACHUSETTS, US33		PROJECT NO. 1060228.00		DATE 07/22/94	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS TO TWO PLACES FRACTIONS TO NEAREST 1/16 HOLE DIMENSIONS TO NEAREST 0.001 DO NOT SCALE DRAWING		DRAWN DON PETERS		CHECK	
MATERIAL 1/16 SS PLATE		FINISH AS NOTED		TITLE XMOOR ACTUATOR WING	
SCALE 1:1		DRAWING NO. 011-4-0204		SHEET NO. 1	
RELEASE DATE		SHEET		OF	



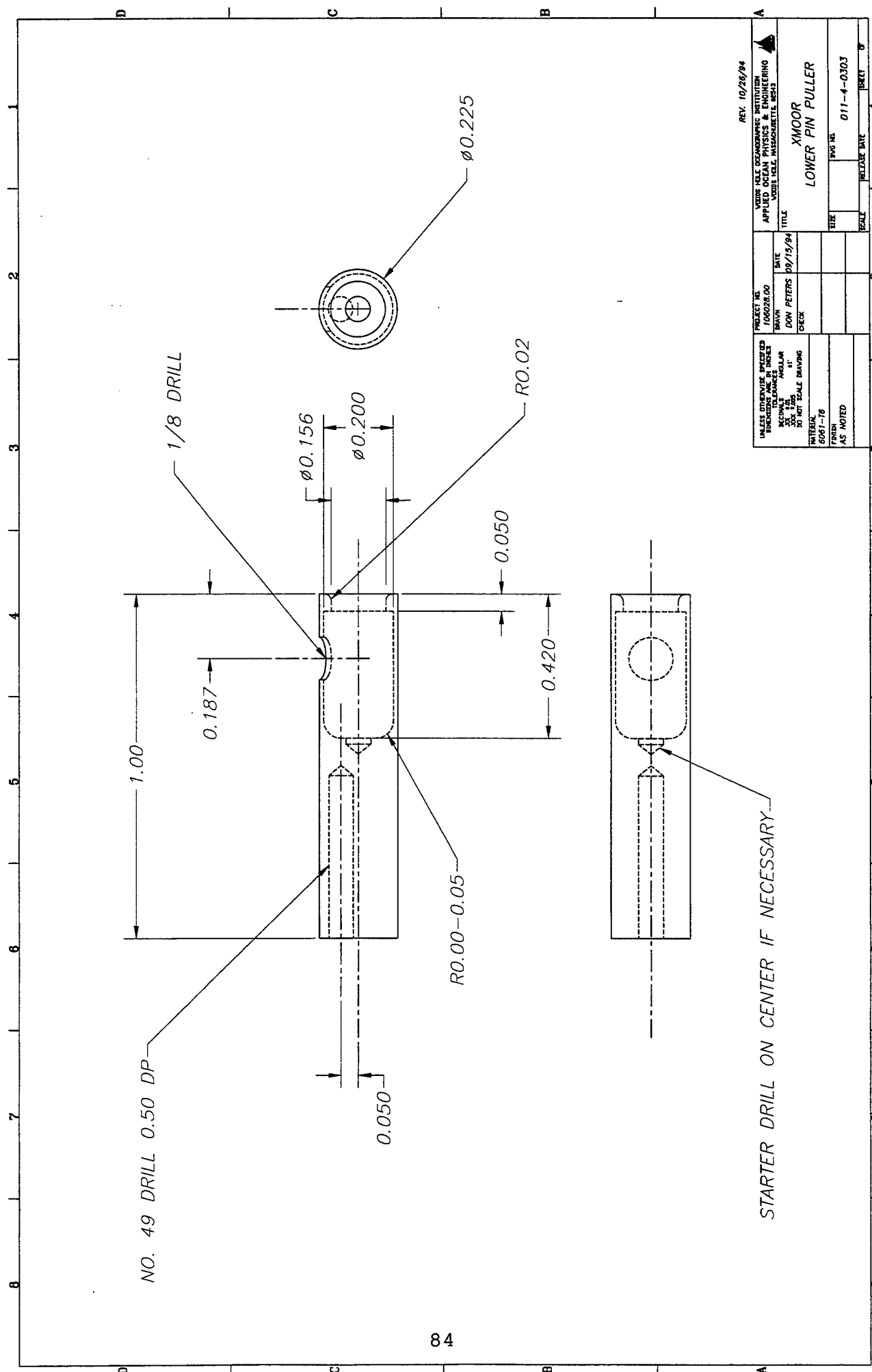
REV 11/23/94  
REV 10/26/94

UNLESS OTHERWISE SPECIFIED STANDARD TOLERANCES ARE: FRACTIONS ±0.005 DECIMALS ±0.015 ANGLES ±0.1 HOLE POSITION ±0.010 DO NOT SCALE DRAWING		PROJECT NO. 1000226.00	DATE 09/21/94	DESIGNED BY DON PETERS	CHECKED BY [ ]
APPLIED OCEAN PHYSICS & ENGINEERING 1000 N. STATE ST. WOBURN, MASSACHUSETTS 01897		TITLE RELEASE ACTUATOR RODS		SCALE [ ]	RELEASE DATE [ ]
XMOOR		DWG. NO. 011-4-0301		SHEET [ ] OF [ ]	



REV. 11/21/94  
REV. 10/26/94

PROJECT NO. 108028.00		DATE 09/21/94		TITLE XMOOR UPPER ROD END	
DRAWN BY DON PETERS		CHECKED BY 		SIZE 	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE TO 2 PLACES ANGULAR DIMENSIONS TO NEAREST 10 MINUTE FINISH TO BE AS SHOWN		MATERIAL 316 STAINLESS STEEL		SCALE 	
PROJECT NO. 108028.00		DATE 09/21/94		TITLE XMOOR UPPER ROD END	
DRAWN BY DON PETERS		CHECKED BY 		SIZE 	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE TO 2 PLACES ANGULAR DIMENSIONS TO NEAREST 10 MINUTE FINISH TO BE AS SHOWN		MATERIAL 316 STAINLESS STEEL		SCALE 	



NO. 49 DRILL 0.50 DP

1/8 DRILL

R0.00-0.05

0.050

0.420

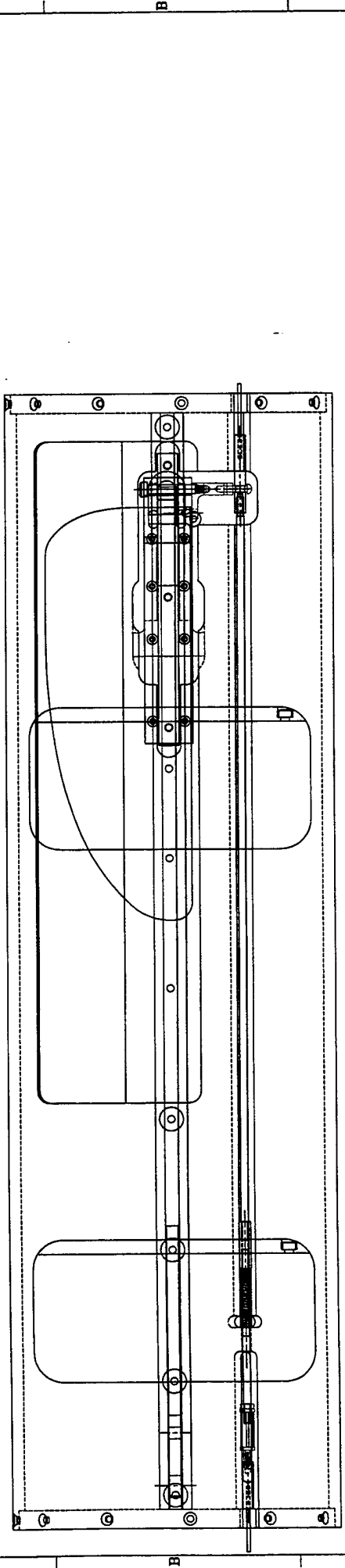
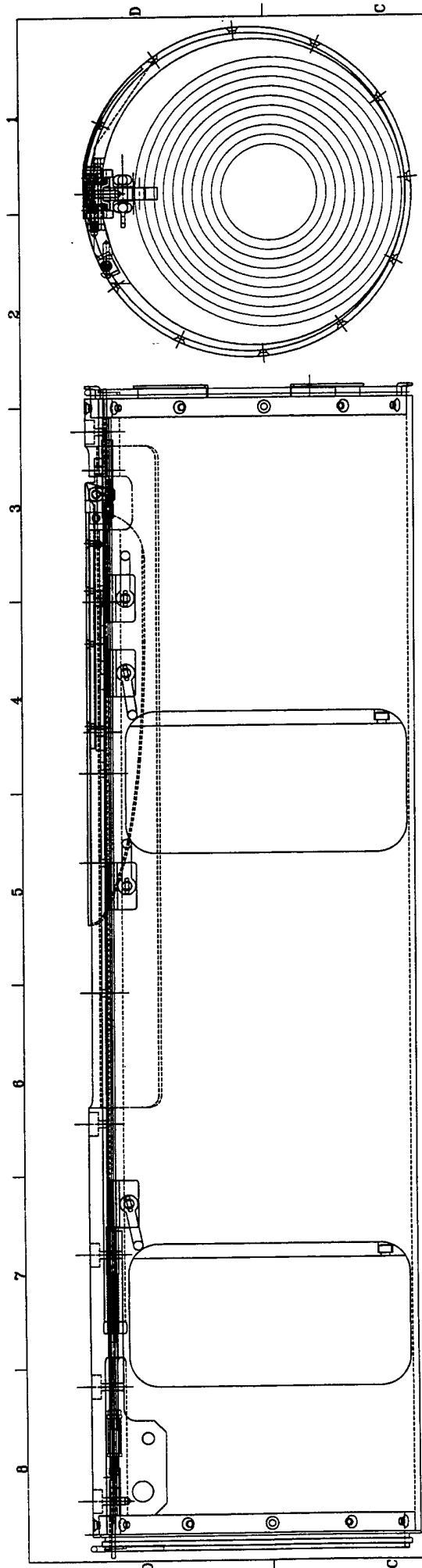
0.156

0.200

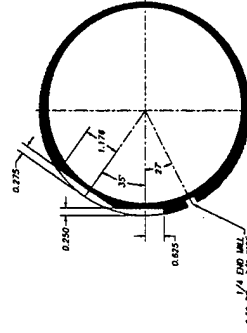
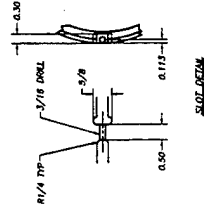
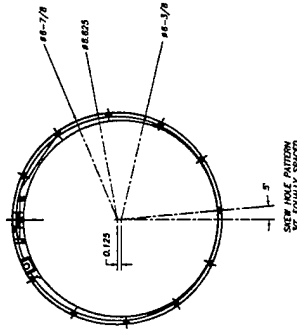
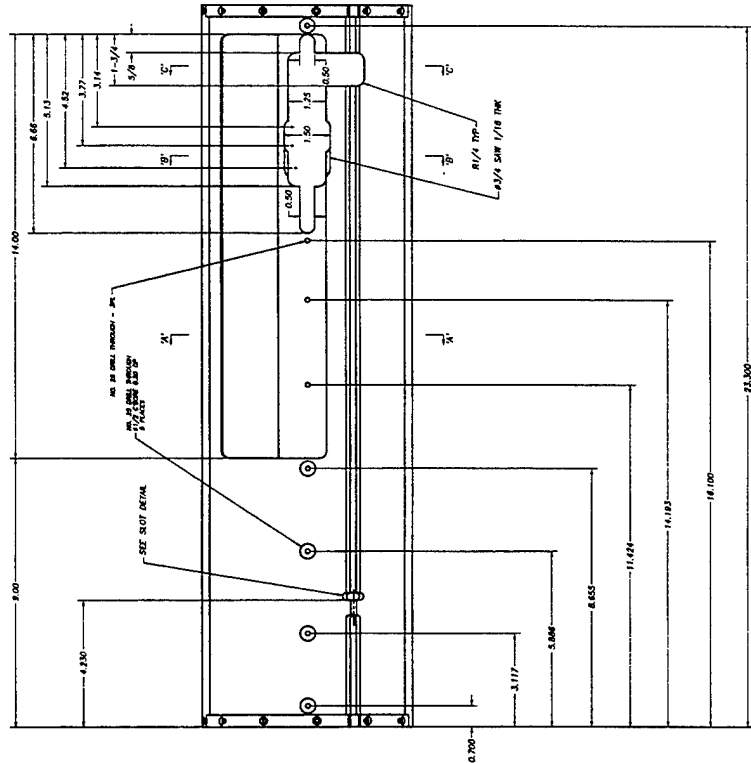
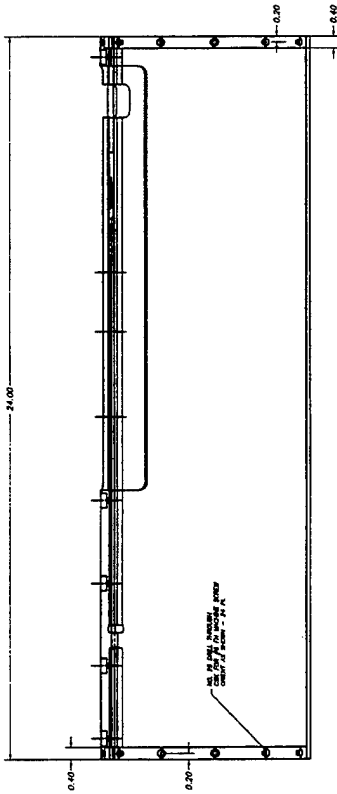
0.225

STARTER DRILL ON CENTER IF NECESSARY

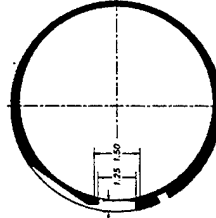
PROJECT NO. 106028.00		DATE 09/19/94		REV. 10/26/94	
DRAWN DON PETERS		CHECKED GREGG		APPROVED [Signature]	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS TO 3 PLACES FRACTIONS TO 16ths HOLE SIZES TO 1/64" DO NOT SCALE DRAWING		TITLE LOWER PIN PULLER		SCALE 1"=1"	
MATERIAL 6061-T6		FINISH AS NOTED		RELEASE DATE 011-4-0303	
8		2		1	



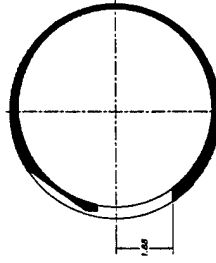
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DIMENSIONS IN PARENTHESES ARE IN MILLIMETERS ALL DIMENSIONS ARE TO CENTER UNLESS NOTED OTHERWISE DO NOT SCALE DRAWING		PROJECT NO. 106028.00	DATE 12/08/84	VOORS OILE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING VOORS HOLE, WISPOUSETTE, BESI3	
DRAWN BY DON PETERS		CHECKED BY [Blank]	TITLE XMOOR LINE CANISTER ASSEMBLY		FIG. NO. 011-4-1100
MATERIALS AS NOTED		FINISH AS NOTED		SCALE [Blank]	SHEET NO. 1



SECTION X-X'



SECTION Y-Y'



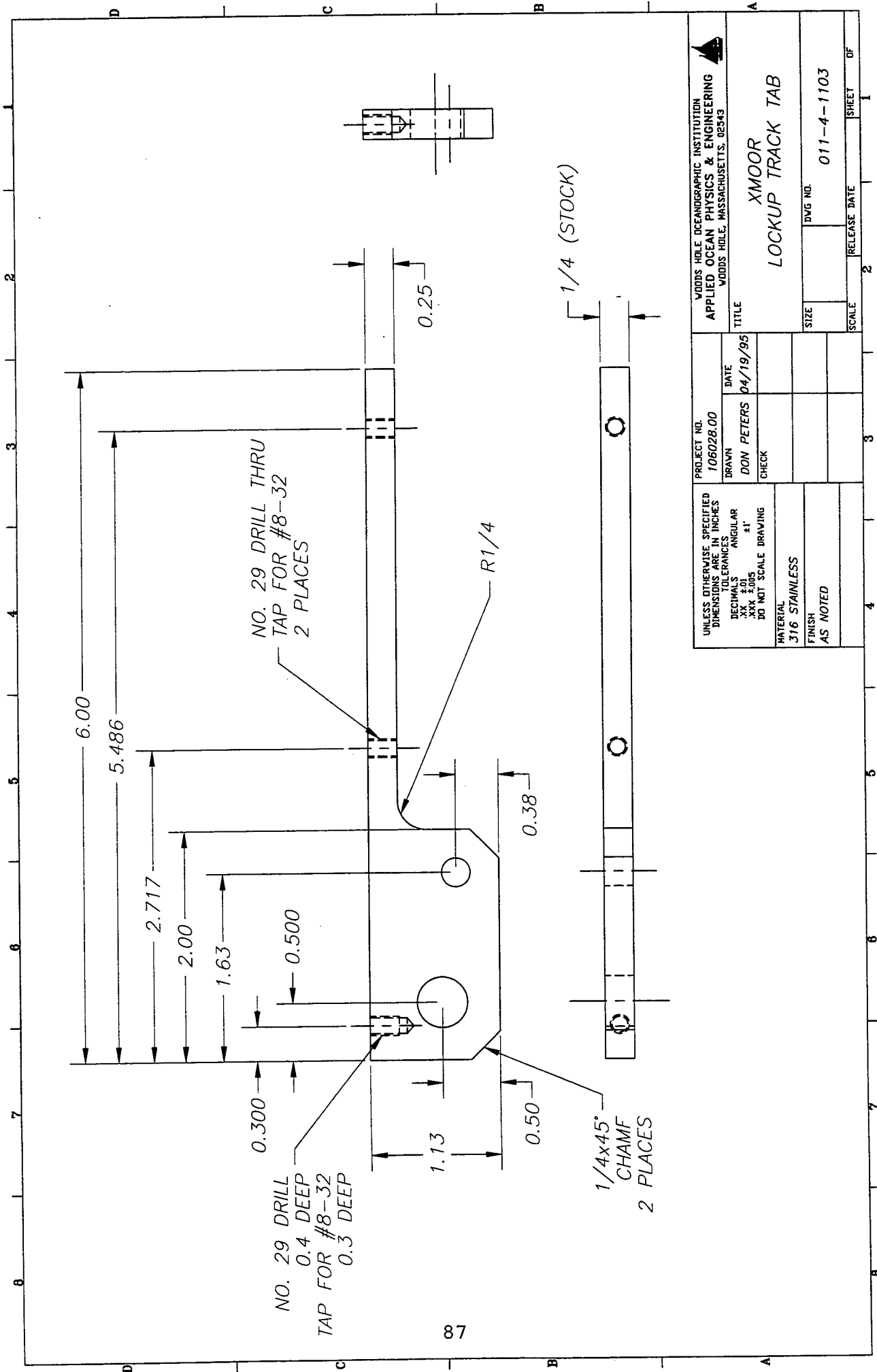
SECTION Z-Z'

ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED ARE IN INCHES AND DECIMALS THEREOF

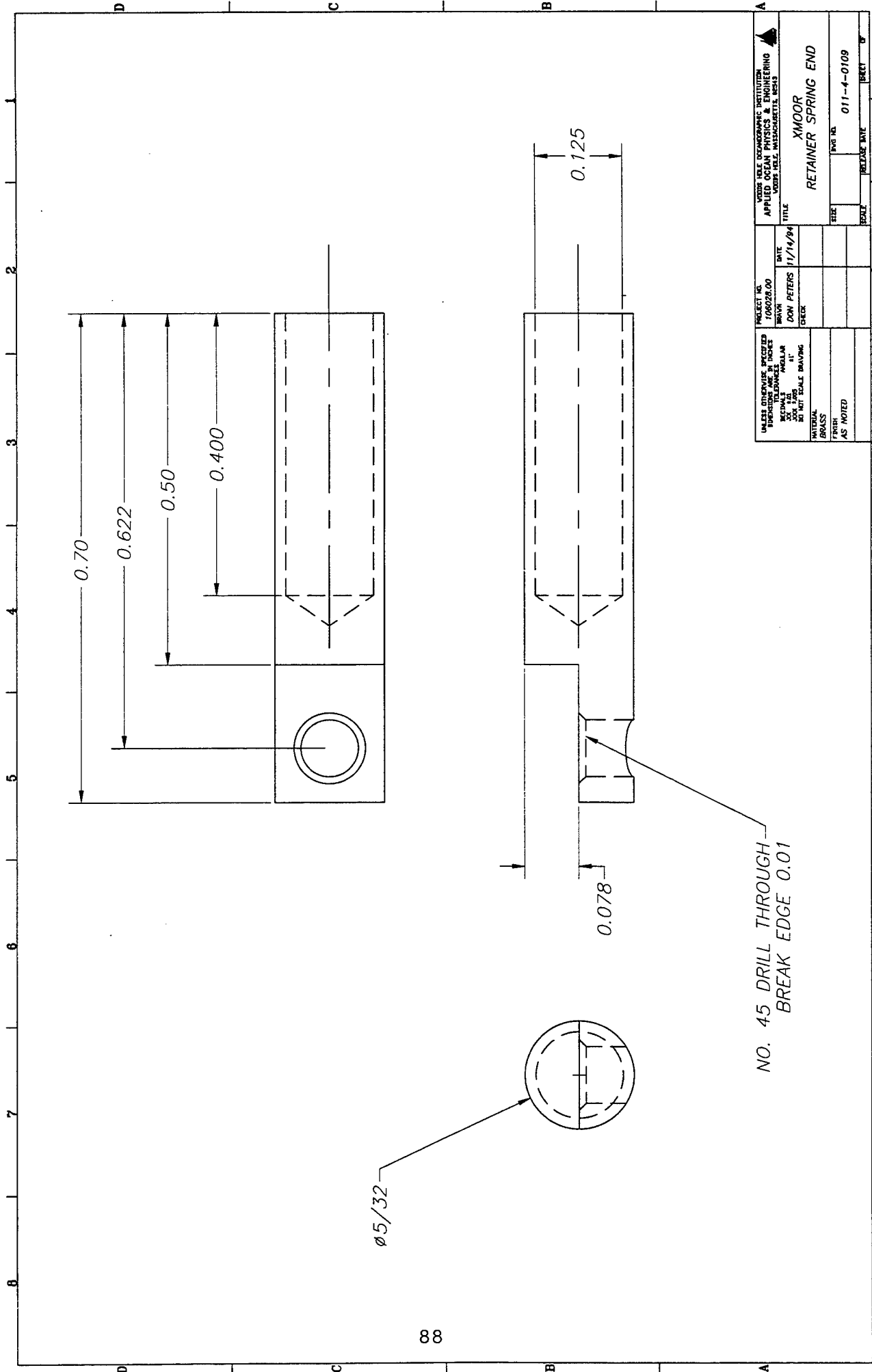
REVISED 11/21/84 MATERIAL NOTE  
 REVISED 11/21/84  
 REVISED 11/16/84  
 REVISED 08/25/84

