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ENGINEERING DESIGN AND ANALYSIS LABORATORY

UNIVERSITY OF NEW HAMPSHIRE

DURHAM, NEW HAMPSHIRE

AN ENGINEERING DESIGN STUDY OF A HIGH-STABILITY BUOY

FOR THE HYSURCH PROGRAM

Part I

A DESIGN STUDY AND PROTOTYPE EVALUATION PHASE

Technical Report No. 108

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The Experimental Astronomy Laboratory of the Massachusetts Institute
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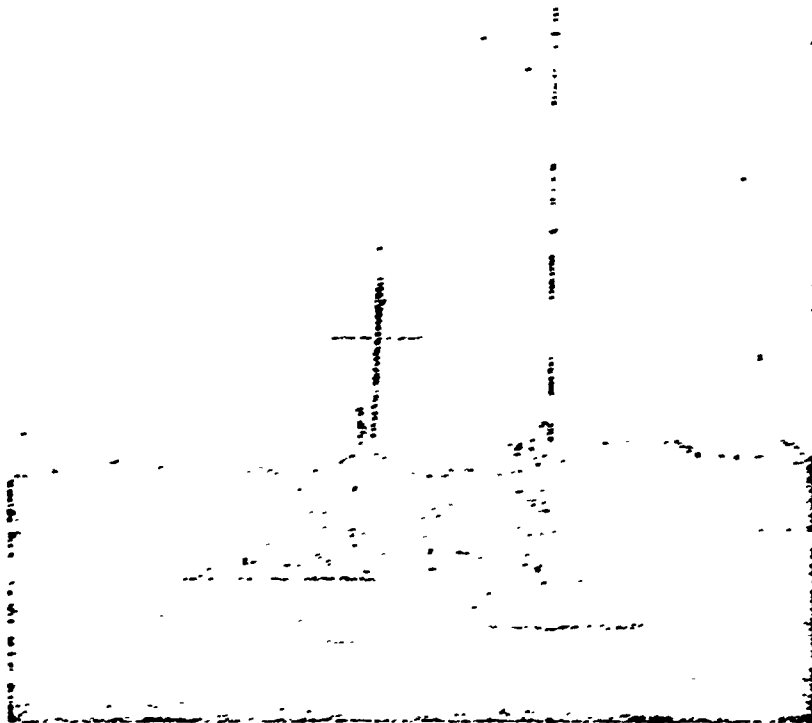
And the M.I.T. Hysurch Staff

CREDITS

We wish to acknowledge the many contributions to this project by individuals from government and private industry, who have given of their knowledge and experience. Those deserving special mention are:

U. S. Coast Guard, Portsmouth/White Island, New Hampshire
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Arben Marine Products, Inc., Long Beach, California
Spar Aerospace Products, Limited, Toronto, Canada
National Waterlift Company, Kalamazoo, Michigan

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Fig. I.   The prototype buoy system, shown above, was developed
during the research reported herein for the U. S. Naval
Oceanographic Office and the Office of Naval Research
for the Hysurch Program (a hydrographic survey and
charting system). The photo was taken in the Great
Bay estuary near Portsmouth, N. H., which provided
ocean currents of two knots for parts of the full
scale experimental study.

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ABSTRACT

This document reports the results of an analytical design
study and a prototype experimental program which investigated the
characteristics and performance of a buoy system for the U. S.
Naval Oceanographic Office Hysurch Program. The buoy system serves
as a reference station for a hyperbolic navigation system for coastal
hydrographic survey. The work reported herein consisted of an
analytical evaluation of several classes of buoy systems, a detailed
design of a prototype system, an experimental program with a full
scale prototype buoy system in two oceanic environments, and an
evaluation of the operational characteristics of the prototype system.

The prototype evaluation showed that a highly compliant taut-
wire moored surface buoy configuration can provide vertical stabili-
ties of less than eight degrees variation and a watch circle of ap-
proximately ten percent of depth, in sea conditions of up to Sea
State four and with ocean currents up to three quarters of a knot.

I. BACKGROUND AND OBJECTIVES OF THE
BUOY DEVELOPMENT STUDY

A. INTRODUCTION

In February 1967 the Experimental Astronomy Laboratory at the Massachusetts Institute of Technology undertook a feasibility study of a new hydrographic survey and charting system for the U. S. Naval Oceanographic Office. The results of that study, published in February 1968 is a system known as Hysurch (Hydrographic survey and charting system).[1*] One of the central purposes of the Hysurch System is to decrease the time required for the acquisition and processing of data associated with hydrographic survey work. For a detailed description of the Hysurch concept, the reader is referred to Reference 1 which provides a rather complete picture of the Hysurch system.

B. NAVIGATION SYSTEM CHARACTERISTICS OF HYSURCH PROGRAM

One of the key ingredients in the Hysurch system, is the acquisition of depth information by high speed sound boats. These boats traveling at speeds up to thirty-five knots, use acoustical sounding techniques to acquire water depth information over the path traversed by the sound boat. For charting purposes, it is critical to know the position of the sound boat to correlate with the acquired depth information. The Hysurch system proposes that a radio-navigation system of the hyperbolic type[2,3,4,5] be used. A description of how a hyperbolic

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*All superscript numerals indicate references listed in Appendix I.

system works, is given in Reference 1 and is quoted here.

"To set up a hyperbolic navigation grid, a logistics boat deploys a transmit-receive buoy (a slave station) within a mile of shore near an endpoint of the whole survey. A monitor craft nominally twenty miles off shore near the center of the to be surveyed coast length, has a similar transmit-receive station called a master station. The radio waves emanating from the slave interfere destructively with or cancel the radio waves from the master at very nearly fixed points on the earth (as long as the stations are securely anchored).

These points all lie on a hyperbola as shown in Figure II, hence, the name hyperbolic system. The hyperbolas are called lanes. Now suppose a second slave station is deployed by a logistic boat at the other endpoint of the survey, again anchoring within a mile of shore. Seventy miles is a nominal slave-station-pair separation. Slave No. 2 also has a transmit-receive capability, on the same carrier frequency---1.5-2.0 MHz---as both slave No. 1 and the master station. This sets up a second set of hyperbolic lines of waves cancellation. It will be seen from Figure III that the two sets of hyperbolas intersect at various angles making up a radiation net. If, now, a sound boat is traveling across this net, it will locate itself within the net if:

1. It has a radio receiver that can count the hyper-
   bolas the boat is crossing by noting the rise
   and fall of the received signal. This signal
   always reflects the degree of cancellation of
   the waves from the master station and one of the
   slaves. The signal goes nearly to zero (or to
   a minimum) as a lane is crossed.

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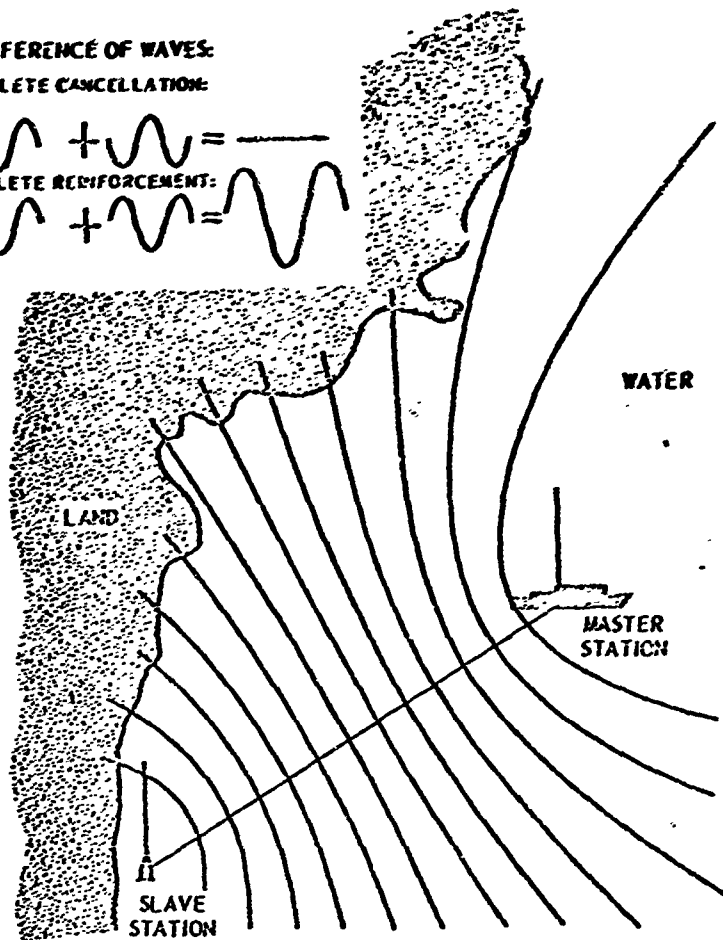
Fig. II Hyperbolic lanes created by cancellation of radio waves from one slave station to one master station.
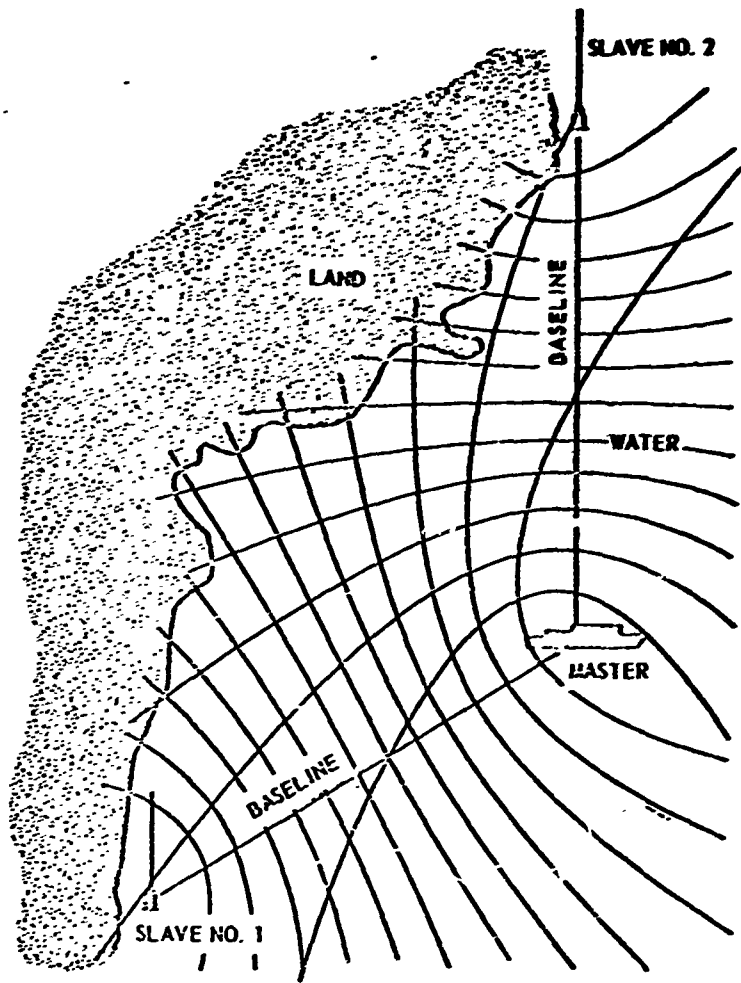
Fig. III Two sets of hyperbolic lanes created by the cancellation of waves
(1) from Slave One and the Master and (2) from Slave Two and the Master.

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2. which slave is being received, i.e., which
   hyperbola set is being counted is determined
   as follows: Each hyperbola set is modulated
   with a different tone built into the master
   and slave stations. Thus, the two tones, de-
   modulated at the receiver, are separately used
   to count hyperbolas or lanes on the two sets
   of lanes.

3. Finally, the master station aboard the monitor-
   craft can know where it is all times relative
   to the slaves, and can keep track of its posi-
   tion, that is, keep stationed about twenty miles
   off shore, accordingly. It does this by dual
   ranging on its slaves. See Reference 1, 2, 3,
   4, 5, for more details on dual-range systems.

C. GENERAL PURPOSES OF BUOY DESIGN STUDY

The Hysurch System, then, requires buoys as slave stations for
the radio navigation system. As one can surmise, the accuracy of lo-
cation for these buoys is of critical importance to the performance
of the Hysurch System. Uncertainty in the slave station position
places a similar uncertainty in the location of the sounding boats,
hence an error in the position associated with the received depth
sounding data. An error analysis, by the M.I.T. group, indicates that
buoy location watch circles should be approximately 10 percent of water
depth, for shallow coastal waters of up to about two hundred feet.

The purpose of the program of research reported in this document, was to conduct a study of various buoy configurations which might meet the performance requirements, and to do a full scale prototype in situ evaluation of the system or systems most likely to provide the requisite characteristics. This report contains a review of the design study, a discussion of trade offs associated with various buoy and mooring configurations, a description of the experimental program under which the prototype was evaluated, and a review of the operational characteristics of the designed buoy in ocean currents up to two knots and wave conditions equivalent to approximately Sea State 4.

II. BUOY SYSTEM DESIGN AND ANALYSIS

A. BACKGROUND

There is considerable interest in taut-wire moored surface buoys on quasi-stable platforms for radio-navigator stations, particularly for hydrographic survey systems.[1,6] Radio-navigation[2] systems, working in either the dual-range mode or the hyperbolic mode require radio frequency transponders at two "fixed" slave stations and a master station at a third location. This report is concerned with the design and evaluation of a buoy system within which to mount such a radio-navigation system to serve as a "fixed" slave station. This section of the report will discuss the specification for such a buoy system, the design alternatives, two specific buoy systems, and the components which might be used for an operational system.

B. BUOY SYSTEM SPECIFICATION

Various strategies for survey navigation systems were considered by Blood, et al, in reference 1. Based upon the recommendation, by Blood, et al, that the Hysurch System should employ a hyperbolic navigation chain, error analyses were conducted to determine the navigation requirements for Hysurch. This error analysis, revealed that the 3σ-buoy position errors over a region of about 70 x 40 nautical miles should be kept below 52 feet due to all causes.[1]

Both Blood, et al, and the U. N. H. group have investigated the inherent position accuracy capabilities of radio-navigation systems.

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Appendix II contains a published survey of electronic positioning systems. The M.I.T. survey[1] and the U. N. H. independent survey strongly suggest that the following navigation systems should be considered further for Hysurch application (not ranked):

    a) Hi-Fix, by Decca Survey Systems, Inc.

    b) Raydist DR-S, by Haysings-Raydist, Inc.

    c) Sea-Fix, by Decca Survey Systems, Inc.

Manufacture data and an analysis by Bigelow[7] generally suggest that the above radio navigators can indicate position with an accuracy of 25 feet or less. Available data does not, however, evaluate these systems under conditions similar to those which will be encountered in Hysurch application. Analysis was conducted of a hyperbolic chain, using the manufacturer's published accuracies of a standard deviation of 0.01 mean lanes. This review suggests that accuracy contours over a 70 x 40 nautical mile grid covered by a hyperbolic lattice are in the worst case 8 meter (26.2 feet). To obtain a specification for a buoy slave station which will have this basic error of 8 meters, let us add a 0.01 lane error for the master station position. A review of Appendix A6.3 of reference 1, indicates that a master station position error of 0.01 lane results in approximately 3 meters (10 feet) error for the worst case. The only remaining errors, will be buoy movements. Starting with an overall position system error specification of 52 feet, of which approximately 26 feet is basic error in the hyperbolic lattice and 10 feet is provided for uncertainties in corrected master station position, one has about 16 feet for buoy position (watch circle) uncertainty. Since the Hysurch system proposes[1]

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buoy installation water depths of 15 to 150 feet, the buoy position uncertainty of water circle specification should be approximately 10% of the deepest water depths proposed. Using this simplified analysis - as a basis, the following specifications for watch circle performance were set:

1) Operating Depths - 15 to 150 feet.

2) Watch Circle - Approximate 10% of Maximum Depth

An analysis by Quinn (ref. 6) indicates that vertical stability of the buoy of $\pm 20^{\circ}$ will provide the necessary antenna gain for the system to operate within specifications. This analysis, assumed a 30 foot whip antenna, which corroborates the published data by Decca. Based upon these analyses, the vertical stability specification was set at:

3) Vertical stability of buoy: ± 20 degrees off vertical for Sea State 4.

The specification set by reference 1 for ocean currents was "each unit will operate reliably in the normal configuration in Sea State 3 condition or with currents of 4 knots in 100 feet of water. With a supplemental anchor, each unit must survive a Sea State 4 condition for one week or currents up to 7 knots in 100 feet of water". Based on the state-of-the-art for buoy systems and based upon discussions with Navoceano personnel, the ocean current specification, during normal operation, was set at a maximum of two knots.

4) Ocean Currents: 2 knots (Max) coupled with Sea State 3.

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The vertical Stability requirements in a State 3 Sea in effect set specifications for the sea wave conditions under which the buoy system must function. The Hysurch specification[1] of Sea State 3 suggests an $H_{1/3} \simeq 4.6$ feet[8]. However, the Sea State 4 requirement set in specification No. 3 above indicates that the system must be able to perform under conditions of $H_{1/3} \simeq 6.9$ feet. There is often difficulty in setting a specification in terms of sea states because of ambiguities in objective interpretation. Therefore, an additional specification beyond the sea state specification of item No. 3 above is included. This specification is based upon data available through the U. S. Naval Oceanographic Office,[1] which shows that seas with 5 foot average waves or less and winds of 17 knots or less are to be expected 80% of the time. These figures are based upon annual averages of combined data from the Vietnam and North Atlantic areas. The system study[1] assumed that hydrograph survey operation could be conducted 5 out of 7 days, or approximately 71% of the time, on the average, which is consistent with the 80% assumed above. Hence, the wave and wind specifications were set at:

5) Wave Conditions: $H_{1/3} \leq 5$ feet from any direction

6) Wind Conditions: Vel $\leq$ 17 knots from any direction

Other operational requirements were indicated by the U. S. Naval Oceanographic Office during the design of the study reported herein:

7) Anchoring Topology: Anchors must function in a spectrum of bottom conditions, ranging from marine sediments to rock and coral.

8) System Weight: An operational, air-deployable system should weigh no more than 1500 pounds including anchor and all buoy sub-

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systems. A ship deployable system should not exceed 2500 pounds. The buoy should be capable of carrying 200 pounds of navigational electronics and components, within the overall operational weights given above.

9) Method and Duration of Deployment:

An operational buoy system should be deployable by helicopter or surface vessel in approximately two (2) hours. Once implanted, the buoy should function for 5 days.

The above specifications serve as a basis for the University of New Hampshire design study, reported herein. These specifications are summarized in Table I.

TABLE I

BUOY SYSTEM DESIGN SPECIFICATIONS*

Specification for a navigation slave station buoy

1. OPERATING WATER DEPTHS . . . . 15 - 150 feet

2. BUOY WATCH CIRCLE** . . . . 10% of Maximum Depth

3. VERTICAL STABILITY OF BUOY . . . . $\pm 20^{o}$ off Vertical

4. OCEAN CURRENTS TO BE SUSTAINED . . . . Up to 2 knots

5. WAVE CONDITIONS . . . . $H_{1/3} \leq 5$ feet

6. WIND CONDITIONS . . . . Vel $\leq$ 17 knots

7. ANCHORING TOPOLOGY . . . . From mud to rock

8. SYSTEM WEIGHTS

   Air Deployable . . . . 1500 lbs (total)
   Ship Deployable . . . . 2500 lbs (total)
   Navigational System Payload . . . . 200 lbs

9. METHOD OF DEPLOYMENT

   Air Deployable . . . . Highly Desirable
   Ship Deployable . . . . Acceptable

10. DEPLOYMENT TIMES

    Time for Implantation. . . . . 2 hrs
    Survey Duration for which buoy is req'd . . . . 5 days

---

* The above specifications were used as guides to design a prototype
navigational buoy system. An operational system will have speci-
fications which are dependent upon the results of this design and
evaluation study.

** The watch circle is that circle within which the buoy will most
probably be for the wave, wind, and current specifications.

C. CRITICAL VARIABLES IN BUOY ANALYSIS

Assume one has a taut-wire mooring as sketched in Fig. IV(a). The taut-wire can be generally viewed as shown in Fig. V. If we confine our analysis to coastal installations, the water depth might be, say, 200 feet. As will be seen later in this analysis, the taut-wire tensions should be in the range of 2000 lbs, in order to obtain "small" watch circle performance. If we assume a drag on the cable (μ), due to 2.5 knot current, to be 2.4 lb/ft, then we can determine the catenary formed due to current drag alone (that is, we'll neglect the weight catenary effects, since the cables which might be used in a taut-wire mooring have distributed weight loads which are at the most 10% of the distributed current drag effects). If:

$$\text{Tension at end of cable} = T$$

$$\text{Tension at mid-point of cable} - T_o$$

$$\text{Length of the cable} = L$$

$$\text{The chordal sag} = y$$

$$\text{The angular difference } \theta_2 - \theta_2 = 2\beta$$

and if $T_o = 2000$ lbs, then using standard catenary analysis, we find that:

$$y = \frac{T_o}{\mu} \left(\cosh \frac{\mu L}{2T_o} - 1\right); \text{ assuming that}$$

$$\mu = \mu_t$$

$$y = 3.3 \text{ feet}$$

$$T = T_o \cosh \frac{\mu L}{2T_o} ; \text{ neglecting the effect of } \mu_p$$

$$\beta = \cos^{-1} \frac{T_o}{T} = \frac{1}{1.00405}$$

$$\beta \doteq 5^o$$

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WAVES $\longrightarrow$

CURRENT $\longrightarrow$

(a) Moorings with Catenary

(b) Idealized Mooring

If $\theta \leq 28°$, then $\geq 415'$

θ

h

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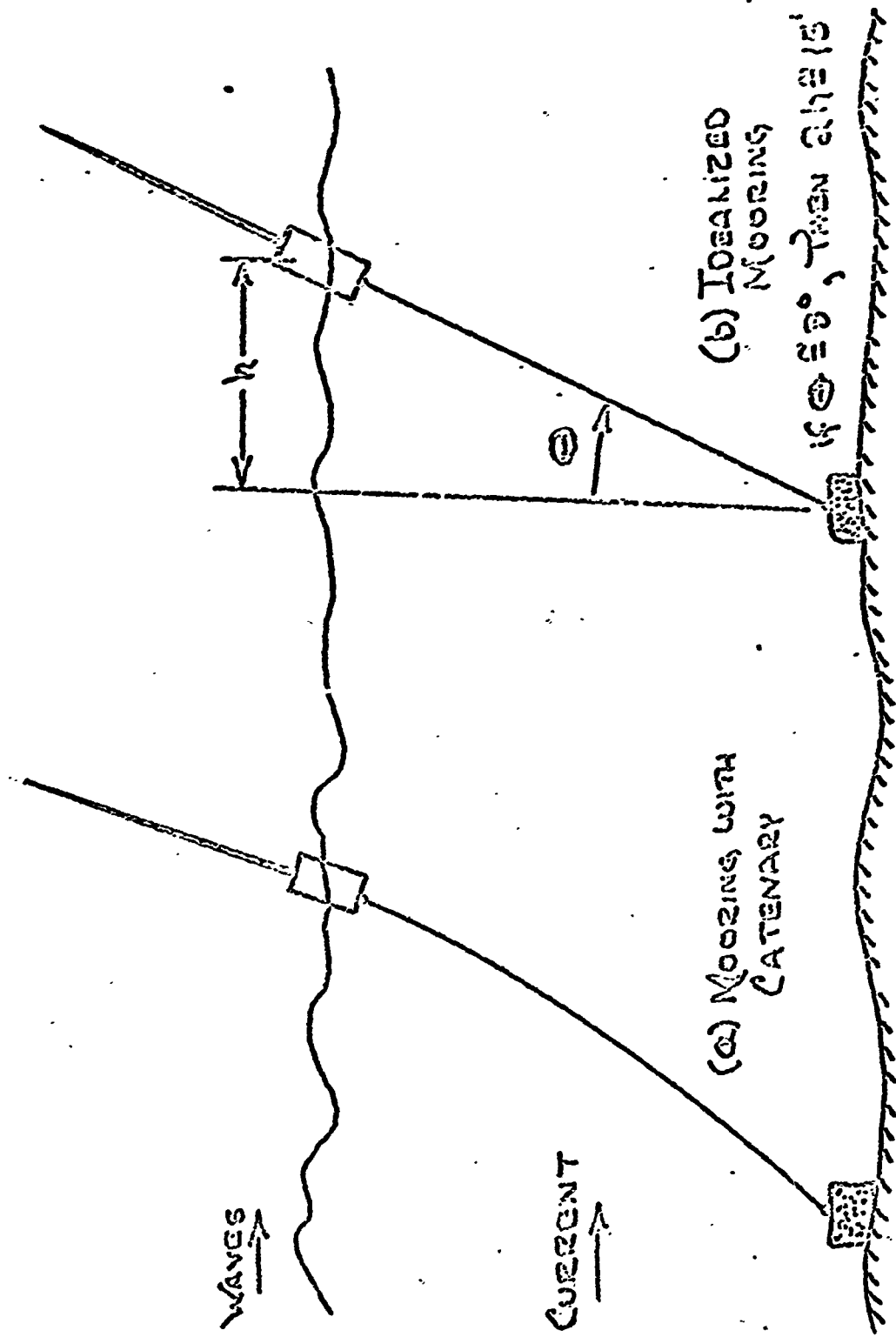
Figure IV

SIMPLIFIED SKETCH OF TAUT-WIRE SURFACE MOORED BUOY
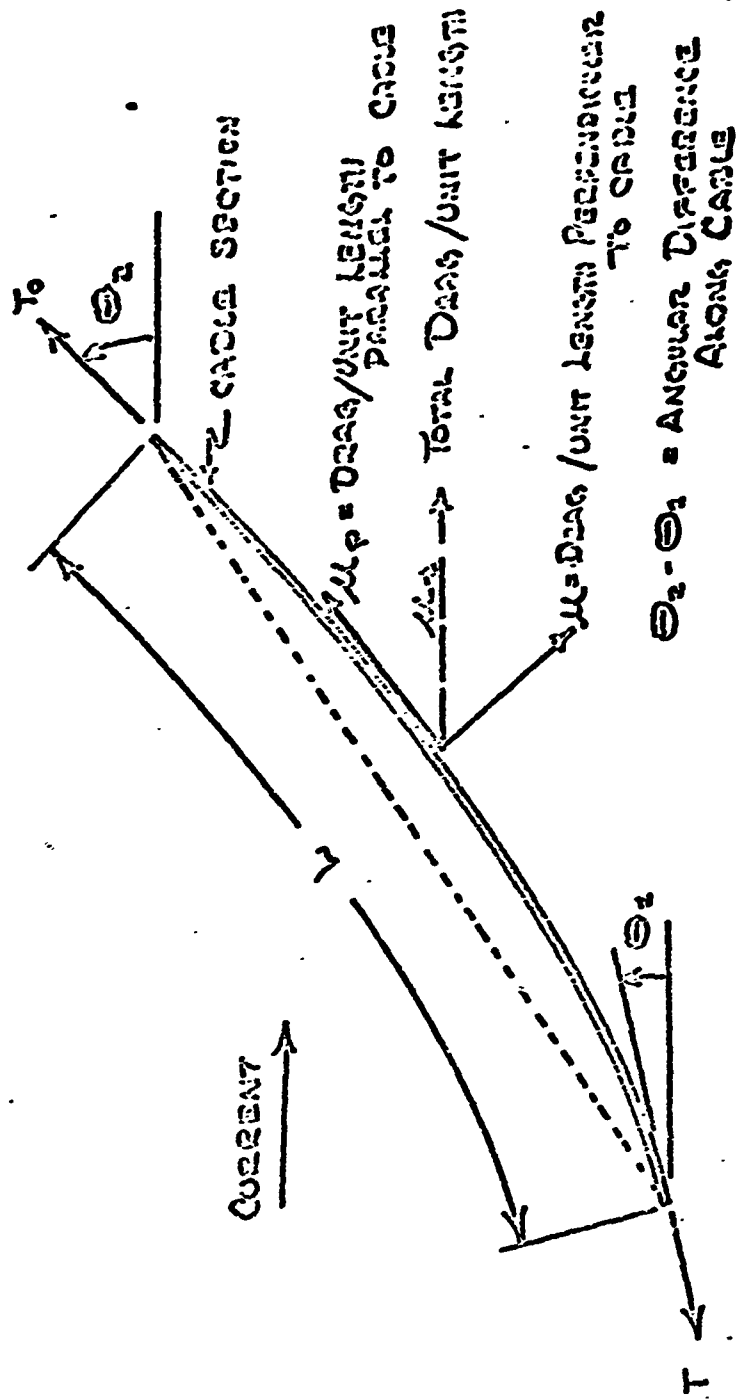
Figure V

SKETCH OF CATENARY WIRE FOR BUOY ANALYSIS

Therefore, $\theta_2 - \theta_1 = 10^0$. Based on this simplified analysis, one can see that the chordal sag is minimal, provided we are dealing with shallow waters ($<200'$). Therefore, for the critical variables analysis will assume that the cable is straight, that is, no catenary is present.

A simplified free body analysis of a straight taut-wire moored buoy, (noting that the watch circle of 10% of maximum depth specification requires that $\theta \leq 3^0$) reveals that:

$$\tan \theta \simeq \frac{\text{TOTAL DRAG FORCES ON BUOY}}{\text{ACTIVE BUOYANCY OF BUOY}}$$

$\tan 3^0 = 0.0524$, which suggests that total drag forces on the buoy should be less than 5% of the active buoyancy of the buoy.

The critical aspect of the buoy design problem then is to keep the total drag force on the buoy small compared to net buoyancy of buoy. Therefore, we seek a favorable drag to displacement ratio, which we will call (λ).

D. DESIGN ALTERNATIVES FOR BUOY SYSTEM

The scope of this report is not such that a detailed analysis can be included. A theoretical analysis of a taut-wire mooring is being prepared in companion report. A summary of the analysis approach is given below:

1) A variety of buoy shapes were analyzed in terms of drag to displacement ratio to determine favorable configurations.

2) Favorable buoy shapes which are commercially available, or which appeared to be relatively easy to manufacture were analyzed to determine watch circle behavior, pitch and heave characteristics, and other performance variables.

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3) Two promising design configurations were analyzed in detail.

As an example of the drag to displacement ratio review, one finds for commercially available buoys the following λ values (these are the most optimistic figures for 2.5 knot currents).

- a) 5' Spherical Buoy $\lambda \doteq .047$
- b) 8' Toroidal Buoy $\lambda \doteq .022$
- c) 6' Parabolic Buoy $\lambda \doteq .014$
- d) 8' Parabolic Buoy $\lambda \doteq .0095$

Since λ is a measure of the expected watch circle, a small λ is the most desirable. The above buoys, among several others, were analyzed in detail to obtain performance characteristics. For example, torpedo-shaped buoys, such as the Honeywell Buoy and the plank-on-edge were discarded because their sea-keeping characteristics in waves and surface currents leaves much to be desired.

Based on the detailed analysis of expected performance, the 8' Parabolic Buoy was selected for detailed design (a computer analysis of this design will be available in another report to be published in May 1969).

A simplified analysis, used prior to the computer study, revealed that an 8' parabolic buoy in 180' of water, with a 2-knot current and 21-knot wind (sea fully developed) will have a watch circle in the range of 25 feet to 50 feet, with the most probable being 30 feet. An independent analysis by another organization suggests a watch circle of 41 feet. The analysis do not reveal reliable predictions of vertical stability.

The 8' Parabolic Buoy had the "best" expected performance, even though the watch circle projections were out-of-specification. It was

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decided that experiments should be conducted to determine the actual performance. The analysis had been highly conservative to account for the lack of detailed hydrodynamic data on the configuration. Therefore, it was felt that the projected 30' watch circle was a conservative estimate. Thus, an engineering prototype evaluation was proposed and accepted by the U. S. Naval Oceanographic Office. Details of that evaluation constitute a major portion of the remainder of this document.

Because of the uncertainty in the performance of the 8' Parabolic Buoy, a second buoy was considered. The Sea-Flyte, as this second buoy became known, is based upon the concept that a hydrodynamic lift in proportion to the ocean current can be generated by an airfoil section. As the ocean current increases, the lift increases, which is precisely what is needed. To obtain the mooring wire tension needed to produce small watch circles, a hydrostatic buoy must use displacement to obtain the "active buoyancy forces." In the high current environment, the necessary taut-wire tensions can be augmented by hydrodynamic lift. This concept was used in a buoy designed and developed in conjunction with Arben Marine Products of Long Beach, California, and is described in Appendix III. A photograph of the wing section, prior to final assembly is shown in Figure VI.

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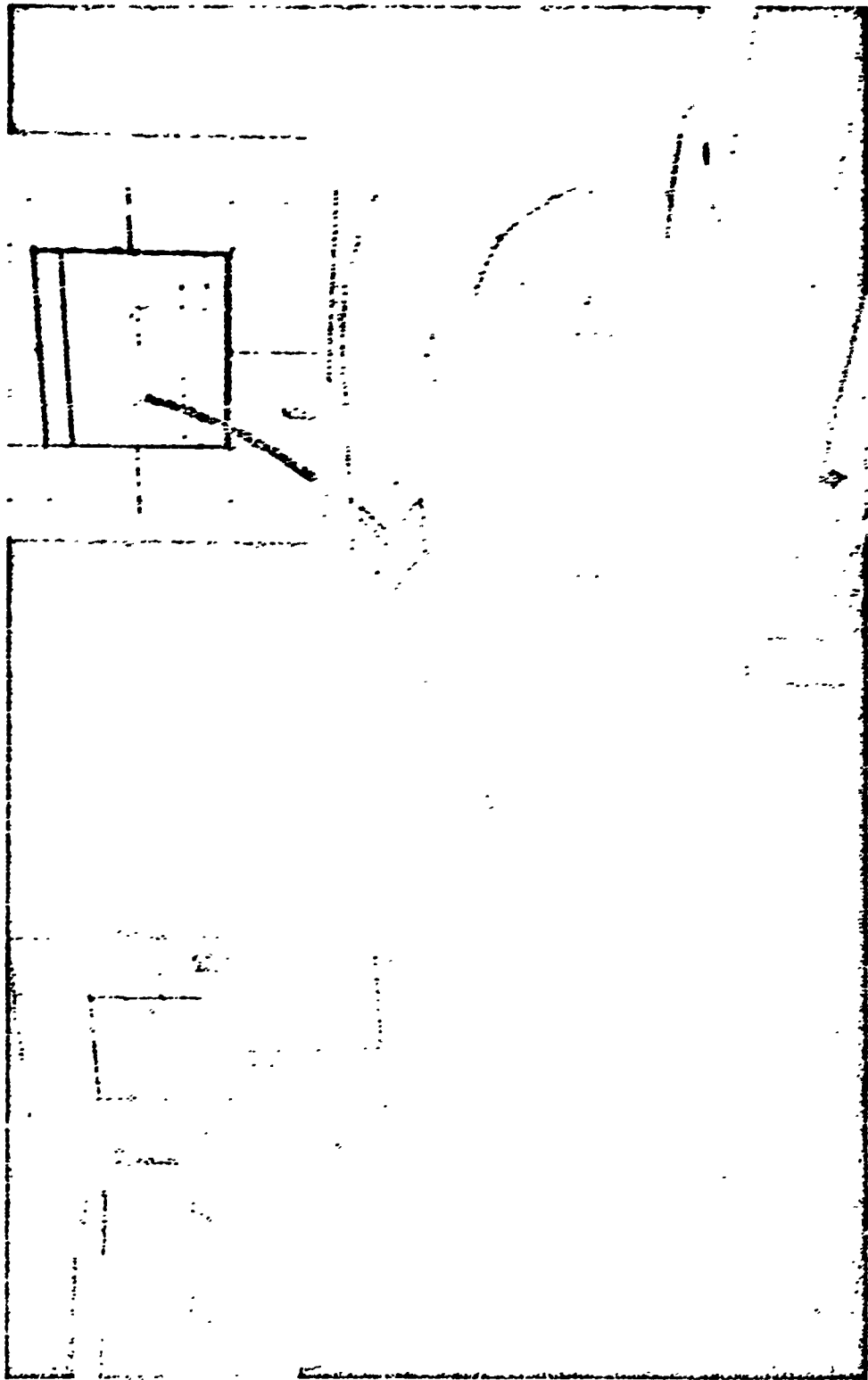
Figure VI

Full Scale Prototype of Sea-Flyte Hydrodynamic Buoy Prior to Final Assemble.

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E. DESIGN OF BUOY SYSTEM

The buoy system, shown in Figure VII, consists of seven major component sections.

1) Surface Buoy

2) Antenna

3) Mooring Bridle

4) Compliant Taut-Wire Mooring

5) Anchor

6) Sea-Fix System

7) Instrumentation and Power Supplies

SURFACE BUOY

The analysis of possible surface buoy configurations suggested that a horizontal attitude PARA-BUOY* would come closest to meeting the specifications. A standard eight-foot (8') buoy, model 8-200 was selected. (Manufacturer's catalog information is shown in Figure VIII) To accommodate the radio-navigation transceiver, instrumentation, and power supplies, four (4) 12" Dia. x 32" Deep instrument compartments were designed into the buoy (The orientation and location of these compartments is shown in Figure VIII.) The four compartments contained:

Compartment 1 - Sea-Fix Slave Station

Compartment 2 - 3 Lead-Acid Batteries (24VDC Supply)

Compartment 3 - Engineering Evaluation Instrumentation .

