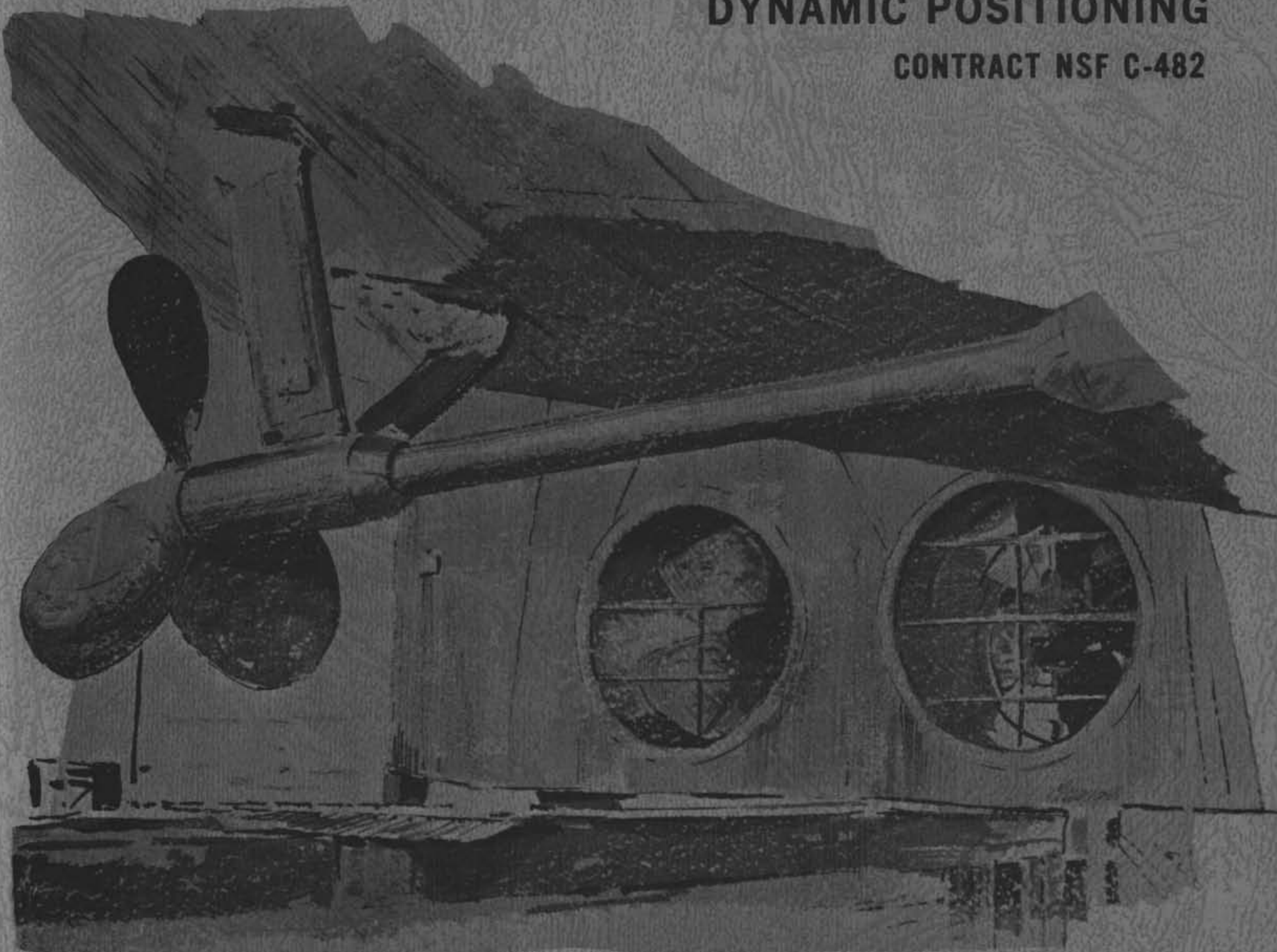
DEEP SEA DRILLING PROJECT

DR. T. A. DAVIES
SCRIPPS INSTITUTION OF OCEANOGRAPHY
P. O. BOX 109
LA JOLLA, CALIFORNIA, 92037

TECHNICAL REPORT NO. 3

DYNAMIC POSITIONING

CONTRACT NSF C-482



PRIME CONTRACTOR
THE REGENTS, UNIVERSITY OF CALIFORNIA

SCRIPPS INSTITUTION OF OCEANOGRAPHY
University of California at San Diego

DYNAMIC POSITIONING FOR D/V GLOMAR CHALLENGER

Prepared For

National Science Foundation
Under Provisions of Contract NSF C-482

By

Deep Sea Drilling Project
Scripps Institution of Oceanography
University of California at San Diego

W.A. Nierenberg, Director
Scripps Institution of Oceanography
Co-Principal Investigator

M.N.A. Peterson
Scripps Institution of Oceanography
Co-Principal Investigator

INTRODUCTION

It was the dream of the oceanographer and marine geologist to recover sedimentary core material from deep under the ocean floor and his belief that a drilling research vessel could be dynamically positioned over a bore hole on the ocean bottom that revolutionized the world of ocean sciences and global geology. This dream culminated in the highly successful Deep Sea Drilling Project and the remarkable D/V Glomar Challenger.

The position reference system on the dynamic positioning system used by Deep Sea Drilling Project was developed by Project Mohole research and development funds which were provided by the National Science Foundation.

The Deep Sea Drilling Project Engineering Division developed and perfected the sonar reference beacons so vital to the success in keeping D/V Glomar Challenger within tolerance over the bore hole at the bottom of the ocean.

Global Marine Inc. of Los Angeles, California, owner of D/V Glomar Challenger and subcontractor to do actual drilling and coring work, was responsible for the development of the thruster system and associated controls.

Performance of the system has been extraordinary with few excursions away from the bore hole. In fact, the system has allowed D/V Glomar Challenger to drill and core sedimentary material in water 20,000 feet deep and 3,888 feet into the ocean floor with only an apparent plus or minus 40 foot excursion for four or five days at a time.

December, 1971

ACKNOWLEDGEMENTS

We are grateful to Project Engineer Darrell L. Sims, of the Deep Sea Drilling Project; Mr. Jack Reed, First Project Manager for Deep Sea Drilling Project at Global Marine Inc.; Mr. Bion Henderson, Project Engineer for General Motors (ACDRL); Mr. Hal Clark, Project Engineer for the Honeywell Company, and Mr. Tom Dixon, Project Engineer on Positioning with Global Marine Inc. for "putting the entire dynamic positioning system together" on D/V Glomar Challenger and making it work beyond expectations.

We also recognize the immense contribution of the National Science Foundation-funded Project Mohole to the development of dynamic positioning.

Brown and Root Inc., of Houston, Texas, was Prime Contractor for Project Mohole; the knowledge and work of Chief Engineer J.N. Biron, Project Engineer for Electronics W.P. Schneider and Project Engineer for Thrusters H. Head brought the dynamic positioning system through factory acceptance tests after which it was placed in storage where it was when the Deep Sea Drilling Project needed it.

We further acknowledge the contribution of the Honeywell Company for its Phase Comparison System (PCS) and long base-line and General Motors (ACDRL) for its Pulse Position Measurement (PPM). We also thank Dr. William Rand and Mr. Kenneth Brunot, prior Project Managers, for the direction they gave to dynamic positioning.

The continuing help of Mr. A. R. McLerran, National Science Foundation Field Project Officer for the Deep Sea Drilling Project and the support of the National Science Foundation is warmly welcomed.

We gratefully acknowledge the overall contribution made to Deep Sea Drilling Project by the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES). Support and guidance of the JOIDES group has contributed much to the technological and scientific success of the Project.

M.N.A. Peterson
Co-Principal Investigator
Deep Sea Drilling Project

CONTENTS

	Page
Dynamic Positioning	1
Appendices	
Appendix A	
Design and Construction of the Dynamically Positioned Glomar Challenger.	15
Appendix B	
General Motors Corporation Proposal for Dynamic Ship Positioning System Equipment for a Deep-Sea Drilling Vessel.	37
Appendix C	
Station Keeping for Deep Sea Drilling.	84
Appendix D	
Emergency Methods of Maintaining "Hole" Position During Casualty Failures to Components of Ship's Computer-Positioning System.	93
Appendix E	
Typical Acoustic Beacon Work Specifications	98
Appendix F	
Beacon Drop Summary Through Leg 18	105
Appendix G	
D/V Positioning Analysis Reports by William P. Schneider	118
Bibliography	223

DYNAMIC POSITIONING

After the prime contract for the Deep Sea Drilling Project was awarded to The Regents of the University of California, by the National Science Foundation on June 24, 1966, Scripps Institution of Oceanography, of the University of California at San Diego, was designated operating institution.

Scripps Institution prepared the Program Plan and the Requests for Proposals for the dynamically positioned drilling vessel. The Request for Proposal did not specify the type of dynamic positioning system, but only that the system keep the vessel within the limits compatible with the total system.

Global Marine Inc., of Los Angeles, California, was picked by a blue ribbon Selection Committee as the subcontractor to furnish a drilling vessel and proposed to furnish a vessel of their Grand Isle Class.

The reference signal for positioning was to be an acoustic pulse from a sonar beacon dropped to the ocean floor. The vessel would have four tunnel thrusters, two aft and two forward. These thrusters, with the two main propellers, would provide the force to hold station. Vessel position, relative to the beacon, would be determined by a short base-line system furnished by General Motors (ACDRL). This system, through a computer, would command the positioning motors.

Although this is the first use of tunnel thrusters as the restoring force for dynamic positioning, the system performance exceeded expectations and is giving excellent performance after three years at sea.

The evolution of the state of the art of dynamically positioning a drilling vessel and Deep Sea Drilling Project involvement in the positioning system aboard D/V Glomar Challenger are discussed in detail on the following pages.

Drilling and coring in deep water at depth below the ocean bottom was first accomplished from a dynamically positioned drill ship (Cuss I) during Phase I of Mohole. This was done during March and April of 1961, off La Jolla, California, and Guadalupe Island, using radar reflectors and acoustic transducers on taut line buoys. Self-positioned drill ship such as the Cal-Drill and Eureka, using a single taut line (Shell Development Corporation) for position reference, were currently operating in 600 to 1,000 feet of water. The single taut line system was tested during Phase I Mohole and found to have too much error for positioning a drill ship in deep water.

In June 1962, Phase II Mohole reviewed positioning systems for a self-positioned ship to drill the Mohole. This review recommended the system used on Phase I was still the best. This was later modified to use bottom implanted acoustic beacons as the reference.

Brown and Root, Inc., Prime Contractor for Phase II Mohole, then subcontracted with Minneapolis-Honeywell to design and build the signal generating and processing systems for, a long base-line and a Phase Comparison System (PCS) which is a short base-line system. The subcontract included an analog computer to relate thruster power response to vessel position. A second subcontract was let to General Motors Defense Division (ACDRL) to design and build a short base-line system using acoustical pulses as the positioning signal. This system was to work through the Honeywell computer.

On August 24, 1966, Congress voted to discontinue Project Mohole. The National Science Foundation authorized completion of the above two subcontracts. The equipment was completed, run through factory acceptance tests, and placed in storage.

Meanwhile, on June 24, 1966, the National Science Foundation entered into a prime contract with The Regents of the University of California, with Scripps Institution of Oceanography as managing institution, to supervise the selection and operation of a dynamically positioned vessel for coring ocean sediments.

Early in 1967, a Request for Proposal for "providing, outfitting and operating a self-propelled dynamically positioned drilling vessel " was sent to leading drilling contractors and offshore operators. This Request for Proposal specified the Phase II Mohole positioning equipment available, but did not constrain the bidders to include this in their designs.

Global Marine Inc. initially proposed a short base-line acoustic system to be furnished by General Motors Defense Division (ACDRL). This system would be comprised of new components with the exception of the hydrophones which would be the ones built for Phase II Mohole. The components would be similar to those used on the U.S. Navy R/V Mission Capistrano, which was operated by Lamont-Doherty Geological Observatory of Columbia University.

The acoustic signal processing section for R/V Mission Capistrano was an upgraded version of the unit built by General Motors Defense Division (ACDRL) for Phase II Mohole. The processed signal was fed to a digital computer for thruster response. The March-April 1967 full-system tests on R/V Mission Capistrano indicated the signal processing and computer sections accurate and reliable. Acoustic beacon signal strength and reliability were not as good.

After Global Marine Inc. was selected as the winning bidder, a four-way discussion between Scripps Institution of Oceanography, National Science Foundation, Global Marine Inc., and General Motors Defense Division (ACDRL), indicated that the equipment built by ACDRL for Phase II Mohole could be updated for the Deep Sea Drilling Project. Global Marine Inc. proposed to incorporate use of this equipment in their positioning system.

The Pulse Position Measurement (PPM) short base-line signal processing equipment and hydrophones were released to ACDRL by the National Science Foundation for upgrading and incorporation into D/V Glomar Challenger's positioning system.

The National Science Foundation and Deep Sea Drilling Project felt the risk of drill string loss due to positioning equipment failure was real enough to require redundancy wherever possible. Inspection of the Minneapolis-Honeywell Phase Comparison System (PCS) short base-line signal processing system indicated this system could be paralleled with the PPM equipment. Deep Sea Drilling Project requested Global Marine Inc. to incorporate the PCS through Supplemental Agreement No. 1.

In addition, this would give the Deep Sea Drilling Project the opportunity to evaluate the relative merits of the two positioning systems.

As the hydrophones to be used were designed for the PPM 16 kHz signal, ACDRL was requested to determine if the hydrophones had sufficient response for the 10 kHz PCS signal. Hydrophones were found to be acceptable so ACDRL proceeded with the modification and installation of the PCS equipment.

Concurrently, a statement of work for the acoustic beacons for both PPM and PCS systems was written and sent to knowledgeable suppliers in the field. Replies were reviewed by a technical panel and Ocean Research and Equipment Company, of Falmouth, Massachusetts, selected as the supplier. The acoustic beacons were Prime Contractor-furnished equipment. Deep Sea Drilling Project felt the experience of Scripps Institution of Oceanography and the Naval Electronics Laboratory in San Diego, could be used to expedite acoustic beacon design.

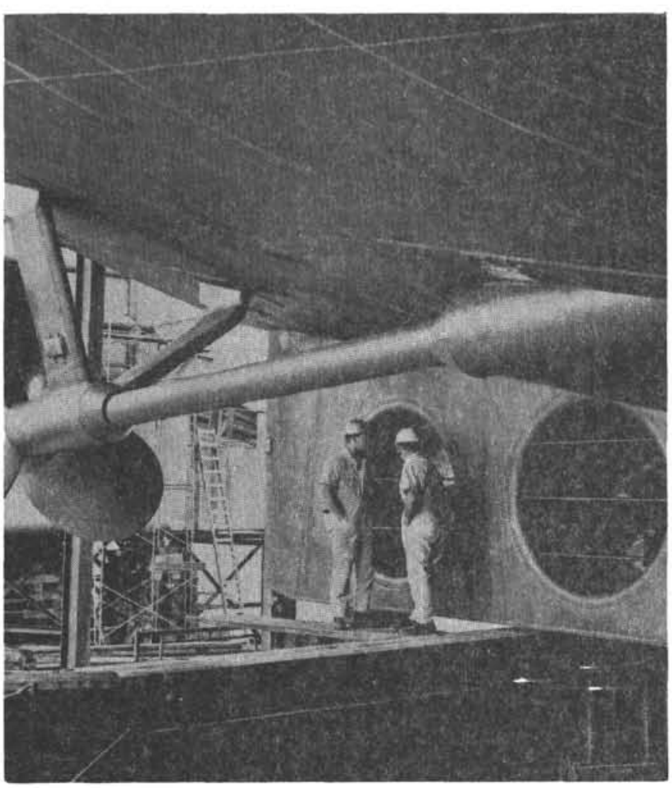
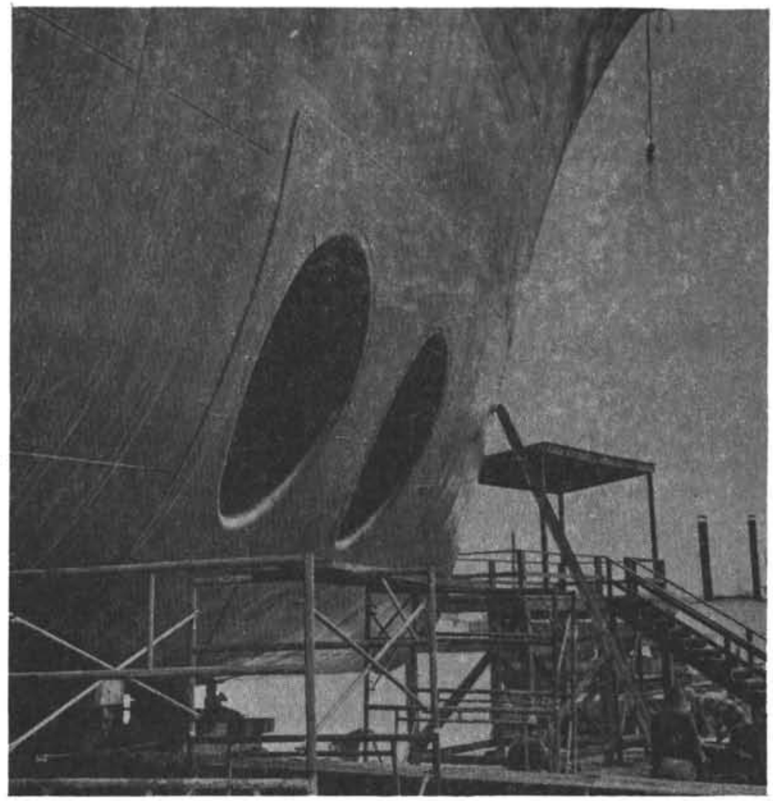


Figure 1
Starboard propeller and aft thrusters on the Glomar Challenger. Eight hundred hp reversible DC Motors drive the thrusters through right angle drives.

Figure 2
Bow thrusters of the Glomar Challenger. The 59 inch fixed blade propellers deliver up to 18,000 pound thrust each.



The tunnel thrusters were tested for bollard pull and acoustic noise as soon as the vessel's power could be applied. The aft thrusters produced design thrust, but the long forward tunnels reduced the bow thruster output. The acoustical noise measurements were much higher than the noise level used for the work statement for the acoustic beacons.

Ocean Research and Equipment Company was contacted immediately and requested to increase the output of both PPM and PCS beacons.

The prototype beacons had been tested and operational units were being constructed. Lead time for delivery was too short to redesign. Ocean Research and Equipment Company incorporated an aluminum reflector behind the transducer to increase the on-axis output. This decreased the cone angle of the beam to approximately six degrees half-angle. Although this would increase the difficulty of holding station in shallow water (3,000 feet or less) including acceptance trials, the beam width would be sufficient for deep water.

A second noise measurement was made during builders trials. This test confirmed the unanticipated high noise level. It was decided not to redesign acoustic beacons until after acceptance trials when the complete positioning system could be tested.

The ship was provisioned for the first leg and on July 20, 1968, the acceptance crew took the ship to 3,000 feet of water for acceptance trials. The ship was accepted August 11, 1968. The scientific crew took over for Leg 1.

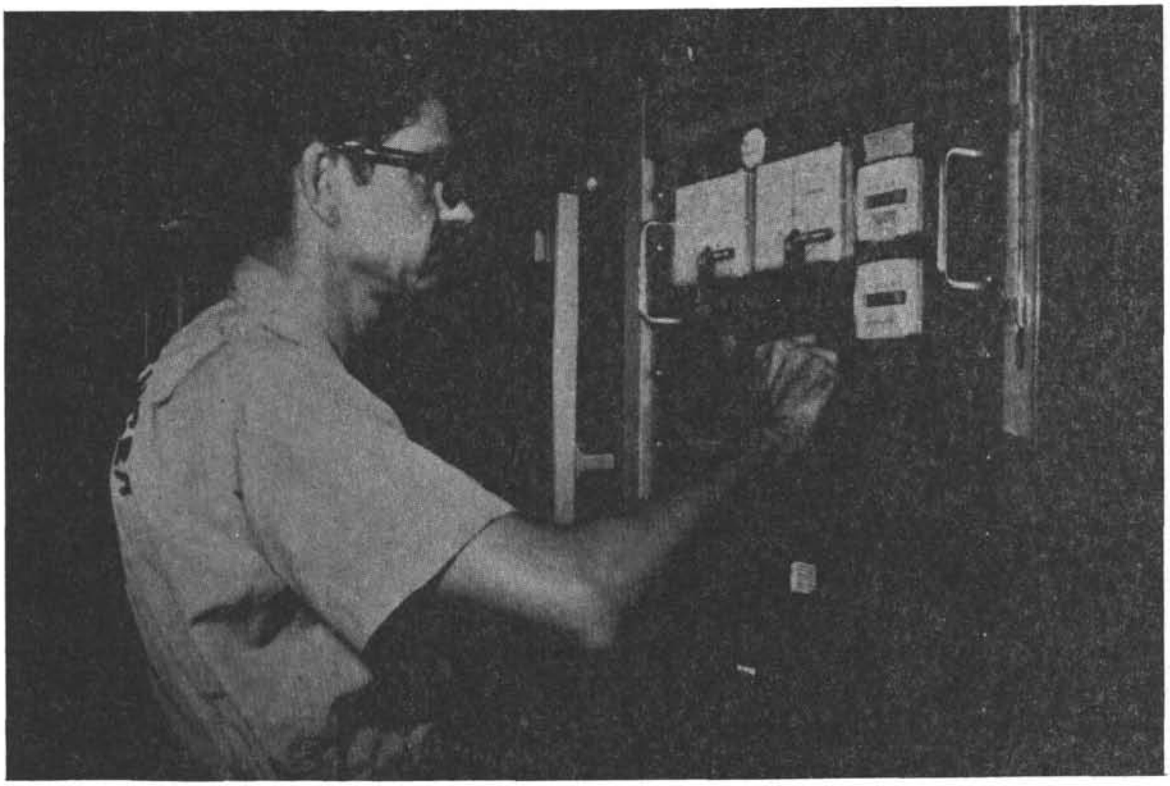


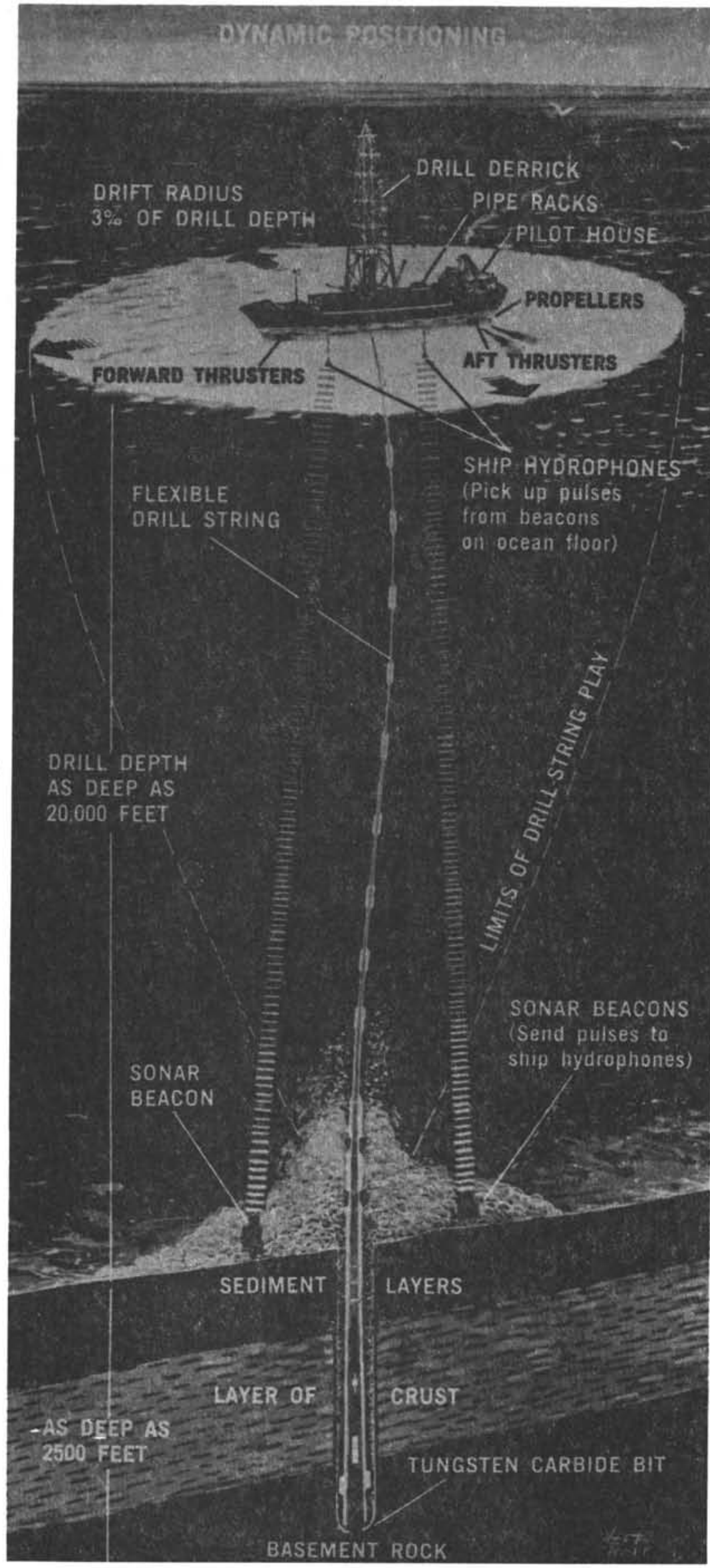
Figure 3
PPM signal processing section. After an acoustic pulse is verified it goes to the computer for positioning.