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND DECIMALS THEREOF DIMENSIONS IN PARENTHESIS ARE FOR REFERENCE ONLY DIMENSIONS IN SQUARE BRACKETS ARE FOR INFORMATION ONLY		PROJECT NO.	DATE	APPLIED OCEAN PHYSICS & ENGINEERING VONNE HALL, WILMINGTON, DE 19383
TITLE		PROJECT NO.	DATE	
MATERIAL		DESIGNER	DATE	XMOOR LINE CANISTER MAIN TUBE
FINISH		CHECKER	DATE	
TOLERANCE		SCALE	RELEASE DATE	011-4-1101
SURFACE		SCALE	RELEASE DATE	



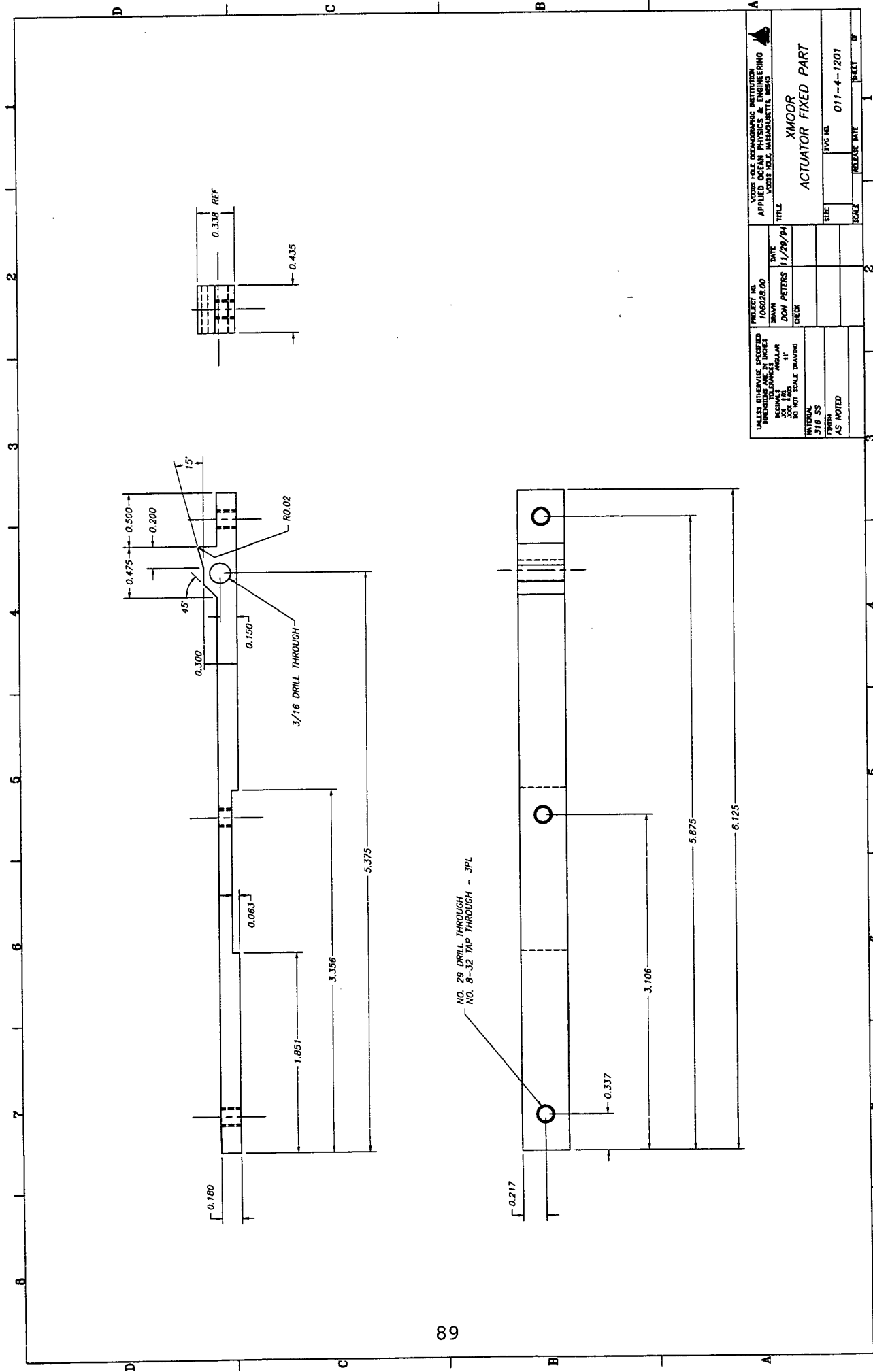


WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, 02543		PROJECT NO. 706028.00		TITLE LOCKUP TRACK TAB	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES DECIMALS ANGULAR .XX ± .005 ±1° DO NOT SCALE DRAWING		DRAWN DON PETERS	DATE 04/19/95	SIZE DVG NO.	SCALE 011-4-1103
MATERIAL 316 STAINLESS		CHECK	RELEASE DATE	SHEET	OF
FINISH AS NOTED		1	2	3	4

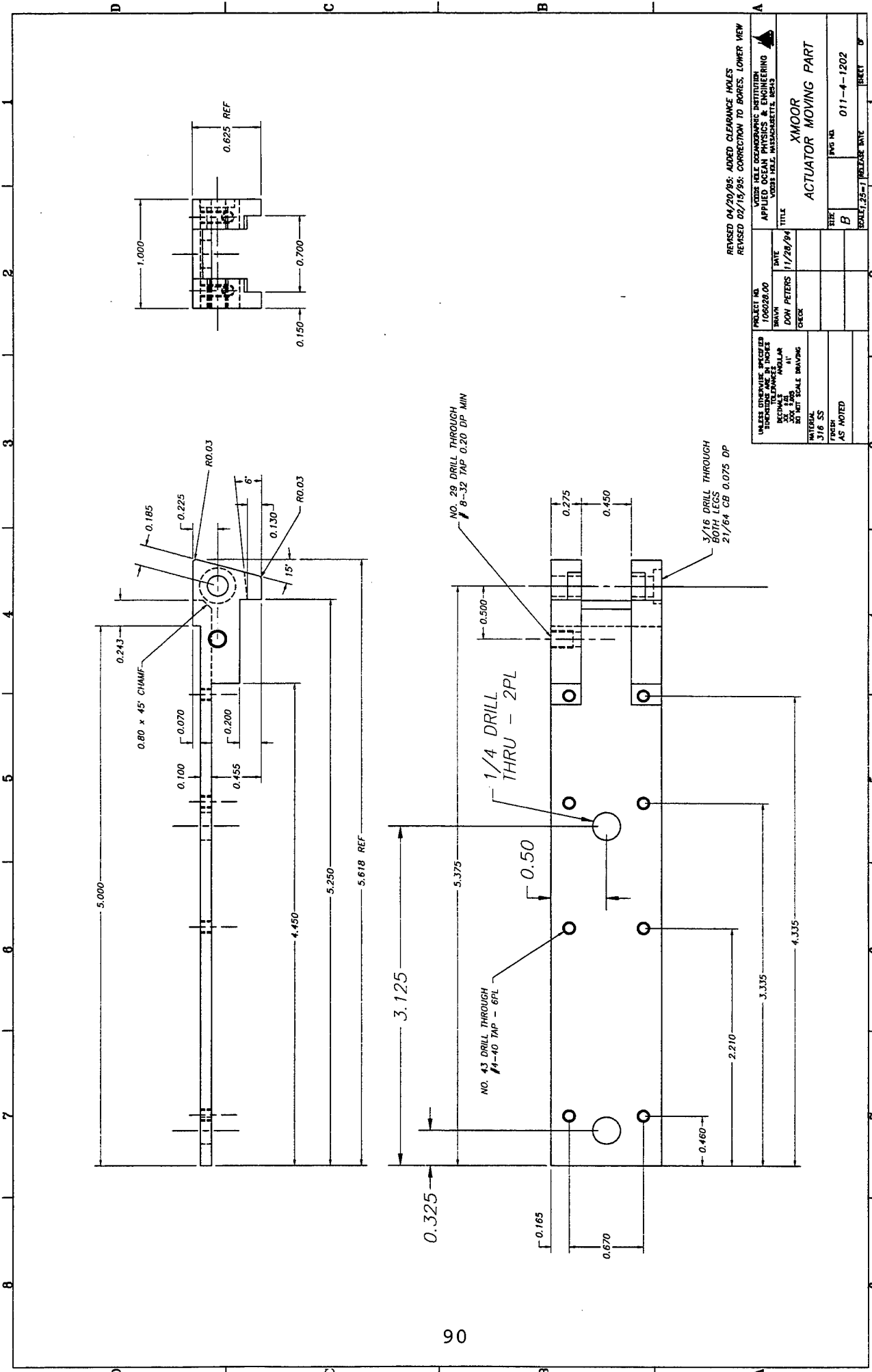


UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE TO BE ANGULAR DIMENSIONS UNLESS NOTED DO NOT SCALE DRAWING		PROJECT NO. 706028.00	APPLIED OCEAN PHYSICS & ENGINEERING 1000 W. HILL, WASHINGTON, D.C.
MATERIAL BRASS	DATE 11/14/94	DESIGNER DON PETERS	TITLE XMOOR RETAINER SPRING END
FINISH AS NOTED	CHECK	SIZE 1/8" X 1/4"	SCALE 1:1
		FIG. NO. 011-4-0109	RELEASE DATE 1994
			SHEET OF

NO. 45 DRILL THROUGH  
BREAK EDGE 0.01

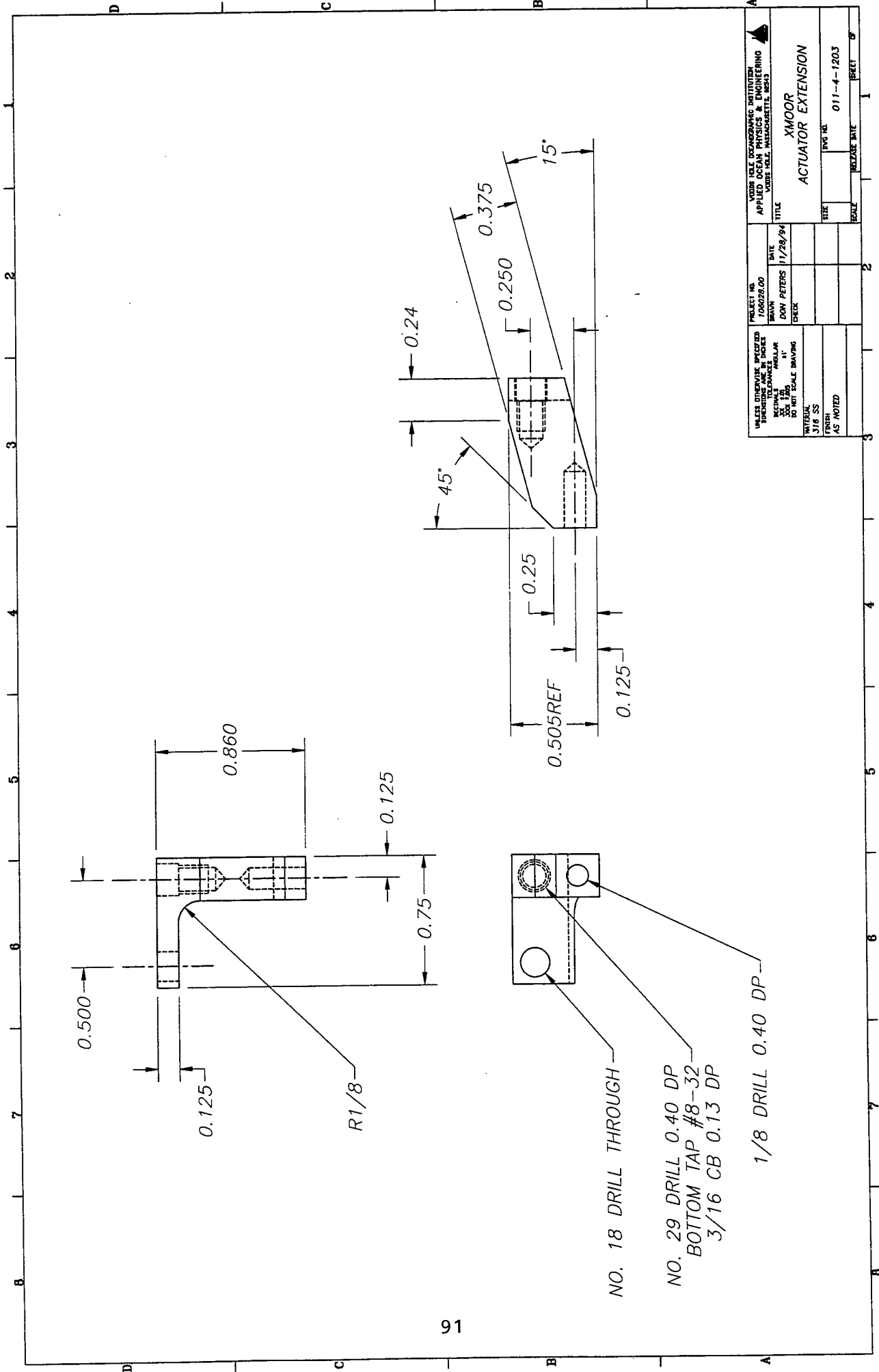


VOIDS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING VOIDS HOLE, MASSACHUSETTS 02533		PROJECT NO. 106028.00	DATE 11/20/94	TITLE XMOOR ACTUATOR FIXED PART	SIZE 011-4-1201
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE TO THE NEAREST 10 THOUSITHS DIMENSIONS ARE NOT TO SCALE UNLESS OTHERWISE NOTED		DRAWN BY DON PETERS	CHECKED BY DON PETERS	SCALE 1:1	SHEET 1 OF 1
MATERIAL 316 SS		FROM AS NOTED		RELEASE DATE 011-4-1201	SHEET 1 OF 1

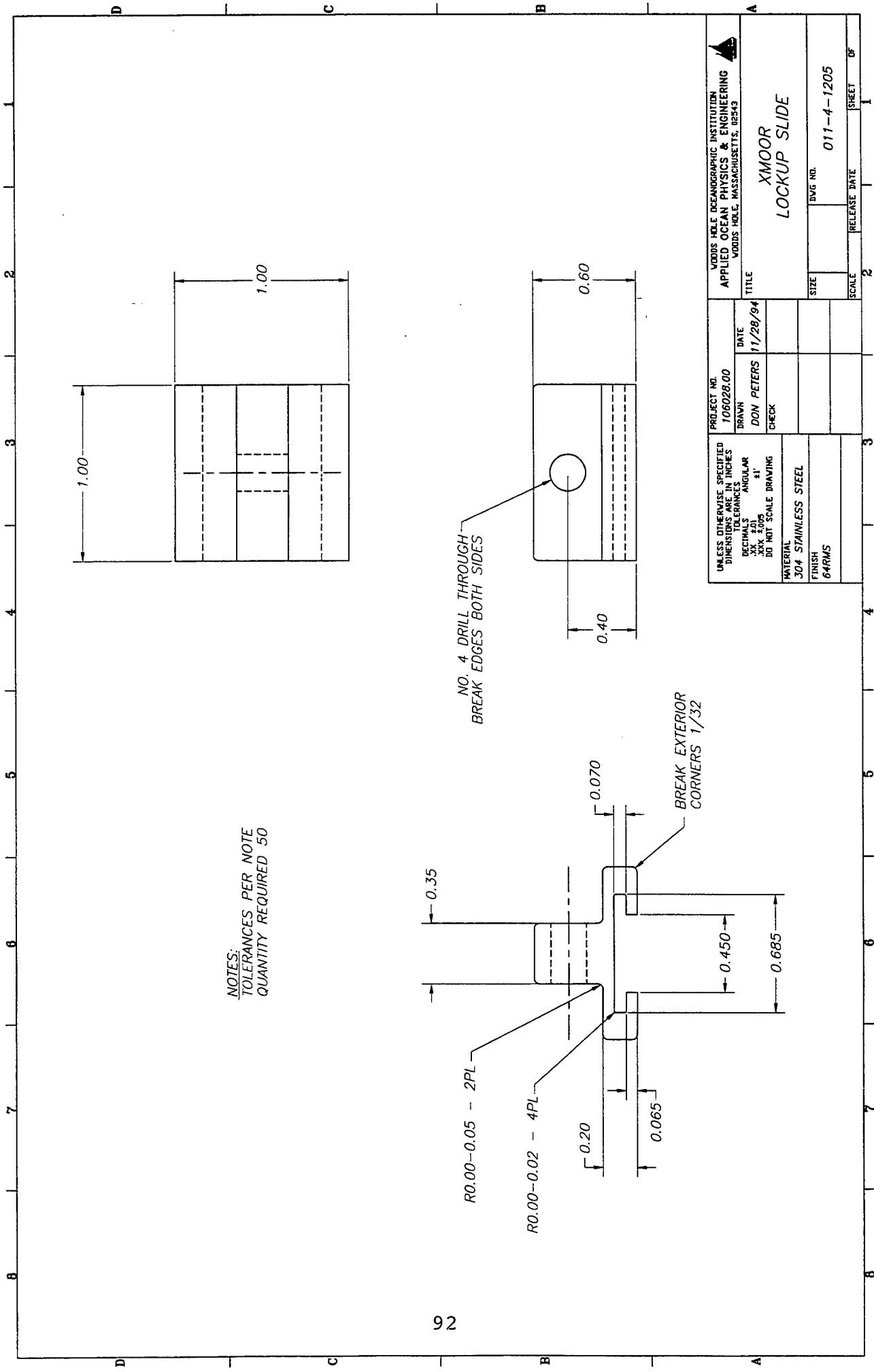


REVISED 04/20/85: ADDED CLEARANCE HOLES  
 REVISED 02/18/85: CORRECTION TO BORES, LOWER VIEW

XMOOR ACTUATOR MOVING PART	
PROJECT NO.	DATE
100220.00	1/7/28/94
DESIGNED BY	CHECK
DON PETERS	
UNLESS OTHERWISE SPECIFIED	
DIMENSIONS IN INCHES	
TOLERANCES	
FINISH	AS NOTED
MATERIAL	
316 SS	
TITLE XMOOR ACTUATOR MOVING PART	
FIG. NO.	011-4-1202
REV.	
DATE	



YOUR TITLE OCEANOGRAPH INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING YOUR HELL INDIANORETTS, MASS		PROJECT NO. 106028.00		DATE 11/28/84	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE TO THE SECOND UNLESS NOTED DO NOT SCALE DRAWING		DRAWN DON PETERS		CHECK	
MATERIAL 316 SS		FINISH AS NOTED		TITLE ACTUATOR EXTENSION	
SCALE 011-4-1203		SHEET NO. 1		OF 1	



NOTES:  
TOLERANCES PER NOTE  
QUANTITY REQUIRED 50

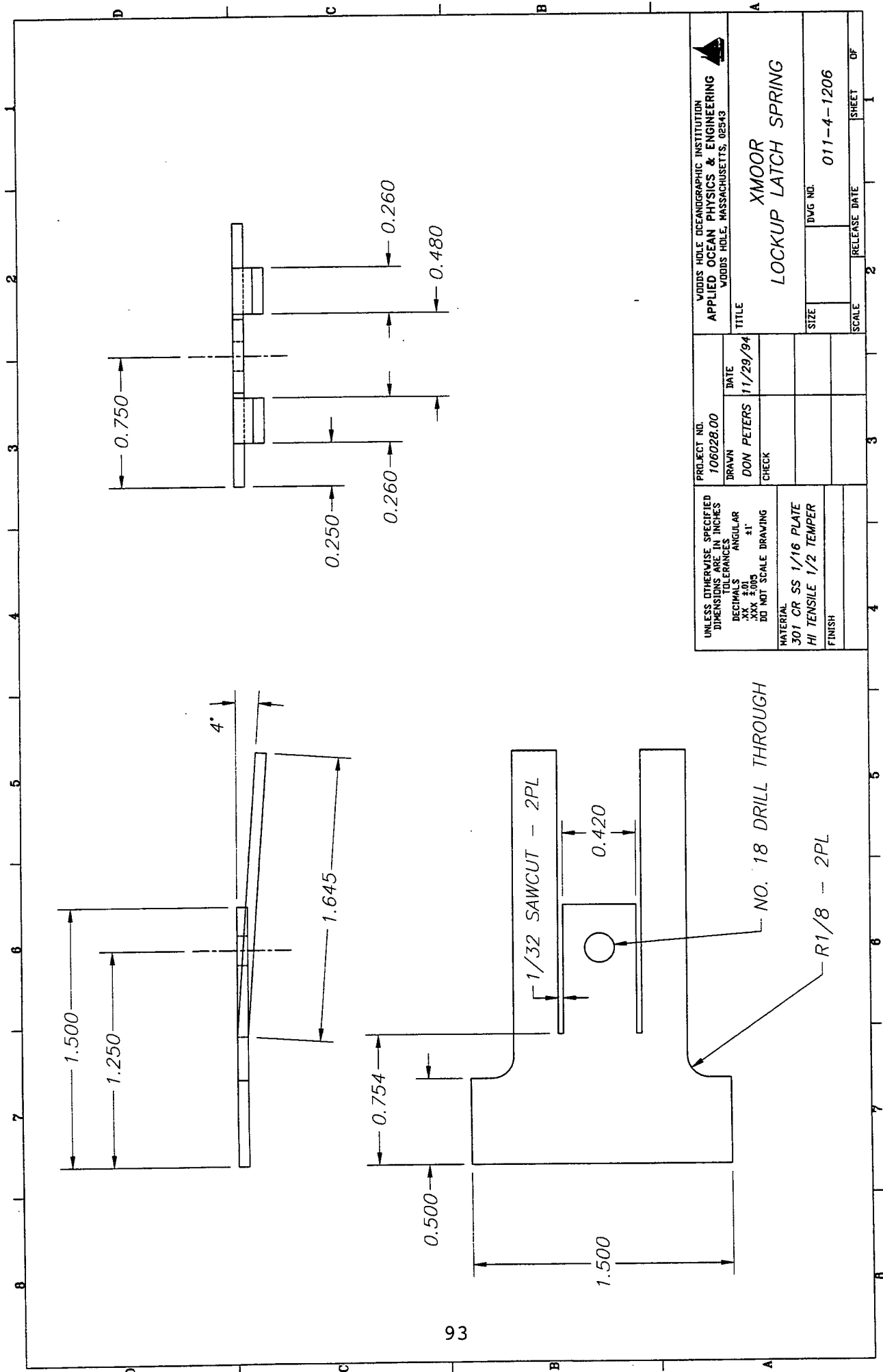
NO. 4 DRILL THROUGH  
BREAK EDGES BOTH SIDES