Compartment 4 - 3 Lead-Acid Batteries (24VDC Supply)

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*A product of Prodelin, Inc., Hightstown, New Jersey.
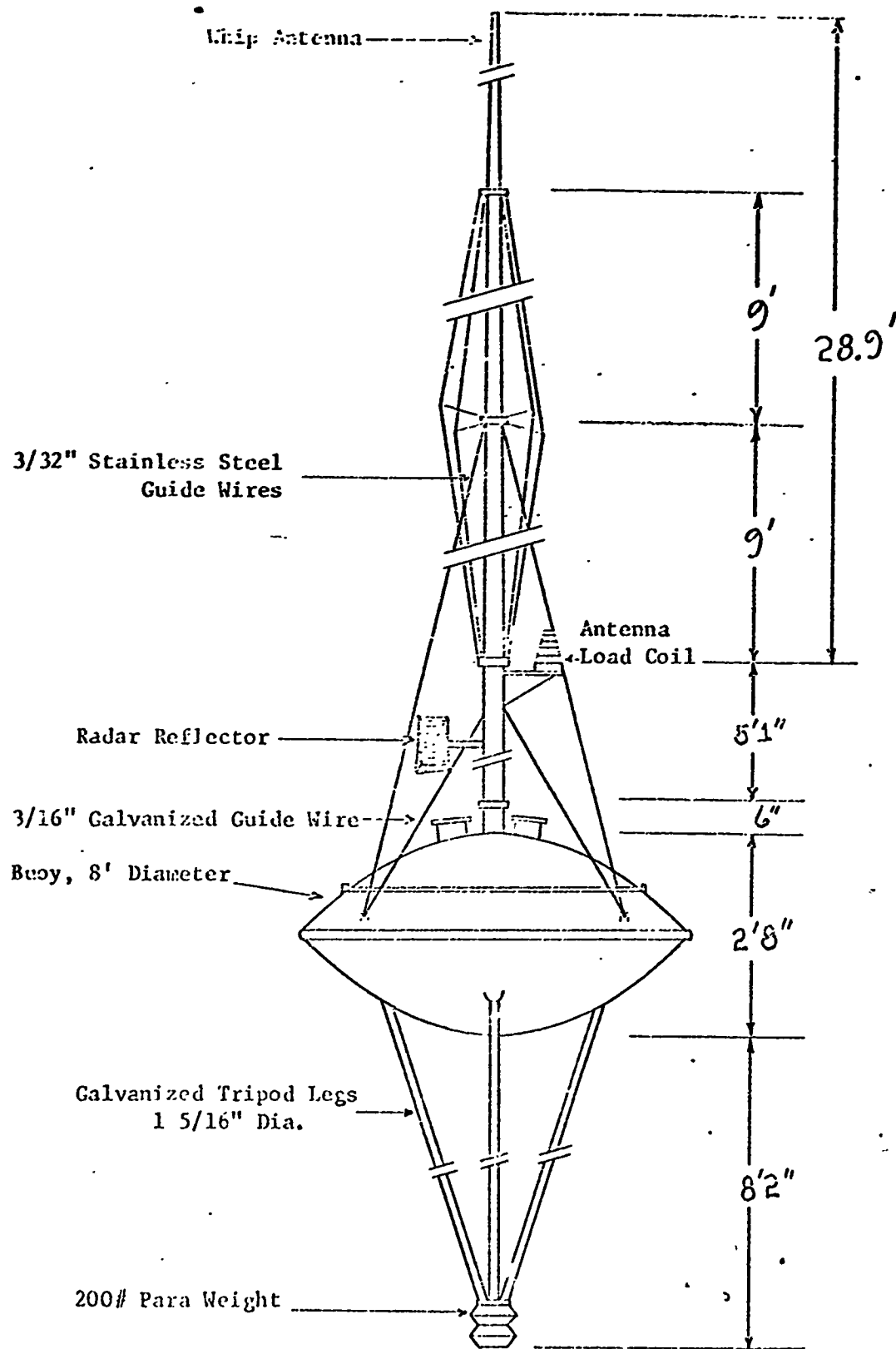
Figure VII

Layout Details of Parabolic Sea-Fix Buoy

SPECIFICATIONS

ORDERING INFORMATION

Cat. No.	Dia. Ft.	Average Net Weight (Lbs.)	Average Buoyancy Net (Lbs.)	Instrument Compartment Qty.	Size Dia.	Lgth.	Standard Mooring Pickup
2-200	2	15	80	0	0	0	Single eye in mooring post
4-200	4	120	500	0 to 2	9"	19"	Single eye in mooring post
6-200	6	370	2,000	0 to 4	10"	36"	Tripod bridle
8-200	8	180	3,900	0 to 4	12"	32"	Tripod bridle
10-200	10	600	10,000	0 to 4	12"	36"	Tripod bridle

NOTE: When ordering specify —
1. Cat. No.
2. Number of instrument compartments
3. Ballasting required if any (At extra charge)
4. Type of mast required (See page 12)
5. Payload including weight of mooring line in CH2O
6. Mooring depth
7. Operational and survival sea states
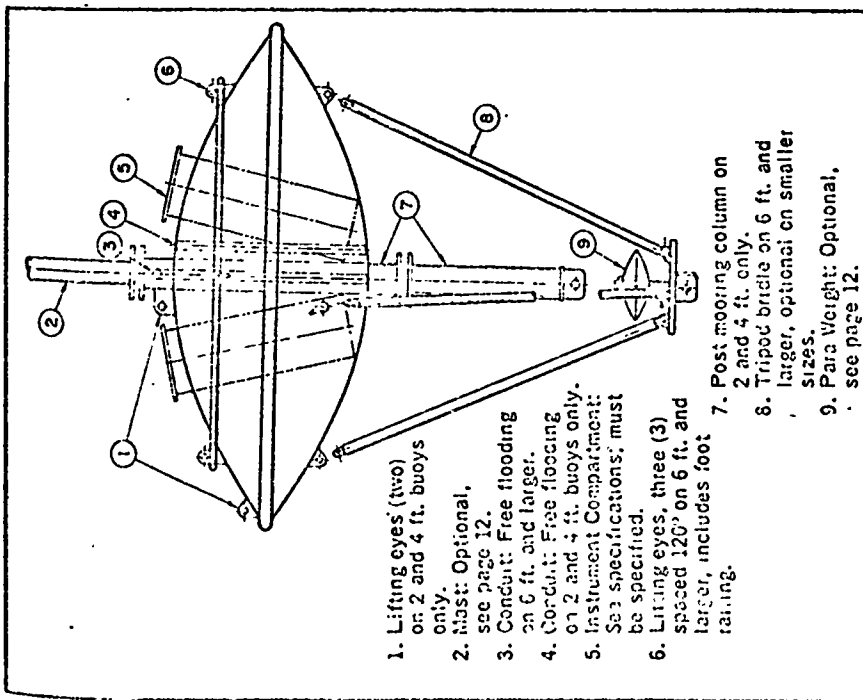
1. Lifting eyes (two) on 2 and 4 ft. buoys only.
2. Mast: Optional, see page 12.
3. Conduit: Free flooding on 6 ft. and larger.
4. Conduit: Free flooding on 2 and 4 ft. buoys only.
5. Instrument Compartment: Sea specifications; must be specified.
6. Lifting eyes, three (3) spaced 120° on 6 ft. and larger, includes foot railing.
7. Post mooring column on 2 and 4 ft. only.
8. Tripod bridle on 6 ft. and larger, optional on smaller sizes.
9. Para Weight: Optional, see page 12.

Figure VIII
Para-Buoy Data Supplied by Manufacturer

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The buoy is constructed of aluminum, with spun parabolic heads. The welded buoy is polyurethane foam filled to assure buoyancy. The aluminum is treated for corrosion resistance and painted with epoxy paint.

ANTENNA

The Hysurch System requires rapidly deployable slave buoys. A 30' rigid antenna presents some obvious handling difficulties. Based upon considerable study, it is recommended that an operational buoy be designed with a STEM* Antenna. Stem antennas are collapsible antennas which can be stored on a drum, much like a clock spring. Upon unreeling the spring, the strip of spring-metal overlaps itself forming a high strength tubular antenna (Detailed information on Stem Antennas is provided in Appendix IV).

The major objective of the study reported herein, was to determine the feasibility of using a buoy as a navigation slave station, and since the stem antennas are relatively costly, it was decided that a solid whip antenna of conventional design would be used for these engineering studies. The stem antennas are recommended for an operational system; however, additional analysis and experiment on stems should be undertaken prior to the final design of a buoy. The dynamic response of a stem antenna, of the lengths contempted for the Hysurch buoys, remains an unanswered question, in our opinion. (Appendix IV does include the results of some sea tests on stem antennas for the Gemini spacecraft in State 4 Seas.)

_____
*An antenna product of Spar Aerospace Products Limited, Toronto, Ontario (A division of de Havilland Aircraft of Canada).

For this study, a Columbia* Model 222 was modified to produce a 30 foot (effective r.f. length) antenna. This fiberglass antenna was mounted on a five-foot (5') aluminum stand-off, which placed the top of the antenna approximately 36' above the ocean surface. The upper 11' of the antenna was not given additional support; however, considerable effort was made to stabilize the lower parts of the antenna. Four diamond spreaders (See Figure VII) were placed in quadrature between the antenna base and a point 18' above the base which is above a known node on the antenna. These spreaders tended to stabilize the antenna from natural frequency oscillations. The antenna was bolted to the five-foot stand-off, which in turn was bolted to the surface buoy mounting flange.

The mid-point of the diamond spreader stabilizers (9' from antenna base) was supported by three guy wires to the surface buoy (Guy wires were, in general, 3/32" stainless stranded wire, terminated with r.f. insulators and "nicopress" fittings). In addition, the five-foot antenna stand-off was supported by 3 - 3/16" guy wires to the surface buoy.

The antenna stand-off also supported the oceanographic buoy warning light, the radar reflector, and the Sea-Fix antenna loading coil.

MOORING BRIDLE

The buoy was designed to operate with a tripod mooring bridle, approximately 8'2" in height. The bridle (See Figures VIII & X) is essential to the operation of the buoy, since it provides the neces-

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* Manufactured by Columbia Products, Inc., Columbia, South Carolina.
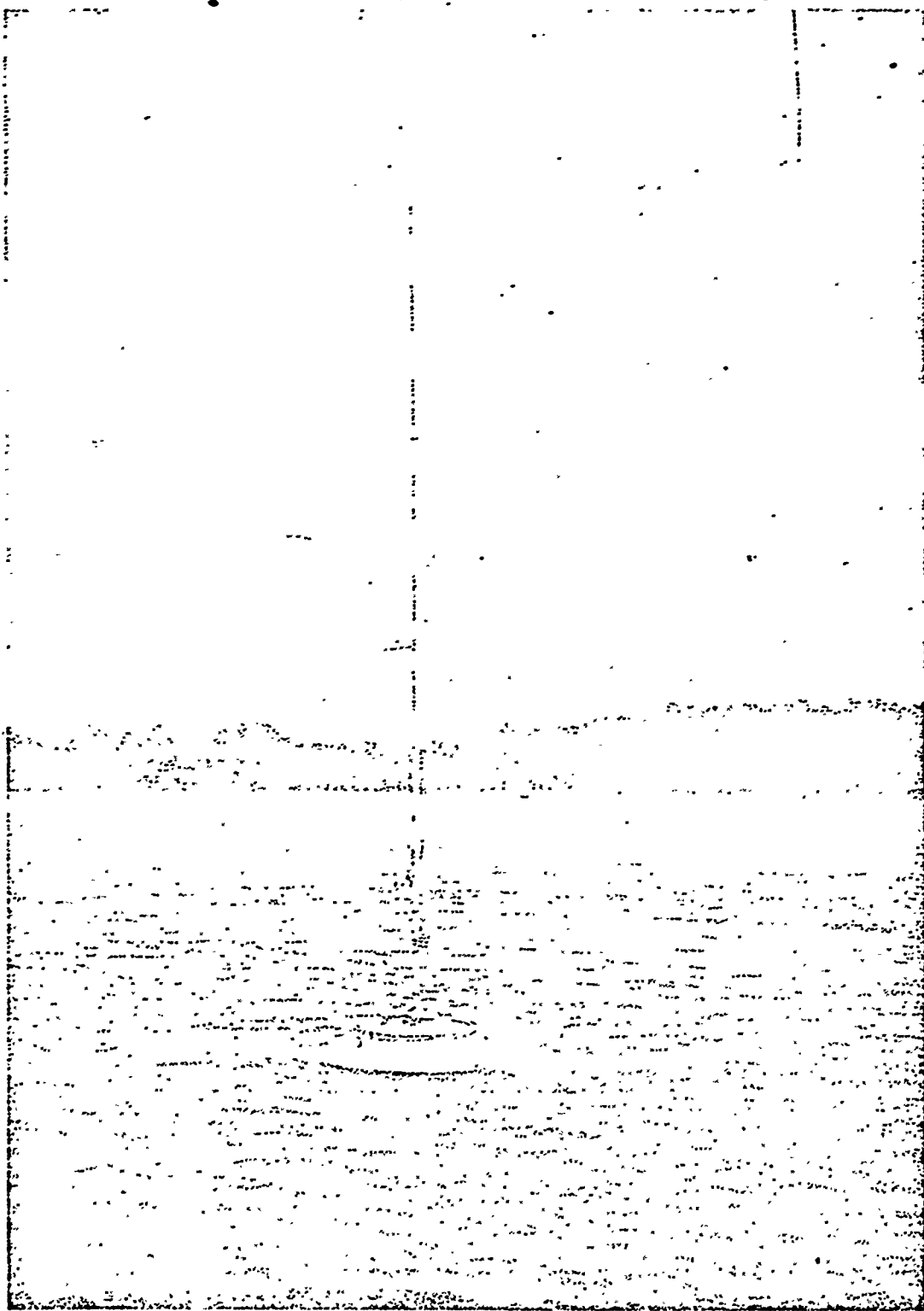
NOT REPRODUCIBLE

Figure IX

Surface View of Parabolic Sea-Fix Buoy

25
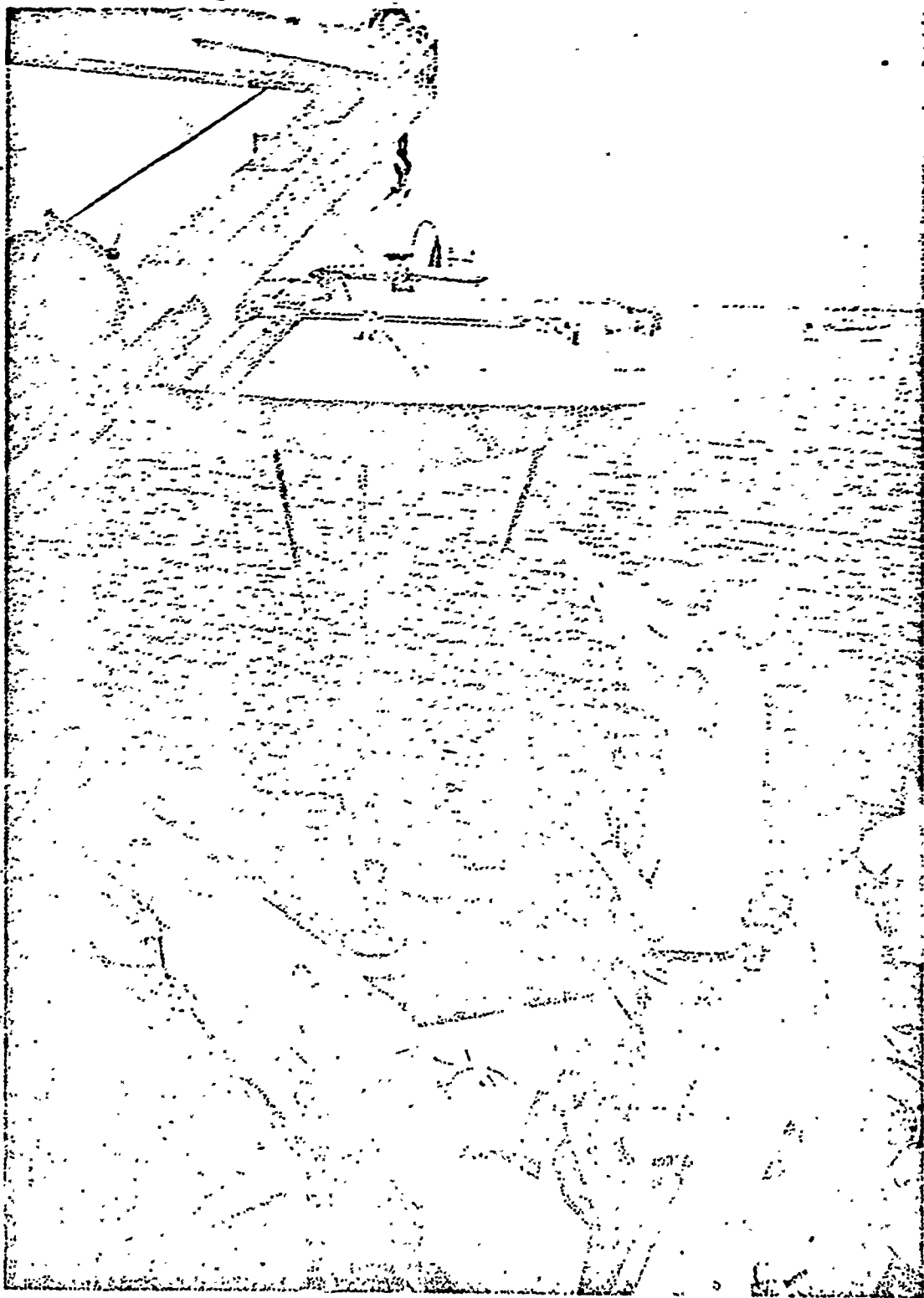
Figure X

Parabolic Sea-Fix Buoy Mooring Bridle

26

sary righting moments for the specified vertical stability. The 1 5/16"
galvanized tripod legs are bolted to the surface buoy at one end and to
an apex yoke at the other. The yoke provides the mooring point as well·
as a mounting point for the dynamic stabilizing weights (shown in Figure
VII as "Para-Weight"). These weights have the effect of substantially
increasing the pitch/roll moment of inertia, which is required for dy-
namic stability.

MOORING

The taut-wire mooring was one of the critical components in the
design. Because of the wide range of expected water depths and tidal
conditions, the mooring must be capable of accommodating length changes.
The study of moorings was focused on methods of overcoming tidal varia-
tions while still maintaining mooring tension and essentially a constant
buoy water-line. As a part of a research program associated with the
Sea-Spider effort of the Office of Naval Research, the U. N. H. design
group had been studying techniques to develop quasi-constant tension
taut-wire moorings. The first major application of the quasi-constant
tension taut-wire mooring was developed for Sea-Spider I. The basic
principle in these moorings is to use a spring-like material with high
compliance compared to the deflections anticipated in a design. This
fact can be easily seen from the basic linearized relationship for a
spring-like material:

$$\text{Force (F)} = \frac{\text{displacement (x)}}{\text{compliance } \left(\frac{1}{k}\right)}$$

Therefore:

$$\frac{df}{F} = \frac{dx}{x}$$

27

which indicates that the % change in displacement results in an equal change in force. Therefore, the length of the spring-like material under load must be large compared to tidal variations (say 10 feet), or the material must be highly compliant (note: a constant force spring is infinitely compliant).

There are numerous ways of obtaining this compliance. In an operational buoy system, one can imagine a constant tension winch on the mooring cable, which would serve both for storing of the mooring cables as well as providing the constant tension.

For the prototype evaluation, a relatively simple approach was used. The mooring used four (4) one-inch(1") diameter solid HATSYR rubber rods, configured as shown in Figures XI & XII. For the load levels used, (approximately 2000 lbs.) this rubber produces approximately 2.0 lb. per percent elongation per rubber rod, which for this mooring resulted in a force change of 50 lb/ft of water depth change. For example, a 10-foot tide would change the mooring-tension by 500 lbs. This tidal effect results in the buoy water-line change of 2 inches, which is negligible.

The rubber links were secured to the anchor with self-aligning mounting yokes and shackles. A standard underwater swivel was used to eliminate torsional rotation problems. All shackles were of the seizable type.

ANCHORING

An operational slave-buoy system, which has a total weight of 1500 to 2500 lbs., presents a difficult anchoring problem. It is clear from the figures below that the buoy system exclusive of an anchor can be built within these specifications:
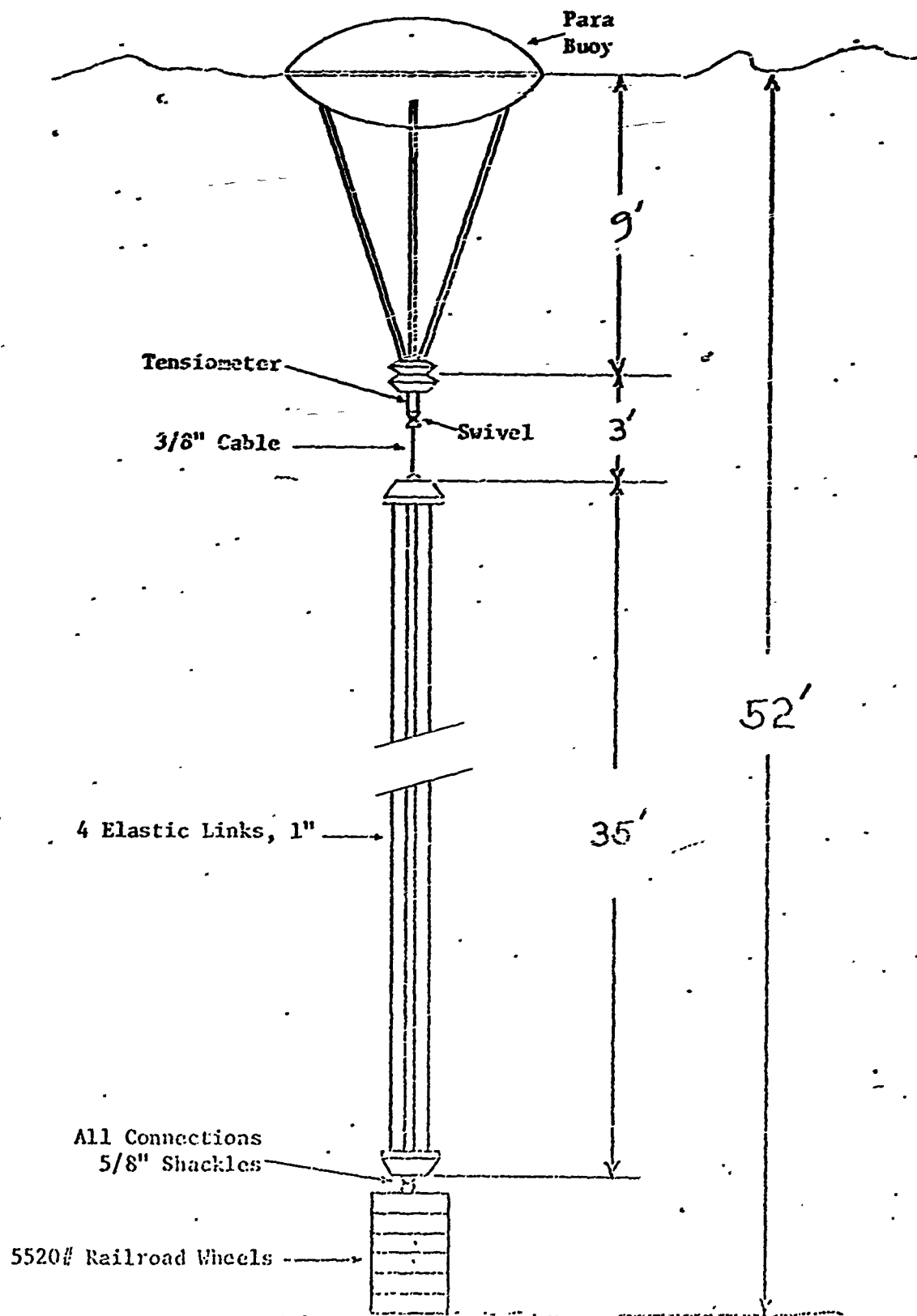
Figure XI
Mooring Details for Shallow Water (52') Installation

29
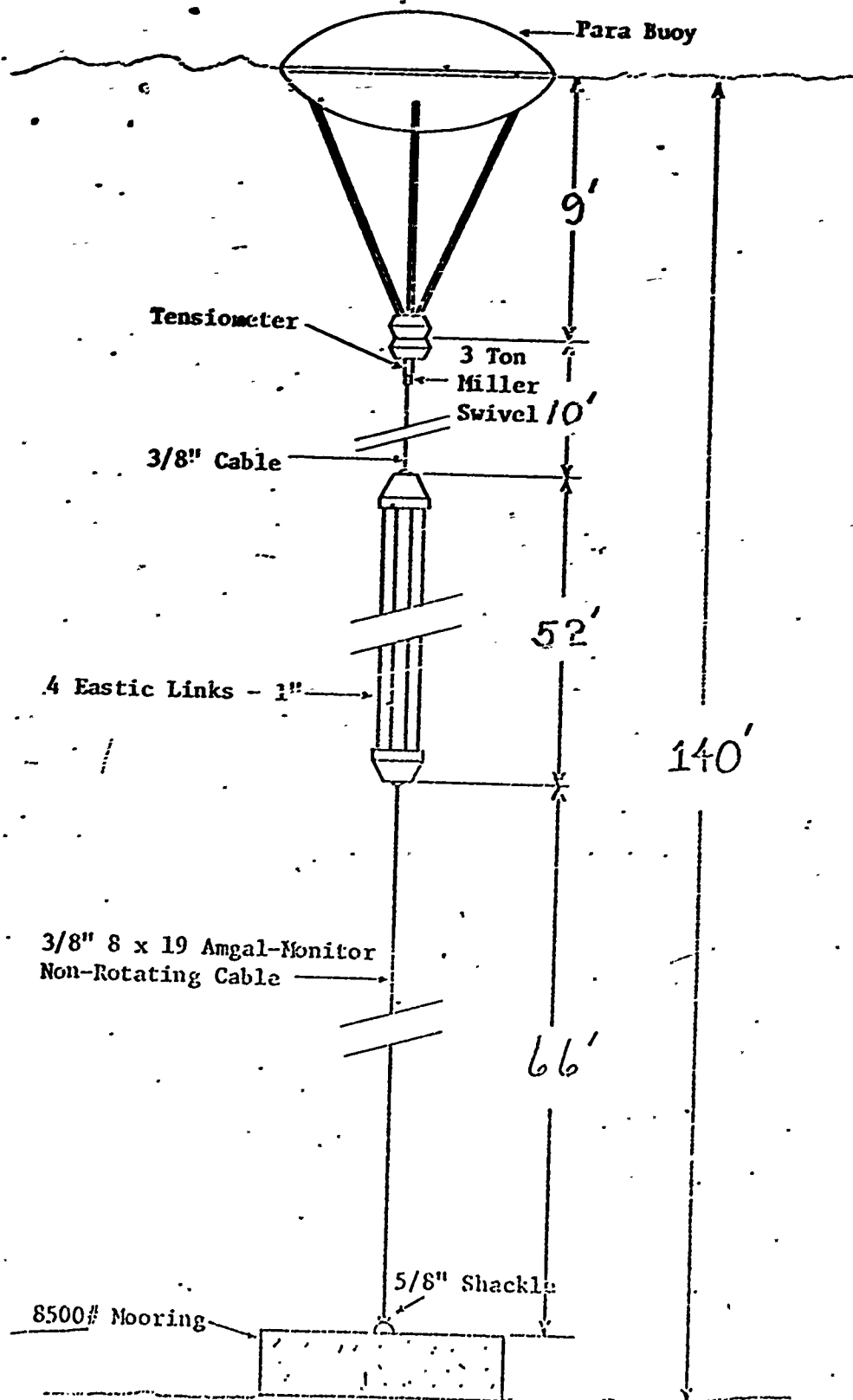
Figure XII
Mooring Details for Deeper Water (140'). Installation

. Antenna Section   - 140 lb.

Buoy (with Sea-Fix,
Instr.,.and 3.4 KW-hrs.
of 24VDC Power)   - 720 lb.

Bridle and Mooring Cables- 300 lb.
                            1160 lb.

However, it is also clear that a deadweight anchor can not exceed
a few hundred pounds. Since mooring tensions must be approximately
2000 lb., some other anchor technique for an operational system must
be found.

For obvious reasons, embedment anchors were studied. This study
revealed that the "Seastable", developed by the National Waterlift
Company holds the greatest promise for the Hysurch application. These
anchors have been evaluated extensively by the Naval Civil Engineering
Laboratory, who can supply detailed reports. Appendix V contains a
summary of data on these anchors, and a list of anchor applications.

To evaluate the buoy performance characteristics, a light-weight
anchor is not necessary; hence, the anchors used in this study were
similar to the Sea-Spider anchor design, reported in Reference 8,

SEA-FIX

A study conducted jointly by NAVOCEANO, M.I.T., and U.N.H. per-
sonnel, revealed that the Sea-Fix radio-navigation system was the most
promising candidate for Hysurch applications. The details of that
study are beyond the scope of this report. However, the key factors
in the decision to use a Sea-Fix system were slave station size and
weight, and the average power requirements. A description of the
system, a proposed diesel-generator power supply, and general

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operating characteristics are given in Appendix VI (The buoy described in that appendix is not recommended by the authors, but it is included in the appendix since the material was prepared by the Sea-Fix manufacturer.)

INSTRUMENTS AND POWER SUPPLY

The engineering evaluation instrumentation is described in the next section. The power supply was a set of 6 standard 12VDC marine lead-acid batteries. These batteries were fully charged, degassed, and sealed prior to installation.

III. EXPERIMENTAL PROGRAM

An experimental program was undertaken to investigate the perfor-
mance of a prototype system consisting of a radio navigation slave sta-
tion mounted on a taut-wire moored surface buoy. The use of a quasi-
stable buoy as the platform for the reference station of a navigation
system poses problems not encountered with land installations. First,
the buoy location is not fixed; there is a region of probable location,
determined by the buoy dynamics and the local weather. Second, the
buoy does not retain a vertical orientation, hence the transmitting/
receiving whip antenna is not always vertical, which can create a re-
duction in transmitted power and which can significantly alter the
antenna radiation pattern. Third, experience has shown that antenna-
to-ground plane interaction is critical at the frequencies commonly
used for this application. The warped ocean surface makes it difficult
to "tune" the antenna to the radio transmitter for maximum radiated
power.

The program consisted of two series of tests: one with the system
exposed to high currents, but relatively light wind and wave disturbance
and the second with moderate to heavy wind and wave conditions, but
relatively low currents. Division of the tests was dictated in part
by physical characteristics of conveniently located water test areas
and in part by the desire to identify the separate effects of wind-wave
and current inputs to the buoy system.

Three primary methods of data collection were employed. Two Wild
T-2 theodolites operated from shore-based observation stations were used
for direct monitoring (see Figure XIII). Two Giannini Scientific data
cameras, mounted near the theodolite stations, provided data for higher

33
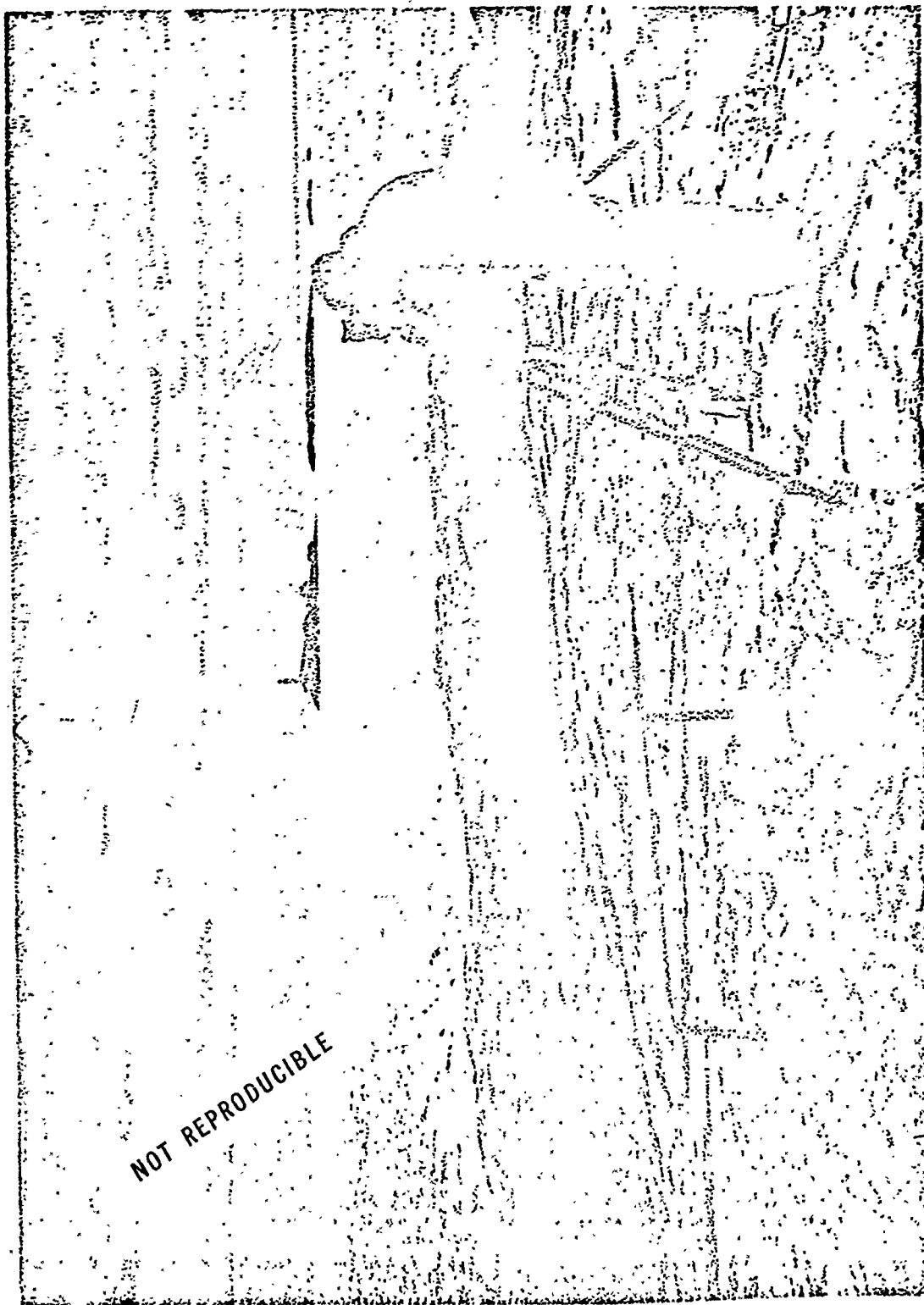
Figure XIII

Theodolite Station, Star Island

34

frequency notions of the buoy. On-board instrumentation was installed to obtain records of the buoy dynamic behavior.

Concurrent with the buoy dynamic testing, a program was conducted by personnel of the Experimental Astronomy Laboratory at the Massachusetts Institute of Technology to obtain operating performance data for the Decca Sea Fix radio navigation system. During test periods, transmission was maintained between the buoy slave station and the master station at Race Point Coast Guard Station near Provincetown (see Figure XIV), Cape Cod, Massachusetts, and the mobile slave station installed in a station wagon (shown in Ref. 6) and operated over the northern shore of Cape Cod from Provincetown to Cape Ann.

A.   On-Board Instrumentation

The following instruments were installed in the test buoy (see Figure XV): a two-axis vertical gyroscope to monitor quadrature tilt components (pitch and roll), an accelerometer to monitor vertical acceleration, and a strain gage tensiometer to monitor mooring cable tension.

A Summers model K7 vertical gyroscope was secured to a platform on the instrument package which was installed in one of the buoy compartments. The gyroscope was aligned with the buoy vertical axis so that departure from vertical could be determined by the readout of the two quadrature pick-off signals. Bias voltages allowed the net output signals to indicate mid-scale deflection on a two channel Rustrak recorder for zero angle of tilt in both axes. Gyroscope circuit connections and calibration curves are shown in Figure XVI.

Figure XIV

Map of Test Area

Hyperbolic Navigation System Tests

University of New Hampshire
Durham ○
Little Bay ○
Portsmouth ○

Isles of Shoals
SEA-FIX SLAVE STATION
ON BUOY (UNH Operation)

Sea-Fix Baseline

N.H.

Mass.

Land's End, Cape Ann
Receiver Test Point

M.I.T.   M A S S A C H U S E T T S   B A Y
Cambridge ○

Nantasket
Receiver Test Point

Race Point, Provincetown
SEA-FIX MASTER
STATION
(MIT Operation)

White Horse Beach,
Plymouth

Receiver Test Point
and Speed Tests

West Barnstable
Receiver Test Point

NOT REPRODUCIBLE

Figure XV

Installing Buoy Instrumentation

37

Gyro Calibration – Pitch
Scale Divisions vs. θ

θ pitch

Div.

+

Div.

Gyro Calibration – Roll
Scale Divisions vs. θ

θ roll

Div.

+

Div.

