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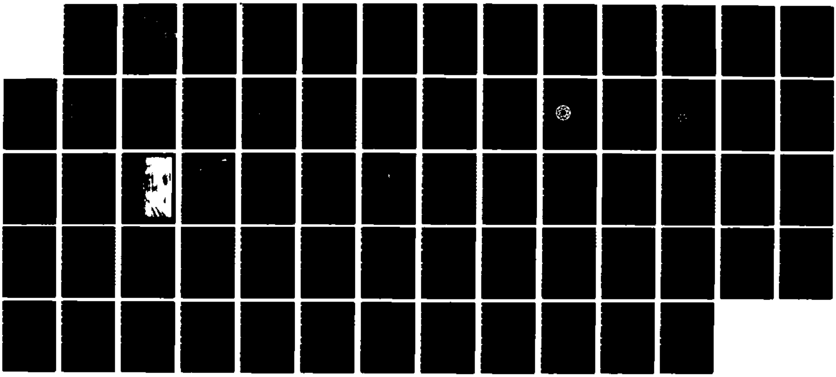

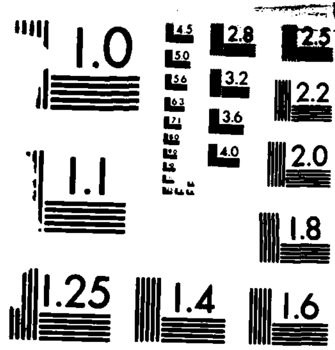

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PROJECT LINEAR CHAIR ARRAY SYSTEM
FY 77 REPORT

KUNO SMITS - PROGRAM MANAGER

OCEAN TECHNOLOGY DIVISION
CODE 350
NAVAL OCEANOGRAPHIC LABORATORY

Prepared For:
Chesapeake Division
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This report describes a preliminary study of the use of a large suspended, Kevlar reinforced, instrumented array for project Linear Chair. Included in the report are candidate array structure, associated cables, mooring components and deployed scenario. Included and presented in graphical (Con't)

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form is a deflection analysis of the array in a selected location.

This study is based on the array requirements as perceived early in FY 77.

ABSTRACT

This report describes a preliminary study of the use of a large suspended, Kevlar reinforced, instrumented array for project Linear Chair. Included in the report are candidate array structure, associated cables, mooring components and deployment scenario. Considerations are also given to repair and replacement requirements. Included and presented in graphical form is a deflection analysis of the array in a selected location.

This study is based on the array requirements as perceived early in FY 77.

EXECUTIVE SUMMARY

This report describes the design of a candidate deep ocean array system which will fulfill the instrumentation and performance requirements of the Intermediate Array for the Linear Chair project.

An array of a trapezoidal base with "goal post" like instrumented sections is described.

Mechanical and electro/mechanical array cable candidates are discussed in detail. All array buoyancy and anchoring requirements are also enumerated.

Computer tested motion analyses were performed on the array. The results showed that motion can be controlled by the amount of buoyancy employed and also that cable strain values are directly proportional to the buoyancy employed.

Areas which require further development and the need for environmental data, which will be utilized during the final array design stage, are defined.

An explicit array structure can not be designed until stability and detailed instrumentation and associated power and communication techniques are specified. In the interim a mechanical structure is described to which the instrumentation and electrical cabling harness can be attached. This is also a candidate for the final design.

Recommended efforts in FY 78 are:

- Continue iteration on array design
- More environmental data on array sites
- Extensive testing on candidate array cable design, particularly on long term stress fatigue

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF TABLES

PART I. REQUIREMENTS AND RELATED PROGRAMS

1. BACKGROUND

Magnetometers with increased sensitivity and detection range have been introduced into fleet ASW operations. Development of a superconducting or cryogenic magnetometer, promises rapid exploitation in increased sensitivity and will improve the search and surveillance capability of fleet (U.S. and U.S.S.R.) ASW forces. Submarines are becoming larger and present a larger magnetic signature to any magnetic detecting device. With the increase in size, the submarines are becoming more complex with internal electric and electronic instrumentation which emits electromagnetic radiation, while instruments capable of detecting electromagnetic interference (EMI) are becoming more sophisticated. Since EMI can be sensed remotely, it is becoming a new tool in ASW. For the above reasons, EMI and magnetic anomaly detection are gaining new importance in ASW search and surveillance operations.

To counteract the increasing detection capability by unfriendly ASW forces, an effort was initiated to gain better knowledge of the signature structures and reduce this type submarine signature. LINEAR CHAIR, with its many project elements was, therefore, conceived to fulfill the above requirements.

Naval Ocean Research and Development Activity (NORDA) has an extensive background in nonmetallic sensor arrays and thus was tasked to provide input in the array design. Many other project elements depend on the successful design and employment of the instrumented arrays for in situ measurements and the quality of the collected data. Therefore, one of the most important requirements of LINEAR CHAIR will be the sensing and collecting of high quality magnetic and EMI signatures of a specially instrumented submarine from multiple sensor arrays at multiple slant ranges.

2. INTRODUCTION

The array requirements for LINEAR CHAIR will be dissimilar from most other deep ocean sensor arrays; that is, in conjunction with other sensors, a number of optical pumping type magnetometers will be employed. This type magnetometer requires orientation of its optical axis in respect to magnetic North and local magnetic inclination. The complete array system will have to be deployed in such a fashion that the intended magnetometer orientation is not misplaced; with the exception of areas where declinations are such that the sensor axis can be orientated vertically and no other orientation is required. Also, the sensor optical axis will require realignment, within the sensor housing, when moving the array to a different geomagnetic latitude; since signal strength relates to the proper orientation.

The variety and number of sensors employed on the same vertical array will require a design that will accommodate all required sensors and provide operational freedom to all sensors without interference, electrical or mechanical, from each other's operation.

Equally important will be the choice of materials in the mechanical/electrical cable design, so that the array will properly support all weight and stability requirements. It must also be easy to handle, maneuverable during attachment or removal of sensors and the complete array must not be difficult to handle during storage, deployment and retrieval.

The above described magnetometers are of a very high sensitivity (.01 gamma). To utilize that sensitivity one has to remember that it is traditionally degraded if the sensors are operated in close vicinity of any ferromagnetic material and, therefore, all magnetic material will have to be excluded from the construction of the array system. The use of any non-ferrous metal will also degrade the sensitivity due to the generated magnetic eddy currents if there is any large displacement of such a metal near the sensor. The magnetometer sensitivity can be degraded by electromagnetic radiation emitted from such sources as power and signal cables if near enough to the sensor.

These possible interference factors will have to be kept constantly in mind when designing the array systems. All possible noise sources which could affect the sensitivity of all the employed sensors will need to be considered and essential methods for avoiding problem areas will be employed. In this fashion oversimplifying any design features which could affect the efficiency of the array systems should be avoided.

Detailed deployment and retrieval methods, sensor attachment methods, physical dimensions, material composition, construction methods and all other detailed specifications are included in this report.

3. RELATED PROGRAMS

Before we discuss array systems related to LINEAR CHAIR, a brief discussion of magnetometer sensors in array configurations is warranted. As pointed out earlier, optically pumped magnetometers usually have more stringent environmental requirements than most other oceanographic sensors employed in deep sea array systems. These highly sensitive magnetometers are also more susceptible to different magnetic phenomena and man-made magnetic noise sources. Most magnetic noise sources, man-made or physical, will be greatly attenuated with increasing water depth and residual effects will be most likely minor. With proper array design and data handling, this can be compensated. One can readily observe that during most previously conducted seabased magnetic measurements, in a towed or stationary mode, a simple magnetic array system is utilized; one where the magnetometer is the only sensor and electronic unit on the array. Therefore, there is no need to route other electric conductors, all possible electromagnetic noise generators, past the magnetometer sensor and degrade its sensitivity. Our own previous work indicated that optical pumping magnetometer sensitivity is easily degraded by nearby power and RF cabling.

The only multi-magnetometer array known to us (successfully employed in a 5 Rb. single cell sensor array in a horizontal configuration) was used in locating buried ordinance during clearing of the Suez Canal. This was a very short towed system with no direct application to LINEAR CHAIR except it pointed out that highly sensitive magnetometer data from multiple mobile single cell sensors were successfully cross-correlated, and its high sensitivity was not degraded. All external magnetic noise sources were removed by employing a reference magnetometer.

EMI sensors, most likely, will be of the receiving antenna type and no interference, electronic or mechanical, is expected from the array system itself to its signal sensing capabilities.

Numerous vertical sensor array systems have been successfully employed during recent years, for a variety of purposes, from shallow water to depths of 6.41 km. During the same period, a continuous improvement took place in array design techniques. Even larger improvements were achieved with the introduction of lightweight components which produced more reliable, easier to handle and less costly systems. One of the largest advances came with the development of Kevlar* fiber reinforced cables. This new fiber has a strength-to-weight ratio in water twenty times that of steel. Because of its low linear elongation characteristics, it is easily adaptable for fabricating as the main strain member during construction of the electromechanical cables. Kevlar, by being a synthetic fiber, and therefore nonmagnetic, is ideally suited for array systems which contain magnetometers.

One of the first hydrophone array systems constructed from the new Kevlar fiber was the second generation Moored Acoustic Buoy Systems (MABS). Notably, many of the restrictions imposed by the previously employed steel electromechanical cable were sharply reduced.

The use of Kevlar resulted in achieving a lightweight, compliant, torgue-free, non-corrosive, more stable array system. Because of its light weight, the configuration of the mooring becomes almost completely independent of the length of cable in the system. The resulting arrays were much cheaper to fabricate, operate and maintain and, at the same time, provided more versatility and reliability. Obviously, because of the materials, the above array is free of corrosion both in and out of water and can be stored wet or dry in a coiling box without maintenance.

At present an advanced deep water array system, VEKA (Versatile Experimental Kevlar Array), is being developed at NORDA (Figure 1). VEKA, a multi-year program, will increase in complexity each year by increasing the number of sensors in the array. It will start out as a 32-element array and will eventually extend to a 128-element system with signal multiplexing capabilities. The array will be deployed in different geometric configurations over the next four years. The electromechanical cable will be constructed in groups of braided Kevlar ropes whose interiors will house twisted electric conductors; the individual Kevlar ropes will be, in turn, braided together and the whole assembly then braided over by a protective outer jacket to which antistrumming fairing will be attached. In addition, the array construction will utilize the most advanced, lightweight components available. The above methods will produce an easily fabricated free flooding array cable. The in-line hydrophone concept previously used with MABS will be incorporated into the design which allows the mounting of the hydrophones coaxially into the cable without cutting the strength members.

The gradual increase in VEKA's design complexity and plans for numerous deployments in different geometric configurations should avoid major design errors. By staging early field tests, if problems arise, they can be identified and changes can be made prior to the next field test. The first year effort is mainly designed for technological developments, testing and performance evaluation.

*Trademark of E.I. DuPont and Co.

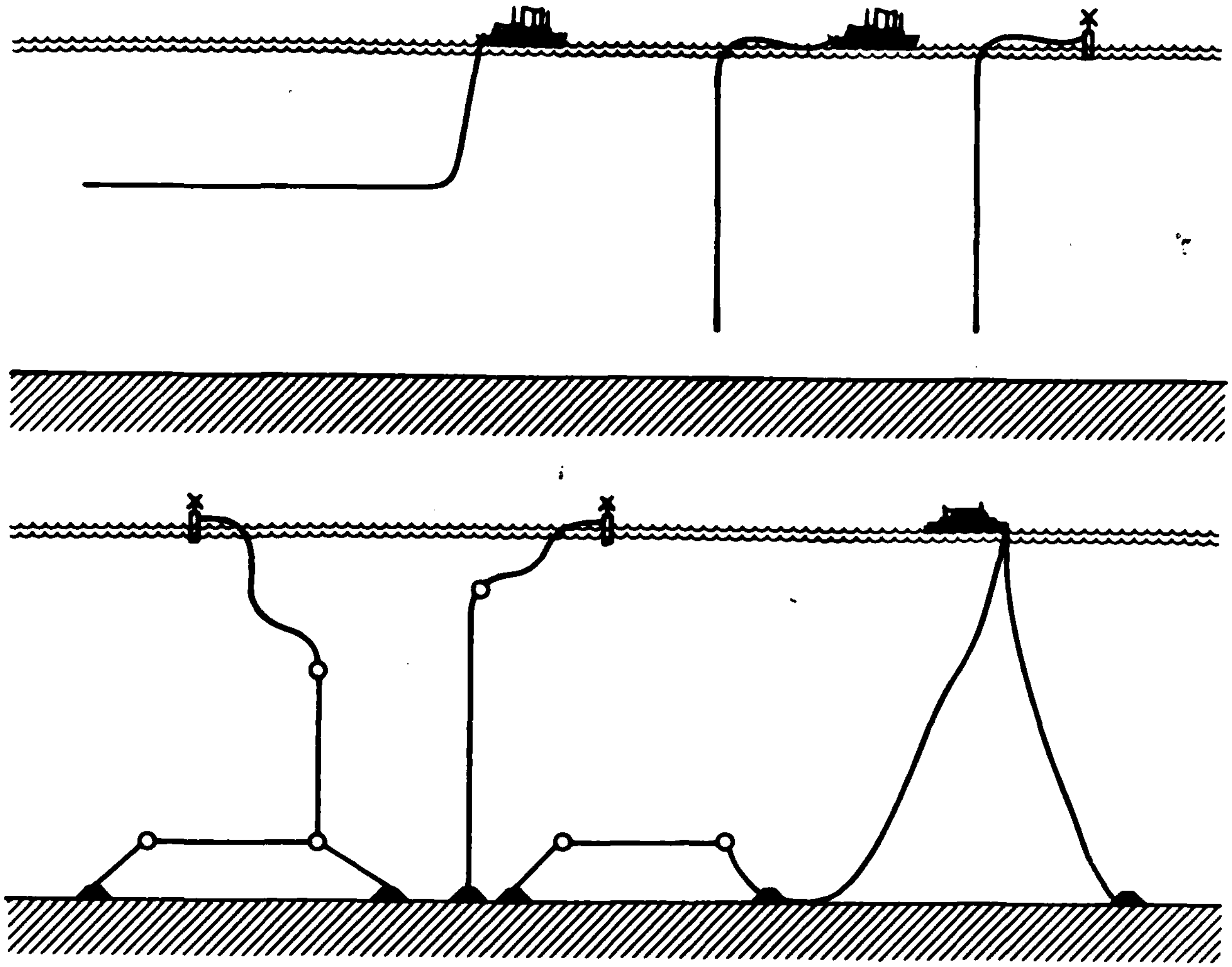


Figure 1. Modes of Operation

The knowledge and experience gained during the different phases of VEKA will be directly applicable in planning and designing LINEAR CHAIR array systems.

4. LINEAR CHAIR ARRAYS

During the LINEAR CHAIR concept stage for semifixed and mobile array systems, the greatest challenge was envisioned in designing the required electromechanical cable with its sensor mounts and connections, electrical and mechanical. The mooring and buoyancy assemblies can be specified for a deep sea array system which will meet the specified stability requirements. Tradeoffs, such as weight, deployment ease and total cost will have to be considered.

The mobile array, while employing the same electromechanical cable and sensor configuration, will require a different hardware configuration for stabilizing the array. The stability of the semi-fixed array will not be possible to duplicate for the mobile mode. In addition, another disadvantage is that any tow ship will have a permanent and induced magnetic field whose total field strength will vary with the magnetic heading and geomagnetic latitude.

The traditional solution is to separate the magnetometers and the ship by that distance where the ship's magnetic field decreases below the threshold of the magnetometer sensitivity. The distance, of course, varies with the ship's size and tonnage and the sensitivity of the magnetometer. At present it is estimated that for LINEAR CHAIR a separation of 426 m or more will be required.

A different solution, perhaps more practical for LINEAR CHAIR, is to make no attempt to remove the complete ship's field by separation; to use less separation, which would be just enough to reduce the major portion of the ship's field and eliminate the small magnetic field changes, which would be generated and sensed by the magnetometers due to minor ship's movements. The remaining ship's field, which will be a steady step-like increase in amplitude as long as the ship is on heading and position, can be removed by a simple software program, or can be left in the recorded data if no interference with signal analysis exists.

EMI sensors would not discriminate between the target and ship's electromagnetic radiation. Physical separation between the two ships would improve signal detecting capabilities from the target vehicle.

Candidate arrays are outlined for semi-fixed ranges and sketches are provided to illustrate these configurations.

A. Shallow Water-Horizontal Array System

This short, 109.73 m array will contain 11 triaxial magnetometers and 5 EFS (electric field sensors) and will be hard wired, approximately 914.40 m, to a shore installation. Since this will be a shallow water array, sensor orientation or replacement will be achieved with the assistance of divers. The proposal for constructing the electromechanical cable and methods for attaching sensor mounts are as follows:

- The first requirement is that the complete array system be constructed from nonmagnetic material and, if possible, from nonmetallic material, especially in close vicinity of the magnetometers, due to possible generation of magnetic eddy currents.

- Due to the physical size of sensors and the required sensor mounts, the complete units would have to be mounted outside the cable, that is, the sensor mounts would be on a different axis from the cable axis. The sensor mounts, which also would serve as pressure and waterproof containers, are envisioned to be of cylindrical or similar shape and tied to the electromechanical cable at both ends; or the whole sensor mount and the adjacent cable could be encompassed in a net type webbing and secured in this fashion. By installing a jumper cable of any required length, the sensors could be positioned by divers at any distance from the main electromechanical cable.
- The electromechanical cable would be constructed of a braided Kevlar jacket which would house all required electrical conductors. The conductors would be coaxial or regular and twisted in bundles.
- The braided Kevlar jacket would be protected from abrasion and fishbite by an outer polyurethane jacket.
- To gain access to the electrical conductors at the proper location, an incision would be made in the outer polyurethane jacket, the Kevlar braids parted and the correct bundle of electrical conductors located, cut and brought out through the incision.

  Waterproof connectors then would be fixed to the cut conductors which would mate with the connectors on the sensor housing.

  For long term protection the short sections of the electrical conductors, brought out through the incisions, should be wrapped in spiral tape. All incisions on the polyurethane jacket would be molded.
- Lead or concrete weights would be attached to the cable to keep it stabilized and in place on the ocean floor following deployment.
- After fabrication, final assembly and testing, the array would be coiled in a specially designed wooden crib for transportation and temporary storage. Shelves should be provided around the periphery of the crib in such a way that during coiling each sensor can be placed on a shelf and be accessible at any time while the array is in the crib for calibration and testing. If need be, the crib would be immersed in salt water for testing.

  During deployment, the array could be played out directly from the crib.