During acceptance trials, the system was de-bugged and calibrated. As anticipated, the signal cone from the Ocean Research Equipment (ORE) acoustic beacon was ragged. One of the acoustic beacons built by ACDRL for use with R/V Mission Capistrano (with 90 degree cone angle and lower signal strength) was used to assist in establishing signal strength. In addition, erratic thruster response to the Ocean Research Equipment beacon thought to be caused by the ragged beam, was also present with the ACDRL beacon. This lead to a review of the program where the cause of the erratic response was located.

Mr. W. P. Schneider, of the University of Houston and also of Petroleum Consultants, did an outstanding report - "Vessel Positioning Analysis" - during acceptance trials. Subject report is Appendix No. 7 to this technical report.

Also, during acceptance trials, it was discovered the hydrophones were least affected by noise when positioned just below the hull than when extended 28 feet below the hull as originally planned. This, as well as giving better protection to the hydrophones while on station, eliminated the necessity of lowering and raising the arms at each station.

Figure 4
DYNAMIC POSITIONING - Illustration shows how the Deep Sea Drilling Project drilling research vessel, Glomar Challenger, remains on station while working in water depths up to 20,000 feet. Dynamic positioning used a computerized system of pulses from acoustic beacons on the ocean floor which are picked up by a ship-mounted hydrophone array, fed in into a computer and translated into corrective action by propulsion units (tunnel thrusters and ship propellers) which automatically keep the Challenger precisely on station. The illustration also shows the flexibility of the drill string which weighs 400,000 pounds at a water depth of 20,000 feet.



The data from the above tests indicated that an on axis strength of 111 db re 1 μb would be minimum to hold station with 80 percent thruster power and sea noise caused by a Sea State 5.

The statement of work for acoustic beacons was changed to reflect this and to establish the cone angle of the beam to the 3 db point as 35 degree full cone angle.

The weather during Leg 1 was good, allowing use of the automatic mode most of the time. The weather was rougher on Leg 2, requiring use of manual and semi-automatic at least half of the time.

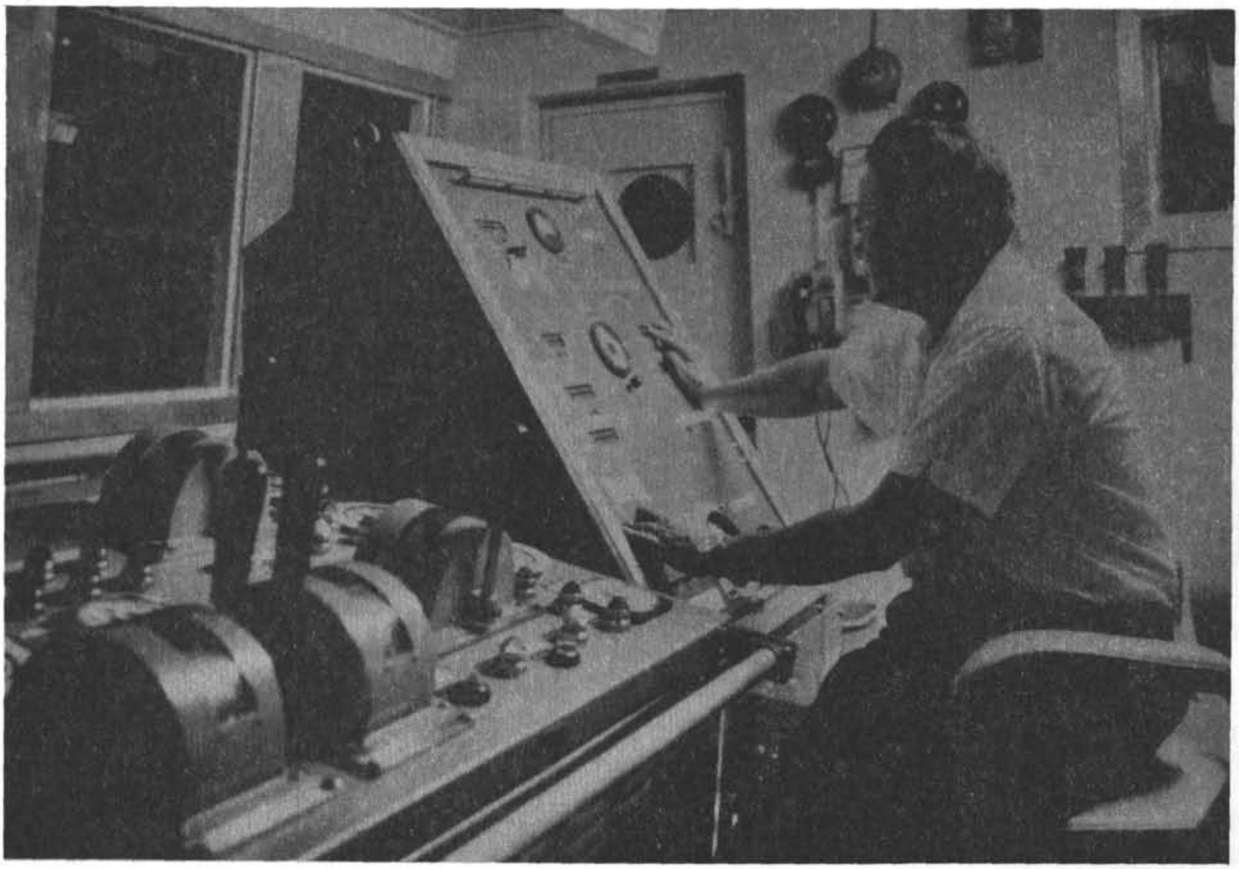


Figure 5
The bridge controls for the positioning system. The console at the right contains the PPI display that shows relative position of the ship and beacon. The manual propeller controls are to the left.

The PPM was the primary system used from acceptance on. It has proved to be remarkably reliable and normally holds the ship on station until weather conditions make operations hazardous. It has been necessary to realign the system on several occasions and the tolerances for pulse form acceptance have been loosened. This allows greater variance in beacon performance.

The positioning system performance was reviewed at the end of Leg 4. The decision was to add 13.5 kHz filters to the PPM system so that either 16 kHz or 13.5 kHz beacons could be used. It was felt the PPM had proved to be sufficiently reliable, that beacon redundancy was sufficient and the cost of placing the PCS in operable condition to be excessive. The 13.5 kHz filters were installed by ACDRL personnel at Honolulu during the port call between Legs 7 and 8. Since installation, several on station beacon failures have proved the two frequency systems to be sufficiently redundant.

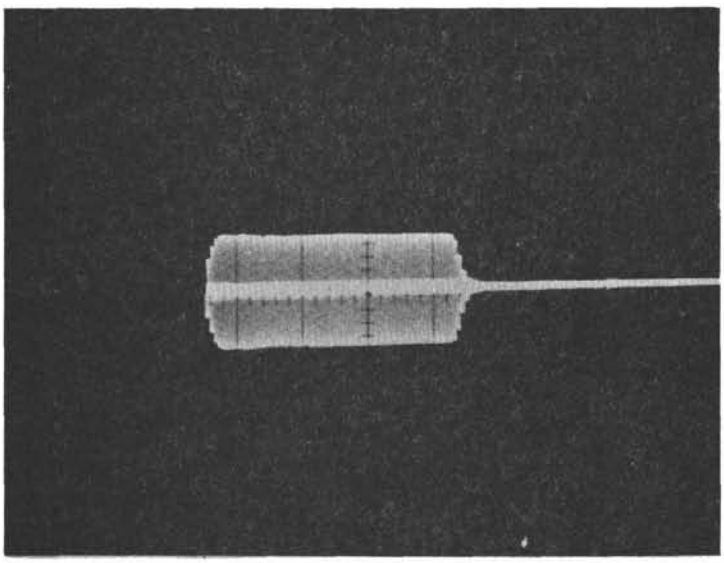


Figure 6
Oscillascope presentation of acoustic pulse as received by the signal processing section. This pulse has excellent shape.

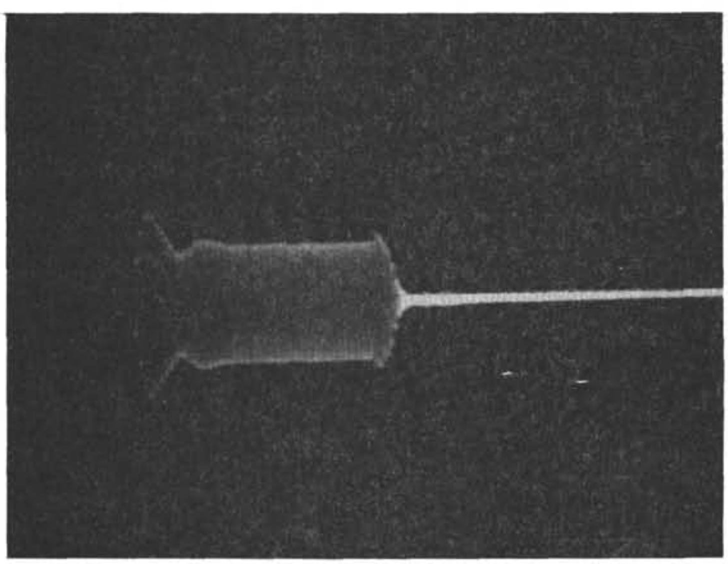


Figure 7
Oscillascope presentation of garbled pulse. As beacons are expendable, isolation of cause is difficult.

The PCS signal and signal processing system was capable of holding station with sufficient accuracy to drill or core. During the first two legs, a PPM and PCS beacon were strapped together and dropped as a unit. The PCS was used on several occasions to hold station while adjustments or repairs were being made on the PPM section. From the start the PCS seemed to have larger vessel excursions while holding station. This increased during Leg 1 so Minneapolis-Honeywell engineers met the ship at Hoboken, New Jersey, and realigned the system. This improved the PCS performance for some time but positioning became increasingly erratic, apparently due to accumulated wear in the mechanical integrator. The high cost of replacing this with a solid state integrator was one of the deciding factors in deciding to use two PPM frequencies for redundancy. The PCS equipment was left on board until the port call at Galveston, Texas, between Legs 9 and 10.

Removal of the PCS equipment caused positioning problems on the first site for Leg 10. The two systems were believed to be physically separated. However, the PPM signal had been looped through the PCS so the two signals could be compared. This loop was left open when the PCS was removed causing the computer to try to hold station on the last acceptable signal it had received.

The ship returned to Port Isabel, Texas, where the trouble was located and corrected.

The long base-line signal processing section which had been built for Phase II Mohole, had been retained by the Deep Sea Drilling Project as a standby in case the short base-line systems were incapable of holding station. As soon as the dependability of the PPM system was established, the long base-line equipment was declared surplus. The PCS equipment was also declared surplus when it was removed at Galveston.

As mentioned previously, after acceptance trials, Deep Sea Drilling Project sent out a Request for Quotation for acoustical beacons having a minimum of 111 db re 1 μb on axis signal strength. The replies were quite varied both as to price and design. The technical panel selected a design which required floatation only for the transducer.

Two types of floatation had been used for the first beacon design. This design used the battery pack as the anchor with the electronics and transducer requiring floatation. A 20-foot electrical and strain cable connected the two. The first PPM and PCS beacons were built with syntactic foam. The float, as originally designed, would have given 16 pounds positive floatation. The necessity of adding the aluminum reflector reduced this by half. Long lead time for syntactic foam led Deep Sea Drilling Project to construct floatation using ten-inch diameter glass spheres. The inability to recover beacons has made it quite difficult to evaluate beacon signal irregularities or failure. Thus the effect of floatation design on beacon performance is largely speculation.

The vendor selected to build the first 111 db beacons advised Deep Sea Drilling Project they had made an error in their design. One hundred and eight db on axis would be the maximum output.

Deep Sea Drilling Project immediately contacted the vendor rated No. 2 by the technical panel. As lead time for delivery was now very tight, major items for the beacon were ordered while the breadboard circuit was being tested. This beacon design was similar to the first in that the battery pack was the anchor and the electronic package and transducer supported by syntactic floatation. Four PPM units were rushed through assembly and forwarded to meet the ship at the end of Leg 3 at Rio de Janeiro. In addition, as a back-up two beacons such as were used for the Mission Capistrano and two converted transponders were also forwarded. The signals from the two beacons were warped but usable.

The first four beacons when implanted would slowly loose signal after 40 to 60 hours. Lab tests found the syntactic foam to have been incorrectly mixed and would slowly absorb moisture until the floatation had lost its positive buoyancy.

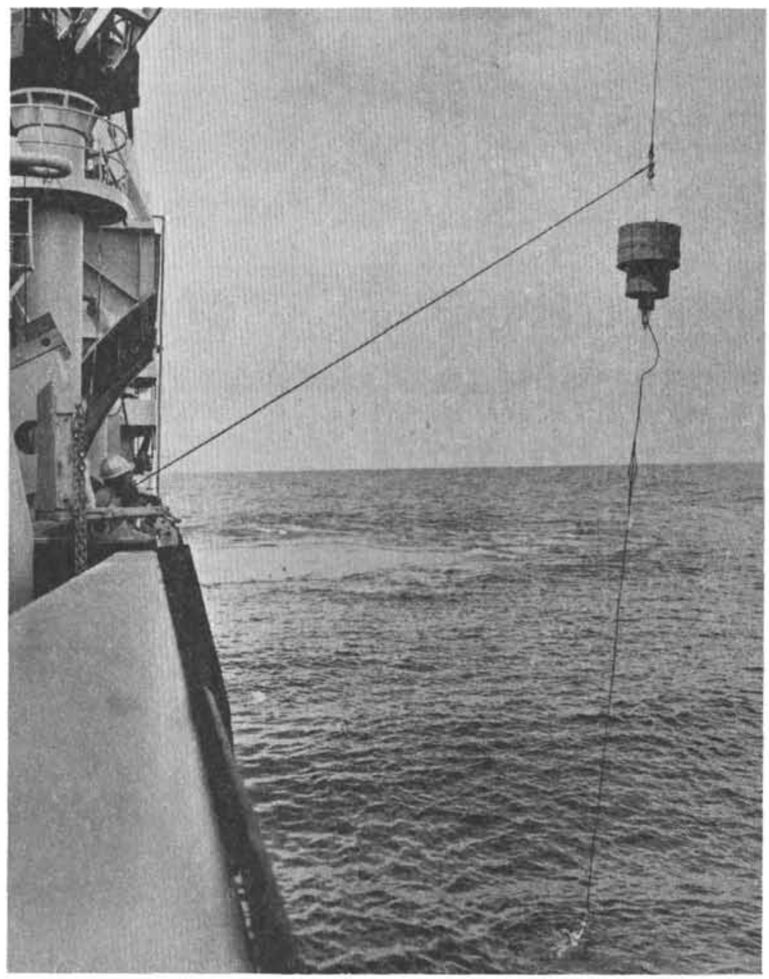


Figure 8
Acoustic beacon with syntactic foam floatation. The transducer and electronics are in the floatation. The battery (just entering the water) used as the anchor, is connected to the electronics by strain and conductor cables.

The excessive loss of bottom hole assemblies required D/V Glomar Challenger to make a port call at San Juan, Puerto Rico, half-way through Leg 4. Additional 111 db PPM beacons were placed on board with correct buoyancy. The increased beacon power greatly improved the performance of the positioning system.

As mentioned, the positioning system was reviewed at the end of Leg 4. The addition of 13.5 kHz filters would require a 13.5 kHz beacon. Preliminary investigation indicated the same transducers used for the 16 kHz signal would work for the 13.5 kHz signal. Two 16 kHz beacons were converted to 13.5 kHz. Tank tests at Transdec indicated an increase in the back lobe emission, but within design limits. As Transdec cannot test the transducer at full power output the pulse shape at full power was not tested. These beacons were sent to D/V Glomar Challenger and when implanted produced a signal inferior to the 16 kHz. Additional 13.5 kHz beacons were built with the transducers matched to the 13.5 kHz input. After this change, the beacons have performed very satisfactorily.

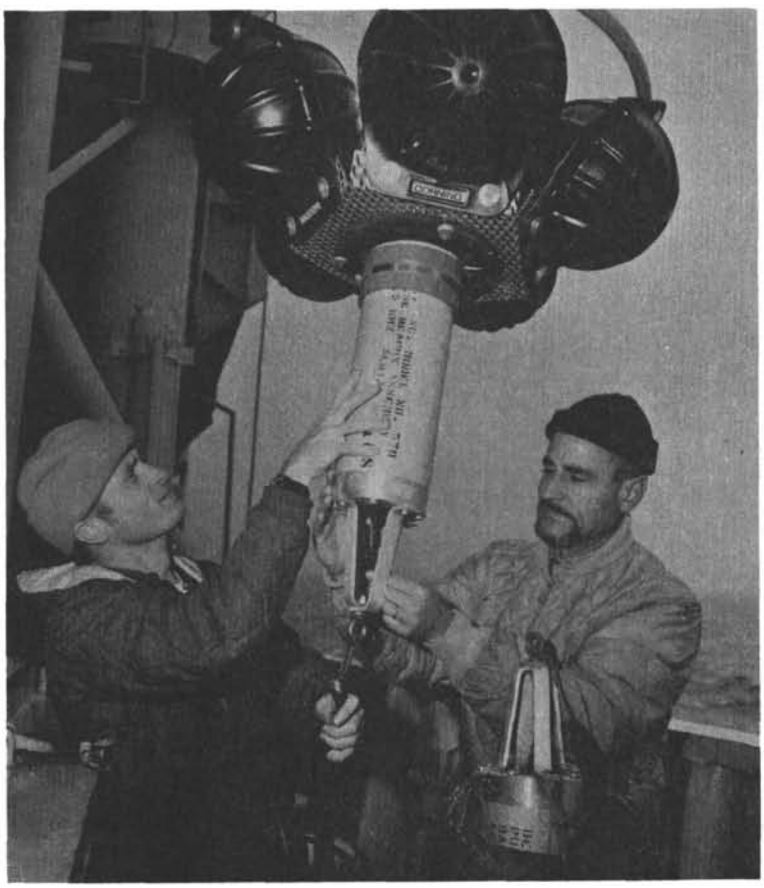


Figure 9
Acoustic beacon with hollow glass sphere floatation. "Hard Hats" hold spheres in position. Battery pack is used as the anchor. This style drops with less planning.

The reaction of the beacon floatation to bottom currents could affect the projected angle of the signal cone or cause the cone to move. Some erratic signals seem to have been caused by currents. One vendor supplied Deep Sea Drilling Project with a beacon designed to minimize the effect of bottom current. This was accomplished by placing the electronics and battery in the same case and floating the transducer. In addition, the transducer was gimballed and tethered to the battery electronics pack so as to weather vane into the current. This configuration reacted as expected during two tests but tendered to sail during actual drops, expecially when dropped with the vessel underway.

The Project now has two or more dependable beacon designs but is constantly trying to improve life and dependability.

The hydrophones used in the positioning system were the ones developed and built by ACDRL for the Phase II Mohole positioning system. The hydrophones were most effective when positioned at the hull level.

Global Marine Inc. planned to drydock the Glomar Challenger at Bethlehem Shipyard, Hoboken, New Jersey at the end of Leg 1, so the forward thruster propellers could be changed. The proximity of the forward hydrophones to the forward thrusters caused signal interference at high thruster rpm.

Global Marine Inc. was requested to investigate installing a third pair of hydrophones correctly spaced aft of the extendable hydrophones. Deep Sea Drilling Project was advised this could be done, so Global Marine Inc. was given the go ahead to make this installation during drydock. The installation was successfully completed and has been extensively used as the four aft phones definitely have less noise interference from the forward thrusters.

The hydrophones for the PCS positioning system had been designed and built with a narrow directivity cone. The Project was advised these hydrophones could increase the sensitivity of the system the equivalent of adding three to six db of output to the acoustic beacon. This would increase the noise level at which the ship could hold station in automatic mode, so plans were started to change out the two forward PPM hydrophones with PCS hydrophones.

As two additional PPM hydrophones were to be installed at this time, it was believed the ship could hold station if it became necessary to replace the PCS hydrophones.

These PCS hydrophones were to be placed on the forward retractable hydrophone arms. Two PCS hydrophones were sent to Transdec for calibrating. The units checked okay and were forwarded to meet the ship at Hoboken, New Jersey.

While the ship was in drydock, an attempt was made to raise the forward port hydrophone arm. This was unsuccessful as the arm was frozen in place. As this precluded changing hydrophones at sea, the decision was not to install a PCS hydrophone.

With all the PPM hydrophones in the water, two spares were ordered to be built to the original ACDRL specifications. These were placed on board the Glomar Challenger during the San Diego port call.

The control linkage between the computer and the thrusters and main shafts was designed and installed by Global Marine Inc. and is proprietary. The installation included interfacing equipment from several manufacturers such as the Caterpillar diesels, General Electric generators and motors, necessary switch gear, etc. The system had some "bugs", but these were rapidly eliminated and since acceptance has required only normal maintenance.

The four thrusters are right-angle-drive Shottel Model S300. The 59-inch diameter fixed blade propellers are driven by 850 hp vertically mounted G.E. D.C. traction motors. This provides approximately 18,000 pounds thrust per unit. Preliminary tests in the ship channel at the boat yard indicated the long tunnels forward deteriorated the performance of the thrusters.

Replacement propellers with increased pitch were obtained during drydock at the end of Leg 1. The replacement propellers did produce the required thrust at maximum rpm. All thrusters were inspected during drydock.

The ship proceeded to the first site where the forward bow thruster became inoperative. The ship drydocked at Newport News, Virginia, Shipyard, where the thruster was replaced.

The thrusters worked very well until the last site on Leg 9 where both bow thrusters became inoperative.

As Leg 10 was to be in the Gulf of Mexico, the ship proceeded to Galveston, Texas, for drydock in Todd Shipyard.

The next thruster problem occurred during Leg 15. The forward bow thruster became inoperative on the first site and the aft bow thruster began to use oil and over heat. The ship was drydocked at Willemstad, Curacao. The bow thruster propellers had apparently been fouled with foreign objects. Both propellers were replaced and the gear trains repaired.