PITCH

ROLL

12.6

8.4

12.6

8.4

A
B
C
D
E
F
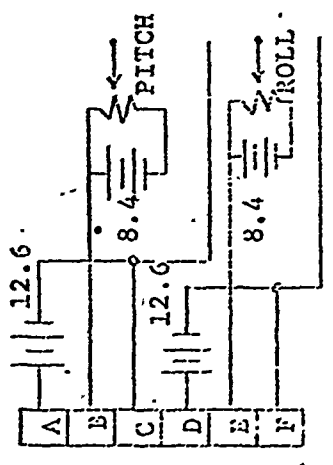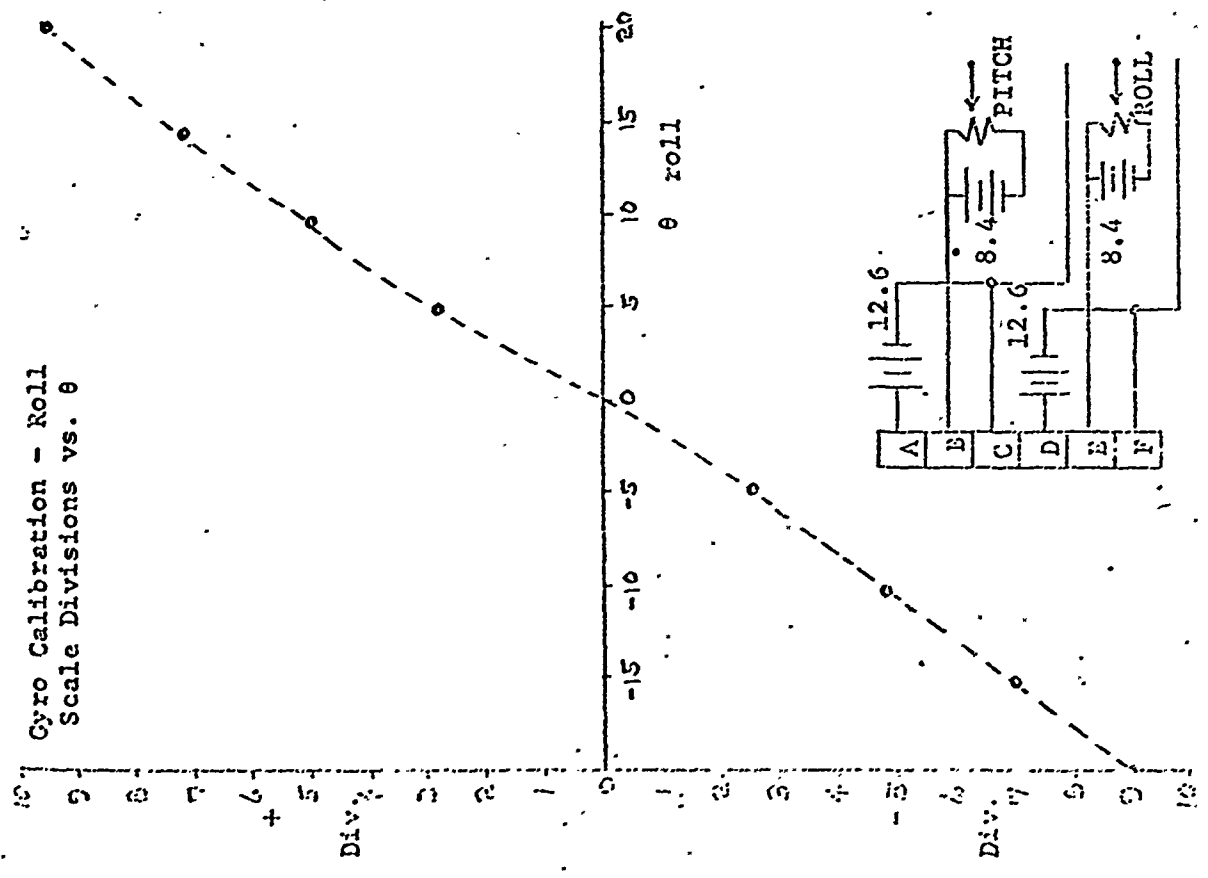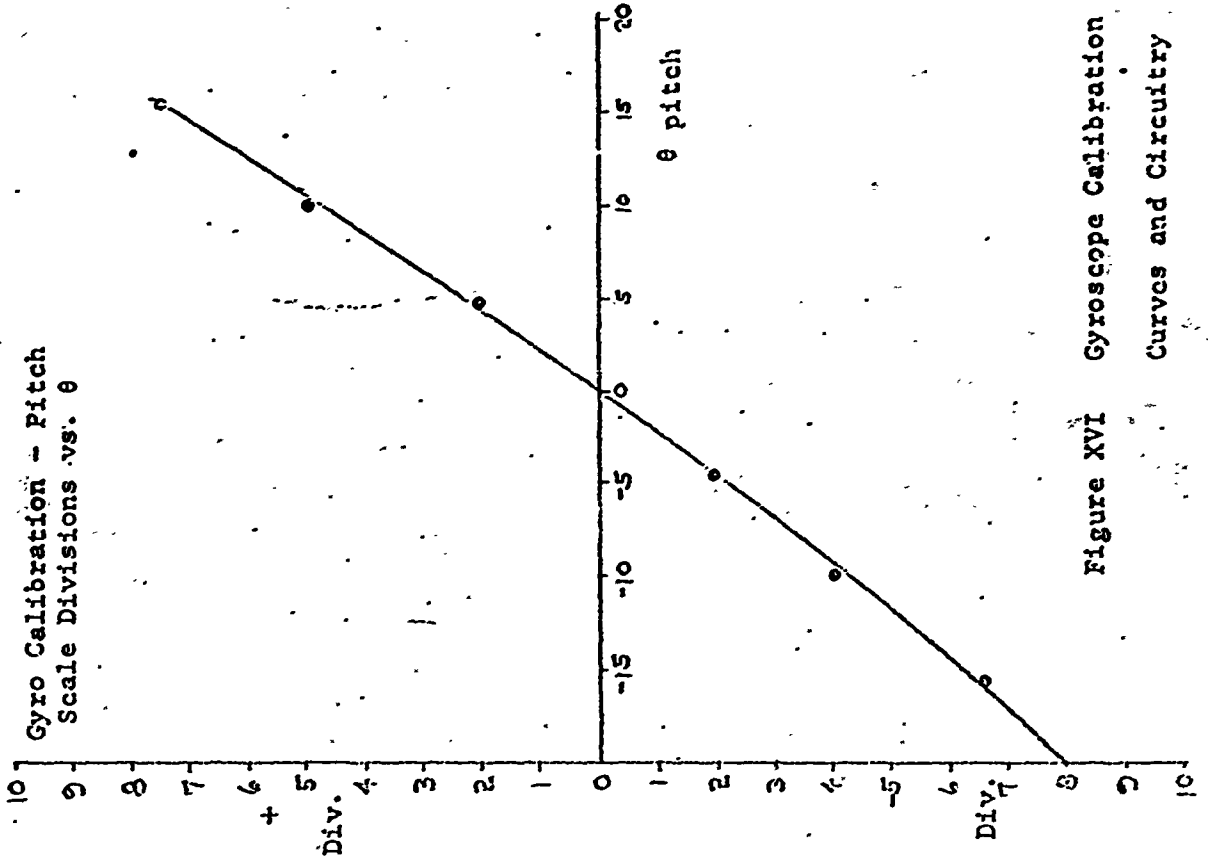
Figure XVI   Gyroscope Calibration
Curves and Circuitry

38

A Kistler model 350A servo accelerometer was used for vertical acceleration measurements. This unit has a maximum range of $\pm$ 50 g but circuits were provided to adjust the operating range to $\pm$ 2 g which was judged to be reasonable for predicted accelerations due to heaving of the buoy. This value was based on estimates of wave amplitudes I periods for sea states to be encountered during the tests. The accelerometer was centrally located in the mast of the buoy which was sealed to prevent water damage to the unit. Accelerometer output was fed to one channel of a second Rustrak on-board recorder which indicated a nearly linear $\pm$ 10 division full scale deflection for $\pm$ 2 g output.

Mooring cable tension was monitored on the second channel of the second Rustrak recorder by means of a compensated SR4 strain gage bridge. The gage elements were mounted on a special link in the moor line and were taped and sealed for protection and waterproofing.

Figure XVII shows the Tensiometer Bridge circuit and mounting. Figure XVIII is a schematic diagram of the accelerometer and tensiometer circuitry, including battery power sources and isolation operational amplifiers.

Two waterproof switches were provided external to the instrument compartment to control power to the Sea Fix transmitter and to the instrument package. Since the buoy compartment covers were fastened with 24 bolts, opening a compartment was a major task. The external switches enabled an operator to merely reach over to the buoy from a small boat and control power to the radio transmitter or to the instruments and recorders. A small panel meter to check the charge condition of the Sea Fix storage battery supply was also installed in the instrument

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TENSIOMETER BRIDGE CIRCUIT

To amplifier
and
recorder

SR4   SR4

120   100

50

CUTAWAY

showing mounting
of longitudinal and
compensating strain gages

waterproofing ---
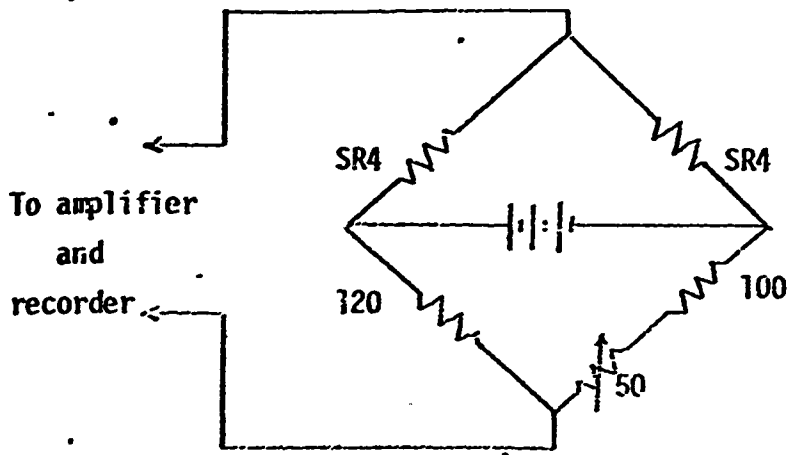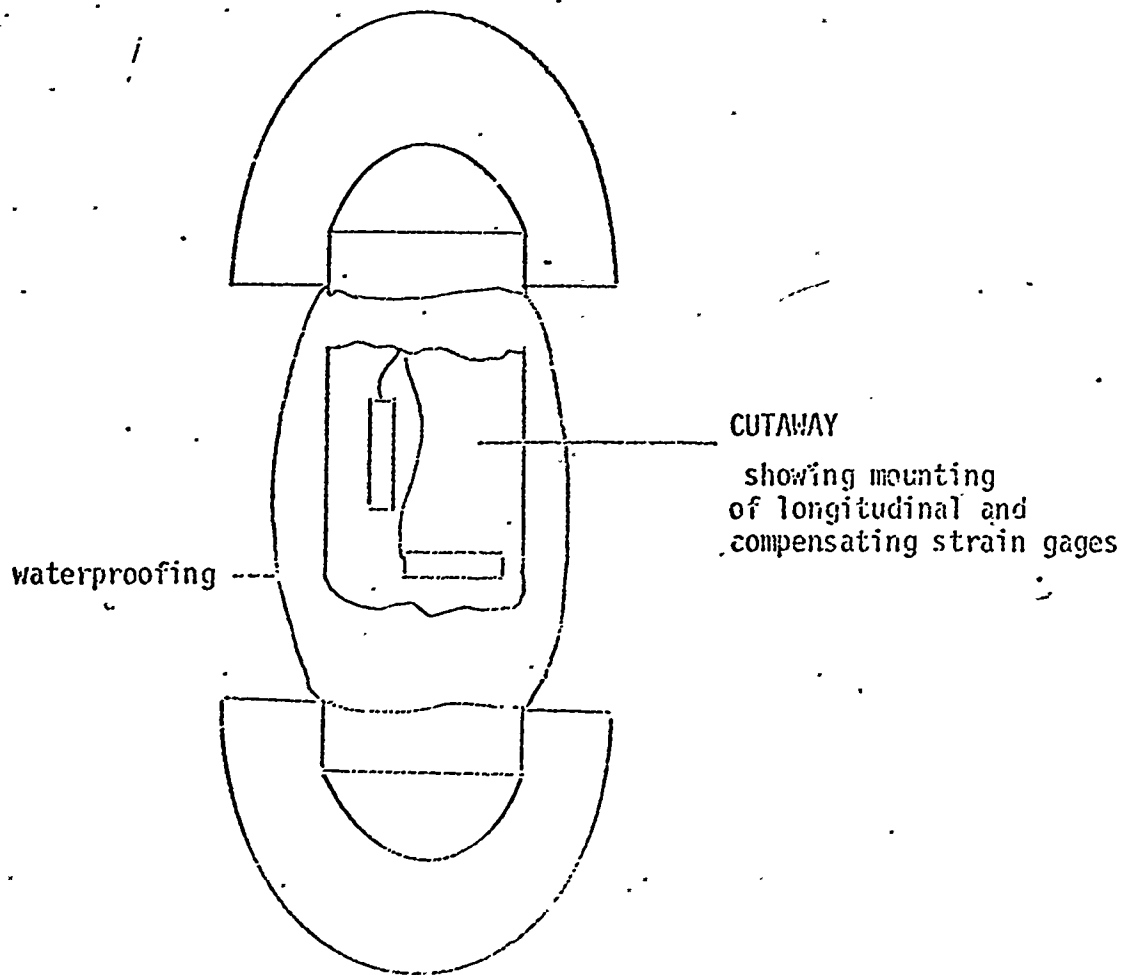
40

Figure XVII   Tensiometer bridge Circuit and
Strain Gage Mounting
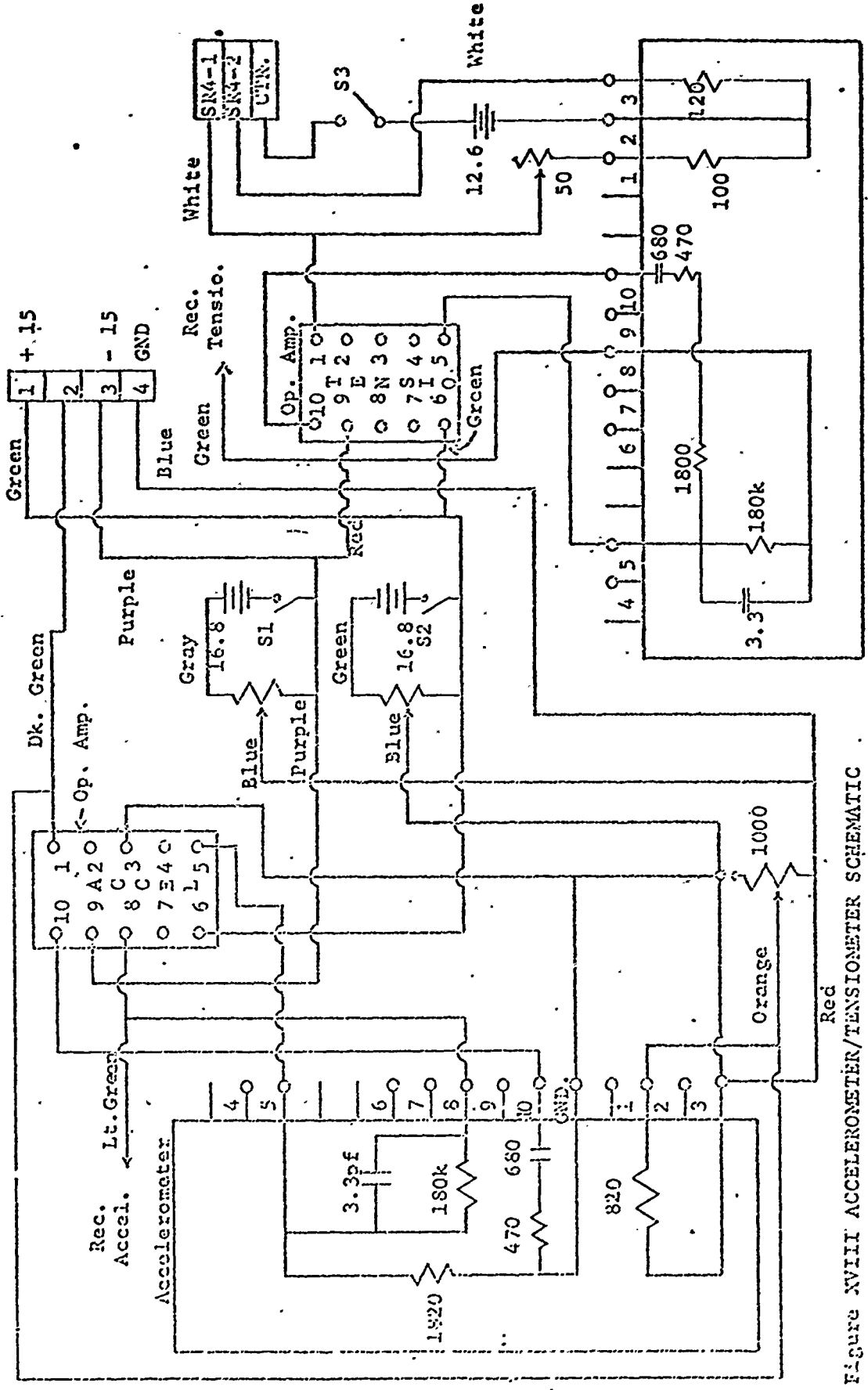
Figure XVIII ACCELEROMETER/TENSIOMETER SCHEMATIC

compartment and visible through the plexiglass cover. It was anticipated that these batteries would have to be recharged periodically to maintain the required minimum voltage for proper operation of the radio navigation equipment.

B. Tidal Current Tests - Little Bay Test Site

The primary objective of this test series was to evaluate the dynamics of the taut-wire moored buoy in a high tidal current environment. The Bay implantation point indicated in Figure XIX, was selected to provide up to 2 knots of current and offered convenient shore observation points. Water depth was approximately 52 feet, tidal variation 6-8 feet during the period of test, and current generally in a north-south direction.

Preparation for the buoy test consisted of first placing the railroad wheel anchor and attaching a temporary cable and tag buoy. The Para-Buoy and taut-wire moor as shown in Figure XI was then installed. Block and tackle loading from the surface was employed to extend the elastic links sufficiently to allow the upper basket support to be made fast to the base of the tripod structure with a short by-pass cable. Baselines were established for the two shore stations and theodolites and cameras installed.

Tests were conducted on 26 and 27 August, during which a total of 13 hours and 25 minutes of data were collected. Current and wind velocity and direction measurements in the vicinity of the buoy were made to provide correlating data and a small amount of on-board instrument data was recorded. Theodolite readings were obtained at five

42
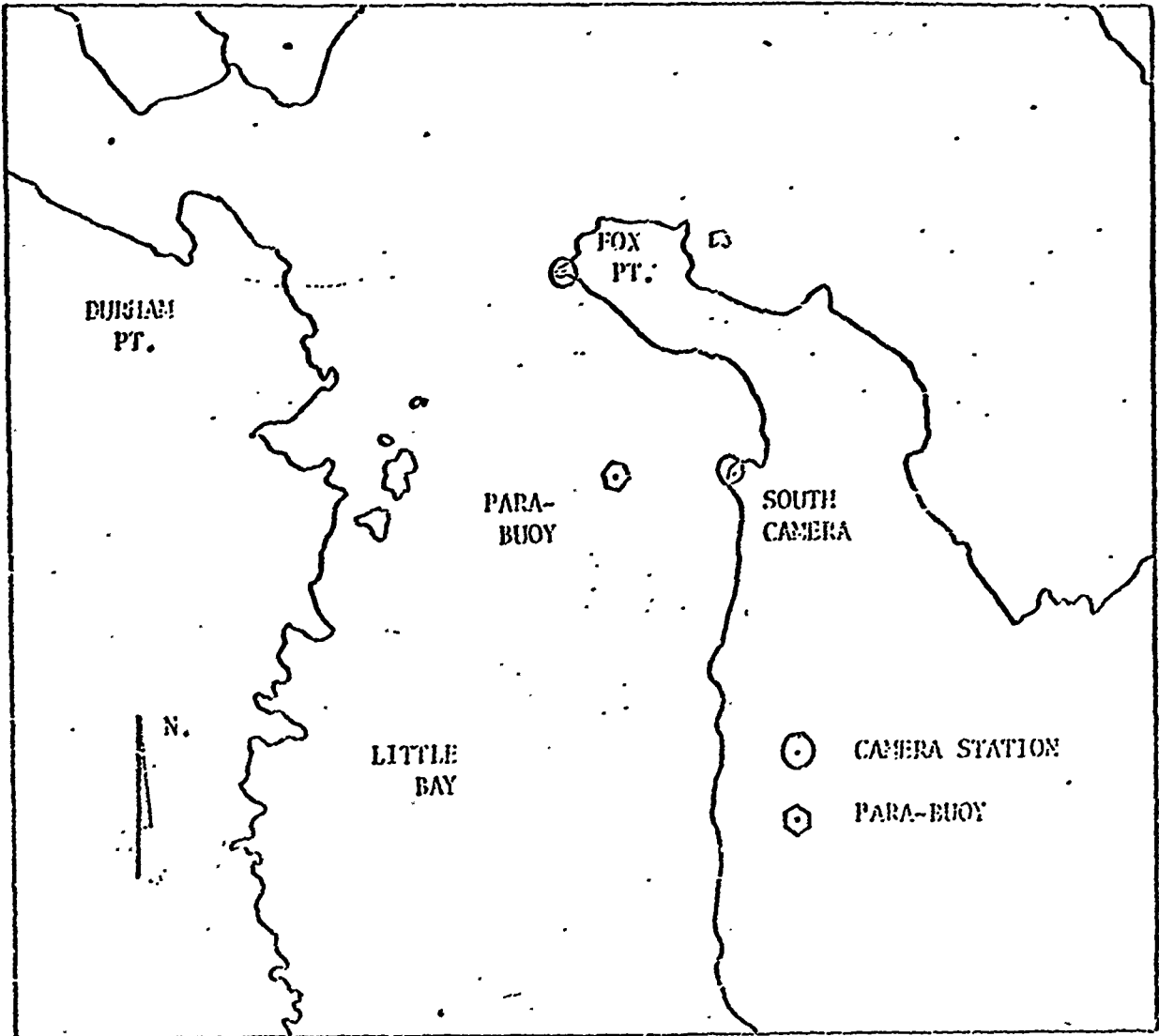
DISTANCE BETWEEN CAMERA STATIONS: 2364.9 feet

DISTANCE BETWEEN THEODOLITE STATIONS: 2353.9 feet

Figure XIX   Little Bay, N. H. Buoy Test Area

43

minute intervals and were synchronized between the two shore stations by two-way radio. Some photographic data was obtained but difficulties were encountered with bore-sighting the cameras to obtain proper framing. Contact with the Sea Fix Master station (approximately 75 miles away) was made successfully after proper tuning of the slave transmitter, but a frequency shift was recommended before the more extensive tests were conducted at the Isles of Shoals.

C.   Wind and Wave Tests - Isles of Shoals Test Site

Open water tests of the buoy system were conducted in the vicinity of Star and White Islands, Isles of Shoals, New Hampshire, during 5 to 12 September, during which a total of 14 hours and 30 minutes of data were collected. Water depth was approximately 140 feet with tidal range of 8-10 feet. The mooring point, shown in Figure XX, was selected to provide realistic exposure to wind and wave forces which prevail in the southeast to northeast sector. The buoy instruments, batteries, and radio equipment were reinstalled after transfer from Little Bay to the Isles location. Assistance in placing the mooring anchor was obtained from the United States Coast Guard and buoy and cable attachment followed the general procedure of the Bay installation. The mooring system is shown in Figure XII.

Observation stations were set up on Star and White Islands. Data runs consisted of theodolite readings at 5 minute intervals plus hourly instrumentation recordings and observations of current, wind and general sea conditions. Radio contact between the base stations and with the small boat operating crew was maintained using VHF-FM transceivers.

44

Appledore Island

Smuttynose Island

Star Island

White Island

⊙ ... Para-Buoy
⊙ ... Camera Station

Figure XX   Isles of Shoals Test Area

45
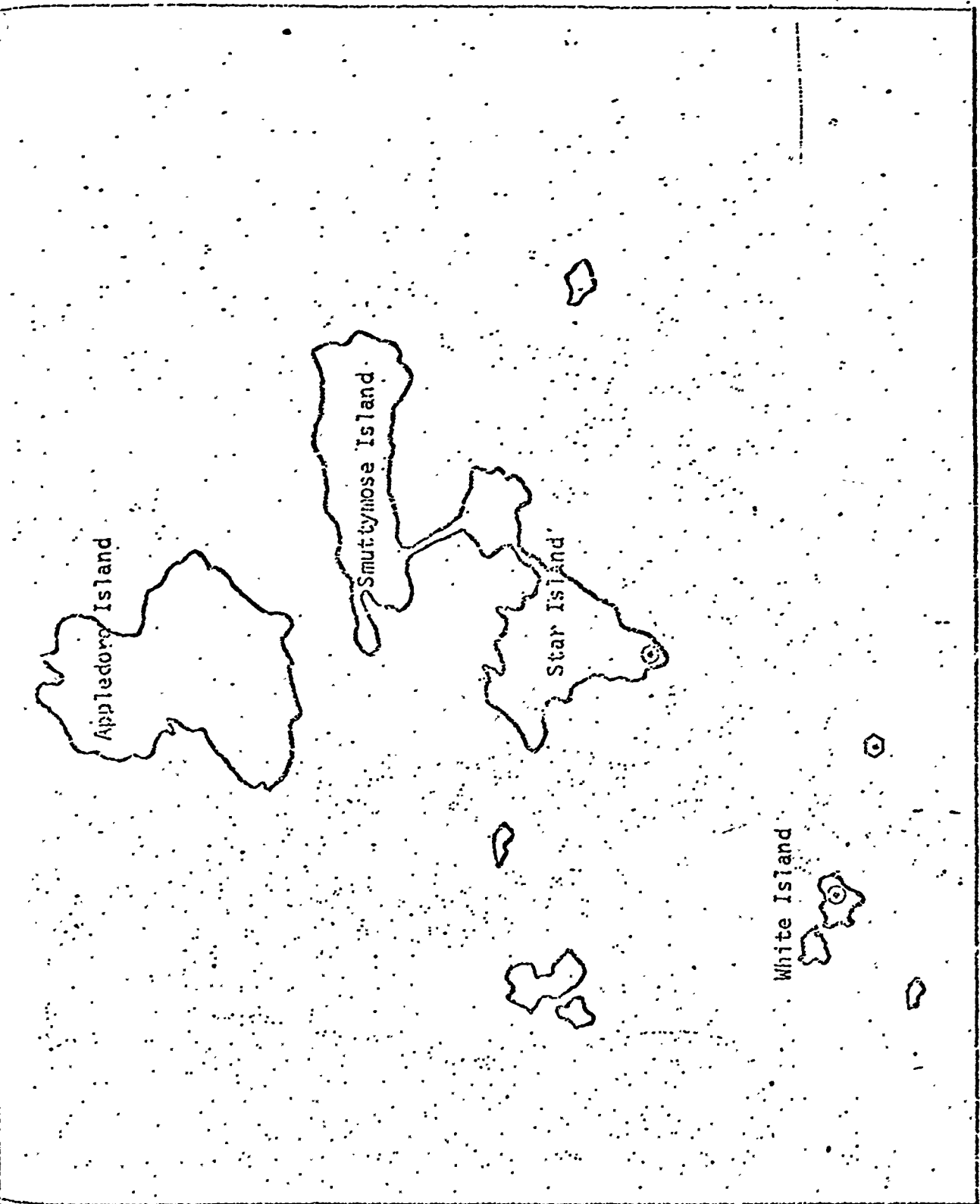
Communication with the MASTER and MOBILE Sea Fix teams to coordinate radio navigation tests was provided by an HF-FM radio system.

D. Test Results

Test conditions in Little Bay were relatively calm, with no storms affecting the buoy. Wave effects were slight, and the buoy was not subjected to much short duration movement. The tests were conducted over approximately a half cycle of tidal current variation, consequently, the buoy was always subjected to uni-directional current during any one test period. This tended to give the buoy a small constant vertical inclination.

Test conditions at the Isles of Shoals were more varied than in the Bay. The buoy was subjected to wave, current, tide, and wind effects. An approaching storm produced sea states close to State 4 on 10 September and a full gale caused tests to be suspended on 11 September (see Figure XXI). Final tests on 12 September were not valid since three of the four elastic links were discovered to have failed sometime during the storm and the buoy was suspended by a single link.

Test data characteristics are summarized as follows:

Theodolite — Visual observation and manual recording. High quality data. Five minute recording intervals. Data reveals buoy watch circle performance. Estimated values of maximum antenna tilt obtained.

Data Cameras — Check on theodolite data to support validity of taking observations at five minute intervals. Antenna tilt angles are readable. Little Bay data fair to good. Shoals data poor due to focus and bore sighting difficulties.

Gyroscope — Tilt angle and period obtained. Two channels of data recorded for part of test period. One channel became inter-

46

Figure XXI

Hysurch Buoy, Storm of 11 September

> mittent but the second channel provided useful data for the Shoals tests because of the random yawing of the buoy.

Accelerometer Periods and maximum values of acceleration obtained. Range of acceleration was only 10-20% of anticipated value.

Tensiometer Cable tension data obtained for short period of tests. Failure in tensiometer circuitry resulted in intermittent operation.

Theodolite data, recorded and processed by personnel from the U. S. Naval Oceanographic Office using the Universal Transverse Mercator Grid Coordinate system[10], was converted to computer plots showing the buoy excursions for each data run. Reduced data for all tests is included as Appendix VII. The computer plots are shown in Figures XXII and XXIII for the Bay tests and in Figures XXIV through XXIX for the Shoals tests.

The most probable location of the buoy for no wind, wave or current disturbance at each site, $\overline{X},\overline{Y}$, was computed by averaging all coordinate data recorded for the site and is indicated on each plot to provide a reference for buoy motions. Although this point is not precise, it does represent a best estimate for the true location of the mooring anchor and the undisturbed buoy directly above it. Current and wind vectors for one of the observed data points are also shown.

A tabulation of Apparent Buoy Motion for each test day at Little Bay and at the Isles of Shoals appears in Figure XXX. These data may be interpreted as the maximum excursions of the buoy as sighted from the theodolite shore stations. Excluding the 12 September test which is invalid due to the loss of three elastic links in the storm of 11 September, and defining the largest apparent total excursion as the

48

26 AUGUST 1968-LITTLE BAY

No wind or current data

1645

1000

X,Y

6 hours - 45 Minutes
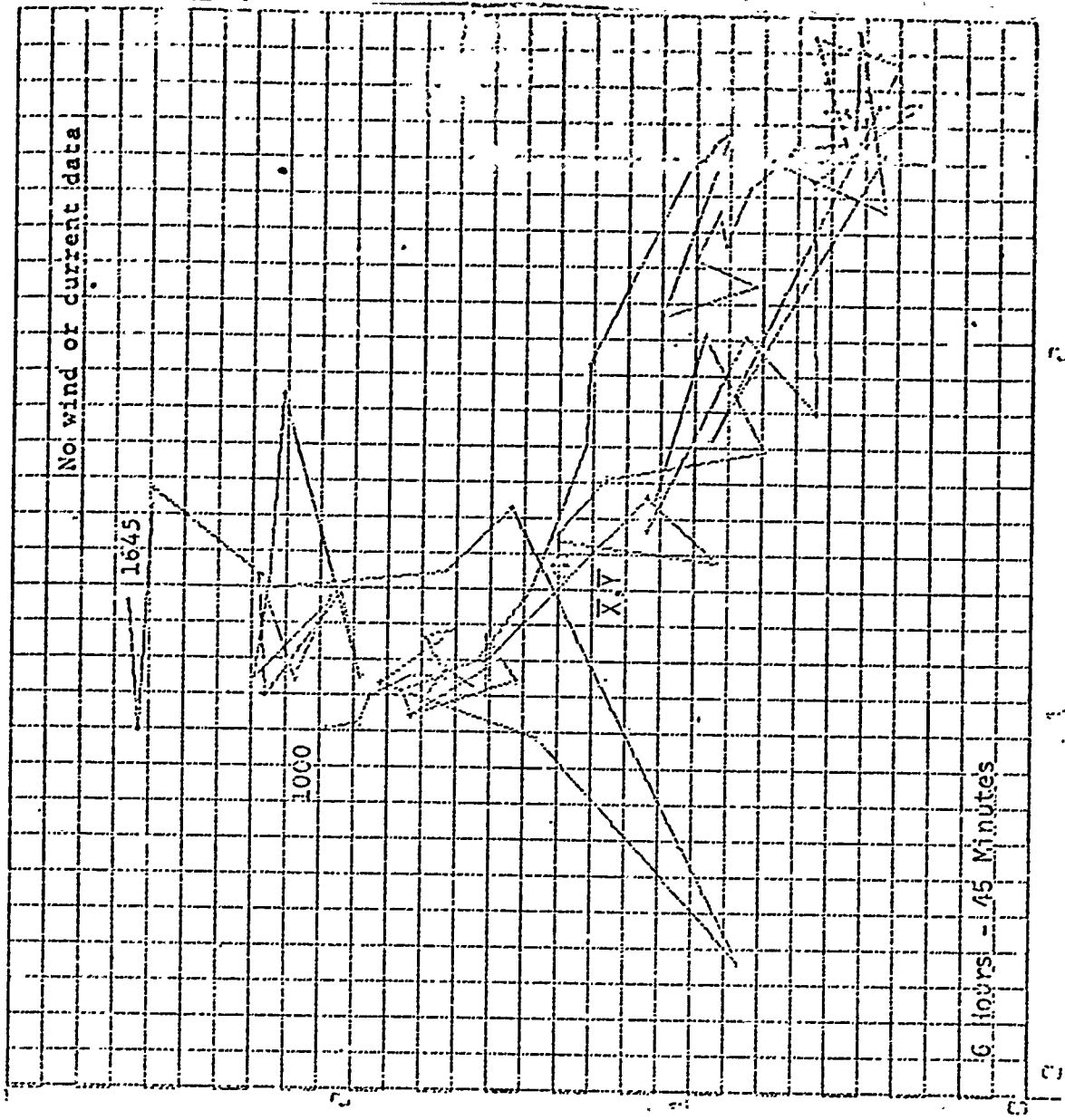
NORTHING

EASTING

Figure XXII   Buoy Motions

26 August 1968

Little Bay, N. H.

49
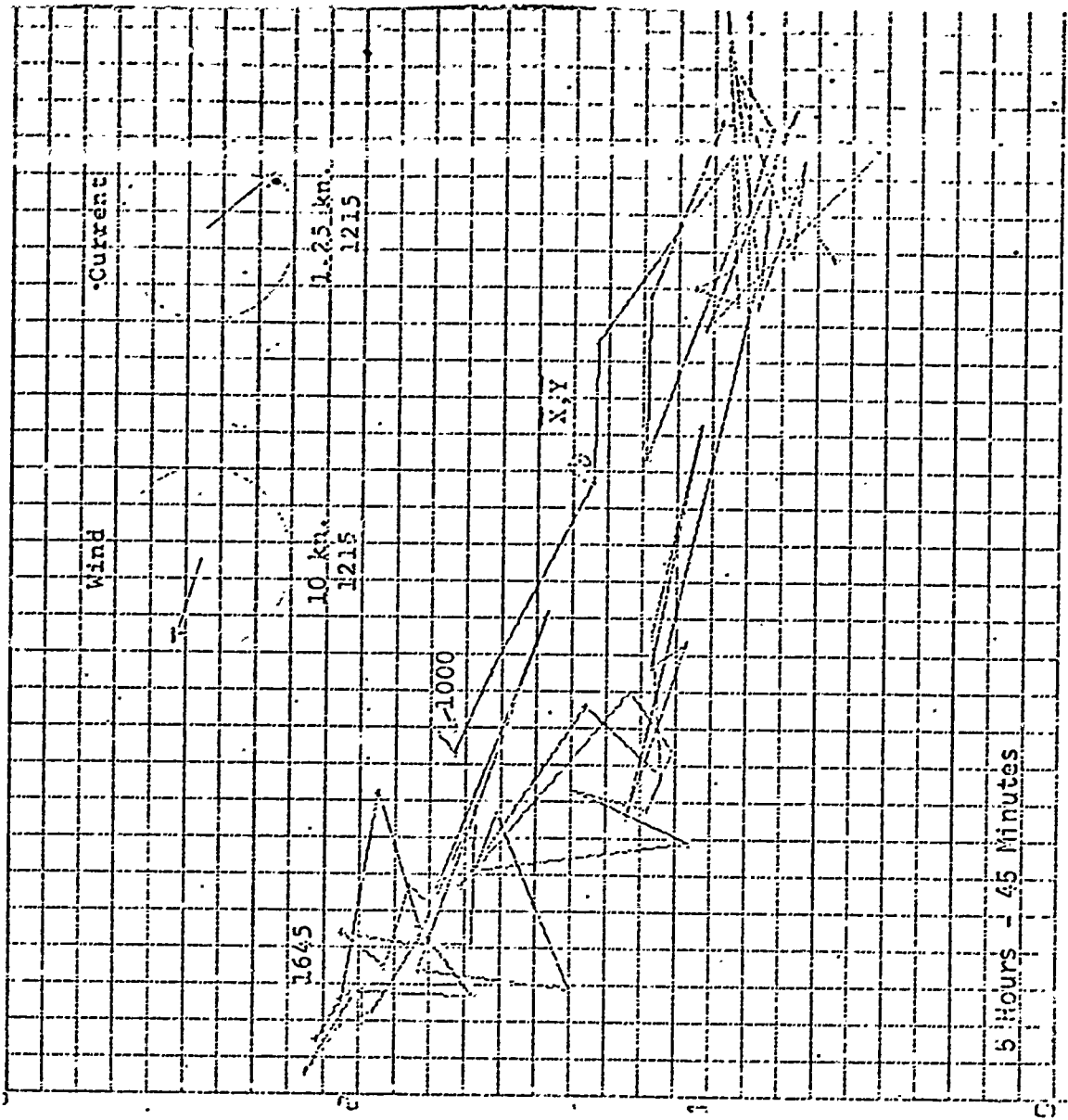
Figure XXIII   Buoy Motions

27 August 1958

Little Bay, N. H.

50

5 SEPTEMBER 1968-SHOALS

Current

Wind

.48 kn.
1505

5.5 kn.
1505

1625

1455

$\overline{X}, \overline{Y}$ ⊙

1 Hour = 30 Minutes

NORTHING

EASTING

Figure XXIV   Buoy Motions

5 September 1968

Isles of Shoals, N. H.
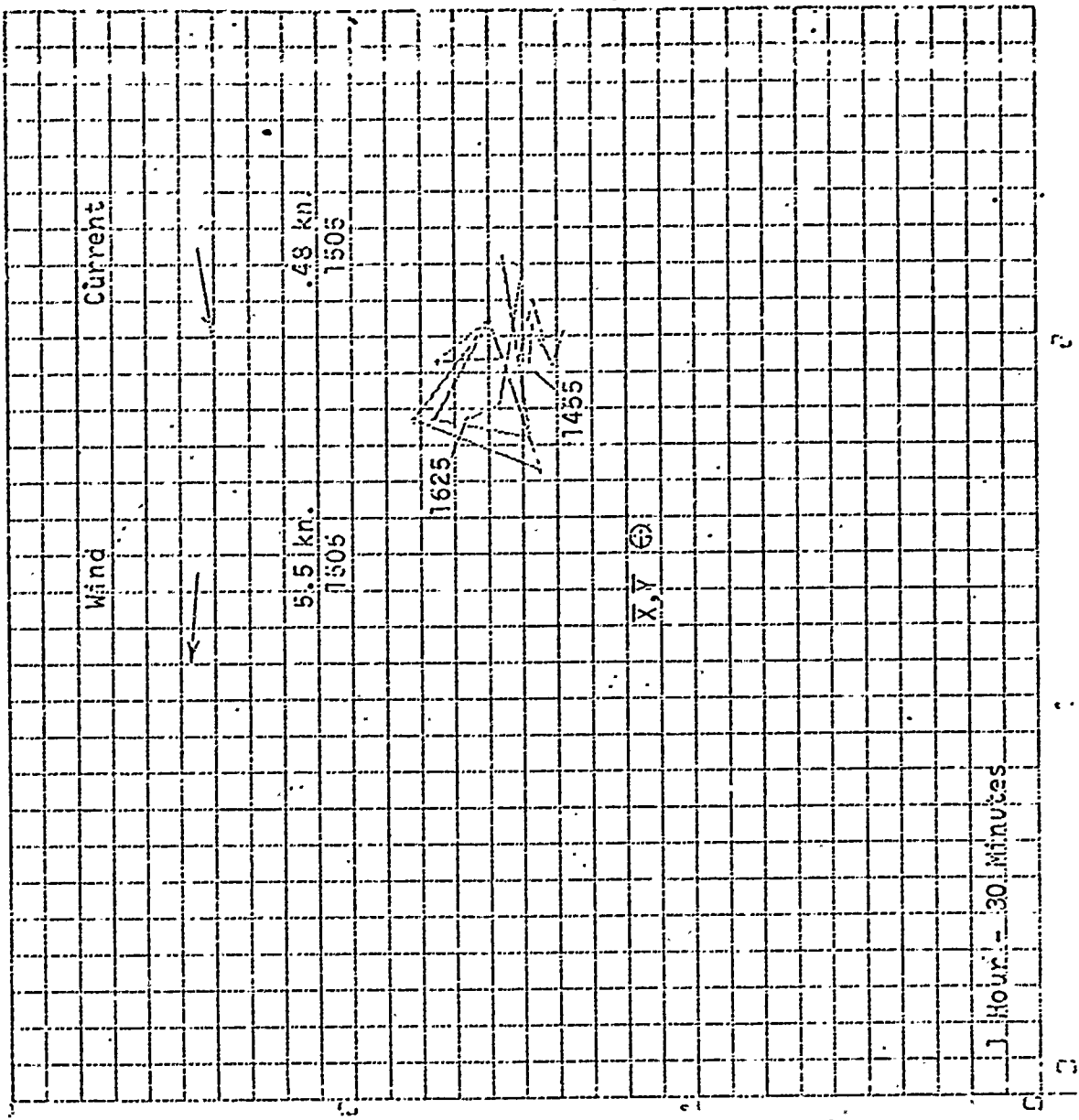
6 SEPTEMBER 1968-SHOALS

NORTHING

Figure XXV   Buoy Motions

6 September 1968

Isles of Shoals, N. H.