R0.00-0.05 - 2PL

R0.00-0.02 - 4PL

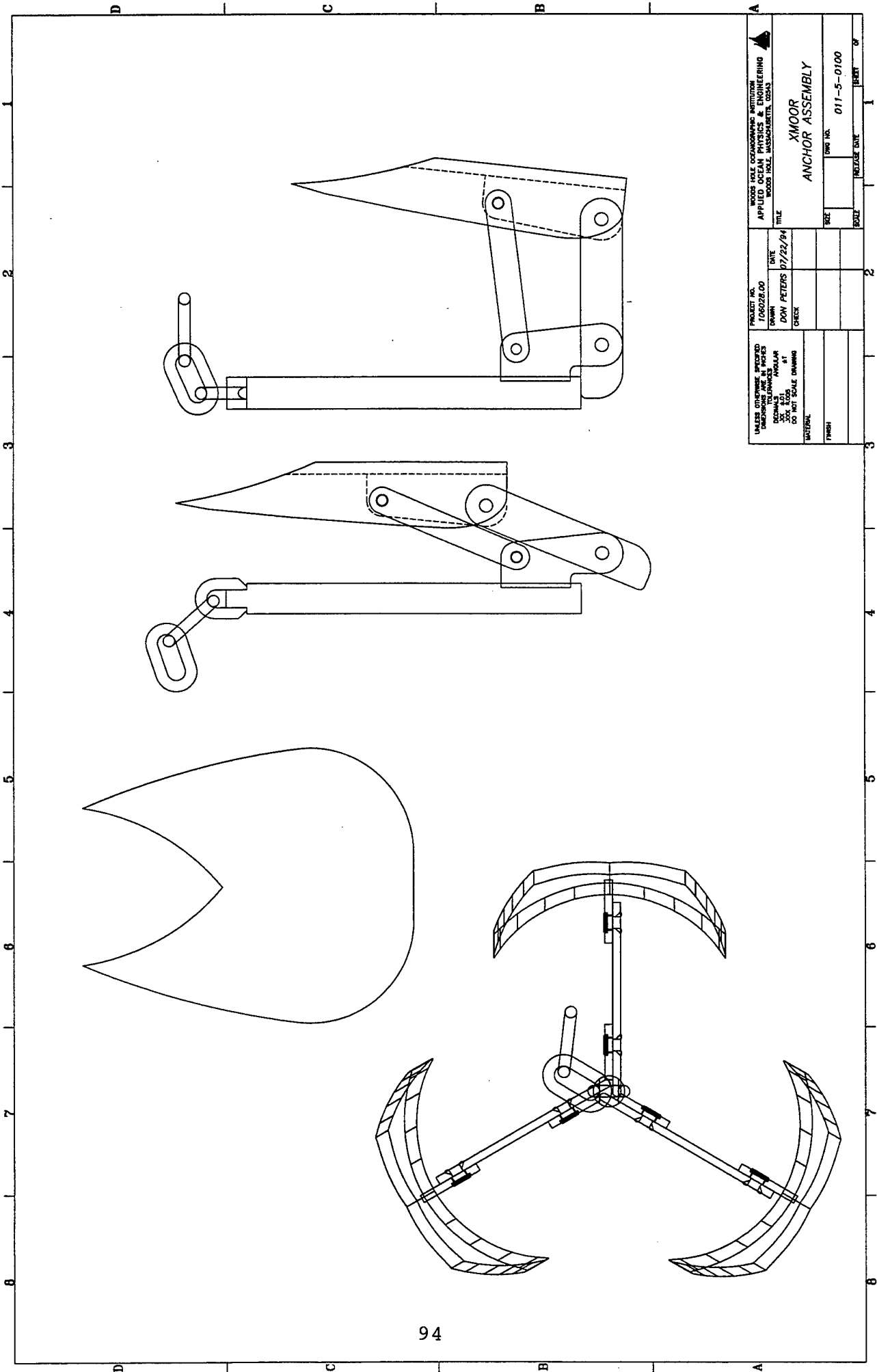
BREAK EXTERIOR  
CORNERS 1/32

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ANGULAR XXX 1/16 1/8 1/4 1/2 1 DO NOT SCALE DRAWING		PROJECT NO. 106028.00	WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, 02543	
MATERIAL 304 STAINLESS STEEL		DATE 11/28/94	TITLE XMOOR LOCKUP SLIDE	
FINISH 64RMS		DRAWN DON PETERS	SIZE	DWG NO. 011-4-1205
		CHECK	SCALE	RELEASE DATE
			SHEET	OF
			2	1



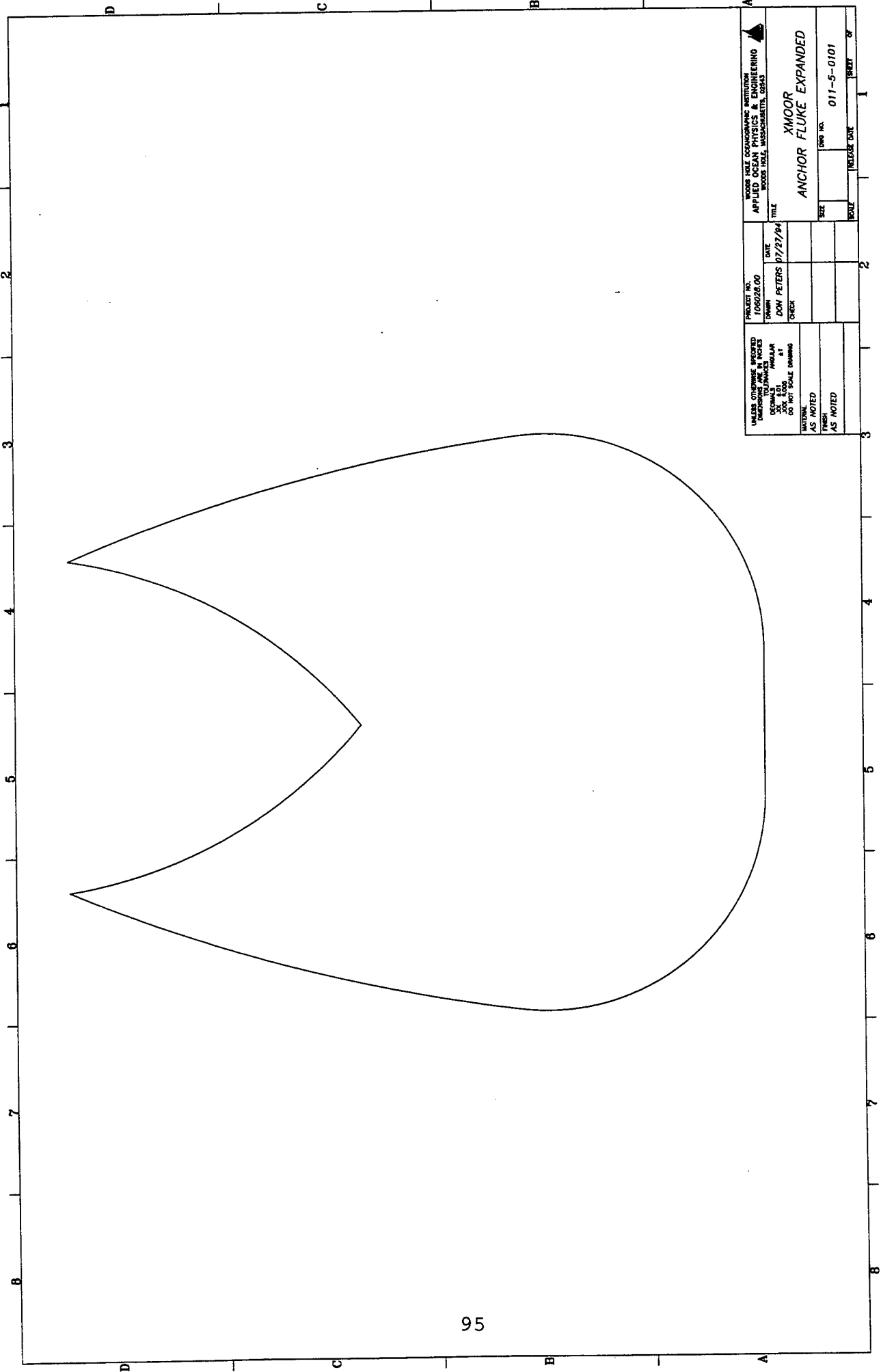
93

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES DECIMALS ±.01 ANGULAR ±1° FINISH AS SHOWN DO NOT SCALE DRAWING		PROJECT NO. 706028.00	DATE 11/29/94	WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, 02543
DRAWN DON PETERS	CHECK	TITLE LOCKUP LATCH SPRING	SIZE DVG NO. 011-4-1206	XMOOR LOCKUP LATCH SPRING
SCALE	RELEASE DATE	SCALE	SHEET 1 OF 1	

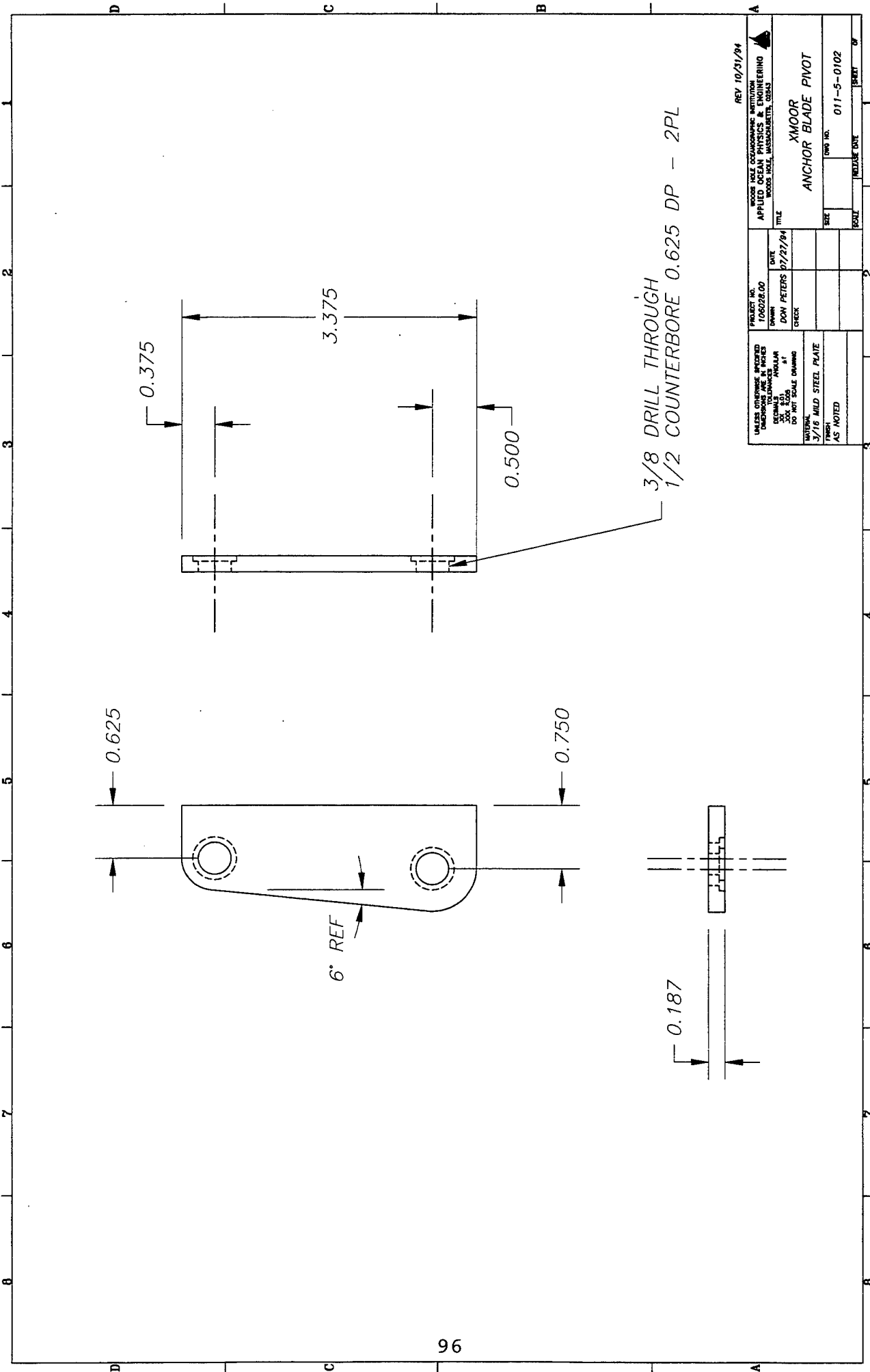


WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, 02543		PROJECT NO. 106028.00		DATE 07/22/94	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES FRACTIONS DECIMALS ANGLES 1/16 1/32 1/64 1/8 1/4 3/8 1/2 DO NOT SCALE DRAWING		DRAWN DON PETERS		CHECK	
TITLE XMOOR ANCHOR ASSEMBLY		SIZE		SCALE	
MATERIAL		DRAWING NO.		RELEASE DATE	
FINISH		011-5-0100		SHEET 1 OF 1	



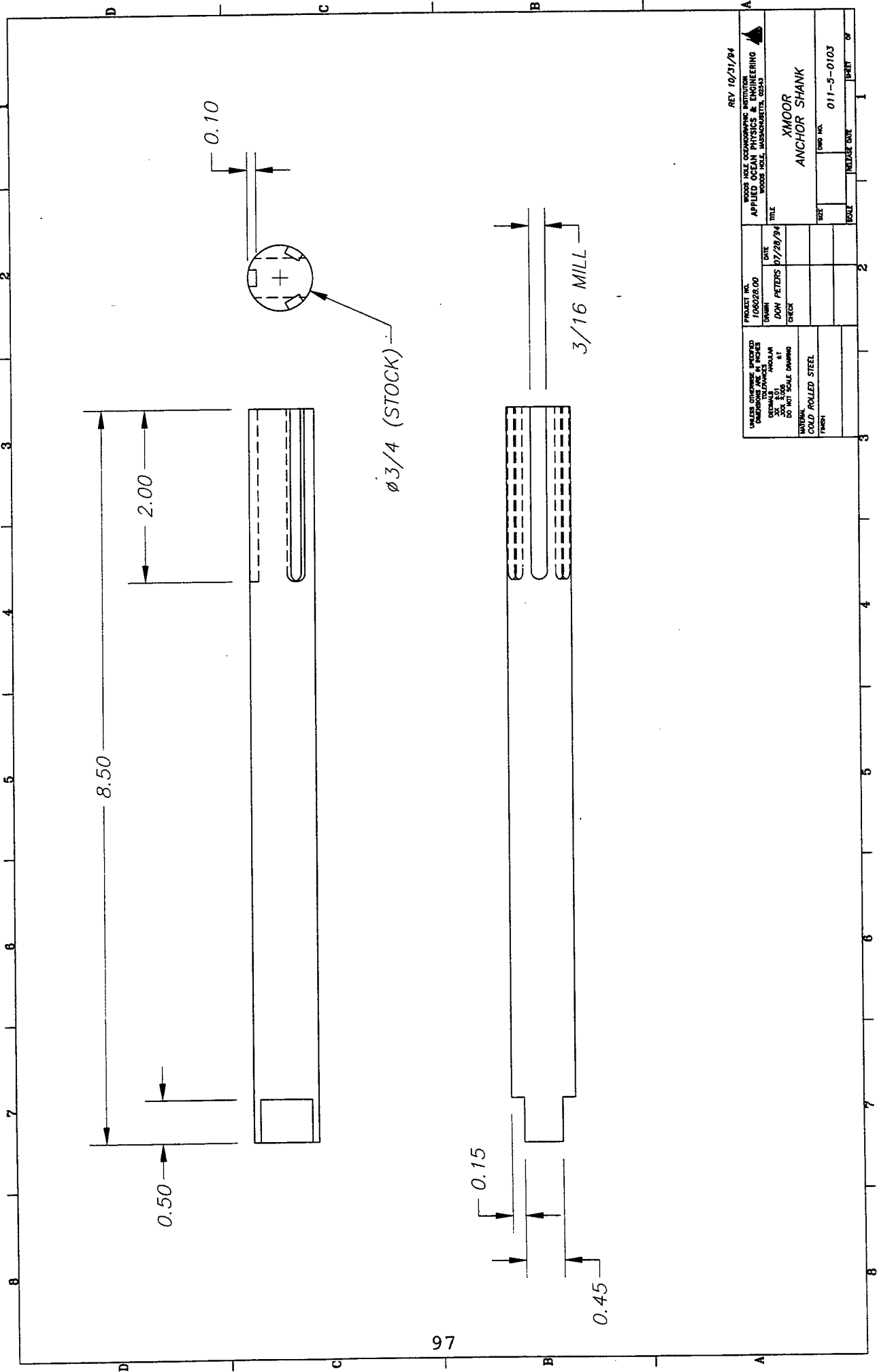


UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS AND FRACTIONS SHALL BE TO THE NEAREST 1/32" AND 1/16" RESPECTIVELY DO NOT SCALE DRAWINGS		PROJECT NO. 100222.00	DATE 07/27/94	TITLE ANCHOR FLUKE EXPANDED	SHEET 1
MATERIAL AS NOTED		CHECKER DON PETERS	DATE 07/27/94	TITLE ANCHOR FLUKE EXPANDED	SHEET OF 1
FINISH AS NOTED		PROJECT NO. 100222.00	DATE 07/27/94	TITLE ANCHOR FLUKE EXPANDED	SHEET OF 1
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS AND FRACTIONS SHALL BE TO THE NEAREST 1/32" AND 1/16" RESPECTIVELY DO NOT SCALE DRAWINGS		PROJECT NO. 100222.00	DATE 07/27/94	TITLE ANCHOR FLUKE EXPANDED	SHEET OF 1



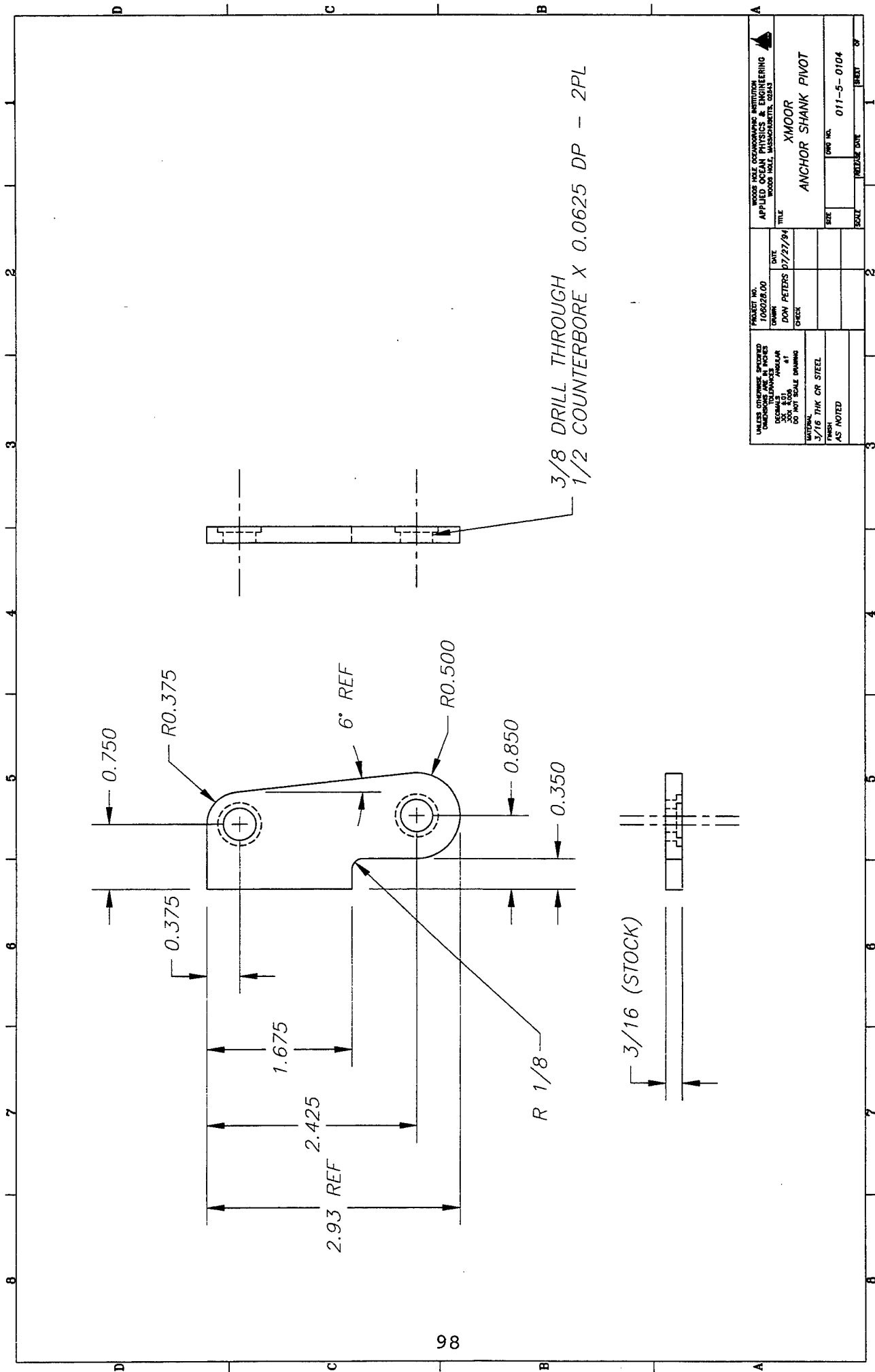
REV 10/31/94

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE TO BE ROUNDED UP 300:1.000 1:1 DO NOT SCALE DRAWING		PROJECT NO. 106022.00	DATE 07/27/94	WMOOR XMOOR
APPLIED OCEAN PHYSICS & ENGINEERING 2005 STEEL INDUSTRIES, SEAS		DRAWN DON PETERS	CHECK DON PETERS	TITLE ANCHOR BLADE PIVOT
MATERIAL 3/16 MILD STEEL PLATE		FINISH AS NOTED		SIZE 011-5-0102
REV 10/31/94		DATE		SCALE
PROJECT NO.		DATE		REVISION
DRAWN		CHECK		BY
MATERIAL		FINISH		DATE
MATERIAL		FINISH		DATE