When the forward bow thrusters became noisy during Leg 16, Global Marine Inc. received Coast Guard approval to install access wells to the two bow thruster tunnels. They also designed closures for the bow tunnel ends that could be diver installed.

This allows repairing the bow thrusters without a drydock. As the bow thrusters are required to operate longer and at higher power than the stern thrusters, the number of drydockings should be reduced.

No. 1 thruster again failed on Site 166 of Leg 17. It was successfully repaired during the port call at Honolulu, Hawaii, without drydocking.

The crew from Leg 16 reported the overall positioning system was becoming erratic. As it had been over a year since anyone other than the ship's electronic technicians had checked the system, Deep Sea Drilling Project and Global Marine Inc. entered in a joint program to have Mr. W.P. Schneider of the University of Houston, Texas, be aboard for Leg 18 and check the positioning equipment. Mr. Schneider took the necessary instruments to measure the ship's operating noise levels and to define the noise envelope.

D/V Glomar Challenger has demonstrated that an acoustic positioning system is accurate and dependable. The operators of the system have noted several changes that should improve the system:

1. Rewrite the program for the computer so that prevailing sea forces such as current, wind direction and intensity could either be fed to the computer or sensed by instrumentation. This would allow the computer to anticipate losing station, instead of reacting after moving off station.

2. Increased thruster power at lower propeller rpm. This would reduce the ship's noise, and allow maintaining station in higher sea states.

3. Install thrusters so they could be retracted for maintenance while the ship is underway.

4. Install the hydrophones so they could be retracted for maintenance. Add covers to the hydrophone baffles to eliminate trapped air bubbles.

5. Have beacons available with decreased power and wider beam angle and a program suitable for positioning in water depths shallower than 1000 meters.

The excellent performance of the positioning system aboard D/V Glomar Challenger has encouraged the incorporation of the same or similar systems aboard other drilling and mining ships. Thus, D/V Glomar Challenger, in order to produce its enviable record of coring in the deep ocean basins, has also advanced the capability of vessels to keep on station in deep water.

APPENDIX A

Design and Construction of the Dynamically Positioned Glomar Challenger.

THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
74 Trinity Place, New York, N. Y. 10006
no. 10
Paper to be presented at its Spring Meeting, Beverly Hills, California, May 21–24, 1969

Design and Construction of the Dynamically Positioned *Glomar Challenger*

By J. R. Graham,[1] *Member,* K. M. Jones,[2] *Member,*
G. D. Knorr, *Visitor,*[3] and T. F. Dixon,[4] *Visitor*

This paper is a description of the dynamically positioned drilling ship, *Glomar Challenger,* referring to novel and unusual practices which should be of interest to marine and petroleum industries. Even today a seagoing ship with a 142-ft derrick is an oddity, although such derricks have been used in this capacity for over ten years. Probably the most noteworthy technological advance of this ship is found in the dynamic positioning system. To be able to hold a fixed position steadily—and within 100 ft of that position—and to be able to maintain position and orient the ship throughout the compass azimuths makes exciting work and oceanic exploration quite practical. The ship itself is a proven combination of marine and petroleum technologies aided by a power plant originally developed for the locomotive and petroleum industries. The aerospace industry has contributed satellite navigation and acoustic position-sensing systems. In total, the *Glomar Challenger* represents a practical and workable combination of industries, proven in service by the drilling to date of more than 20 core holes in the deepest parts of the North and South Atlantic Oceans. In four months of operation there has been no lost time due to weather or malfunctioning of the positioning system while drilling.

A DYNAMICALLY POSITIONED, ultra-deep-water major drilling unit is an anticipated extension to today's offshore drilling needs. That the first such unit is a self-propelled ship is a result of the catalytic needs of the oil industry and the scientific community. While in recent years it seemed that the petroleum industry alone would sponsor this development, the economic risks could not be justified due to as yet unproven technological breakthroughs.

In 1964, a multi-university sponsored deep-sea drilling proposal was initiated by "JOIDES" (Joint Oceanographic Institutions Deep Earth Survey). Participating institutions were Scripps Institution of Oceanography, Woods Hole Oceanographic Institute, Lamont Oceanographic Laboratory of Columbia University, and Miami University's Institute of Marine Science. This program envisioned retrieving sediment cores in 12,000 to 18,000 ft of water. Its planning led to the current Deep Sea Drilling Project (DSDP), funded by the National Science Foundation and with the same participating institutions. Scripps Institution has been designated as the manager for the DSDP.

Simultaneously the authors' company had been preparing for the needs of the industries and, when the proposal request for DSDP was released, responded with a ship already under construction and which ideally could meet the need. The startling fact that Scripps, as manager of DSDP, accepted the *Glomar Challenger* only 270 calendar days after signing the contract is a testimonial to Global Marine's engineering and design capabilities, Levingston Shipbuilding Co.'s remarkable fabrication effort, and Scripp's competent contract management. All three may take deep pride in their participation in the evolution of this sophisticated and pioneering vessel.

[1] Manager of Engineering, Global Marine Inc., Los Angeles, Calif.
[2] Senior Naval Architect, Global Marine Inc.
[3] Chief Design Engineer, Global Marine Inc.
[4] Commander, USN (Ret.), electrical and electronics engineer, Global Marine Inc.

Hull Design

The principal dimensions and characteristics of the *Glomar Challenger* are as follows:

L_{OA}, ft	402.2
L_{WL} (20-ft WL), ft	380.
Beam, molded, ft	65
Depth, molded side, ft-in	26-9
Designed draft, ft	20
Displacement (20-ft WL), LTSW	10,500
Light ship, LT	4,303
Total deadweight, LT	6,197
L/D	14.6
L/B	6.15
B/D	2.46
CB (20-ft WL)	0.744
LCB aft (20-ft WL), ft	1.05
LCF aft (20-ft WL), ft	9.64
Transverse KM (20-ft WL), ft	28.74
TPI (20-ft WL), LT/in	50.35
Trans. radius of gyration, ft	30
Long'l. radius of gyration, ft	93

Fig. 1 delineates the ship's arrangements.

Since 85 to 90 percent of a drilling ship's life is spent on drilling location, and not underway, the design considerations are quite different from normal commercial ship design. The principal criteria are minimum motion at zero forward velocity and adequate stability during drilling operations for safety. The hull form meets the criteria to an unusual degree by application of the philosophy of maximum in-water mass, low profile, and maximum radius of gyration.

The *Glomar Challenger*'s hull is the *third generation* of Global Marine designs, all of which have been model-tested in waves at zero velocity and various headings, as well as undergoing conventional resistance tests. Typical roll, pitch, and heave responses are shown in Figs. 2 and 3. Fig. 4 summarizes the results of the resistance tests.

Thruster tunnel openings were evaluated by photographing the reaction of flumes spaced around various opening configurations while influenced by various velocities of water flow. The configuration selected was estimated to reduce ship's speed by about 0.25 knots at maximum propeller rpm. Fig. 5 is a photograph of one of the flow tests.

Stability

The ability to maintain reasonably safe stability under survival conditions or the more extreme hazards of offshore oil drilling has been a vital consideration of the authors' company in the design of all its vessels. The earlier designs were in service before the US Coast Guard established separate criteria for drilling ship stability. The *Glomar Sirte* class was being commissioned at the time the new criteria were invoked. The hull form for the *Glomar Challenger* was designed to the new criteria, which require, during drilling operations, an initial *GM* satisfying a righting arm curve 1.4 times in area that of a 100-knot wind heeling curve at the point of down-flooding. Fig. 6 is a plot of the required *GM* while underway and the required *GM* while drilling.

Roll Stabilization

An extensive analysis of roll stabilization systems had been underway for some time prior to initiating final design of the *Glomar Challenger*. Considerations of compatibility with drilling operations and noninterference with the positioning system eliminated most systems from detailed analysis. Final selection was between passive and controlled passive stabilizing tanks. Roll damping while drilling frequently must occur in wave systems whose period is well removed from the ship's resonant period of roll. Studies indicated that the effectiveness of passive tanks is seriously reduced away from synchronism, while a controlled passive system provides reasonable roll reduction in this area even though its effectiveness at synchronism may be less. This was verified in an independent analysis by Hydronautics, Inc. after Global Marine had selected the Brown-Muirhead controlled passive tank system for installation. In general, it was calculated that roll reductions of 40 to 50 percent could be expected in the range of random sea spectra most commonly experienced at sea. Roll reduction in regular seas could be expected to be even better. This would permit drilling operations to extend to at least one full sea state beyond undamped roll limitations and confidently permitted the prediction of less than 6-deg roll angles in state-7 seas. Heave, in most cases, becomes the limiting motion factor while drilling in moderate to heavy sea states.

While there have been few real opportunities to verify roll stabilization results at sea, some observations appear to confirm the predictions. Quoting in part from a message from Capt. R. A. Wilson, master of the *Glomar Challenger*, on December 4, 1968: ". . . in trough, roll was 8°. With (stabilization) tanks energized roll has been reduced to 4° . . . ."

The *Glomar Challenger* uses a total of 550 tons of fresh water in two pairs of wing tanks amidships, frames 91-110. Each pair of tanks is cross-connected by one large water flume at the tank top level and by two valved air ducts at the 'tween deck. In the Brown-Muirhead system the flow of water from one side to the other is restrained to be out of phase with the ship's roll by the closing or opening of the air valves appropriately. The ship's roll velocity is measured with a vertical axis rate gyro located near the centers of ship motion. This signal is differentiated to yield acceleration, and the two are combined in a fixed proportion to produce the valve command signal.

To operate properly, the tanks must be unvented and essentially sealed. Accidental overpressurization due to pumping or filling is avoided by the use of 8-in. pressure-vacuum relief valves and a water-column emergency vent on the sides of each tank.

/17

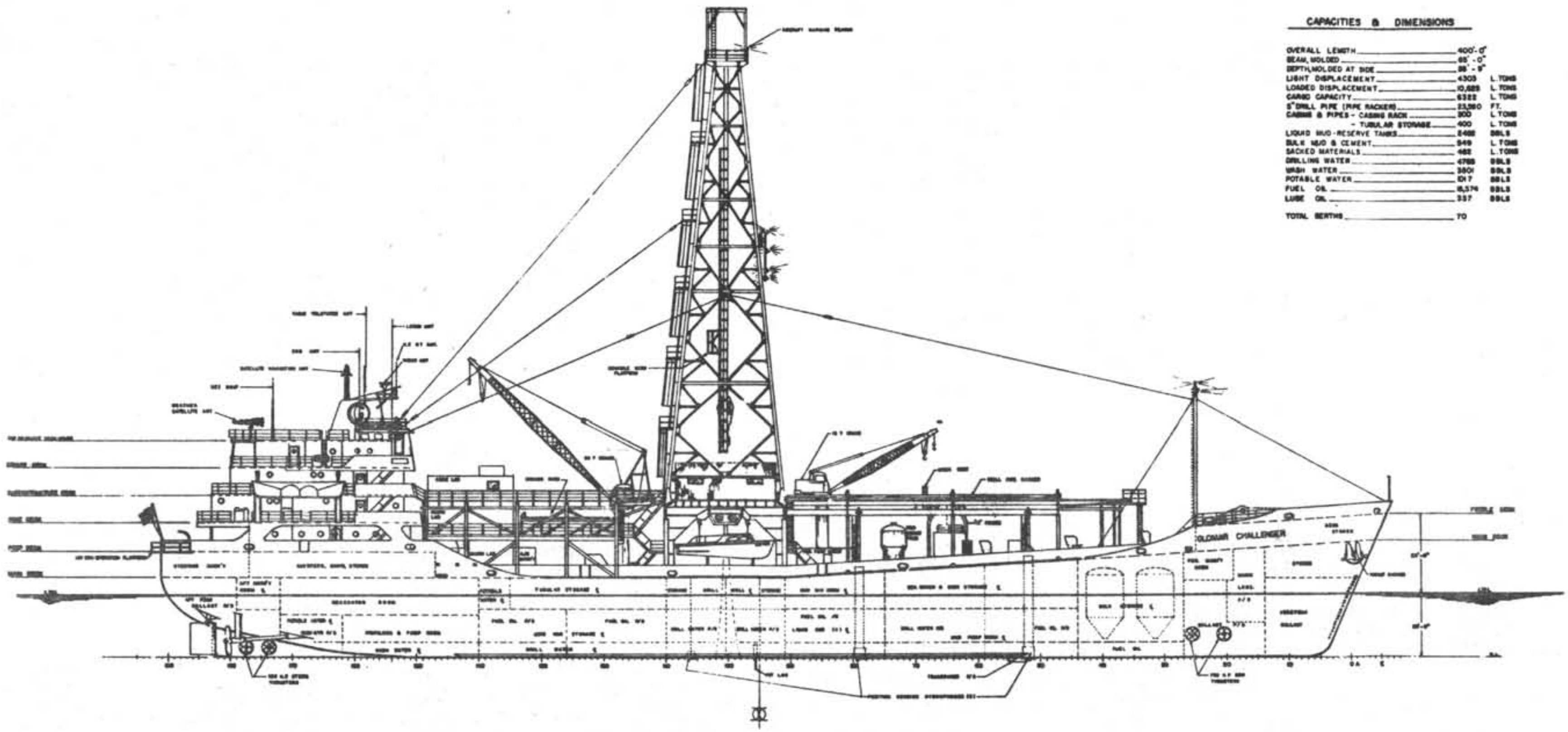


Fig. 1 Outboard profile and arrangements

/18

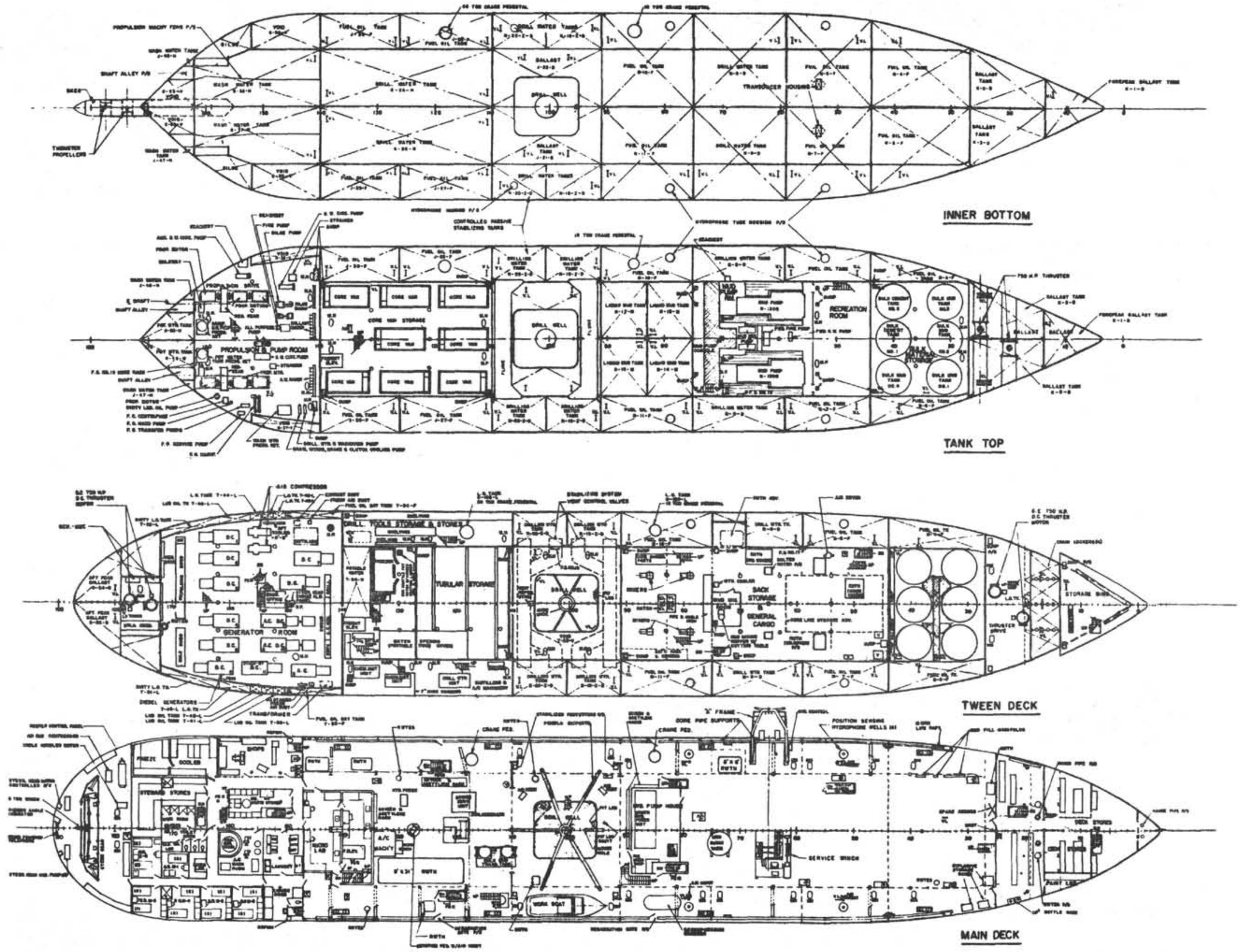


Fig. 1 (continued)

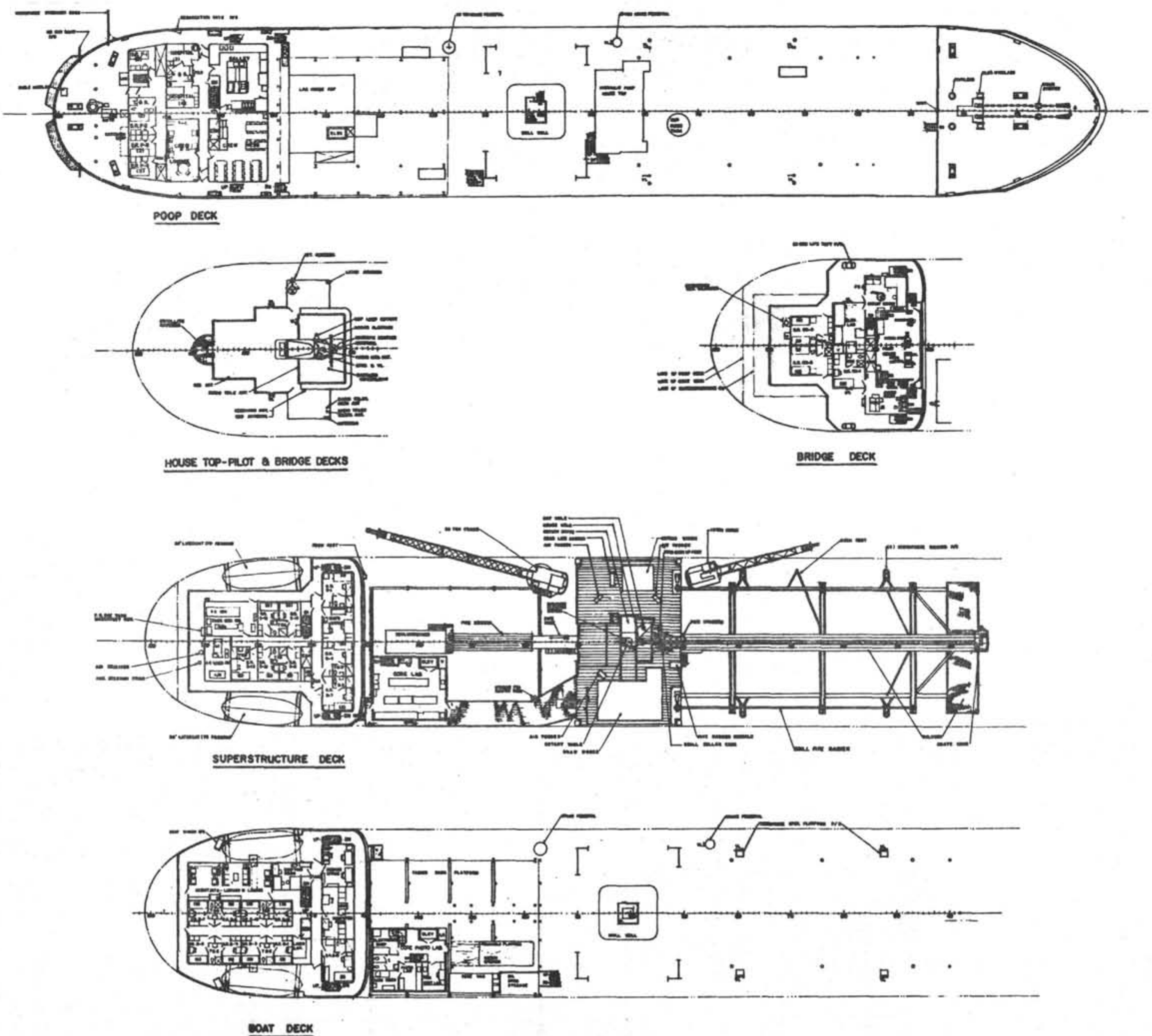


Fig. 1 (continued)

/20

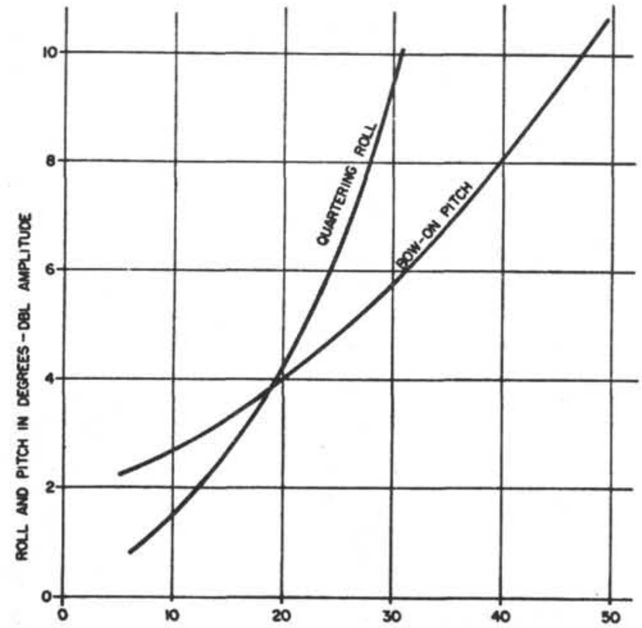


Fig. 2 Roll and pitch in 8-sec wave period

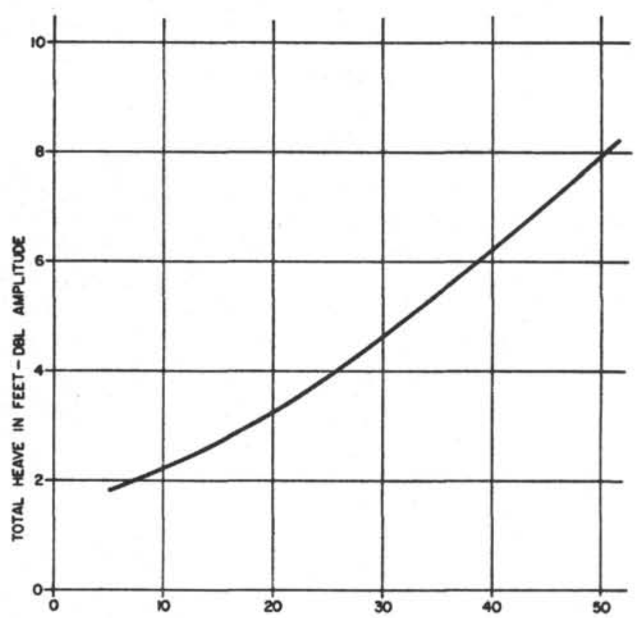


Fig. 3 Heave in 8-sec wave period bow-on

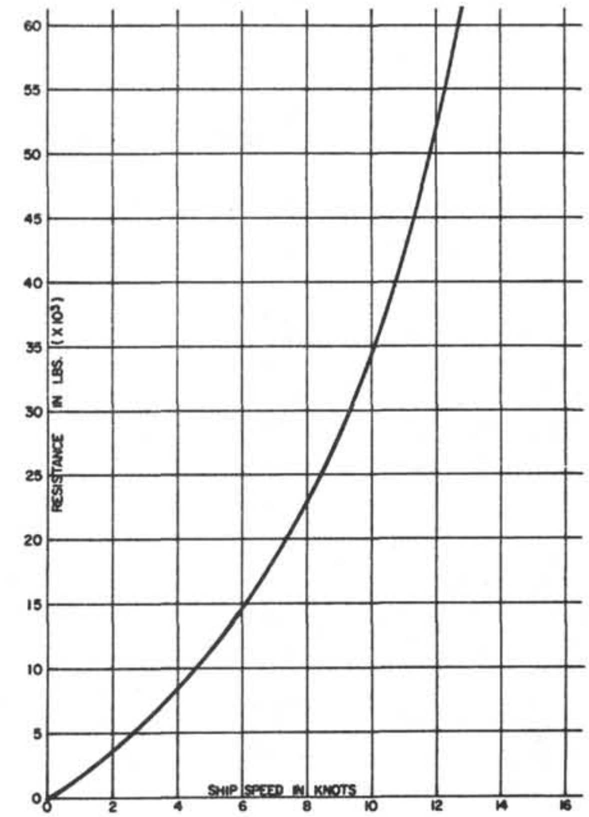


Fig. 4 Resistance versus ship speed

Hull Structure

The ship is transversely framed, all-welded, and generally exceeds American Bureau of Shipping scantling requirements. There are eight main watertight transverse bulkheads and two main watertight longitudinal bulkheads 20 ft-0 in. off-centerline, running essentially the length of the ship from generator room to forward deep ballast tanks. While technically a one-compartment ship by virtue of the generator-pump room and the mud pump-sack storage space, the foregoing bulkheading — along with a 5 ft-0 in. deep double bottom — provides two-compartment flooding protection in all other spaces. Fig. 7 shows the typical midship section.