EASTING

8 SEPTEMBER 1968-SHOALS

NORTHING

EASTING

Current

.43 kn.
1600

Wind

4 kn.
1600

1715

⊙ X̄,Ȳ

1520

1 Hour – 55 Minutes

Figure XXVI   Buoy Motions

8 September 1968

Isles of Shoals, N. H.

53
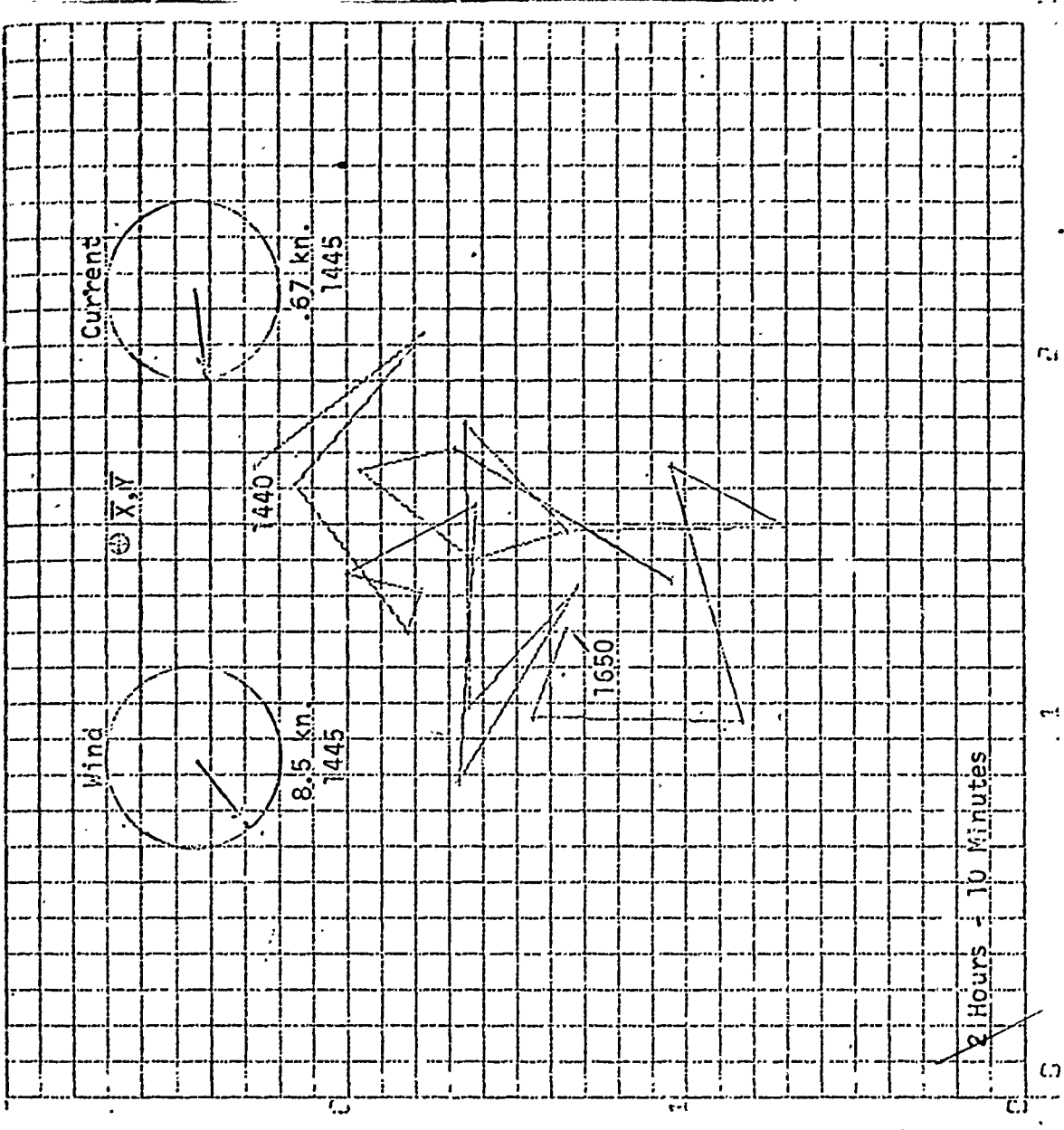
Figure XXVII   Buoy Motions

9 September 1968

Isles of Shoals, N. H.

NORTHING

EASTING

54

16 SEPTEMBER 1968-SHOALS

NORTHING

EASTING

No wind or current data

⊕ X̄, Ȳ

1427

1035

2 Hours - 8 Minutes
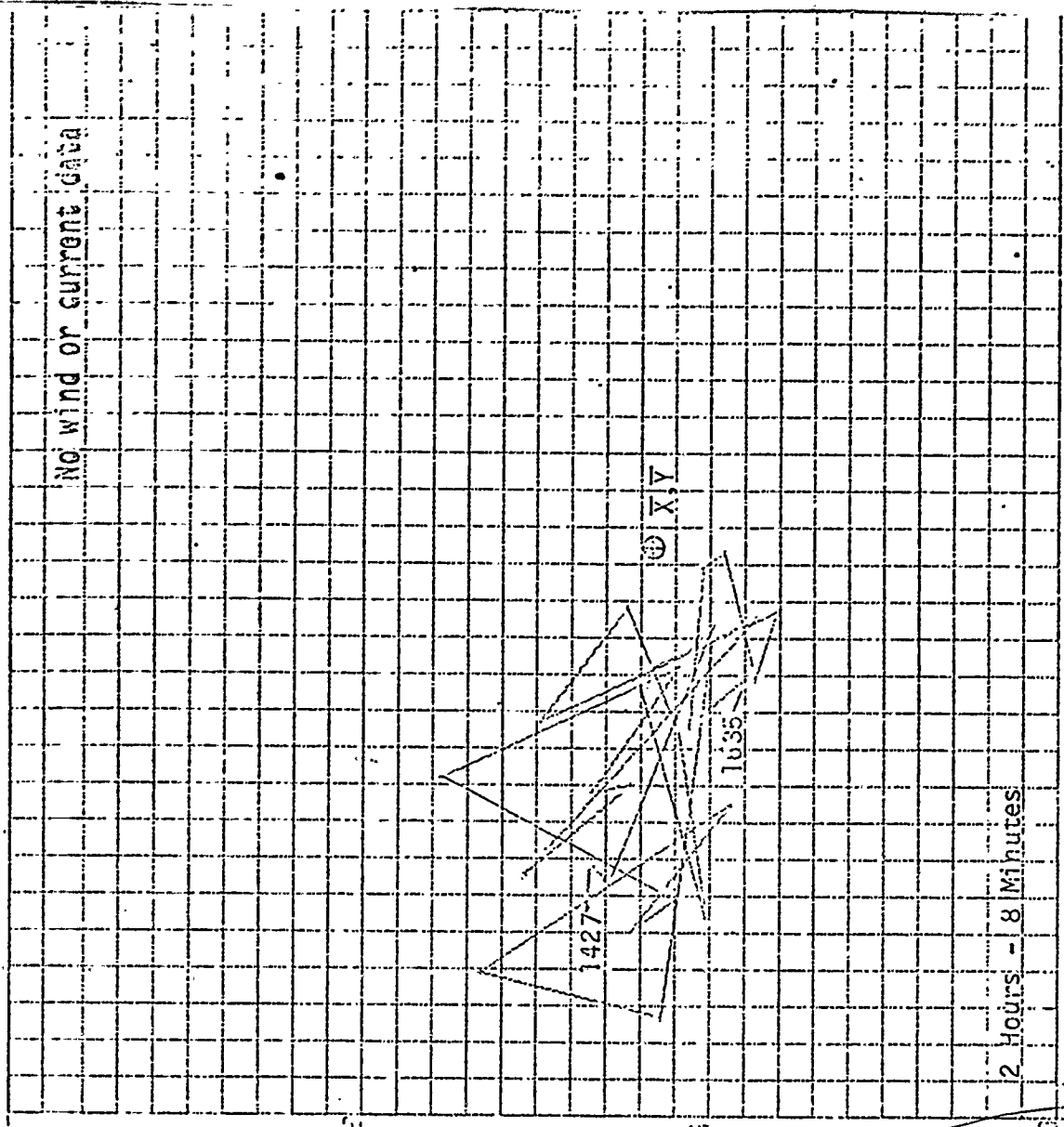
Figure XXVIII   Buoy Motions

10 September 1968

Isles of Shoals, N. H.

55

12 SEPTEMBER 1968-SIGNAL

No wind or current data

5 Hours - 40 Minutes

1700

0126

X,Y ⊕
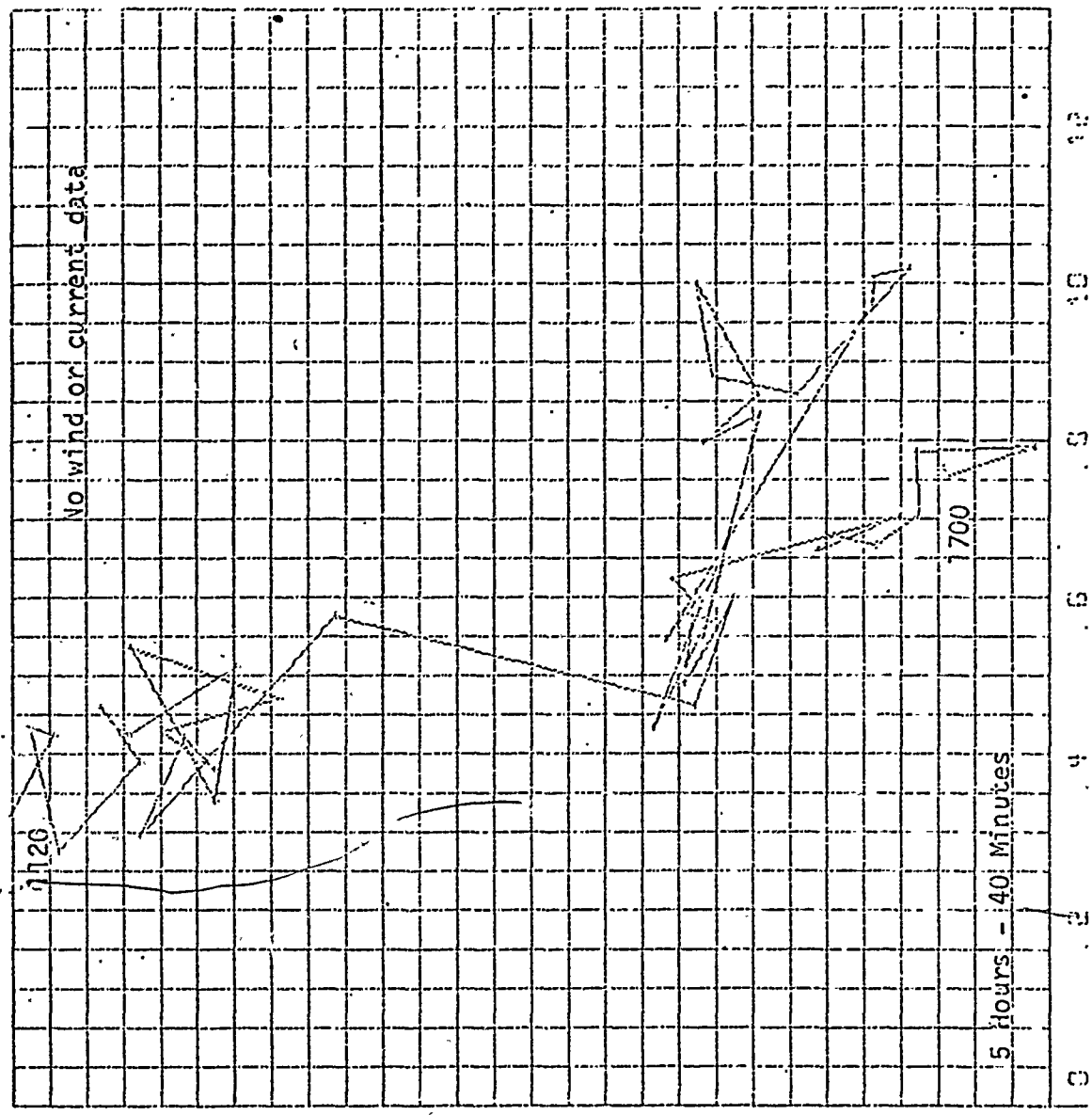
NORTHING

EASTING

Figure XXIX   Buoy Motions
12 September 1968
Isles of Shoals, N. H.

56

ISLE OF SHOALS N. H.; 1968
APPARENT BUOY MOTION

DATE	TIME	STATION STAR	STATION WHITE	WIND FORCE	WIND DIRECTION	SEA STATE
5 Sep	1455-1625	1.68 ft.	1.43 ft.	5 to 6	SE by S	State 2
6 Sep	1500-1550	8.06 ft.	2.77 ft.	9 to 11	SSE	State 3
8 Sep	1520-1840	6.32 ft.	2.98 ft.	1 to 7	Variable E to SSE	State 2
9 Sep	1400-1705	2.99 ft.	5.62 ft.	8 to 10	E	State 3
10 Sep	1420-1635	4.67 ft.	2.68 ft.	up to 18		State 3-4
*12 Sep	1120-1245	12.74 ft.	8.91 ft.	25 to 30	WSW	4, Swell State 4
*12 Sep	1415-1700	21.81 ft.	16.89 ft.	25 to 30	WSW	4, Swell State 4

*Only one of four rubber cables intact following rough seas and strong winds of 11 Sept.

LITTLE BAY, N.H., 1968
APPARENT BUOY MOTION
TIDES: 1000 LOW; 1600 HIGH ON 27 Aug.

DATE	TIME	FOX PT. STATION	SOUTH CAMERA	CURRENT SPEED	DIRECTION
26 Aug	0945-1645	6.1 feet	5.8 feet	Up to 1.8K	Generally North-South
27 Aug	1030-1655	7.7 feet	6.4 feet	1400-1.7K 1500-1.6K Up to 1.8K	Generally North-South

Figure XXX   Apparent Buoy Motions, Little Bay and Isles of Shoals

resultant of two quadrature excursions listed in the above tables, the data for 27 August yields $\sqrt{(7.7)^2 + (6.4)^2}$ = 10.0 feet (3.05 meters) for the Bay tests. Similarly, for the Shoals tests on 6 September, $\sqrt{(8.06)^2 + (2.77)^2}$ = 8.5 feet (2.59 meters).

When watch circle performance about the computed average buoy position is considered, a circle scribed about the $\overline{X}$, $\overline{Y}$ point and including all buoy locations has its largest radius of 1.83 meters (6.00 feet) for the Bay data of 27 August (Figure XXIII) and a radius of 2.05 meters (6.72 feet) for the Shoals data of 6 September (Figure XXV).

To provide a measure of distribution of the five minute interval sightings of the buoy position, maxima, median, mean, and standard deviation values for the Bay and Shoals data were computed and are presented in Figure XXXI.

The fifteen-foot diameter watch circle specification was met by a maximum resultant motion, $\sqrt{(6.96)^2 + (6.98)^2}$ = 9.90 feet (3.02 meters) for the Bay tests. This specification was approximately met for the 150-foot depth of the Shoals tests by a maximum resultant motion, $\sqrt{(13.97)^2 + (8.59)^2}$ = 16.4 feet (5.00 meters). Included in Figure XXXI is a summary of samplings of camera, gyro, and accelerometer data. Analysis of the photographic record of the 27 August Bay test indicated a maximum buoy motion of 6.89 feet and a maximum antenna tilt equal to 6.5° with 4.757° mean and 0.685 SD/Mean. Gyro data from the Shoals tests of 6 and 8 September yielded a maximum antenna tilt of 8.0° and a maximum acceleration of 3/16 g (6.05 ft./sec.^{2}) for the buoy.

As noted previously, cine data was collected to establish the validity of the sampling rate of the theodolite observations as well as to

TEST SITE	PARAMETER	DESIGN SPECIFICATION	DATE/SOURCE	MEASURED MAXIMA	COMPUTED UTM FALSE COORD. OR TILT ANGLE		
					MEDIAN	MEAN	SD/MEAN
LITTLE BAY Mean Water Depth 52 Ft.	WATCH CIRCLE	10% of Depth = 5 Ft.	27,28 Aug./ Theodolite	X- 6.98 Ft. Y- 6.96 Ft.	2.44 m. 60.90 m.	2.472 m. 60.886 m.	0.426 m. 0.386 m.
			27 Aug./ Photo, South Camera	6.89 Ft.			
	VERTICAL STABILITY	±20° Off Vertical for Sea State 4	27 Aug./ Photo, South Camera	+6.5°	4.757°		0.685°
ISLES OF SHOALS Mean Water Depth 140 Ft.	WATCH CIRCLE	10% of Depth = 15 Ft.	5,6,8-10, Sept./ Theodolite	X- 8.59 Ft. Y- 13.97 Ft.	96.58 m. 74.83 m.	96.547 m. -74.666 m.	0.526 m. 0.766 m.
	VERTICAL STABILITY	±20° Off Vertical for Sea State 4	6 Sept./Gyro 7 Sept./Gyro 8 Sept./Gyro	+8° +5° +8°			
	VERTICAL ACCELERATION	None	5 Sept./Accel. 6 Sept./Accel. 8 Sept./Accel. 9 Sept./Accel.	±1/8 g. ±3/16 g. ±1/8 g. ±1/8 g.			

Figure XXXI Buoy Motion, Tabulation of Measured and Computed Values

59

provide a crude back-up for the on-board instrument data system. The effects which cause surface motions include waves, tides, currents, and wind. Tidal effects are of low frequency variation and are taken to be faithfully reproduced by the five-minute sampling period chosen for theodolite observations. Current variations in the test areas were observed to have gross periods corresponding to tidal periods and minor periods of one-half hour to several hours. Again, their effects on buoy motion should be amply included in the theodolite data. Wind and waves may be classed in the field of relatively short period distrubances, with periods approaching several minutes. Theodolite observations were considered to also be appropriately spaced to include these disturbances in so far as watch circle performance was concerned for the following reasons. First, the period of the forces approaches that of the theodolite readings, and second, the short term forces acting on the buoy system contribute more to such responses as heave, yaw, and tilt (pitch and roll) than to watch circle motions. Support for the choice of theodolite sampling rate was provided by detailed inspection of the photographic record for 27 August. Cine samples at one-half minute intervals showed only smooth horizontal buoy motions between theodolite observations and no wide excursions that might have escaped theodolite observation. Photographic data for 26 and 27 August also indicated that the antenna tilt remained within 6.5°.

One gyro axis data unit failed shortly after the Shoals tests commenced. However, it was judged appropriate to consider that a single axis would provide information about periods and maximum values of the antenna tilt response due to the random yawing of the buoy, although the

60

intention was to obtain a resultant motion from a two-axis record. Tensiometer data proved to be of limited value due to a failure of the transducer resulting from water seepage through the encapsulation material.

Tensiometer calibration curves are shown in Figure XXXII. Sample gyroscope pitch and roll recordings appear in Figure XXXIII and sample accelerometer and tensiometer recordings appear in Figure XXXIV.

Fast Loading - Continuous to 6000 lbs. - 15 3/4
Slow Loading - Continuous to 6000 lbs. - 16

Figure XXXII   Tensiometer Calibration
Curves

1000 Lb. Step Loading

2-Step Loading

1000 Lb. Step Unloading

2-Step Unloading

Loading - Pounds

Deflection - scale divisions

20
18
16
14
12
10
8
6
4
2
0

1000   2000   3000   4000   5000   6000
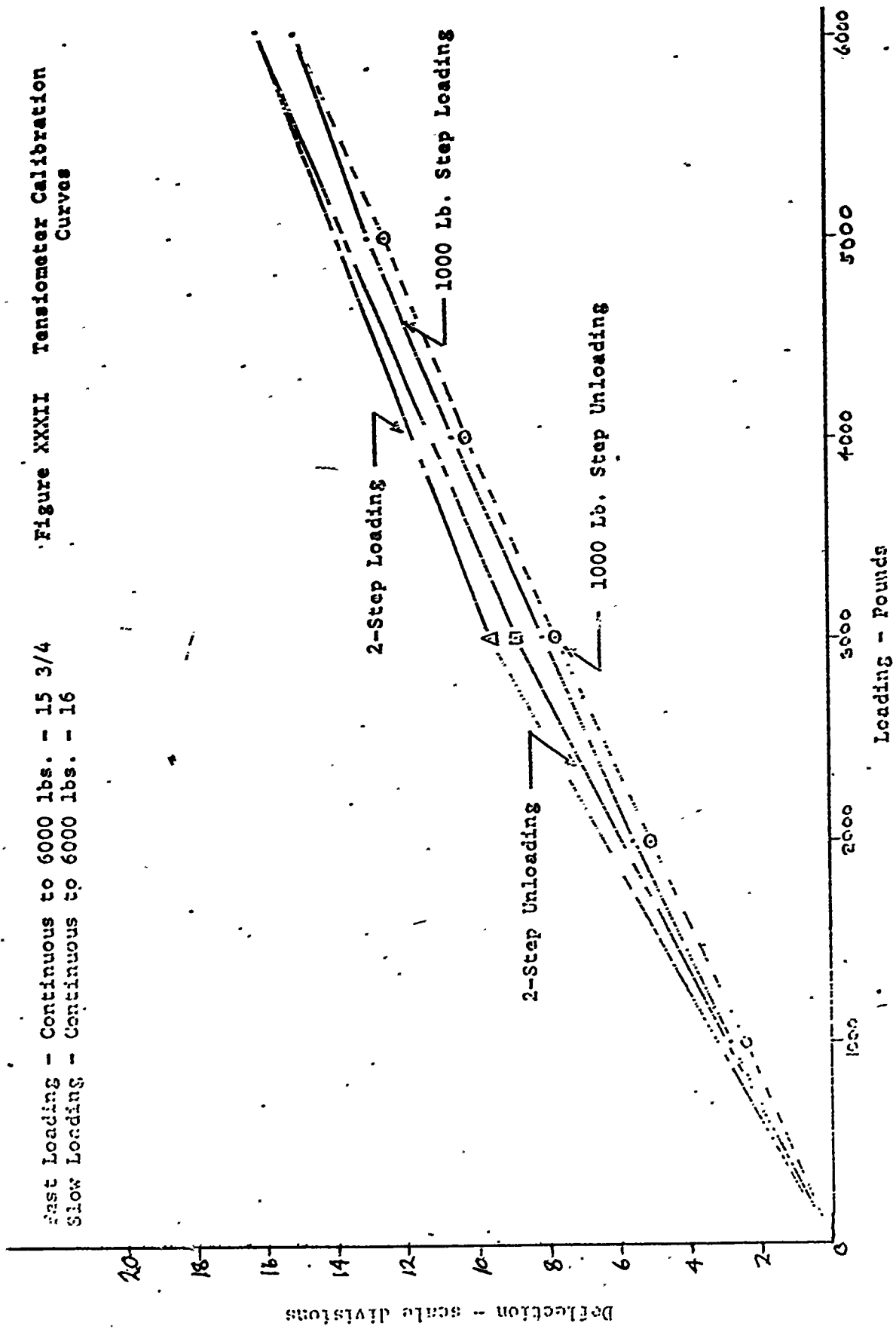
5 September 1958   Isles of Shoals
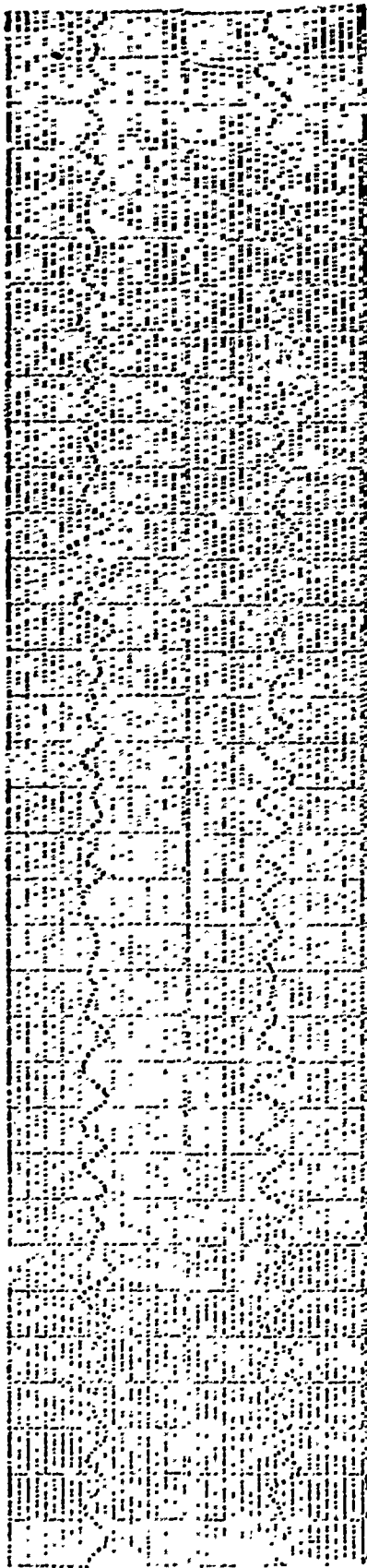
Top: Gyro pitch

Bottom: Gyro roll

Scales: see calibration data   (Approx. 2°/div.)
        Figure XVI

Figure XXXIII   Sample Gyroscope
                  Pitch and Roll Recordings

ISLES OF SHOALS

5 September 1968 1405 Hrs.

Wind: 5.5 knots
110° off north

Wave Height: 2 feet

Current: 0.48 knots
260° off north

Down

Up
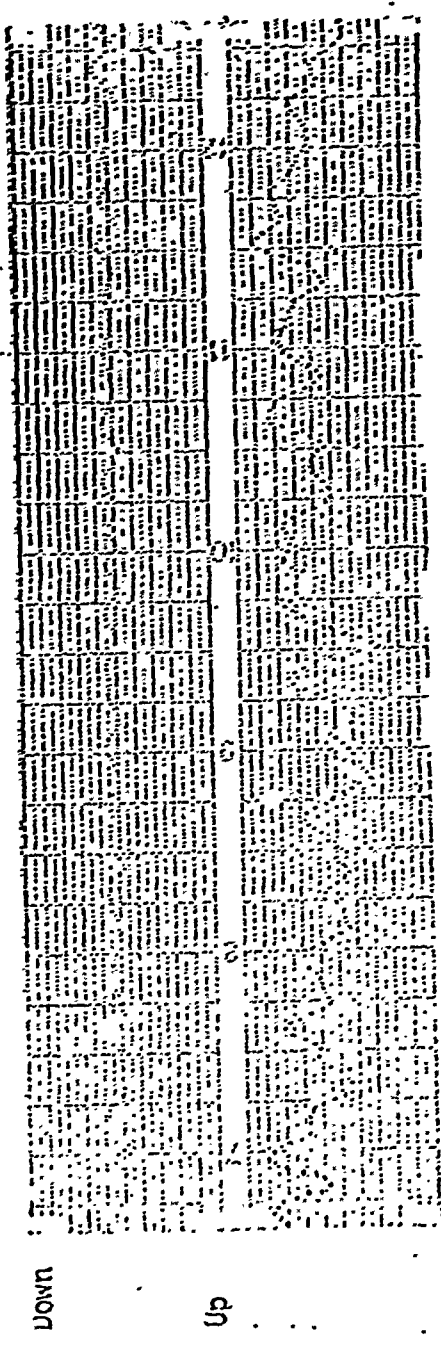
Top: Accelerometer (approx. 0.2 g/div.)
Bottom: Tensiometer (approx. 375 #avg./div.)

Scales: see calibration data

Figure XXXIV   Sample Accelerometer and
Tensiometer Recordings

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IV. CONCLUSIONS

The full scale prototype buoy studies were conducted in two locations and produced the following results:

Current Tests (Little Bay Tests) These tests were conducted in tidal currents of up to 1.8 knots with a tidal variation of 6.5 feet in approximately 52 feet of water (mean water depth) and winds up to 18 knots. Under these conditions, the 3σ - buoy position error was $\pm$ 5.6 feet (calculation based on all data recorded at this site - note that for normally distributed data, 99.7% of all data falls within $\pm$ 3σ) about the mean position, or a 3σ - buoy position watch circle of 11.2 feet. All recorded data fell within a watch circle of 9.9 feet. Antenna vertical inclination was a maximum of 6.5^0.

Open Sea Tests (Isles of Shoals Tests) These tests were conducted in the open ocean with sea conditions up to about state 3-4 seas, with measured winds up to 18 knots, surface currents up to 0.8 knots, and tidal variations of 8.5 feet with a water depth of 140 feet (mean low water). Under these conditions, the 3σ - buoy position error was $\pm$ 9.15 feet (calculation based on all data recorded for this site through 10 September - the 12 September data was not used since only one of the four rubber links in the mooring was intact) about the mean position, or a 3σ - buoy position watch circle of 18.3 feet. All recorded data fell within a watch circle of 16.4 feet. The antenna vertical inclination stayed within a cone of $\pm$ 8^0, while the vertical heave acceleration never exceeded .6 ft./sec.^{2}.

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Based upon these results, it is apparent that the PARA-BUOY design will essentially meet the performance specifications outlined in Table 1. Therefore, the data support a recommendation that a buoy-mounted navigation slave station be used in the Hysurch System.

Engineering Design and Analysis Laboratory

University of New Hampshire

March 1969

APPENDIX I

References

1. Blood, B. E., "A System Concept for Hysurch (Hydrographic Survey and Charting System)," Report 39, Experimental Astronomy Laboratory, Massachusetts Institute of Technology, Cambridge 39, Massachusetts.

2. "Radio Aids to Maritime Navigation and Hydrography," Supp. Paper 3 to Special Publication 39, INST. HYD. BUR. Monaco, June 1961.

3. Bigelow, H. W., "Electronic Surveying: Accuracy of Electronic Positioning Systems," Jour. Surv. and Map. Div., Proc. ASCE (SU3), October 1963, p. 37.

4. O'Day, J., Hyperbolic Systems One, University of Michigan, Summer Conference Notes, 1965.

5. Gruenberg, E. L., Editor, Handbook of Telemetry and Remote Control, McGraw-Hill Book Company, New York, 1967.

6. Hovorka, J., Report on Tests of A Hyperbolic Navigation System for Hysurch Utilizing Decca Sea-Fix. Report No. RE-51, Experimental Astronomy Laboratory, Massachusetts Institute of Technology, 1968.

7. Bigelow, H. W.," Electronic Survey: Accuracy of Electronic Positioning Systems," Jour. Surv. and Map. Div. Proc. ASCE (SU3), Oct. 1963, page 37.

8. Sea State Charts, Prepared by Wilbur Marks, David Taylor Model Basin.

9. Savage, G. H., & Hersey, J. B., Project Seaspider: The Design, Assembly, Construction and Sea Traisl of a Tri-Moored Buoyant Structure with Neutrally Buoyant Legs to Provide a Near-Motionless Instrument Base for Oceanographic Research. Woods Hole Oceanographic Institute, June 1968. (WHOI Reference N. 68-42, DDC Ref. No. AD-673-956.

10. Paradis, " The Mercator Projection and its Variations", Informal Report No. 67-37, Naval Oceanographic Office, May, 1967.

APPENDIX II

Data on Navigation Systems

The tables which follow were prepared by C. G. Welling and M. J. Cruickshank. They were contained in a paper entitled "Review of Available Hardware Needed for Undersea Mining," present at the 2nd Annual MTS Conference, Washington, D. C. 1966.

Additional material on the subject of navigation systems is contained in references 1, 2, 3, and 4, shown in Appendix 1, and in a report by D. H. Clegg and G. H. Savage, entitled "A Study of the Feasility of Various Navigation Systems for Use in Installation of the Pacific Seaspider," Technical Report No.105, Engineering Design and Analysis Laboratory, University of New Hampshire, Durham, New Hampshire, September 1967.

*TABLE OF ELECTRONIC POSITIONING SYSTEMS

Name	Range Naut-Miles	Accuracy Feet	Signal Type	System	Users	Area Coverage	Manufacturer
Long Range >500 Miles							
Loran A	8-1400	1000'	Pulsed	Hyperbolic	Multi	See Chart	Various
Loran E	1500	500'	Pulsed	Hyperbolic	Multi	See Chart	Various
OMEGA	6000	3000'	Pulsed	Hyperbolic	Multi	Experimental	Omega
CONSOL	700	36-144,000	C.W.	Azimuthal	Multi	Not in general use	? U.K.
DELRAC	3000	60,000	Pulsed	Hyperbolic	Multi	Not in general use	Decca U.K.
TRANSIT	Worldwide	High	C.W.	Satellite	Multi	Experimental	A.P.L. (U.S.N) U.S.
Intermediate Range 100-500 Miles							
Loran B	250	45-300	Pulsed	Hyperbolic	Multi	See Chart	Various
Loran A	200	10-150	C.W.	Hyperbolic	Multi	See Chart	Seiscor Okla.
Loran B	300	10-150	C.W.	Hyperbolic	Multi	See Chart	Seiscor Okla.
Decca Navigator	250-500	1500-12000	C.W.	Hyperbolic	Multi	See Chart	Decca Navigator Co. Eng.
Decca Survey	200	25-300	C.W.	Hyperbolic	Multi	See Chart	Decca Navigator Co. Eng.
Low Ambiguity Decca	150-400	25-250	C.W.	Ranging	1	Local	Decca Navigator Co. Eng.
Decca 2 Range	150-	12-	C.W.	Ranging	1	Local	Decca Navigator Co. Eng.

Table 1

*TABLE OF ELECTRONIC POSITIONING SYSTEMS

Name	Naut-Miles	Accuracy Feet	Signal Type	System	Users	Area Coverage	Manufacturer
Decca Hi Fix	200	3-	C.W.	Hyper or Range	1	Local	Decca Navigator Co. Eng.
E.P.I.	400	195-1500	Pulsed	Ranging	1	Local	
D.M. Raydist	100-250	1-150	C.W.	Range-Hyperbolic	2	Local	Hastings Raydist Inc. Va.
RANA	84-129	60-120	C.W.	Range	?		France
HIRAN	550	.2 (?)	C.W.(?)	Range	1	Local	Raydist (?) U.S.
Short Range>100 Miles							
Radar	30	300	C.W.	Range or Azimuth	1	Local	Multi
P.R.S.	50	150	C.W.	Ranging	1	Local	Alpine Geophys. Co. Tex.
R.O.F.	50	5000	C.W.	Azimuth	Multi	Local	Multi
Hi Fix	30	12-200	C.W.	Ranging	1	Local	Decca Navigator Co. Eng.
Shoran	30	30-50	Pulsed	Ranging	1	Local	Raydist (?)
Hi Fix	40	25-150	C.W.	Hyperbolic	Multi	See Chart	Decca Navigator Co. Eng.
Hydrodist	25	5	C.W.	Ranging	1	Local	Hastings Raydist (?)
M.P.F.S.	30	V 50	C.W.	Azimuthal	Multi	N. Canada	Canada
Raydist	75	15-150	C.W.	Composite	2	Local	Hastings Raydist Va.

Table 1 (Contd)

*TABLE OF ELECTRONIC POSITIONING SYSTEMS

Name	Range Naut-Miles	Accuracy Feet	Signal Type	System	Users	Area Coverage	Manufacturer	
Auto Tape	60	3+	C.W.	Ranging	1	Local	Cubic Corp.	U.S.
Mini Fix	30	2.5-7	C.W.	Ranging or Hyperbolic	1	See Chart	Decca Navigator Co. Eng.	
Doppler Navigator		Very Accurate	C.W.	Sonic Ranging	1	Local	Raytheon Co.	R.I.
Deep Sub-mergence R.O.F.	10	5 degrees		Azimuth	1	Local	Oceanographic Eng. Co.	Calif.
Electro Tape	< 50	> 0.01	C.W.U.H.F.	Ranging	1	Local	Cubic Corp.	U.S.

*Based upon information published or made available by the manufacturer.

Table 1 (Contd)

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APPENDIX III

Sea Flyte Buoy for Hysurch System

The design analysis of hydrostatic buoys, that is, a buoy configuration which does not inherently produce lift, had revealed that a state-of-the-art design would not necessarily meet the specifications. As a result of discussions with personnel at Arben Marine Products, Inc. at Long Beach, California, an experimental buoy configuration was designed. This appendix contains some of the materials supplied by Arben concerning the buoy, which is called Sea Flyte. The design sequence for this buoy was:

1) An analysis of the potential performance of a submerged airfoil-shaped buoy in the environments predicted for the Hysurch system.

2) A 1/4 scale model study of two airfoil configurations, i.e., conventional wing and swept-back wing.

3) Design and construction of a full scale prototype.

The analysis was sufficiently promising that Arben Marine Products built two 1/4 scale models and tested them in equivalent full scale currents of 7.5 knots. The conventional wing section stayed within the equivalent full scale watch circle of 15 feet in 150 feet of water up to an equivalent full scale current of 4.0 knots. The characteristics in equivalent Sea State 3 were also promising. Therefore, a full scale prototype was designed and constructed. At this writing, open sea evaluations are in progress.

The material in this appendix is provided to enable the reader to gain an understanding of the basic concepts behind the Sea Flyte buoy. Detailed information on the design can be supplied by Arben Marine Products. When open-sea tests are completed, test results will most likely be available through the Naval Oceanographic Office or Arben Marine Products.

June 7, 1968

Department of Mechanical Engineering
University of New Hampshire
Durham, New Hampshire

Attention: Dr. Robert Corell
             Kingsbury Hall

Gentlemen:
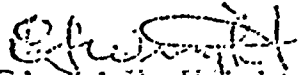
Arben Marine Products, Inc. (AMP) is pleased to propose,
on an unsolicited basis, a firm fixed price of $8500.00
covering the engineering and fabrication services necessary
to produce and deliver one each buoy fabricated in accordance
with the attached Technical Work Statement No. 6548-DB-235.