B. Two String Vertical Array System

The array configuration is shown in Figure 2. The trapezoidal configuration has definite advantages over two separate vertical systems and are listed below:

- Better stabilization
- Easier to deploy (versus two separate vertical arrays)

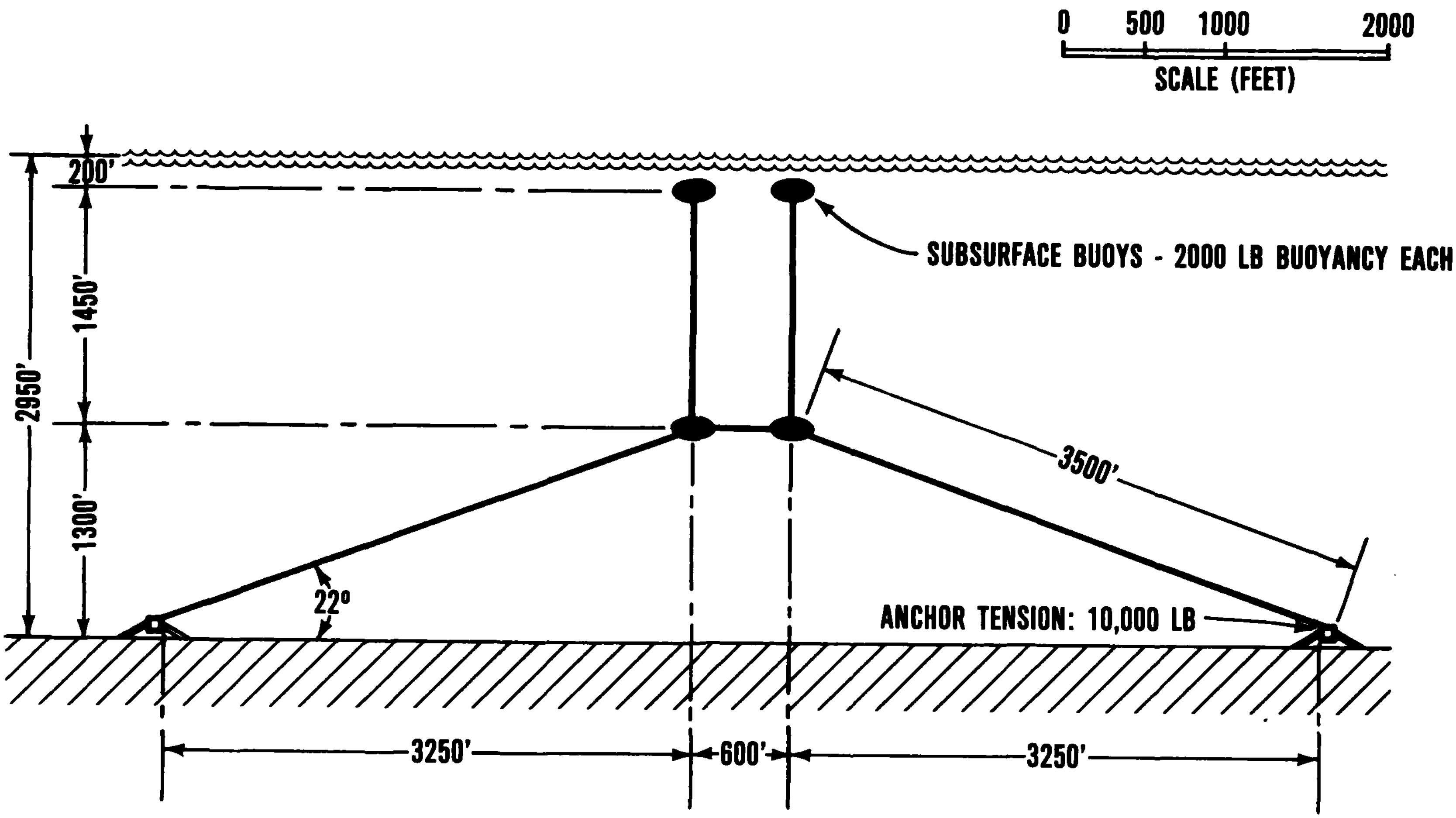


Figure 2. Two String Semi-mobile Array Structure

- Because of geometric configuration, the vertical sensor section is under less tension.
- Horizontal separation of the two sensor sections is fixed.
- Easier to return the sensor portion to the surface (for instrument replacement and repair) and then redeploy at the same location.
- Reorientation in vertical plane is possible (which is important for proper reorientation of Cs magnetometers).

C. Modified For A Four String Vertical Array System

The array configuration is shown in Figure 3.

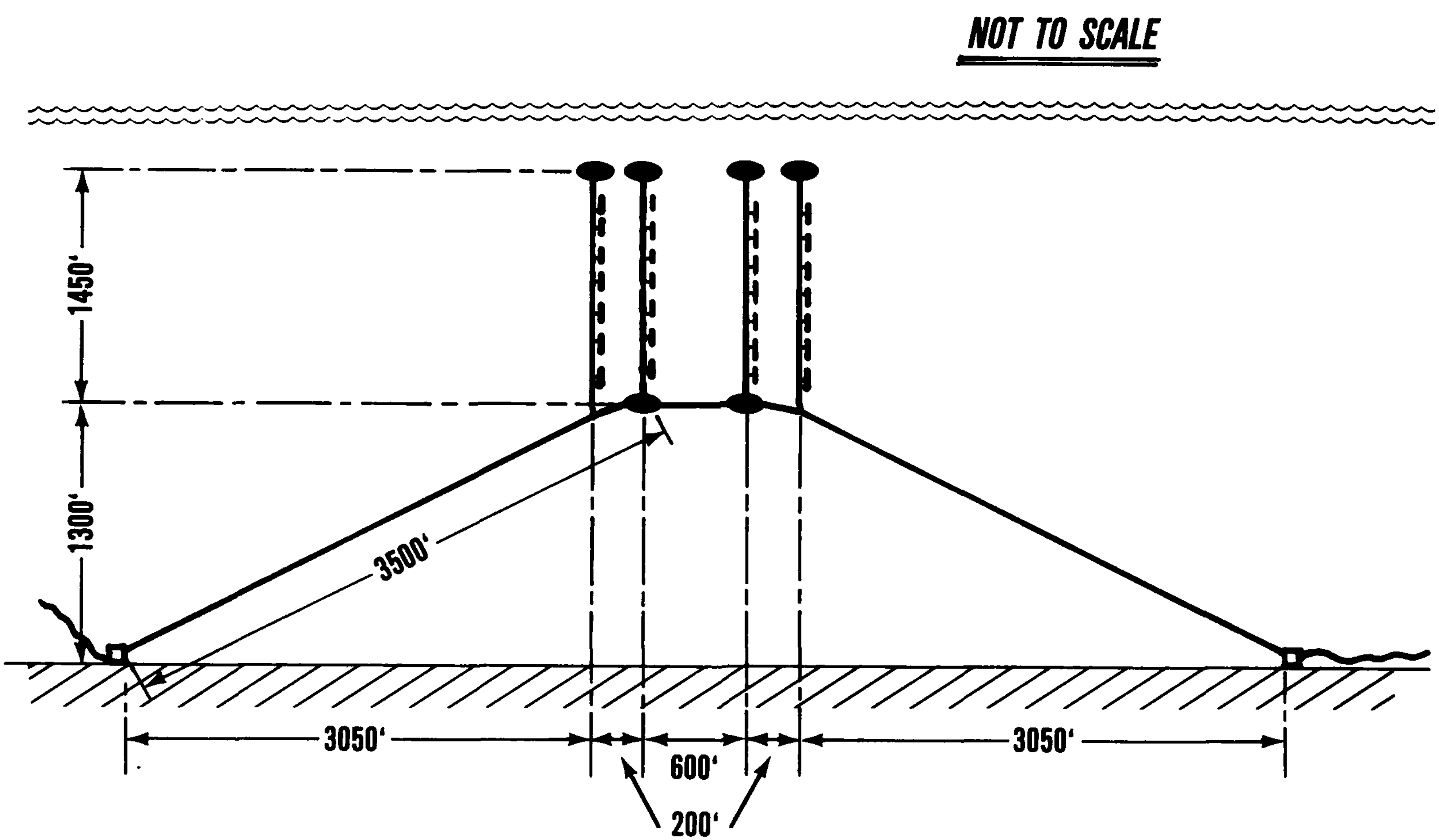


Figure 3. Four String Semi-mobile Array Structure

PART II. REFINED ARRAY CONFIGURATION AND COMPONENT DATA

1. THE SEMI-FIXED ARRAY

The proposed semi-fixed array will consist of two major sections: the trapezoidal shaped base and the two instrumented vertical "goal post" sections (Figure 2). The array will be constructed from different types of electromechanical and mechanical cables. The separate sections of the array are labeled in Figure 4 as a, b ... g, and their individual functions and construction methods are discussed below. The major buoyancy and anchoring locations are labeled A, B, C and D in Figure 4.

The relationship of different array components of the trapezoidal configuration to ocean surface and bottom can be seen in Figure 4. The advantages of the trapezoidal configuration over two completely separate units are numerous. The major advantages are:

- Better relative sensor stabilization
- Ease of deployment (versus two separate vertical arrays)
- Reduced tension in the vertical sensor sections for the same relative displacement
- Horizontal separation of the two sensor sections is fixed.
- Ease of return of the sensor sections to the surface (for instrument replacement and repair) and redeployment at the same location
- Reorientation in vertical plane possible (important for proper reorientation of Cs. magnetometers)
- Only single bottom transmission cable required

A. Cable Sections a and b

a. Mechanical Design

The most critical electromechanical cable requirements will be for cable sections a and b. The availability of Kevlar fiber, which is non-magnetic, has high strength-to-weight ratio and is compliant and non-corrosive, will greatly facilitate the design and fulfill the requirements imposed for the array strength member.

At present there are two candidates for the cable sections: one with an outer polyurethane jacket and the other without. Outer polyurethane provides a degree of fishbite protection to the Kevlar strength member and electrical conductors, but results in a very rigid cable; which makes cable handling and array fabrication more difficult and requires large bending radii. Without the outer polyurethane jacket, the cable is very flexible and easy to handle, and small bending radii can be used during storage, deployment and retrieval. Conductor fishbite protection is provided by a polyurethane jacket on each conductor bundle.

The first cable candidate (Figure 5) is constructed with a central (or inner) strength member consisting of parallel laid Kevlar fibers. This type construction offers maximum strength and minimum fiber elongation. Because there is no interlocking structure in the fibers, this rope will be jacketed for retaining all the fibers in place. Therefore, it is

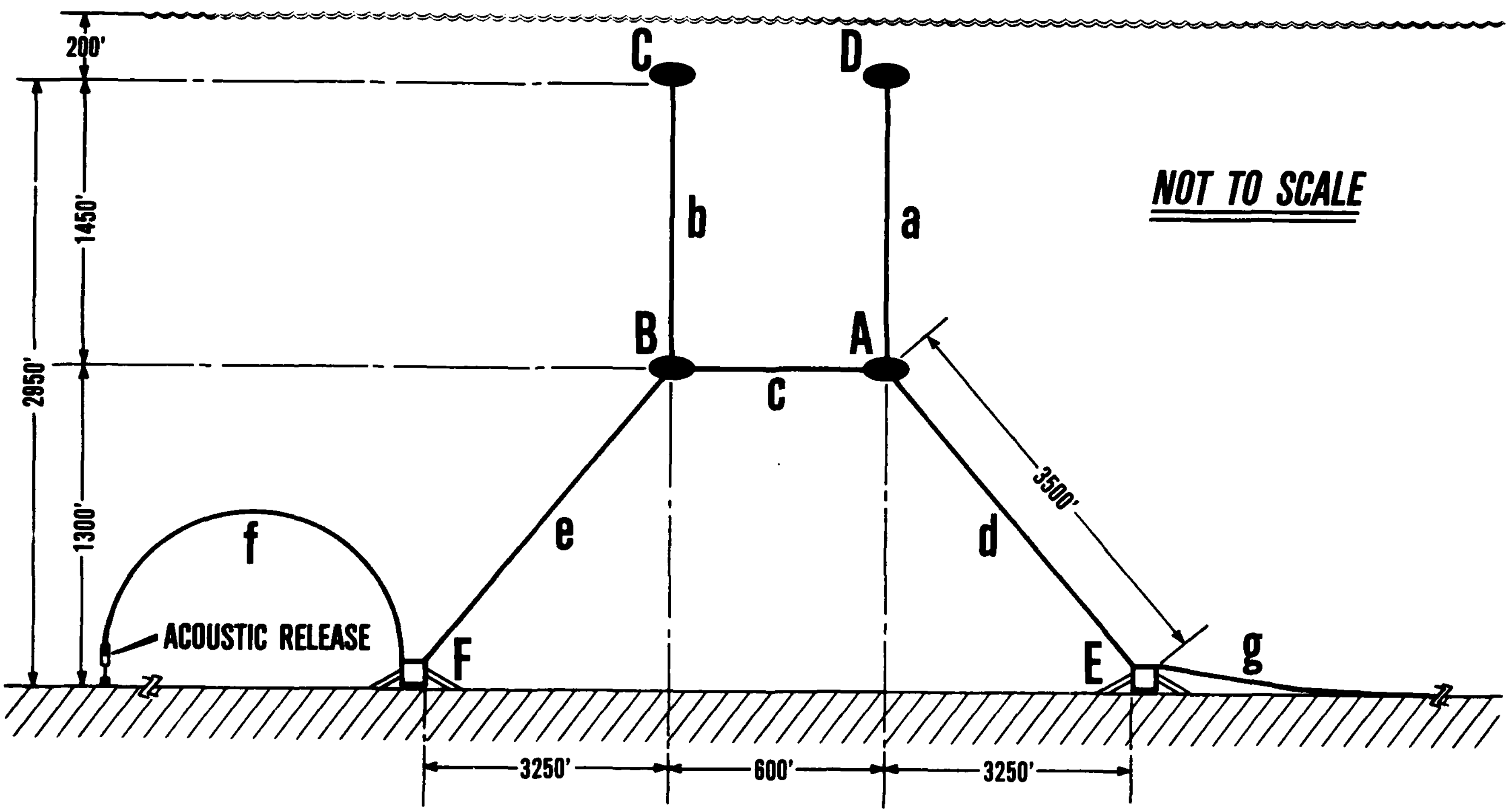


Figure 4. Array Component Identification

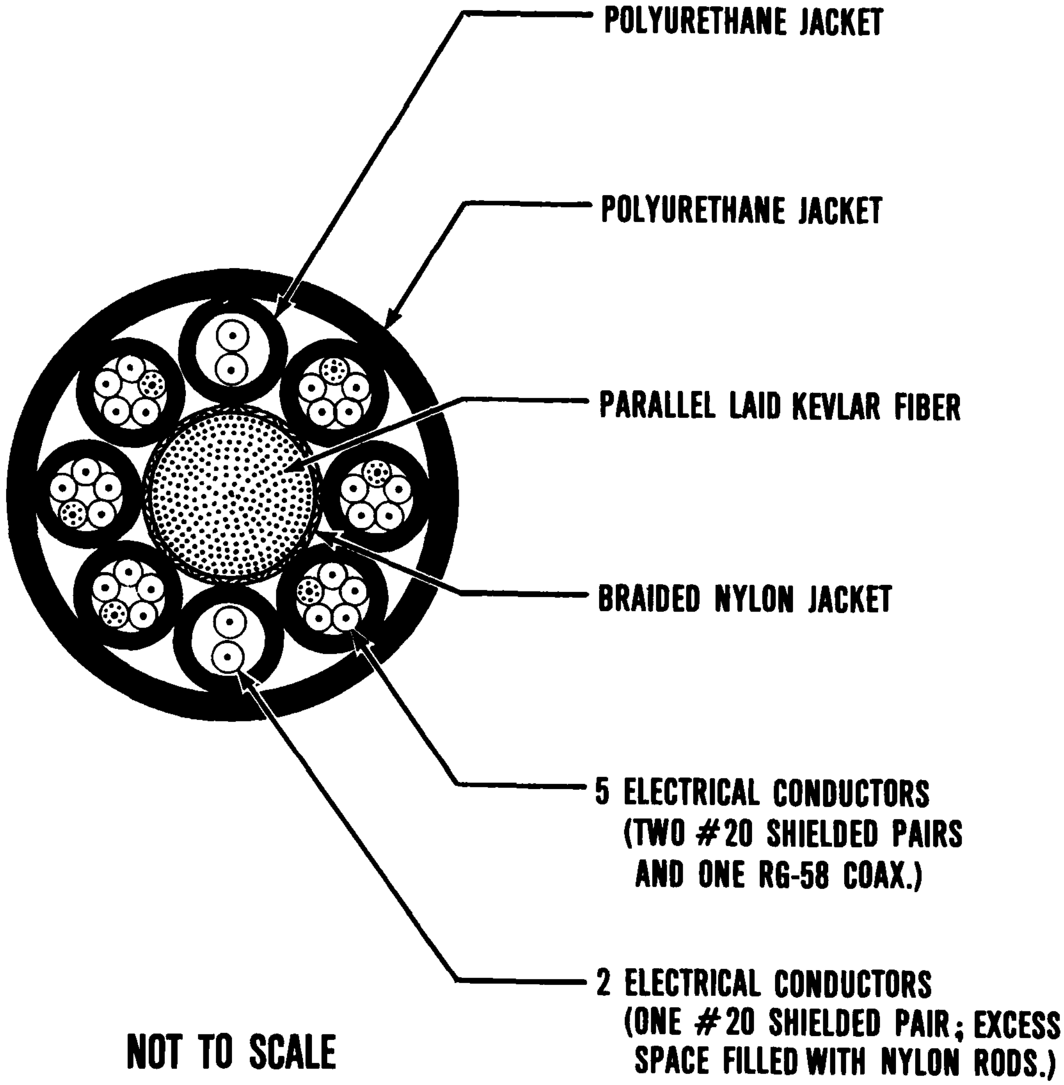


Figure 5. Proposed E/M Cable with Fishbite Protection

planned to use a braided nylon jacket. The parallel laid fibers will be impregnated with a low modulus material, such as neoprene, to improve the rope's mechanical properties and reduce internal abrasion. The Kevlar strength member will serve as a central core encompassed by the eight individually grouped and polyurethane jacketed electrical conductors, spiraled around the central core. Exterior fishbite protection will be provided by a 100 mil outer jacket of hard polyurethane.

The second cable candidate (Figure 6) consists of an outer strength member in the form of a braided Kevlar jacket with an approximate diameter of 3.81 cm. The braided jacket will house eight electrical conductors in bundles. Each bundle will contain the proper conductors as required for each instrument station and will be protected by a 100 mil jacket of polyurethane. For abrasion protection the Kevlar jacket will be overbraided by a nylon outer jacket.