Conventional longitudinal strength calculations indicate hull stress values substantially below the maximums allowed by ABS and the Load Line Regulations. The calculated shear and bending stresses are:

	Bending Stress, psi
Deck tension, hogging	12,780
Bottom compression, hogging	14,800
Deck compression, sagging	9,190
Bottom tension, sagging	10,530

	Shear Stress, psi
Hogging, shear fwd.	6,950
Hogging, shear aft	7,400
Sagging, shear fwd.	5,830
Sagging, shear aft	6,050

Special Compensation

The 22 by 24 ft drillwell causes a discontinuity in hull structure almost exactly at the area of maximum bending moment. The drillwell corners are generously radiused and the bottom plating and main deck plating are increased to 1¼ and 1⅛ in. thickness, respective-

/21

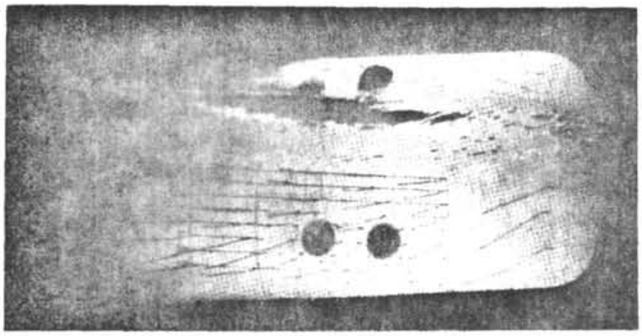


Fig. 5 Model test — water flow lines at forward thruster openings

ly. These increased plates are carried well forward and aft of the drillwell and are tapered to produce a smoothly changing stress pattern.

The concentrated loads from the four derrick subbase legs are introduced to the hull structure near the drillwell; hence special care was taken in design of the subbase supporting structure. Essentially, the substructure webs were oriented to fall on main bulkheads, which were locally increased throughout their depth. The face plates were effectively continued into the main hull structure by heavy plate inserts in the bulkheads which are tapered from full width of the face plates at the main deck to a nominal width at the bottom of the bulkhead. These inserts are continuous through the bulkheads as well as the main deck, and all welding is of x-ray quality designed to develop 100 percent of the parent metal strength.

Thruster tunnel support structure is especially rugged and carried well into the ship's prime members (bulkheads, floors, and stringers), which were locally increased to accept these added loads. It was found in service that, while the supporting adjacent structure was adequate, there were structural panels well removed from the area (particularly in the deckhouse) whose natural frequency responded to thruster frequency at full rpm. Fortunately, full rpm has rarely been required in service.

Superstructures

All superstructures for drilling and accommodation are tied into the hull by continuous members extending through the main deck and into the structural bulkheads below. There are four main superstructures: pipe racker, derrick subbase, casing rack and laboratories, and accommodations deckhouse. Each is an independent structure of short enough length not to be effective in the longitudinal strength of the hull girder. As a result, each can work independently of the others.

Similarly, the two elevated cranes are supported on independent columns extending into the double-bottom structure. They do not interrupt the longitudinal continuity of hull structure, nor do they contribute to longitudinal strength; hence they move in response to hull flexure without effect or influence from other superstructures.

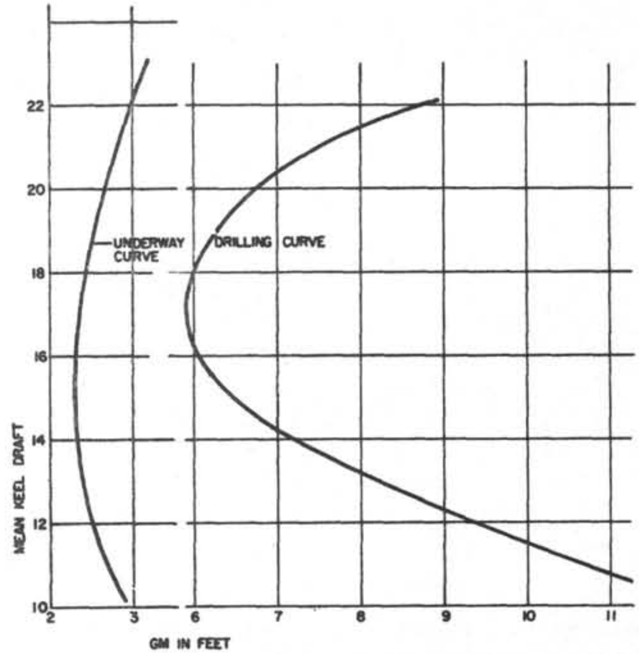


Fig. 6 GM required curves

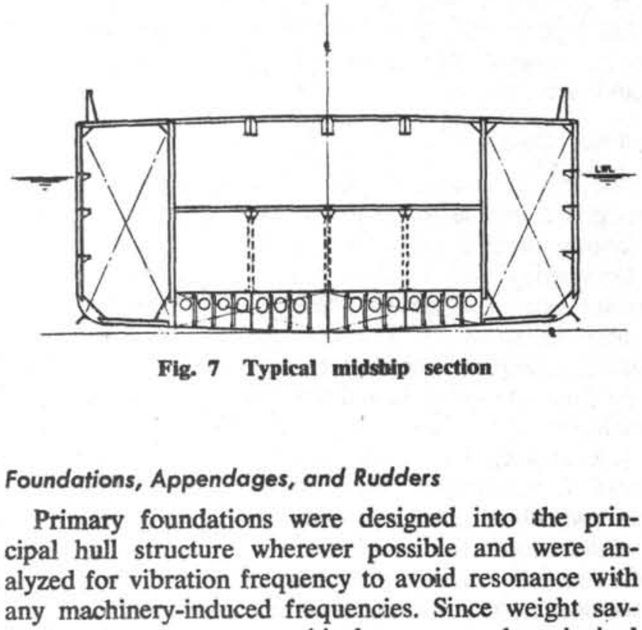


Fig. 7 Typical midship section

Foundations, Appendages, and Rudders

Primary foundations were designed into the principal hull structure wherever possible and were analyzed for vibration frequency to avoid resonance with any machinery-induced frequencies. Since weight saving in structure was not critical, mass was the principal technique employed to avoid criticals, thus avoiding special vibration damping materials such as are forced upon necessarily lightweight structures like combatant ships.

The 18-in. bilge keels are relatively large for this size vessel and, together with the large centerline skeg, contribute substantially to the roll damping characteristics.

The rudders and rudder stocks are designed to exceed ABS requirements. The rudders are of the semi-balanced, airfoil-shaped spade type — quite conventional except for two features: They, along with the

/22

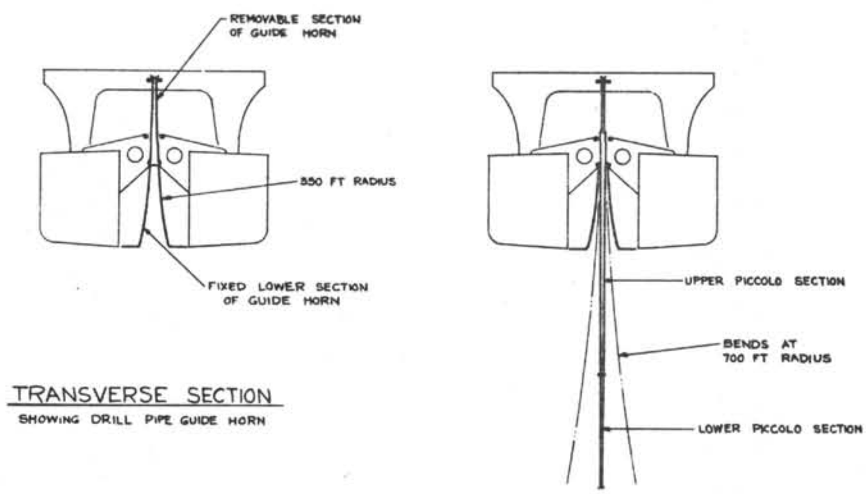


Fig. 8 Drill pipe guide horn and piccolo

propellers, were placed farther outboard than usual, to obtain a maximum turning moment. The rudders and stocks are supported at the main deck by a "Dunstos" Improved Gland Packed Rudder Carrier manufactured by Taylor Pallister & Co. Ltd. This carrier serves three purposes: sealing gland, thrust bearing, and radial load carrier. This is a departure from previous designs and to date appears simple, efficient, and trouble-free.

Drill Pipe Guides

The last structures of major importance to be discussed are unique, indeed, to even drilling ships and of critical importance to the life of the drill string.

Drill string analysis showed that maximum bending stresses occur at the top; the longer the string the greater the stress for a given angularity to the ship's axis. The simplest means of preventing excessive stress is to limit the bending radius of the drill string mechanically.

A horn-shaped cone was designed whose length extended from close up under the rotary table to the keel and whose inner contour conformed to the desired limiting curvature of the drill pipe. Built in two pieces of stiffened steel plate, the upper half (from the main deck up) is portable while the lower half is permanently welded to the ship's structure. Principal supporting members carry most of the load from the drill pipe into the main deck area, while the bellmouth of the horn is supported by the shell at the bottom of the drillwell.

Drill strings for ultra-deep water (say over 17,000 ft) were found to require bending restraint over a distance substantially longer than from the rotary table to the keel. A mathematical model of the requirement, developed by Dr. Thad Vreeland of California Institute of Technology, developed a structure about 80 ft long, supported at its upper end only, with a constantly varying section modulus and a constant radius of curvature under side loadings. The result was a long, tapering tube of fixed inner diameter and constantly varying section modulus. It is in two pieces for ease of handling and is supported by the saddle at the main deck level of the horn which also supports the portable upper half of the horn. While simple in requirement, it proved sophisticated in design and fabrication. The final structure was forged in two pieces out of HY 140 steel by Jorgensen Iron Works, Seattle. HY 140 was selected since it was considered to best meet the three principal requirements of high fatigue life, weldability, and high strength. Since the loss of a drill string would represent a loss of nearly $200,000, drastic steps for its preservation are justified. Fig. 8 diagrammatically illustrates these structures.

Propulsion and Thrusters

Estimates of resistance for both propulsion and positioning were verified by model tests in the first case and by a dynamic simulation analysis for the latter. The power requirement to sustain a 12½-knot speed was established at 2250 hp per shaft. Positioning power was based upon maintaining location in a 45-knot head wind coupled with a 1½-knot cross current. While efficient use of dynamic positioning power depends upon intelligent orientation of ship to sea conditions, it was also estimated that the vessel could maintain position in a 35-knot beam wind. Power per thruster was established as 750 hp, which provides approximately 18,000 lb of thrust per thruster.

Main Propellers and Shafting

The three GE model 752 DC traction motors per shaft each produce 750 continuous horsepower. With a 5.1:1 gear reduction, the propellers utilize 2250 hp per shaft at 225 rpm. The propellers designed for this are 10 ft-0 in. dia, 6.7-ft pitch, three-bladed, stainless steel. The blades are elliptical, of modified ogival

/23

section with a BAR of 0.50 (developed) and blade thickness ratio of 0.050. The pitch distribution is constant and there is no rake angle.

Independent analysis using computer techniques confirmed the selection of the propellers as designed for propulsion, but it was noted that at full rpm incipient cavitation would cover about 1½ percent of the area of the back of the blade. This was not considered serious and no change in design was made since to do so would seriously affect operation in the positioning mode.

Performance of the propellers at zero velocity of advance was estimated to be 33,000 lb of thrust at 150 rpm (two propulsion motors) ahead and about half that in reverse. Again, an independent analysis was made which confirmed the design figures. In-service experience indicates performance matches predictions to an unusual degree.

Shafting is ABS Grade 2 forged steel. Tail shafts are about 32 ft long, 10 in. dia, with continuous 11¼-in. dia bronze liners in stern tubes and shaft struts. Exposed shafting between liners is covered with epoxy-reinforced fiber glass. Line shafts are about 14 ft long by 10 in. dia, coupled to the tail shafts by rigid split couplings. Stern tubes and shaft struts have Goodyear "Cutlass" bearings.

Reduction Gears

The 5.1:1 reduction between propulsion motors and shafting is provided by Philadelphia Gear Corp. model 30 HMGH single-reduction, horizontally offset gears. The double extension pinion shaft connects to one 750-hp traction motor aft and two motors in line forward. Shafting and motors are coupled with suitably sized Thomas Flex couplings.

An electrically driven lube oil pump, an oil filter, and cooler are mounted on each gear case.

Thrusters

The four fixed thrusters are Schottel model S300, four-bladed, 59 in. dia, 35½ in. pitch, generating about 18,000 lb of thrust at 545 rpm. The 2.57:1 right-angle reduction gear in each hub is driven by a spline-connected, vertically mounted GE model CD-6513 DC traction motor which develops 850 hp at 1400 rpm. Lubrication is gravity-fed, totally filled, which provides circulation through heat generated in the gears and bearings.

Trials indicated marked cavitation at full rpm. Also, the very long tunnels forward (50-ft maximum) deteriorated the performance of the forward thrusters markedly, in spite of the tunnel diameters having been built larger (70 in. dia) outboard of the thruster shrouds. Trimming and shaping the forward thruster blade tips by about 1/4 in. on the diameter and increasing the pitch to about 37 in. alleviated the situation to the extent that bow and stern thrusters perform essentially equally at any given rpm.

Dynamic Positioning System and Controls

The technique of holding a fixed position, under power, at sea is commonly referred to as "dynamic positioning." This technique requires two engineering components not heretofore generally accepted as state-of-the-art marine systems:

(*a*) A means of providing an absolute and accurate "fix" with respect to the ocean bottom in any depth of water.

(*b*) A quickly responsive power plant, with infinite variation of power in direction and azimuth rotation, computer-controlled in an integrated system with the "fix" mentioned in paragraph (*a*).

Any experienced boat operator knows that it is quite easy to control a boat in the open ocean and to hold it quite steady in a seaway, practically motionless, when next to a buoy, anchor mooring, or any other stationary object. The amount of power it takes to do this is quite small. The only trick is to have a stationary reference point and to have good control of the power plant. In reality this is the only major problem of dynamic positioning.

The amount of power made available for dynamic positioning is a question of engineering judgment. The power actually developed, as measured in bollard pull tests, was 72,000 lb laterally and 30,000 lb fore and aft. Actually, at the time of writing this paper, sea experience with the *Glomar Challenger* has shown the design criteria (see section on Propulsion) were conservative. Beam winds of 45 knots and beam currents of 2 knots have been experienced without losing position. In the four months of operation to date (August to December, 1968) the *Challenger* has drilled over twenty holes in the sea floor (water depths 11,000 to 18,000 ft) and has not once experienced drilling problems or delays due to vessel motion in a seaway or inability to hold station due to weather.

Dynamic Positioning Power

There are three accepted methods of thrust thus far tried in the new area of dynamic positioning, with the fourth type of application in the experimental stage. They are the use of (1) Voith-Schneider cycloidal propellers, (2) fully rotatable outboard-type propellers, (3) fixed propellers (in or outside of tunnels), with method (4) being hydraulic nozzles using large centrifugal pumps for power. Global Marine chose fixed propellers primarily because of anticipated better reliability, and protection from drilling activities and from storms. There is installed a total of four transverse tunnel thrusters, two at the bow and two at the stern. Fore-and-aft thrust is provided by one or both of the main propellers. The bow thrusters are in relatively long tunnels (the longest tunnel is approximately 50 ft in length) and the after thrusters are installed in the centerline skeg (7 ft in width). The choice of two thrusters at each end of the ship instead of only

/24

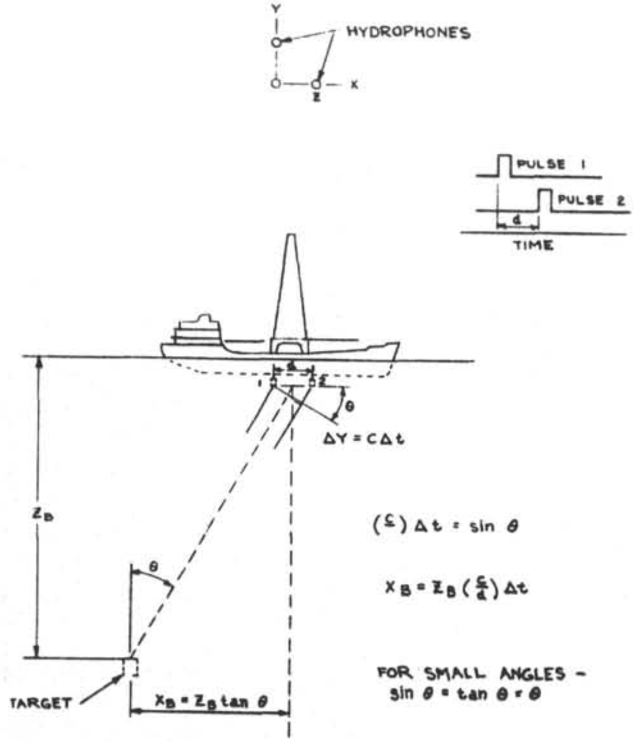


Fig. 9 Calculations used to determine position of beacon in relation to ship

one was to provide redundancy of power in the event of damage or failure of a thruster. In normal weather the ship is dynamically positioned by one thruster at bow and stern and one main screw operating at reduced power. The use of fixed thrusters means that more connected hp must be provided than would be required for the other two types, where the thrust can be made in the exact direction required. Although the connected hp is higher, the actual hp used is not appreciably different from that required by the directional-type thrusters.

Positioning and Propulsion Control Systems

In developing the overall concept of a self-positioning vessel, considerable research was entered into in an effort to select a positioning system that would, first of all, be dependable under the most adverse conditions that might be encountered. No commercially available equipment was found that had been proven in water depths greater than 6000 or 7000 ft. A number of well-known companies in the electronics field were found to be engaged in development of systems; however, only one, the AC Electronics Division of General Motors, possessed a system which had previous sea experience and which seemed immediately available and adaptable to this ship.

Therefore, the system chosen for primary ship positioning control was the AC Electronics package. The principle of operation of this system is quite simple, and is basically the same as proposed by other manufacturers. The ship is provided with four hydrophones installed in the hull at the four corners of a square. These hydrophones are for listening only, and are peaked for reception of sound waves centered at 16 kHz. The spacing on each side of the square is dependent on the width of the hull, but in any case is kept as great as possible. A suitably rigged sonar beacon, with self-contained batteries, is dropped over the side, falling to the ocean floor at the selected site. This beacon is automatically triggered at a fixed pulse rate, and radiates 16-kHz sound waves of fixed duration (40 milliseconds). The beacon is provided with a baffle and reflector to direct the sound wave front toward the surface of the water. If the vessel is positioned precisely over the beacon, the sound wave front will arrive at all hydrophones simultaneously. If the ship is not directly over the beacon, the wave front will arrive at the nearest hydrophone first, and a number of milliseconds later at the other hydrophones. This difference in time of arrival of the wave front is suitably processed, as will be discussed later, changed to X and Y coordinate information, see Fig. 9, and finally converted from analog to digital-type information. It is then inserted into the computer, which serves the primary function of determining corrective action by the ship's propulsion system to maintain the ship in the selected position.

The installation, as finally completed, involves considerable additional equipment to obtain the necessary sensitivity to weak signals, freedom from spurious or false signals, reliability, and redundancy. Although four hydrophones are installed, three provide the necessary angular information; therefore, switching is provided permitting selection of any three hydrophones for use, with the fourth hydrophone considered to be a spare. Because of the low signal level at the hydrophone when operating in extreme depths of water, a transistor-type, battery-operated preamplifier is provided for each hydrophone. The output of each preamplifier is carried by coaxial cable to the main equipment location, the computer room. Switching between selected hydrophones is accomplished at this point, and the selected hydrophones are each connected to a signal processor. The signal processor is basically a low-frequency receiver, peaked to provide maximum gain at a frequency of 16 kHz. The output of each signal processor is next inserted into a 16-kHz filter and thence into a slope detector. From this point the signal is verified for pulse shape and duration and fed into an accumulator, which, in conjunction with a precision clock, compares signal arrival times and computes the digital angle.

In computing the digital angle, certain corrections are required because of the effect of the ship's roll and/or pitch on the angular accuracy of the hydrophone. Two small gyros, one in use and one on stand-by, are located at the ship's center of roll and pitch. Movement of the ship from a normal level plane causes the gyro to develop signal voltages which are transmitted

/25

to the digital angle computation unit and related to the angle developed by the beacon signal. The corrected angle information is now transferred to storage registers for readout by the control computer. The output of the storage registers is also converted to an analog voltage for use in a visual display at the pilothouse control console.

Direct operator control of the positioning system is done at the control console located in the pilothouse (see Fig. 10). This console contains a five-inch oscilloscope upon which is displayed the beacon's position in relation to the ship in either true or relative position mode. A ship's heading gyro repeater, with manual facilities for inserting the desired ship's heading information, and an indicator which displays any deviation from the commanded heading are also a part of this console. Facilities are provided here for manually inserting any desired offset from the beacon's position in the event it is desired to position the ship other than directly over the beacon. This control operates by inserting calibrated time delays into selected signal circuits, thus simulating an angle change. Insertion of water depth, which is essential in calculating the angular position of the ship, is accomplished by operation of the appropriate control on this console.

The control digital computer, which accepts the previously generated information and performs all the numerical computations and control functions to dynamically position the ship, is a Scientific Data System model Sigma 2. A number of analog-to-digital and digital-to-analog converters are a part of the installation to provide signals of the proper characteristics into and out of the computer.

Certain additional information is required to be inserted into the computer to insure that the calculations take into consideration all of the physical conditions affecting positioning of the vessel. Contact closures within the propulsion switchboard provide a signal indicating whether the port or starboard screws are in use, and whether one or both thrusters in the bow or stern are on the line for automatic control. This signal, in the case of the main propellers, permits the computer to develop a control voltage biased to overcome the tendency of the ship to swing when only one propeller is in use. Similarly, the command signal to initiate thrust power is modified to suit the added thrust developed when both thrusters are in service.

The control signals developed by the computer are converted to analog voltages, with a value within the range of 0 to 10 volts DC. Zero represents zero thrust or propeller turns, while 10 volts represents 100-percent thrust, or maximum propeller turns. The polarity of this signal remains constant. Change in direction of rotation of the controlled motor is accomplished by a contact closure within the positioning circuitry which ultimately reverses the associated generator field current. The normal open condition of this relay represents an ahead movement of the ship's propellers, and a starboard thrusting force of the associated thruster.