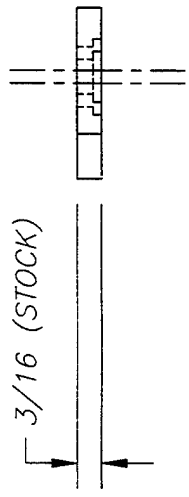


REV 10/31/84

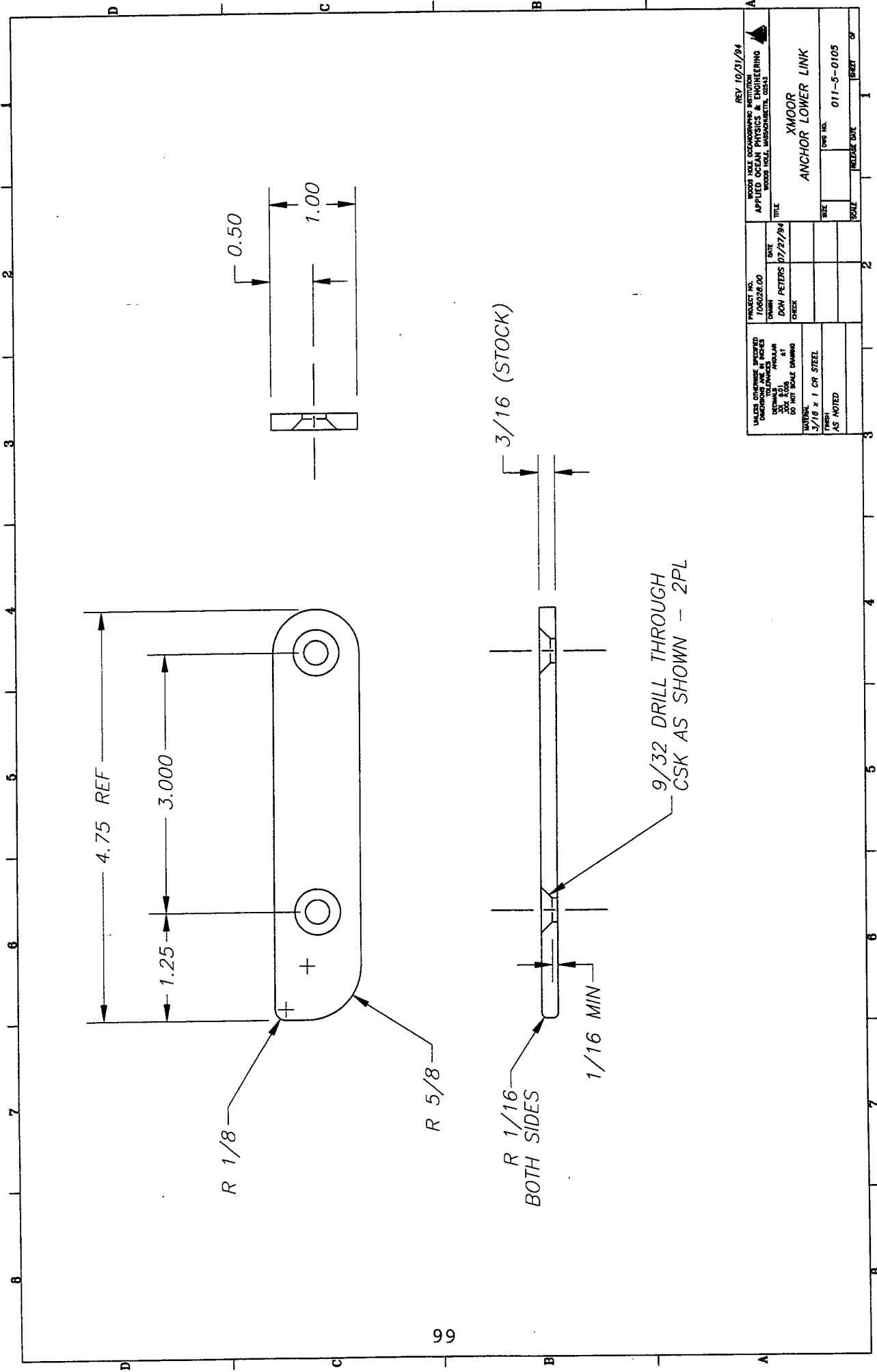
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE ROUNDED UP DO NOT SCALE DRAWING MATERIAL COLD ROLLED STEEL FINISH		PROJECT NO. 1000200.00	DATE 07/20/94	TITLE ANCHOR SHANK
WOOD JOLE OF ARCHITECTS & ENGINEERING 1000 N. STATE ST. SUITE 200 WOODVILLE, MASSACHUSETTS 02553		DRAWN DON PETERS	CHECK DON PETERS	SIZE 1/8" x 1/2"
XMOOR ANCHOR SHANK		SHEET NO. 011-5-0103	RELEASE DATE	SHEET OF 1



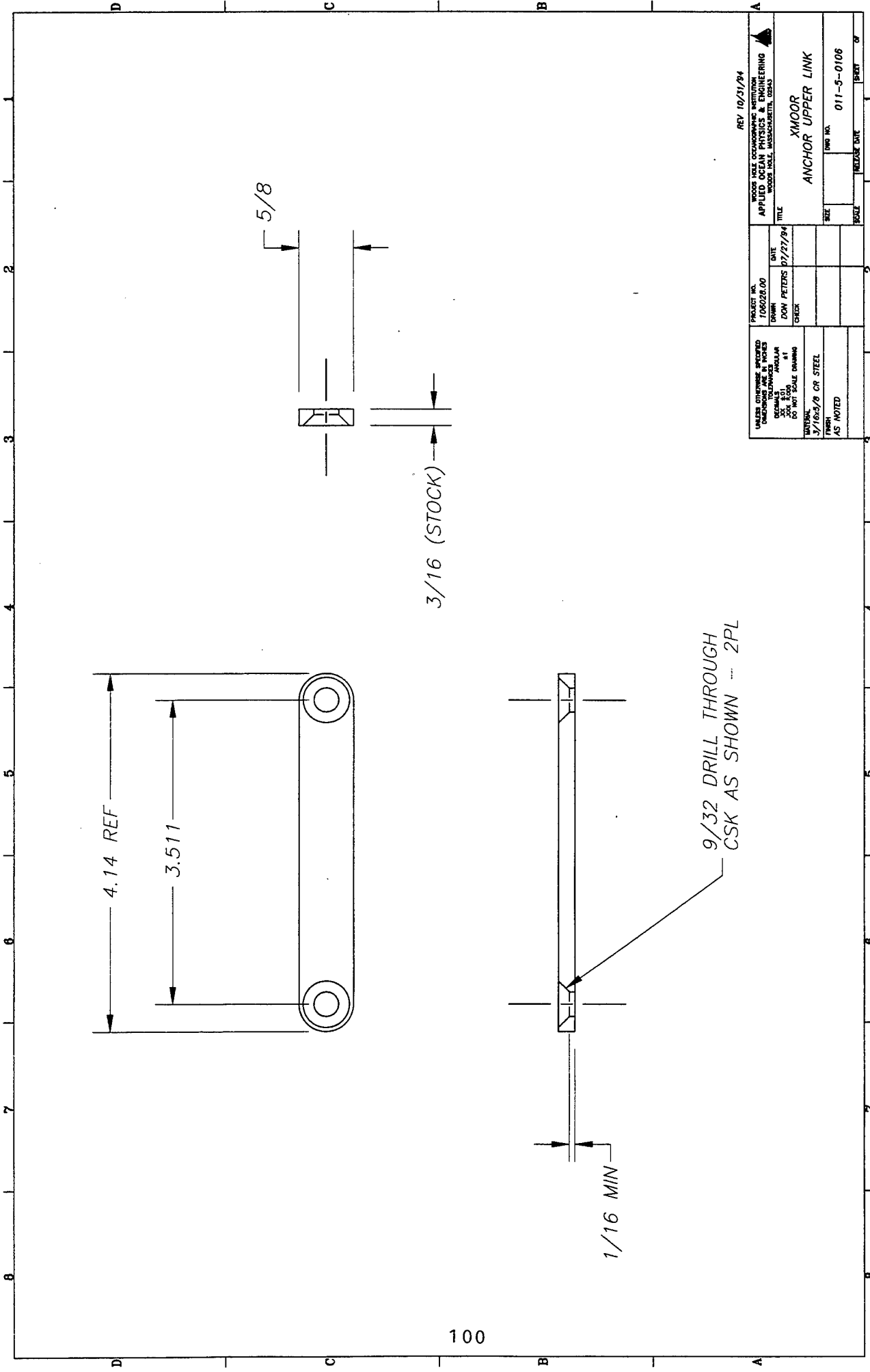
3/8 DRILL THROUGH  
1/2 COUNTERBORE X 0.0625 DP - 2PL



UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE IN THOUSANDS ANGULAR DIMENSIONS ARE IN DEGREES DIMENSIONS ARE TO BE SHOWN AS NOTED DO NOT SCALE DRAWINGS MATERIAL: 3/16 THK CR STEEL FINISH: POLISHED AS NOTED		PROJECT NO. 10020200 DRAWN BY DON PETERS 07/27/94 CHECK	APPROVED BY DON PETERS DATE 07/27/94 TITLE ANCHOR SHANK PIVOT	XMOOR ANCHOR SHANK PIVOT SIZE 011-5-0104 SCALE 1:1 SHEET NO. 1 OF 1
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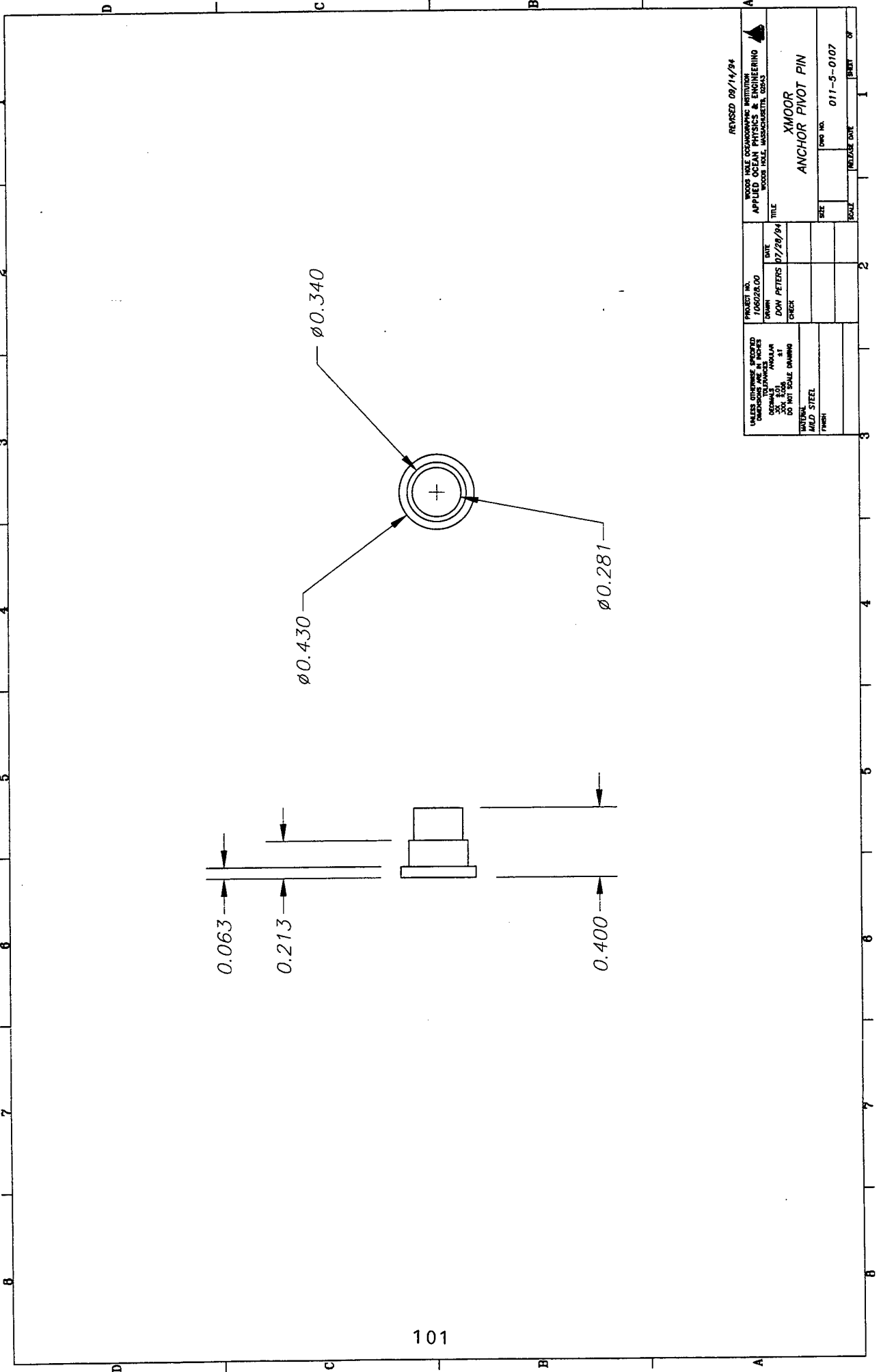
WOODS HOLE OCCUPANCY INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, USGS			REV 10/31/94	
PROJECT NO.	DATE	TITLE	SIZE	SCALE
1060268.00	07/27/94	ANCHOR LOWER LINK	DWG NO. 011-5-0105	REDUCE DATE
DESIGNED BY	CHECK	DATE	SCALE	SHEET
DON PETERS				OF
UNITS: DIMENSIONS IN MILLIMETERS DIMENSIONS ARE IN INCHES TOLERANCES 0.015 (1/16) FRACTIONS 0.025 (1/32) DECIMALS DO NOT SCALE DRAWING				
MATERIAL 3/16 x 1 CR STEEL				
FINISH AS NOTED				



100

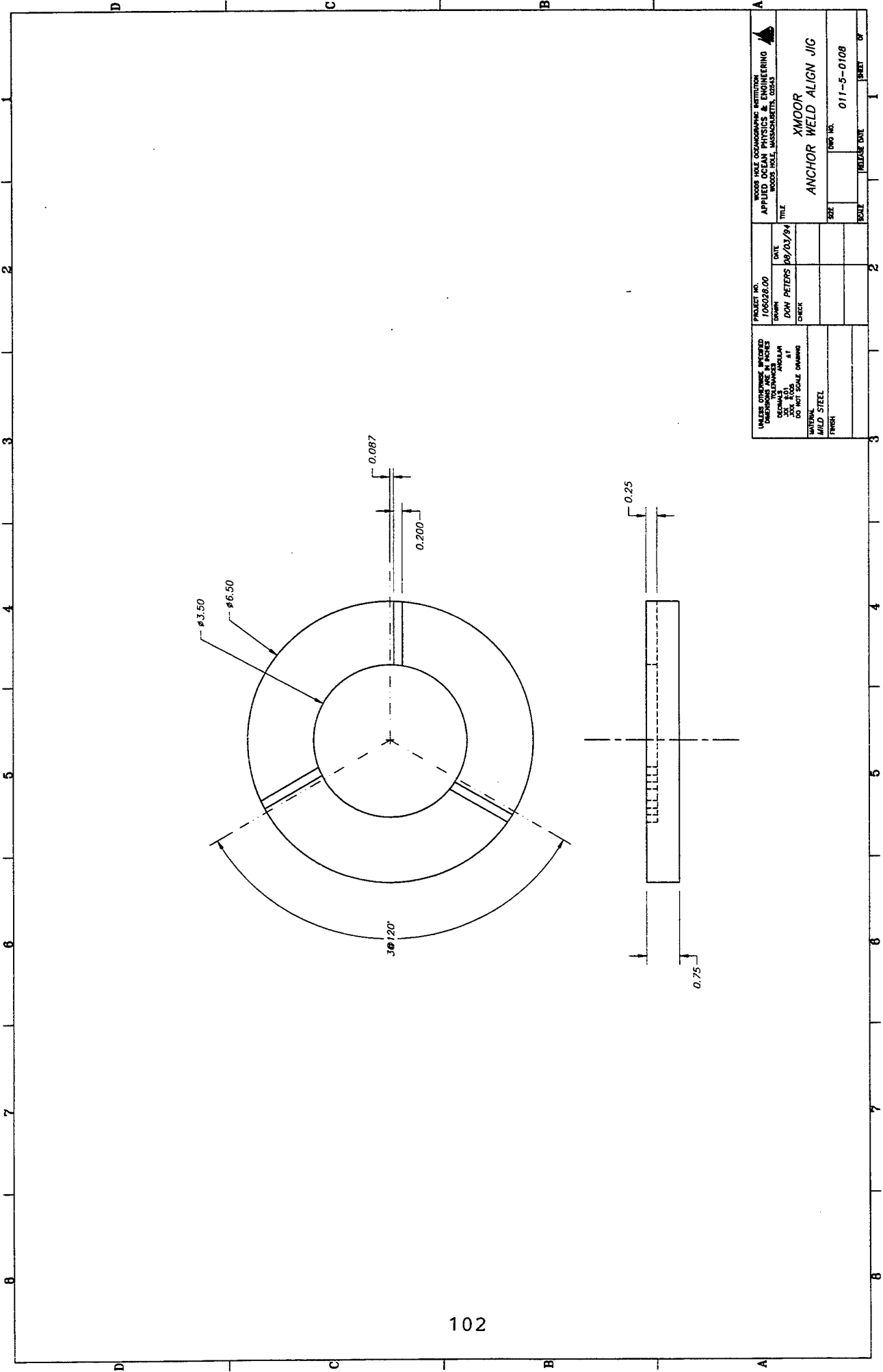
REV 10/31/94

WOOD HOLE OCCUPANCY INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, USA		PROJECT NO. 106026.00		DATE 07/27/94	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS FRACTIONS .001 .000 .01 DO NOT SCALE DRAWING		DRAWN DON PETERS		CHECK	
MATERIAL 316L/304 CR STEEL		FINISH AS NOTED		TITLE XMOOR ANCHOR UPPER LINK	
SCALE 1:1		SHEET NO. 011-5-0106		SHEET OF 09	