AMP feels uniquely qualified to produce such a buoy in that
the proposed proprietary design configuration is believed
to represent a composite solution to two major problems
inherent in maintaining an optimum on-station watch circle
in shallow water by incorporating design parameters which
maximize hydrodynamic lift and minimize drag.

AMP, designers and manufacturers of the world's most complete
line of surface and sub-surface buoys, flotation devices and
associated equipment, have over five years experience in the
design, development, fabrication and testing of sophisticated,
non-standard buoys and buoy systems which meet the special
requirements generated by today's state-of-the-art marine
technology.

Should you have any questions or desire additional information,
please contact the undersigned or Mr. R. G. Bertholf at your
earliest convenience.

                              Very truly yours,

                              Edward W. Wright
                              Marketing Manager

WWH

enclosure

ARBEN MARINE PRODUCTS INC.

2030 W. 16th ST., LONG BEACH, CALIFORNIA 90813
(213) 432-0971

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ARBEN MARINE PRODUCTS, INC.
2030 West 16th Street
Long Beach, California 90813   A/C 213-432-8971

Technical Work Statement
(Proprietary Data)

Unsolicited Proposal 6568-DB-235
Rysearch Buoy Program

1. **Configuration of Flotation Section:**

   1.1 The flotation portion of the buoy is comprised of an airfoil section similar to NASA 653-618 (see attached drawing) with modifications as follows:

      1.1.1 Incorporated into the trailing edge of the section is a Reflex Section which may be adjusted.

      1.1.2 Tip fences are incorporated on the lower surface only.

   1.2 The span of the section is presently fifteen feet, the chord is six feet and the Fineness Ratio is 5.46.

   1.3 The unit has a gross displacement of 2500 lbs. when submerged to the Mean Static Waterline.

   1.4 The unit has a dynamic lift of 639 lbs. @ $4°$ $\propto$ @ 2 knots current flow.

   1.5 Static dry weight of the flotation unit is 600 lbs. $\pm$ 100 lbs.

   1.6 The unit is fabricated of Glass Reinforced Plastic, hand laminated of marine flexible Polyester, with skin thickness to be determined by Arben Marine Products.

   1.7 The interior of the unit is filled with polyurethane foam, and sealed.

   1.8 Battery and instrumentation chambers are incorporated into the flotation unit with suitable access panels and aerial leads to the mast.

2. **Configuration of Mast:**

   2.1 The lower section of the mast is comprised of three aluminum tubes forming a tripod to support the transmitting aerial.

   2.2 The tubes are supplied with fixed fairings of NASA 654-021 section (see attached drawing) below the mean water line and with free pivoting fairings above the mean water line.

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2.3 Horizontal stiffeners of aluminum are placed at appropriate
intervals and supplied with fixed by-convex fairings.

2.4 The aluminum tubes are filled with polyurethane foam to
deny seawater intrusion.

2.5 The mast is comprised of two vertical sections; joined by
bolt plates, to facilitate handling and shipping.

2.6 The upper section of the mast is a fiberglass monopole
mounted to the top of the aluminum structure.

2.7 Dry weight of the mast is approx. 150 lbs.

3. <u>Mooring Attachment Structure</u>.

3.1 The mooring attachment structure is fabricated of glass
reinforced plastics with internal structure to absorb
mooring loads, and is filled with polyurethane foam.

3.2 A swivel fitting accepts the cable shackle in order to
allow the buoy to fair into the existing current.

4. <u>Recommended Mooring Cable</u>.

1) Aluflex Aluminum Coated Steel Cable. 5/16"x6x19 (C_D=1.3)
S.F.=2.425 (Preferred source: American Chain and Cable)

2) Aluflex 3/8"x6x19 (C_D=.6) S.F.=3.44 with integrated hair
fairing. (Preferred source: American Chain and Cable)

5. <u>Recommended Anchor</u> - DeHaviland explosive anchor or equivalent
w/11,000 lb. restraining force.

6. <u>System Dynamics</u>.

6.1 The combination of net buoyancy, low drag, dynamic lift,
and the forward lift vector of the airfoil section are
designed to produce a buoy system which will maintain an
extremely small watch circle and excellent dynamic and
static stability.

6.1.1 The static stability of the buoy is dependent upon
the net static buoyancy of the flotation section,
which pivots about the taut-wire mooring point
located below it, to provide Righting Moments.

6.1.2 The dynamic lift of the buoy is provided by current
flow along the chord of the airfoil configuration.
The basic purpose of the dynamic lift is to provide
a small component of forward lift which increases
with current flow to overcome the additional drag
of the current. Neither the dynamic lift nor its
forward component are present or required in a zero-
current situation.

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6.1.3 A secondary purpose of the dynamic lift is to provide Righting Moments about the airfoil center of pressure at all angles of attack, positive and negative, in current flow. The Reflex Section is incorporated into the airfoil section to aid in this function.

6.1.4 The drag of the particular airfoil section employed vs. the forward lift vector of that section are tradeoffs which must be employed to provide the overall stability and dynamic characteristics required of the system.

6.1.5 The buoy system is designed to be directionally reactive to current flow and to have a mean rotational velocity of .25 radians/sec in 2 knot current and may not react as well in eddy currents in which the current directional shift exceeds parameter.

7. **System Design Parameters.**

Airfoil Section 65_3-618 $\qquad L=C_L \, \rho/2 \cdot V^2 \, \text{fps} S_C$

$C_L @ 4^o \, \alpha = .9$

$L_D @ 4^o \, \alpha = .006 \qquad D=C_D \, \rho/2 V^2 \, \text{fps} S_C$

Corrected to .016 to accomodate Eddyflow and Aspect Ratio

$C_M @ 4^o \, \alpha = +1.1$

Reynolds No. - 3.0×10^6

Airfoil Section 65_4-021

$C_L @ 0^o \, \alpha = 0$

$C_D @ 0^o \, \alpha = .0053$

$C_M @ 0^o \, \alpha = 0$

Reynolds No. $= 3.0 \times 10^6$

Gross Overturning Moments - 3200 lbs.

Gross Righting Moments - 8500 lbs. +

TRANSMITTER ANTENNA
LEADS IN THIS MAST

AFT MAST SUPPORT
STRUCTURE

MAIN LATERAL SPAR
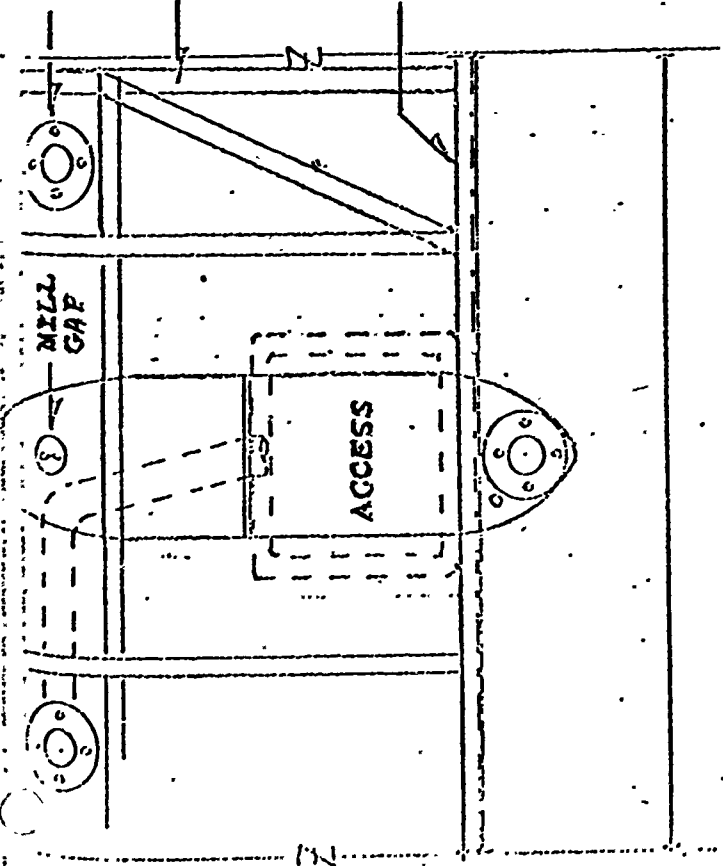
FWD. MAST FAIRING

FUEL TANK VENT TO MASTHEAD

MASTHEAD
DIESEL ENTAKE STANDPIPE
(SLIP FIT IN MAST BASE)

WATERTIGHT HATCH
COVER

AFT MAST
MOUNT PLATE
AND DIESEL
EXHAUST

FILL
PIPE

BILGE
PUMP

BATT.
COMP.

FUEL

TIME-O
WINCH
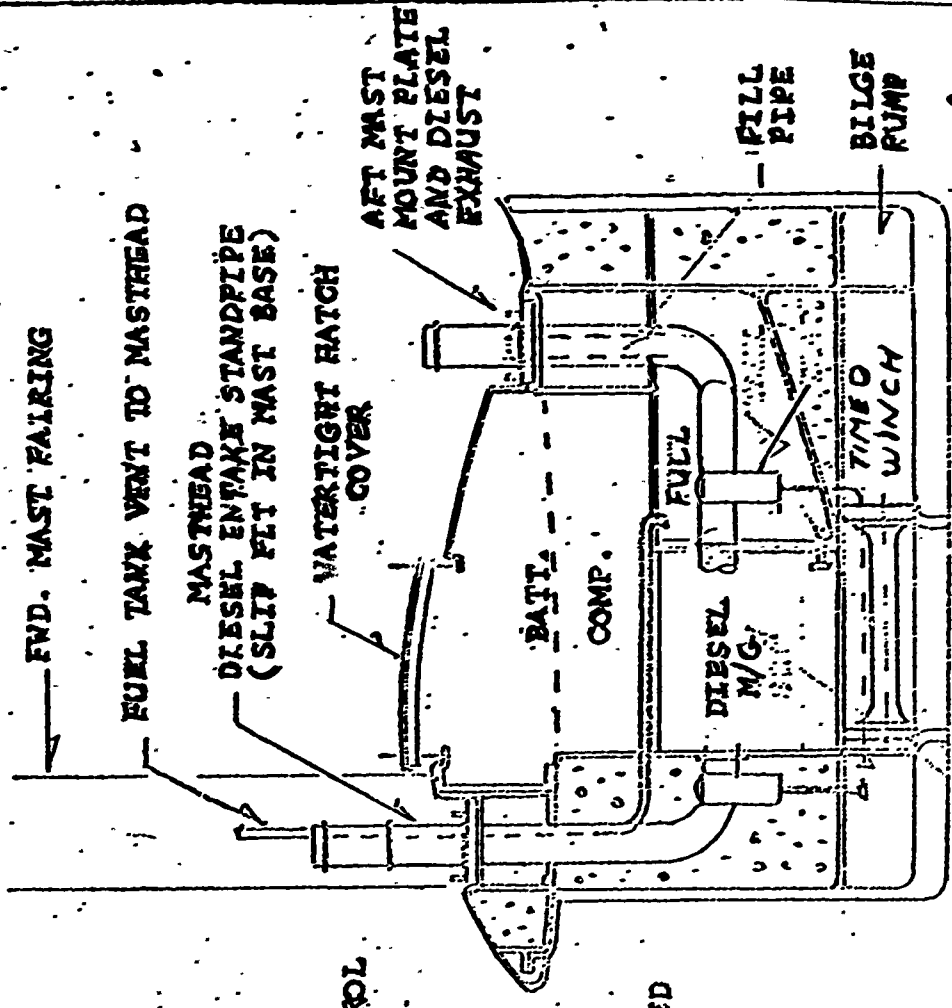
DIESEL
M/G

ADDITIONAL PTH CAPACITY IN DIESEL & FULL BANKS

MILL
GAP

ACCESS

TRANSMITTER & CONTROL
UNIT COMPARTMENTS

ALL EMPTY BAYS
P.U. FOAM FILLED

APPENDIX IV

Background Materials on Stem Antennas

This appendix contains background materials on the Stem antenna, manufactured by the Spar Aerospace Products Limited Division of de Havilland Aircraft of Canada, Toronto, Canada.

SPAR

Sales Reference
C9G-375-4103

May 10, 1968.

Mr. F. Hess,
EDAL, Kingsbury Hall,
University of New Hampshire,
Durham, New Hampshire 03824.

Dear Fred,

      With reference to our telephone conversation of today, we are
pleased to enclose our standard data package, and Outline and Installation
Drawings of typical mechanisms, which may suit your hydrographic buoy
application. We would also be pleased to deliver to you, for your evalu-
ation, one single 35 ft. long, stainless steel element. This would be our
standard 3 1/8 inch diameter, overlapped STEM tube. The cost for this
item would be $100.00 U.S., F.O.B. Malton, Ontario, exclusive of all
taxes, tariffs and duties; terms net 30 days. The quotation is valid for
days from the date of this letter.

      From the description of your requirements, it would appear
that actual production hardware might utilize multi-element, 2 inch
diameter BI-STEM. For this reason, we are also enclosing an extract,
describing a similar application. To be truly representative of opera-
tional hardware, the 3 1/8 inch sample should be equipped with proper
root and tip plug fixations. We would be pleased to provide you with
details for these components at a later date.

      We trust that the enclosed information is adequate for your
present needs, and look forward to your further communication in this
matter.

Yours very truly,

SPAR AEROSPACE PRODUCTS LIMITED

H. N. Weyman,
Chief Applications Engineer
STEM Products Department

/rm
ccl:.

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Aerospace Products Limited
6022, Toronto International Airport
    Canada/Phone(416)676-3333
    2-29362 Sparmalt Tor/Cable Sparmalton Tor

S T E M

STORABLE TUBULAR
EXTENDIBLE MEMBER
for ground environment

ANTENNAS

MASTS

BOOMS

In response to a long-acknowledged need
for antenna members with a high degree of
extendibility, minimum space storability,
light weight and utmost reliability, SPAR
Aerospace early in 1960 undertook a re-
search project to develop such a product
for a major spacecraft system.

This program, a resounding success, pro-
duced the first of an entire system of such
devices, which have become widely known as
STEMs (Storable Tubular Extendible Members).
Within a year a similar program was
launched to develop the device for ground
environment use; the applications shown
overleaf are typical of what can be
achieved with this unique development.

THE STEM PRINCIPLE
The key to the STEM system is a con-
tinuous strip of
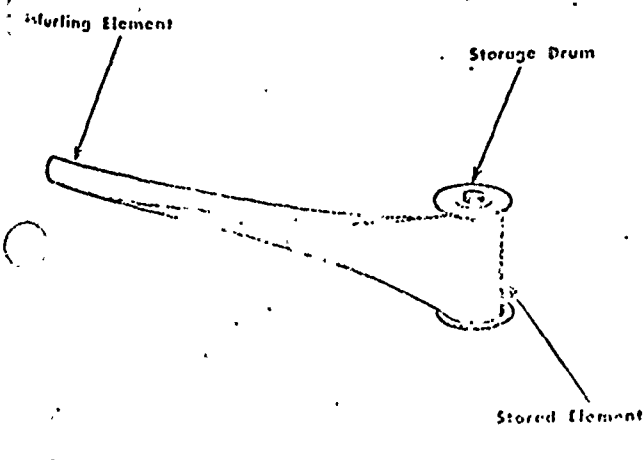
resilient spring metal, heat-treated
for maximum flexibility with an unfurled
overlap characteristic of about 180°.
This provides the tubular element with
strength equal to a complete seamless
member of similar diameter and wall
thickness.

Storage of the member is accomplished by
coiling the tube around or into a cylin-
drical drum, which rotates for extension
and retraction either by means of a motor
drive or hand crank. Push-pull and self-
extendible concepts are also available.

Since retraction of the element requires
supplying strain energy to the flattening
spring tube, the stored element has a
natural tendency to self-extend; thus
very little unfurling power is required.
In application, of considerable strain,
the deployed bending and torsional stre-
ngth of the member may be increased by
simply nesting several spring elements
together in a given diameter.

Unfurling Element

Storage Drum

Stored Element

SPAR AEROSPACE CAPABILITIES

SPAR is a proven and trusted supplier of extendible structures for all NASA and DOD applications. A wide variety of ground and sea environment antennas and masts have been provided to customers throughout Canada, the United States and Europe.

SPAR maintains complete facilities for the custom design and manufacture of a great range of extendible STEM structures. These include approved Quality Control and Reliability Systems; "Clean Room" Assembly Areas; Development, Environmental Test, Materials Research, and Materials Test Laboratories. The resources of SPAR's highly-trained design, development and program management group are completely available to STEM customers.
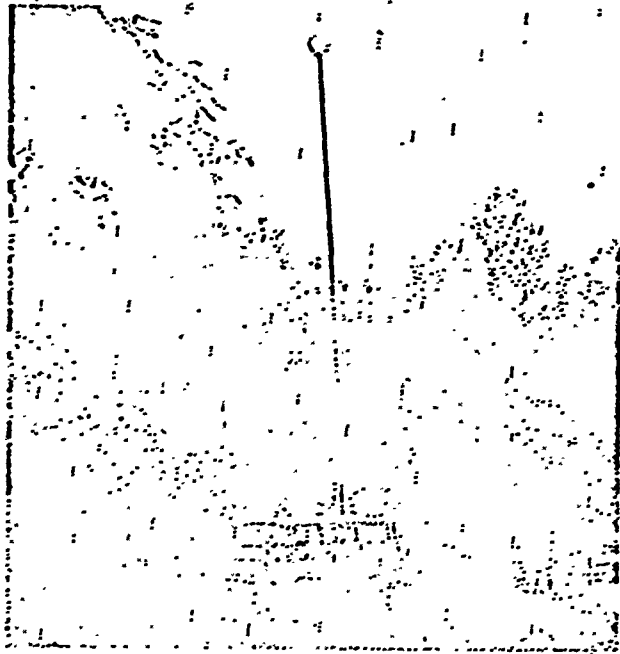
The STEM 3-1/8-inch-diameter elevating mast raises electronic sensing apparatus far above vehicular height for greater distance penetration.

Installed on a "man-pack" communications unit, this push/pull STEM antenna provides a readily-extendible and easily withdrawn element for military, fire, emergency and industrial applications.

This 1-3/8-inch-diameter elevating mast, installed on the rear of a jeep, permits remote extension and withdrawal from the driver's position.

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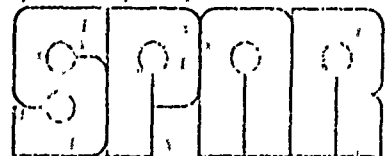
MODEL SPECIFICATION

ON A

GENERAL PURPOSE TRANSPORTABLE

3-1/8 INCH DIAMETER STEM MAST

MODEL 5439

1.0 INTRODUCTION

1.1 This specification covers the performance capabilities, installation, data, standard and optional features, on a quick-erectable, transportable mast of the STEM type, employing an unfurlable tube formed by heat treating a metal strip into a circular section in such a manner that the edges overlap by approximately 180°. The mast is of a general purpose design capable of elevating a variety of tiploads varying from antennas and reflectors to light beacons and television cameras, unsupported or guyed.

2.0 PERFORMANCE SUMMARY

2.1 Tipload, weight and geometry determine the allowable windspeed for a given height (or vice versa). It is, therefore, impracticable to provide an all encompassing set of data covering every possible combination of weight and drag area. De Havilland has prepared a computer program which permits quick assessment of feasibility. It optimizes the mast configuration for minimum weight considering also such variables as ice thickness, tip slope limitation, base tilt angle and differentiation between operational and survival windspeed. The following data is typical and indicative of the STEM's capabilities.

2.2 Unsupported (Cantilever) Mast

	Case 'A'	Case 'B'
Extended height..	45 ft.	50 ft.
Tipload...	75 lbs.	--
Tip Area (equivalent flat plate).............	2 ft.²	--
Base Tilt Angle......................................	15 degrees	15 degrees
Survival Windspeed...(calculated)...........	50 m.p.h.	70 m.p.h.

3.0 PHYSICAL DIMENSIONS AND WEIGHT

3.1 Dimensions

Mast diameter...	3-1/8 inch
Overall retracted height (less tipload).....................	75-1/2 inch
Overall width (excluding mounting flange).................	19-1/2 inch
Overall depth (excluding mounting flange).................	17-1/4 inch

3.2 Weight

Total weight (depending on mast length) approximately 550 lb.s maximum

4.0 LEADING PARTICULARS

4.1 Quick replaceable tape unit facilitates the exchange of damaged masts and permits the use of the same mast housing and winding mechanism with several mast configurations designed and optimized for specific applications.

4.2 Stainless steel mast material for maximum corrosion resistance.

4.3 Extension and retraction by 110 VAC, 60 cps, single phase, fractional horsepower universal motor (1/4-3/4 hp). Self-extending tendency of wound tape counter balances tip load and reduces peak winding torques.

4.4 Maximum strength is obtained by using a multiple of STEM tubes concentrically nested, yet wound on a single drum.

4.5 Electrical cables leading to tip-load can be conveniently fed through the bore of the mast.

4.6 Provision for manual operation in case of motor or power failure.

4.7 Reduction gearing integral with tape spool.

4.8 Includes motor drive control providing automatic maximum extension and retraction limiting as well as height readout potentiometer 2000 ohms, 1 watt for remote height indication.

5.0 INSTALLATION DATA

5.1 Model drawing 5439 shows all the leading dimensions and illustrates how the equipment can be installed.

5.2 The basic unit comprises the mast housing, c/w winding mechanism, quick replaceable tape unit, tape spool cover, mast endcap, mounting flange and electrical motor drive assembly.

6.0 OPTIONAL FEATURES

6.1 To permit higher wind speeds single point guying kit Part No. 5439F2-1 may be ordered.

6.2 In lieu of the AC drive, a 28 volt DC electric motor may be installed.

Specifications furnished by de Havilland are believed to be accurate and reliable. However, all specification data is subject to change without notice.

The De Havilland Aircraft of Canada, Limited,
Special Products and Applied Research Division,
Halton   Ontario   Canada

SECTION 'A-A' (PARTIAL)

MAST SHOWN EXTENDED TO 350 FT

MAST EXTENSION TO SUIT CUSTOMER'S REQUIREMENTS
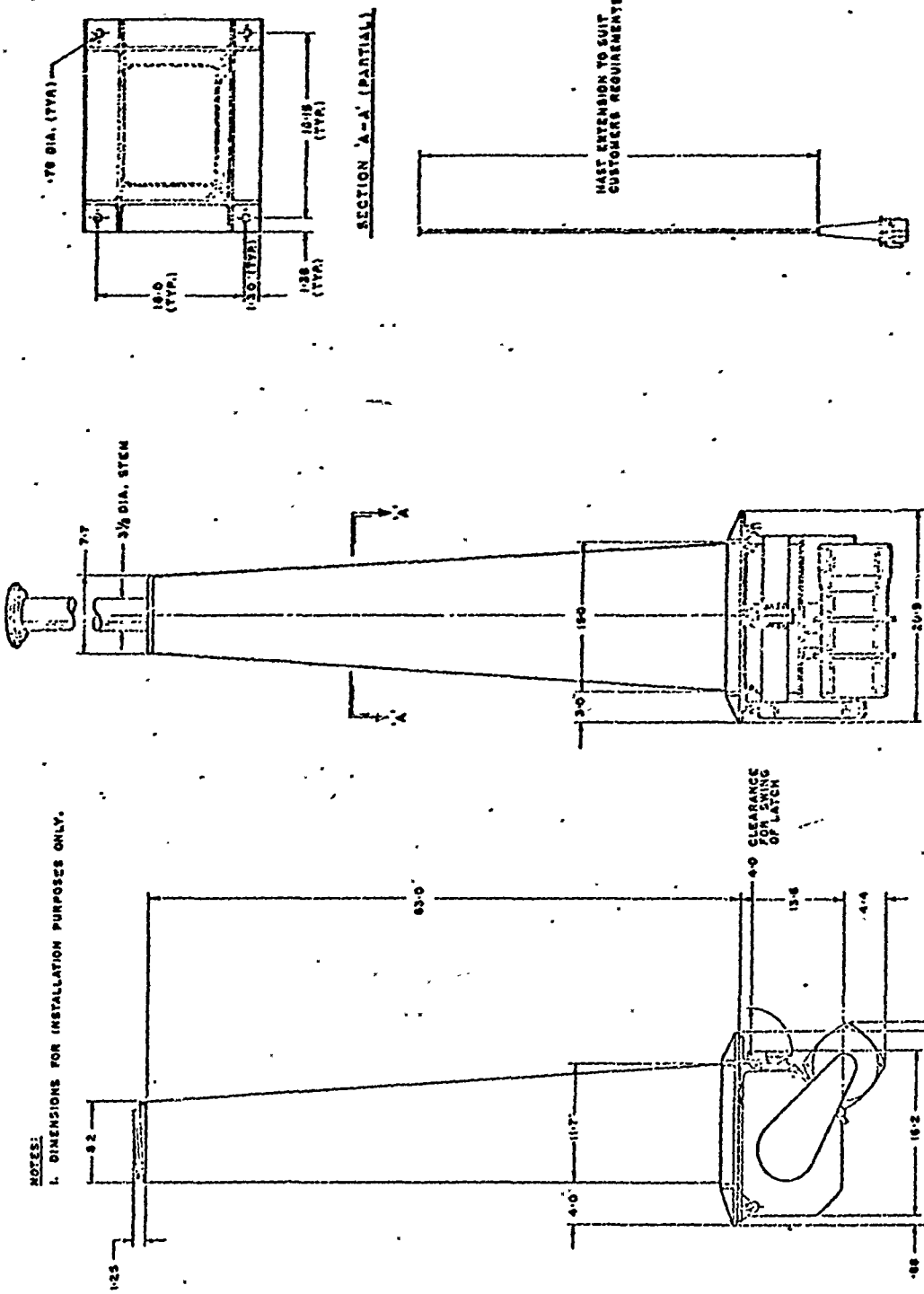
NOTES:
1. DIMENSIONS FOR INSTALLATION PURPOSES ONLY.

CLEARANCE FOR SWING OF LATCH

OUTLINE AND INSTALLATION – STD. 3½ DIA. GROUND STEM

Model 5500

HOUSING SUPPORTS (3)

1⅞ DIA.

-A-

VIEW SHOWING MAST EXTENDED

PART NO.	-A-
5500F1-1	35 FT.
5500F1-3	25 FT.

NOTES:
1. ALL DIMENSIONS ARE FOR INSTALLATION PURPOSES ONLY.

OUTLINE — 1⅞ DIA. GROUND MAST

SECTION A-A (HOUSING SUPPORT RING)

.80 (TYP.)
.25 DIA.
1.0 RAD (TYP.)
120° (TYP.)

CABLE ACCESS-CLOSURE PLATE

STOWED HANDLE POSITION
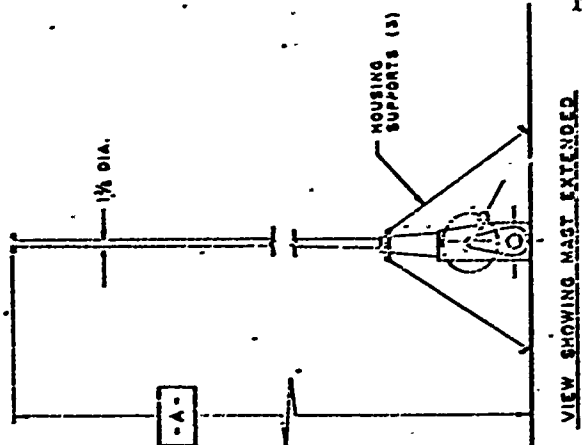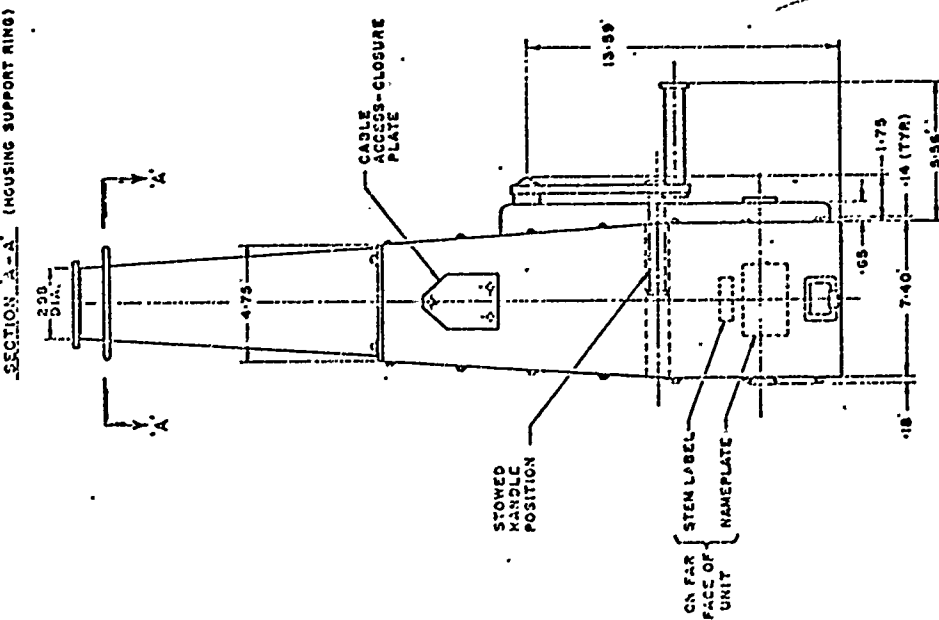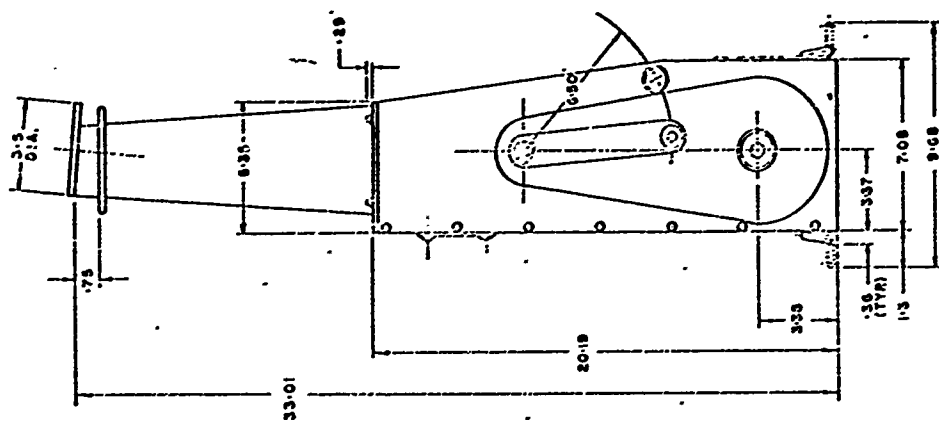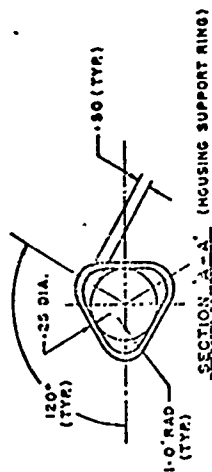
STEN LABEL
NAMEPLATE
ON FAR FACE OF UNIT

2.0 OCEAN VIBRATION

Sea Tests were conducted on April 2, 1964 in the Gulf of Mexico. The sea state was judged to be state 4. The spacecraft has 3 natural frequencies which are approximately

f_{n1} = 0.07 (cps)   for heave motion
f_{n2} = 0.25 (cps)   for roll motion
f_{n3} = 0.33 (cps)   for pitch motion

It would be desirable to have these values more accurately established by an experiment.

Roll seemed to be the most severe and an analysis of the transfer of ocean vibration via roll motion of the capsule to the antenna is presented in appendix A.

3.0 BUCKLING UNDER VERTICAL LOADING

An antenna subjected to its D'Alembert force due to heave acceleration may buckle. In Appendix B it is shown that the vertical acceleration would have to be of the order of 12g before the antenna would buckle.

4.0 BEAT PHENOMENON

The Gemini High Frequency Whip Antenna was observed to exhibit beating when carrying out free vibration. Some coupling between flexure in two perpendicular directions exists and when a flexural free vibration is commenced in y-direction it is observed to die away and motion in x-direction builds up. Subsequently the motion in x-direction dies away, while beat in y-direction builds up again. The period of this exchange of flexural vibration is computed in Appendix C and is found to be 90 (s).

5.0 BENDING

In Appendix D the distribution of the bending moment for booms of 15 (ft), 14 (ft), and 13 (ft) length is plotted. The bending moment was obtained by assuming that the boom was rotated through 57° at a maximum angular acceleration of 2.18 (rad/s^2). The extreme position of the boom is 47.5° from the vertical. Acting on the boom is a 15 knot horizontal wind. A tip load of 0.31 (lb) is also present.

-2-

The bending moment distributions were linearized and then used
to recommend optimum lengths for the 5 nested elements of the boom,
2 of which go all the way to the tip.

6.0 TORSION

STEM tubes do not exhibit much torsional stiffness. By preventing
warping at the ends of a tube, the torsional stiffness can be improved
considerably. The improvement depends on the length of the tube. The
shorter the tube, the greater the improvement. In Appendix E, it is
shown that for the Gemini HF Whip Antenna, prevention of warping at
both ends increases the torsional stiffness by almost 700%. The pro-
vision of a ploy guide and of a tip plug, both designed such that they
prevent warping effectively, is therefore strongly recommended.

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APPENDIX A

ON THE TRANSFER OF OCEAN VIBRATION TO STEM ANTENNAS OF FLOATING SPACE CAPSULES (HF WHIP ANTENNA, GEMINI SPACECRAFT)

1.0 PURPOSE OF INVESTIGATION

The purpose of the present investigation is to obtain an estimate of the spectral density of antenna vibration caused by ocean vibration at sea state 4.

2.0 HEAVE VIBRATION

2.1 The displacement spectral density of ocean waves at sea state 4 is given in Figure A1.

2.2 The natural frequency of roll vibrations of the Gemini space-craft capsule is approximately 0.25 (cps). The damping factor is assumed to be $\gamma = 0.5$. The square of the transfer function is shown in Figure A2.

2.3 The roll displacement spectral density is obtained by multi-plying the curves of Figures 1 and 2 and is shown in Figure A3.

2.4 Based on the assumption that the antenna carries out flexural vibration and that it has a very small damping factor ($\gamma = 0.01$) and that its natural frequency is 1.5 (cps), the square of its trans-fer function for flexural vibration is as shown in Figure A4. It is also assumed that heave and pitch motion of the capsule do not contribute to the flexural vibration of the antenna, rendering the analysis presented here only approximate.

2.5 The flexural displacement spectral density of relative antenna vibration (i.e. antenna bending with respect to the capsule) is obtained by multiplying the curve of Figure A3 by that of Figure A4. The resulting spectral density is shown in Figure A5.

3.0 RESULTS

An inspection of Figure A5 indicates that at sea state 4, the Gemini HF Whip Antenna should exhibit pronounced flexural vibration at 0.09 (cps)

-4-

and 0.25 (cps). Vibration records taken during the spacecraft stability test (see letter of April 9th, 1964) have not been made available to deHavilland. It is expected than an analysis of the record would show the presence of large amplitudes at frequencies of 0.25 and 0.09 (cps).

-5-

FIGURE. A2.

Oceanto Capsule Transfer Function Square, H_a

Frequency. f (c.p.s)

FIGURE. A1.

Frequency. f (c.p.s)

Ocean Displacement Spectral Density (in.²/c.p.s).

$fn = 1.5.$

FIGURE.A4.

Capsule to Antenna Transfer
Function. Square, H₁²

Frequency. f. (c.p.s)

Capsule.

FIGURE.A3.