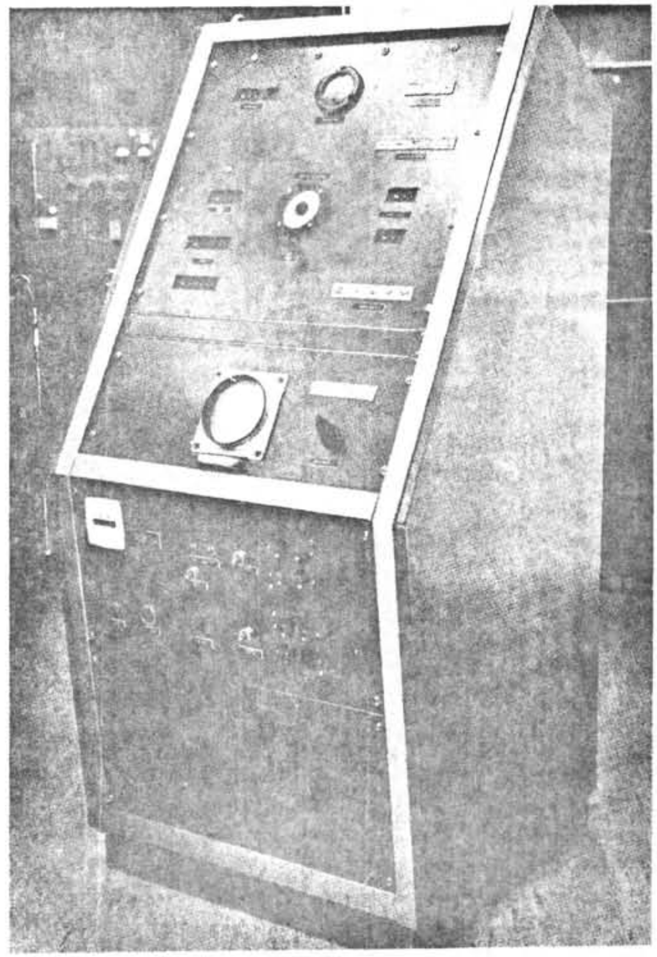


Fig. 10 Dynamic positioning control console

To provide some degree of backup permitting operation of the vessel in the event of failure of the system just described, a decision was made to install the positioning equipment developed by the Honeywell Corporation originally for use on the Mohole program. This equipment was to be for stand-by use, since it had never operated in water depths to be encountered by the *Challenger*. The principle of operation of this system is quite similar to that of the AC/DRL system except that, instead of a pulsed signal, a continuous wave signal is emitted by the beacon, and the frequency selected was 10 kHz. At the receiving end, a measurement of phase difference of arrival of each cycle at the hydrophone is converted into angular information. Modifications to the equipment to make it compatible with the AC/DRL system consisted of providing voltage scaling in the output circuitry to the analog/digital converters of the AC/DRL system. The hydrophones provided with the AC/DRL installation were found to be sufficiently broad in frequency response to provide the required signal sensitivity at the lower frequency; however, the preamplifiers were bypassed, and the 10-kHz signal was fed directly into the Honeywell equipment.

/26

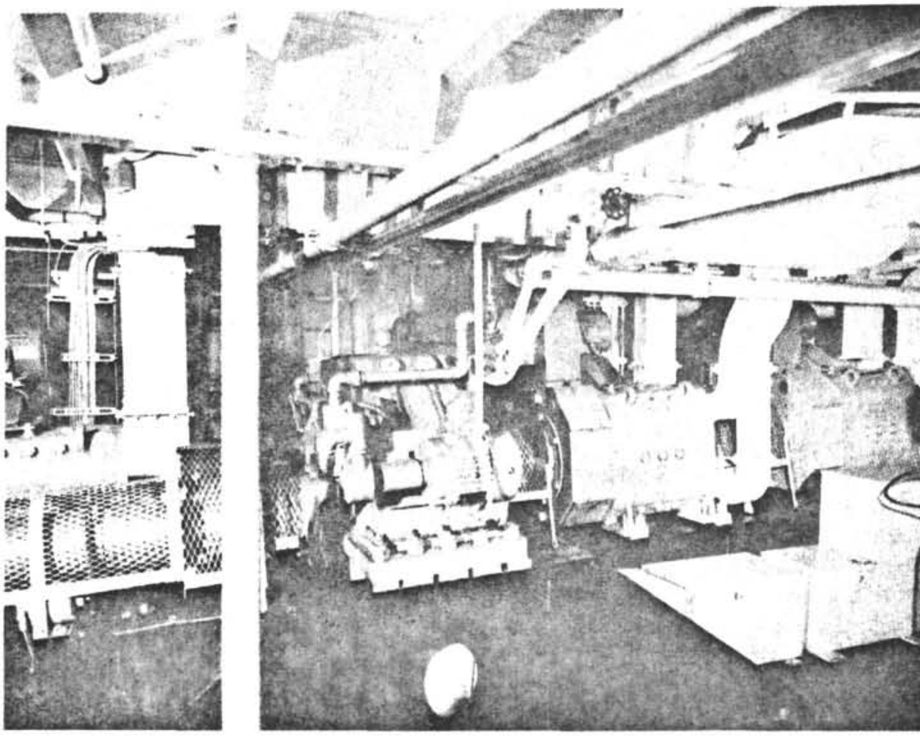


Fig. 11 Main reduction gear, center, with one DC traction motor to left and two motors to right, driving common double-ended pinion shaft

A number of problems usually associated with "firsts" were encountered during checkout and preliminary testing. Although the ship's service AC power operated within a three-percent maximum variation from the designed voltage, some disruption of computer operation was observed. Because of this, electronics-type voltage regulators were installed in both the computer and the electronics equipment power lines. The type chosen provides regulation within one percent, and corrects on the first half cycle.

Another problem which consumed a great number of test hours before a solution was obtained involved the sudden erratic transmission of command signals by the computer without apparent cause. This was eventually traced to large DC signal spikes which developed in the propulsion switchboard when certain contactors operated. These spikes traveled through the signal lines back to the computer, and were of sufficient amplitude to appear as an input signal to the computer. R/C filters, with isolating relays where required, were installed in all signal lines between the computer and the DC switchboard, eliminating the spikes.

The initial design of the listening hydrophone installation provided means of extending the hydrophones as far as 20 ft below the hull. This design was based on information developed during the original Mohole project. In actual tests, which included measurements of sound and interference levels, it was determined that the hydrophones operated most efficiently when almost flush with the hull. Apparently certain reflections from the hull were being picked up by the hydrophones and either cancelling direct route signals or causing false signal reception. We feel that further experience may prove that different depths of water and different operating conditions will require changes in the vertical positioning of the hydrophones. Sound measurements tests also disclosed that cavitation of the thrusters at high rpm tended to interfere with signal reception in extreme depths of water. Because of this, upon drydocking of the *Challenger* in Hoboken in September, the thruster propeller blade tips were altered, and all nonfaired surfaces in the thruster tunnel and around the thruster housing were carefully faired. Measurements subsequent to this work showed a 10 to 12-db reduction in noise level.

One problem which developed on trials was caused by the extremely rapid response of the static exciters to signal commands from the computer. On signals demanding a large increase in thrust, or high propeller rpm, the reaction of the exciter placed a load on the generator that exceeded the diesel recovery time, lugging the engine down. Upon achieving demanded power, on occasion the diesel governor overspeed trip would actuate, dropping the engine off the line. To overcome this, a time-delay electrical network, consisting of a timing resistor and a large capacitance, was installed. This network eliminated the engine lugging and dropout problem, and improved the smoothness of control generally.

Other malfunctions and operational difficulties encountered during the checkout period and the first few months of operation consisted of minor equipment failures, improper computer programming, and the usual "learning errors."

Electric Power System

Because of the very satisfactory experience and service with DC traction-type drilling motors, it was decided to develop the propulsion and positioning plant based on these motors. Three motors are provided on each main propeller shaft and one motor for each of four thrusters (total of ten motors for propulsion and positioning). Fig. 11 shows the method in which three of these motors are used in tandem with the reduction gear to drive the propeller shaft. Among the advantages associated with the use of these motors are extreme long life, reliability, and economy, with the added feature of interchangeability with any of the ship's seven drilling motors. Motors of the drilling type were not available with suitable thrust bearings to permit vertical operation, so the thruster motors are DC motors of similar characteristics and rating, with high-capacity thrust bearings. All motors are conservatively rated 750 continuous horsepower at 1200 rpm, with intermittent drilling rating up to 1000 hp. The associated drilling generator has also proven to be a rugged unit, and, with the proper switching facilities, serves a dual purpose since it may be switched to either drilling or propulsion service.

General Electric model 606 generators were chosen to develop the direct current, each being driven by a Caterpillar D-398B, 12-cylinder diesel engine. These generators are each capable of continuously supplying 800 horsepower to a motor load but are limited to 750 horsepower by field limiting controls. Eleven generators are installed with switching facilities, with a twelfth stand-by generator available but not tied into the main control panel.

Control of motor revolutions and power is accomplished by means of a modified Ward-Leonard system. One DC generator, with voltage and current characteristics matching one associated motor, is used. The motor is provided with an independent fixed shunt field, while the generator shunt field is supplied from a separate variable source. By means of suitable switching, the generator armature terminals are connected directly to the motor armature terminals. With zero voltage on the generator field, no voltage is developed and the motor does not rotate. By applying voltage to the generator field and gradually increasing the field current, the generator output increases to maximum, as will the motor power output. Reversing the motor may be accomplished by changing the polarity of the generator field. Since the field current does not exceed approximately five amperes for full output of a 750-hp motor, it can be seen that very simple controls are required. The system of one generator to one motor has a high degree of reliability and excellent torque and rotational speed control, but does require a large number of independent generators.

The *Glomar Challenger* installation provides each generator with a heavy-duty armature switch, permitting transfer of the generator output between several propulsion or thruster services and drilling service. The generator field control is transferred simultaneously so that the service to which the generator has been switched has controlled motor output.

Because of the rather precise control requirements inherent in the automatic positioning system, a number of refinements and modifications were found to be necessary. A means of controlling the generator output with the 0 to 10-volt computer signal was devised using General Electric amplistats to control the firing of a silicon-controlled rectifier (SCR) which serves as a field power source for an associated generator. Referring to Fig. 12, note that the SCR package contains a number of input signal circuits. The input circuit designated "Bias" determines the "at rest" operating condition of the SCR. This is adjusted in conjunction with the input marked "Cont Signal" to provide the range of output voltage necessary to control the generator from 0 to 100-percent power output. The "Over Current" input samples the voltage drop across a resistance in series with the motor armature. When this voltage exceeds a predetermined value, the signal input here will tend to reduce the exciter output. The "Feed Back" input samples the attained motor rpm as indicated by the tachometer generator and levels the exciter output to a value that maintains the ordered motor rpm. The final input signal operates on voltage fluctuation or circuit instability and develops a signal which is essentially in opposition to the disturbance. Note that the signal to this input is picked up directly across the motor armature terminals, then reduced in value and filtered before being applied to the exciter.

When manual control of the propulsion plant is used, a ten-volt signal, developed across a voltage divider connected to the 120-volt motor field supply rotary exciters, is connected to the outer terminals of a throttle potentiometer. The slider of this potentiometer then is used to pick up the desired value of voltage. Transfer switches permit this function to be controlled from either the pilothouse or the generator room.

Ship's Service Power System

Power for operation of the ship's auxiliaries such as pumps, air compressors, ventilation, heating, cooling, and hotel services is provided by three main AC generators, each rated at 500 kw. The primary generator voltage is 450 volts at 60 cycles, three phase, and frequency stability is maintained at less than three percent by means of static voltage regulators. In port, under average conditions, 300 to 350 kw is the generator loading. Under drilling conditions with mud mixers and other drilling machinery in operation, the load may increase to as high as 750 kw. These con-

/28

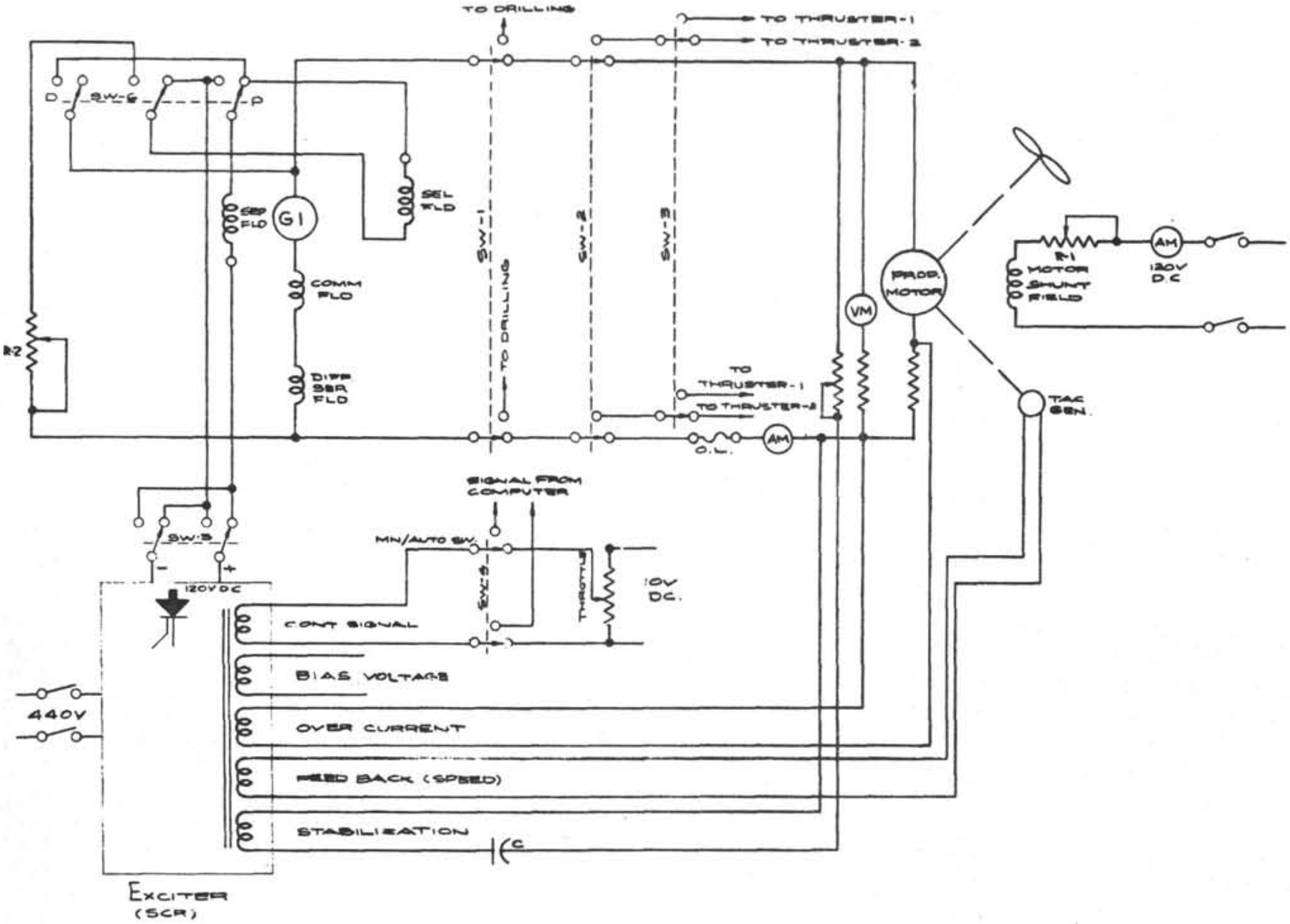


Fig. 12 Typical control and switching arrangement for a single generator-motor setup

ditions permit use of a single generator in port, with one or two in use when underway or during drilling operations. The total connected load on the AC system is approximately 1650 kw; thus the above conditions indicate a use factor of 0.45. The overall power factor under the 750-kw load condition is estimated to be 0.77.

Control of the generators and distribution of the AC power are effected by means of a single main switchboard, into which are incorporated all motor starters (57) except those which are a part of the air-conditioning systems, and those serving the boat winches and the anchor windlass. Generator controls occupy the six center switchboard sections, three containing electrically operated generator circuit breakers and three containing the individual generator controls, voltage regulators, and metering.

Each motor starter, with its associated circuit breaker, is provided with facilities to permit ready removal and/or replacement by means of suitable "stab-in" contacts. These "stab-in" units are less than nine inches from front to back, and are installed in both front and rear of the switchboard. Locking facilities are provided on each circuit breaker to insure that power may not be inadvertently reapplied while work is being done at the motor location.

A section of the switchboard contains the shore power circuit breaker and a phasing relay which prevents closure of the shore power breaker if the shore power applied is not properly phase-matched. The capacity of the shore power circuit is 250 kw.

Power at 115 volts for ship's lighting as well as 208 volts for small appliances is supplied by means of a 300-kva, delta/wye connected, dry-type, air-cooled transformer. A section of the main AC switchboard provides distribution facilities for this lower voltage.

A 350-kw, diesel-driven, emergency generator with automatic air starting and load transfer is installed on the superstructure deck. Associated with it is the emergency switchboard, emergency lighting transformer, and line voltage regulators for those loads sensitive to minor voltage variations.

Power is normally supplied to the emergency switchboard from the main switchboard by way of the bus tie circuit breakers. Distribution is accomplished by means of the various emergency load circuit breakers on the emergency switchboard. In the event of a power

/29

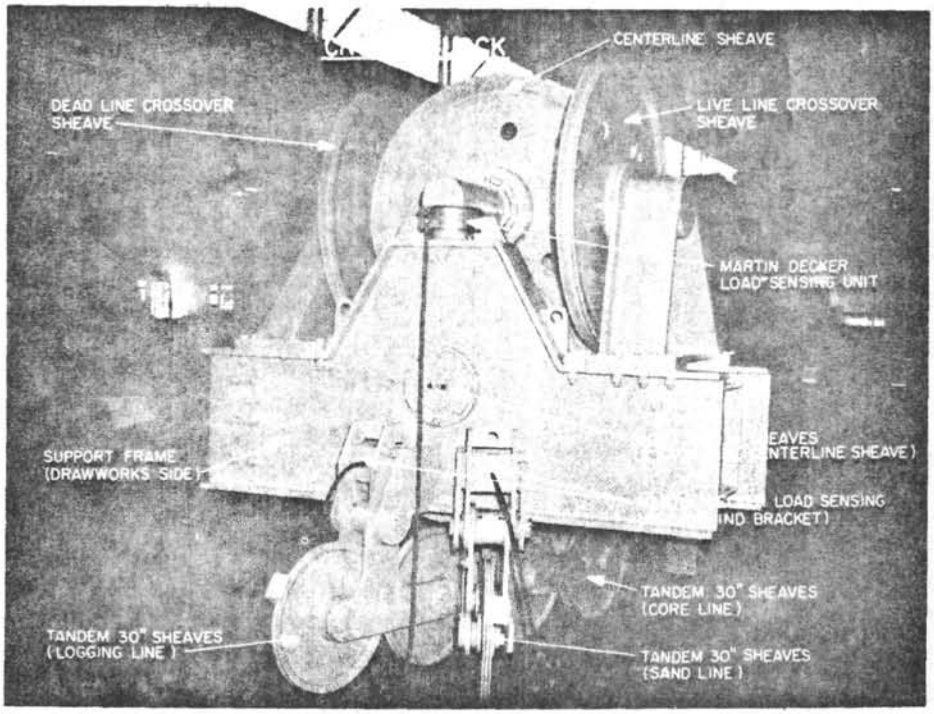


Fig. 13

failure, the emergency generator is programmed to start and develop full voltage in less than 16 sec. Upon development of 85 percent of full voltage, the automatic transfer of power is accomplished, and the emergency generator assumes these loads. In addition to those loads normally required by regulatory bodies to be supplied from an emergency source, all units of the positioning system, excitors and control voltages for the propulsion and drilling systems, and derrick lighting are connected to the emergency source. These additional loads have been connected to the emergency source since, in a vessel whose prime function is drilling, an emergency may be confined to the drilling area. Furthermore, in an emergency involving the ship's safety, it is often necessary to withdraw the drill string from the hole or take other action in connection with the drilling system.

An interesting feature of this installation was the use of a common exhaust trunk for all diesel exhausts. All 12 diesels tie tangentially into a cylindrical exhaust chamber where the exhaust gases are given a spinning vortex as they start up the exhaust trunk. Each exhaust line has a quick-operating shutter valve before it enters the exhaust trunk. As designed and in actual service, the exhaust gases create a slight negative pressure within the trunk, and repairs have been carried out on earlier vessels of the class with open exhaust pipes, without back pressure or contamination of the engine room from the exhausts of others that were running. Circulating water is pumped from high or low sea chests with salt water running to each diesel in parallel, each engine having its own jacket water and aftercooler heat exchangers. Lubricating oil is cooled by jacket-water heat exchangers. No attempt was made to utilize waste heat for other purposes.

Drilling System

The taking and retrieving of cores from below the ocean floor in deep water (up to 20,000 ft) as compared to exploratory drilling for hydrocarbons, in shallow water, has required design changes in both equipment and procedures. Several of the major modifications would not be apparent to the casual observer.

The discussion of the drilling system will cover the hardware and its design based on the needs to meet the coring program. Down-hole tools are not included. The drilling system is subdivided into derrick, including the traveling block, swivel, power sub and guidance system; subbase-rig floor equipment; pipe racker; piping systems relating to drilling; and miscellaneous.

Derrick

The GMI dynamic 142-ft derrick, 1,000,000-lb rated capacity, as designed for the *Glomar Grand Isle* class, was determined adequate to handle the anticipated drilling loads.

The 500-ton rated capacity, National special type 760H crown block (Fig. 13), as used on the *Grand Isle* class, was modified for this project. The most significant feature is the addition of a Martin-Decker sensing element on the support of the center sheave. The prime purpose was to provide a more sensitive weight indicating system for the traveling block during

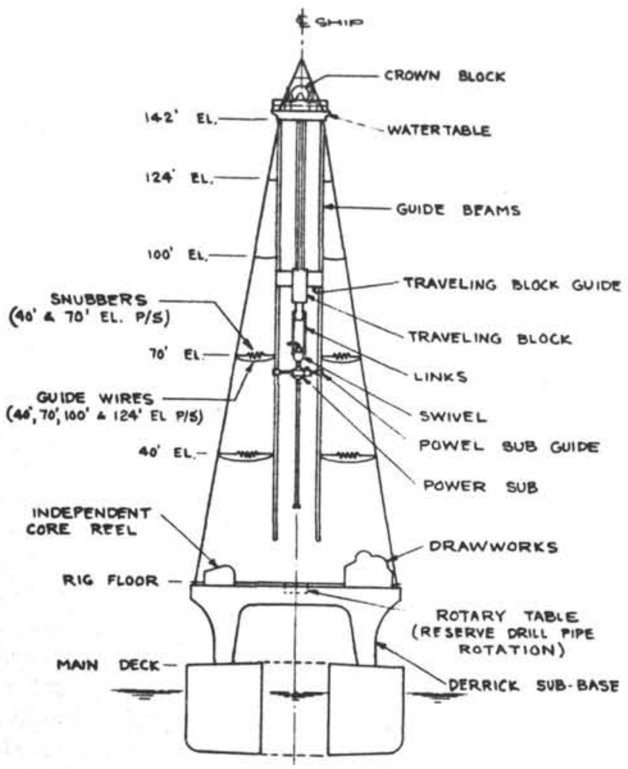


Fig. 14 Derrick drilling equipment

hoisting or lowering loads. The crown block has a total of seven 60-in. sheaves for the 1½-in. drilling line. Five of these sheaves are mounted with the shafts 90 deg to the centerline of the vessel. The center sheave in the group of five has an independent shaft mounted above the shaft that is common for the other four sheaves. The remaining two sheaves are independently mounted and are used as crossover sheaves; one is for the live line and the other for the dead line. This is the manner by which the traveling block can be reeved 90 deg to the drawworks. The shaft of the independent single sheave (located on centerline) has a hinged support on one end, with a simple support at the opposite end where the sensing element is mounted. The three sets of tandem 30-in. sheaves are mounted on the side of the crown block skid beams. Two sets of sheaves are located on the drawworks side of the block (starboard) and the other is located on the opposite (port) side. Each of these sheave frames has sensing units in its supports to provide an accurate measurement of line loads. These tandem sheaves are for the sand line, core reel line, and the logging line. The frames are attached to the crown block frame in such an arrangement to permit any one of the three ½-in. wire lines to be approximately on the vertical centerline of the derrick. The mounting of the sensing element on the center sheave limits the reeving of the main traveling block to either a 4, 8 or 12-part line.