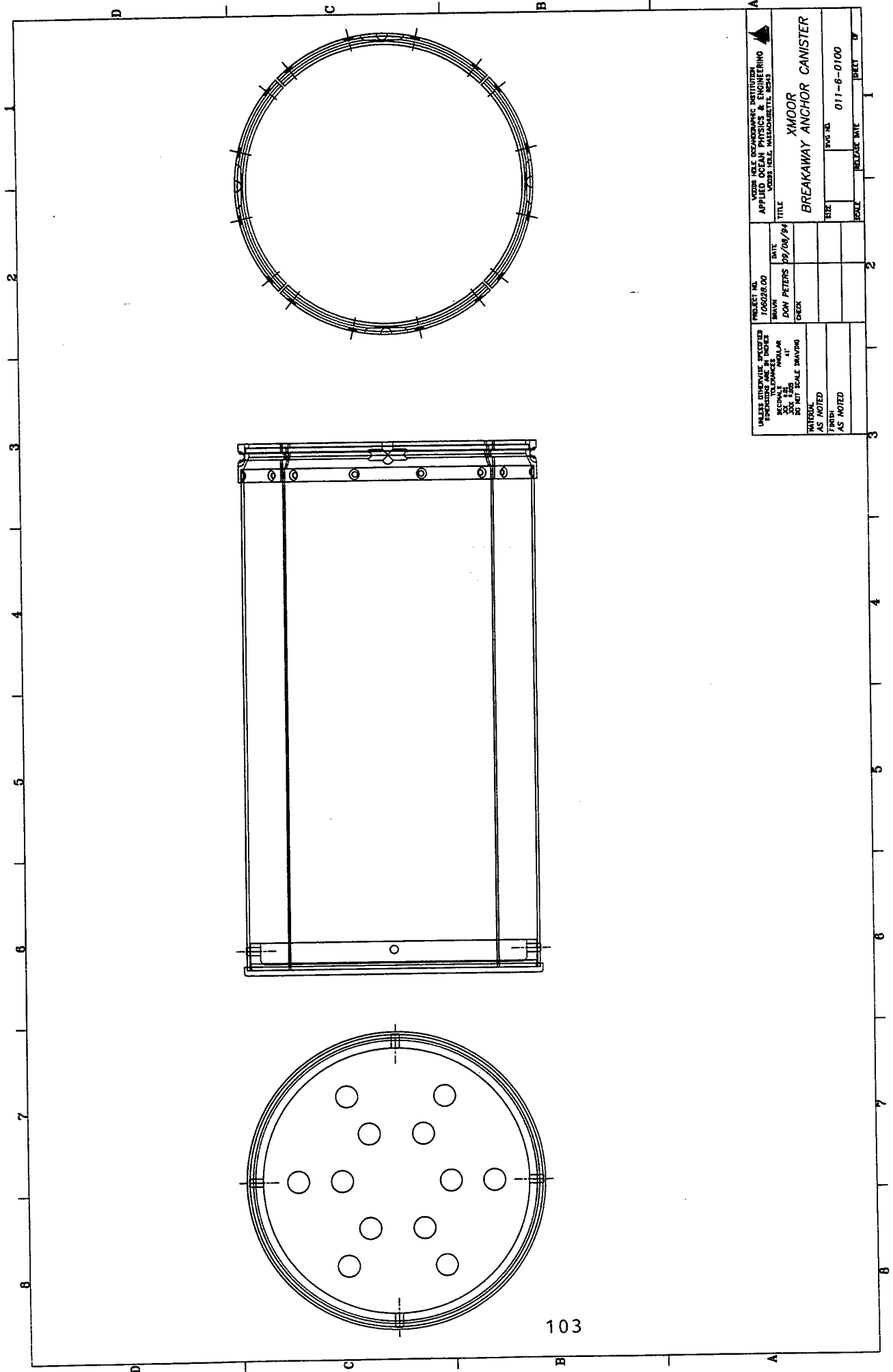
REVISED 08/14/94

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TO 3 DECIMALS ANGULAR DIMENSIONS ARE IN DEGREES TO NEAREST WHOLE NUMBER MATERIAL: MILD STEEL FINISH:		PROJECT NO. 110022400	DATE 07/28/94	DESIGNED BY DON PETERS	CHECKED BY	SCALE	SHEET 1 OF 1
APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, 02543		DESIGNED BY DON PETERS	DATE 07/28/94	TITLE ANCHOR PIVOT PIN		SEE	REVISE DATE
APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, 02543		DESIGNED BY DON PETERS	DATE 07/28/94	TITLE ANCHOR PIVOT PIN		SEE	REVISE DATE
APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, 02543		DESIGNED BY DON PETERS	DATE 07/28/94	TITLE ANCHOR PIVOT PIN		SEE	REVISE DATE

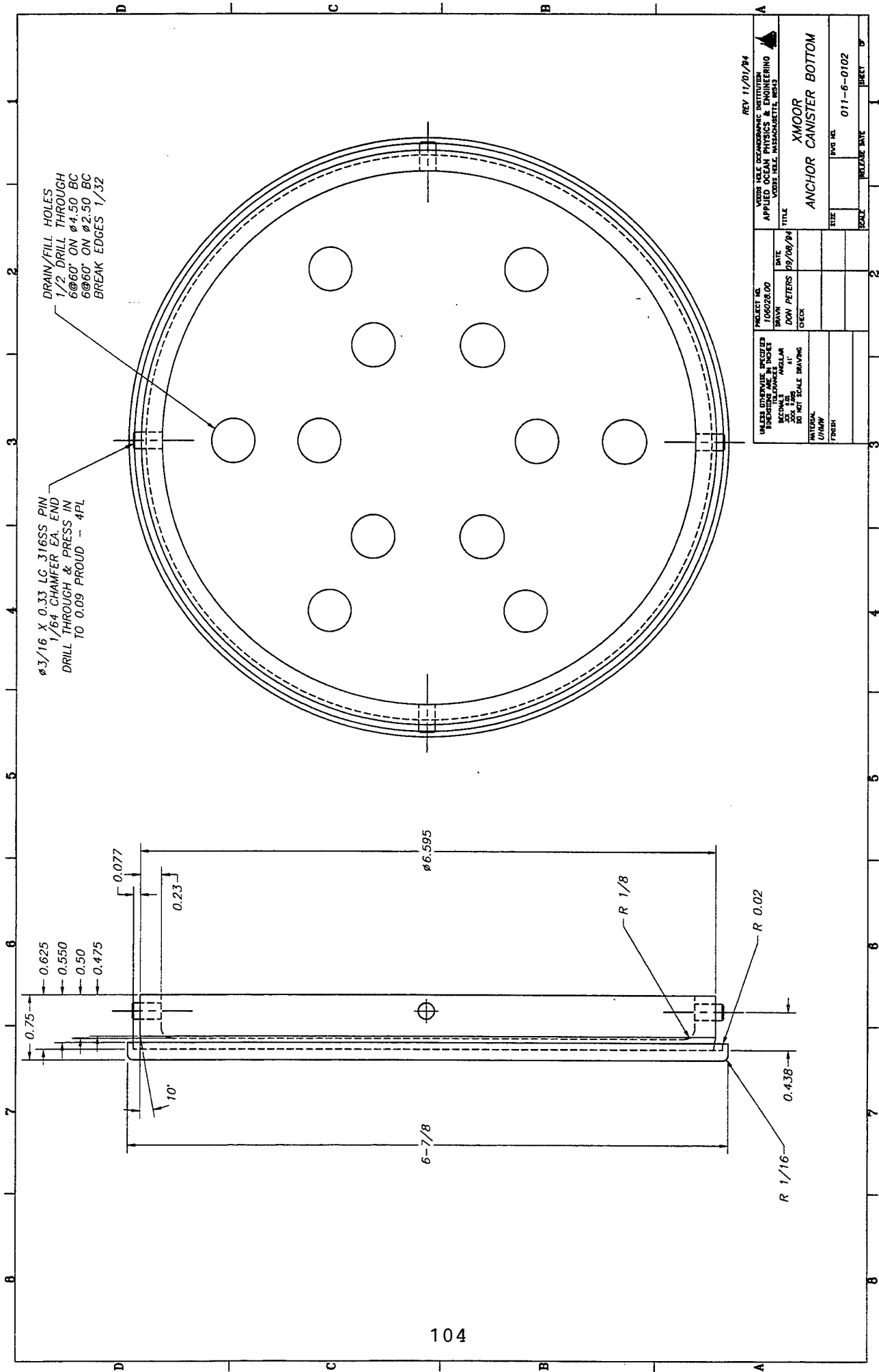


WOODS HOLE OCEANOGRAPHIC INSTITUTION APPLIED OCEAN PHYSICS & ENGINEERING WOODS HOLE, MASSACHUSETTS, U.S.A.		PROJECT NO. 106028.00		DATE 06/03/84		TITLE ANCHOR WELD ALIGN JIG	
UNLESS OTHERWISE INDICATED DIMENSIONS ARE IN INCHES DECIMALS ARE TO 0.01 DIMENSIONS ARE TO BE HIDDEN DIMENSIONS ARE TO BE SHOWN DO NOT SCALE DRAWING		DRAWN DON PETERS		CHECK		SIZE 011-S-0108	
MATERIAL MILD STEEL		FINISH		RELEASE DATE		SHEET OF	



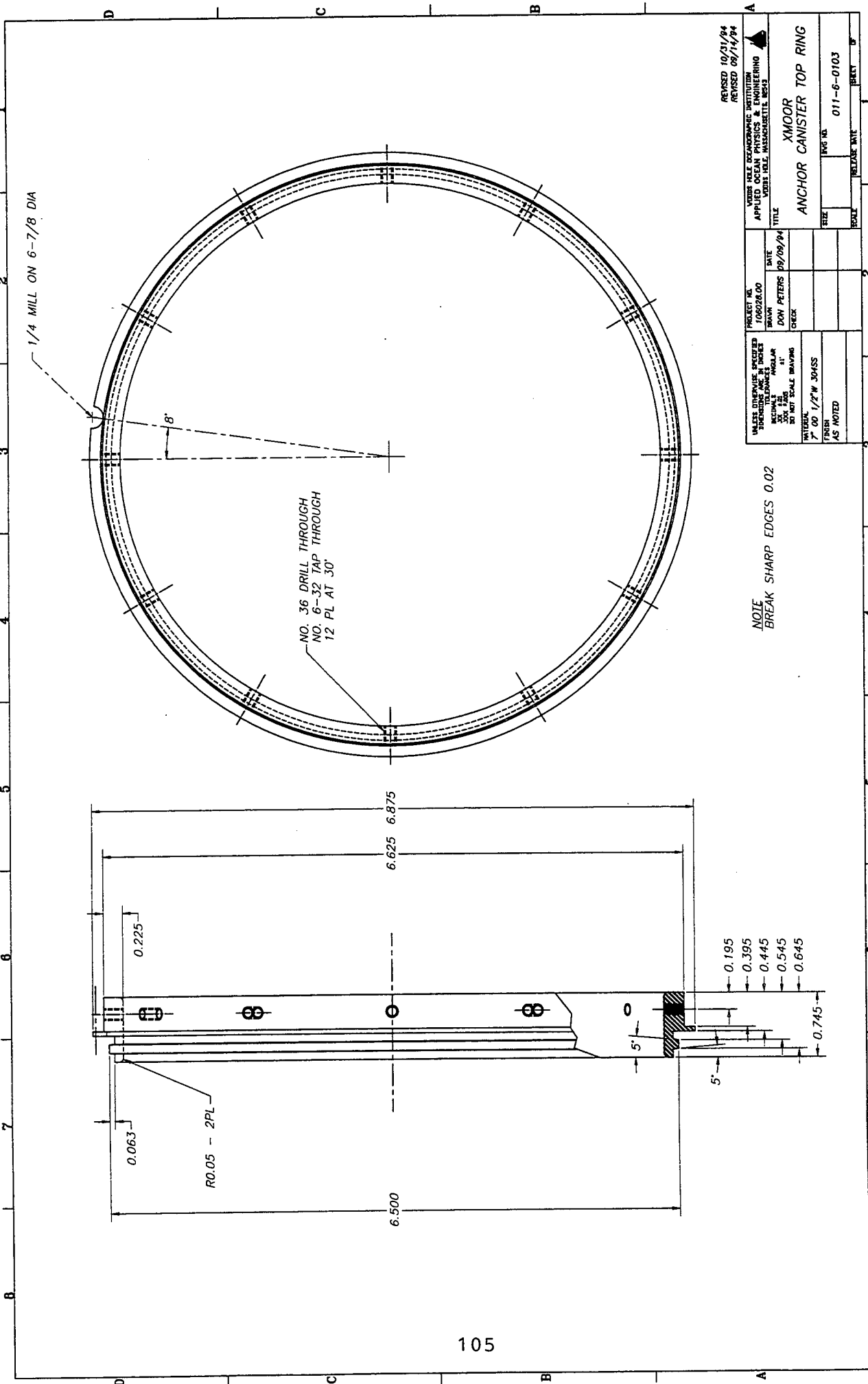


PROJECT NO. 100026.00		DATE 09/09/94		TITLE XMOOR BREAKAWAY ANCHOR CANISTER	
DRAWN DON PETERS		CHECK [Blank]		FIG. NO. 011-6-0100	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE TO THE NEAREST 0.001 DIMENSIONS IN PARENTHESIS ARE IN FEET DIMENSIONS IN PARENTHESIS ARE TO BE USED ONLY IF NOT NOTED OTHERWISE		MATERIAL AS NOTED		FINISH AS NOTED	
RELEASE DATE [Blank]		SCALE [Blank]		SHEET NO. 1	



REV 11/01/84

PROJECT NO. 100028.00		DATE 09/08/84	
DRAWN BY DON PETERS		CHECK	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS ARE TO 0.001 ANGULAR DIMENSIONS TO 10' UNLESS OTHERWISE SPECIFIED FINISHES ARE TO BE AS SHOWN MATERIALS TO BE AS SHOWN			
APPLICABLE SPECIFICATIONS MIL-STD-883C		TITLE ANCHOR CANISTER BOTTOM	
REVISIONS 011-6-0102		SCALE AS SHOWN	
RELEASE DATE		DRAWN BY	



REVISED 10/31/84  
REVISED 08/14/84

UNIVERSITY OF MASSACHUSETTS  
APPLIED OCEAN PHYSICS & ENGINEERING  
UNIVERSITY OF MASSACHUSETTS, BOSTON

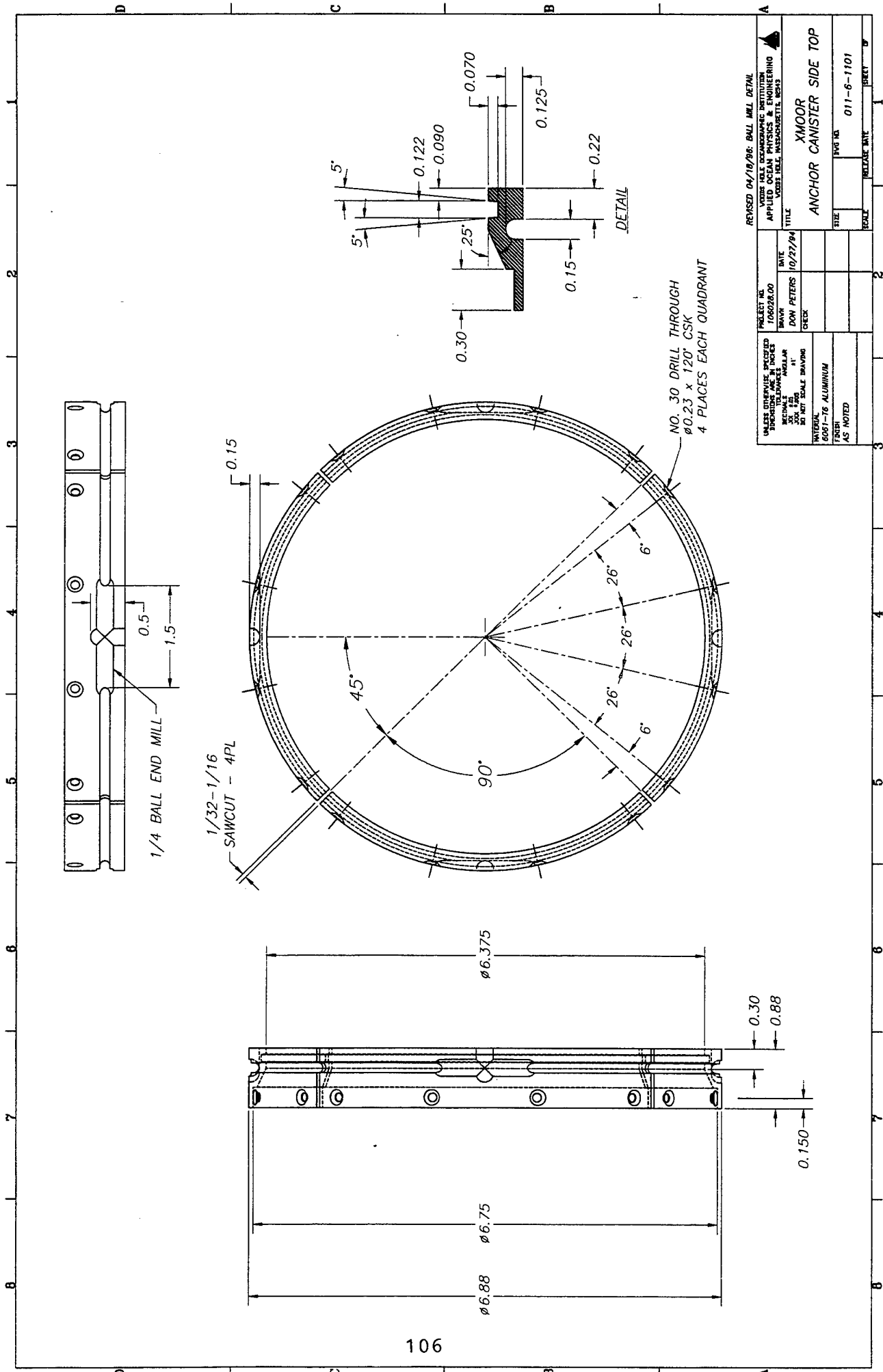
PROJECT NO. 10802AL00  
DATE 09/09/84  
DRAWN BY DON PETERS  
CHECKED BY

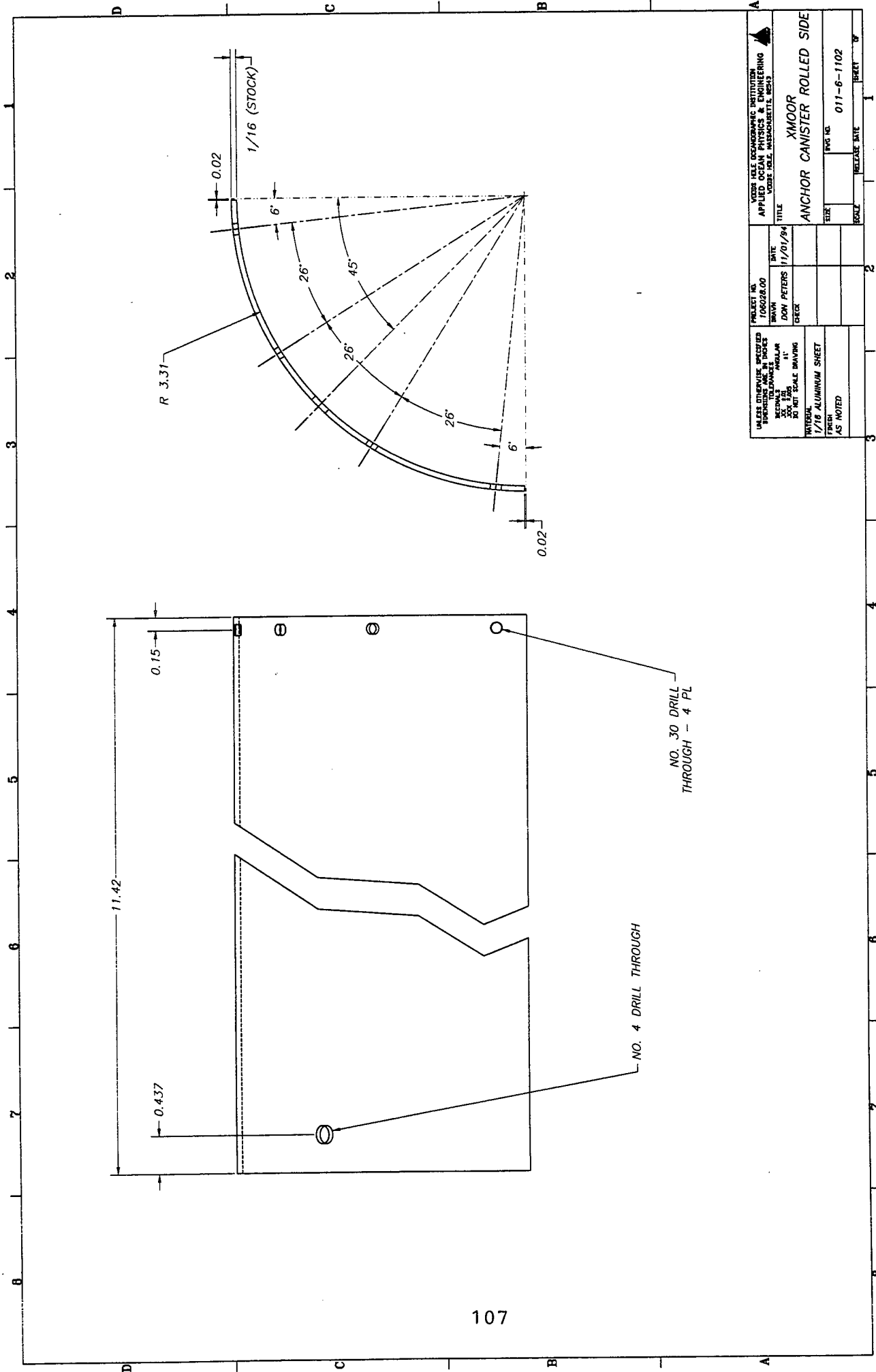
TITLE  
ANCHOR CANISTER TOP RING

SCALE  
DATE

FIG. NO. 011-6-0103

NOTE  
BREAK SHARP EDGES 0.02





NO. 30 DRILL THROUGH - 4 PL

NO. 4 DRILL THROUGH

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: FRACTIONS DECIMALS 0.001 0.005 0.015 0.030 0.060 0.150 0.300 0.600 1.200 2.400 AS NOTED		PROJECT NO. 106028.00	DATE 11/01/94	UNIVERSITY OF MASSACHUSETTS APPLIED OCEAN PHYSICS & ENGINEERING WORCESTER, MASSACHUSETTS 01603	
DRAWN BY DON PETERS		DATE 11/01/94	TITLE XMOOR ANCHOR CANISTER ROLLED SIDE		
CHECKED BY [Blank]		DATE [Blank]	SIZE [Blank]	SCALE [Blank]	REV. NO. 011-6-1102
MATERIAL 1/16 ALUMINUM SHEET		DATE [Blank]	SCALE [Blank]	RELEASE DATE [Blank]	SHEET NO. 1

## 6.2 Selected Model Runs

XMOOR response to steady horizontal currents was examined using the NOYFB mooring program described in [7]. This program computes the shape of the mooring based on mooring tension and drag of each of the mooring elements. It was designed for use with subsurface moorings but was implemented for XMOOR by iteratively varying the effective buoyancy of the surface float to constrain it to the surface. The mooring line tension then balanced the drag forces and the mooring shape was determined. Wave forcing is not considered. The analysis was performed for four cases ranging from typical (Case 1) to moderate (Case 2) to extreme (Case 3 and Case 4). Figure 6.2-1 shows the mooring configuration used in each case for reference.

Case 1: Typical conditions - 50m of water, current at the surface is 50 cm/sec decreasing linearly to 25 cm/sec at the bottom.