Frequency. f. (c.p.s)

Capsule Displacement Spectral
Density (in.²/sec.)
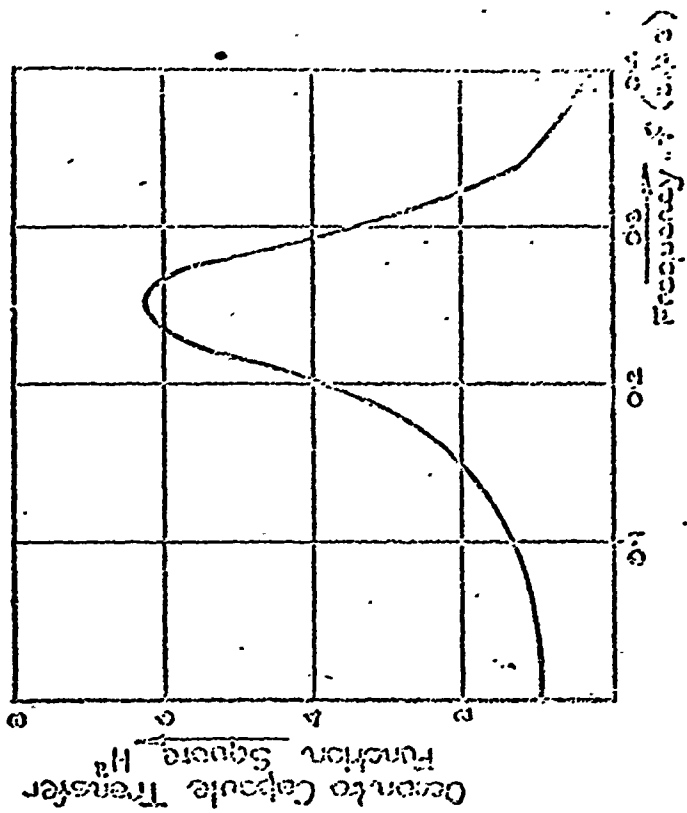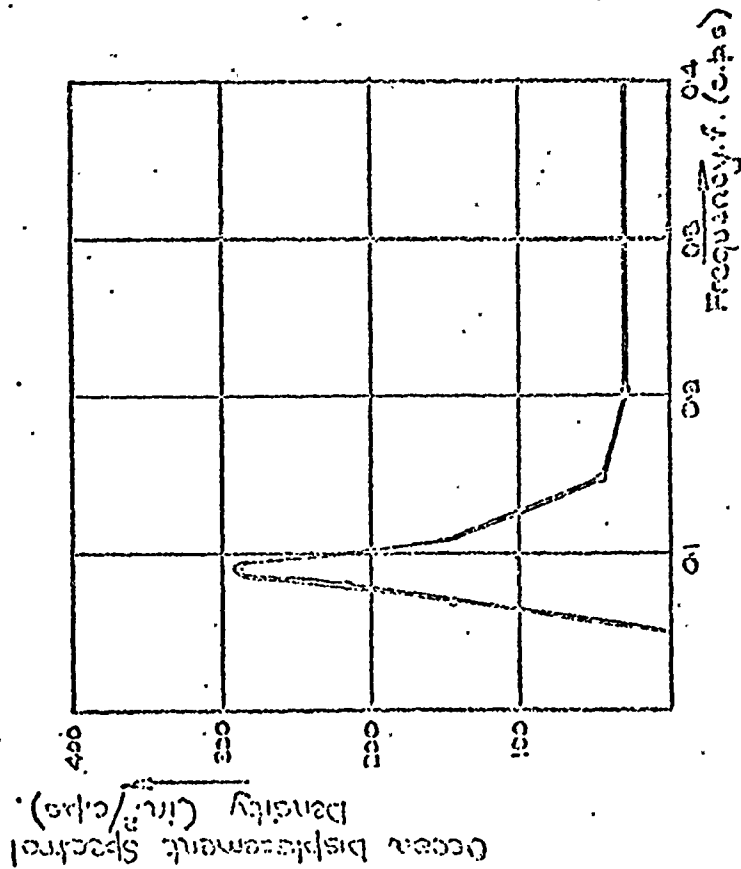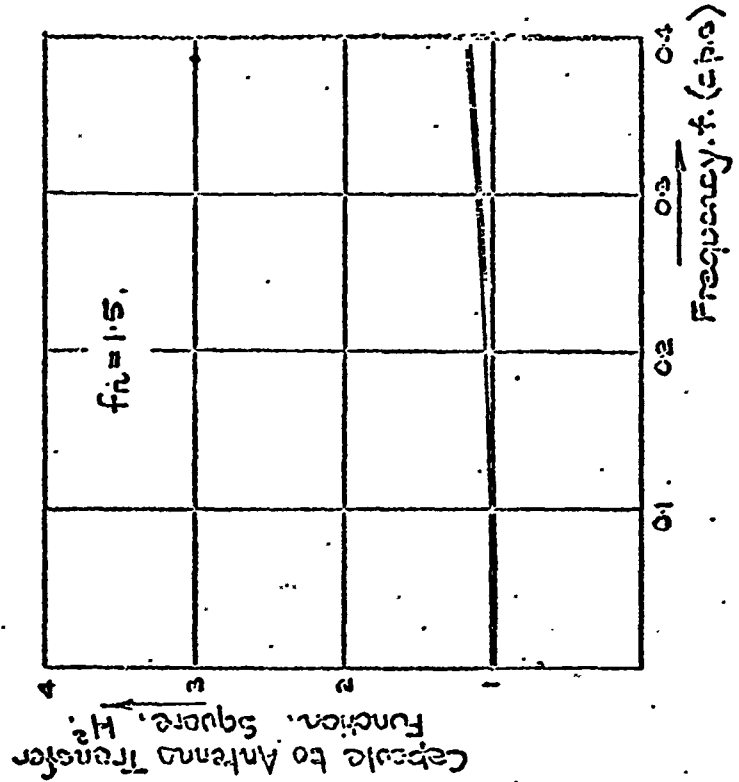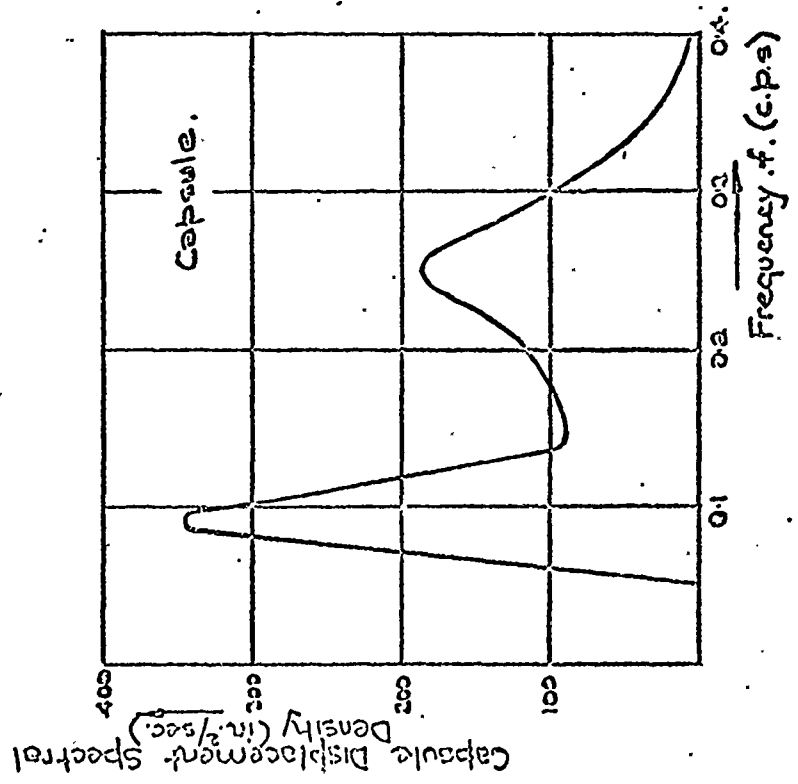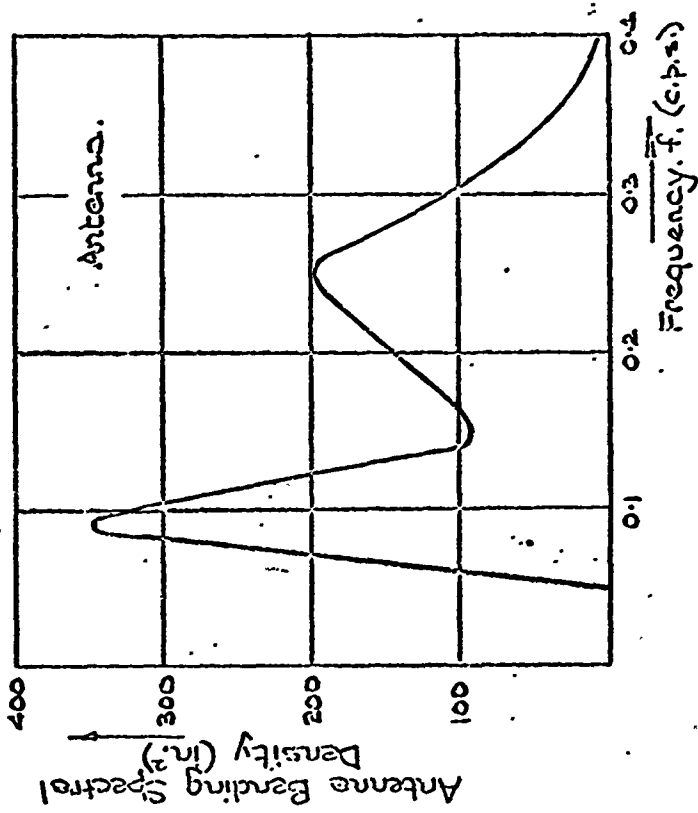
FIGURE. A5.

APPENDIX B

BUCKLING UNDER VERTICAL ACCELERATION, GEMINI HF WHIP ANTENNA

Assume that a 15 (ft) antenna is mounted vertically as a cantilever. The critical load causing Euler buckling (Timoshenko and Gere) is then approximately

$$P = \frac{7.837 \, EI}{l^2}$$

With $E = 29(10^6)$ (lb/in^2),

$$I = 1.73 \, (10^{-3}) \, (in^4)$$

and $l = 180$ (in).

$$P = 12.2 \, (lb)$$

The quantity P is the total load. For one element of 180" length

$$m = \rho \, (\not\delta \, \pi \, d) \, t \, l = \frac{0.283}{386} \quad (4) \, 0.005 (180)$$

$$m = 0.00264 \, (lb \, s^2/in)$$

The acceleration is obtained by writing

$$a = \frac{P}{m} = \frac{12.2}{0.00264} = 4620 \, (in/s^2)$$

or $\quad a = 12 \, g$

Neglected are:

The tip weight (which would give a reduced value of "a").

The shorter elements (which would give an increased value of "a").

- 9 -
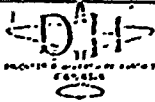
APPENDIX C

ON THE BEAT PHENOMENON OF THE GEMINI HF WHIP ANTENNA

The fundamental flexural natural frequency in one plane is

$$f_n = 0.94 \; (cps)$$

or

$$\omega_n = 5.92 \; (rad/s) = \omega_1 \approx \omega$$

In the other plane, the natural frequency is slightly different, because the inertia moment is different.

$$\frac{\omega_1}{\omega_2} = \sqrt{\frac{I_1}{I_2}}$$

or

$$\omega_2 = \sqrt{\frac{I_2}{I_1}} \, \omega_1 = \sqrt{\frac{1.81}{1.73}} \; 5.92 = 6.06 \; (rad/s)$$

The resulting motion of the system may be regarded as being made up of superposed principal modes. Thus we can write.

$$x = A_1 \cos \omega_1 t + B_1 \cos \omega_2 t$$

$$y = A_2 \cos \omega_1 t + B_2 \cos \omega_2 t$$

If the system is started off with $y = 0$ and $X = A$

$$x = \frac{A}{2} \cos \omega_1 t + \frac{A}{2} \cos \omega_2 t$$

$$y = \frac{A}{2} \cos \omega_1 t - \frac{A}{2} \cos \omega_2 t$$

By employing trigonometric identities

$$x = A \cos \frac{\omega_2 - \omega_1}{2} t \cdot \cos \frac{\omega_2 + \omega_1}{2} t$$

- 10 -

$$y = A \sin \frac{\omega_2 - \omega_1}{2} t \cdot \sin \frac{\omega_2 + \omega_1}{2} t$$

New let

$$\omega_2 - \omega_1 = 2\Delta = 0.14 = 2(0.07)$$

$$\omega_1 + \omega_2 = 2\omega = 5.92 \text{ (rad/s)}$$

then

$$x = A \cos \Delta t \cos \omega t$$

$$y = A \sin \Delta t \sin \omega t$$

One complete beat cycle has a period of

$$\tau = \frac{2\pi}{\Delta} = \frac{2\pi}{0.07} = 90 \text{ (s)}$$

APPENDIX D

BENDING MOMENTS OF GEMINI HF WHIP ANTENNA

The bending moment applied to a boom is assumed to consist of
(see also Figure D1):

Self weight (at 47.5° from vertical)   52.5°
Angular Acceleration (2.18 rad/s²) of self weight   253/s² ⊸ 4.42/s²
Wind Load (due to a 15 knot horizontal wind)   28.5
Tip weight (0.31 lb)
Acceleration of tip weight

Booms of 15 (ft), 14 (ft) and 13 (ft) were considered. Optimum
lengths for the nested elements were obtained and are indicated. Five
elements are nested in each case, two of which are of full length. To
simplify the analysis, the bending moment distribution was linearized.
The results are shown in Figures D2, D3 and D4.

The following assumptions were made in the analysis:

(a) Any influence of the normal load component of self weight
and tip weight has been disregarded.

(b) The influence of deformation upon the load has been neglected.

(c) The aerodynamic drag coefficient C_D has been taken to equal
1.20.

(d) The maximum permissible bending moment for a STEM
section was taken to be that defining local instability, viz:

$$M = k n \frac{E}{(1 - \nu^2)} \frac{d}{2} t^2 \quad \text{(in lb)}$$

with: k = 0.75 = experimental constant
      v = 0.3   = Poisson's ratio
      d (in)   = diameter
      t (in)   = thickness
      n = number of elements

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15 KNOT WIND.

0·3.lb.

47·5°

Centre of Rotation.

48"

α = 2·18 rads/sec.²

STEM DETAILS.

5 elements.

Nominal Diameter   0·86. ins.

Material Thickness   0·005 ins.

Developed Width   4·0 ins.

Material : Stainless Steel.
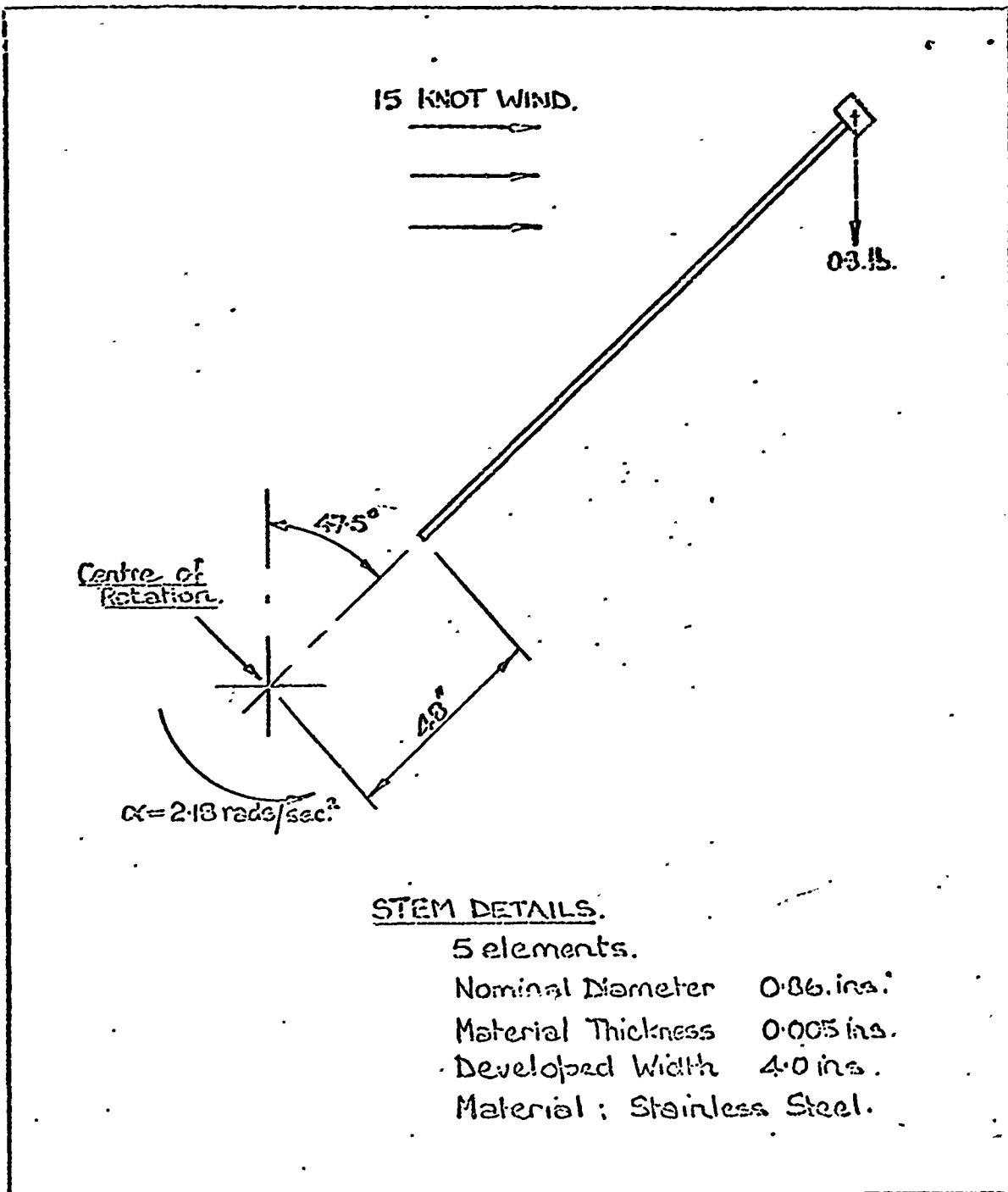
FIGURE. D1

FIGURE D2.

FIG. 3.
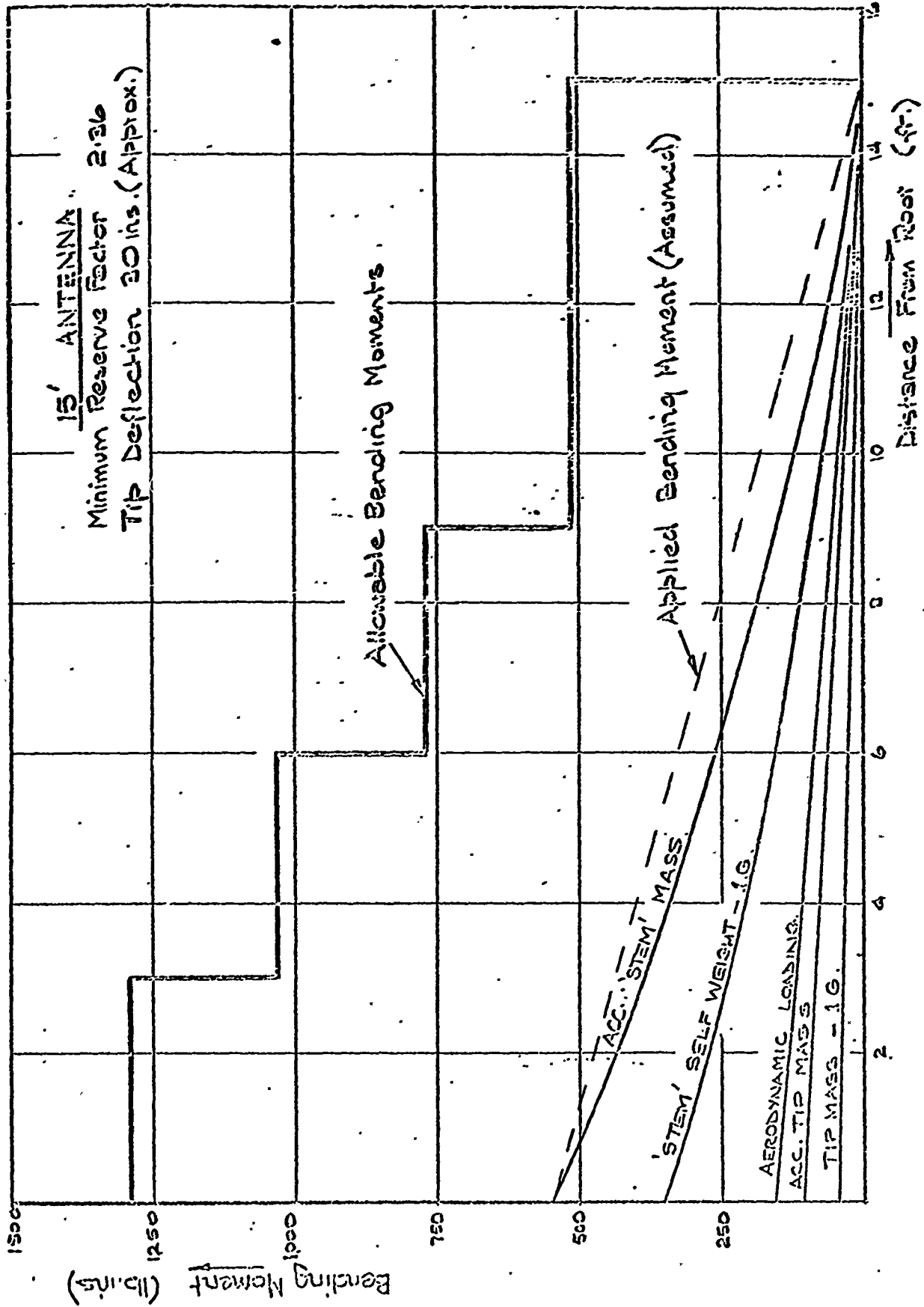
GP-R.101

14' ANTENNA.

Minimum Reserve Factor 2.74.

Tip Deflection 29 ins. (approx.)

Allowable Bending Moment.

Applied Bending Moment (Assumed).

RUNNING LOADING.

ACC. TIP MASS.

TIP MASS — 1 G.

Bending Moment (lb. ins.)

1500 1250 1000 750 500 250

Distance. From Root. (ft.)

2 4 6 8 10 12 14

FIG. 3.
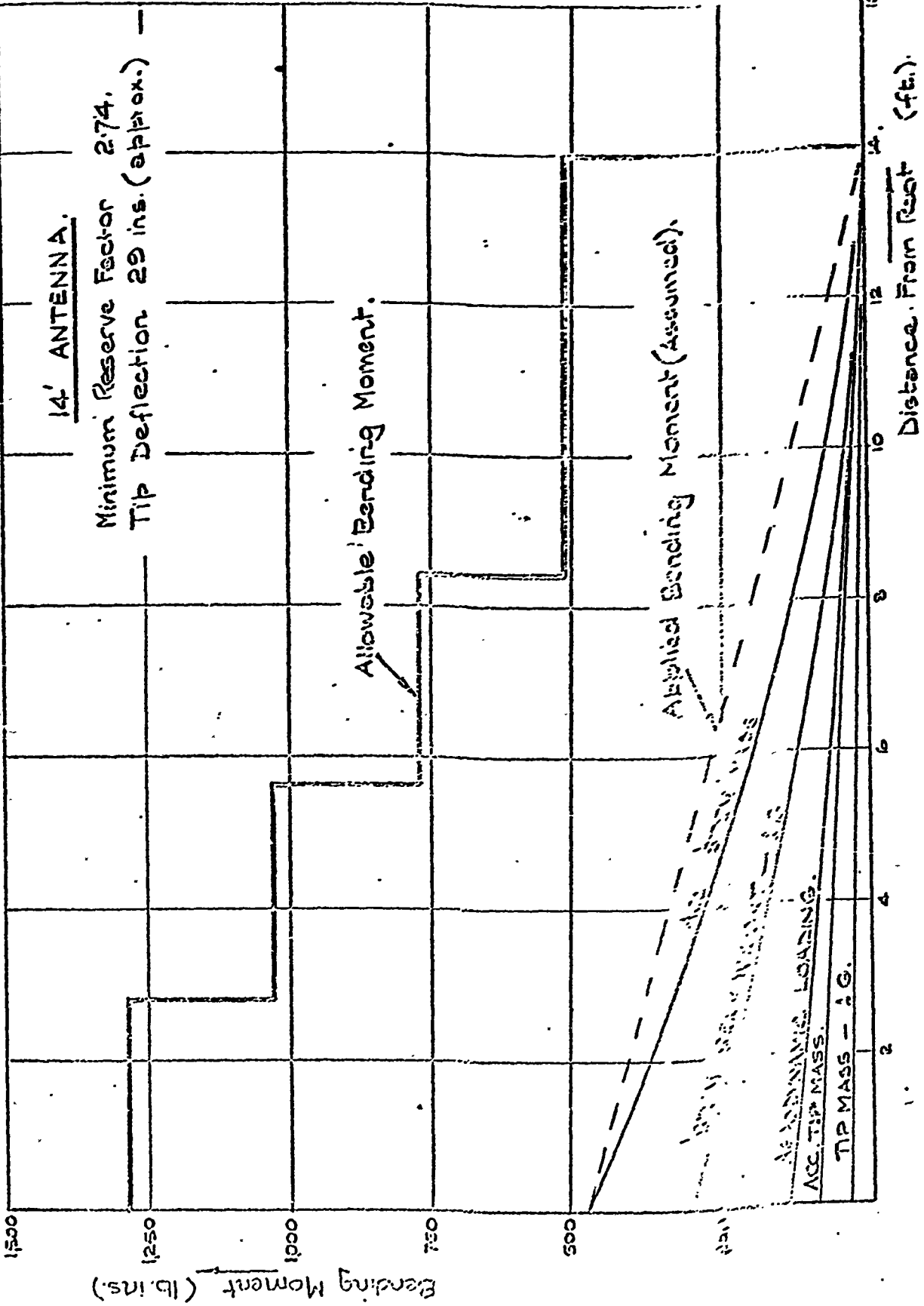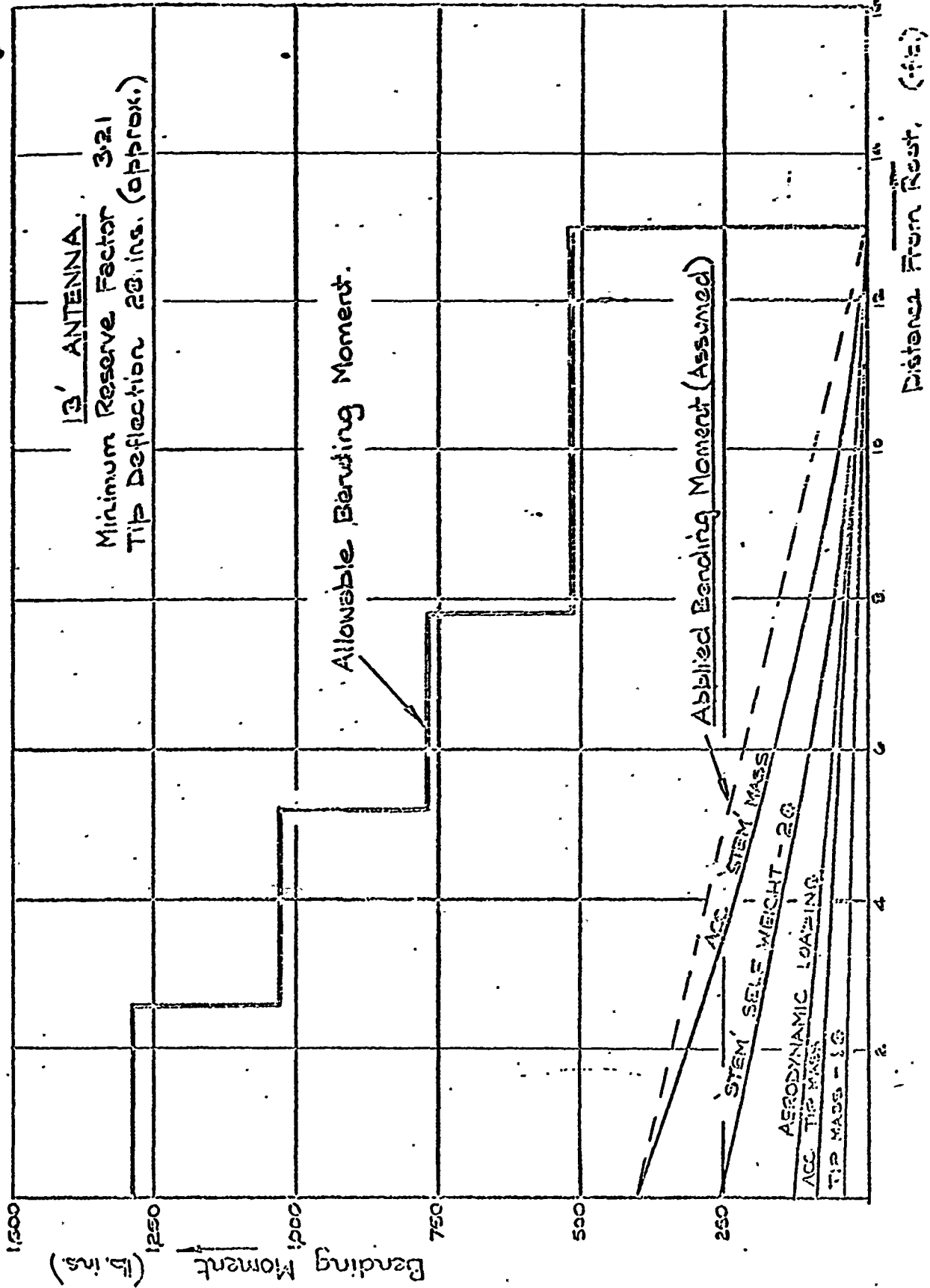
FIGURE D.4.

APPENDIX E

TORSION OF GEMINI HF WHIP ANTENNA

The equation relating torque T (in lb) and twist angle φ (rad) of a Gemini HF Whip Antenna of 16 foot length, where warping is prevented at both ends, can be shown to be:

$$\varphi = \frac{7.87}{C} \, T$$

where C = 1.85 (in^2lb) is the torsional rigidity.

With ploy guide, but without tip plug (i.e., with warping prevented at root and warping permitted at tip), the twist versus torque relation becomes

$$\varphi = \frac{1.97}{C} \, T$$

Without ploy guide and without tip plug (i.e. warping permitted at both ends), the twist versus torque relationship is

$$\varphi = \frac{1}{C} \, T$$

A comparison of the results indicates that prevention of warping at one end (e.g. by a ploy guide), increases the torsional stiffness by 97% and prevention of warping at both ends (e.g. by a ploy guide and a tip plug), increases the torsional stiffness by 68%.

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APPENDIX V

Background Materials on "Seastaple" Anchors

This appendix contains background material on the "Seastaple"
embedment anchor; developed by the National Water Lift Company of
Kalamazoo, Michigan.

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17 May 1968

Mr. Frederick Hess
University of New Hampshire
Kingsbury Hall
Durham, New Hampshire 03824

Dear Mr. Hess:

Your inquiry regarding embedment anchors has been referred to
me for reply. I am pleased to enclose all written material
currently available.

The NWL SEASTAPLE anchor is the result of approximately six
years of development covering a wide range of military and
commercial moorings. You will note that NWL has placed over
200 anchorages as a part of the SEASTAPLE program, with
considerable success in moorings in a variety of bottoms.

For a period of approximately two years NWL has manufactured
and sold a production design of the MK 5 and MK 50 described
in the attached brochure. Additionally, the operating
instruction booklet may provide certain information pertinent
to assembly and placement of the anchors.

Early this year we received an inquiry from Movible Offshore,
P.O. Box 51936 O.C.S., Lafayette, Louisiana 70501 (Dr. Murphy
Thibodeaux, Chief Engineer), which over a period of approxi-
mately three months has matured into an active interest on
Movible's part in purchasing the entire National Water Lift
SEASTAPLE anchor product line for use both in their own
activities and for manufacture and sale to companies such
as yourself. The status of negotiations with Movible at this
point is that they have taken an option to buy the anchor
program with contract completion anticipated by early summer.

During this period of negotiations with Movible the two
companies have agreed to follow up any important requirements
for the anchor through Movible Offshore, with the direct
technical assistance of National Water Lift supporting Movible
in this venture. The present inventory of anchors at NWL are
available to Movible Offshore and all NWL "know-how" is also
available to them.

While a transition of this type sometimes generates customer
problems, you may be sure that both NWL and Movible will do
their best to minimize them. Under present status a discussion
of procurement of any anchor for your current requirements
should be made through Movible Offshore, with the full assistance
of NWL. I am sure Movible will be happy to accommodate you.
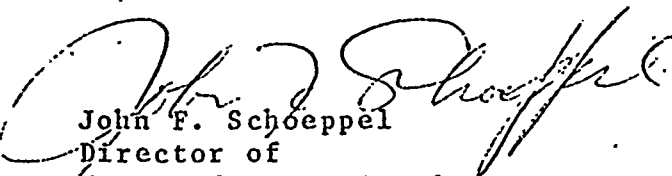
Please note that we have had particularly good test results with
SEASTAPLE anchors in rock (shale and coral) as well as in more
conventional bottoms. We have fired several test anchors into
hard concrete with results similar to natural rock. Pull
ratings in rock generally exceed the anchor ratings by 50% to
100%.

The anchors are rated in a sand or sand-clay mix and are believed
to be conservative in that type of bottom.

I am sure that you will find the SEASTAPLES a most interesting
product, capable of providing low cost anchorages in difficult
bottom conditions. I have notified Dr. Thibodeaux of your
interest in order that he can follow up your inquiry.

Very truly yours,

NATIONAL WATER LIFT COMPANY

John F. Schoeppel
Director of
New Products & Development

JFS:cc

enclosures: (1) NWL SEASTAPLE Brochure
               (2) NWL SEASTAPLE Operating Instructions
               (3) NWL SEASTAPLE Background

Table of Physical Characteristics

	MK 5	MK 50	MK 200 plus	(Approx. Value) MK 500	(Approx. Value) MK 1M
Total Weight (Gun and Fluke)	60.5 lbs.	1,850 lbs. (sand & clay)	3,900 lbs.	10,000 lbs.	25,000 lbs.
Overall Length	27 inches	8 ft.	15 ft.	25 ft.	45 ft.
Maximum Diameter	13 inches	4 ft.	5 ft.	10 ft.	14 ft.
Fluke and Piston:					
Weight	115 lbs.	418 lbs. (sand & clay)	2,000 lbs.	4,400 lbs.	10,000 lbs.
Length	16 inches	44 inches	7 ft.	11 ft.	18 ft.
Area	0.83 ft^2	8.3 ft^2	30 ft^2	60 ft^2	120 ft^2
Charge (Smokeless Powder)	.125 lbs.	3.5 lbs.	25 lbs.	54 lbs.	125 lbs.
Penetration (Sand & Sand Mix)	7 ft.	22 ft.	47 ft.	70 ft.	100 ft.
Holding Force (Vertical or with Scope)	5,000 lbs.	50,000 lbs.	over 200,000 lbs.	500 kips	1,000 kips
Status	Production Design	Production Design	Full Scale Tested, then Design Enlarged	Extrapolation Only	Extrapolation Only

ANCHOR USAGE

The following list indicates some of the more recent anchor applications:

Keyport Naval Torpedo Test Station

    1 MK 50 to anchor instrumentation barge.

Naval Ordnance Laboratories

    Lauderdate Test - 10 MK 5's to evaluate NWL anchor vs. competition anchors.

NOL Project White-hat

    20 MK 5's, puchased as a result of the outcome of the Lauderdale test to be used to hold instrumentation packages in an underwater explosion test.

Point Conception, California

    1 MK 50, 2 MK 5's - demonstration test for the oil companies (planting anchors into shale).

FRG, Emden

    1 MK 50 - planted in the North Sea off of Emden, Germany, to moor an AMODCO type buoy.

Standard and Union Oils

    4 MK 50's - planted off of the Oregon coast in shale to moor a drilling rig.

Naval Civil Engineering Laboratories

    10 MK 5's - to evaluate deep water firing of the anchor.

Hudson Laboratories

    22 MK 50's - planted on continental shelf off of Bermuda as part of the AUTEC Program.

NWL " SEASTAPLE" ANCHOR

National Water Lift Company has developed and placed on the
market two models of the SEASTAPLE embedment anchors. These
models are the MK 5-4000 series which is normally rated at
5,000 pounds and the MK 50-4003 series rated at 50,000 pounds
of holding capacity. The NWL anchor rated holding power is
based on a sand, silt, and clay combination, with the anchor
being pulled in a true vertical position. A variation from
this type of bottom has some effect on holding characteristic,
with tendencies toward 100 percent silt reducing the holding
capacities, and tendencies toward hard-packed sand increasing
the holding capacities. NWL anchors have been installed in
mud, clay, sand and gravel, coral, shale, and concrete in the
course of a large number of firing tests.

Two fluke configurations are available for the MK-4000 series.
Model 4000-1 is for sand, mud and clay, and Model 4005-1 is for
coral, concrete, and shale. Both of these configurations can
be interchangeably fired from the MK 5, Model 4000-3 gun.

The MK 50-4003 has a single type of fluke which has been
installed in mud, clay, sand and gravel, coral and shale with-
out changes. The MK 50-4003 series anchors are fired from the
MK 50, Model 4006 gun.

Both the MK 5 and the MK 50 anchors can be surface fired or
bottom contact fired. Surface firing is recommended where
practical. Both have pressure switches in the firing circuit
to assure safe handling when out of the water or in shallow
water conditions. The guns have provisions to incorporate
legs to form a tripod for setting the gun assembly on the
bottom for shallow water firing or precise location firing.

The life of a SEASTAPLE when set in the bottom is known to
be quite long. However, the full life an an anchorage is
still unknown. In 1963, 22 MK 50 SEASTAPLES were used in the
Artemis project off Bermuda. Indications are that these units
are still in service.

Holding power tests made on the SEASTAPLES have clearly shown
that holding power varies with bottom conditions, such as
water content, soil structure, etc. The average holding
power on 20 test units of the MK 5-4000 series sand fluke was
7,400 pounds. All these units were tested in sand, sand-gravel,
sand-clay, and mud-sand-clay bottom conditions. The MK 5-4005

coral flukes test fired into concrete test blocks were loaded
to 11,000 pounds without failure or pull-out. Coral flukes
embedded in shale held to the breaking strength of the wire
rope pendant, which is 13,000 pounds.

The MK 50-4003 series flukes rated at 50,000 pounds have held
to a breaking strength of the wire rope pendant 170,000 pounds
and have also held 74,000 to 100,000 pounds in bottoms, such
as sand, sand-clay, and extremely soft shale. When the ground
structural strength capabilities are exceeded the SEASTAPLE
is pulled free from the bottom. In the higher loaded conditions
the wings of the anchor are usually bent. In this condition
the anchor could be readily rebuilt and reused again.

The materials used in the manufacturing of the anchor is 4130
steel, heat treated to RC 40-43, T1 steel at Brinnel 321 and
1020 steel as rolled. The steels selected are based on the
structural requirements as dictated by the various loads
imposed upon the anchor.

The pendant for the MK 5-4000 and 5-4005 anchors is improved
plow steel with IWRC. The MK 50-4003 anchor uses VHS wire
rope with IWRC. Corrosion resistant material could be used,
depending upon the oxygen content expected.

Anchor holding capacity is a function of the anchor penetration.
The MK 5 penetrates from 4 to 20 feet and the MK 50, 4 to 30
feet. An an example, the MK 50 penetrates shale approximately
5 to 6 feet. The MK 5 has been driven into solid concrete
to a depth of one and one-half feet, with resulting holding
up to the breaking strength of the pendant. Likewise, the
MK 50 has held over 100,000 on a shale installation and in
several cases up to the breaking strength of 175,000 pounds
of the pendant.

The anchor guns have proven capabilities of firing 15 to 20
times and can be extrapolated to over 100 shots with a chromed
bore.

Preparation of the anchors, such as pre-assembly, final
installation of the cartridge, and final checkout prior to
lowering can be accomplished by one man. However, NWL has
found it sometimes saves time to use a two-man crew.

The shipping container is designed to serve as an assembly
fixture and rotating bed to ready the anchor and to elevate
it to the vertical position prior to swinging over the side
and lowering. With two men working as assemblers and a good

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winch or crane operator, anchers can be implanted as fast as
the crane operator can lower the anchor to the bottom and
fire it. By using several guns the assemblers can keep
ahead of the emplacement crew.

JM:cc

COMMENTS ON CERTAIN FEATURES OF INTEREST ON THE NWL "SEASTAPLE" ANCHOR SYSTEM

Test Background

An attachment to these comments summarizes past tests of our anchor. Approximately 200 anchors of various sizes and weights have been set. Approximately 75 percent of the large anchors tested have been set in various kinds of bottoms. Our experience in both heavy and light anchors is adequate to support the operational use of this equipment at this time.

A large percentage of the anchor settings were used for test purposes and the retrieving pull required (on a vertical pull) was tested and recorded on most settings. Based on these actual tests in various oceans around the United States we have a high level of confidence on the pulling power of these anchors in various kinds of bottoms and have quantitative data on the vertical pull in a large number of tests.

Reuse of Fluke

The fluke is retrievable by means of a vertical pull which exceeds the holding power of the anchor by 50 to 100 percent. Thus, in any type of soft to firm bottoms, such as silt, sand, and silt-sand combinations, the retrieving force will be found within the limits of 50 to 100 percent over the rated pull, on a vertical basis. In case of fluke salvage of this sort you can expect a certain amount of damage to the flukes of unpredictable type. However, since the flukes are not what is known as a precision assembly the parts can be straightened or can be cut out with a torch and new parts welded in, with a consequent saving in cost from reuse. In the case of an anchor set in coral or shale reuse is not recommended, since repair costs due to the damage would exceed the cost of a new fluke.