Fig. 14 shows diagrammatically the arrangement of principal drilling components in the derrick. The traveling block is a National special-type 660J500 connector block rated at 500 tons. A 4⅛-in. hole is located on the vertical centerline of the block. The connector shank is hollow (4⅛ in. hole) to allow passage of wire line and coring barrel. The traveling block is of a split design to provide the space for the hole. The tongue that normally is located on the connector shank and used to carry the bail of the swivel was eliminated. The ears that normally are used only to carry the links for the elevators have been pressed into service to accommodate the swivel on the links as well.

The swivel, a modified National 1324, is hung below the traveling block using 3½ by 144-in-long links rated at 500 tons. The bail of the swivel was replaced by ears to receive the links.

Connected directly below the swivel is the Bowen power sub, model SP-4. This is the primary power for rotating the drill string and it can develop up to 28,000 ft lb of torque, more than adequate for the coring operation.

It is noted that the modification of all the foregoing equipment was for the sole purpose of passing the core barrel through a 4⅛-in. hole in each unit.

To prevent the traveling block, swivel and power sub swinging horizontally within the derrick, from roll and pitch of the vessel, a guidance system is built into the derrick. The guides consist of two fabricated beams supported from the watertable beams by hangers. The beams are located 13 ft on center, port and starboard of the centerline of derrick. The guide beams are tied off to the derrick with one-inch galvanized wire rope at the 40, 70, 100, and 120-ft levels. At the 40 and 70-ft levels, spring-loaded snubbers are mounted between the guide beams and the derrick. Without snubbers the guide beams could swing into the sides of the derrick. All inertial loads from the traveling block are transmitted to the guide beams which in turn are restrained by the one-inch guide wires. The relatively flexible guide beam supports (by wires and spring snubbers) reduce shock forces which would otherwise be transmitted into the derrick as vibrations were these supports fixed, solid stays. The traveling block and the power swivel transmit all loads to the guide beams through a fabricated guide assembly mounted on each side of the traveling block and power sub. Six sets of rollers at the guide beam side roll within the guide beams, transmitting forces of the traveling block to the guide beams.

The combined traveling block and guide roller assembly are free to move vertically but restrained from horizontal motion. The core barrel with its retrieving wire is threaded through the traveling block, swivel, power sub, and through the drill pipe. The core barrel can be run at any point in the drilling of the hole. This means that the traveling block could be at any location in the derrick. The core barrel requires manual guidance to feed it through the traveling block. This is provided by a man-lift, comprising a cage with wheels that run in an auxiliary set of guide beams attached to the main guide beams. The motive power is provided by an air tugger with automatic brake, mounted at the 70-ft level in the derrick, with a double wire line running up to a system of 12-in. sheaves in the watertable and back down to the man-lift. Two valve locations control the operation of the man-lift. One location is on the man-lift, and the second location at the rig floor at the aft port derrick leg. Either station can operate the man-lift.

To assist the derrickman in racking the drill collars in the derrick at the 85-ft level, an air tugger is provided with a remote control readily accessible to the derrickman. The upper end of the drill collars can be pulled back into the finger racker more safely and efficiently than heretofore.

Sub-Base, Rig Floor

The derrick and rig floor are supported by the subbase. The lower end, below the main deck, is an integral part of the ship's hull structure. The subbase is designed for the dead load of the drilling equipment, dynamic loadings, plus the rated load (1,000,000 lb) of the derrick or a 1,000,000-lb load at the rotary table, but not both 1,000,000-lb loads simultaneously. Fig. 15 is a diagram of the general arrangement of the main members of the subbase. For clarity, many of the bracing members have been omitted.

The two stress-relieved box beams running longitudinally, approximately 13 ft center to center, support the rotary table. The end reactions of the box beams are carried by the forward and aft arches located at frames 91 and 110. The arch at frame 110 in reality is two separate units. This provides a slot opening in the aft side of the subbase for future handling of BOP stacks. The forward and aft transverse arches are tied together by two longitudinal arches located 20 ft off centerline, P/S. The derrick base plates are located at each corner.

A National 1625-DE drawworks, 1½-in. drilling line, is located on the starboard side of the subbase facing inboard. The two changes to the basic unit are: one, the sand line capacity is increased to handle 26,000 ft of 1/2-in. wire line; two, an Elmagco 3010 eddy current brake is added to the sand line reel.

Across from the drawworks on the port side of the subbase, approximately 4 ft aft of the centerline of the derrick, is the National wire line type "E" anchor with a Martin-Decker type E load cell. This load cell is a backup for the prime unit located on the center sheave in the crown block.

The rig floor is structurally framed around the drawworks, rotary, dead-line anchor, and the two ratchet assemblies that are part of the pipe racker. The top of the rig floor is 18 in. above the main steel of the subbase and is covered with 3 by 12 planking. Fig. 16 shows the arrangement of the rig floor.

Forward of the dead-line anchor on the port side is a National independent core reel, drum capacity 26,000

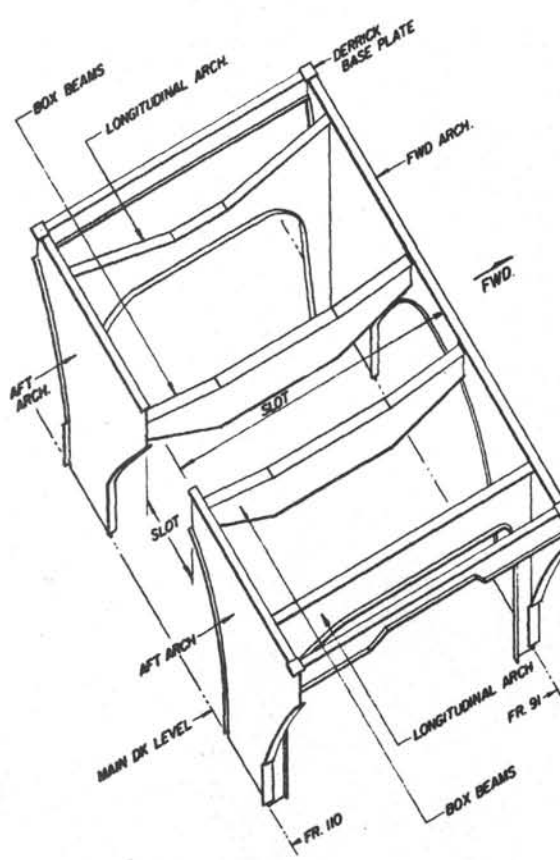


Fig. 15 Derrick subbase

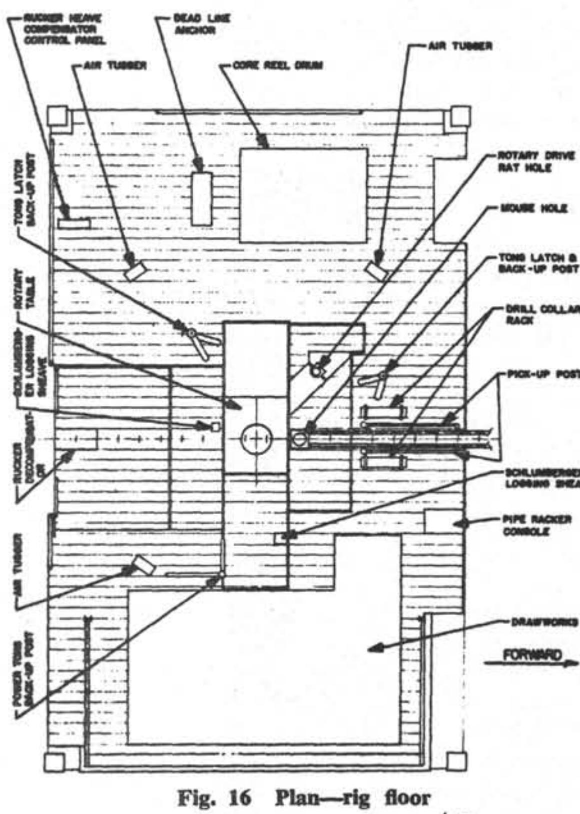


Fig. 16 Plan—rig floor

/32

ft of 1/2-in. wire line. This unit is a modified National 1625-DE drawworks sand line reel, skid-mounted. An Elmagco 3010 eddy current brake is added to the standard mechanically braked system and is the prime brake for the system. Power for the core reel is supplied by two Denison 60 series fluid motors of 263 hp each.

A National model C-365 rotary table, driven by a GE 752 RI DC motor, mounted on a GMI-designed base, is located at the center of the rig floor. It is supported by the two stress-relieved box beams. This unit with its related kelly and kelly bushing is the backup equipment for rotating the drill string; the prime source of rotation is the power sub. To improve on the round trip time and to eliminate slips, an Ideco dual elevator system is mounted on the rotary table.

To assist the rig floor personnel in handling the lower end of drill pipe coming to or leaving the rig floor, a hydraulic-operated pipe stabber, GMI-designed, is provided. It is located on the centerline of the vessel, forward of the rotary table. The head of the unit does not rotate as in previous models. Its sole purpose is to take the lower end of the 90-ft stand of drill pipe after breakout at the rotary table and move it forward to the skate for transportation to storage in the pipe racker. Conversely, it will handle pipe from the skate to the rotary table for make-up of the drill string for drilling.

The mouse hole, a 10 in. pipe, is located forward of the rotary table on centerline. It extends through the drillwell to the bottom of the vessel, with the bottom end open to the sea. The mouse hole is open to permit a 60-ft stand (two joints) of drill pipe to be inserted. A mouse hole spider is provided to support the upper end of the drill pipe. The upset on the drill pipe lands on the spider and the spider has a taper on its outside diameter to match the taper on the upper 10 in. of the mouse hole.

A rat hole, for storage of the swivel and power sub, is located at a 45-deg angle to the centerline from the center of the rotary, forward and port. The unit is mounted on two wheels and rolls on tracks to move the swivel to and from the center of the rotary table. The unit is moved by a hydraulic cylinder with a 36-in. stroke.

Three Ingersoll-Rand HUL air tuggers of 2000-lb line pull, at 120-psi air pressure, are located on the rig floor. Two units are on the port side and one to starboard. They are for miscellaneous moving of equipment in the area of the rig floor.

Pipe Racker

The pipe racker is an upgraded version of those used on other vessels in the Global Marine fleet. The capacity is increased to handle 262 stands (triples) of range 2 drill pipe, approximately 25,000 ft. Without increasing the width of the conveyors, the number of stands of drill pipe is increased by stacking three high on the top. Previous conveyors have the drill pipe stacked two high.

The increased capacity requires a greater force to rotate the conveyor for loading or unloading. This is accomplished by using 1500-psi hydraulic cylinders. The other assemblies composing the pipe racker are powered by air cylinders and air motors. Three conveyors are located on either side of the ship's centerline. The conveyors are tied together by torque tubes at the outboard side. The torque tubes run back to the rig floor where the ratchet assembly furnishes the power to turn the conveyors.

During the unloading cycle the indexers control the loading of drill pipe to the skate, one at a time. The skate pushes the drill pipe to the rotary table, and the lift arm raises the rig floor end of the drill pipe for latching the elevator to the box end. The pickup post confines the drill pipe, limiting its sideways swinging, as it is lifted to a vertical position in the derrick. Throwouts are provided to load the conveyors, P/S, when coming out of the hole. After the skate travels to the forward end of the pipe racker with the drill pipe, the throwouts lift it to the conveyor. The derrickman selects which conveyor is to be loaded and controls which throwouts will be raised.

The skate rides in rails located on either side of the centerline of the vessel. The drive is provided by a 13-hp air motor with a 30-in. sheave driving a 1/2-in. wire rope, which in turn is connected to either end of the skate. A system of sheaves supports the wire rope between the drive sheave and the idler sheave at the rotary table.

Piping Systems—Drilling

The mud system in the *Glomar Challenger* is essentially the same as that in its sister ships. The major difference is the lack of a choke manifold, mud manifold, and an active mud tank. The drilling in the ocean floor is accomplished with salt water with no returns to the vessel. The salt-water drilling also eliminated the need for a shale shaker, desanders, and degassers. To force the salt water down the drill pipe to the rotary bit, two National N-1300, 7¼ by 16 mud pumps driven by two GE 752 RI DC motors are located on the inner bottom forward of the moonpool. Each pump is rated at 1300-hp input.

Six 2050-cu ft, pressurized, bulk mud tanks are located between frames 27 and 44 from the tank top to the main deck. Mud and weight material are used to provide mud "pills" for the core hole as required.

The mud system including suction and discharge piping has been installed below the main deck. The piping above deck is limited to the high-pressure mud lines to the derrick stand pipes.

Miscellaneous

To provide power to operate the National independent core reel and the power sub, a hydraulic power

/33

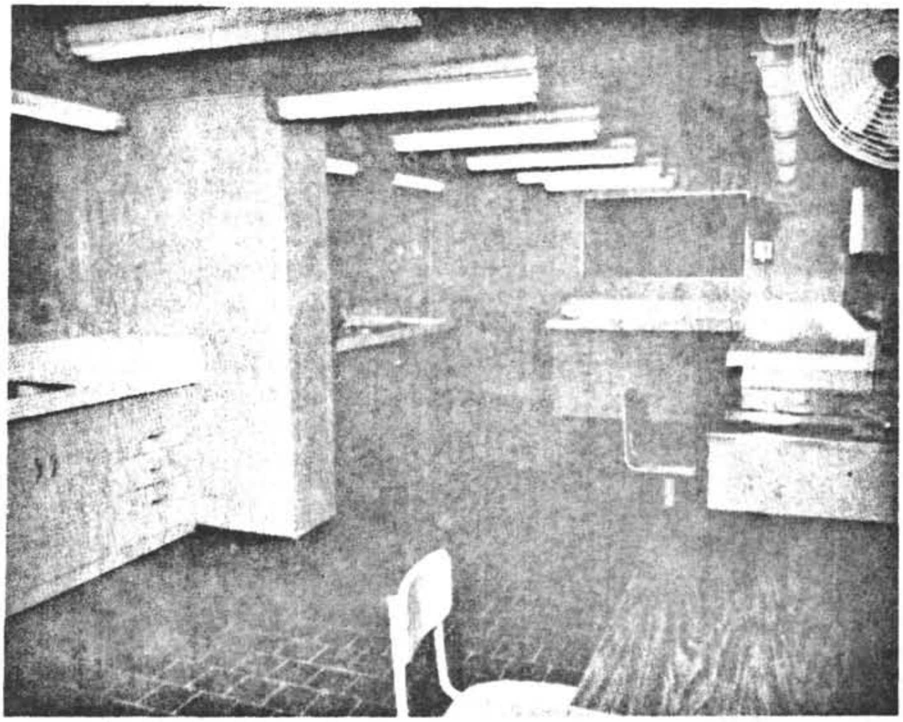


Fig. 17 Microscopy lab, typical laboratory outfitting

system is used. The power package is skid-mounted and located in the structure used for the active mud tanks on conventional drilling vessels.

The power system is really two separate hydraulic systems but with a common GE 752 RI DC motor driving two hydraulic pumps for each system. Either system can operate the other system through crossover valves that are normally closed to keep each system isolated. Each system is composed of two main pumps, a servopump to supply hydraulic pressure to the main pump servos, a replenishing pump to keep the hydraulic system supplied with ample, cool hydraulic fluid, and a replenishing relief valve. Maximum hydraulic pressure is limited to 3750 psi in the system to deliver 3500 psi to the power sub and core reel motors.

Accommodation, Outfit, and Miscellaneous Services

Accommodations and Hotel Services

The ship is comfortably outfitted for a total crew and scientific personnel of 68. Of these, 23 are Scripps scientists and electronics technicians. The Global Marine crew is 45, and includes a drilling crew of 14, 9 stewards and storekeepers, and a marine crew of 22.

Living spaces are generally on four deck levels with ship's officers and drilling supervisors on the superstructure deck, scientists and technicians on the boat deck, stewards and hospital on the poop deck, and crew spaces on the main deck. As proven desirable on all Global Marine ships, a common galley and mess serves all persons aboard. The one messing area on a working ship of this type has been found to improve crew morale and leads to a better exchange of ideas and information between all hands. The scientists have been provided with a separate library and lounge, which can be separated into two spaces for study, consultations, or other purposes. There has been provided more office and laboratory space than normally required for a drilling ship. Various labs and offices are as follows:

Electronics Lab
Scientists' Offices
Drafting Room
Scientists' Library and Lounge
Microscopy Lab
Sediment and Chemistry Lab
Thin Section Lab
Photography Dark Room
Electronics Shop
Core Lab
Refrigerated Core Storage

Fig. 17 shows the typical lab outfit, with quarry tile decking, stainless steel shelving and sinks, and high candlepower fluorescent lighting.

To expedite the handling of cores, an elevator has been provided extending from the core lab down to the lower hold, a total lift of about 42 ft. Refrigerated storage vans (total of eight), each with unitized Freon refrigeration compressors, are triced down to the tank top and provide portable containers for storage and later transportation of core samples. A ninth core van is stowed on the casing rack just outside the laboratories for temporary storage of cores while awaiting processing through the laboratories.

Because of the 60-day legs on each of the various coring expeditions, and since many of the areas traveled are relatively inaccessible, the ship carries a large complement of spares, tools, food and liquids. The refrigerated stores capacity of the ship is 2800 cu ft, enough for a 90-day supply of frozen and chilled foods. Two distillers are provided for potable and wash water, with a continuous capacity of 300 barrels per day, fresh water. Fuel capacity is also adequate for 90 days continuous operation.

Air Conditioning and Heating

The entire accommodation spaces and laboratories are completely insulated and sheathed, and are temperature-controlled by chilled water cooling and electric grid heating. Two 40-ton-capacity water chillers supply five air systems and five air handling units. There is one system for each deck for four deck levels and one system for the laboratory house. Because of the importance of the computer room, its cooling can be supplied by each of three separate air handling systems. The cooling and heating systems are designed to good marine standards for service in any climate, from arctic to tropic.

Life Saving Equipment

The *Glomar Challenger* meets all requirements of SOLAS 60 and US Coast Guard with respect to lifesaving equipment. Two lifeboats, one 72-person hand-propelled and one 70-person diesel-propelled, are aft on gravity davits. In addition, there is one 15-man inflatable life raft forward on the main deck, just aft of the forecastle, and two 20-man inflatable life rafts aft of the bridge wings. This is nearly double the regulatory requirements and provides quick and automatic-launching lifesaving gear for all hands. Of course, each person on board is provided with a life jacket, as well as life rings, hard hats, and other conventional safety equipment provided by both the oil and marine industries.

A 32-foot stock Equitable Equipment Co. diesel twin-screw work boat, outfitted especially for the *Glomar Challenger,* is carried on the starboard side amidships and is provided with a specially designed retractable bridge crane for launching and retrieving at sea in reasonable weather.

Cranes

Two rotating, diesel-powered cranes are provided on the port side, each one mounted on an elevated cylindrical pedestal nearly the height of the rig floor above the main deck. The forward one, just forward of the rig floor, is a 15-ton-capacity Unit Mariner with a 35-ft boom. Just abaft the rig floor is the 50-ton-capacity Unit Mariner with a 60-ft boom.

Ship's Service Equipment and Miscellaneous Outfit

In general, the layout and choice of pumps, compressors, winches, blowers, heat exchangers, and other equipment follows established marine practices with emphasis being placed on ease of maintenance, a complete backup system for all critical functions, and generally complete control of all machinery (except drilling equipment) by the ship's chief engineer. A function of high importance is the pumping of liquids within the hull to keep the derrick and drill floor level at all times. There are three compound manifolds, easily accessible in the pump room below the generator flat, for the pumping of drill water, fuel oil, and ballast water. On most drilling ships the trim is controlled by the pumping of drilling water, but since the *Glomar Challenger* has a large number of fuel oil tanks, her trim is more easily controlled by pumping fuel oil.

Steering of the ship is controlled by a Sperry electrohydraulic steering system with 5-in. rams by 33-in. stroke, with dual compressors and control wiring from the pilothouse. An after steering station, complete with control stand, is provided on the boat deck at the after end of the deckhouse. Twin spade rudders each with a lateral area of 80 sq ft turn the ship at a minimum turning radius less than one ship's length.

The following list includes the major ship's service auxiliaries:

Air Compressors (2)	Worthington, Model M80, 100-hp motor
Air Dryers (4)	Van-Air Dryers, misc. sizes
FO Transfer Pumps (2)	Blackmer, Model GX3, 3 x 3, 7 1/2 hp
FO Service Pump (1)	Blackmer, Model GL1-1/4, 1 x 1, 1 hp
Fire Pumps (2)	Ingersoll-Rand, Type 3 CRVH, 4 x 3, 40 hp
SW Circ. Pumps (2)	Ingersoll-Rand, Line No. 11, 12 x 11, 60 hp
SW & DW Transfer Pumps (2)	Ingersoll-Rand, Type 3 CRVL, 4 x 3, 15 hp
Bilge Pump (1)	Gorman-Rupp Model O3F-B, 3 x 3, 10 hp
Misc. FW Pumps	Ingersoll-Rand, Type 2 CRV, 3 x 2, 5 hp
Eductor Pump (1)	Ingersoll-Rand, Type 3 CRVH, 4 x 3, 25 hp
Ship's Anchor Windlass	Rebuilt surplus w/50 hp AC motor
Aft Warping Capstan	Rebuilt surplus w/30 hp AC motor
Vent Blowers (16)	Buffalo Axial type, miscellaneous sizes
Distillers (2)	Aqua-Chem, Model S300SPE-E
Freight Elevator	Robt. Gillespie Co. Type PWE
Engine Room CO_2 System	Walter Kidde, as per USCG requirements
Rig Floor Air Tuggers (9)	Ingersoll-Rand K4UL and HUL
Air Winches for Hydrophones	Beebe Bros., Model 5000P140-8AB

Conclusion

Considering that the research and design effort leading to the *Glomar Challenger* was the result of the efforts of private industry, without government subsidy, the concept, construction, and operation of the first full-sized, seagoing ship with dynamic positioning must be accepted as a remarkable achievement. The electronic de-bugging was far less than experienced observers noted to occur on even third or fourth units of a class of naval ships and, while there were troubles stemming from hurried technical analysis and compressed production schedules, the actual performance of the *Glomar Challenger* has exceeded all hopes. The authors are more convinced than ever that a dynamically positioned ship, coupled with other imminent technological accomplishments, will become an accepted tool for offshore exploratory drilling in far shallower water depths than met during the ASAP.

The truly remarkable accomplishment of Levingston Shipbuilding Co. in fabricating this ship within schedule and the intelligently hands-off but competent cooperation from Scripps in integrating the ship's scientific functions are gratefully acknowledged.

APPENDIX B

GENERAL MOTORS CORPORATION

Proposal For

Dynamic Ship Positioning System Equipment for a Deep-Sea Drilling Vessel.

GENERAL MOTORS CORPORATION

A PROPOSAL FOR

DYNAMIC SHIP POSITIONING SYSTEM EQUIPMENT FOR A DEEP-SEA DRILLING VESSEL

Submitted to
GLOBAL MARINE, INC.
Los Angeles, California

Permission to use ACDRL report entitled "General Motors Corporation, A Proposal for Dynamic Ship Positioning System Equipment for a Deep-Sea Drilling Vessel" has been given to Deep Sea Drilling Project by ACDRL.