### Mooring Statistics - Summary - Case 1

Comp	Length (m)	Weight (lbs)	Depth (m)	Incline (deg)	Tension (lbs)	Excur (m)	Drag (lbs)	Backup (lbs)
1	.3	200.0	0	12.4	29.1	42.6	6.2	-42.5
2	.5	.0	.7	17.8	29.5	42.5	8.9	-42.5
3	30.0	-.3	28.0	27.9	29.2	30.2	14.0	-42.2
4	.2	-2.0	28.2	30.3	27.7	30.1	14.2	-40.2
5	30.0	-.3	53.1	35.9	27.4	13.4	16.8	-39.9
6	.4	-5.0	53.4	44.3	24.6	13.1	17.3	-34.9
7	15.0	-34.9	50.0	---	24.5	.0	16.7	.0

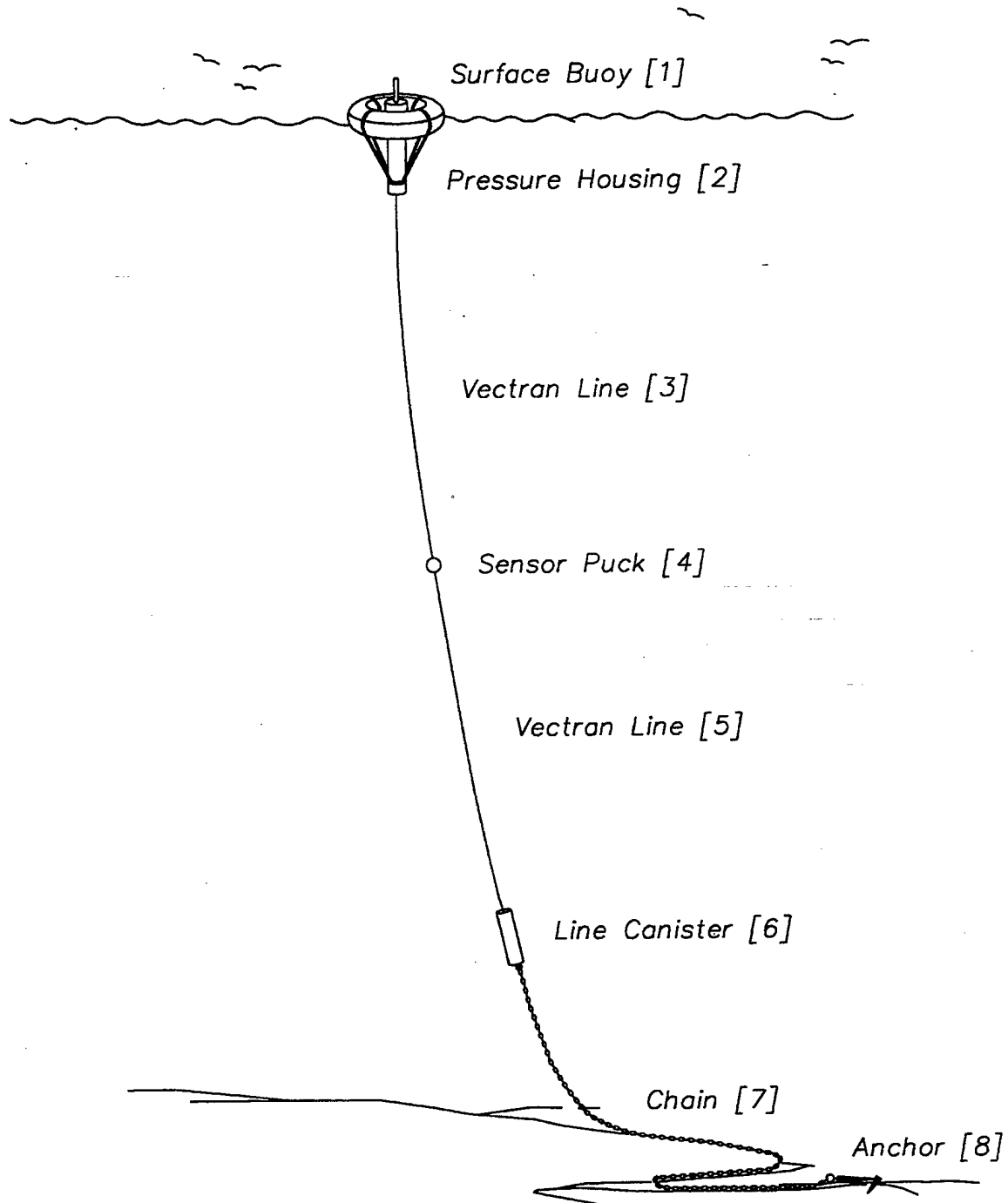


Figure 6-2-1: XMOOR mooring configuration used in the model runs

Case 2: Moderate conditions: 100m of water, current at the surface is 100 cm/sec decreasing linearly to 50 cm/sec at the bottom.

**Mooring Statistics - Summary - Case 2**

Comp	Length (m)	Weight (lbs)	Depth (m)	Incline (deg)	Tension (lbs)	Excur (m)	Drag (lbs)	Backup (lbs)
1	.3	200.0	0	15.1	93.9	96.0	24.2	-43.2
2	.5	.0	.7	21.3	97.0	95.8	34.4	-43.2
3	30.0	-.3	27.0	33.5	96.5	81.4	54.8	-42.9
4	.2	-2.0	27.1	34.8	95.9	81.3	55.8	-40.9
5	95.0	-.9	94.2	50.8	95.5	14.2	81.9	-39.9
6	.4	-5.0	94.5	53.8	97.3	13.9	83.0	-34.9
7	15.0	-34.9	100.0	75.8	82.4	.0	85.6	.0

Case 3: Extreme conditions: 50m of water, current is 150 cm/sec top to bottom.

**Mooring Statistics - Summary - Case 3**

Comp	Length (m)	Weight (lbs)	Depth (m)	Incline (deg)	Tension (lbs)	Excur (m)	Drag (lbs)	Backup (lbs)
1	.3	200.0	0	20.6	152.7	55.8	51.0	-42.5
2	.5	.0	.9	28.3	165.3	55.6	71.5	-42.5
3	30.0	-.3	24.7	43.0	164.6	37.4	113.7	-42.2
4	.2	-2.0	24.9	44.3	168.0	37.3	115.9	-40.2
5	30.0	-.3	44.1	53.7	168.1	14.2	143.4	-39.9
6	.4	-5.0	44.4	57.5	204.7	13.9	150.2	-34.9
7	15.0	-34.9	50.0	72.6	191.3	.0	170.4	.0



Case 4: Extreme conditions: 100m of water, currents at the surface are 150 cm/sec decreasing linearly to 100 cm/sec at the bottom

**Mooring Statistics - Summary - Case 4**

Comp	Length (m)	Weight (lbs)	Depth (m)	Incline (deg)	Tension (lbs)	Excur (m)	Drag (lbs)	Backup (lbs)
1	.3	200.0	0	19.9	204.0	99.2	66.5	-42.6
2	.5	.0	.6	26.9	217.8	98.9	91.5	-42.7
3	30.0	-.3	25.7	37.6	217.3	82.2	131.6	-42.5
4	.2	-2.0	25.9	38.6	220.1	82.1	134.5	-40.6
5	95.0	-.9	91.6	50.2	220.0	13.2	178.2	-39.8
6	.4	-5.0	92.0	51.7	223.7	12.8	180.1	-34.8
7	15.0	-34.9	100.0	60.9	204.4	.0	185.5	.0

### **6.3 Test Reports**

1. Mooring line test report from Tension Member Technology, April 11, 1996.
2. Anchor testing memo, October 13, 1994.
3. Vineyard Sound deployment memo, October 13, 1994.
4. XMOOR deployments to date memo, November 4, 1996
5. Surface buoy test documentation from Lamcotec, Inc.

**Tension Member Technology**  
5721 Research Drive  
Huntington Beach, CA 92649-1616  
Tel: 714-898-5641 Fax: 714-893-1925

**Shipping Document**

**Date:** April 11, 1996

**Ship To:** Woods Hole Oceanographic Institute  
Attn: Receiving Department  
266 Woods Hole Road  
Woods Hole, MA 02543

**Telephone:** 508-457-2000

**Order Number:** M100237

**TMT Project:** 2144

**Ship Via:**  UPS  U.S. Mail  
 Federal Express  
 Motor Freight

Prepaid  
 Collect  
 Air Freight

**Value:** \$2,000

Item	Quantity	Description	Dimensions	Weight
0001	1 each	Test Report on: Cyclic-Tension Fatigue and Breaking Strength Tests as Outlined in WHOI Fax of 01/19/96		

**Shipped By:** Philip T. Gibson

**Received By:** \_\_\_\_\_

**Date:** \_\_\_\_\_

11 April 1996

Mr. Don Peters  
Advanced Engineering Laboratory - Smith 310  
Woods Hole Oceanographic Institution  
Woods Hole, MA 02548

Dear Don,

Subject: Tests of Buoy Mooring Line  
Purchase Order M100237  
TMT Report FR-2144

Please find enclosed a summary of the procedures and data collected during cyclic-tension and breaking strength tests of your five Vectran®-strengthened electromechanical cable specimens. The tests were conducted in accordance with your testing description dated 19 January 1996.

The tests were conducted in a horizontal load frame equipped with a hydraulic cylinder and tension monitoring strain gage load cell. Cable elongation was measured on the first and last cycle of each sequence using an extensometer with a 33-inch gage-length. The extensometer was attached to the midsection of each specimen between the terminations. Displacement of the central conductor package relative to the termination grips was measured prior to and following each cyclic-straight-tension (CST) test.

The central conductor of each specimen was cut to a length approximately that of the mechanical eye-to-eye length so that any changes in resistance in the tested length would be more apparent. Conductor DC Resistance was also measured prior to and following each CST test and was continuously monitored throughout the cycling as well as during the final pull to break.

The CST test involved repeated loading and unloading of each cable specimen between two tension limits for a number of cycles. The tension limits and numbers of cycles for each specimen are summarized below in Table 1. A different cycling rate was used for each specimen to expedite those specimens having large numbers of test cycles. Following each CST test, the specimens were pulled to break while measuring elongation vs tension. Electrical continuity was also measured up to the point of break.

Each specimen retained a breaking strength within the specified range of 1,200 to 1,800 pounds. All of the specimens showed less than 1 percent change of DC resistance during the cycling (see Table 2) and all conductors remained continuous during the final pull to break until the point of cable mechanical failure. With the exception of Specimen A3 which suffered during a malfunction in the extensometer and tension control system, all five specimens had approximately 5% total elongation at break. The only anomalous behavior during testing occurred during the pull to break of Specimens A2 and A3. At slightly more than 1,000-pounds tension, they both began to suffer partial strength member breakage up to the point of

complete failure. There is no obvious explanation why these two specimens, but none of the others, suffered from this problem.

TABLE 1. SUMMARY OF TEST PARAMETERS AND RESULTS

Specimen Number	Load Range, pounds	Load Cycles	Elongation at Failure	Breaking Load, pounds
A1	10 to 1,000	250	4.93	1,740
A2	10 to 500	1,000	5.10	1,630
A3	10 to 300	3,000	3.79*	1,455
A4	10 to 200	10,000	5.05	1,630
A5	10 to 50	100,000	4.52	1,610

\*- Constructional Stretch lost due to extensometer failure.

TABLE 2. SUMMARY OF CONDUCTOR RESISTANCE MEASUREMENTS

Specimen	Resistance, $\Omega$ /1000 Feet @ 20 °C		% Change
	Prior	Following	
A1	25.2	25.0	-0.8
A2	25.1	25.2	0.4
A3	25.4	25.2	-0.8
A4	25.3	25.5	0.8
A5	25.5	25.6	0.4

The pages which follow are the load-elongation curves recorded for each of the specimens during each CST test and final pull to break.

If there are any questions regarding the testing or data, please feel free to call.

Sincerely,



Frederick Murdock  
Project Engineer

1250 Tension (lbf.)

**bmt** tension member technology  
HUNTINGTON BEACH, CA

FIGURE #1  
SPECIMEN 2144-A1  
DATE April 1996

Elongation vs. Tension

\* Cycles 1, 10 and 250  
\* No Grip Slippage

101250

46 1510

10 X 10 TO THE CENTIMETER  
KEUFFEL & ESSER CO. MADE IN U.S.A.

1250  
1000  
750  
500  
250  
0

0.0 1.00 2.00 3.00 4.00 5.00 6.00 7.00

Elongation (%)

116

0

7.00

2000 Tension (lb.)

**tmt** tension member technology

HUNTINGTON BEACH, CA

FIGURE #2

SPECIMEN 2144-A1

DATE 1 April 1996

Elongation vs. Tension

- \* Breaking Load = 1,740 lb.
- \* Following 250 Cycles between 10 and 1000 lb.
- \* Failed Mid-Span
- \* Total Elongation at failure = 4.93%
- \* Maintained electrical continuity until mechanical failure

1500

1000

500

0

1.00

2.00

3.00

4.00

5.00

6.00

7.00

Elongation (%)

251

117

46 1320

10 X 10 TO 1/4 INCH 7 X 10 INCHES  
KEUFFEL & ESSER CO. MADE IN U.S.A.

1250 Tension (lb.)

Elongation vs. Tension

\* Cycles Load 1000 to 500 lb.  
\* No Grip Slippage

**tmt** tension member technology

HUNTINGTON BEACH, CA

FIGURE #3

SPECIMEN 2144-A2

DATE 3 April 1996

46 1510

KE 10 X 10 TO THE CENTIMETER 10 X 25 CM  
KEUFFEL & ESSER CO. MADE IN U.S.A.

1000

750

500

250

0

1.00

2.00

3.00

4.00

5.00

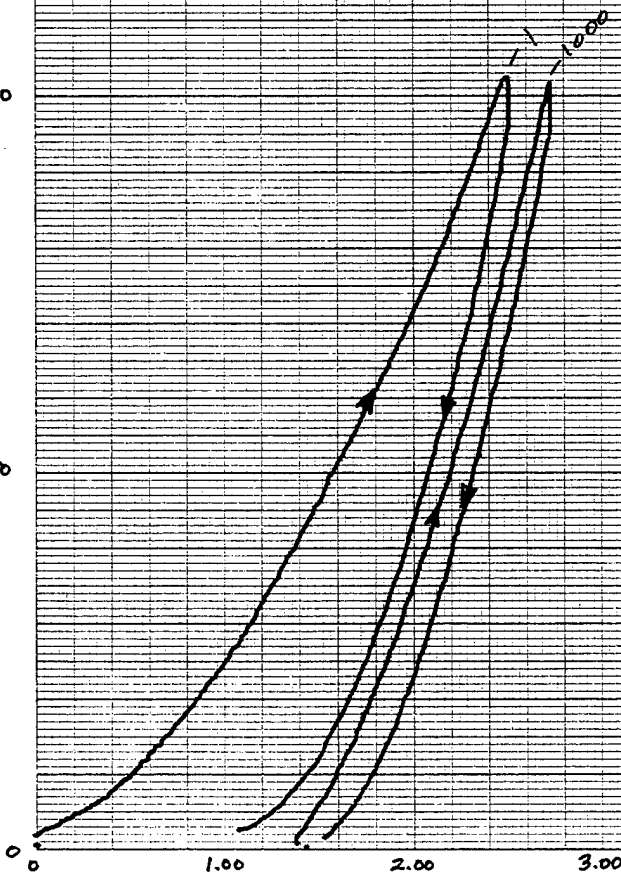
6.00

7.00

Elongation (%)

1000

118





2000 Tension (lbf.)

**tmt** tension member technology

HUNTINGTON BEACH, CA

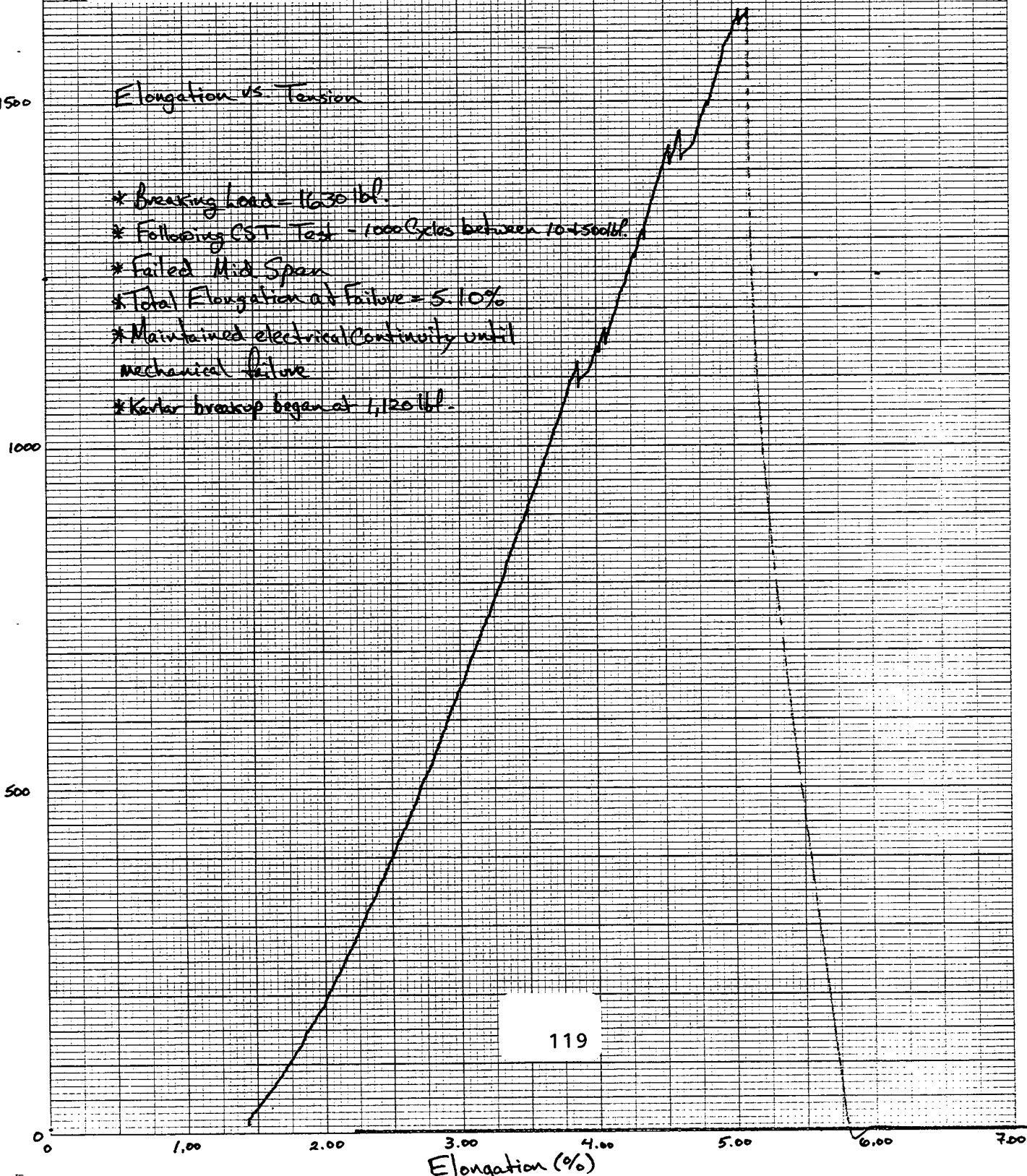
FIGURE #4

SPECIMEN 2144 - A2

DATE 3 April 1996

Elongation vs. Tension

- \* Breaking load = 1630 lbf.
- \* Following CST Test - 1000 Cycles between 10 + 1500 lbf.
- \* Failed Mid-Span
- \* Total Elongation at Failure = 5.10%
- \* Maintained electrical continuity until mechanical failure
- \* Kevlar breakup began at 1,120 lbf.



119

46 1320

KE 10 X 10 TO 1/2 INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

1250 Tension (lbf.)

Elongation vs. Tension

- \* Cycles load 3000 to 300 lbf
- \* Extensometer failure on load cycle prior to test
- Initial constructional stretch lost
- \* No Grip Slippage

**tmt** tension member technology  
 HUNTINGTON BEACH, CA

FIGURE #5  
 SPECIMEN 2144-A3  
 DATE 4 April 1996

46 1510

K&E 10 X 10 TO THE CENTIMETER 18 X 25 CM KEUFFEL & ESSER CO. MADE IN U.S.A.

1000

750

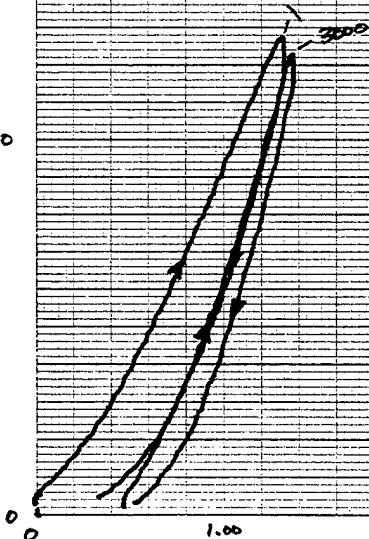
500

250

0 1.00 2.00 3.00 4.00 5.00 6.00 7.00

Elongation (%)

120



2000 Tension (lbf.)

**tmt** tension member technology

HUNTINGTON BEACH, CA

FIGURE #6

SPECIMEN 2144-A3

DATE 4 April 1996

Elongation vs. Tension

- \* Breaking load = 1,455 lbf.
- \* Following CST Test - 3000 Cycles between 10 and 300 lbf.
- \* Failed in Tension - End Grip Termination
- \* Total Elongation at Failure = 3.79% - does not include initial constructional stretch
- \* Maintained continuity until mechanical failure
- \* Kevlar breakup began at 995 lbf.