The final determination of which cable to use will be made after more extensive studies are conducted on fishbite incidents and on the severity of the bites on array cables.

b. Electrical Conductors

The weight of copper contained in the electrical conductors contributes practically the entire weight of the array cables when deployed in salt water. Therefore, to minimize total array weight and magnetic eddy current interference on magnetic sensors, the cables will be electrically tapered (i.e., the required conductors for each sensor station will be terminated at that location). The voided space, due to the termination of electrical conductors, will be replaced with a TPR (thermo plastic rubber) rod to retain a constant cable diameter required for applying an extruded outer polyurethane cable jacket. It has been shown that total cable motion and drag are not significantly reduced by tapering the cable mechanically. However, if the cable design with the braided Kevlar jacket is employed, the cable may be tapered mechanically.

The cables will be separated into individual bundles as required by each sensor station. The present requirements for each magnetometer/E-field sensor station are one coaxial RG-58 cable and two pairs (four conductors) of stranded and twisted #20 shielded conductors. Each transducer (pinger) station will require one pair (two cables) of the stranded, twisted #20 shielded conductors.

Each bundle will be jacketed in an outer polyurethane jacket. Since polyurethane lends itself to easy bonding, it will facilitate the molding of electrical connectors to the cable ends which then will mate with the connectors on the sensor housings.

The total weight of copper in the cables, including shields, will be approximately 133.64 kg in air per one vertical instrument section.

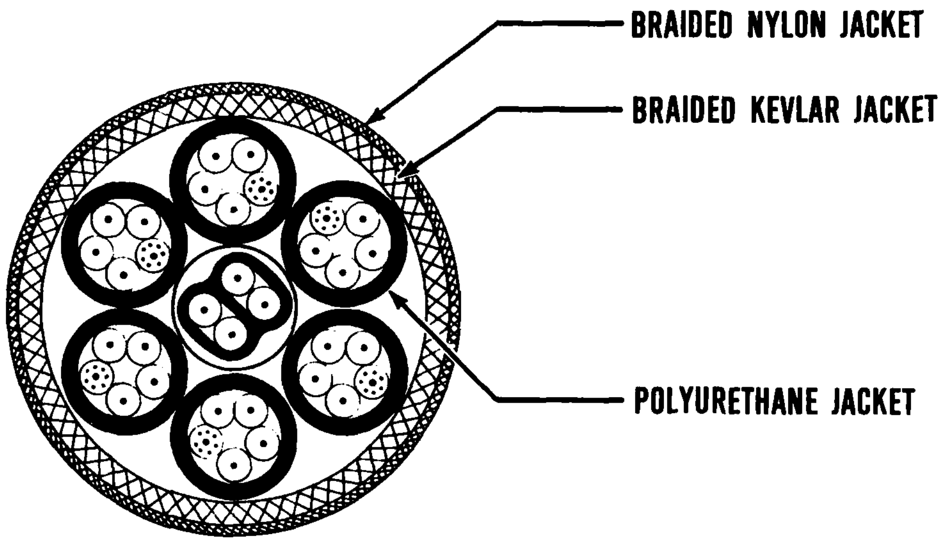
c. Protective Jacketing

The type of protective jacketing used will depend upon which final cable design will be employed.

If additional studies indicate that the planned deployment site is in a fishbite area, then the cable with the 100 mil polyurethane jacket will be utilized in this array system. The same polyurethane jacket will also provide excellent protection against abrasion and other

2 - 3-D TRANSDUCER (PINGER) CABLE BUNDLES ARE SHOWN IN CENTER (EACH BUNDLE CONTAINS ONE #20 SHIELDED PAIR)

6 - MAGNETOMETER/E-FIELD SENSOR CABLE BUNDLES ARE SHOWN SURROUNDING THE CENTRAL CORE (EACH BUNDLE CONTAINS ONE RG-58 COAX. AND TWO #20 SHIELDED PAIRS)



NOT TO SCALE

Figure 6. Proposed E/M Cable without Fishbite Protection

physical damage of mechanical nature during handling, deployment and retrieval. To gain access to the electrical conductors, an incision will be made in the jacket at each sensor location and the proper conductors brought out through the incision. Repairs on each incision may be performed with polyurethane molding. The major disadvantage of the external jacketed cable is its stiff pipe-like handling characteristics. Thus it will be more difficult to fabricate, test and deploy the array. At the present time we have one report concerning mooring line failure due to fishbite in the St. Croix area (included in Appendix A).

On the other hand, if fishbite is determined not to be a serious hazard, then the cable with braided Kevlar and nylon jacket will be utilized. This cable will be much more flexible and easier to use in fabricating an array. Access to the electrical conductors will be provided during the braiding process, when each conductor bundle will be "brought through" each braided jacket at its termination point.

d. Anti-strumming Protection

The primary purpose for incorporating anti-strumming fairing on hydrophone array cables is to reduce noise; the secondary purpose, to reduce end-fitting and cable fatigue, and, to some degree, to lessen fishbite incidents. Anti-strumming fairing generally increased cable drag.

The types of sensors required for LINEAR CHAIR arrays are designed for sensing magnetic and electromagnetic phenomena and the incorporation of anti-strumming devices will not improve their capabilities. Therefore, from the array's instrumentation standpoint such devices are probably not required, but at present it has not been determined if the anti-strumming devices will enhance the array's overall performance.

B. Cable Section c

This cable section is a 182.88 m long horizontal electromechanical cable section connecting the two instrumented sections a and b.

The physical arrangements of all electrical conductors will be identical with sections a and b, the only exception being that all 34 conductors will occupy the entire 182.88 m section and there will be no termination of any conductors in this section. Electrically, this cable section will be continuous with sections b + c as one continuous cable section. The weight of copper due to electrical conductors and shields for this 182.88 m section is approximately 113.25 kg in air.

C. Cable Section d

This section will utilize an electromechanical cable whose design length will depend on the water depth at the array implantation site. At present, for implantation off St. Croix, the required cable length is 1066.80 m. In all cases this section (and section e) will be longer than the water depth at any chosen implantation site, both for successful deployment and for returning the instrumented array section to the surface for repair.

This section will be a specially designed Kevlar reinforced coaxial cable. A similar cable is being developed at NORDA for another application (Figure 7).

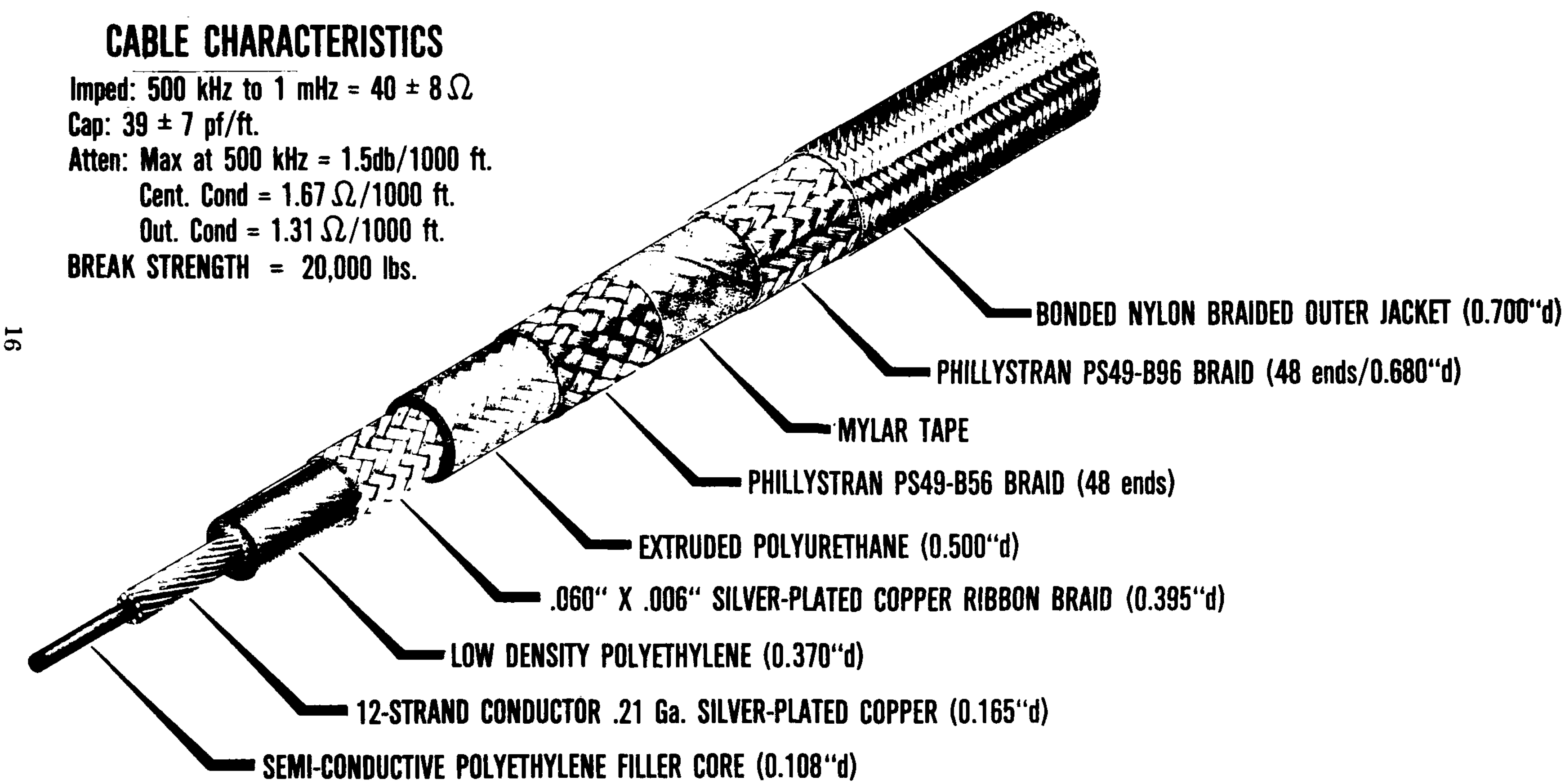


Figure 7. E/M Coaxial Cable

The basic cable configuration, for our requirements, will be similar to this cable, modified in electrical specifications, breaking strength, and utilization of a polyurethane outer jacket with possible attachments of anti-strumming fairing. It is estimated that the total copper weight in this cable will be approximately 333.4 kg in air.

This coaxial cable will be designed to transmit the multiplexed signals, from all the sensors, to the base of the array where it will connect to section g which will transmit the multiplexed signals to a shore facility. Employment of the same cable for section d as planned for section g (described below) is being considered at this time, providing magnetic field, weight, and other mechanical and physical requirements permit this approach. If this approach is adopted, cable section d + g will be continuous and the cable shown in Figure 7 will not be employed. This approach will also eliminate the need for one underwater connector.

D. Cable Section e

This array section will consist only of a mechanical cable of the same length as section d. This cable will be constructed from parallel-laid Kevlar fiber, designed for a breaking strength of approximately 165.344 m tons. Parallel fiber construction offers a smaller diameter cable (for constant strength requirements) which decreases construction costs, reduces cable drag and facilitates handling and storage requirements. With this type construction, a jacketing material is necessary to the cable's structure, and a 100 mil polyurethane outer jacket which will provide fishbite and abrasion protection at the same time is planned.

E. Cable Section g

This cable will be a double caged armored coaxial, torgue free cable with the same minimum electrical requirements as detailed for section d, connecting electrically with cable d at the base of the array (location E, Figure 4) and laid on the ocean bottom to the shore facility for an estimated length of 7.61 km.

F. Cable Section f

This section is a retrieval line whose function is to recover the first anchor (location F) and to retrieve or directionally reposition the complete array system. The retrieval line length has to be longer than the water depth at any given deployment site and, for deployment off St. Croix, will be over 914.40 m. The line will be constructed from parallel laid Kevlar contained within a braided polypropylene jacket, which will make it positively buoyant. The other end, from the anchor, will be attached to a disposable weight and a combination float and acoustic release (Figure 4) which will position this line at a depth where it will not interface with range operations. By activating the acoustic release, the cable can be returned to the ocean surface, when required, for recovering anchor F.

G. Cable Termination

Upper termination of cable sections a and b will be at subsurface buoys C and D where they will be mechanically attached. At the lower subsurface buoy B, cable b will be attached mechanically, and will continue as section c, which will terminate mechanically and electrically at subsurface buoy A. The mechanical termination will be the physical attachment to the buoy, and all electrical conductors will terminate at a signal multiplexing unit. The lower termination of section a will be accomplished in a likewise fashion. Cable d will be mechanically attached to subsurface buoy A and anchor E, electrically originate at the signal multiplexer and connect electrically with cable g at E. Cable e will terminate and will be mechanically attached to subsurface buoy B and anchor F. Line g will be mechanically attached to anchor E and, likewise, cable f will be attached to anchor F.

H. Buoys

The array's geometry and stability requirements call for four major subsurface buoys. The total buoyancy requirements are not determined, especially as related to stability and array motion, and will have to await computer analysis of the complete array system. The general design and construction methods will be very similar to MABS II subsurface buoys (Figure 8), which have been successfully employed and retrieved numerous times.

The buoys used were oblate spheroids with 2.13 m major axis and 1.07 m minor axis and provided 588.90 kg of buoyancy. It was fabricated with an internal aluminum frame which was encapsulated with 17.21 kg/0.028 cubic meter density syntactic foam and covered with a fiberglass coating.

For mechanical termination of array cables, the buoy was equipped with a "pad eye" which provides cable attachments without pinching the cables when the buoys are on deck. In addition, these buoys are equipped with permanently attached deck skids, lifting bridle and handling fixtures.

The subsurface buoy, at location A, will have a central instrument well for housing the multiplex unit in its own pressure vessel.

The array cable sections a, b and c will also contain, at predetermined intervals, clamped-on, football-shaped, syntactic-foam floats to make these array sections positively buoyant for deployment and recovery ease.

I. Anchors

Two anchors will be employed at locations E and F for securing and stabilizing the array in place. The anchors will be specially designed dead weight with spade type attachments to make the anchors resist any directional movement, due to any drag forces, to which the array may be subjected. The same attachments will not restrict retrieval from a soft ocean bottom.

2. MOBILE ARRAY CONFIGURATION

At this time the array is visualized as being used as a single vertical array system consisting of an instrumental cable section, umbilical cable for connecting the array mechanically and electrically with the support ship, and the floats and weights required to keep the instrumented array section stabilized in a vertical position (Figure 9). The instrumented section is conceived as identical in physical, mechanical and electrical properties as section a of the semi-fixed array, including the above listed construction methods and materials utilized with one exception below.