Rated Pull

The rated anchor holding power is understood to be a straight vertical pull by means of a winch operating at a slow rate of speed.

Effect of Scope

The effect of scope of the SEASTAPLE anchor is quantitavely unknown. We do know that holding power increases with scope up to a limiting value. At this time the vertical holding power can be assumed to be conservative when the anchor is used with scope. As experience is gained an improvement factor can be assigned to various degrees of scope.

Non-Destructive Test of Holding Power

Once the fluke is in the dead-man position the force required to pull the anchor free can be estimated by pulling vertically on the anchor and measuring the creep of the anchor at various tensions. In other words, a 50,000 pound anchor could be tensioned to 25,000 pounds and the rate of creep of the winch noted, then 50,000 pounds and creep noted. From these two values the probable pull-free force can be estimated.

Safety Precautions

In general we can say that any normal kind of powder storage would be quite satisfactory with this anchor. The 50,000 pound anchor uses 3.5 pounds of smokeless powder of a conventional type. Such cargos of powder can be stored in a water-proof fashion in an area of a ship where accidental fire would not seriously damage the ship. The powder will not explode until confined and thus is reasonably safe. The use of electric firing systems with conventional igniters and conventional charging schemes means that these anchors can be set by anyone skilled in the use of conventional explosives.

With regard to conflict with regulations of different countries, we have no background in this. We would presume that handling the powder charges would involve the same regulations as one would find on use of powder explosives. These are in common use throughout the world. Powder charges for these anchors can be handled by Air Freight in the U.S. under proper shipping classification.

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Substitute for Wire Rope Pendant

An investigation has been performed by NWL and engineering details worked out to replace the wire rope pendant by a chain. It appears that a chain coupling is feasible and practical. A chain coupling would last longer on the bottom, particularly in sand. Also, heavy plastic coated cable could be applied here as an alternate solution. However, to date, no test firings have been performed on this type of installation.

"Wear" on Wire Rope Pendants

One installation of MK 50 anchors has been in use since 1963. The usage is on an intermittent basis. Most design criteria has been based on a five-year life for the anchor system. However, complete data is not available to determine the exact life expentancy for various bottom conditions. Wire rope life is based on the cyclic motion at the water-bottom interface, the action of sand particles within the wire rope pendant creating chafing on the individual strands, the oxygen content of the emersion and other factors associated with the location of the anchor implantment. It is recommended that a clump be used to remove the dynamic effect of wave action on the riser to increase the mooring life. A MK 50 implanted in shale was maintained at an operating load of over 100,000 pounds with the ultimate breaking strength of the wire rope rated at 170,000 pounds.

Danger to Divers

Calculations have been made, both by the Navy and by NWL relative to the danger zone for divers during firing of the anchors. Actual experience has been had on the 5,000 pound anchor, wherein a diver was within 12 feet of the anchor. The shock wave effect pushed the diver back with no ill effects. To date, we have experienced no fish kill during the firing of any of the anchors, except for one case in which the anchor was fired in a horizontal position. Fish have been seen to jump in the area directly over the anchor when fired; however, they have swum away with no ill effects. The Navy was unwilling to comment on their theoretical calculations in the event that there may be some problem area arise. I believe that this is a consensus of opinion of anyone when being asked for a commitment of this nature. This is an area wherein each contractor must develop his own experience with his own divers to determine the level at which he wishes to work.

This appendix contains background materials on the Sea-Fix radio navigation system, developed by Decca Survey Systems, Inc., Houston, Texas.

SEA—FIX

A Preliminary Introduction

by

SEA-FIX

CONTENTS

ILLUSTRATIONS

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SEA-FIX

INTRODUCTION

SEA-FIX is an accurate electronic position-fixing system intended for hydrographic use. It was developed in answer to the need for a quick reaction time, readily transportable, reliable and accurate system for offshore operations concerning surveys, salvage, mine-sweeping, and oceanography, at a distance from land too far for the employment of accurate shore-based electronic position-fixing systems; or in a hostile situation where the land mass is untenable for any reason. SEA-FIX consists of three or four buoys housing transmitting stations, and shipboard receiving equipment. Buoy stations are designed to withstand severe weather conditions and maintain an efficient watch circle in cur ... , to 4.5 knots.

The transmitting buoys are moored at sea in a predetermined geographical pattern and energized. These buoys, designated "Master" and "Slaves", radiate electromagnetic energy on a selected frequency within the 1600-2000 Kh/z range. Each radiates in turn, synchronized in time sequence and phase by control signals generated by the Master station buoy. These radiated signals form stationary wave patterns in space, known as a "lattice". A receiver moving across this lattice gives continuous indication of its position with respect to the transmitting buoys. If the positions of the buoys have been accurately determined, the data given by the receiver may be converted into geographical coordinates by reference to a map or chart on which the SEA-FIX patterns (lattice) are shown.

Two types of lattice may be generated. These are hyperbolic and circular. The hyperbolic lattice consists of lines of equal phase difference between the signals received from two transmitting stations. (See figure 1). These form navigational position lines; intersection of a position-line of one pattern with a line of the other at a user's receiver fixes his position. A hyperbolic lattice, therefore, needs at least two pairs of transmitting stations to provide a "fix". In practice, the master station is common; the remaining stations are known as "Slaves". To provide all around coverage, three slaves may be used. The imaginary line drawn from the master to a slave is termed a base line. In a hyperbolic lattice, the position lines diverge as they recede from the baseline, resulting in a decreasing accuracy with distance. This decrease is shown in figure 2, a typical hyperbolic accuracy contour chart.

In cases where a high order of accuracy is required over a larger area, the SEA-FIX system may be operated in the range/range mode. The same number of patterns are generated as in the hyperbolic mode but the master station is now installed in the user's ship; this results in patterns of a circular shape, which are centered on the slave stations (See figure 3). Whereas in the hyperbolic mode any number of user's receivers may be operated on one lattice, in a range/range mode, only one receiver may use the lattice. An accuracy contour of a typical range/range configuration is shown in figure 4.

The peculiar benefit of SEA-FIX lies in the fact that it is not dependent upon shore sites for installation. It can either be sited in at known geographical points in the sea or arranged to provide a relative lattice when exact geographical reference is not required, but accurate coverage of an area is desired.

DESCRIPTION

A SEA-FIX installation ready for use is called a "Chain". In a hyperbolic chain the master control unit injects the trigger and master pulses into a transmitter at the master station. The slave stations receive these pulses, the first of which triggers the electronic timer, the second locks the control unit to the phase and frequency of the master. The slave now is "locked" to the master and

on the shipboard receiver counters which, when compared with the predrawn lattice charts, will give the exact distance travelled. (2) This too is predetermined. At the appropriate counter reading, a second slave is placed in operation and lowered over the side. (3) There then exists a Range/Range configuration which can be used to position the Master-station. In practice the ship steams along the required range circle from one slave and lays a marker buoy in the required position as indicated by the readings obtained from the second slave. (4) Predetermined readings are taken from the standard chain configuration cables.

The master buoy is moored over the position buoy, the baseline extensions of the two slaves crossed and the chain is fully operational.

Any number of vessels may simultaneously use a hyperbolic chain, with only a receiver and track plotter aboard. However, when a high order of accuracy over a large area is desired, and the use of only one active vessel is permissible, the sea-fix chain may be rearranged into the Range/Range mode. This entails operation of the Master station and the Sea-Fix receiver aboard the vessel.

The Range/Range system offers several distinct advantages over the hyperbolic method of operation:

A. Only two stations need be moored, thus saving time and maintenance.
B. Computation of a hyperbolic lattice is avoided. The position lines are circles centered on the two slaves.
C. The measurements are unaffected by "lane expansion" and so the effects of phase errors in terms of distance are relatively small over the whole area of coverage. The area covered by the high-accuracy contours is much greater than that of the hyperbolic chain.

To establish a range/range chain, only the slaves are moored, as in a hyperbolic chain. The ship then steams off a distance and measures accurately the range to each of the slaves. Several of these measurements compared with receiver counter readings will indicate the fractional lane constant error which must be subtracted in preplots and post plots of the area coverage.

Accuracy contours for typical hyperbolic and range/range chains have been shown in figures 2 and 4. Each of the systems have their appropriate use and either will give repeatability accuracy well within the practical requirements of modern hydrography and oceanography. Repeatability of the hyperbolic mode of operation is accurate to within .01 Lane: Of the range/range mode, .015 Lane.

MAINTENANCE

The SEA-FIX buoys are constructed of a low-maintenance material and require only occasional cleaning. A Lister LP1 diesel motor generator is utilized to provide long life and minimum maintenance. It can, however, be removed from the buoy and serviced by any competent diesel mechanic when required. It is recommended that at the end of each survey, the diesel be removed from the buoy and thoroughly cleaned.

The electronic equipment is of solid-state modular construction and requires a minimum of attention.

An operating chain must be serviced at least each 30 days.

One qualified technician is required for overall maintenance of the chain. He will be stationed aboard ship with the receiver. Utilizing the receiver aboard ship he can make rough checks of the slave operation, and with the proper test equipment can provide field maintenance and overhaul of the total chain when it is hoisted aboard ship.

A space aboard ship is required for the maintenance technician, in which he can store test equipment and spare parts, and perform bench maintenance of electronic units. In chains which operate for very long periods between recovery, it is advisable to have spare transmitters and control units to facilitate servicing. This permits replacement of units and assures a minimum down time of the chain.

SYSTEM CHARACTERISTICS

Transmission (frequency)	Nominally in the band 1600-1800 kc/s (kHz)
Trigger frequency	Transmission frequency less 60 c/s (Hz)
Type of transmission	Interrupted continuous wave, time multiplex
Switching rate	Five times per second
Radiated power	Approximately 1.5 watt from 30 feet vertical antenna
Maximum operating range (over sea)	30 N Miles
Maximum receiver speed	One lane per second
Power supply	From 22V to 28V d.c. provided by Lister LP1 Diesel M/G delivering 15 A at 24 VDC
Refuel time	30 days
Fuel	10 gallon-consumption rate of 1 lb/day
Instrumental Accuracy	Better than 0.01 lane
Typical Positioning Accuracy of the System	Better than 1 meter on the baseline under optimum conditional. This figure represents long-term and short-term repeatability over sea water at the 65% probability level.

BUOY STATION CHARACTERISTICS

Buoy station complete (without moor block)	1000 lbs dwt. 2800 lbs net buoncy 18' loa. 4' draft, 32' height above water to tip of antenna.

THE BUOY

Length	18' divided into two 9' unsinkable sections
Depth	4'
Beam	2'
Weight in air (less equip)	600 Lbs.
Mooring Equipment	Integral mounted reel w/200' of 3/16" wire rope. 60' elastic accumulator. (1500 lb concrete block with short length 2" chain is customer furnished)
Watch Circle	5' in 180' water depth @ 1.5 Knot current 10' in 200' water depth @ 2.5 Knot current

OPERATION

On preparing the chain for operation, (figure 12) the two halves of each buoy are married and mated. The ballast block is secured to the bottom section of the mooring mast pipe. The electronic equipment is checked for proper operation and the batteries are tested. The diesel generators are started to ensure proper operation and the fuel supply is checked. Then, when the ship is exactly in position, the first buoy is lifted clear of the ship, the anchor block is fitted and made ready for lowering. The anchor block is lowered by a separate, buoyed line (figure 13) which is allowed to float after the station is moored, and is used to retrieve the block and anchor line. If circumstances do not permit recovery of the mooring gear, it may be released from the reel and allowed to fall to the bottom of the sea.

As the anchor block is lowered, the wire rope on the buoy reel will pay out until the block reaches the bottom. At this instant, the reel is locked and will maintain a tension of 500 lbs on the line to ensure the minimum watch circle for the buoy. The station is operating.

The ship will then proceed to each of the other predetermined locations and follow a similar launching procedure for the other buoys.

There are several methods of laying the chain and placing it in operation. Among which are:

A. Known predetermined geographical positions for master and each slave.

B. Crude positioning of the master by means at hand and positioning of slaves by electronic relationship to master.

C. Laying the chain to match a predetermined lattice.

It is to be noted that the exact geographical coordinates of an offshore operating area required for A above will seldom be known within the accuracy of a few feet. Consequently, the SEA-FIX system will more often be positioned using method B (figure 14) by fixing the position of the master station by dead reckoning, astro-fix, or some other electronic positioning means such as radar.

The master station is planted based on such location information as is best determined with the tools at hand. (1) the ship steams on a bearing along one edge of the desired operating area, estimating its position from the master station by the best means available. When a baseline of appropriate length, say 15 miles, has been covered, the first slave is lowered into the water in the same manner as the Master, operation checked, and moored. (2) The ship then steams across the extension of the baseline from master to slave and the pattern reading of the appropriate counter in the receiver is logged. (3) From the slave, the ship steams off on a bearing such that the angle made with the first baseline is 30 degrees. After a further 25 miles, the second slave is lowered and moored as before. (4) The baseline extension of this slave/master combination is crossed and the appropriate pattern reading on the ships receiver is logged. (5) Finally, the vessel returns to the master station, approximately 15 miles away. (6) This chain will then have an angle between baselines of about 120 degrees. For most purposes, base angles of 120-150 degrees have been found to give the best compromise between accuracy and area of coverage. At the master both baseline extensions are crossed and the pattern counter readings again logged; subtraction of these readings from the previous individual slave baseline readings gives the length of each baseline in lanes.

This information is given to the cartographer who will prepare the hyperbolic lattice. In addition to this input, the cartographer must know the general layout of the chain and the speed of propagation of radio waves within the area illuminated by the chain.

Although less accurate, method C (figure 15) is preferred for speed of establishing operations. In this method, lattice charts are prepared by the cartographer to suitable scales, in advance. Each vessel engaged in the operation is provided a quantity of each lattice chart. The chain-laying vessel then prepares the buoys for launching as indicated above. However, in this method the slaves are laid first. The master and one slave are placed in operation on deck of the vessel. (1) The slave is lowered over the side and moored. The vessel proceeds on a heading toward the desired location of slave number two. The master buoy aboard the vessel and the slave in the water will provide a reading

contains a phase datum which is continually updated by and kept in phase with the master trans-mission. Each slave control unit then in time sequency injects a pulse into its associated transmitter. The slave radiated signal, together with that of the master, is picked up by the user's receiver, which sees two sets of hyperbolae as it traverses the operations area. Where three slaves are used, three sets of hyperbolae are generated called patterns I, II, and III. Any two patterns are selected by the user; the position lines of each are registered on numerical counters. At any given instant, a fix is provided by the observed readings on both counters.

In a range/range chain two slaves are positioned as in the hyperbolic chain; however, the master station is installed aboard the ship together with the user's receiver. When the ship traverses the operations area, the baselines created between the master aboard ship and the anchored slaves vary in length and the user's receiver sees patterns of circular position lines centered on the respective slave stations. Fixes are registered by the lane counters as before, except that counts are arranged to ascend as distance from the slaves increases, whereas in the hyperbolic chain, the counts increase with distance from the master station.

As indicated in figure 5 (timing chart) a sequence of transmissions occurs five times a second or once every 200 milliseconds. The trigger pulse occupies the first 20 milliseconds of a sequence followed by a 10 millisecond buffer period to ensure that the slave timer is synchronized. The master transmitter buoy then radiates for 40 milliseconds, followed in time sequence by each of the slaves. All of the buoys radiate on the same frequency with the same power and bandwidth.

The master station consists of a Master Control Unit and Transmitter (see figure 6), Diesel Generator, batteries, fuel supply and antenna mounted in a buoy and designed for unattended operation for periods extending as long as 30 days. Alternate power supplies are available. Batteries alone may be used for operating periods up to four days. A "pinger" can be added to each buoy to facilitate location and recovery in emergencies.

Each slave station consists of the same elements as the transmitter station except that a slave control unit is used.

Each of the buoys is identical in appearance (see figure 7) and each is moored with an identical, one-point moor consisting of 200' of 3/16" wire rope cable wound on a winch atop the buoy and attached at its free end to a block of concrete and a danforth anchor.

As an alternative floating station, Decca offers SEA-FIX mounted in inflatable rafts suitable for short-term operations in moderate to smooth sea environments (see figure 8). The equipment is housed in water-tight fiberglass molded containers and is secured in the raft at time of launching. The raft reduces to two packages: a 42" x 20" cylinder and a 34" x 25" x 5-1/2" carrying case.

The shipboard installation consists of a SEA-FIX receiver, associated power source, and an antenna mounted as near the electrical center of the vessel as possible. The receiver is generally mounted at the plotting position within the bridge and can be installed either temporarily or permanently (See figure 9).

In addition to the receiver, a Decca Track Plotter is installed. (See figure 10). The Track Plotter accepts SEA-FIX receiver outputs and displays lane count readings in rectilinear coordinates plotted on a graph by a stylus. By use of the track plotter a continuous recording of position is maintained as an aid to steering and/or as a permanent record of the area covered by the vessel.

The mooring system (see figure 11) consists of a 4" diameter drum wire reel with a disc brake, upon which is rolled 200' of 3/16" diameter wire rope. The reel is mounted atop the buoy and feeds the mooring wire through the center of the buoy and its ballast, to end in a 60' length of elastic shock cord. The shock cord consists of 4 elastic cords 3/4" diameter. Permanently secured to the free end of the cord is a three foot length of 1/2" chain. This chain connects the mooring harness to a 1500 lb. concrete block and a steadying danforth anchor. The system is designed to maintain a mooring tension of 500 lbs which will ensure that the buoy maintains a minimum watch circle in conditions of heavy seas or high current.

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THE GENERATOR

Type	Lister LP1 Diesel generator developing 1.8 hp. 1800 RPM
Output	15 amps @ 24 volts
Batteries	2,12 volt 100 AH heavy duty
Operation	Demand. Automatically starts when battery voltage decreases to 22.5V and runs until batteries are charged to 90% of maximum capacity.
Fuel	Diesel fuel
Fuel Capacity	10 gallons to provide an operating period of 30 days
Fuel consumption	1 lb per day
THE ANTENNA	30' fiberglass
THE TRANSMITTER	Decca SEA-FIX solid state
Power output	1.5 watt
Power input	2 amps at 24 volts, key down condition—.6 amp Ave current
THE CONTROL UNIT	Decca SEA-FIX master and slave control units
Power input	.6 amps at 24 volts
SHIPBOARD INSTALLATION	
THE RECEIVER	Decca SEA-FIX receiver designed for shipboard temporary or permanent mounting
Power input	2.7 amps at 24 volts (provided from batteries or vessel)
Readout	Decca counter numerically indicating lanes and parts of a lane suitable for 2 simultaneous readouts

THE TRACK PLOTTER   Rectangular coordinate plot of course made good by vessel.

er input   2.5 amps at 24 volts

paper   Decca #350/VG Graticulated rolls 20' or 120'

stylus   Biro ballpoint 6/346A — Red, Green or Blue

TABLE OF WEIGHTS AND DIMENSIONS

ITEM	WEIGHT	LENGTH	WIDTH	HEIGHT
BUOY STATION COMPLETE	1000 lb	18'	2'	32' to tip of antenna
MOORING HARNESS COMPLETE	1750 lb		(including 1500 lb concrete block)	
TRANSMITTER	6 lb	24"	9"	6"
CONTROL UNIT	10-1/2"	24"	9"	6"
ANTENNA	64 lb	30'	whip base mounted	
GENERATOR	140 lb	17-3/8"	12-7/8"	17-1/8"
TTERIES	60 lb ea	16"	8"	8"
FUEL CONTAINER	10 gallons integral to buoy			
RECEIVER	29-3/4 lb	17-1/4"	12-7/8"	8-1/2"
TRACK PLOTTER	54 lb	17-1/2"	15"	15-3/4"
INFLATABLE STATION	900 lbs	12' 6"	4' 10"	3' (top of case to bottom of raft)
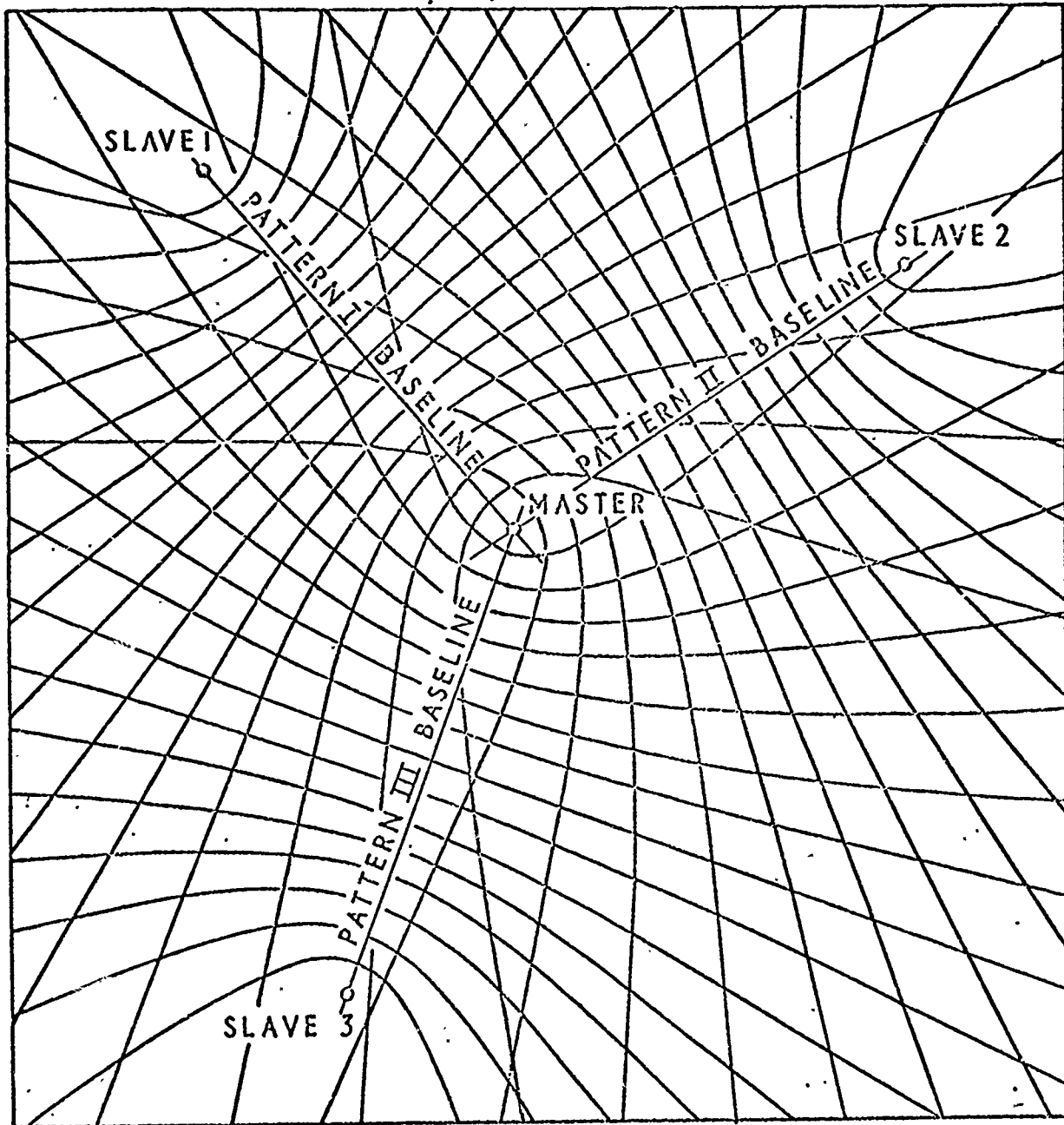
Fig. 1. Typical Hyperbolic Lattice for all-round Coverage
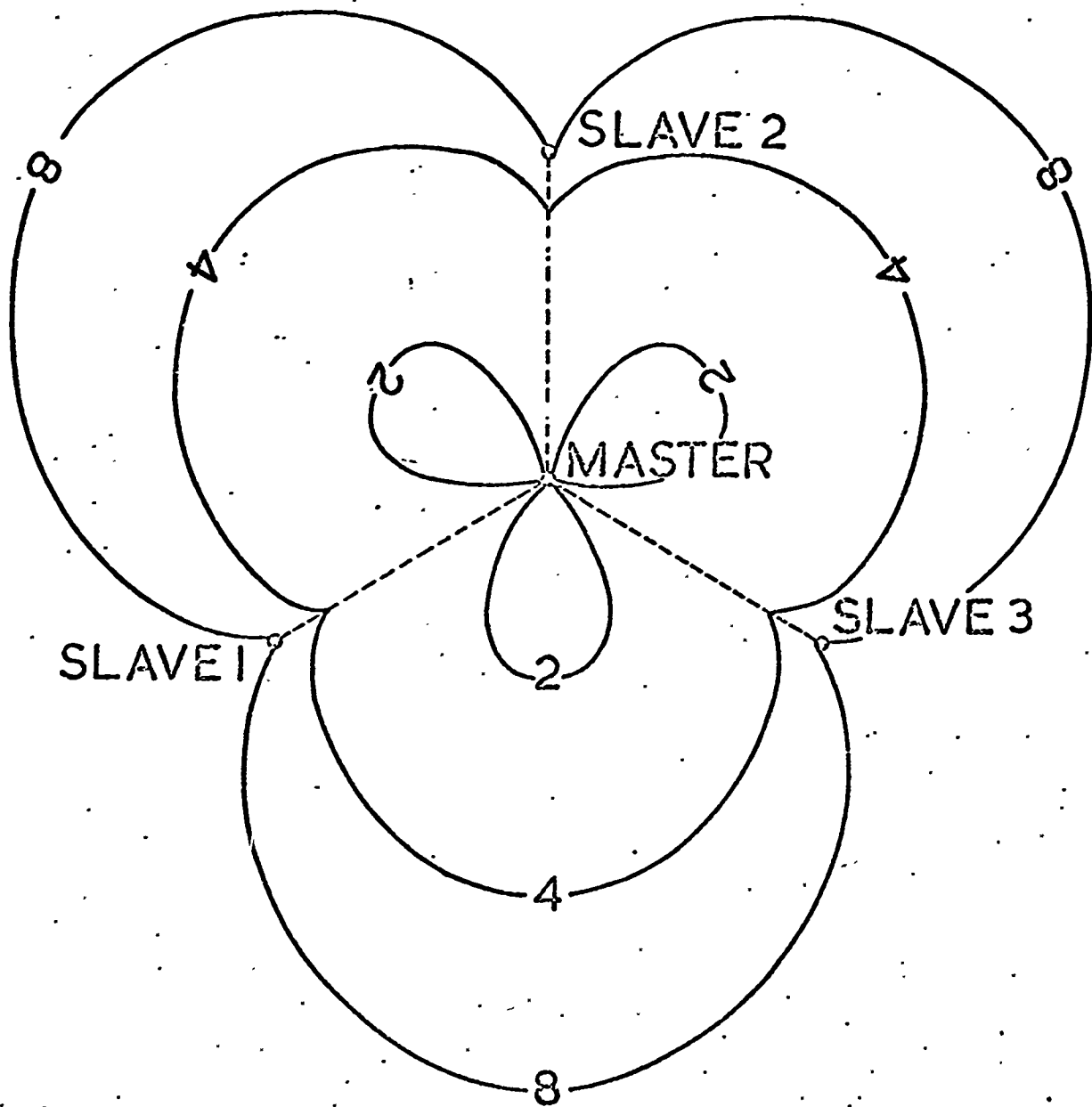
Fig. 2. Accuracy Contours in metres for the Chain Layout of Fig. 1. Standard Deviation of 0.01 Lane.
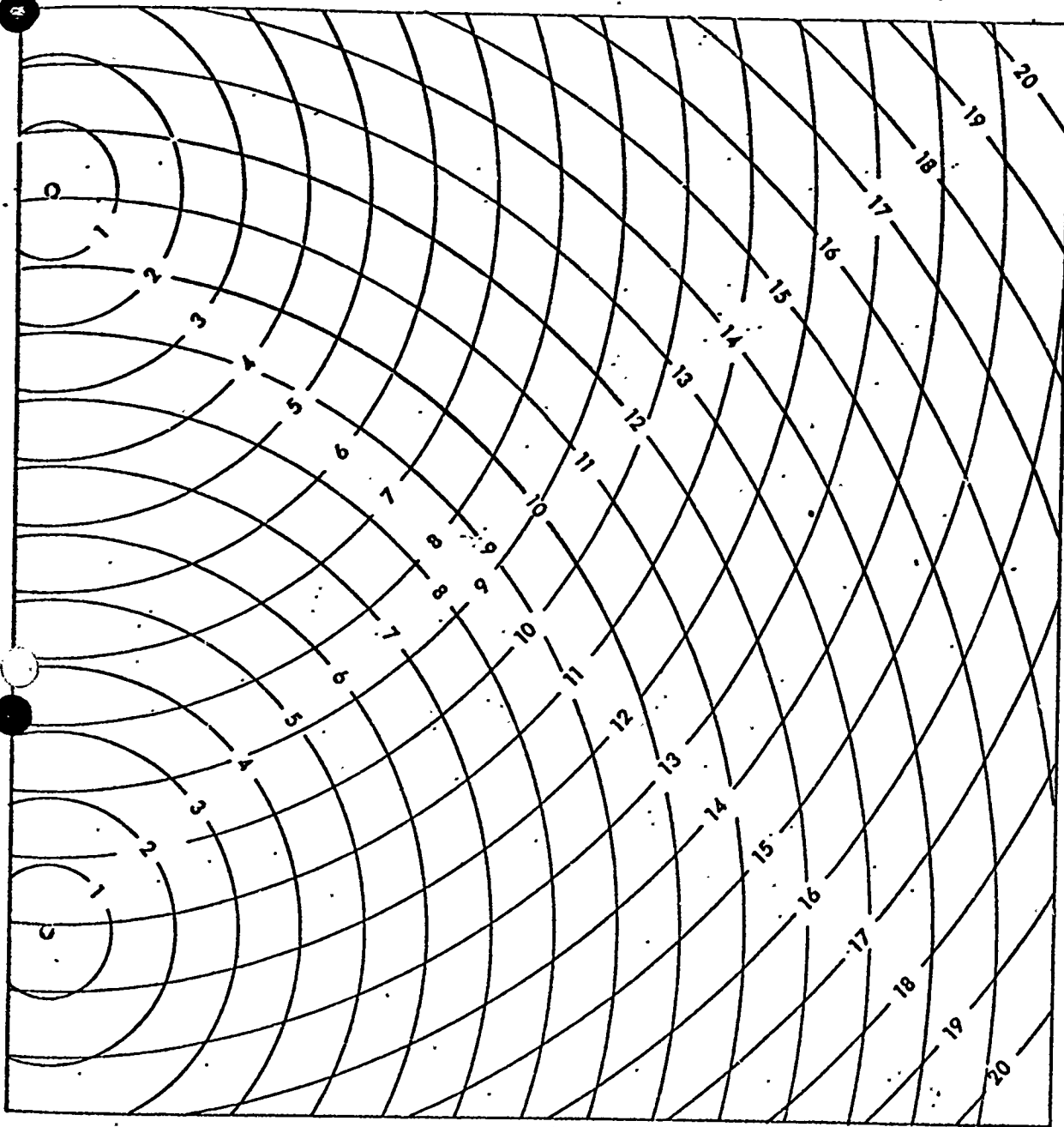
Fig. 3   Typical Two-Range Configuration
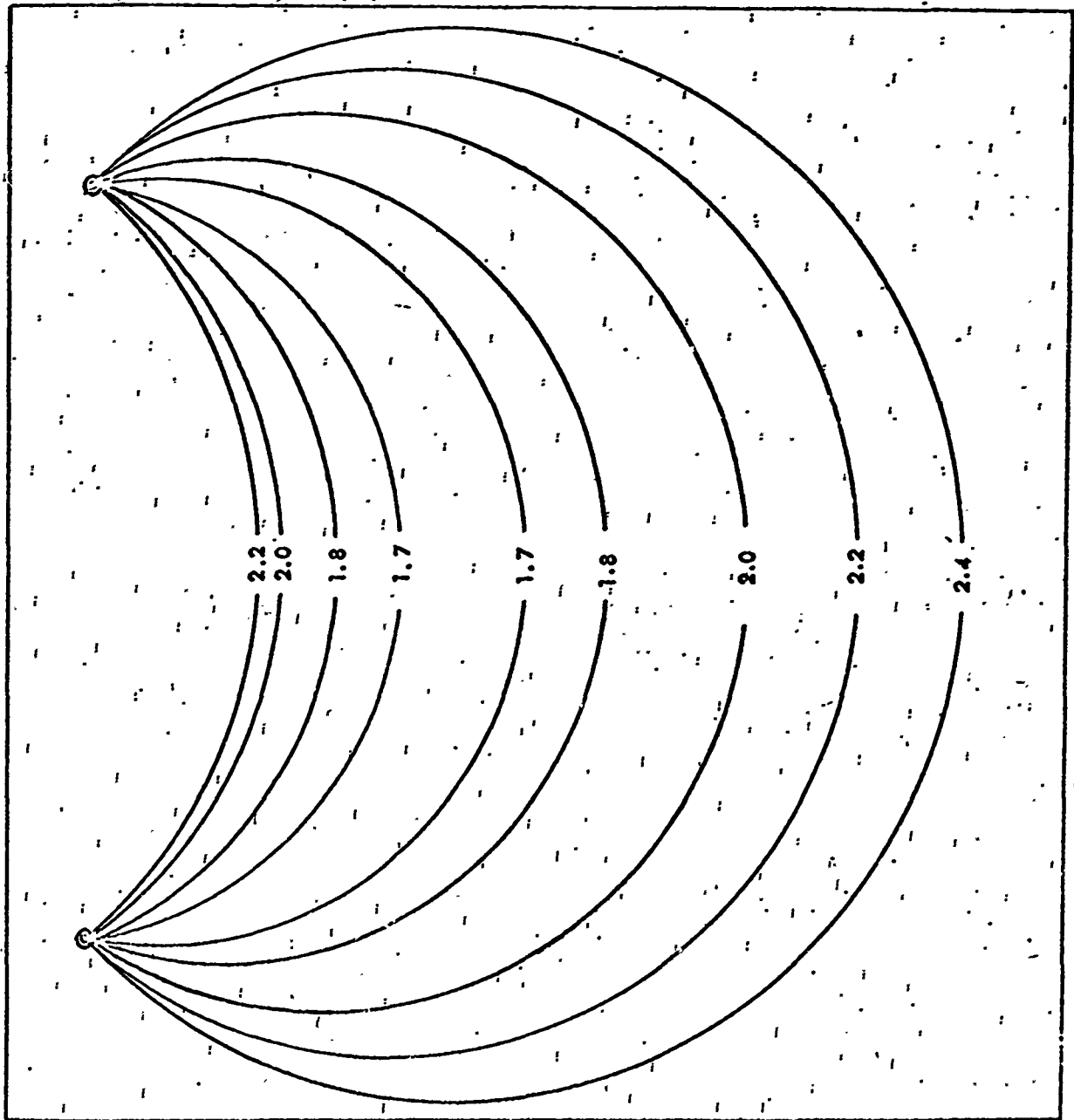
Accuracy contours in meters for the chain layout of the two-range mode shown in fig. 3

fig. 4

TIME IN MILLI-SECONDS
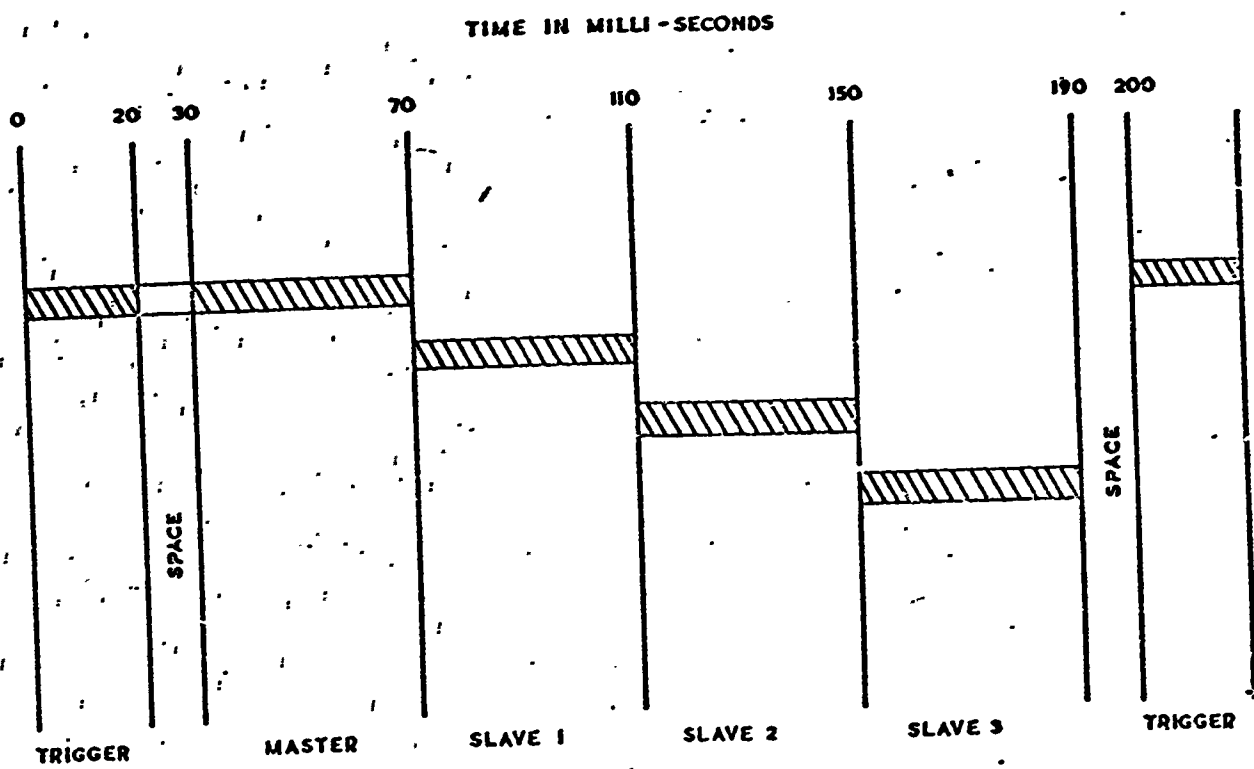
Fig. 5. Time Sharing of Master & Slave Transmissions

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NOT REPRODUCIBLE

Fig. 6   131

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BATTERIES ⟶

ELECTRONIC PACKAGE.