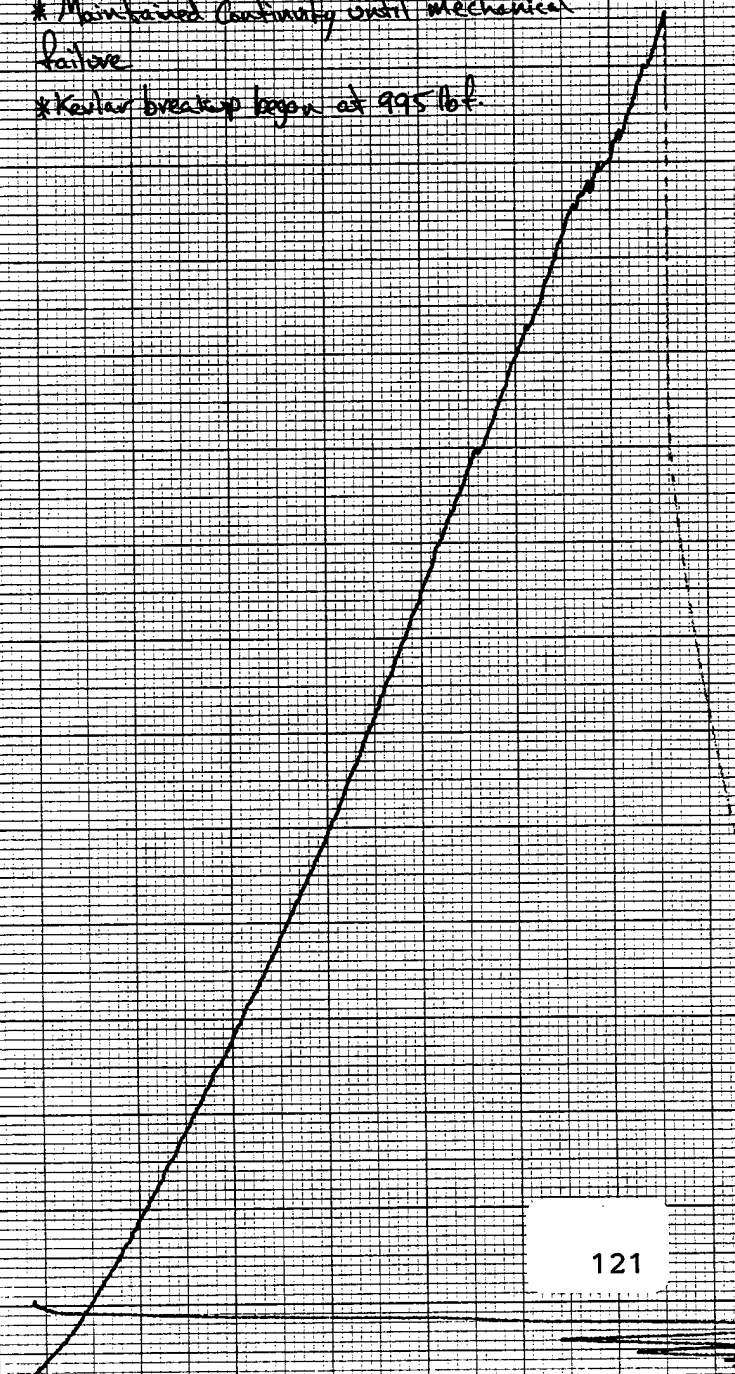
1500

1000

500

0 1.00 2.00 3.00 4.00 5.00 6.00 7.00

Elongation (%)



121

46 1320

KE 10 X 10 TO 1/2 INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.

Tension (lbf.)

Elongation vs. Tension

\* Cycles 1, 2 and 10,000  
\* No Grip Slippage

**tmt** tension member technology

HUNTINGTON BEACH, CA

FIGURE #7

SPECIMEN 2144 - A4

DATE 9 April 1996

46 1510

10 X 10 TO THE CENTIMETER 18 X 25 CM  
KEUFFEL & ESSER CO. MADE IN U.S.A.

1000

750

500

250

0

1.00

2.00

3.00

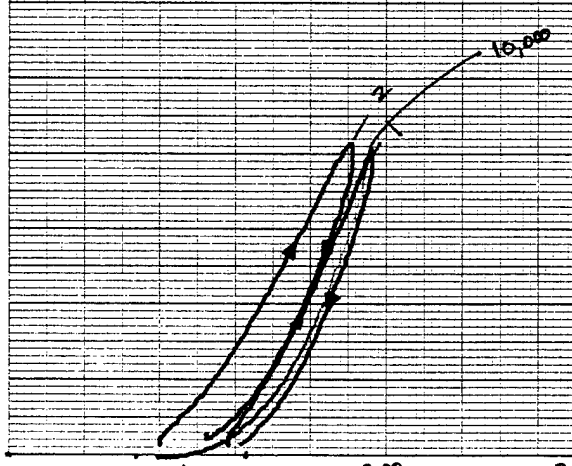
4.00

5.00

6.00

7.00

Elongation (%)



122

2000 Tension (lb.)

**tmt** tension member technology

HUNTINGTON BEACH, CA

FIGURE #8

SPECIMEN 2144-A4

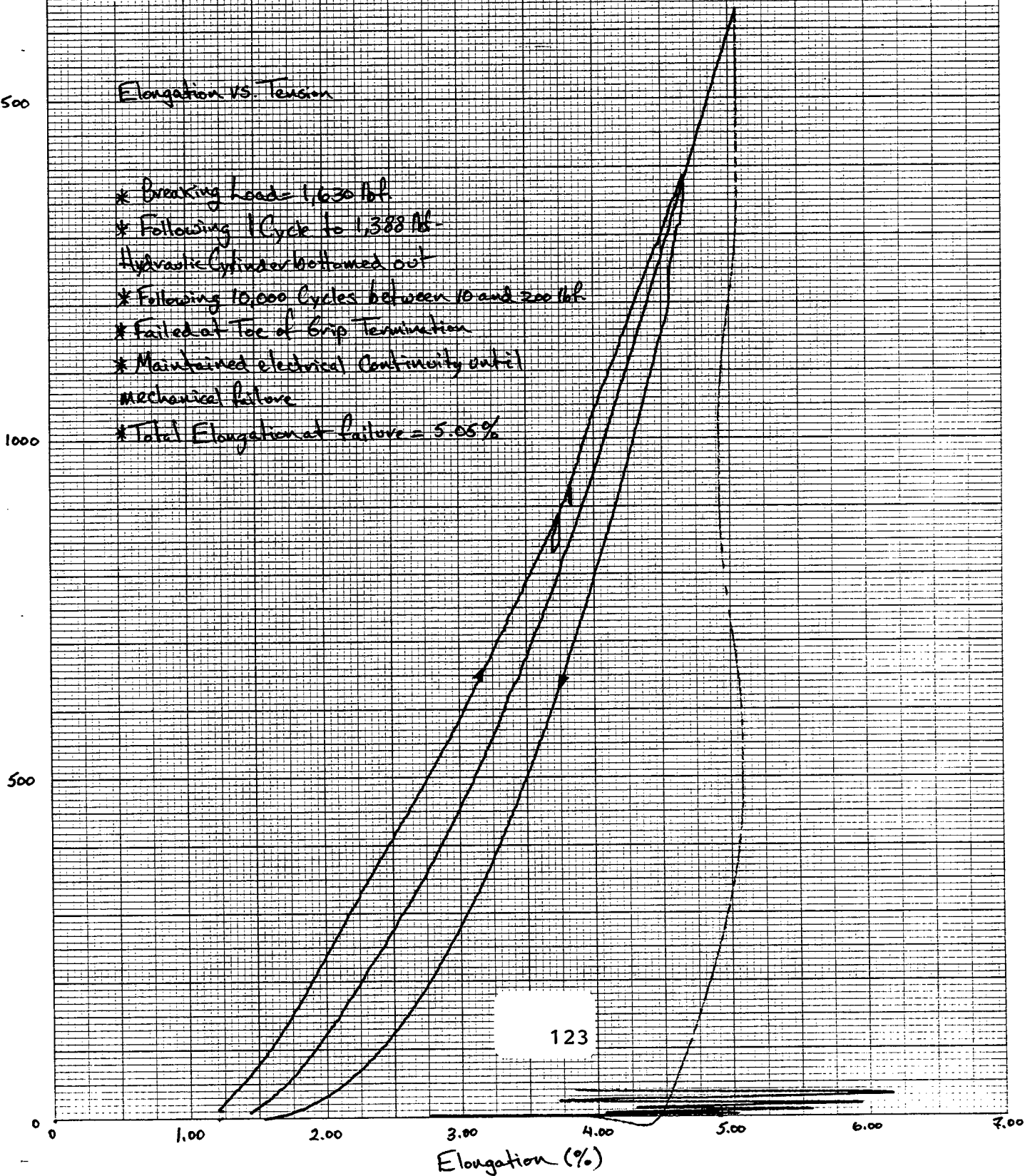
DATE 9 April 1996

Elongation vs. Tension

- \* Breaking Load = 1,630 lb.
- \* Following 1 Cycle to 1,388 lb - Hydraulic Cylinder bottomed out
- \* Following 10,000 Cycles between 10 and 300 lb.
- \* Failed at Toe of Grip Termination
- \* Maintained electrical continuity until mechanical failure
- \* Total Elongation at failure = 5.05%

46 1320

KE 10 X 10 TO 1/4 INCH 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.



123

Elongation (%)

1250 Tension (lbf.)

Elongation vs. Tension

\* Cycles Load 100,001 to 50 lbf.  
\* No Grip Slippage

tmt tension member technology

HUNTINGTON BEACH, CA

FIGURE #9

SPECIMEN 2144-A5

DATE 5 April 1996

46 1510

KE 10 X 10 TO THE CENTIMETER 10 X 25 CM KEUFFEL & ESSER CO. MADE IN U.S.A.

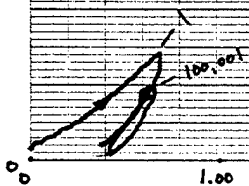
1000

750

500

250

124



Elongation (%)

1.00

2.00

3.00

4.00

5.00

6.00

7.00

Tension (lbf.)

**bmt** tension member technology  
HUNTINGTON BEACH, CA

FIGURE #10  
SPECIMEN 2144-A5  
DATE 8 April 1996

Elongation vs. Tension

- \* Breaking Load = 1,610 lbf.
- \* Following 100,000 Cycles between 10 and 50 lbf.
- \* Failed Mid Span
- \* Maintained electrical continuity until mechanical failure
- \* Total Elongation at failure = 4.52%

2000  
1500  
1000  
500  
0

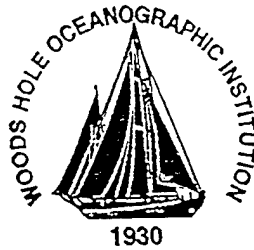
Elongation (%)

125

0 1.00 2.00 3.00 4.00 5.00 6.00 7.00

46 1320

KE 10 X 10 TO 1/4 INCH 7 X 10 INCHES  
KEUFFEL & ESSER CO. MADE IN U.S.A.



## ADVANCED ENGINEERING LABORATORY

## MEMO

-----

DATE: 10/13/94

TO: XMOOR Files

FROM: Don Peters

SUBJECT: Anchor Testing

FILE: xm090294.mem

-----

On 08/26/94, XMOOR folding anchor embedment observations were made, and on 09/02/94, embedded anchor force measurements were obtained. This memo documents these tests.

The XMOOR anchor was tested in fine soft sand and shallow water, on Seawall Beach, Maine. The observation tests included the following:

- Embedment observations (see photographs). Anchor was started out folded, on its side. It was pulled and observed to open and embed. Mean distance pulled to embed was about 4 ft. One fluke opened followed by a second fluke, and both embedded until the third fluke lay flush on the bottom. The shank was then parallel with the bottom about 2 in. down. About 2 ft. of chain was embedded as well. This test was repeated numerous times without any failures to embed.
- Re-embedment observation. Anchor was started out embedded, and was then pulled from the "wrong" direction. It was observed pulling out and turning over, and was pulled until it re-embedded. This was to simulate a situation where the mooring experiences a tide reversal. In several instances the "up" fluke failed to open immediately due to grit in the joints. This impaired re-embedment. A modified joint design with increased clearances is expected to solve this problem. In general, however, the anchor turned over and re-embedded normally. Turning over took about 3 ft. and re-embedment took about 4 ft.



● Observation of erosion around embedded anchor. The anchor was embedded in the downstream direction on the bottom of a tidal river with water depth of 3 ft. and current speed of about 1.5 knot. This test was tried with the "up" fluke both folded and extended. There was no discernable erosion in the vicinity of the anchor during a 20 minute period.

● Chain packing and pullout (see photographs). The anchor and 16m of 1/4" chain was packed in a 6.75" i.d. tube. The tube was pulled off the package from above, and the chain pulled from the side until all of it was stretched out. This was repeated five times with no tangling problems. It should be noted that in packing, the chain must be flaked in carefully and not twisted around the anchor shank.

Force measurements involved the following:

● Static pull. A 200 lb. spring scale was placed between the XMOOR anchor and a 5kg Bruce anchor. Both anchors were embedded and slack was taken up. The tension was then increased to 200 lb. Since the spring scale had a full scale deflection of only about 8 in., a small amount of creep in either anchor resulted in a large reduction of tension in the system. The system repeatedly crept down to approximately 70 lb. static force (no creep).

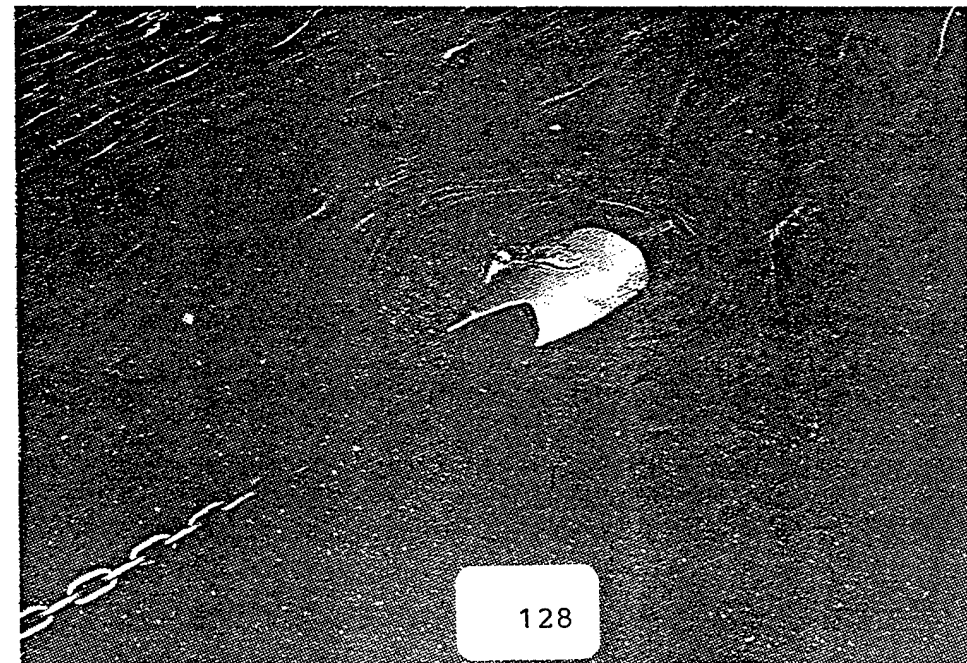
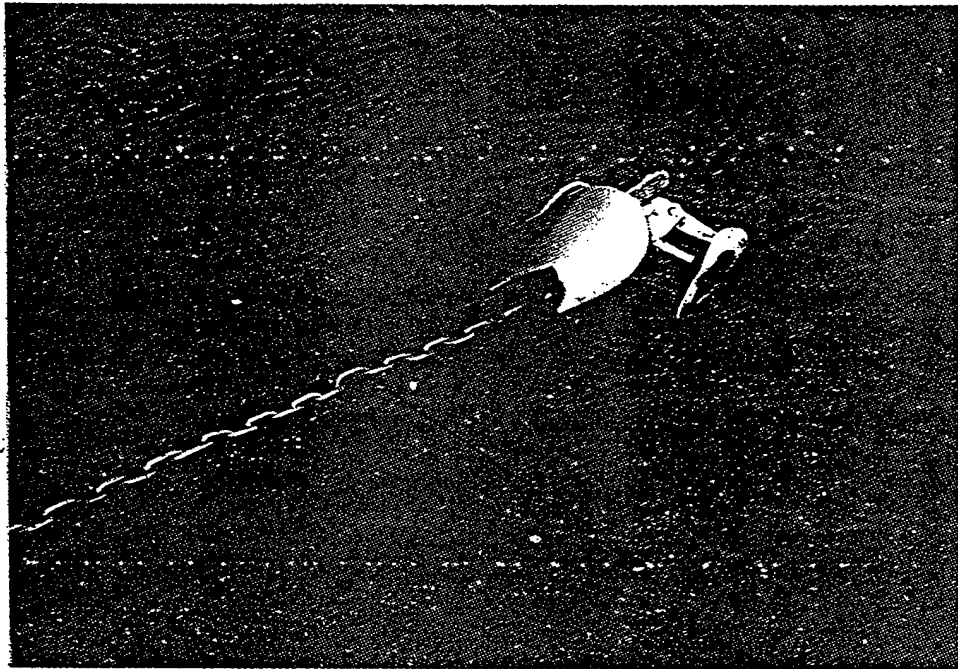
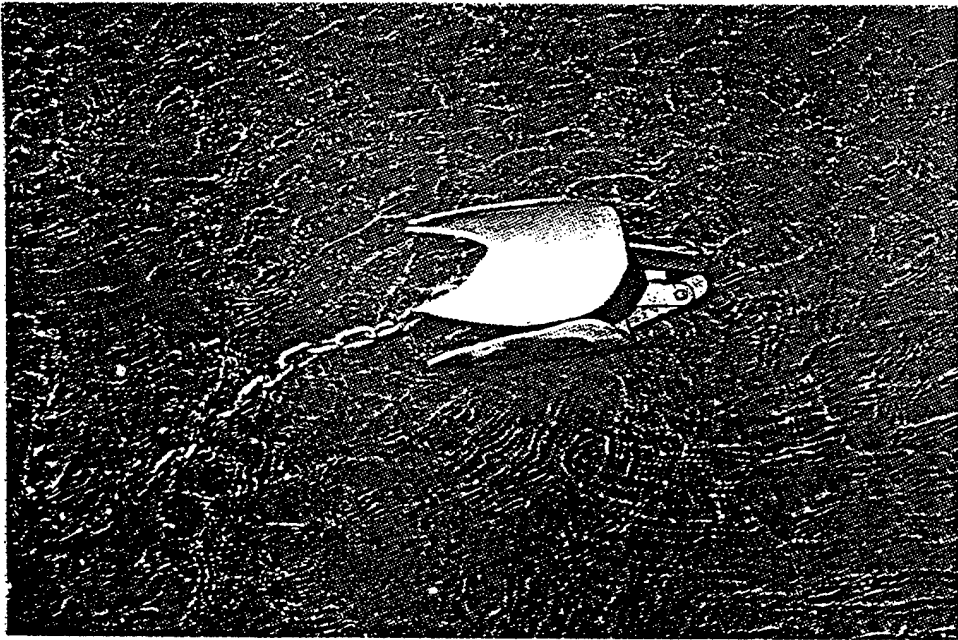
● Impulse pull. The Bruce anchor was disconnected and the XMOOR anchor pulled directly with the scale. Repeated short pulls of 200 lb. produced no anchor pullout. More sustained pulls of 150 lb. resulted in steady anchor creep of approximately 1/2 cm/sec.

● Bruce vs. XMOOR. In this test the two anchors, about 100 ft. apart, were connected with a taut line. The scale was connected in between the two anchors and a perpendicular pull was exerted. At an angle of  $107^\circ$  between the pull line and either anchor, a scale reading of 120 lb. produced a steady creep in both anchors of about 1 cm/sec. The force on each anchor at this point was approximately  $60/\sin(17^\circ)$  or 205 lb.

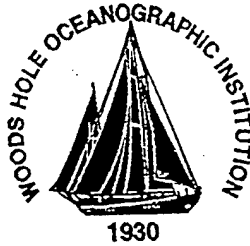
The weights of the tested equipment were as follows:

Bruce anchor 12 lb.  
XMOOR anchor 11 lb.  
Chain 35 lb.

DBP/dbp  
encl.  
cc:  
Dan Frye  
Richard Arthur







## ADVANCED ENGINEERING LABORATORY

## MEMO

-----

DATE: 10/13/94

TO: XMOOR Files

FROM: Don Peters

SUBJECT: Vineyard Sound Deployment 10/07/94

FILE: xml00794.mem

-----

On 10/07/94, XMOOR system #2 was deployed in Vineyard Sound, SE of WHOI, at approximately 41°-30'N, 70°-40'W. Water depth at this location, given by the WHOI 19' Whaler depth sounder, was 80 ft., or 24m. The system was deployed at approximately 1430 EDT, or about 3 hrs 10 min after ebb begins at Pollock Rip Channel (see attached copy: Eldridge; Tidal Current Chart, Buzzards Bay, Vineyard and Nantucket Sounds). The expected current was 1 knot flowing SW. Wind was SW, approximately 12 knots. Myself, Richard Arthur, and Steve Murphy were present.

A 100 ft. preventer line was attached from the boat to the pressure housing skirt. The system was deployed to windward (SW) of the boat, which was drifting about 1/2 knot to the NE due to wind and 1 knot to the SW due to tide (net drift 1/2 knot SW). The buoy separated, surfaced and inflated, at which time the boat had drifted away about 50 ft due to wind. At this point the anchor bit in, and the boat set down on the buoy with the current. The boat was brought around to hold station with the buoy, and landmarks were sighted to verify that our position was holding.

Current was visually estimated at 1 knot and a sponge thrown from the bow of the boat travelled the boat's 19 ft length in 11 seconds as we held station with the buoy. Thus current speed was approximately 1.7 ft/s or 1 knot.

Due to a damaged inflator on one gas bottle, only three of the four bottles fired upon deployment. The buoy filled adequately and the antenna deployed successfully, however. The problem with the inflator had been noticed when the buoy was being packed, and can be avoided in the future.