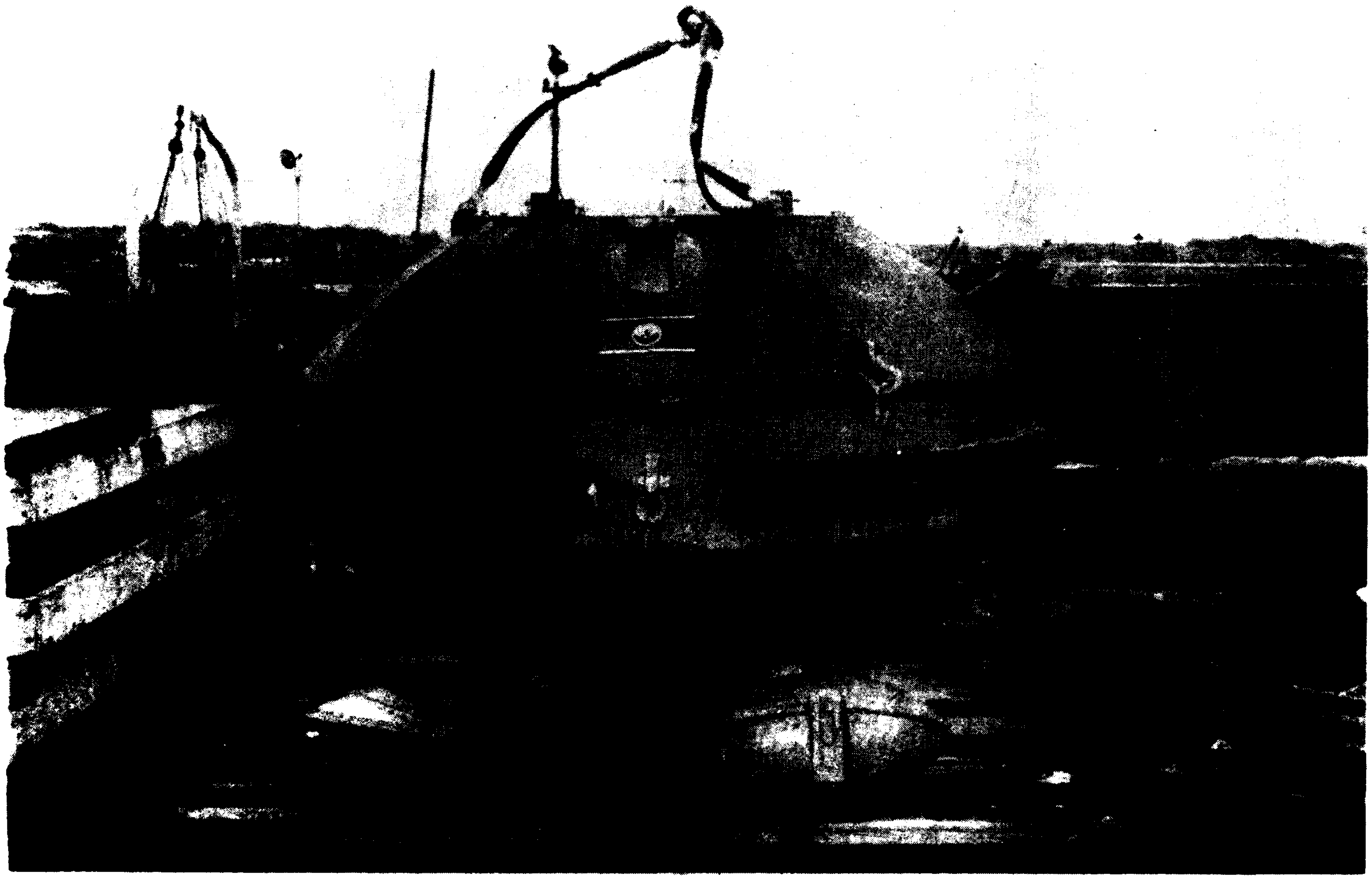


Figure 8. Major and Minor Buoyancy

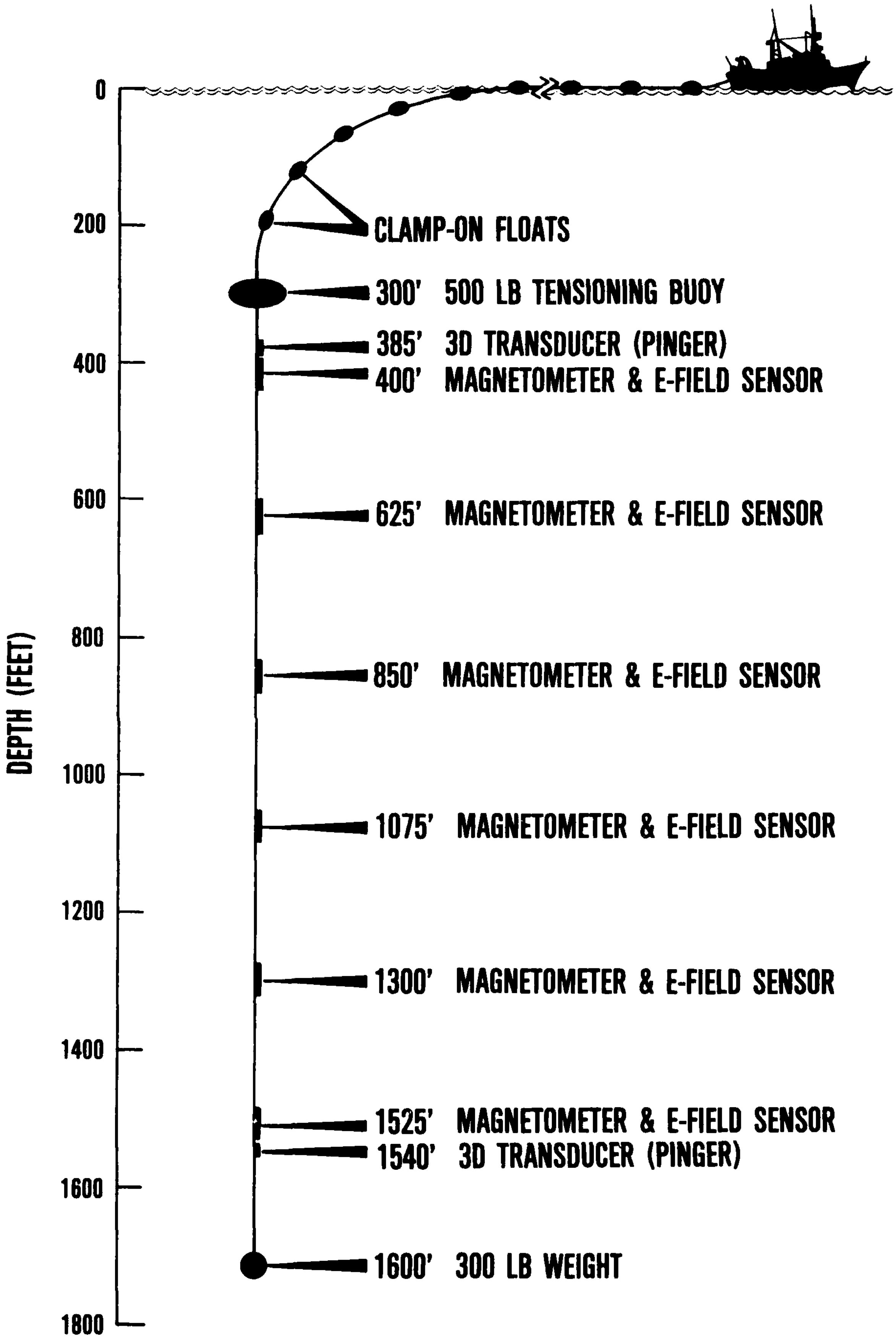


Figure 9. Mobile Array Structure

However, if a duplicate section "a" of the semi-fixed array is employed, then the only difference will be the electric conductors tapered in the opposite direction from section a (the number of conductors will decrease with depth).

The umbilical cable will be identical in mechanical and electrical makeup as cable section d of the semi-fixed array. This coaxial electro/mechanical cable length will be determined as soon as the horizontal separation between the array and the support ship is specified.

Tensioning will be provided at the top and bottom of this section to stabilize the instrumented section of the array in a vertical position. For bottom tension approximately 135.90 kg dead weight, made of nonmetallic material, will be connected to the cable and at the top of this section an approximate 226.50 kg float will be connected to the strength member of the cable. The above figures are preliminary, and ocean current profiles at implantation site and stability requirements will determine the final values.

The upper subsurface tensioning float will be designed and constructed in similar fashion to the larger subsurface buoys employed in the mobile array system. The tensioning float will contain an instrument well for housing the data multiplexer where all electrical conductors from the sensors will terminate. At this point the electrical connection from the umbilical cable to the data multiplexer will be made.

Additional clamp-on, football-type floats will be attached, at predetermined locations, to the umbilical cable for positive buoyancy to support the array at a given depth and decouple it from the surface waves.

Consideration is also being given to an array configuration where the umbilical cable will terminate at a surface buoy equipped with telemetry equipment. The array would be stabilized in place by an expandable bottom weight equipped with an acoustic release. This should remove the requirement for the ship to be in a station-keeping mode, with the advantage of removing the ship's magnetic field from the vicinity of the magnetometers. The ship can then be free to drift at considerable distance from the array and still receive all sensor data, in real time, via the telemetry equipment.

PART III. ARRAY DEPLOYMENT AND RETRIEVAL

1. INTRODUCTION

The array was designed to have physical shape and component dimensions to fulfill the basic array requirements and facilitate array deployment and retrieval. The same properties will also allow for readjustments of the array in the vertical and horizontal plane. Furthermore, the array design allows for return of the instrumented array components to the ocean surface for instrument repair or replacement, and redeployment at the original location and attitude. The array is designed so that the instrumented array sections are under no tension while being deployed or retrieved.

If cables with fishbite protection are utilized, the resultant cable will be stiff and will require large diameter coils aboard the deployment ship.

At present we foresee the need for only one deployment ship, with enough deck space (such as the SEACON) for the different array components to be arranged properly beforehand and stored for deployment in the correct sequence.

It is intended that the following deployment and retrieval description be used by NAVFACENGCOM as a guide in preparing the final deployment and retrieval sequence.

2. ARRAY DEPLOYMENT

The deployment sequence starts with the ship approaching, approximately 304.80 m from anchor F deployment location. While the weighted end of the retrieval line f (Figure 4) is dropped overboard and payed out, the ship is proceeding along the deployment axis. Above anchor F location, the deployment ship assumes station-keeping position, anchor F is lifted and dropped overboard and sinks toward bottom with the attached mooring cable e; which is being payed out at the same time at a rate equal to or faster than the sinking rate of anchor F. When anchor F reaches bottom, the anchor retrieval line, by being positively buoyant, assumes the configuration shown in Figure 4. At this time, the ship proceeds very slowly along the deployment axis; the remaining cable section e is payed out until the connection with subsurface buoy B (which is still aboard), and N is almost reached. At this time the ship assumes a station-keeping position.

At this deployment stage, subsurface buoy B is placed on the ocean surface, followed by subsurface buoy C, to which a temporary tow line is attached. Using this tow line, a workboat proceeds to tow the buoy at right angles to the deployment axis; while the array cable, section b, which is affixed to the buoy, is payed out from the ship's deck. Due to the positive buoyancy of this cable section, it will remain on the ocean surface (Figure 10-1).

After completing the deployment of cable section b, the ship again proceeds slowly along the deployment axis for about 182.88 m, while cable section c is being payed out behind the ship. This section, also having positive buoyancy, will remain on the ocean surface for the present time.

As the connection of cable c to the subsurface buoy A is almost reached, the ship assumes station-keeping position and subsurface buoy A is lifted overboard and placed on

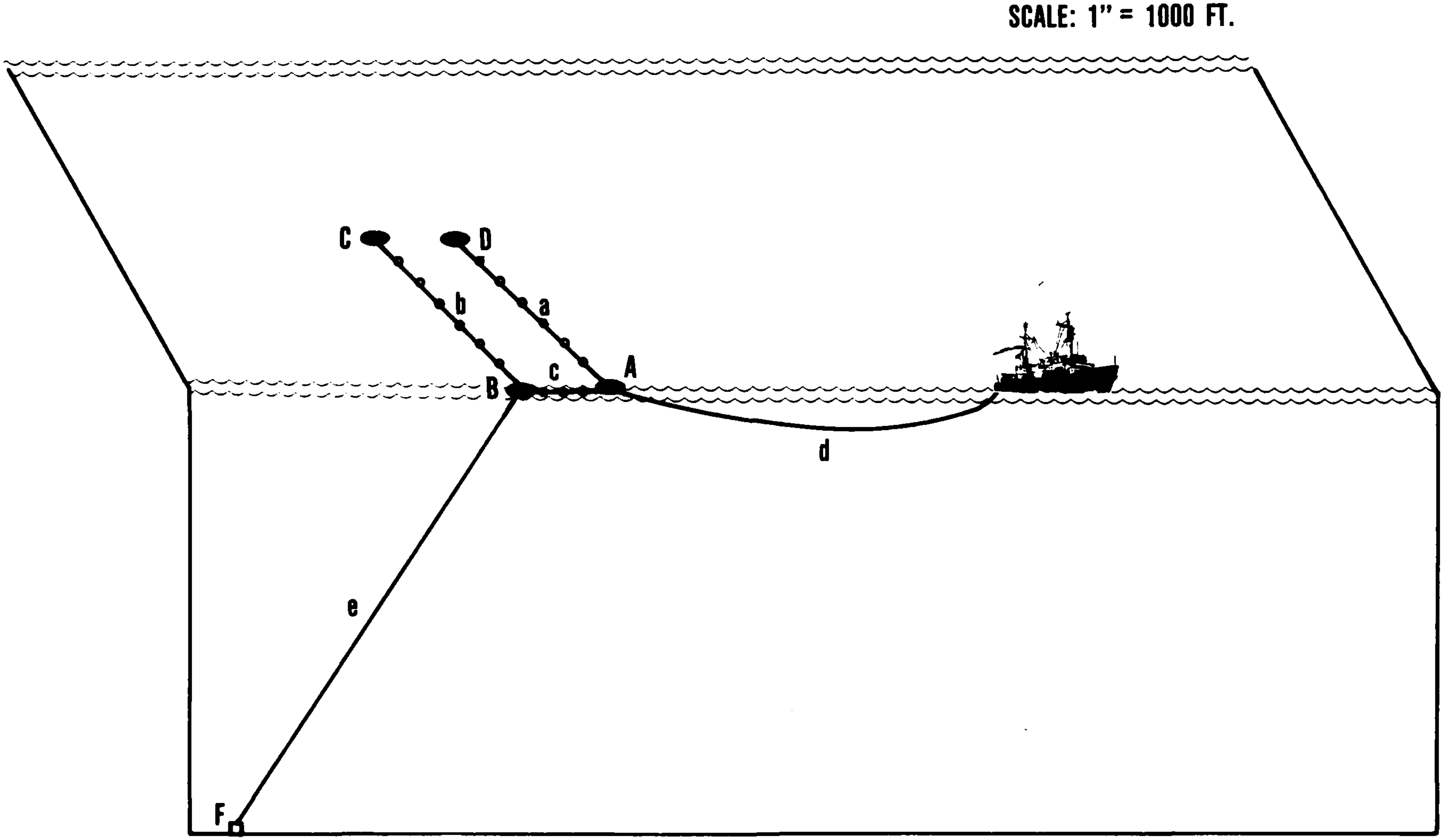


Figure 10.-1 Array in Semi-deployed Position

the ocean surface. Next, subsurface buoy D is lifted overboard and positioned in an identical manner as subsurface buoy C (Figure 10-1). This completes the departure of the instrumented array sections from the ship. Both sections will be positioned at their required operational depth during the next deployment sequence.

The lowering and placing of anchor E at its predetermined location will complete the array's deployment. Cable g, which is mechanically attached to anchor E, will serve as a deployment cable during anchor E's placement sequence. The anchor's weight will be supported by this cable and the payout rate will be controlled with an onboard winch.

This deployment sequence begins with the ship slowly proceeding along the deployment axis. Cable d, which is mechanically attached to subsurface buoy A and anchor E, is payed out at a higher rate than the ship's forward speed so that this section is under no tension. When connection with anchor E is reached, the anchor is lifted overboard and lowered, while supported with cable g.

For previously deployed trapezoidal arrays, it was determined that a ship speed of 1.25 knots and anchor deployment cable payout rate of 1.0 knot was the most practical relative speed needed to properly approach the anchor touchdown location. The ratio of the two variables was used for about 90 percent of total deployment time or until the forward anchor approaches the depth of approximately 152.40 m from the ocean bottom, at which time the payout ratio was decreased.

It was also shown that for any ratio less than the above, the anchor will touch the ocean floor ahead of its designated location and for any ratio greater than the above, unnecessary additional tension would be introduced into the array system.

We are suggesting employing the same procedure with the Linear Chair array system (Figure 10-2), and utilizing both bottom array pingers during the last 152.40 m. This will provide the geometric configuration and relative depth data of the instrumented array sections. By utilizing this method, the deployment ship can maneuver as needed so that the anchor touch down location will result in proper array deployment with no relative tilt in the instrumented array sections (Figure 10-3).

The remaining task is to make the electrical connection with the shore facility. This is accomplished by the deployment ship's changing course toward the shore facility while paying out the remainder of cable section g and transporting the cable end ashore.

3. ARRAY READJUSTMENTS

Array readjustments can be accomplished, if required, as long as the deployment ship, or an equally equipped ship, is available. The end of the retrieval line is secured by activating the acoustic release, and it is brought aboard and affixed to a ship's winch. Anchor F is now raised for a short distance, clearing the ocean floor and freeing the array for mobility.

For tilt adjustments the ship can proceed in either direction along the deployment axis, transporting and separating (or closing in) anchor F from anchor E which will adjust subsurface buoy B upward or downward. After completion of these adjustments, anchor F is lowered again to the ocean floor.