AC ELECTRONICS - DEFENSE RESEARCH LABORATORIES

SANTA BARBARA, CALIFORNIA

P67-26

JUNE 1967

/38

CONTENTS

Section		Page
I	Introduction	1
II	Statement of Work	2
	Scope	2
	Deliverable Items	2
	Customer-Furnished Equipment and Data	3
	Inspection and Acceptance Testing	4
III	System Description	5
	Configuration	5
	Modes of Operation	5
	Typical Operation	8
	Equipment Description	9
IV	Simulation Study	17
	Simulation Results	33
V	System Installation	37
	General	37
	Electronic Equipment	37
VI	Related Experience	39
	General	39
	Ship Positioning and Precision Sonar System	39
VII	Facilities	43
	General	43
	Overall Facility Description	43
	Sea Operations Department Facilities Description	43
	Appendix	46

/39

ILLUSTRATIONS

Figure		Page
1	Dynamic Positioning System	6
2	System Elements	7
3	Control Console Arrangement	10
4	Digital Computation Equipment	13
5	Position Measurement Subsystem	15
6	System Simulation Conditions	18
7	Performance of Recommended Ship Positioning System for Conditions 1 and 2	19
8	Performance of Recommended Ship Positioning System for Conditions 3 and 4	20
9	Performance of Recommended Ship Positioning System for Condition 5	21
10	Performance of Recommended Ship Positioning System for Condition 6	22
11	Performance of Recommended Ship Positioning System for Condition 7	23
12	Performance of Recommended Ship Positioning System for Condition 8	24
13	Performance of Recommended Ship Positioning System for Condition 9	25
14	Performance of Recommended Ship Positioning System for Condition 10	26
15	Performance of Recommended Ship Positioning System for Condition 11	27
16	Performance of Recommended Ship Positioning System for Condition 12	28
17	Performance of Recommended Ship Positioning System for Condition 13	29
18	Performance of Recommended Ship Positioning System for Condition 14	30
19	System Performance for Maximum Controllable Quartering Wind	31
20	System Performance for 50 Knot Wind at Maximum Controllable Angle Off Bow	32
21	Axes System for Simulation	34
22	Simulated X-Axis Control Loop	34

Figure		Page
23	Simulated Y-Axis Control Loop	35
24	Simulated ψ-Axis Control Loop	35
25	Thruster Arrangement and Force Convention	36
26	Basic Hydrophone Mounting Technique	38

/41

SECTION I
INTRODUCTION

This proposal describes certain key elements of a dynamic positioning system for the Global Marine deep sea drilling vessel. A complete dynamic positioning system consists of three basic subsystems: position measurement, control and display, and propulsion. Although AC-DRL is proposing to provide only the display and control console, control computer, and acoustic position measurement subsystems, the overall dynamic positioning system, its operation, and expected performance is discussed for the sake of clarity and to show equipment relationships. To further strengthen the system design, AC-DRL has completed a simulation study, funded by Global Marine, for the complete system using experimental data on propulsion and position measurement performance. The results of the study are presented in Section IV.

The selection of equipment and design techniques is based on past AC-DRL experience with dynamic ship positioning systems. AC-DRL is presently evaluating a dynamic positioning system on the USNS MISSION CAPISTRANO, a ship similar in size and displacement to the proposed Global Marine vessel. The MISSION CAPISTRANO has been able to accurately maintain position when headed into 40 knot winds under sea state 6 conditions. This station keeping ability was demonstrated in an ocean depth of 12,000 feet, using an AC-DRL-developed acoustic position measurement system.

This dynamic ship position system, for which AC-DRL is the prime systems contractor, is

- The only proven operational dynamic positioning system for large ships
- Uses the only proven short baseline acoustic position measurement subsystem, also developed by AC-DRL
- The only dynamic positioning system to successfully operate from radio location signals
- The only proven dynamic positioning system which will satisfy the Deep Sea Drilling Project requirements.

This experience will be applied to the design of dynamic positioning equipment for the Global Marine deep sea drilling vessel.

/42

SECTION II
STATEMENT OF WORK

SCOPE

AC Electronics - Defense Research Laboratories (AC-DRL), General Motors Corporation, proposes to provide the necessary personnel, material, and facilities to design, fabricate, modify, test, and provide documentation for specific equipment of a dynamic positioning system for a deep-sea drilling vessel.

DELIVERABLE ITEMS

Hardware

AC-DRL will supply the following hardware:

1. Ship Control Computer (Digital)

   The computer is composed of the following:

   a. Central computation unit
   b. Interface equipment for the AC-DRL position measurement subsystem
   c. Interface equipment for the AC-DRL control console
   d. Typewriter input-output unit.

2. Ship Display and Control Consoles

   The consoles are composed of the following:

   a. Ship position command unit
   b. Positional display unit
   c. Ship heading command unit
   d. Ship heading error display unit
   e. Ship fore-aft, port-starboard speed command unit.

3. Acoustic Position Measurement System

   The short baseline sonar system, delivered to the National Science Foundation for Project Mohole, will be modified and updated. The modifications will consist basically of converting the system for operation with an acoustic beacon (instead of a transponder) and for output signal processing by the control computer.

/43

<u>Documentation</u>

AC-DRL will supply the following documentation:

1. Ship Control Equations

   Equations which relate the vessel dynamic characteristics and vessel position errors to the propulsion unit actions to eliminate errors in vessel position. These equations will be programmed into the ship's control computer.

2. Computer Programming and Interfacing

   Programming and interfacing required for proper interaction between the ship control computer, display and control console, and acoustic position measurement system.

3. Drawings (five sets, commercial format)

   a. Installation drawings describing mountings, clearances, and access requirements for electronic equipment.
   b. Installation drawings showing mounting recommendations for the hydrophones and vertical references for the acoustic position measurement system.
   c. Cable interconnect drawings showing cable connections and cable specifications.
   d. Equipment assembly and outline drawings. (Not manufacturing dwgs.)

4. Manuals (five copies, commercial format)

   The technical manual will delineate the requirements for operation, maintenance, installation, repair, and trouble shooting by qualified electronic personnel.

CUSTOMER-FURNISHED EQUIPMENT AND DATA

The following equipment and data are required by AC-DRL upon program initiation.

<u>Equipment</u>

The Project Mohole Short Baseline Sonar equipment, presently stored by NSF, to be modified by AC-DRL (see Deliverable Hardware, item 3).

Data

1. Number, type, and general description of thrusters
2. Thruster response rates and rpm-thrust relationship
3. Drawings of vessel size and shape and thruster location
4. Vessel displacement
5. Expected center of pressures for wind and current.

INSPECTION AND ACCEPTANCE TESTING

All deliverable equipment will be subjected to formal inspection and acceptance tests, to be conducted at AC-DRL's facility to assure proper equipment functioning. A formal test procedure will be prepared and submitted for customer approval five (5) months after initiation of the program. Acceptance of the equipment will be made at the AC-DRL facility upon completion of these tests. Customer representatives will be invited to observe.

DELIVERY POINT

All deliverable equipment and documentation will be supplied f.o.b. AC-DRL, Goleta, California.

SCHEDULE

All deliverable equipment and documentation will be delivered April 1, 1968 on receipt of order prior to September 29, 1967.

/45

SECTION III
SYSTEM DESCRIPTION

CONFIGURATION

The overall configuration for the proposed dynamic positioning system is shown in Figure 1. Those portions to be furnished by AC-DRL are indicated by the shaded blocks.

The acoustic position measurement system is a short baseline system originally built by AC-DRL for Project Mohole and supplied as GFE to Global Marine. The system will be modified and updated by AC-DRL to match the current state of the art, and to integrate it into the Global Marine system. Thrusters and main propulsion units including interfaces are to be supplied as CFE by Global Marine. Figure 2 shows the locations and actions of these various elements.

The dynamic positioning system is obviously not a simple set of hardware which can be placed on a ship and be expected to operate. Elements of the system are scattered throughout the vessel and must be properly located and integrated to result in a working system. Questions of location, cable routing, electrical background noise, supply voltages, etc., must be resolved and considered as part of the installation activities.

MODES OF OPERATION

The computation and display subsystem will provide signals to operate the overall dynamic positioning system in four modes: AUTOMATIC HEADING, AUTOMATIC POSITIONING, SEMIAUTOMATIC or MANUAL. The Automatic Heading mode allows the operator to select the ship's heading, which will be maintained automatically by the dynamic positioning system. This mode is used in combination with both automatic and semiautomatic operation. The Automatic Positioning mode enables the operator to select a desired ship's position relative to the ocean floor beacon, and the overall positioning system will maintain the ship at this spot. The selected position is described in an earth-oriented coordinate system centered on the beacon's local vertical and may be offset from the beacon's location by as much as 100% of the water depth. In this mode, the computer automatically generates control signals for the propulsion units, based on position signals generated by the acoustic position measurement system. The net result is to generate propulsive forces to maintain the ship at the selected position.

/46

/47

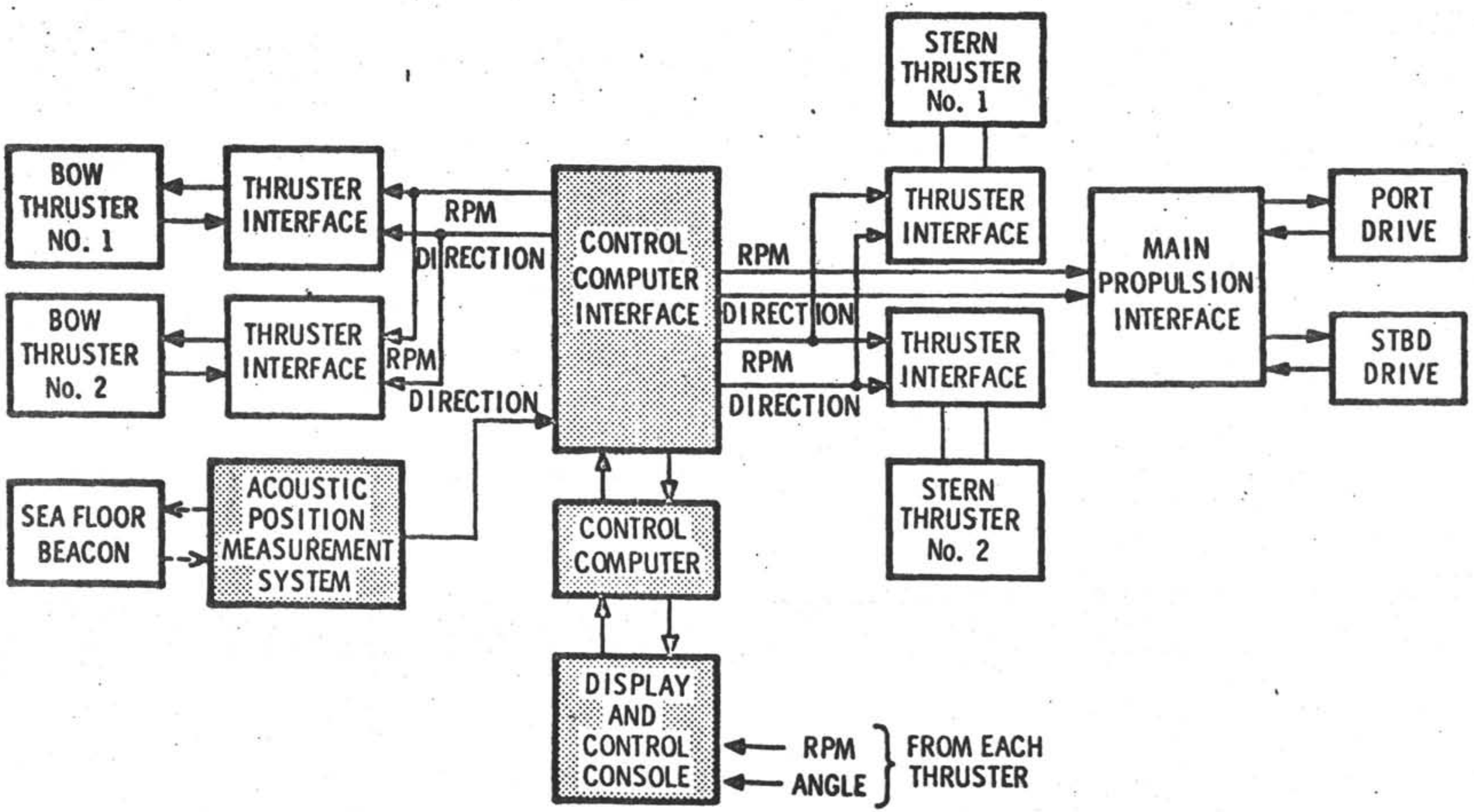


Figure 1 Dynamic Positioning System

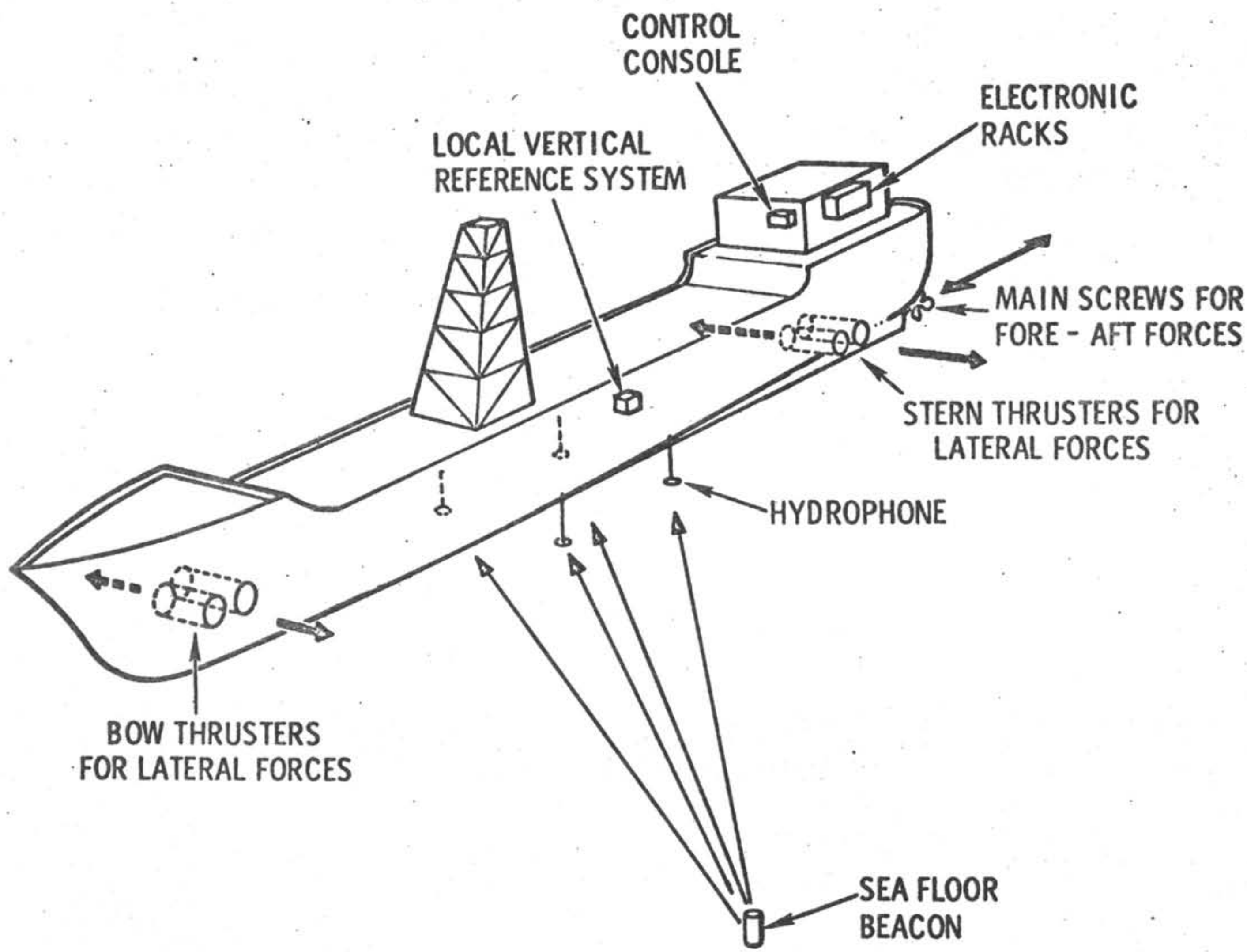


Figure 2 System Elements

In the Semiautomatic mode, the operator, in effect, replaces the position measurement system. Controls on the console allow the operator to command all combinations of fore-aft and broadside velocities. Thus, the operator can steer the ship in any direction while maintaining constant heading. This mode is useful primarily when maneuvering from one position to another during drilling operations.

In the Manual mode, control of the propulsion units is completely separate from the computer, and the positional display is used as a position reference. The operator directly sets the thrust and direction of each propulsion unit, using the ship's regular propulsion controls, located other than on the control console.

TYPICAL OPERATION

When moving into the operating area, a changeover from main propulsion (making headway) to station keeping is obviously required. Based on past experience, a good sequence to follow is:

- Activate dynamic positioning electronics
- Direct primary power to the lateral thrusters
- Place main propulsion on standby and allow ship to lose headway while pointed into prevailing weather
- Select a commanded heading to hold bow into weather
- Activate AUTOMATIC HEADING
- Prepare and implant acoustic beacon
- Activate SEMIAUTOMATIC, steer ship to near the desired position relative to the beacon
- Activate AUTOMATIC to allow ship to acquire desired position
- Proceed with drilling operation.

When changing position, it is not normally necessary to leave the AUTOMATIC mode unless changes of more than 2,000 feet are planned. New positions within this distance from the last may be established by setting the coordinates into the control console. Beyond 2,000 feet, the SEMIAUTOMATIC mode should be used, switching back to AUTOMATIC when within 2,000 feet of the desired position.

When deactivating the dynamic positioning system, the AUTOMATIC HEADING mode should be retained until main propulsion is available. This avoids falling off into the trough during the transfer period.

/49

PERFORMANCE

The simulation results included in Section IV describe the expected performance of the overall system. The simulation includes estimated effects of short term errors in the position measurement subsystem.

As noted later, the position measurement system is designed to operate within a 90° cone centered on the beacon position. This permits position offsets up to distances equal to the ocean depth in the operating area. Within this region, the distorting effects of ocean temperature and velocity profiles are reduced by proper system design. (These distortions tend to stretch the coordinate system. This is a biasing effect not related to short term measurement accuracy.) The maximum error in indicated position to be expected would be less than 300 feet at maximum offset in water depths of 15,000 feet.

The bias error decreases to zero for zero offset at any depth and also becomes proportionally less with decrease in ocean depth.

EQUIPMENT DESCRIPTION

General

This section contains a description of the computer, control console and position measurement system proposed for the Global Marine dynamic positioning system. A brief description of the customer-furnished propulsion units is included for completeness in order to cover all subsystems involved in the dynamic positioning system.

Control Console

The control console is located in the wheelhouse and contains all of the controls necessary to operate the dynamic positioning system. The console (Figure 3) is a simplified and modernized version of the console used for the MISSION CAPISTRANO dynamic positioning system.

The controls and displays are as follows:

- Depth Setting, 0—20,000 ft. A control to preset the system to operate with the acoustic position measurement system including the sea floor beacon. The beacon depth (i.e., fathometer reading) is set into the system prior to operation.
- Position Display. A high-brightness cathode ray tube with selectable range scales of 500, 1,000, 5,000 and 20,000 feet. Provision is made for permanent recording of position via external chart recorders.
- Display Mode Selectors.
  - TP — True position. Gives ship's position with respect to the beacon in earth-oriented coordinates.
  - TE — True Error. Gives ship position with respect to offset point in earth-oriented coordinates.
  - RE — Relative Error. Gives position in ship-oriented coordinates (fore-aft, port-starboard) with respect to offset point.
- Offset Selectors. Two switches, one for North-South and one for East-West are provided. These, in conjunction with the offset distance selectors, enable the operator to select his position in true earth coordinates relative to the acoustic beacon local vertical.
- Heading Command. A switch enabling selection of the ship's heading to be maintained.
- Heading Error. Indicator showing ship's head in relation to commanded heading on an expanded scale.

/51

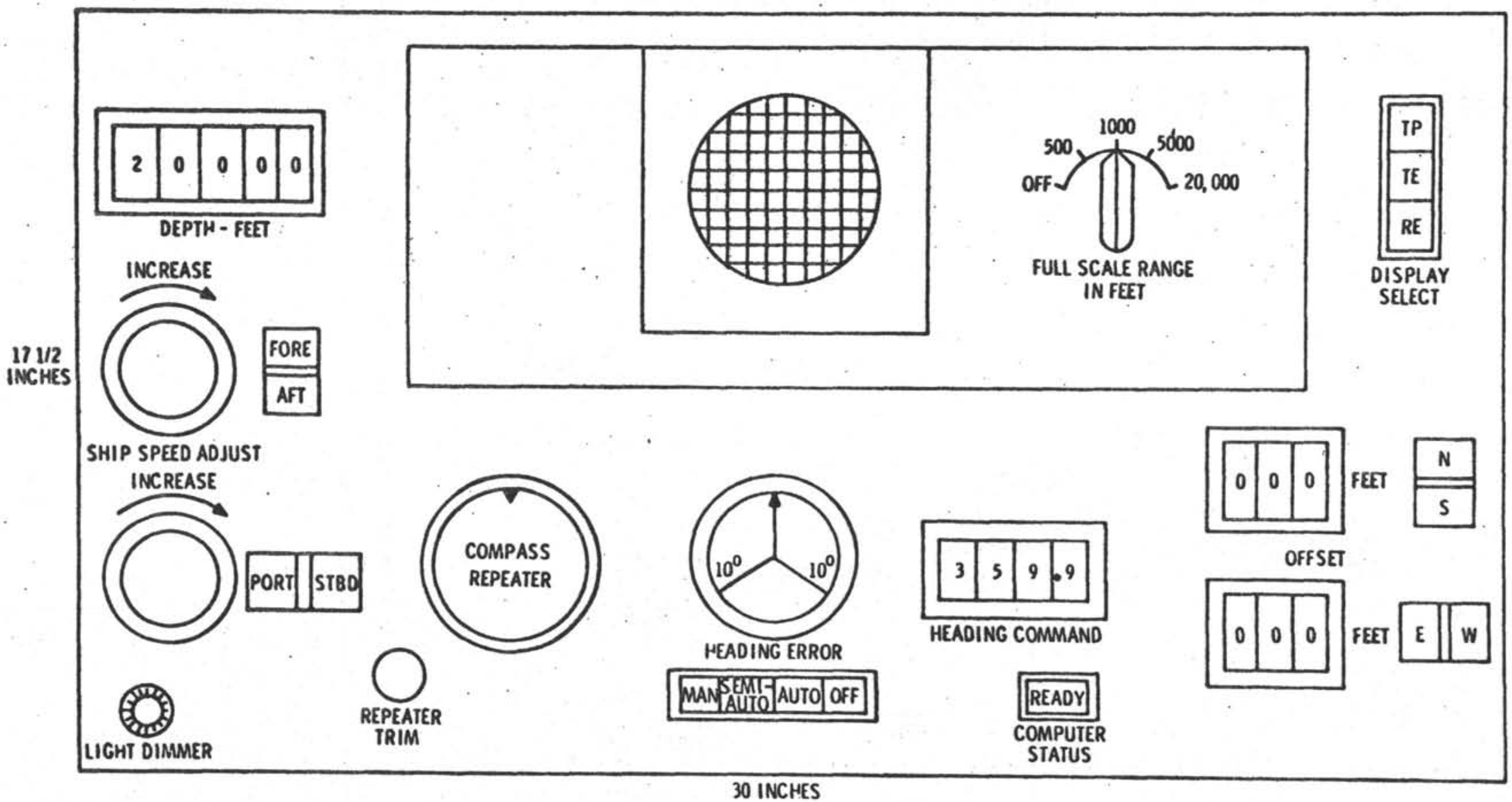


Figure 3 Control Console Arrangement

/52

- Compass Repeater. A repeater compass from the main ship's gyro. A compass pickoff assembly behind the panel performs many computational operations.
- System Control Switches.