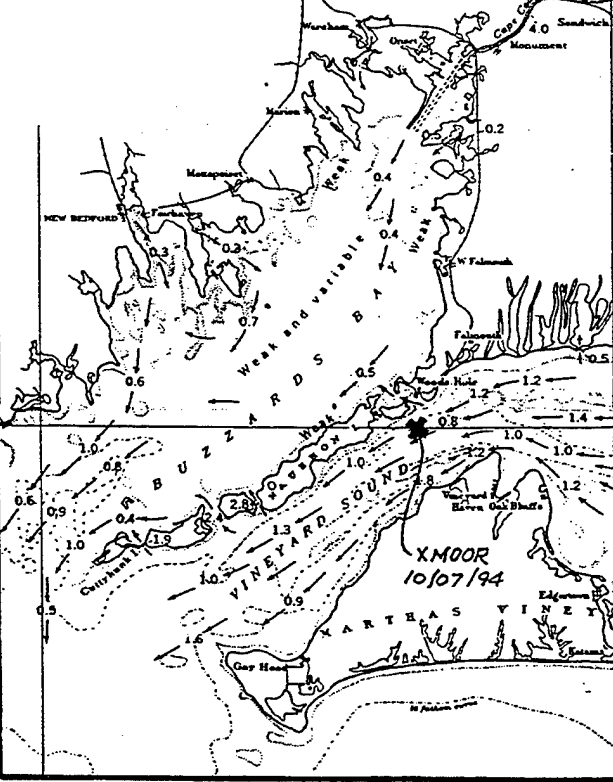
This was the first time that an XMOOR had been deployed using an actual line pack incorporating a thermistor string and pucks. The water depth was such that a lockup was expected at 31m, with the midwater puck pulling out just before lockup. Upon retrieval it was found that the puck had pulled out successfully and the 31m lockup had functioned.

The system was recovered by hand by two of us. The boat was run against the current to aid in recovery. All mooring components were found to be paid out without twists or tangles. The anchor retained material from the bottom, which was muddy sand.

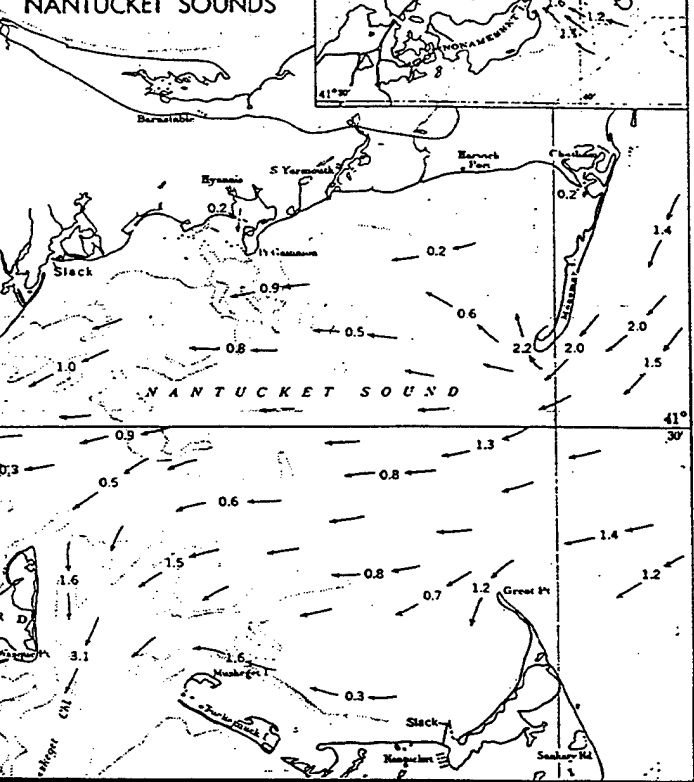
DBP/dbp  
encl.  
cc:  
Dan Frye  
Richard Arthur  
Janice Boyd (NRL)

**CURRENT FLOODS EAST  
CURRENT EBBS WEST**

0 5 10  
Nautical Miles  
1-7/16" = 10 Miles



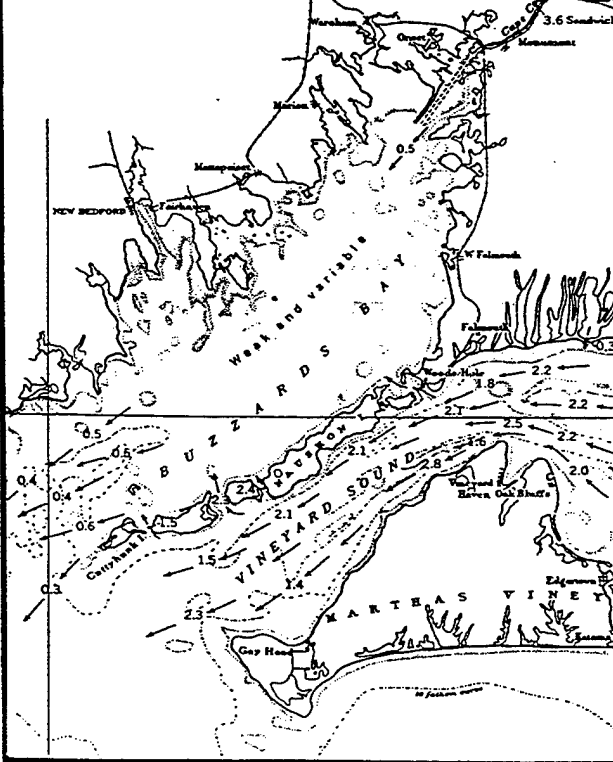
**TIDAL CURRENT CHART  
BUZZARDS BAY  
VINEYARD  
AND  
NANTUCKET SOUNDS**



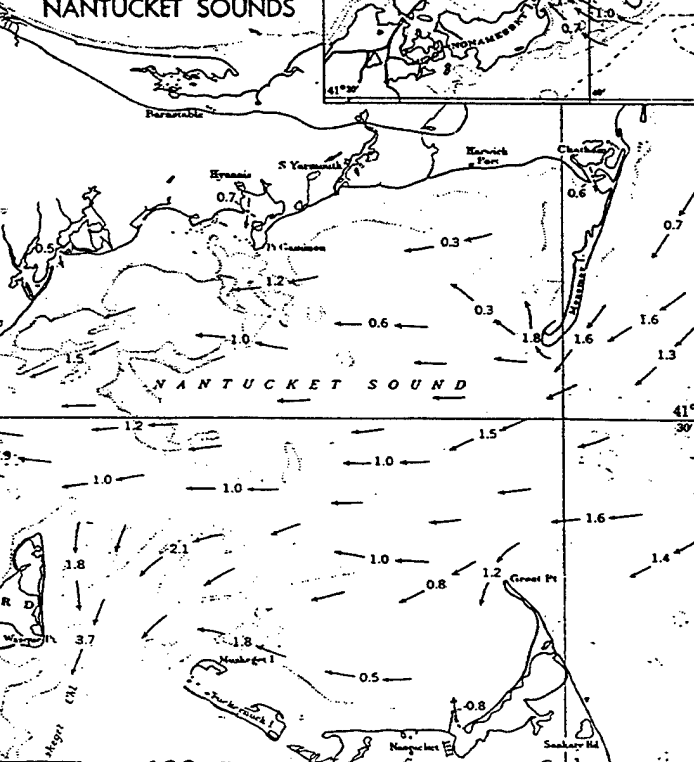
**3 HOURS AFTER EBB STARTS AT POLLOCK RIP CHANNEL  
OR: 1 HOUR AFTER HIGH WATER AT BOSTON**  
Velocities shown are at Spring Tides. See Note at bottom of Boston Tables:  
Rule-of-Thumb for Current Velocities. (Pollock Rip Ch. is SE of Monomoy Pt.)

**CURRENT FLOODS EAST  
CURRENT EBBS WEST**

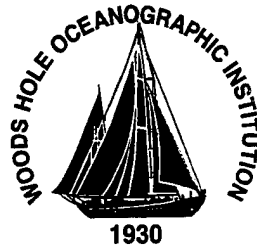
0 5 10  
Nautical Miles  
1-7/16" = 10 Miles



**TIDAL CURRENT CHART  
BUZZARDS BAY  
VINEYARD  
AND  
NANTUCKET SOUNDS**



**4 HOURS AFTER EBB STARTS AT POLLOCK RIP CHANNEL  
OR: 2 HOURS AFTER HIGH WATER AT BOSTON**  
Velocities shown are at Spring Tides. See Note at bottom of Boston Tables:  
Rule-of-Thumb for Current Velocities. (Pollock Rip Ch. is SE of Monomoy Pt.)



ADVANCED ENGINEERING LABORATORY  
**MEMO**

---

**DATE:** 11/04/96  
**TO:** File  
**FROM:** Don Peters, x3377  
 Smith 310, MS 17  
**FILE:** xm110496.doc

---

The XMOOR system #2 which was self-deployed in Vineyard sound on 10/07/95 was deployed for several extended periods. This memo summarizes the activity.

Great Harbor

The first round involved deployment in Great Harbor, Woods Hole. This tested the system in the absence of currents and waves, i.e. wind only, and within easy sight of the town dock. The sight chosen was a 50 ft. deep hole approximately 0.15 naut. mi. west of the town dock, relatively clear of moorings.

The system was put in Great Harbor on November 4, 1994. The inflatable was filled to 3 psi guage at room temperature, with air. CO<sub>2</sub> was not used as problems with diffusion had not been solved yet. A lobster float on 3/8" yellow polypropylene was shackled onto the anchor chain about 3m up from the anchor, as a backup recovery float. The 30m lockup point was engaged with the actuator wing bolted down, as there was no un-latch preventer in the initial prototypes.

The mooring line conductor was fitted with a 100kOhm resistor at the bottom and was electrically terminated to the stainless steel lower line canister ring. At the top the line was plugged into the bulkhead connector in the lower endcap of the pressure housing. Two leads were brought out of the top of the pressure housing and antenna stem: one connected to the mooring line conductor and one to the buoy seawater return. The intent was that by measuring resistance between the seawater returns at the top and bottom of the system, conductor integrity could be checked periodically without pulling the system out of the water.

Between November 4 and 10, the mooring was seen from shore to swing with the wind (anchor float to windward of the buoy) and remain tautly inflated. Several cold fronts, one with gusts to 45 kts,

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passed through during this period, and though there were only very small waves the buoy was observed to "kite" almost clear of the water during some puffs.

On November 10 the buoy was checked for electrical continuity, and shorting was indicated. The system was recovered and brought ashore. Upon examination the pressure housing was found to have leaked, causing test lead shorting inside the buoy. The leak was due to a misalignment of the conductivity head caused by fastener interference. The mooring line was undamaged, and the system was re-deployed.

From November 10 until 21 the mooring behaved as expected. On the 21st the anchor float was observed to leeward of the buoy, and after that date the relative position of the float and the buoy remain unchanged. On November 30 the system was recovered. The mooring line between the buoy and line canister was found to have snagged on the bottom in two places. The polyester sleeving was chafed through in two locations but the strength member and conductor were intact.

### Buzzards Bay

System #2 was re-fitted with the new 0.165" O.D. mooring line from line canister to buoy. A 15m lockup length was used, since water depths less than 45 ft. were expected, and a chinese finger upper termination was made to replace the potted chain/swivel/boot combination. The lockup point and chain of the new lockup type was shackled to a u-bolt fitted through the line canister wall, as the new lockup slides had not been delivered yet. No thermistor string was married to the line and no sleeving was installed except at the upper termination over the chinese finger. The remainder of the original linepack from the Vineyard Sound deployment was left in the canister for weight simulation purposes, and although in a final system the midwater node would not have pulled out at 15m, for test purposes a dummy node was installed above the 15m lockup. The same anchor float was used, and a new anchor (made to better tolerances than the prototype) was used. The instrument housing was fitted with an Argos transmitter and a circuit to detect mooring line conductor integrity.

This system was deployed on January 13, 1995, in Buzzards Bay at approximately 41°-32.1'N, 70°-40.6'W, or about 1/3 naut. mi. NNW of the MBL Beach. This site is sheltered from the SW to E, but is relatively exposed (4-6 mi fetch) to the NE, and exposed (full Buzzards Bay fetch) from N to W. Water depth is approximately 40 ft. and tides are not likely to exceed 1/2 kt. The bottom is shown on the chart as mud. This site has the advantage that it is visible from the MBL beach.

Upon deployment it was noted that the anchor float was perhaps on too long a line, and by next morning the float had fouled the buoy. Bad weather prevented going to fix this for several days. On January 19 the anchor float line was cleared from the buoy and shortened up to about 6 ft. more than the water depth. ARGOS not receiving sufficient hits for position more than about once a day. Antenna problems suspected.

On January 31, 1995 the buoy was not on station, although the marker float was present. ARGOS position had not been recently updated. The lower part of the system was hauled using the marker float. It was noted that the line canister had become fully embedded in the very sticky bottom at this site. The vectran line was found to have broken just below the puck. The buoy was spotted where it had gone ashore a short distance to the northeast and lodged in a riprap wall. The inflatable was intact and holding air, though the buoy had evidence of a bad pounding on the rocks. The line had pulled out of the puck and the puck was gone.

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This failure led to the following conclusions: First, that the combined bending and tension occurring at the puck needed to be eliminated. Second, the unwanted embedment of the line canister resulted in a system without the scope and shock-absorption that the anchor chain was designed to provide. Third, that the inflatable buoy was surprisingly tough in abrasion resistance.

#### Design Changes Resulting from Failure

The first problem led to a design whereby mechanical lanyards above and below the puck take the tension from the mooring line and pass it directly through the puck housing, resulting in a site of bending without tension at the puck. The lanyards are the same as those used for the lockup points and the buoy termination.

A number of ideas for preventing line canister embedment were discussed. One involved adding enough flotation to the canister to keep it off the bottom. It was found that to make the canister neutrally buoyant using foam of 6 pcf, about 8 inches of interior length would have to be filled (with the OD constraint on the design, no flotation could be added to the outside of the package.) A canister was fitted with foam inside and tested. It was found to exhibit a great deal of undamped motion, which would clearly result in line tangling. The lack of available interior room for foam-filling and the extreme activity of the neutrally ballasted canister led us to abandon floating the line canister as a solution to the problem for this design. A second solution discussed, but never implemented, was to provide a flexible fabric collar around the upper canister opening, which would allow line and pucks to pull out, while keeping mud from coming in.

It should be noted that both problems resulted when the system was deployed at a site with little tidal action, causing the mooring to stay very slack. It is interesting that this may be a design condition more difficult to engineer for than our target conditions of maximum depth and current, where the mooring stays taught for a large part of the time.

#### System #3 Deployments

During the winter and spring of 1995, a redesign of XMOOR was performed, and 8 units of the modified design produced. Modifications were largely made to simplify production and reduce the mechanical parts count.

In June of 1995, two systems were self-deployed at Woods Hole for testing of telemetry systems. Subsequent to that testing, one unit was retained for mechanical testing in waters around Woods Hole. This unit was fitted with a battery pack and PTT only, for position during testing. A large portion of the retrieval/redeployments performed during these tests resulted from continuing problems with low ARGOS hit rates. A change of PTT units and adaptation of a whip antenna eventually resulted in reliable position updates. The large number of retrievals had the advantage of allowing for a good visual check on any wear point development over the course of the testing. A summary of the testing follows.

6/29-6/30	Great Harbor
6/30-7/20	Buzzards Bay, off MBL Beach
7/20-7/21	Refit with new PTT, Overnight on dock to check position hits
7/21-7/26	Redeploy system at position 41°-33.3'N 70°-42.5'W, referred to as "XMOOR1" position, approx. 2 NM Northwest of Woods Hole Passage, in Buzzards Bay. Water depth 17 m.

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7/26-8/3	PTT not working, system retrieved, fitted with new unit
8/3-8/17	On station. Numerous visual checks, ARGOS positions unreliable
8/17	Whip antenna fitted for PTT
8/17-9/11	On station
9/11	Inflatable appears soft. Has been outside in water or on land 137 days. Replaced with new inflatable. No change in inflation noted after replacement. Possible temperature/pressure effect?
9/15	System deployed at "XMOOR2" in Vineyard Sound, position 41°-29.6'N, 70°-41.8'W, about 1/2 NM south of Lackey's bay. Water depth 24 m. Tides running NE/SW approx 2.5 knots max. Separate marker float located 15 m downstream of buoy with tide flowing SW.
9/15-10/14	On station. Various checks reveal no change in position or mechanical wear points
10/14	Southwest gale, winds 40-50kt
10/15	ARGOS Position bad, buoy off station to northwest, weather still rough
10/17	Buoy recovered using ARGOS position and visual, Bishop Shoal, south of Hyannis

#### Failure Discussion

Failure of the mooring was once again at the puck. The puck-bypass lanyard below the puck had chafed through at the thimble, and once it parted the mooring line parted at the location it passed into the puck. The puck was recovered with the buoy, and the mooring line had noticeable weakening where it passed into the puck from above.

The total time in Buzzards Bay was 62 days, and time in Vineyard Sound was 32 days before failure, for a total of 94 days. The puck-bypass lanyard that failed was, as were all lockup and termination lanyards on that particular test mooring line, made of a hollow-braid Vectran strength member from the previous, larger version of XMOOR. The use of this Vectran hollow-braid was a choice of convenience only, for the purpose of getting a line assembled for the June electrical tests. Subsequently, a hollow-braid Spectra line was used for the lanyards. This is significant, since Vectran is poor in abrasion resistance and is not usually used without an abrasion-resistant cover. This failure mode would not be expected from a line using the Spectra lanyards.

The apparent weakening of the line at the puck would eventually have led to electrical failure of the mooring conductor and thus the system. There is a great deal of motion at the points where the line passes into and out of the puck. A softening of the puck pass-through edges to allow for a more gradual entrance and exit would be expected to reduce line damage at these locations.

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LAMINATING COATING TECHNOLOGIES, INC.  
LAMCOTEC, INC.  
152 BETHANY ROAD  
MONSON MA 01057 - 0279

LABORATORY REPORT

NUMBER: APPENDIX 6.3.5  
DATE:

TEL: (413) 267 - 4808  
FAX: (413) 267 - 5265

LCT SPECIFICATION  
NUMBER: XXXX

PRODUCT DESCRIPTION:

HEAT SEALABLE URETHANE  
SEA RESCUE ORANGE, 210 DENIER NYLON OXFORD

LCT SPECIFICATION NUMBER
LCT FACTORY ORDER NUMBER
LCT INVOICE NUMBER
LCT MANUFACTURING DATE
TRIMMED WIDTH, CENTIMETERS
TRIMMED WIDTH, INCHES
NUMBER OF ROLLS
NUMBER OF NET LINEAL METERS
NUMBER OF NET LINEAL YARDS
BILL OF LADING NUMBER
SHIPPED VIA

TEST REFERENCES: MIL-C-83489 (18 MAY 1977)  
FEDERAL STANDARD 191A (JULY 20, 1978)

COMPLIANCE CERTIFICATE: I HEREBY CERTIFY THAT THE MATERIALS TENDERED BY THIS REPORT HAVE BEEN MANUFACTURED AND TESTED IN COMPLIANCE WITH THE AFOREMENTIONED SPECIFICATIONS.

TEST	TEST METHOD	RESULT	REQUIREMENT
WEIGHT	5041	261.65 GRAMS / SQUARE METER	MIN. MAX.
		(1) 7.71 OUNCES / SQUARE YARD	MIN. MAX.
BREAKING STRENGTH	5102	1606.73 NEWTONS / 50 MILLIMETERS	MIN.warp
		1098.88	MIN.fill
(2)		367.00 POUNDS / 2 INCH	MIN.warp
		251.00	MIN.weft
BREAKING STRENGTH GRAB	5100	1203.95 NEWTONS / 25 MILLIMETERS	MIN.warp
		919.38	MIN.fill
(3)		275.00 POUNDS / 1 INCH	MIN.warp
		210.00	MIN.weft
TONGUE TEAR	5134	15.12 NEWTONS	MIN.warp
(4)		3.40 POUNDS	MIN.warp
		2.00	MIN.weft
TRAPEZOID TEAR	5136	30.25 NEWTONS	MIN.warp
	5100	20.46	MIN.fill
(5)		6.80 POUNDS	MIN.warp
		4.60	MIN.weft
BREAKAWAY ADHESION	PARA.	356.81 NEWTONS / 25 MILLIMETERS	MIN.warp
	4.4.1		
(6)	5102	81.50 POUNDS / 1 INCH	MIN.warp

TEST	TEST METHOD	RESULT	REQUIREMENT
STRIP ADHESION (7)	5970 5102	166.36 NEWTONS / 25 MILLIMETERS 38.00 POUNDS / 1 INCH	MIN.warp MIN.warp
PERMEABILITY TO HELIUM GAS (8)	TSO C13f APP. 1 (6) ASTM D1434-82 V	TEST NOT RUN	2.00 LITERS / SQ.M. / 24 HRS. MAX
AIR RETENTION (9)	PARA. 4.4.2	PASS PASS	NO LEAKS / 10 PSIG / 5 MINUTES NO LEAKS / 69 kPa / 5 MINUTES
LOW TEMPERATURE (10)	PARA. 4.4.3	PASS	NO CRACKING, FLAKING OR SEPARATION

SIGNED:

-----  
RICHARD J. ANDERSON, JR.  
VICE PRESIDENT - OPERATIONS

SIGNED:

-----  
RICHARD J. MALO  
QUALITY CONTROL DEPARTMENT

SIGNED:

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WILLIAM P. REED  
LABORATORY

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16. Abstract (Limit: 200 words)  An expendable, self-deploying mooring (XMOOR) for shallow water applications has been developed to address Navy requirements for environmental monitoring. The project has been conducted jointly between the Woods Hole Oceanographic Institution and the Naval Research Laboratory at Stennis, MS. WHOI has taken the lead on the mechanical design of the system while NRL has developed the electronics.  Eight prototype XMOOR systems have been built. They are designed for water depths between 10 and 100m, for deployments of up to 3-months duration, and for automatic deployment. Their sensor suite includes barometric pressure, air temperature, water temperature at up to 25 levels, and conductivity and pressure at up to 3 levels. Data telemetry is accomplished via the Argos DCS and by line-of-sight VHF configuration of the data collection program.  This report describes the XMOOR mechanical system. The data collection and telemetry systems are described separately in (1) and (2).			
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