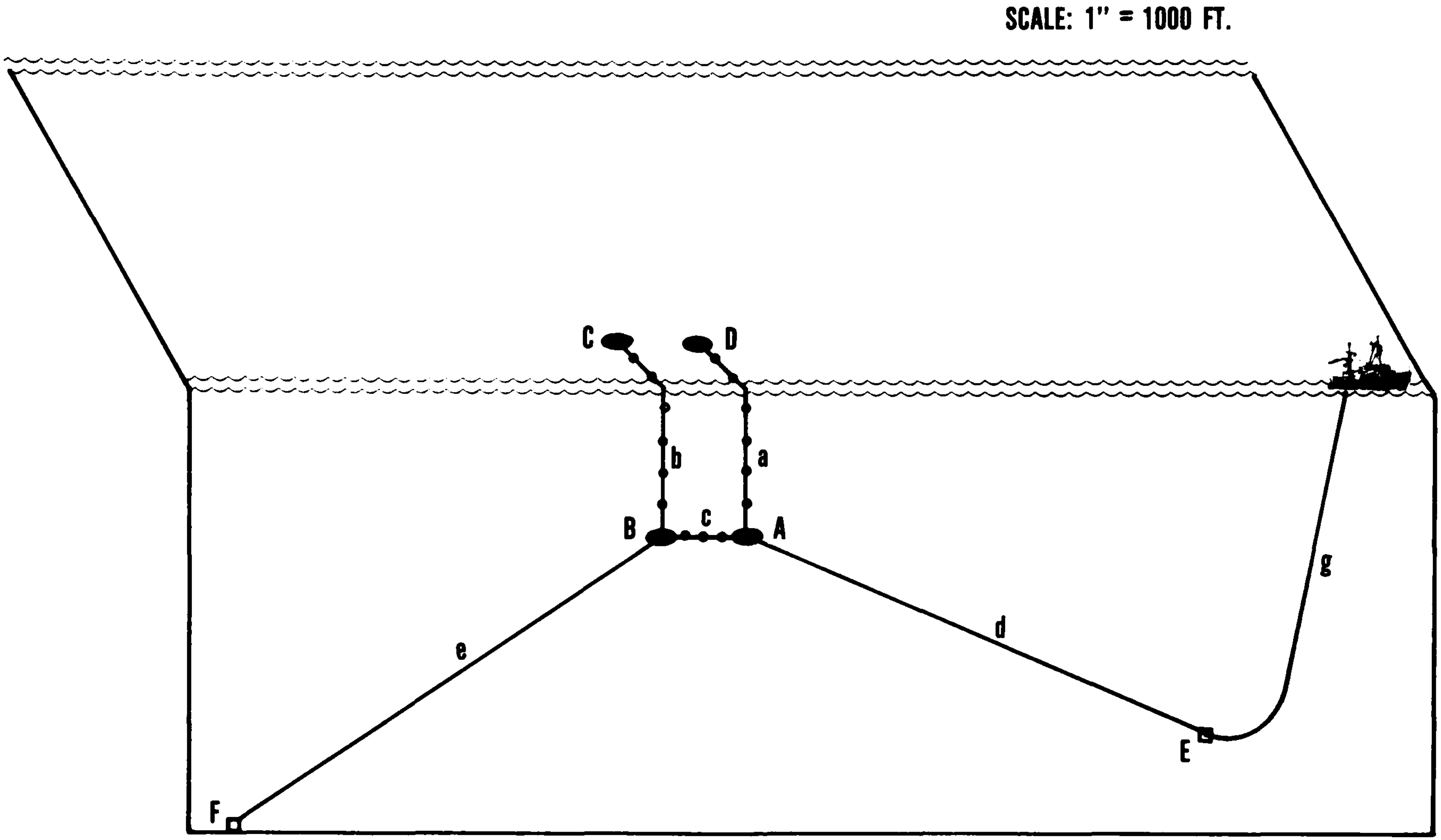


Figure 10.-2 Array in Semi-deployed Position

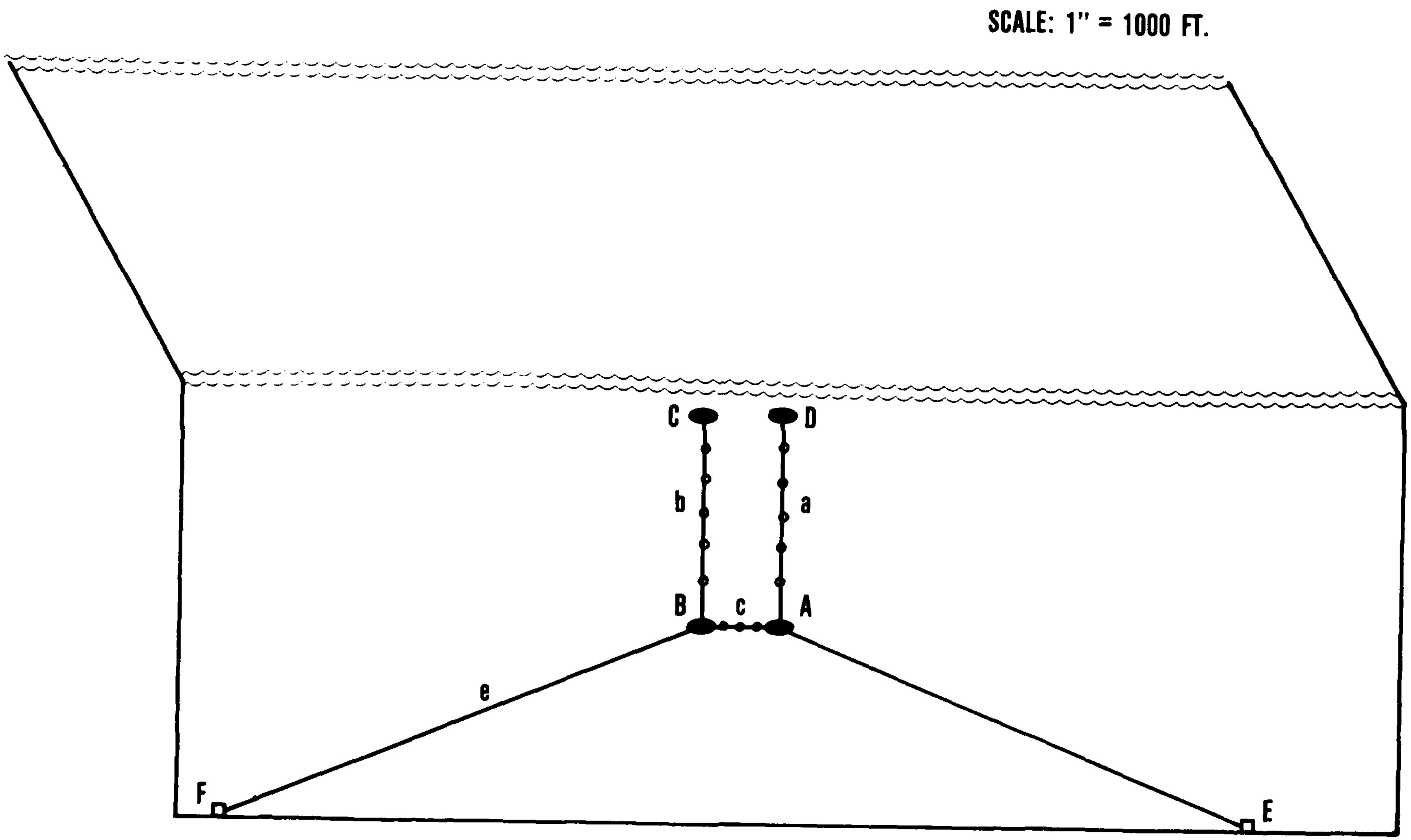


Figure 10.-3 Array in Deployed Position

For required array adjustments in the vertical plane, the ship (after anchor F is raised off the ocean floor) moves at right angles (in the required direction) from the deployment axis and pulls the array in a new alignment while anchor E serves as a pivot point. Anchor F is lowered again to the ocean floor and the end of the retrieval line is put overboard similar to the original deployment.

4. ARRAY SENSOR RESURFACING

If necessary, the return of the instrumented cable sections to the surface, for sensor repairs or replacements, can be accomplished by initiating the same tactics as for the array readjustments described above; but in this case anchor F is allowed to recede back toward anchor E until buoys A and B surface. Cable sections a, b and c will rise to the surface and remain there because of their positive buoyancy. The array can be redeployed at the same location by moving anchor F to its original position.

5. ARRAY RETRIEVAL

The retrieval sequence will be almost the reverse of the deployment sequence. The shore end of cable g is secured aboard the ship and reeled in while the ship is moving at the same rate toward anchor E location. As the ship approaches, the cable will serve as a retrieval line to raise and bring anchor E aboard. As anchor E is brought to the surface, cable sections a, b and c and subsurface buoys A, B, C and D will rise to the surface. Once anchor E is aboard, mooring cable d is reeled in while the ship proceeds at the same rate toward anchor F location. When cable d is secured, the ship assumes station-keeping position while subsurface buoy D is towed in by a work boat and retrieved. The instrumented cable section a is next secured aboard.

Cable section c is reeled in while the ship proceeds at the same rate toward subsurface buoy B. At this point the ship again assumes station keeping position and subsurface buoy C and the instrumented cable section b is retrieved in the same manner as buoy D and cable a.

To remove tension and provide slack to the remaining subsurface buoy B and cable e, the ship proceeds very slowly to the location directly above anchor F while towing buoy B. Once above the anchor location, there will be enough slack in cable e to bring buoy B aboard.

In the last retrieval step, the upper end of the retrieval cable f is raised to the ocean surface, by activating the acoustic release, and brought aboard by a work boat. With the aid of a ship's winch, anchor F is raised and secured aboard, and the last mooring cable e is reeled in and secured.

PART IV. ARRAY PHYSICAL PERFORMANCE IN THE OCEAN

1. ARRAY MOTION ANALYSIS

The deflection of the LINEAR CHAIR "goal post" array, due to ocean currents (utilizing the best available current data off St. Croix Island) was calculated by using the DESAD computer program. The deflection was computed for four buoyancy conditions and three different ocean current profiles. All calculations were performed for a mooring angle of 22° (included angle between mooring line and the sea floor) since the value is fixed by the array dimensions, configuration, and water depth.

The array, in its moored configuration, was treated as five separate cables (Figure 11). Letters J and C designate the cable junctions and cable numbers, respectively. Each cable length S begins with S=O feet to S=L feet, where L is the maximum length of the cable. The direction of increasing values of S in each cable is shown with arrows in Figure 11.

All the devices on the array are located by cable number and S distance and the physical arrangements of all devices are shown in Figure 11 and in detail in Table 1. The total number of the small clamp-on floats (Figure 12) could change in the final array specifications, since they are used to keep cable sections C3, 4, and 5 positively buoyant. Table 1 also gives frontal areas for the array devices and Figures 13 and 14 show device dimensions. Table 2 shows drag coefficients used in calculations.

Spheroidal shapes were used to determine the frontal areas of the large subsurface buoys with different buoyancy values. A constant diameter of 3.18 cm was assumed for all array cables.

The array deflection was calculated for three ocean current conditions:

- The first current profile was constructed by using 90 percent of maximum current speed from the D. Burns data (NORDA Code 330), which is the most recent ocean current data available from the St. Croix area.
- The second current profile was provided by NAVFACENGCOM.
- The third profile exceeds the maximum current recorded off St. Croix and was used for predicting array motion. Most calculations were performed with the first current profile (Figure 15).

The current angle was varied from 0° to 90° in 30° increments and the array structure is subjected to current forces in the x and y direction.

In the first set of calculations, using the first current profile, the array deflection in the x, y, and z plane was calculated at locations J3, J4, J5 and J6 using 453 kg to 3.63 mt buoyancy for each subsurface buoy.

The results show that the maximum deflection occurred at J4 and J5 at current angle of 0°. Figure 16 shows x-deflection in feet and tension at anchor as related to buoyancy.

In the y axis, the maximum deflection occurred at J4 and J5 at current angle of 90°. Figure 17 shows y-deflection versus buoyancy.

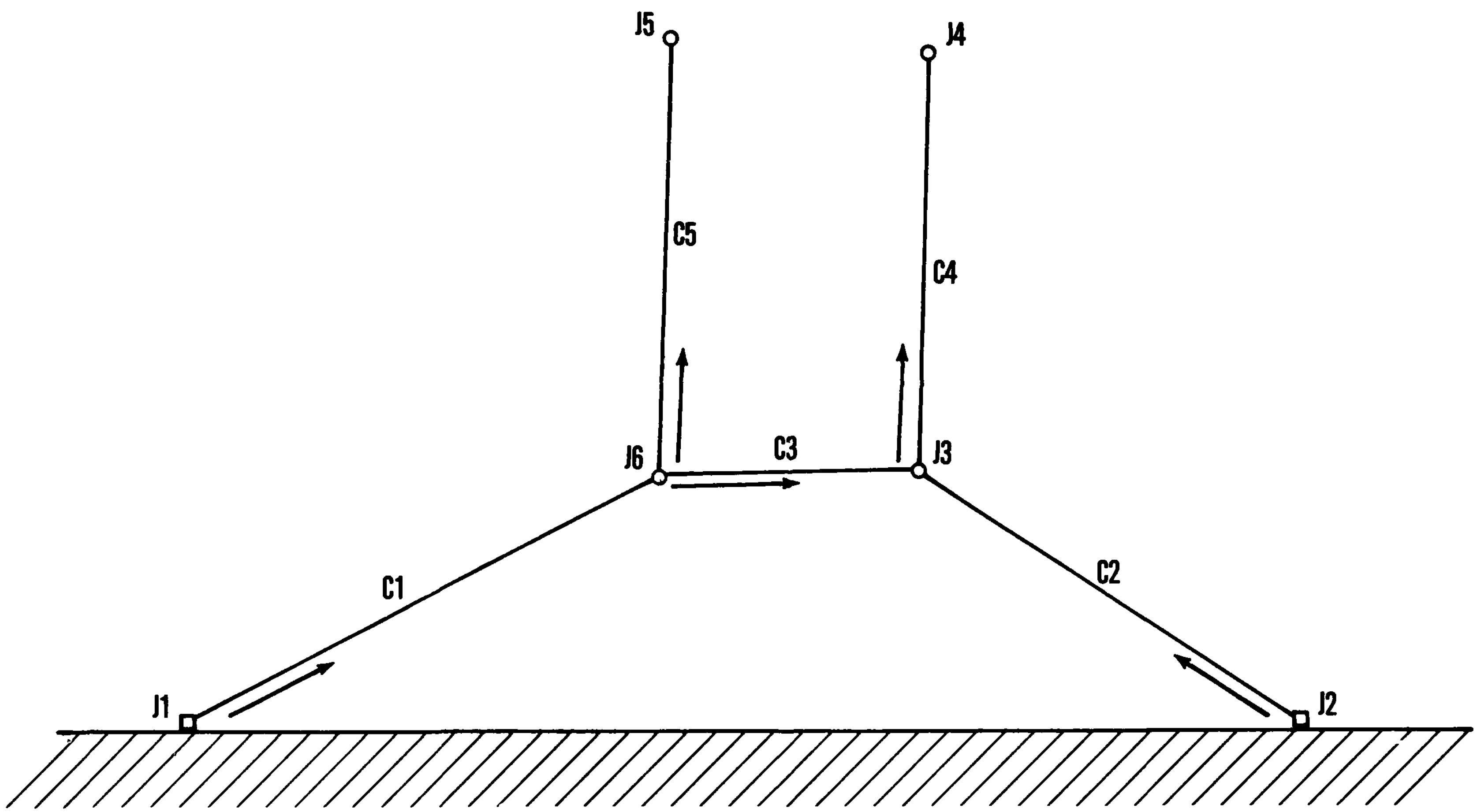


Figure 11. Array Component Motion Identification

Table 1. Device Listing

DEVICE NUMBER	DEVICE NAME	LOCATION (S-DISTANCE)	WEIGHT IN WATER LB.	FRONTAL AREA IN FT^2	NOTES
CABLE C1					
1	Float	3500	+3000	22.9	Large subsurface buoy
CABLE C2					
2	Float	3500	+3000	22.9	Large subsurface buoy
CABLE C3					
3	Float	67	+25	1.0	Football type clamp-on float
4	Float	134	+25	1.0	Football type clamp-on float
5	Float	201	+25	1.0	Football type clamp-on float
6	Float	268	+25	1.0	Football type clamp-on float
7	Float	335	+25	1.0	Football type clamp-on float
8	Float	402	+25	1.0	Football type clamp-on float
9	Float	469	+25	1.0	Football type clamp-on float
10	Float	536	+25	1.0	Football type clamp-on float
11	Float	600	+3000	22.9	Large subsurface buoy
CABLE C4					
12	Instrument	110	0	1.5	Tracking Transducer (Pinger)
13	Instrument	125	0	3.0	Magnetometer
14	Float	132	+25	1.0	Football type clamp-on float
15	Float	264	+25	1.0	Football type clamp-on float
16	Instrument	350	0	3.0	Magnetometer
17	Float	396	+25	1.0	Football type clamp-on float

Table 1. Device Listing (Cont'd)

DEVICE NUMBER	DEVICE NAME	LOCATION (S-DISTANCE)	WEIGHT IN WATER LB.	FRONTAL AREA IN FT^2	NOTES
18	Float	528	+25	1.0	Football type clamp-on float
19	Instrument	575	0	3.0	Magnetometer
20	Float	660	+25	1.0	Football type clamp-on float
21	Float	792	+25	1.0	Football type clamp-on float
22	Instrument	800	0	3.0	Magnetometer
23	Float	929	+25	1.0	Football type clamp-on float
24	Instrument	1025	0	3.0	Magnetometer
25	Float	1056	+25	1.0	Football type clamp-on float
26	Float	1188	+25	1.0	Football type clamp-on float
27	Instrument	1250	0	3.0	Magnetometer
28	Instrument	1265	0	1.5	Tracking Transducer (Pinger)
29	Float	1320	+25	1.0	Football type clamp-on float
30	Float	1450	+3000	22.9	Large subsurface buoy

Table 2. Drag Coefficients

DEVICE	VALUE
All Cables	1.5
Subsurface Buoys	.45
Clamp on football type floats	.07
Instrument Containers	.80

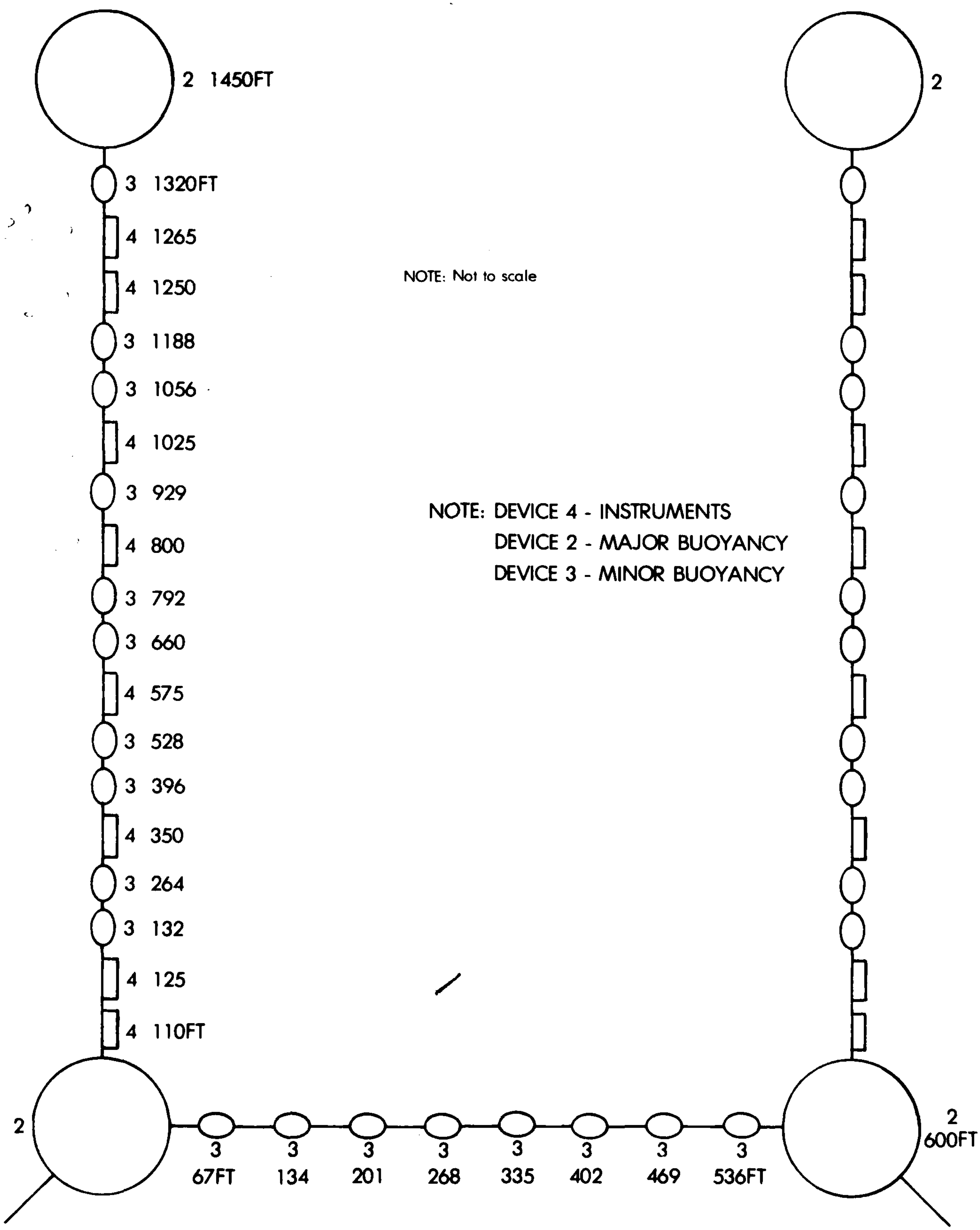
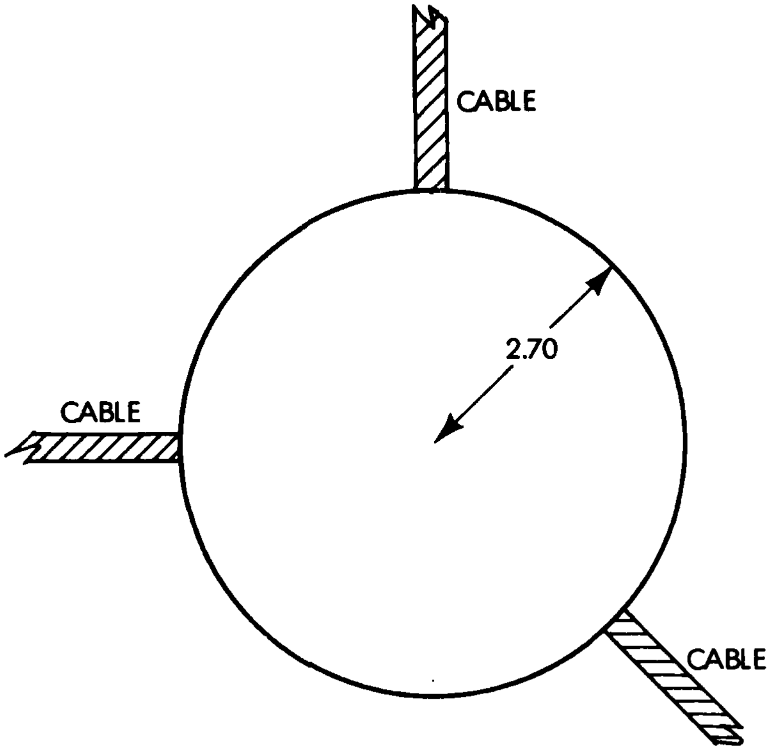