FUEL

DIESEL GENERATOR

COVER

ANTENNA 10'

RADAR REFLECTOR

COVER

12' 6"

SEAFIX RECEIVER

NOT REPRODUCIBLE

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Fig. 9

NOT REPRODUCIBLE

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Fig. 10

4" DIA. DRUI/WIRE REEL

LIFTING EYE

3 ft.

TYPE 552 P.O.E. BOUY

L.W.L.

8ft. X 2" dia PIPE

300 lb. BALLAST

3 ft.

3/16" WIRE ROPE—200 ft.

NOT REPRODUCIBLE

4 ELASTIC SHOCK
CORDS 3/4"O.D.

60 ft.
free lgth.

1/2" CHAIN

3 ft.

LOCKING LINK

DANFORTH ANCHOR

1800 lbs.

10 ft.

FIG. 11   136

Fig. 12

Fig. 13

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C

① ② ③

15 MILES

30

30°

25 MILES

30°

④

⑤

METHOD "B"

Fig. 14

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APPENDIX VII

Reduced Theodolite Readings
In
Universal Transverse Mercator Grid Coordinates

(Zone 19, False Northing, False Easting, Time)

26 Aug. 1968

Clarke 1866		UTM Grid Zone	False Northing	False Easting	TIME
pl s					
0430657655	0705134758 s				
43 6 57.655	70 51 34.758	.19	4775161.58	348702.01	1000
0430657652	0705134757 s				
43 6 57.652	70 51 34.757	.19	4775161.48	348702.03	1005
0430657651	0705134754 s				
43 6 57.651	70 51 34.754	.19	4775161.45	348702.10	1010
0430657647	0705134751 s				
43 6 57.647	70 51 34.751	.19	4775161.33	348702.16	1015
0430657645	0705134751 s				
43 6 57.645	70 51 34.751	.19	4775161.27	348702.16	1020
0430657641	0705134749 s				
43 6 57.641	70 51 34.749	.19	4775161.14	348702.20	1025
0430657636	0705134740 s				
43 6 57.636	70 51 34.740	.19	4775160.98	348702.40	1030
0430657631	0705134722 s				
43 6 57.631	70 51 34.722	.19	4775160.82	348702.80	1035
0430657631	0705134712 s				
43 6 57.631	70 51 34.712	.19	4775160.81	348703.03	1040
0430657622	0705134688 s				
43 6 57.622	70 51 34.688	.19	4775160.52	348703.57	1045
0430657618	0705134683 s				
43 6 57.618	70 51 34.683	.19	4775160.40	348703.68	1050
0430657624	0705134706 s				
43 6 57.624	70 51 34.706	.19	4775160.60	348703.16	1055
0430657615	0705134702 s				
43 6 57.615	70 51 34.702	.19	4775160.32	348703.25	1100
0430657621	0705134699 s				
43 6 57.621	70 51 34.699	.19	4775160.50	348703.32	1105
0430657619	0705134693 s				
43 6 57.619	70 51 34.693	.19	4775160.43	348703.45	1110
0430657618	0705134697 s				
43 6 57.618	70 51 34.697	.19	4775160.41	348703.36	1115
0430657616	0705134690 s				
43 6 57.616	70 51 34.690	.19	4775160.34	348703.52	1120
0430657612	0705134685 s				
43 6 57.612	70 51 34.685	.19	4775160.21	348703.63	1125
0430657610	0705134670 s				
43 6 57.610	70 51 34.670	.19	4775160.15	348703.97	1130

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43 6 57.607′ : 70 51 34.684	.19	4775160.06	348703.65	1135
0430657610 0705134671 ...s 43 6 57.610′ 70 51 34.671′	.19	4775160.15	348703.94	1140
0430657602 0705134674 ..s 43 6 57.602′ 70 51 34.674′	.19	4775159.90	348703.37	1145
0430657619 0705134721 ...s 43 6 57.619′ 70 51 34.721′	.19	4775160.45	348702.82	1150
0430657603 0705134685 ...s 43 6 57.603′ 70 51 34.685′	.19	4775159.94	348703.62	1155
0430657615 0705134686 ...s 43 6 57.615′ 70 51 34.686′	.19	4775160.31	348703.61	1200
0430657603 0705134692 ...s 43 6 57.603′ 70 51 34.692′	.19	4775159.94	348703.46	1210
0430657606 0705134670 ...s 43 6 57.606′ 70 51 34.670′	.19	4775160.02	348703.96	1215
0430657606 0705134682 ...s 43 6 57.606′ 70 51 34.682′	.19	4775160.03	348703.69	1220
0430657607 0705134680 ...s 43 6 57.607′ 70 51 34.680′	.19	4775160.06	348703.74	1225
0430657609 0705134680 ...s 43 6 57.609′ 70 51 34.680′	.19	4775160.12	348703.74	1230
0430657600 0705134679 ...s 43 6 57.600′ 70 51 34.679′	.19	4775159.84	348703.76	1235
0430657610 0705134689 ...s 43 6 57.610′ 70 51 34.689′	.19	4775160.15	348703.54	1240
0430657609 0705134717 ...s 43 6 57.609′ 70 51 34.717′	.19	4775160.14	348702.90	1245
0430657616 0705134708 ...s 43 6 57.616′ 70 51 34.708′	.19	4775160.35	348703.11	1250
0430657625 0705134732 ...s 43 6 57.625′ 70 51 34.732′	.19	4775160.64	348702.57	1255
0430657620 0705134708 ...s 43 6 57.620′ 70 51 34.708′	.19	4775160.47	348703.11	1300
0430657614 0705134722 ...s 43 6 57.614′ 70 51 34.722′	.19	4775160.29	348702.79	1305
0430657629 0705134726 ...s 43 6 57.629′ 70 51 34.726′	.19	4775160.76	348702.71	1310
0430657634 0705134734 ...s 43 6 57.634′ 70 51 34.734′	.19	4775160.92	348702.54	1315
0430657618 0705134736 ...s 142 43 6 57.618′ 70 51 34.736′	.19	4775160.43	348702.42	1320

0430657625 0705134723 _s				
43 6 57.625′ 70 51 34.723′	.19	4775160.64	348702.66	1330
0430657640 0705134749 _s				
43 6 57.640′ 70 51 34.749′	.19	4775161.11	348702.20	1335
0430657640 0705134750 _s				
43 6 57.640′ 70 51 34.750′	.19	4775161.11	348702.18	1340
0430657640 0705134746 _s				
43 6 57.640′ 70 51 34.746′	.19	4775161.11	348702.27	1345
0430657637 0705134751 _s				
43 6 57.637′ 70 51 34.751′	.19	4775161.02	348702.15	1350
0430657647 0705134756 _s				
43 6 57.647′ 70 51 34.756′	.19	4775161.33	348702.05	1355
0430657640 0705134750 _s				
43 6 57.640′ 70 51 34.750′	.19	4775161.11	348702.18	1400
0430657640 0705134753 _s				
43 6 57.640′ 70 51 34.753′	.19	4775161.11	348702.11	1405
0430657644 0305134750 _s				
43 6 57.644′ 70 51 34.750′	.19	4775161.23	348702.18	1410
0430657647 0705134756 _s				
43 6 57.647′ 70 51 34.756′	.19	4775161.33	348702.05	1415
0430657644 0705134753 _s				
43 6 57.644 70 51 34.753	.19	4775161.24	348702.11	1420
0430657644 0705134751 _s				
43 6 57.644′ 70 51 34.751′	.19	4775161.23	348702.16	1425
0430657646 0705134746 _s				
43 6 57.646′ 70 51 34.746′	.19	4775161.29	348702.27	1430
0430657643 0705134745 _s				
43 6 57.643′ 70 51 34.745′	.19	4775161.20	348702.29	1435
0430657650 0705134752 _s				
43 6 57.650′ 70 51 34.752′	.19	4775161.42	348702.14	1440
0430657635 0705134758 _s				
43 6 57.635′ 70 51 34.758′	.19	4775160.96	348701.99	1445
0430657615 0705134785 _s				
43 6 57.615′ 70 51 34.785′	.19	4775160.36	348701.37	1450
0430657638 0705134730 _s				
43 6 57.638′ 70 51 34.730′	.19	4775161.04	348702.63	1455
0430657644 0705134738 _s				
43 6 57.644′ 70 51 34.738′	.19	4775161.23	348702.45	1500
0430657661 0705134741 _s				
43 6 57.661′ 70 51 34.741′	.19	4775161.75	348702.40	1505
0430657660 0705134717 _s				
43 6 57.660′ 70 51 34.717′	.19	4775161.71	348702.94	1510

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0430657652 0705134751 s				
43 6 57.652′ 70 51 34.751′	.19	4775161.43	348702.16	15:3?
0430657654 0705134741 s				
43 6 57.654′ 70 51 34.741′	.19	4775161.54	348702.39	1530
0430657661 0705134754 s				
43 6 57.661′ 70 51 34.754′	.19	4775161.76	348702.10	1535
0430657662 0705134739 s				
43 6 57.662′ 70 51 34.739′	.19	4775161.73	348702.44	1540
0430657658 0705134752 s				
43 6 57.658′ 70 51 34.752′	.19	4775161.67	348702.15	1545
0430657655 0705134742 s				
43 6 57.655′ 70 51 34.742′	.19	4775161.57	348702.37	1550
0430657662 0705134752 s				
43 6 57.662′ 70 51 34.752′	.19	4775161.79	348702.15	1555
0430657661 0705134740 s				
43 6 57.661′ 70 51 34.740′	.19	4775161.75	348702.42	1600
0430657672 0705134729 s				
43 6 57.672′ 70 51 34.729′	.19	4775162.09	348702.67	1635
0430657673 0705134759 s				
43 6 57.673′ 70 51 34.759′	.19	4775162.13	348702.00	1640
0430657674 0705134743 s				
43 6 57.674′ 70 51 34.743′	.19	4775162.16	348702.36	1645

computed 10/23/68

T.W.L.

✓ DV 10/24/68

p0430657647 8 0705134
sc5f1 s
0430657647 8 0705134753 s
6 57.64.780 705 13 47.533 .29 770168.25 474608.51
0430657648 0705134753 s

43 6 57.648′ 70 51 34.753′	.19	4775161.36	348702.12	1420

computed 10/24/68

T.W.L.

✓ DV 10/24/68

C.A. -- 7 Uf. 71   S7 Mj.

C
7

p1 = Clarke 1866		Zone No.	North	East	TIME
0430657644 0705134736 s					
43 6 57.644 / 70 51 34.736 /		.19	4775161.23	348702.50	1055
0430657646 0705134736 s					
43 6 57.646 / 70 51 34.736 /		.19	4775161.29	348702.50	1100
0430657644 0705134739 s					
43 6 57.644 / 70 51 34.739 /		.19	4775161.23	348702.43	1105
0430657641 0705134729 s					
43 6 57.641 / 70 51 34.729 /		.19	4775161.13	348702.65	1110
0430657632 0705134706 s					
43 6 57.632 / 70 51 34.706 /		.19	4775160.84	348703.17	1115
0430657632 0705134689 s					
43 6 57.632 / 70 51 34.689 /		.19	4775160.83	348703.55	1120
0430657620 0705134666 s					
43 6 57.620 / 70 51 34.666 /		.19	4775160.45	348704.06	1125
0430657619 0705134684 s					
43 6 57.619 / 70 51 34.684 /		.19	4775160.43	348703.66	1130
0430657623 0705134682 s					
43 6 57.623 / 70 51 34.682 /		.19	4775160.55	348703.70	1135
0430657620 0705134680 s					
43 6 57.620 / 70 51 34.680 /		.19	4775160.46	348703.75	1140
0430657616 0705134663 s					
43 6 57.616 / 70 51 34.663 /		.19	4775160.33	348704.13	1145
0430657620 0705134655 s					
43 6 57.620 / 70 51 34.655 /		.19	4775160.45	348704.31	1150
0430657614 0705134678 s					
43 6 57.614 / 70 51 34.678 /		.19	4775160.27	348703.79	1155
0430657613 0705134667 s					
43 6 57.613 / 70 51 34.667 /		.19	4775160.24	348704.04	1200
0430657617 0705134684 s					
43 6 57.617 / 70 51 34.684 /		.19	4775160.37	348703.65	1205
0430657616 0705134668 s					
43 6 57.616 / 70 51 34.668 /		.19	4775160.33	348704.01	1210
0430657610 0705134678 s					
43 6 57.610 / 70 51 34.678 /		.19	4775160.15	348703.73	1215
0430657616 0705134667 s					
43 6 57.616 / 70 51 34.667 /		.19	4775160.33	348704.04	1220

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0430657614 0705134669 s

0430657606 0705134665 s				
43 6 57.606′ 70 51 34.665′	.19	4775160.02	348704.03	1235
0430657621 0705134662 s				
43 6 57.621′ 70 51 34.662′	.19	4775160.43	348704.15	1240
0430657627 0705134683 s				
43 6 57.627′ 70 51 34.683′	.19	4775160.68	348703.68	1245
0430657627 0705134703 s				
43 6 57.627′ 70 51 34.703′	.19	4775160.69	348703.23	1250
0430657619 0705134674 s				
43 6 57.619′ 70 51 34.674′	.19	4775160.43	348703.88	1255
0430657621 0705134647 s				
43 6 57.621′ 70 51 34.647′	.19	4775160.47	348704.49	1300
0430657617 0705134680 s				
43 6 57.617′ 70 51 34.680′	.19	4775160.37	348703.74	1305
0430657628 0705134746 s				
43 6 57.628′ 70 51 34.746′	.19	4775160.74	348702.26	1310
0430657623 0705134725 s				
43 6 57.623′ 70 51 34.725′	.19	4775160.57	348702.73	1315
0430657626 0705134728 s				
43 6 57.626′ 70 51 34.728′	.19	4775160.67	348702.67	1320
0430657622 0705134699 s				
43 6 57.622′ 70 51 34.699′	.19	4775160.53	348703.32	1325
0430657626 0705134724 s				
43 6 57.626′ 70 51 34.724′	.19	4775160.67	348702.76	1330
0430657625 0705134741 s				
43 6 57.625′ 70 51 34.741′	.19	4775160.64	348702.37	133:
0430657632 0705134733 s				
43 6 57.632′ 70 51 34.733′	.19	4775160.86	348702.56	134?
0430657643 0705134755 s				
43 6 57.643′ 70 51 34.755′	.19	4775161.21	348702.07	134.
0430657628 0705134731 s				
43 6 57.628′ 70 51 34.731′	.19	4775160.73	348702.60	135
0430657624 0705134738 s				
43 6 57.624′ 70 51 34.738′	.19	4775160.61	348702.44	135
0430657626 0705134745 s				
43 6 57.626′ 70 51 34.745′	.19	4775160.68	348702.28	140
0430657633 0705134743 s				
43 6 57.633′ 70 51 34.743′	.19	4775160.89	348702.33	140:
0430657622 0705134749 s				
43 6 57.622′ 70 51 34.749′ 146	.19	4775160.56	348702.19	141(

0430657642 0705134753 s				
43 6 57.642 70 51 34.753	.19	4775161.17	348702.11	1415
0430657640 0705134746 s				
43 6 57.640 70 51 34.746	.19	4775161.11	348702.27	1420
0430657633 0705134767 s				
43 6 57.633 70 51 34.767	.19	4775160.90	348701.79	1425
0430657647 0705134765 s				
43 6 57.647 70 51 34.765	.19	4775161.33	348701.84	1430
0430657636 0705134722 s				
43 6 57.636 70 51 34.722	.19	4775160.97	348702.81	1435
0430657646 0705134757 s				
43 6 57.646 70 51 34.757	.19	4775161.30	348702.02	1440
0430657648 0705134755 s				
43 6 57.648 70 51 34.755	.19	4775161.36	348702.07	1445
0430657650 0705134765 s				
43 6 57.650 70 51 34.765	.19	4775161.43	348701.85	1450
0430657654 0705134761 s				
43 6 57.654 70 51 34.761	.19	4775161.55	348701.94	1455
0430657648 0705134762 s				
43 6 57.648 70 51 34.762	.19	4775161.36	348701.91	1500
0430657642 0705134762 s				
43 6 57.642 70 51 34.762	.19	4775161.18	348701.91	1505
0430657642 0705134745 s				
43 6 57.642 70 51 34.745	.19	4775161.17	348702.29	1510
0430657647 0705134761 s				
43 6 57.647 70 51 34.761	.19	4775161.33	348701.93	1515
0430657651 0705134770 s				
43 6 57.651 70 51 34.770	.19	4775161.46	348701.73	1520
0430657652 0705134771 s				
43 6 57.652 70 51 34.771	.19	4775161.49	348701.71	1525
0430657652 0705134772 s				
43 6 57.652 70 51 34.772	.19	4775161.49	348701.69	1530
0430657652 0705134768 s				
43 6 57.652 70 51 34.768	.19	4775161.49	348701.78	1535
0430657642 0705134768 s				
43 6 57.642 70 51 34.768	.19	47751.61.18	348701.77	1540
0430657647 0705134760 s				
43 6 57.647 70 51 34.760	.19	4775161.33	348701.96	1545
0430657651 0705134744 s				
43 6 57.651 70 51 34.744 147	.19	4775161.45	348702.32	1550

0430657654	0705134769	s			
43 6 57.654	70 51 34.769	.19	4775161.55	348701.76	1600
0430657656	0705134774	s			
43 6 57.656	70 51 34.774	.19	4775161.62	348701.65	1615
0430657656	0705134775	s			
43 6 57.656	70 51 34.774	.19	4775161.62	348701.65	1626
0430657655	0705134774	s			
43 6 57.655	70 51 34.774	.19	4775161.59	348701.65	1625
0430657654	0705134772	s			
43 6 57.654	70 51 34.772	.19	4775161.55	348701.69	1630
0430657657	0705134778	s			
43 6 57.657	70 51 34.778	.19	4775161.65	348701.56	1635
0430657653	0705134769	s			
43 6 57.653	70 51 34.769	.19	4775161.52	348701.76	1640

Computed 10/23/68

T.W.L.

TDV 10/24/68

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G.P. → U.T.M.

5 Sept. '66

Sphere :
Clarke, 1866

	UTM Zone	Northing	Easting	TIME
0425757008 0703702347 s 42 57 57.008 : 70 37 2.347 - w Lat. Long	.19	4758074.98	368097.02	1455.
0425757008 0703702342 s 42 57 57.008 70 37 2.342	.19	4758074.97	368097.13	1500.
0425757006 0703702347 s 42 57 57.006 70 37 2.347	.19	4758074.91	368097.02	1505.
0425757005 0703702343 s 42 57 57.005 70 37 2.343	.19	4758074.88	368097.11	1510.
0425757007 0703702344 s 42 57 57.007 70 37 2.344	.19	4758074.94	368097.09	1515.
0425757008 0703702339 s 42 57 57.008 70 37 2.339	.19	4758074.97	368097.20	1520.
0425757009 0703702346 s 42 57 57.009 70 37 2.346	.19	4758075.01	368097.04	1535.
0425757017 0703702347 s 42 57 57.017 70 37 2.347	.19	4758075.25	368097.03	1530.
0425757012 0703702342 s 42 57 57.012 70 37 2.342	.19	4758075.10	368097.14	1535.
0425757019 0703702354 s 42 57 57.019 70 37 2.354	.19	4758075.32	368096.87	1540.
0425757007 0703702360 s 42 57 57.007 70 37 2.360	.19	4758074.95	368096.73	1545.
0425757012 0703702342 s 42 57 57.012 70 37 2.342	.19	4758075.10	368097.14	1553
0425757017 0703702354 s 42 57 57.017 70 37 2.354	.19	4758075.26	368096.87	1555.
0425757008 0703702356 s 42 57 57.008 70 37 2.356	.19	4758074.98	368096.82	1600.
0425757011 0703702334 s 42 57 57.011 70 37 2.334	.19	4758075.06	368097.32	1610.
0425757009 0703702335 s 42 57 57.009 70 37 2.335	.19	4758075.00	368097.29	1615.
0425757011 0703702352 s 42 57 57.011 70 37 2.352	.19	4758075.07	368096.91	1620.
0425757014 0703702354 s 42 57 57.014 70 37 2.354	.19	4758075.16	368096.87	1625.

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conf. T.S. 10/31/68

circle 1266

				TIME
0425757055 0703702421 s				
42 57 57.055 70 37 2.421	.19	4758076.46	368095.37	1500
0425757022 0703702355 s				
42 57 57.022 70 37 2.355	.19	4758075.41	368096.85	1505
0425757046 0703702338 s				
42 57 57.046 70 37 2.338	.19	4758076.14	368097.25	1510
0425757024 0703702364 s				
42 57 57.024 70 37 2.364	.19	4758075.48	368096.64	1515
0425757022 0703702344 s				
42 57 57.022 70 37 2.344	.19	4758075.41	368097.10	1522:30
0425757025 0703702318 s				
42 57 57.025 70 37 2.318	.19	4758075.49	368097.69	1525
0425757032 0703702365 s				
42 57 57.032 70 37 2.365	.19	4758075.72	368096.63	1530
0425757049 0703702368 s				
42 57 57.049 70 37 2.368	.19	4758076.25	368096.57	1535
0425757044 0703702352 s				
42 57 57.044 70 37 2.352	.19	4758076.09	368096.93	1540
0425757053 0703702376 s				
42 57 57.053 70 37 2.376	.19	4758076.38	368096.39	1545
0425757046 0703702373 s				
42 57 57.046 70 37 2.373	.19	4758076.16	368096.45	1550

computed 10/18/68 T.W.L.

✓ DV 10/21/68.

				TIME
0425756996 0703702380 s				
42 57 56.996 70 37 2.380	.19	4758074.62	368096.27	1530
0425757003 0703702370 s				
42 57 57.003 70 37 2.370	.19	4758074.83	368096.50	1535
0425757013 0703702368 s				
42 57 57.013 70 37 2.368	.19	4758075.14	368096.55	1530
0425757013 0703702363 s				
42 57 57.013 70 37 2.363	.19	4758075.14	368096.66	1535
0425757009 0703702375 s				
42 57 57.009 70 37 2.375	.19	4758075.02	368096.39	1540
0425757009 0703702394 s				
42 57 57.009 70 37 2.394	.19	4758075.03	368095.96	1545
0425757005 0703702360 s				
42 57 57.005 70 37 2.360	.19	4758074.89	368096.72	1550
0425757001 0703702353 s				
42 57 57.001 70 37 2.353	.19	4758074.76	368096.88	1555
0425757003 0703702378 s				
42 57 57.003 70 37 2.378	.19	4758074.83	368096.31	1600
0425757010 0703702352 s				
42 57 57.010 70 37 2.352	.19	4758075.04	368096.91	1605
0425757006 0703702370 s				
42 57 57.006 70 37 2.370	.19	4758074.92	368096.50	1610
~~0425757011 0703702377 s~~				
~~42 57 57.011 70 37 2.277~~	~~.05~~	~~4759560.78~~	~~694324.86~~	
~~0425757011 0703702377 s~~				
42 57 57.011 70 37 2.377	.19	4758075.08	368096.34	1615
0425757018 0703702392 s				
42 57 57.018 70 37 2.392	.19	4758075.30	368096.01	1620
0425757004 0703702373 s				
42 57 57.004 70 37 2.373	.19	4758074.86	368096.43	1625
0425757002 0703702364 s				
42 57 57.002 70 37 2.364	.19	4758074.80	368096.63	1630
0425757008 0703702346 s				
42 57 57.008 70 37 2.346	.19	4758074.97	368097.04	1640
0425757001 0703702352 s				
42 57 57.001 70 37 2.352	.19	4758074.76	368096.90	1645
0425756991 0703702340 s				
42 57 56.991 70 37 2.340	.19	4758074.45	368097.17	1650
0425756994 0703702337 s				
42 57 56.994 70 37 2.337	.19	4758074.54	368097.24	1655

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0425757005  0703702319  s
   42 57 57.005 / 70 37  2.319 /              .19      4758074.87      368097.65      ~.s

0425757001  0703702308  s
   42 57 57.001 / 70 37  2.308 /              .19      4758074.74      368097.90

0425757005  0703702351  s
   42 57 57.005 / 70 37  2.351 /              .19      4758074.88      368096.93      1215
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8 Sept

computed 10/21/88 T.W.C.
VDV 10/21/88

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Clarke 1866

                                                                TIME

0425756985   0703702358 s
  42 57 56.985   70 37 2.358   .19   4758074.27   368096.76   1440

0425756969   0703702341 s
  42 57 56.969   70 37 2.341   .19   4758073.77   368097.13   1445

0425756981   0703702360 s
  42 57 56.981   70 37 2.360   .19   4758074.15   368096.71   1450

0425756970--s
----------.000----42-57-56.970----------.23----------.00------726403.10

0425756970   0703702378 s
  42 57 56.970   70 37 2.378   .19   4758073.82   368096.30   1455

0425756969   0703702373 s
  42 57 56.969   70 37 2.373   .19   4758073.78   368096.41   1500

0425756976   0703702371 s
  42 57 56.976   70 37 2.371   .19   4758074.00   368096.46   1505

0425756964   0703702362 s
  42 57 56.964   70 37 2.362   .19   4758073.62   368096.65   1510

0425756965   0703702396 s
  42 57 56.965   70 37 2.396   .19   4758073.67   368095.88   1515

0425756954   0703702372 s
  42 57 56.954   70 37 2.372   .19   4758073.32   368096.42   1520

0425756964   0703702387 s
  42 57 56.964   70 37 2.387   .19   4758073.64   368096.09   1525

0425756965   0703702352 s
  42 57 56.965   70 37 2.352   .19   4758073.65   368096.88   1535

0425756955   0703702365 s
  42 57 56.955   70 37 2.365   .19   4758073.35   368096.58   1540

0425756957   0703702362 s
  42 57 56.957   70 37 2.362   .19   4758073.41   368096.65   1545

0425756945   0703702371 s
  42 57 56.945   70 37 2.371   .19   4758073.04   368096.44   1550

0425756966   0703702355 s
  42 57 56.966   70 37 2.355   .19   4758073.68   368096.81   1555

0425756975   0703702358 s
  42 57 56.975   70 37 2.358   .19   4758073.96   368096.75   1600

0425756964   0703702369 s
  42 57 56.964   70 37 2.369   .19   4758073.63   368096.50   1605

0425756955   0703702365 s
  42 57 56.955   70 37 2.365   153 .19   4758073.35   368096.58   1615

0425756944   0703702366

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0425756934  0703702364  s
   42 57 56.934    -70 37  2.364        .19      4758072.70      368096.59      EMC
                                                                                  40
0425756945  0703702357  s
   42 57 56.945     70 37  2.357        .19      4758073.04      368096.76      16
                                                                                  5
0425756938  0703702388  s
   42 57 56.938     70 37  2.388        .19      4758072.83      368096.05      1640
0425756958  0703702388  s
   42 57 56.958     70 37  2.388        .19      4758073.45      368096.06      1645
0425756955  0703702377  s
   42 57 56.955     70 37  2.377        .19      4758073.35      368096.31      1650
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9 Sept.

completed 10/21/68 T.W.L.
✓TJV 10/21/68

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0425756985   0703702358   s
  42 57 56.985 / 70 37 2.358 /   .19   4758074.27   368096.76   1440

0425756969   0703702341   s
  42 57 56.969 / 70 37 2.341 /   .19   4758073.77   368097.13   1445

0425756981   0703702360   s
  42 57 56.981 / 70 37 2.360 /   .19   4758074.15   368096.71   1450

0425756970 s
-------------.CO8----42-57-56.970------------.23-----------------.00------726403.10

0425756970   0703702378   s
  42 57 56.970 / 70 37 2.378 /   .19   4758073.82   368096.30   1455

0425756969   0703702373   s
  42 57 56.969 / 70 37 2.373 /   .19   4758073.78   368096.41   1500

0425756976   0703702371   s
  42 57 56.976 / 70 37 2.371 /   .19   4758074.00   368096.46   1505

0425756964   0703702362   s
  42 57 56.964 / 70 37 2.362 /   .19   4758073.62   368096.65   1510

0425756965   0703702396   s
  42 57 56.965 / 70 37 2.396 /   .19   4758073.67   368095.88   1515

0425756954   0703702372   s
  42 57 56.954 / 70 37 2.372 /   .19   4758073.32   368096.42   1530

0425756964   0703702387   s
  42 57 56.964 / 70 37 2.387 /   .19   4758073.64   368096.09   1530

0425756965   0703702352   s
  42 57 56.965 / 70 37 2.352 /   .19   4758073.65   368096.88   1535

0425756955   0703702365   s
  42 57 56.955 / 70 37 2.365 /   .19   4758073.35   368096.58   1540

0425756957   0703702362   s
  42 57 56.957 / 70 37 2.362 /   .19   4758073.41   368096.65   1545

0425756945   0703702371   s
  42 57 56.945 / 70 37 2.371 /   .19   4758073.04   368096.44   1550

0425756966   0703702353   s
  42 57 56.966 / 70 37 2.355 /   .19   4758073.68   368096.81   1555

0425756975   0703702358   s
  42 57 56.975 / 70 37 2.358 /   .19   4758073.96   368096.75   1600

0425756964   0703702369   s
  42 57   .964 / 70 37 2.369 /   .19   4758073.63   368096.50   1605

0425756955   0703702365   s
  42 57 56.955 / 70 37 2.365 /   .19   4758073.35   368096.58   1615

0425756944   0703702366   s
  42 57 56.944 / 70 37 2.366 /   .19   4758073.01   368096.55   1620

Clarke 1866   TIME

0425756942 0703702357 s.
  42 57 56.942 70 37 2.357   .19   4758072.94   368096.75   1655

0425756930 0703702372 s.
  42 57 56.930 70 37 2.372   .19   4758072.58   368096.41   1700

0425756950 0703702384 s.
  42 57 56.950 70 37 2.384   .19   4758073.20   368096.15   1705

computed 10/18/68 T.W.L.

DV 10/21/68

Clede 1766

					TIME
0425757003 0703702405 s					
42 57 57.003′ 70 37 2.405′	.19	4758074.85	368095.70		1427
0425757001 0703702403 s					
42 57 57.001′ 70 37 2.403′	.19	4758074.79	368095.63		1430
0425756992 0703702377 s					
42 57 56.992′ 70 37 2.377′	.19	4758074.49	368096.33		1435
0425756996 0703702424 s					
42 57 56.996′ 70 37 2.424′	.19	4758074.64	368095.27		1440
0425757013 0703702419 s					
42 57 57.013′ 70 37 2.419′	.19	4758075.16	368095.39		1445
0425756990 0703702398 s					
42 57 56.990′ 70 37 2.398′	.19	4758074.44	368095.85		1450
0425756999 0703702414 s					
42 57 56.999′ 70 37 2.414′	.19	4758074.73	368095.50		1455
0425756995 0703702410 s					
42 57 56.995′ 70 37 2.410′	.19	4758074.60	368095.59		1500
0425747893 0703724247 s					
42 57 47.893 70 37 24.247	.19	4757803.37	367595.44		1505
0425756995 0703702382 s					
42 57 56.995′ 70 37 2.382′	.19	4758074.59	368096.22		1510
0425757003 0703702397 s					
42 57 57.003′ 70 37 2.397′	.19	4758074.84	368095.88		1515
0425756999 0703702432 s					
42 57 56.999′ 70 37 2.432′	.19	4758074.73	368095.09		1520
0425757009 0703702407 s					
42 57 57.009′ 70 37 2.407′	.19	4758075.03	368095.66		1525
0425756988 0703702376 s					
42 57 56.988′ 70 37 2.376′	.19	4758074.37	368096.35		1530
0425756999 0703702383 s					
42 57 56.999′ 70 37 2.383′	.19	4758074.71	368096.20		1535
0425756992 0703702412 s					
42 57 56.992′ 70 37 2.412′	.19	4758074.51	368095.54		1540
0425756995 0703702390 s					
42 57 56.995′ 70 37 2.390′	.19	4758074.59	368096.04		1550
0425757000 0703702375 s					
42 57 57.000′ 70 37 2.375′	.19	4758074.74	368096.38		1555
0425757008 0703702389 s					
42 57 57.008′ 70 37 2.389′	157 .19	4758074.99	368096.07		1600 (1603)

10 dept

⊙   Clarke 1856   •   FWD   G.P.
sc5E1 s

4258047000   White → Sea Bcy
4258047000   07037228000   /29703349400   009005196650 s
  42 58 4.700   70 37 22.800   297 8 34.940 ✓   519.6650 ✓
  42 57 57,0168   70 37 2.3956   117 8 48.8472 x site to white

              G.P. ⇒ U.T.M.

  Clarke 1856
pl   s
0425757017 0703702396 s   Position of Bcoy   TIME
  42 57 57.017   70 37 2.396 ✓   .19   4758075.27   368095.92   1505

                                   computed 10/22/68
                                      T.W.C.

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```
0425756933  0703702383  s
   42 57 56.988   70 37  2.383          .19       4758074.37      368096.19      1610

0425756991  0703702368  s
   42 57 56.991   70 37  2.368          .19       4758074.46      368096.53      1615

0425756993  0703702370  s
   42 57 56.993   70 37  2.370          .19       4758074.52      368096.49      1620

0425756994  0703702389  s
   42 57 56.994   70 37  2.389          .19       4758074.56      368096.06      1630

0425756989  0703702383  s
   42 57 56.989   70 37  2.383          .19       4758074.40      368096.19      1635
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10 Sept

completed 10/18/68 T.W.C.
UTJV 10/22/68

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p¹ s Clarke 1224

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0425757060  0703702168  s
   42 57 57.060    70 37  2.168          .19      4758076.50      368101.11      1120

0425757042  0703702122  s
   42 57 57.042    70 37  2.122          .19      4758075.93      368102.14      1125

0425757052  0703702117  s
   42 57 57.052    70 37  2.117         .19.      4758076.23      368102.26      1130

0425757039  0703702185  s
   42 57 57.039    70 37  2.185          .19      4758075.86      368100.71      1135

0425757005  0703702135  s
   42 57 57.005    70 37  2.135          .19      4758074.79      368101.82      1140

0425757022  0703702106  s
   42 57 57.022    70 37  2.106          .19      4758075.30      368102.49      1145

0425757013  0703702118  s
   42 57 57.013    70 37  2.118          .19      4758075.03      368102.21      1150

0425757010  0703702121  s
   42 57 57.010    70 37  2.121          .19      4758074.94      368102.14      1155

0425756964  0703702081  s
   42 57 56.964    70 37  2.081          .19      4758073.50      368103.02      1200

0425756972  0703702156  s
   42 57 56.972    70 37  2.156          .19      4758073.78      368101.33      1205 (nc)

0425757009  0703702072  s
   42 57 57.009    70 37  2.072          .19      4758074.89      368103.25      1215

0425756946  0703702098  s
   42 57 56.946    70 37  2.098          .19      4758072.95      368102.62      1220

0425756996  0703702118  s
   42 57 56.996    70 37  2.118          .19      4758074.51      368102.20      1225

0425756972  0703702138  s
   42 57 56.972    70 37  2.138          .19      4758073.77      368101.73      1230

0425756986  703702121   s
   42 57 56.986    70 37  2.121          .19      4758074.20      368102.13      1235

0425757004  0703702176  s
   42 57 57.004    70 37  2.176          .19      4758074.78      368100.89      1240

0425756922  0703702053  s
   42 57 56.922    70 37  2.053          .19      4758072.19      368103.63      1245
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compiled 10/21/68

check 11/27/68   T. W. L.

Clarke 1866

TIME

pl s0425756767 0703702038 s
42 57 56.767 70 37 2.098   .19   4758067.43   368102.52   1415

0425756751 0703702073 s
42 57 56.751 70 37 2.073   .19   4758066.93   368103.08   1420

0425756772 0703702086 s
42 57 56.772 70 37 2.086   .19   4758067.58   368102.79   1425

0425756768 0703702035 s
42 57 56.768 70 37 2.035   .19   4758067.44   368103.95   1430

0425756780 0703702062 s
42 57 56.780 70 37 2.062   .19   4758067.82   368103.34   1435

0425756759 0703702026 s
42 57 56.759 70 37 2.026   .19   4758067.15   368104.14   1440

0425756766 0703702061 s
42 57 56.766 70 37 2.061   .19   4758067.39   368103.36   1445

0425756785 0703702111 s
42 57 56.785 70 37 2.111   .19   4758067.99   368102.23   1500

0425756753 0703702002 s
42 57 56.753 70 37 2.002   .19   4758066.96   368104.68   1505

0425756765 0703702061 s
42 57 56.765 70 37 2.061   .19   4758067.35   368103.36   1510

0425756741 0703701936 s
42 57 56.741 70 37 1.936   .19   4758066.56   368106.17   1515

0425756765 0703701953 s
42 57 56.765 70 37 1.953   .19   4758067.31   368105.80   1520

0425756742 0703701926 s
42 57 56.742 70 37 1.926   .19   4758066.59   368106.40   1525

0425756770 0703701865 s
42 57 56.770 70 37 1.865   .19   4758067.42   368107.80   1530

0425756762 0703701917 s
42 57 56.762 70 37 1.917   .19   4758067.20   368106.62   1535

0425756726 0703701925 s
42 57 56.726 70 37 1.925   .19   4758066.09   368106.41   1545

0425756678 0703701854 s
42 57 56.678 70 37 1.854   .19   4758064.58   368107.99   1550

0425756693 0703701859 s
42 57 56.693 70 37 1.859   .19   4758065.05   368107.89   1555

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0425756694 0703701874 s
42 57 56.694 70 37 1.874   .19   4758065.08   368107.55   1600

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0425756761  0703702050  s
  42 57 56.761    70 37  2.050         .19      4758067.23    368103.60    1610

0425756778  0703702028  s
  42 57 56.778    70 37  2.028         .19      4758067.74    368104.11    1615

0425756681  0703701992  s
  42 57 56.681    70 37  1.992         .19      4758064.73    368104.87    1620(1622)

0425756715  0703702011  s
  42 57 56.715    70 37  2.011         .19      4758065.79    368104.46    1625

0425756709  0703702003  s
  42 57 56.709    70 37  2.003         .19      4758065.60    368104.64    1630

0425756690  0703702007  s
  42 57 56.690    70 37  2.007         .19      4758065.02    368104.53    1635

0425756672  0703701991  s
  42 57 56.672    70 37  1.991         .19      4758064.46    368104.89    1640

0425756674  0703701955  s
  42  57 56.674   70 37  1.955         .19      4758064.50    368105.70    1645

0425756623  0703701951  s
  42 57 56.623    70 37  1.951         .19      4758062.93    368105.76    1650

0425756660  0703701968  s
  42 57 56.660    70 37  1.968         .19      4758064.08    368105.40    1655

0425756662  0703701964  s
  42 57 56.662    70 37  1.964         .19      4758064.14    368105.49    1700
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12 Sept

Compiled 10/21/68
   T.W.L.

V_DV 10/22/68

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