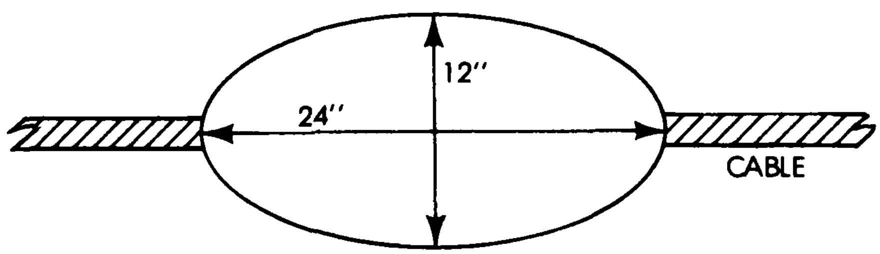
Figure 12. Array Device Location

MAJOR FLOTATION BUOY



BUOYANCY FORCE = +3000LB
FRONTAL AREA = 22.9FT^2
DENSITY = 26 LBS/CU FT

MINOR FLOTATION



BUOYANCY FORCE = +25LB
FRONTAL AREA = 1.0FT^2

Figure 13. Buoyancy Device Dimensions

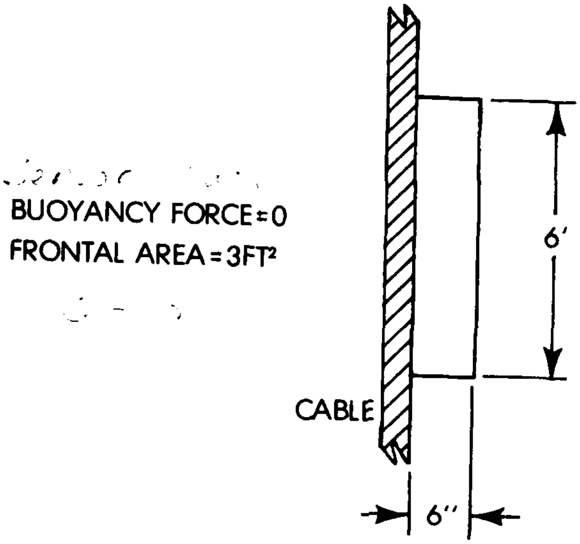


Figure 4a

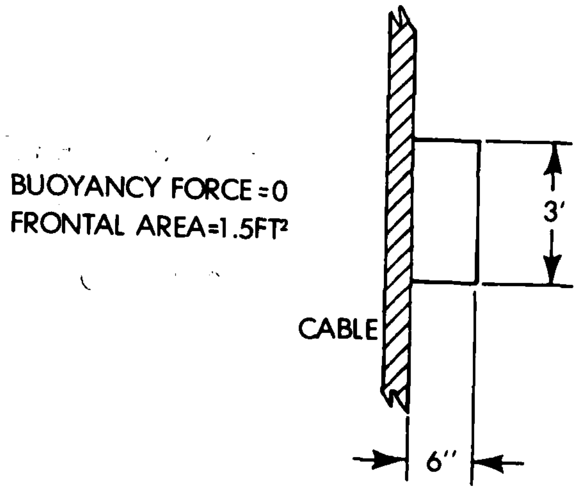


Figure 14. Instrumentation Dimensions

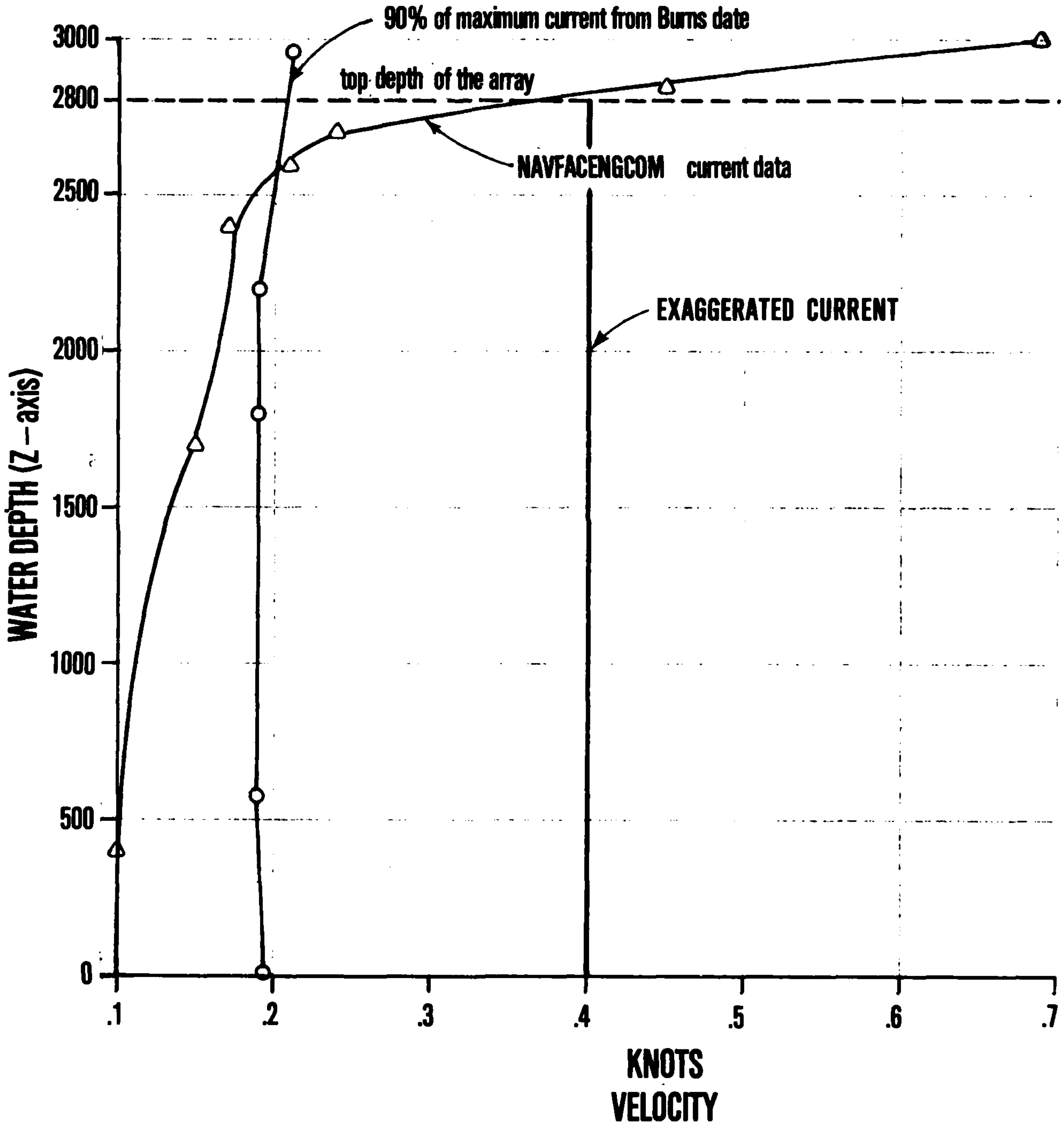


Figure 15. Ocean Current Profiles for St. Croix Area

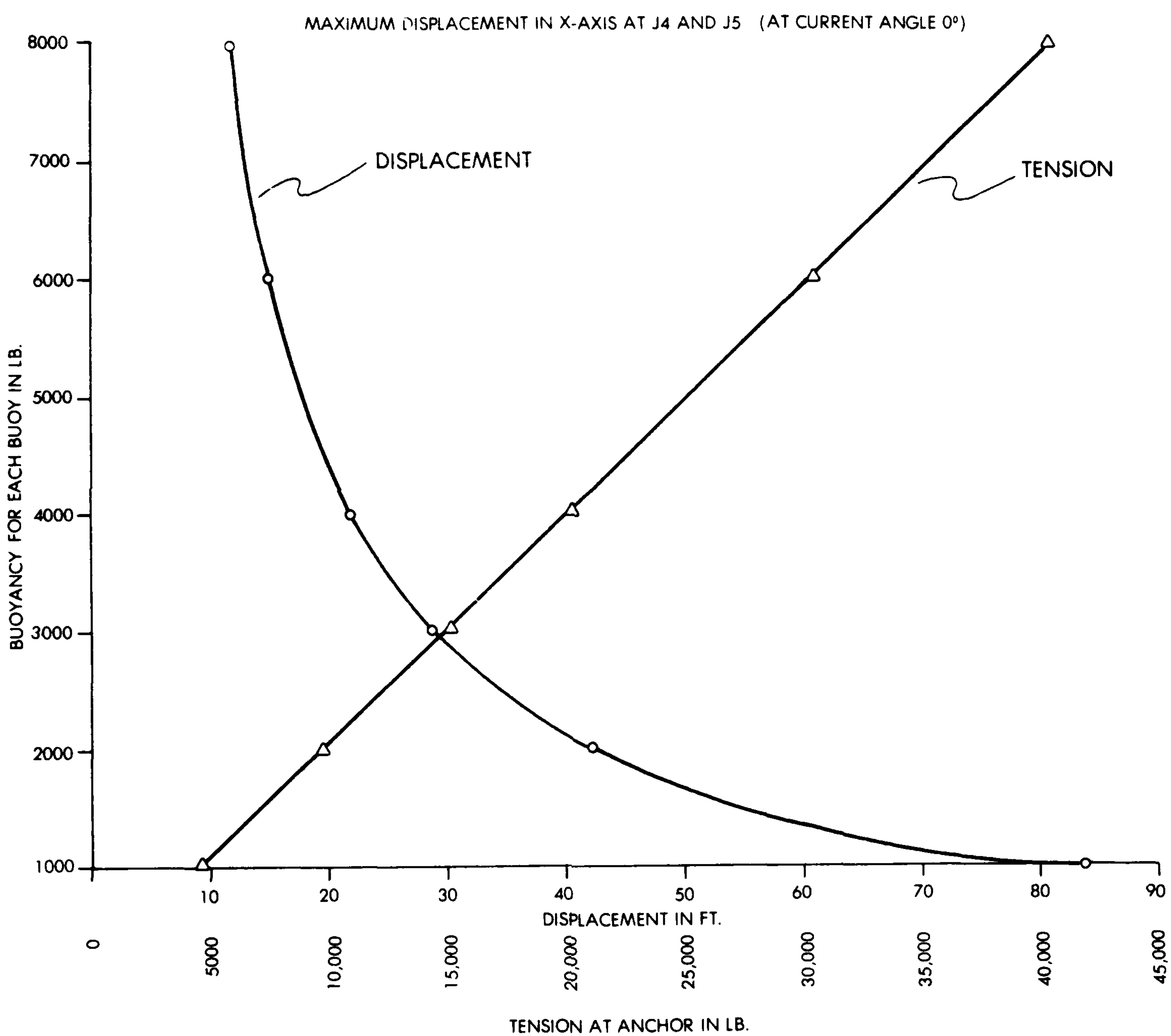


Figure 16. Displacement in x-axis (with .2 Knot Current)

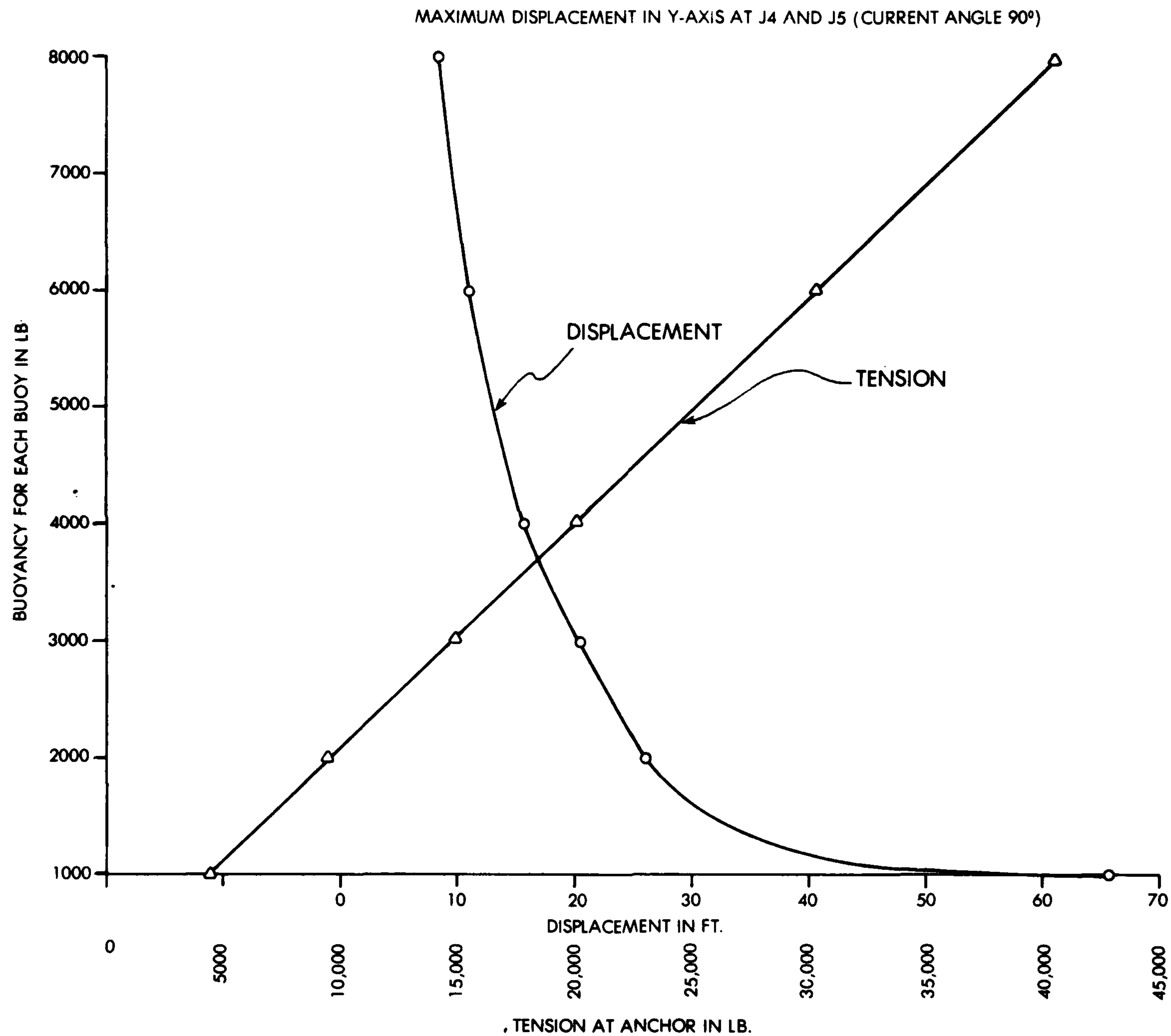


Figure 17. Displacement in y-axis (with .2 Knot Current)

The maximum deflection in z-axis occurred in J4 and J5 at 30° current angle, however, the true maximum deflection in z-axis will occur at current angle 45°, for which there was no computer call out. Figure 18 shows the z-deflection versus buoyancy. In the z-axis all the values are negligible and no array deflection is expected.

One set of calculations was performed to determine the maximum deflection at each device location for all devices or cables C4 and C5, with 3000 lb buoyancy for each subsurface buoy. The maximum deflection of each device in the x and y axes is shown in Figures 19 and 20, respectively. For the z-axis, at all device locations, there is a constant +0.3 ft deflection for cable C4 and a constant -0.3 ft deflection for cable C5, for a current angle of 30°. It was also shown that there is no bow type deflection in cable C3 for any current direction.

A second set of calculations was performed with current profile provided by NAVFACENGCOM. The displacement at array junctions is shown for all three axes in Table 3. Table 4 lists similar data derived by employing D. Burns' current data. Direct comparison of the two tables shows the difference in displacements using the two current profiles. Figures 21, 22 and 23 show the expected array displacement when subjected to exaggerated current profile, and Figure 24 shows absolute and relative device locations due to the same current profile.

2. REMARKS

The results of the above array deflection studies show that the absolute maximum array motion is of small value for a complex array. Furthermore, Figures 19 and 20 show that for two adjacent magnetometers, the relative displacement is approximately one foot in the x and y axes, and is negligible in the z axis.

The direct comparison of Tables 3 and 4 indicate that (NAVFACENGCOM current data and D. Burns data) array deflection values are in close agreement.

Figures 16 and 17 indicate that if buoyancy for the four major buoys is decreased from 3000 to 2000 pounds each, the mooring line tension would be reduced from 15,000 lbs to 10,000 lbs and array displacement would only increase by approximately 6 feet in the x and y direction. The same figures also show that when the major buoyancy is decreased from 2000 to 1000 lb, the array motion increases drastically 20 feet in the x direction and 40 feet in the y direction.

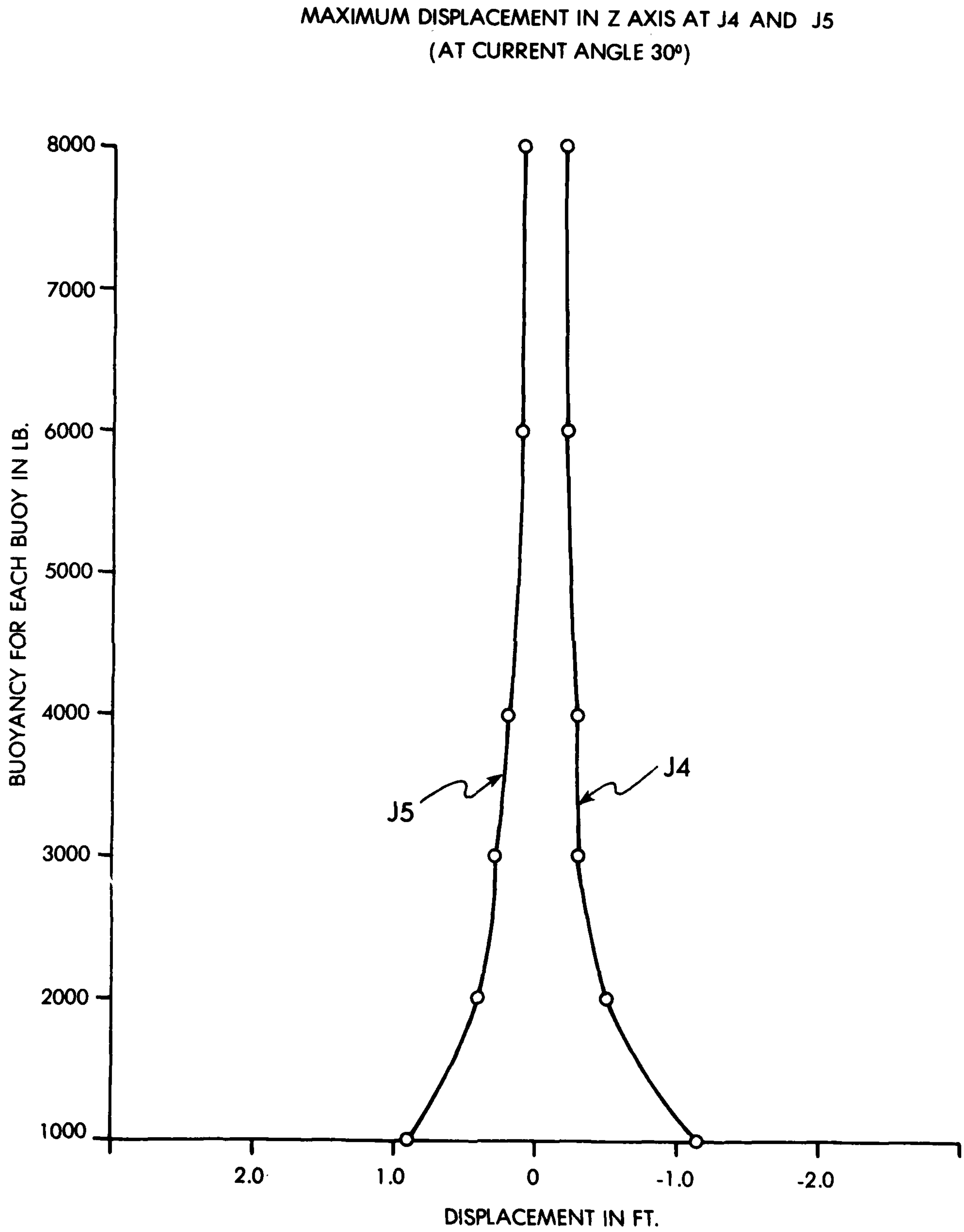


Figure 18. Displacement in z-axis (with .2 Knot Current)

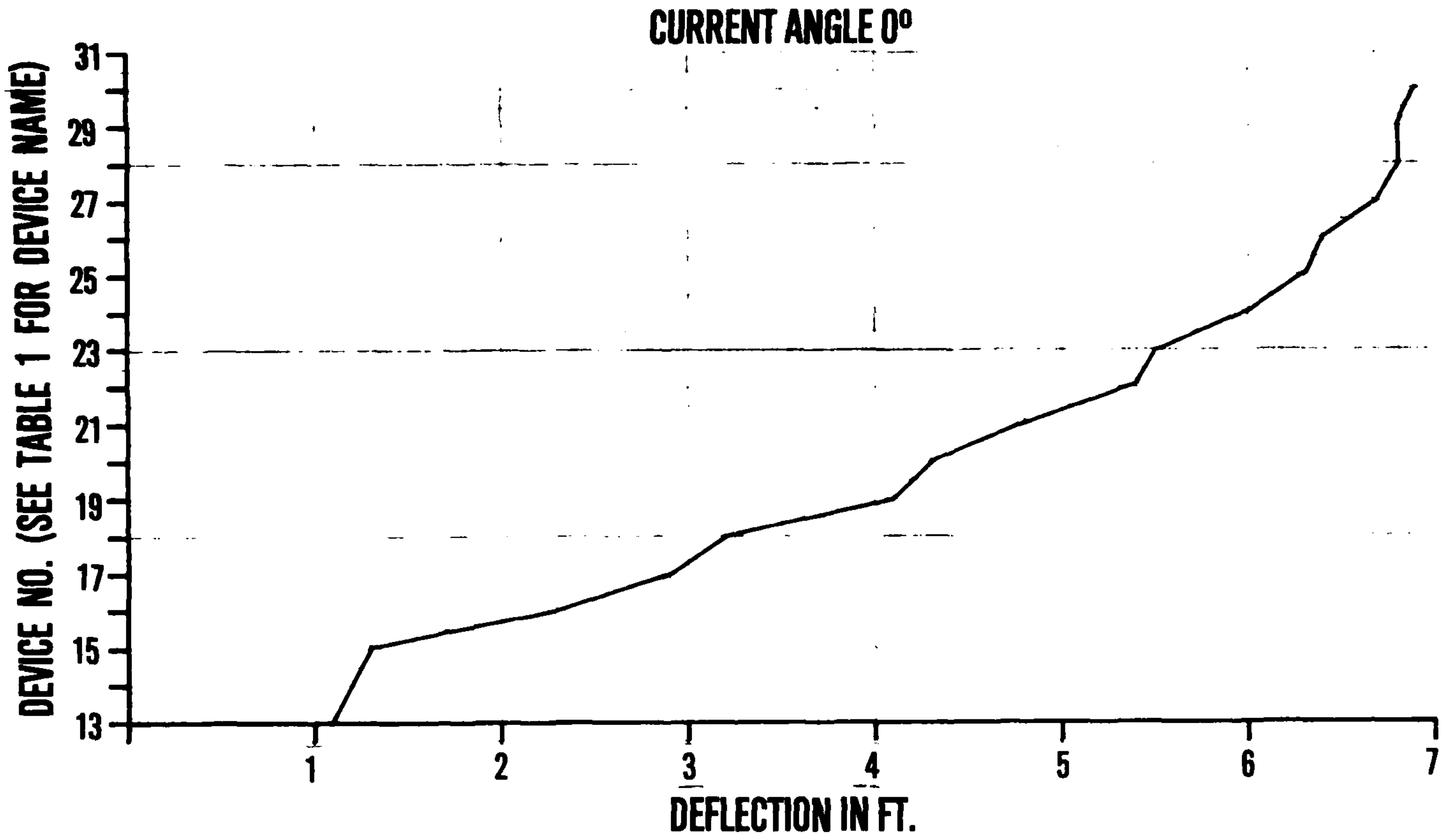


Figure 19. Device Deflection in x-axis (with .2 Knot Current)

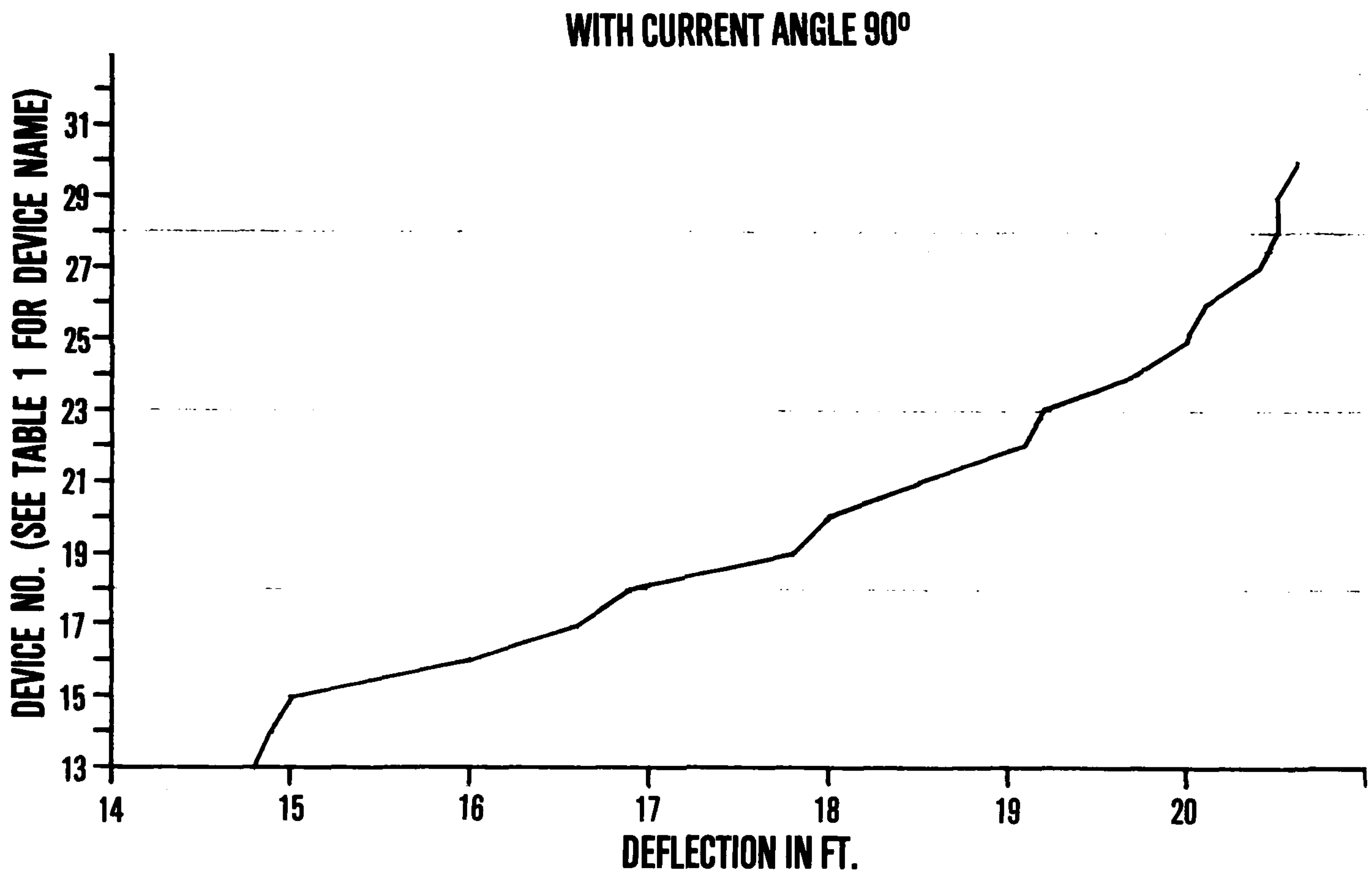


Figure 20. Device Deflection in y-axis (with .2 Knot Current)

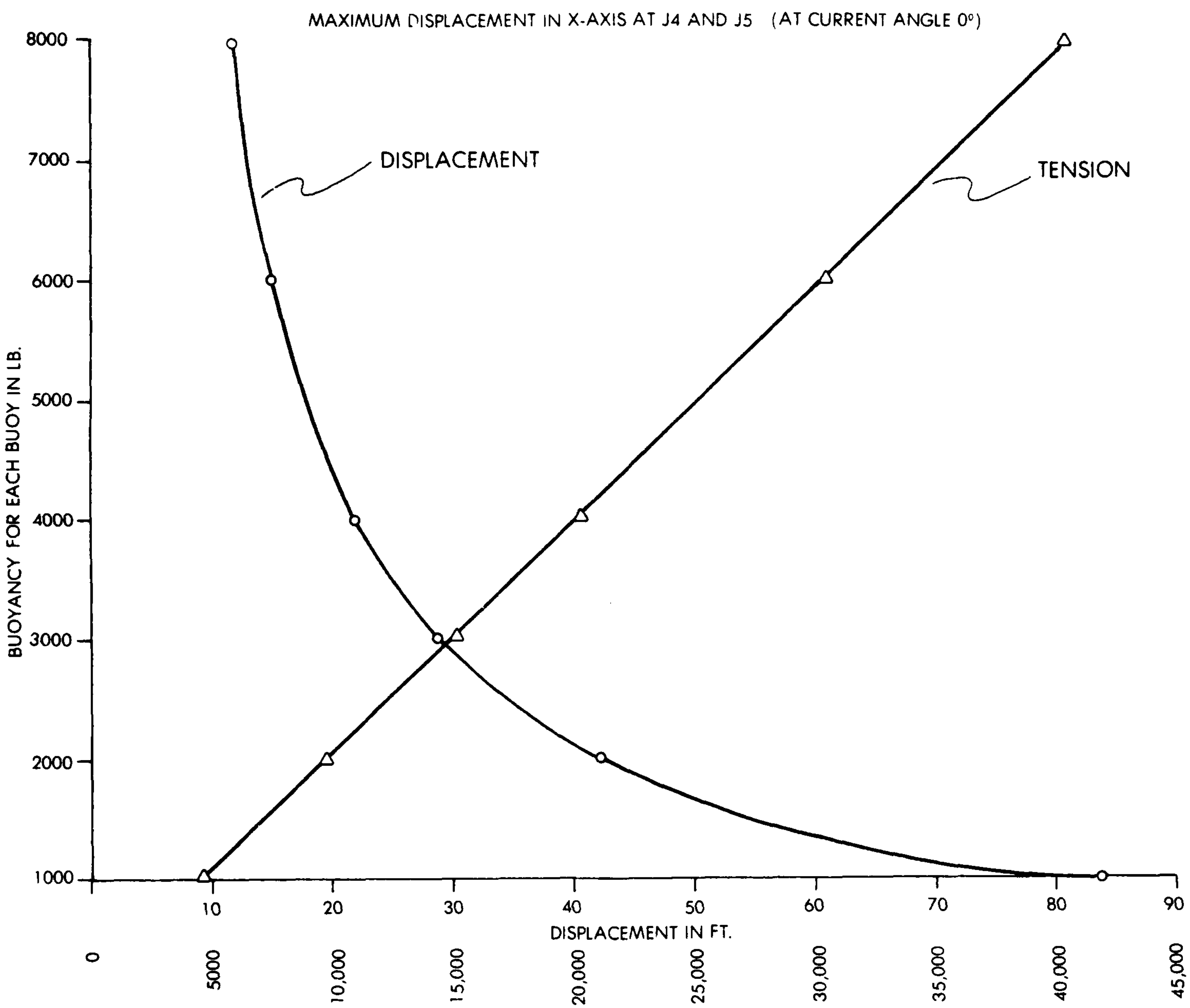


Figure 21. Displacement in x-axis (with .4 Knot Current)

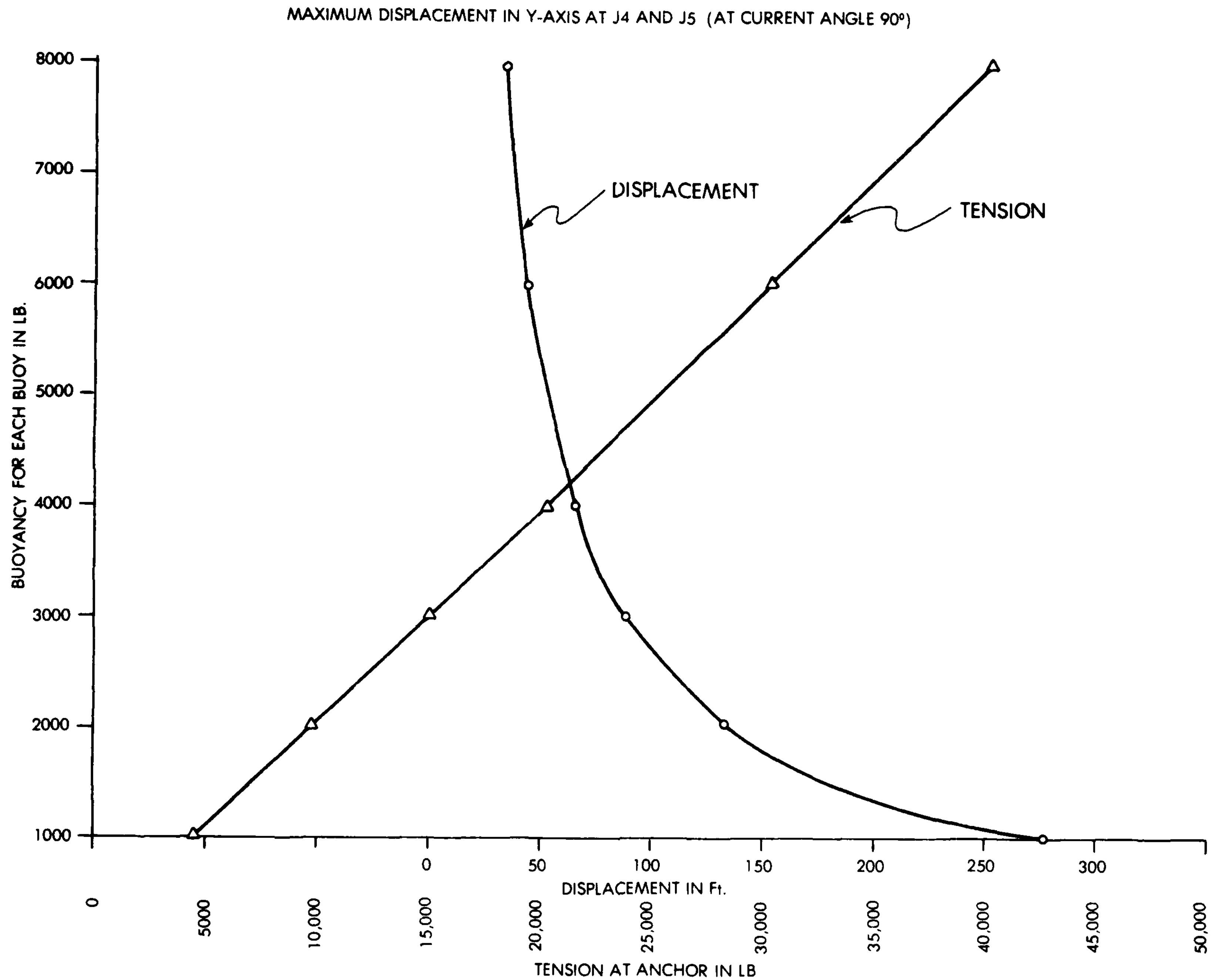


Figure 22. Displacement in y-axis (with .4 Knot Current)

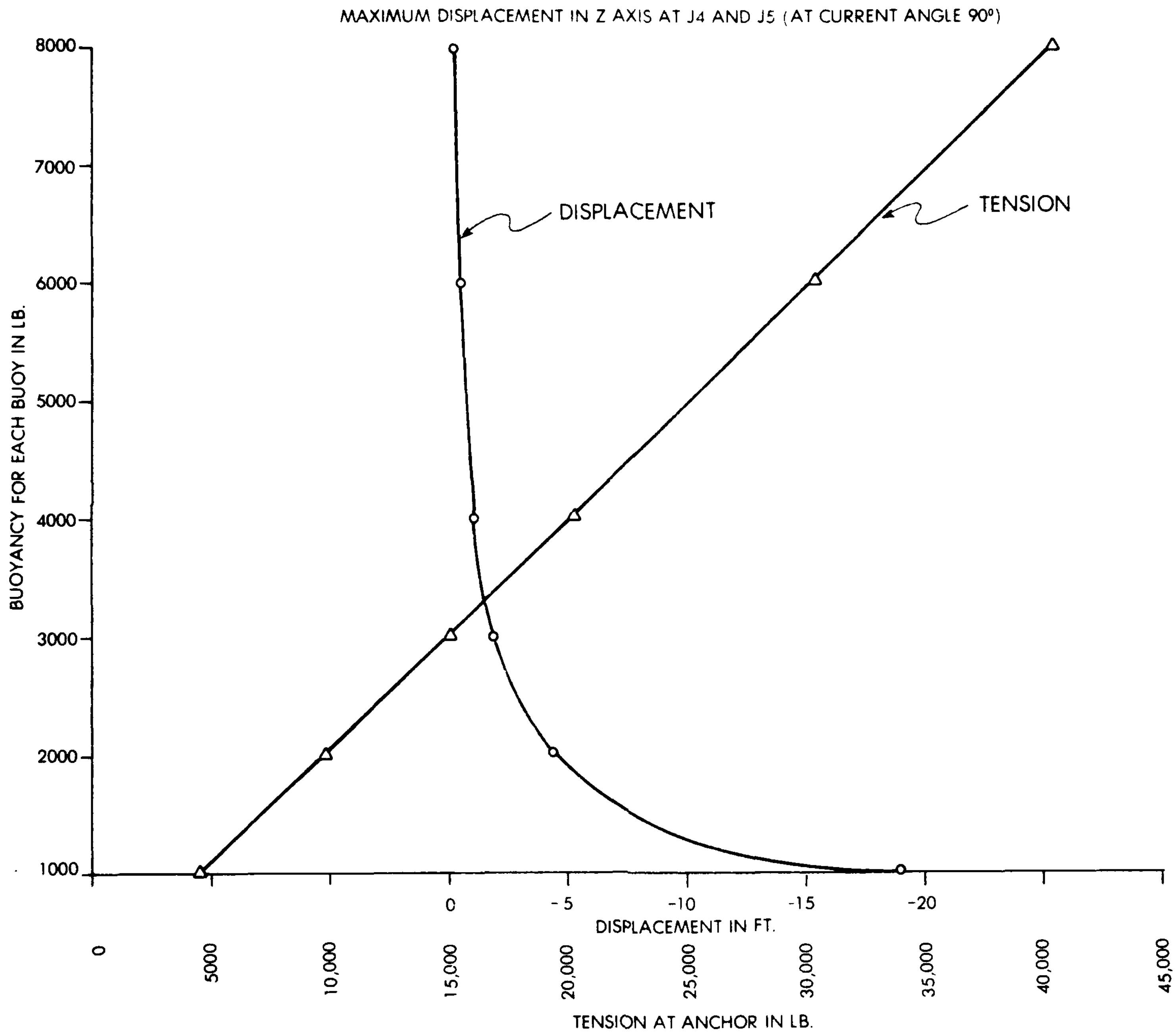


Figure 23. Displacement in z-axis (with .4 Knot Current)

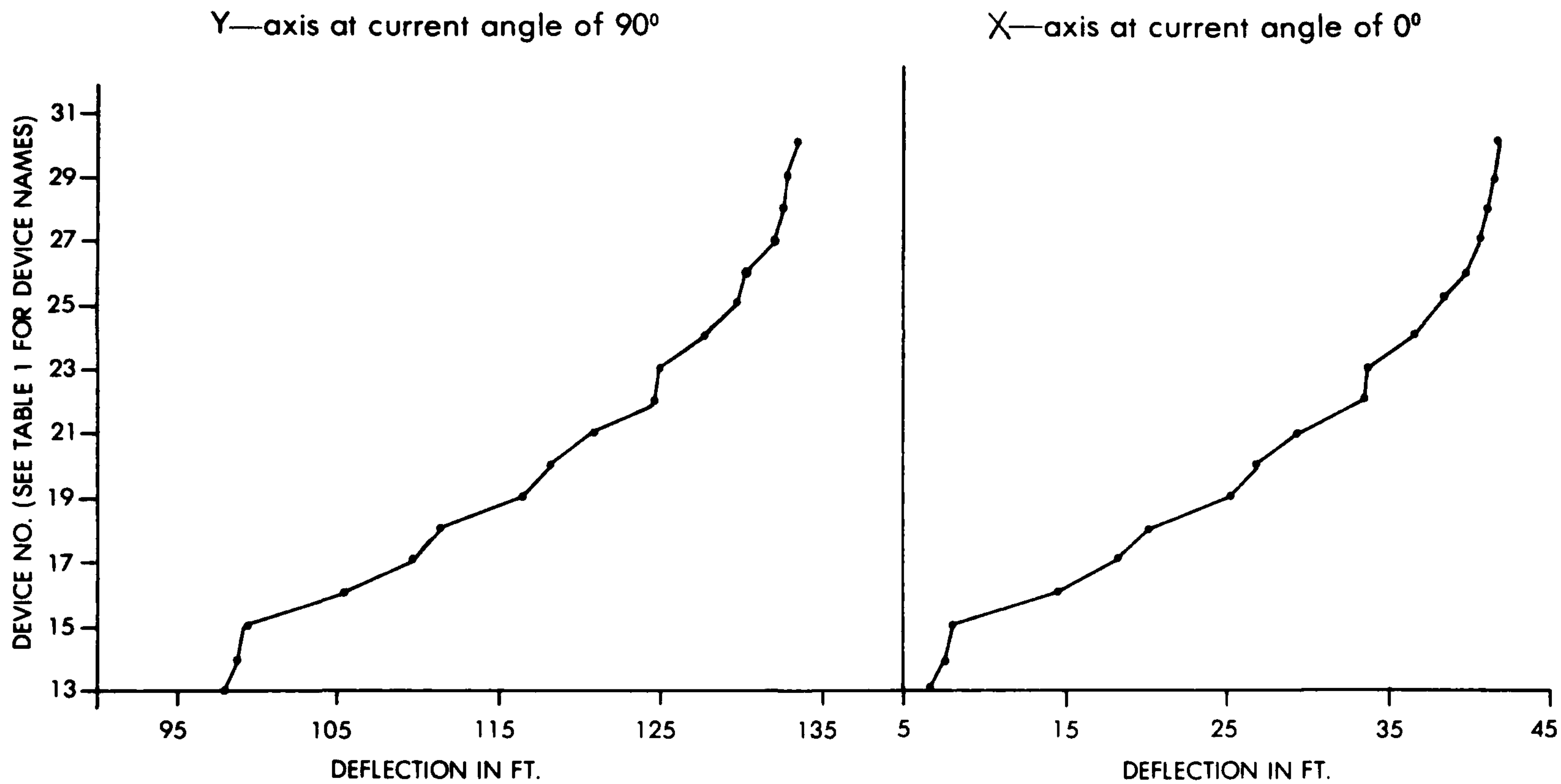


Figure 24. Device Displacement (with . 4 Knot Current) (Buoyancy 2000 lb. per buoy)

Table 3. Displacement in Ft. - NAVFACENGCOM Current Data

Location (Array Junction)	X-AXIS				Y-AXIS				Z-AXIS			
	Current Angle				Current Angle				Current Angle			
	0°	30°	60°	90°	0°	30°	60°	90°	0°	30°	60°	90°
J3	0.1	0.1	0.1	0.0	0.0	3.7	7.2	8.7	0.2	0.2	0.1	-0.0
J4	7.6	6.5	3.8	0.0	0.0	7.4	13.7	16.2	0.1	0.2	0.1	-0.1
J5	7.7	6.6	3.8	0.0	0.0	7.4	13.8	16.3	-0.3	-0.2	-0.2	-0.1
J6	0.1	0.1	0.1	0.0	0.0	3.7	7.2	8.7	-0.3	-0.2	-0.2	-0.0

Table 4. Displacement in Ft. - D. Burns Current Data

Location (Array Junction)	X-AXIS				Y-AXIS				Z-AXIS			
	Current Angle				Current Angle				Current Angle			
	0°	30°	60°	90°	0°	30°	60°	90°	0°	30°	60°	90°
J3	0.2	0.1	0.1	0.0	0.0	5.4	11.3	13.9	0.2	0.3	0.2	-0.1
J4	7.0	6.1	3.5	0.0	0.0	8.8	17.2	20.7	0.2	0.3	0.1	-0.1
J5	7.0	6.1	3.5	0.0	0.0	8.8	17.2	20.7	-0.4	-0.3	-0.3	-0.1
J6	0.2	0.1	0.1	0.0	0.0	5.4	11.3	13.9	-0.4	-0.3	-0.2	-0.1

PART V. REQUIREMENTS IN FURTHER DEVELOPMENT AND ENVIRONMENTAL DATA

1. INTRODUCTION

During the past months NORDA's effort has been devoted to investigating the design of a deep ocean array system which will fulfill the requirements of the Intermediate Array for the Linear Chair project. The principal effort has consisted of developing a concept for the array, based on preliminary instrumentation and performance requirements.

This array concept stage is now completed. A candidate array is described which will generally meet the known requirements.

This report defines the areas which require development and environmental data before the final array design and component requirements are completed.

2. ARRAY WORKSHOP

An array workshop was held late in the 1977 Fiscal Year. This workshop was composed of the technical staff involved in the electronic and mechanical design.

One of the first tasks for this workshop was the critical examination and evaluation of the proposed "straw-man" array system. The evaluation consisted of questioning such areas as:

- Does the array meet all the mechanical and electrical requirements? Can they be optimized?
- If weaknesses are found; then by what basic array or component changes can they be corrected?
- Will the array meet all the requirements for a moving target?
- Can the array be simplified, made more reliable at less cost?
- What is the test and repair scenario?
- What is the fabrication and schedule scenario?

It was exceedingly important that the first priorities be the evaluation of the number and type of electrical conductors and their power-carrying requirements, the type of multiplexing, power distribution, switching, fail safe, sensor gauging, connectors, moding, etc. It was also proposed that the workshop should continue to meet on a regular basis until the final array design, fabrication, and assembly is completed.

3. DYNAMIC MOTION ANALYSIS

Naval Ocean Research and Development Activity has completed an analysis of current induced static deflection for a structural cable array as proposed for LINEAR CHAIR. The results of that study provide predicted array motion resulting from different current conditions.

It is recommended that complete dynamic motion studies be performed on the proposed array system. Predictions should be provided on the maximum motion at major junctions and at all devices in the x, y and z planes. The study should also include a strumming analysis on individual array cables.

4. OCEAN CURRENT MEASUREMENTS

The array's deflection at each deployment site will depend on the ocean current. At the first implantment site, off St. Croix, the most complete and latest current data was collected by D. Burns (NORDA Code 330) which covers only the depth from 2451 feet (747m) to 3491 feet (1064m). His report includes data from 0 to 1220 feet (372m), which was collected by Applied Physics Laboratory (APL). No data is available between 1220 feet (372m) and 2451 feet (747m).

A more complete current profile should be obtained at the first prototype array implantment site and it is recommended that this task be given to Mr. D. Burns (NORDA Code 330).

5. FISHBITE STUDIES

Limited information exists on fishbite incidents on array cables at the first deployment site. Fishbite protection, if required, will produce a more rigid cable which will make assembly and handling more difficult. It will also increase cable size (diameter) producing larger array motion due to ocean currents.

It is possible to gather fishbite data in conjunction with the proposed ocean current measurements.

6. ARRAY CABLE TESTING

It is vital to the LINEAR CHAIR array program that the proposed cables, both mechanical and electromechanical (including the cable employed in the instrumented array section and the coaxial mooring cable), be extensively tested. Prototype array cables (91.44 m to 152.40 m long) should be manufactured for testing purposes.

The test procedure will include cyclic tension and bending, breaking strength, elongation, long term stress fatigue and the molding of a water tight connector to one bundle of conductors, with subsequent wet pressure testing.

It is recommended that this task be assigned to NORDA, Code 350, since this code has broad experience and background in preparing array cable specifications and cable testing.

7. MAGNETIC BACKGROUND DATA

Naval Ocean Research and Development Activity has not been tasked to provide magnetic background data for locating acceptable array deployment sites. In conjunction with involvement in array development, we are interested in seeing that the array magnetometers sense the true magnetic signals of the target vehicle.

It was observed that certain of the suggested array deployment sites may be located on magnetic anomalies. This could result in the collection of misleading magnetic data due to the magnetic amplification effect. As an aid in selecting the proper array deployment sites, the best available magnetic background data should be consulted to avoid placement of the array over magnetic anomalies. This information is available in NAVOCEANO, Code 3500. This code has the most complete, detailed and updated magnetic data library available, covering all ocean areas.

A. Remarks on Array Workshop

During the array workshop, the main topic was the presentation and discussion of the progress made in designing array instrumentation, electrical conductors and the physical structure.

One of the major conclusions was that the array sensors, instrumentation, conductor requirements and associated multiplexing requirements are not well defined, and will probably not be defined in the near future. Based on the above, NORDA recommends utilizing a basic mechanical array structure (Figure 2) to which the electrical harness can be attached. The following array cost breakdown, therefore, addresses only the array's mechanical structure.

Another workshop conclusion was that NORDA be tasked to conduct additional array motion studies. These are completed and are incorporated in this report.

B. Array Cost Breakdown

The following array cost breakdown addresses only the mechanical array structure as shown in Figure 2, and does not include any components of the electrical harness.

Refer to Figure 4 for identification of the various array components.

a. Array Component

	Price/Unit	Total Price
• Cable Sections a and b 2-1450' sections (Kevlar* 3/4" diameter 18,000 lb break strength)	$2.00/ft	$ 5,800.00
• Cable Section c 1-600' section (Kevlar* 1 1/4" diameter 74,000 lb break strength)	5.00/ft	3,000.00
• Cable Section c 1-3,500' section (Kevlar* 1 1/4" diameter 74,000 lb break strength	5.00/ft	17,500.00
• Cable Section f 1-3,000' section (Kevlar* 1 1/4" diameter 74,000 lb break strength)	5.00/ft	15,000.00
• Cable Section d 1-3,500' section (Kevlar* coaxial 1 1/2" diameter 74,000 lb break strength)	10.00/ft	35,000.00
• Subsurface Buoys A, B, C, D	5,000/ea	20,000.00
• Anchors E, F	10,000/ea	20,000.00
• Fittings & Hardware	-	20,000.00
	TOTAL	$136,000.00

* Cable contains polyurethane jacket

APPENDIX A

(Letter from Tracor MAS)

05 April 1972

Professor P. B. Stimson
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Dear Professor Stimson,

Enclosed are two photographs of a mooring line failure that looks similar to the ones described in several Woods Hole reports. The line is Columbian Pli-mor (8 strand, 2 in. diameter, nylon) and it moored a buoy in 4300 meters of water at a point 5 miles north of Hams Bluff, St. Croix, Virgin Island. The failure point was at a depth of approximately 390 meters and there were other cuts at a depth of approximately 340 meters.

According to the April 1965 and October 1967 reports by Turner and Prindle, it would appear that the cuts were caused by fishbite with an eventual stress failure. Does this failure appear to you to be fishbite? Also, if fishbite is the cause of these failures, has there been any further work to identify the type of fish or to devise means of protecting the line? I would appreciate any information you can give me.

Sincerely,

M. Lowell Collier
Senior Staff Scientific

MLC/vkm

(Letter from Woods Hole Oceanographic Institution)

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Dr. M. Lowell Collier
Tracor MAS
Box 13107
Port Everglades, FL 33316

Dear Dr. Collier:

Thank you for the fine pictures of your failed mooring line, which arrived this morning. The report is of particular interest, first because it is the only documentation I have received from the vicinity of the Leeward Islands, and (more important) it is the only record of failure of a mooring line of such large diameter.

In my opinion, the damage is unquestionably fishbite. The species responsible is difficult or impossible to trace unless they have been so considerate as to leave a few tooth fragments. In the top 500 meters or so, all recovered tooth fragments I have seen or heard of have been of sharks, notably the mako and the blue. The Atlantic white-tip is also strongly suspect, but we haven't yet proved it.

For the record, damage in the 500-2000 meter zone is most likely attributable to Sudis hyalina or Alepisaurus ferox. These species bite more frequently than the sharks do, but they do less damage.

Dr. Prindle and I have been working on the problem of preventing such damage, but progress has been slow, largely because of the acute shortage of funds. New funds are pending at this moment, and I hope we will make some progress this summer. Briefly, we have concluded that there is little hope for any repellent methods, whether chemical, electrical or acoustic; our main hope lies in devising a suitable plastic armor. We have a pretty good idea of what the requirements are, but haven't yet found the right formulation.

I appreciate your painstaking documentation of this failure. If everyone in the buoy business were so conscientious, we would know more about fishbite than we do. One more facet would be of great interest, if available: a tension record, by indicating tension at the time of failure, would show the residual strength of the line and therefore the severity of the bite.

Dr. Brindle and I are preparing a paper on our recent work in this area. I will send you a copy when it is available, probably a few months hence.

Cordially yours,

Signed by: Paul B. Stimson

St. Croix Deep Moor Failure

Woods Hole Oceanographic Institution has studied mooring line failures in the vicinity of Bermuda and concluded that the cuts in the line were due to fishbite (see references). Teeth recovered in some of the lines suggested that the attacks were all made by members of the fish family Paralepididae. One member of this family, alepisaurus ferox is commonly called a Lancet fish and is described in the Encyclopedia Britannica as:

> "an elongate, compressed, silvery fish reaching a length of 3 feet or more. The mouth is very large with unequal, formidable, knife-like teeth suggesting those of a barracuda ... They are supposed to swim at a considerable depth in the ocean, ..."

In reference 2, the following description is given:

> "Typically, two strands of a three-strand polypropylene rope would be cut off cleanly at nearly the same level and the third strand would be frayed out in a "horse tail". Microscopic examination of the individual fibers confirmed that the first two strands had actually been cut and that the frayed-out strand had parted from stress failure."

This statement describes quite accurately the St. Croix line failure, and after reviewing the WHOI reports and consulting with Professor Paul B. Stimson (letter attached) it is the opinion of TRACOR/MAS that this failure was caused by fishbite.

References

1. Stimson, P. B., 1965, "Synthetic-Fiber Deep-Sea Mooring Cables: Their Life Expectancy and Susceptibility to Biological Attack". Deep-Sea Research, 12:1-8

2. Turner, Jr., H. J. and Prindle, B., April 1965, "Some Characteristics of 'Fishbite' Damage on Deep-Sea Mooring Lines". WHOI Reference No. 65-22, unpublished manuscript.

3. Turner, Jr., H. J. and Prindle, B., October 1967, "The Vertical Distribution of Fishbites on Deep-Sea Mooring Lines in the Vicinity of Bermuda". WHOI Reference No. 67-58, unpublished manuscript.

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