  MANUAL — Activates computer, console, and position measurement system.

  SEMIAUTOMATIC (AUTOMATIC HEADING) — Activates the automatic heading loop and fore-aft, port-starboard speed command controls. This mode enables the operator to maintain a selected heading automatically while changing position.

  AUTOMATIC — Activates full positional control. The ship will move to the offset position set into the two OFFSET DISTANCE dials.

  OFF — Completely shuts down the system.
- Speed Commands. These controls function only in the SEMIAUTOMATIC mode and enable the operator to select speeds as he desires. Any combination of fore-aft and port-starboard may be selected.

Each control is individually illuminated. The illumination level is adjustable by a dimmer control located in the lower left corner of the panel.

Computer

A digital computer is proposed for this system. The basic computer is manufactured by Scientific Data Systems Inc. (SDS) and modified for this application. The digital computer is a powerful tool and represents the state of the art for dynamic positioning systems. It presents several advantages not found in existing analog systems:

- Flexibility — The basic control equations may be changed completely by re-programming without modifying the equipment configuration. In addition, the control scheme may be changed to accommodate extra propulsion units, or to handle other types of positional inputs etc., with minimal changes.
- Additional uses — The digital computer has the ability to handle problems other than dynamic positioning. Scientific or operational problems may be programmed as an extra feature. By adding incremental memory banks, the capacity of the computer can become quite large and the machine, therefore, extremely versatile.

/53

The computer will occupy one standard instrumentation rack plus an associated teleprinter input console. It may be located with other equipment racks which comprise the overall dynamic positioning system.

The functional configuration of the computer, with its input and output channels, is shown in Figure 4.

Acoustic Position Measurement System

The basic acoustic position measurement system is to be provided CFE from Project Mohole equipment. The system was originally developed by AC-DRL as a prime short baseline position reference for the project.

There are three distinct advantages in using this system over any other short baseline system:

- It is the only acoustic position measurement system that was actually tested in deep water during the Project Mohole development
- An almost identical system has been proven out in the deep ocean as part of the MISSION CAPISTRANO dynamic positioning system (also developed by AC-DRL)
- The system, as supplied, can readily be modified to provide the technical and economic advantages available with current designs.

AC-DRL will modify and update the supplied short baseline system to bring it up to the state of the art. Primarily, the modification will consist of converting the system to use a sea floor acoustic beacon as a reference point instead of a transponder. In addition, certain signal processing advances will be incorporated. This enables significant reduction in system complexity and a great reduction in the cost of the ocean floor reference.

A brief description of the modified system is presented below.

The short baseline position measurement system measures horizontal displacement of the ship from an acoustic beacon located on the ocean floor. When fully installed and calibrated, the system will provide measurements accurate to 50 ft in 20,000-ft water depths, and 20 ft in 5,000-ft water depths. The measurements are in ship-oriented

/54

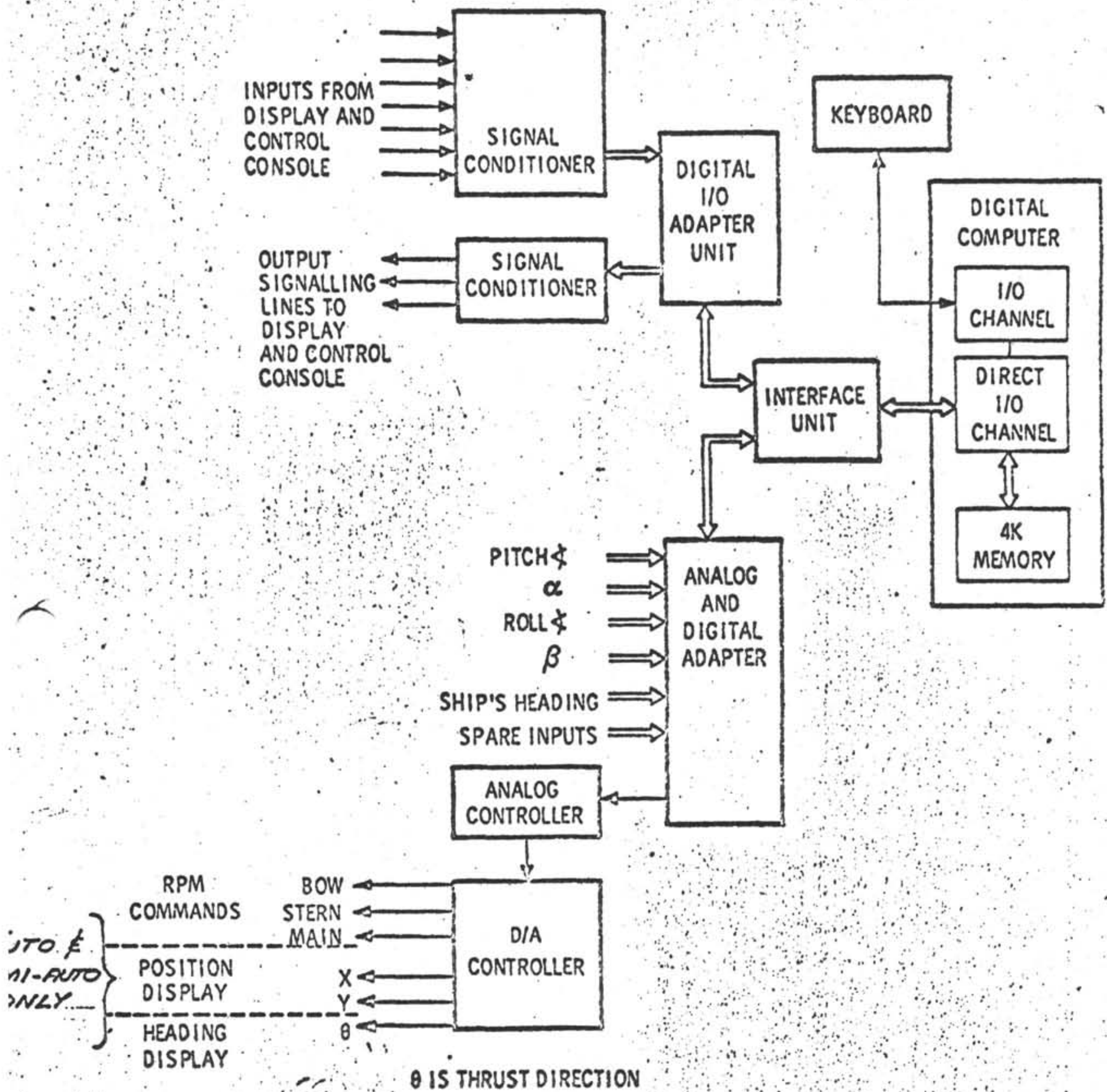


Figure 4 Digital Computation Equipment

distances, fore and aft designated as X and port-starboard designated as Y. The basic system outputs are two independent signals which are functions of the angle of arrival of the acoustic signal from the beacon. These signals are fed into the control computer along with signals representing ship pitch and roll, and ocean depth. A subroutine within the control computer provides the conversion into horizontal distance measurements.

The prime elements of the system (Figure 5) are:

- One acoustic beacon, located on the ocean floor.
- Four receiving hydrophones, located below the hull and mounted on support arms.
- Four signal receivers, located on deck above each support arm.
- One gyroscopic platform tilt indicator, located near the ship's center.
- Signal processing equipment, located in two racks in the positioning control room.

Electrical cabling connects all the elements of the shipboard system equipment.

The system operates as follows:

- An acoustic pulse is transmitted from a single acoustic reference point in the ocean, the ocean-floor beacon.
- The arrival angle of the signal is measured by the ship-mounted hydrophones placed in a known geometry.
- Ship's pitch, roll, and heading are recorded simultaneously.
- The shipboard control computer converts these arrival angles and ship attitude indications into both ship- and earth-oriented X-Y cartesian coordinate systems.

Although there are four hydrophones on the ship, only three are required to establish the two-axis coordinate system. One hydrophone is redundant and is used to increase system reliability.

The signal processor incorporates four signal reception channels, one for each hydrophone. These channels amplify the received signal and generate a timing mark for use by the angle computation circuitry. Pulse differentation is employed in each reception channel to remove any effects of varying signal amplitude between channels. The signal

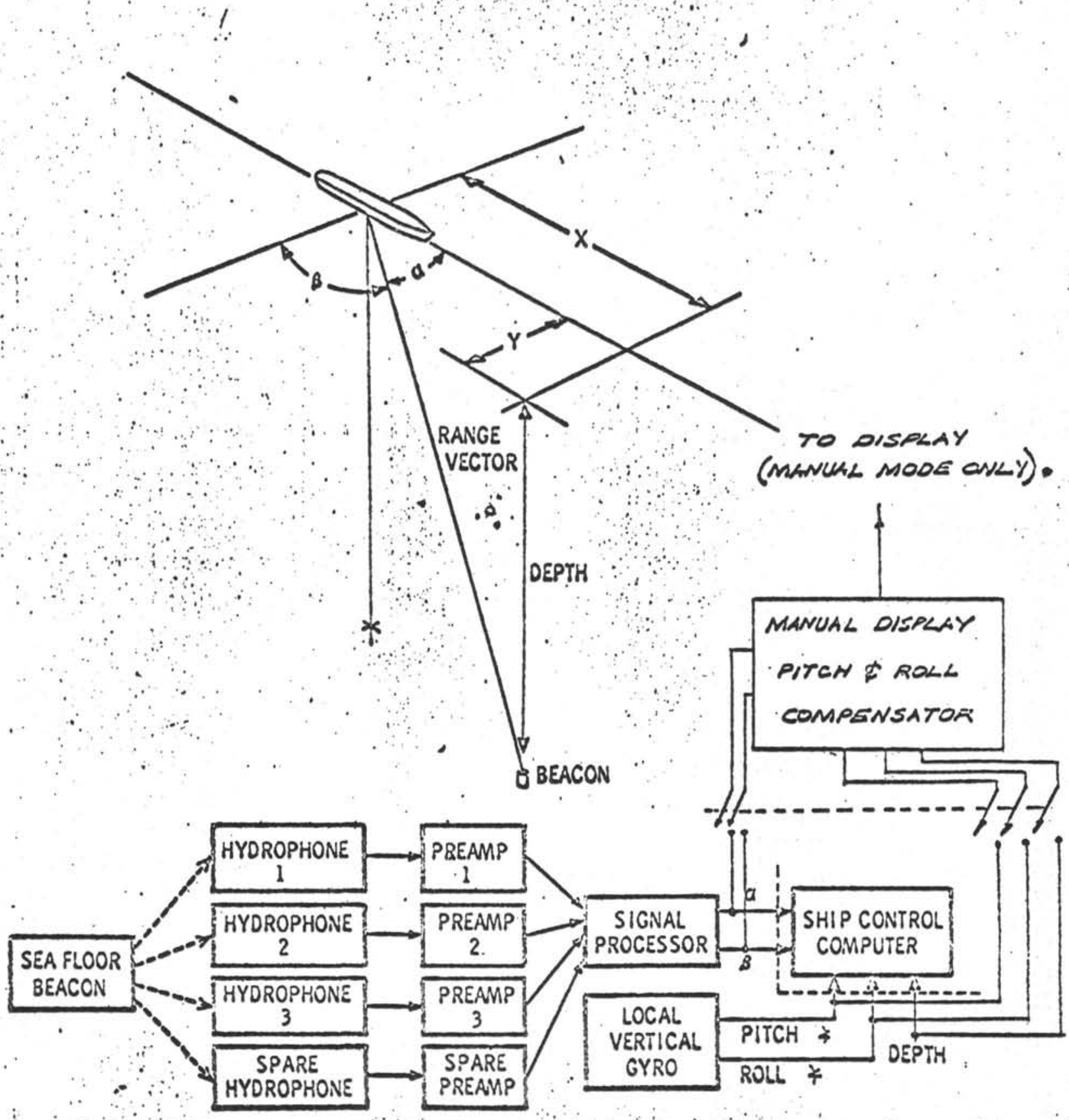


Figure 5 Position Measurement Subsystem

/57

reception channels are connected to two angle generators, one for α and one for β. Each angle generator consists of pulse counting, transfer, and storage circuitry. The function of the angle generator is to create a binary word representing the angle value, and to store this word for further processing by the computer. A selective gating network enables use of any three of the four hydrophones, and their respective signal processing channels.

Propulsion Units (CFE)

The Global Marine dynamic positioning system will use two fixed bow thrusters, two fixed stern thrusters, and controllable main screws to generate thrust vectors. All propulsion equipment, including interface controls, is provided by Global Marine. The propulsion units to be controlled by the AC-DRL-furnished equipment must be equipped with interface equipment to accomplish the following (Note: Interface equipment must present high impedance, 500 Ω min, to the AC-DRL signal):

- RPM Command
  Propulsion units must be controlled to the rpm specified by an AC-DRL control voltage. This voltage will be 0—(+) 10 vdc, signifying 0-full rpm for rotatable units.
- Direction Command
  The thrust direction of rotatable units must be controlled in accordance with an AC-DRL-supplied voltage. The voltage will be (-) 10—0—(+) 10 vdc, and will correspond to an angle ($^{\circ}$) with a scale factor to be determined.
- RPM Readout
  A permanent magnet tachometer generator for each propulsion unit must be provided.
- Direction Readout
  A 60 Hz synchrotorque transmitter for each propulsion unit must be provided. Gearing shall be such that the transmitting shaft rotation and thrust direction change are on a 1:1 basis.

Shipboard Cabling

All equipment interconnect cables, as specified by AC-DRL, are to be supplied by Global Marine.

Gyrocompass

The ship's gyrocompass provided by Global Marine must be capable of driving a Mk 14 Mod 1 compass repeater unit.

/58

SECTION IV
SIMULATION STUDY

GENERAL

Evaluation of a dynamic positioning system is best accomplished, short of actual sea trials, by computer simulation. Simulation technology is widely applied in the aerospace and aircraft fields as a development tool. AC-DRL has applied the same techniques to the Global Marine dynamic positioning system. In essence, the ocean environment, the ship, the propulsion units, the computer, and the position measurement system are mathematically described and their interactions studied. The results are then presented in terms of position-keeping ability under various ocean environment conditions.

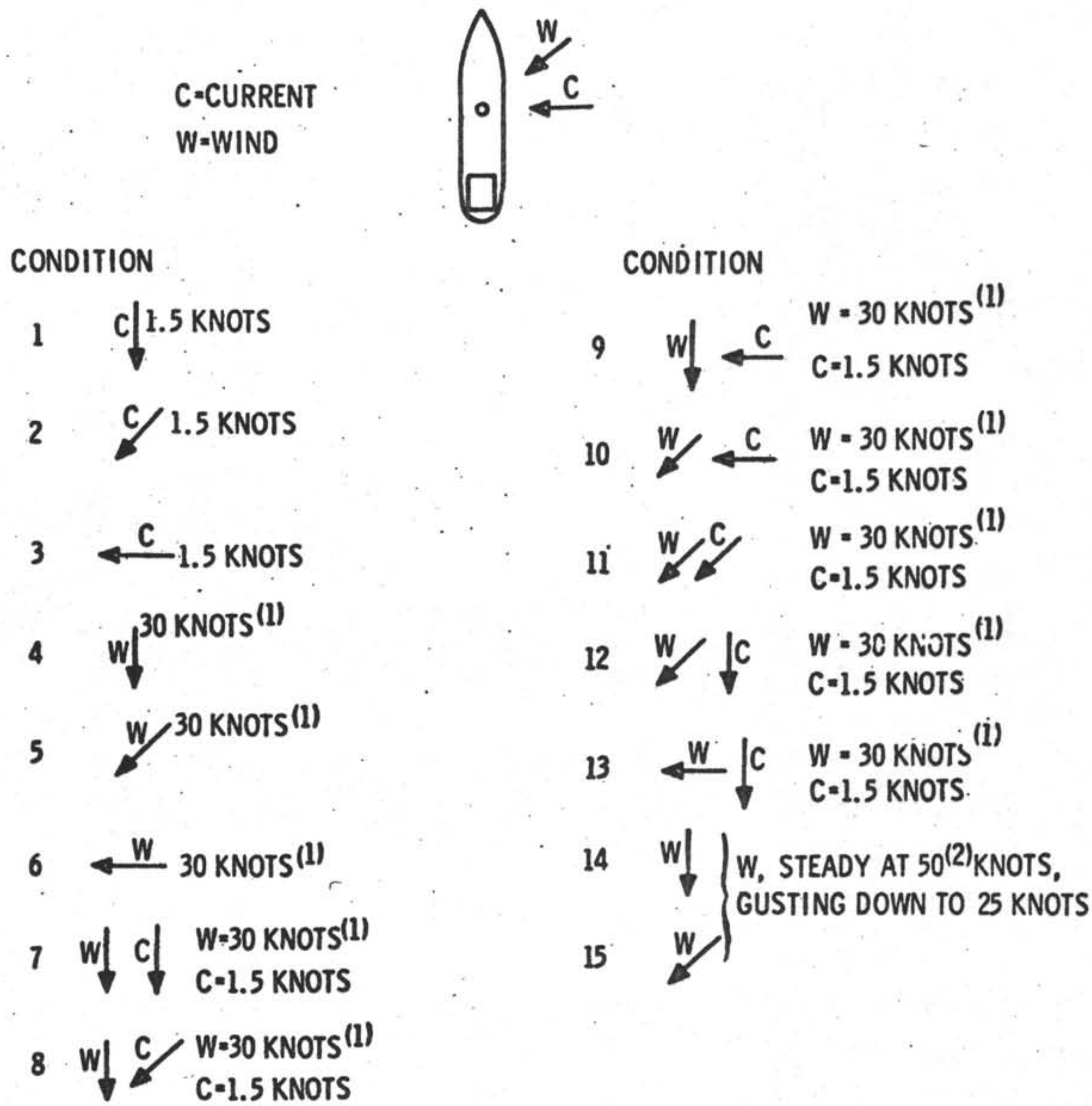
The Global Marine dynamic positioning system has been evaluated under a variety of conditions, many of which are considerably more severe than expected during actual operations. The conditions (Figure 6) include ocean currents and winds striking the ship broadside, quartering, etc., and conditions of gusting and variable winds. The position-keeping ability under these conditions are shown in Figures 7—20. In general, expected performance of the system is excellent and promises to be most satisfactory for the Deep Sea Drilling Project.

DESCRIPTION

This was a three-degree-of-freedom simulation which included translational and rotational freedom in the horizontal plane. Pitch and roll were not considered because the position measuring system, as well as the ship's compass, compensate for this motion in the positional and heading data sent to the control system. Some "leakage" will occur in the positional data in heavy seas, and this was simulated by modulating the position inputs with ± 70 ft, 10 sec period sine waves for all runs. This is roughly equivalent to sea state of 5 or greater.

The equations and data used for this simulation are given in the appendix. A compilation of the symbols used in the following discussion (and in the appendix) are also included in the appendix. The equations for lateral and longitudinal wind forces were derived from an empirical formula furnished by Global Marine. The form of the current force equations was derived mathematically, and the coefficients were selected to match the model test data obtained in tests at General Dynamics' Marine Technology Center.

/59



NOTES

(1) THREE SEPARATE WIND CONDITIONS WERE USED: (a) STEADY STATE OF 30 KNOTS (b) 30 KNOTS WITH ± 10 KNOT GUSTS (c) 30 KNOTS WITH ± 10 KNOT GUSTS AND ± 10 DEGREE DIRECTIONAL VARIATION.

(2) THE QUARTERING 50-KNOT WIND CONDITION EXCEEDED THE AVAILABLE THRUST. THE MAXIMUM CONTROLLABLE QUARTERING WIND OF 40 KNOTS WAS USED, AS WELL AS THE MAXIMUM ANGLE OF 30° FOR THE 50-KNOT WIND.

Figure 6 System Simulation Conditions

/60

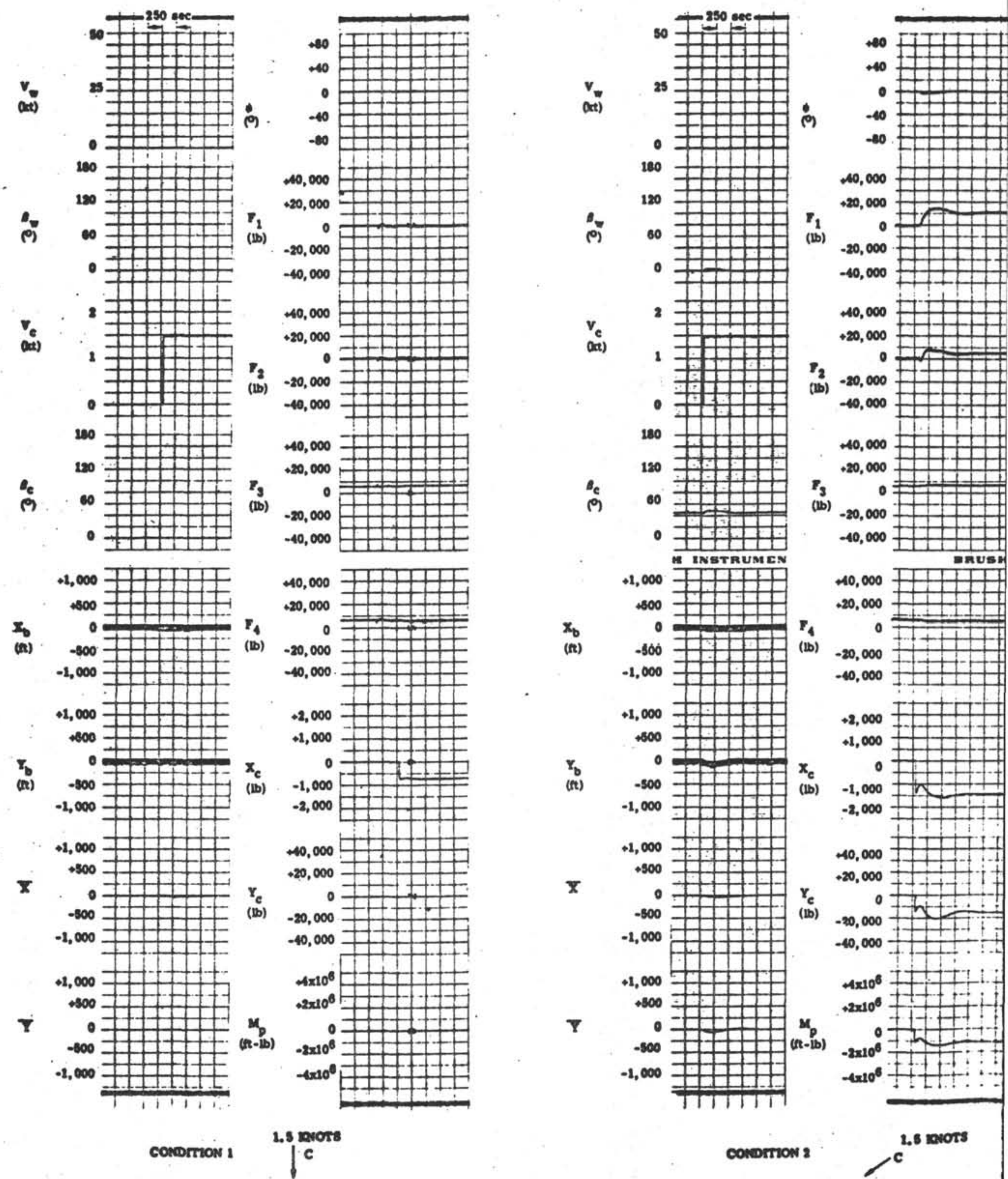


Figure 7 Performance of Recommended Ship Positioning System for Conditions 1 and 2

/61

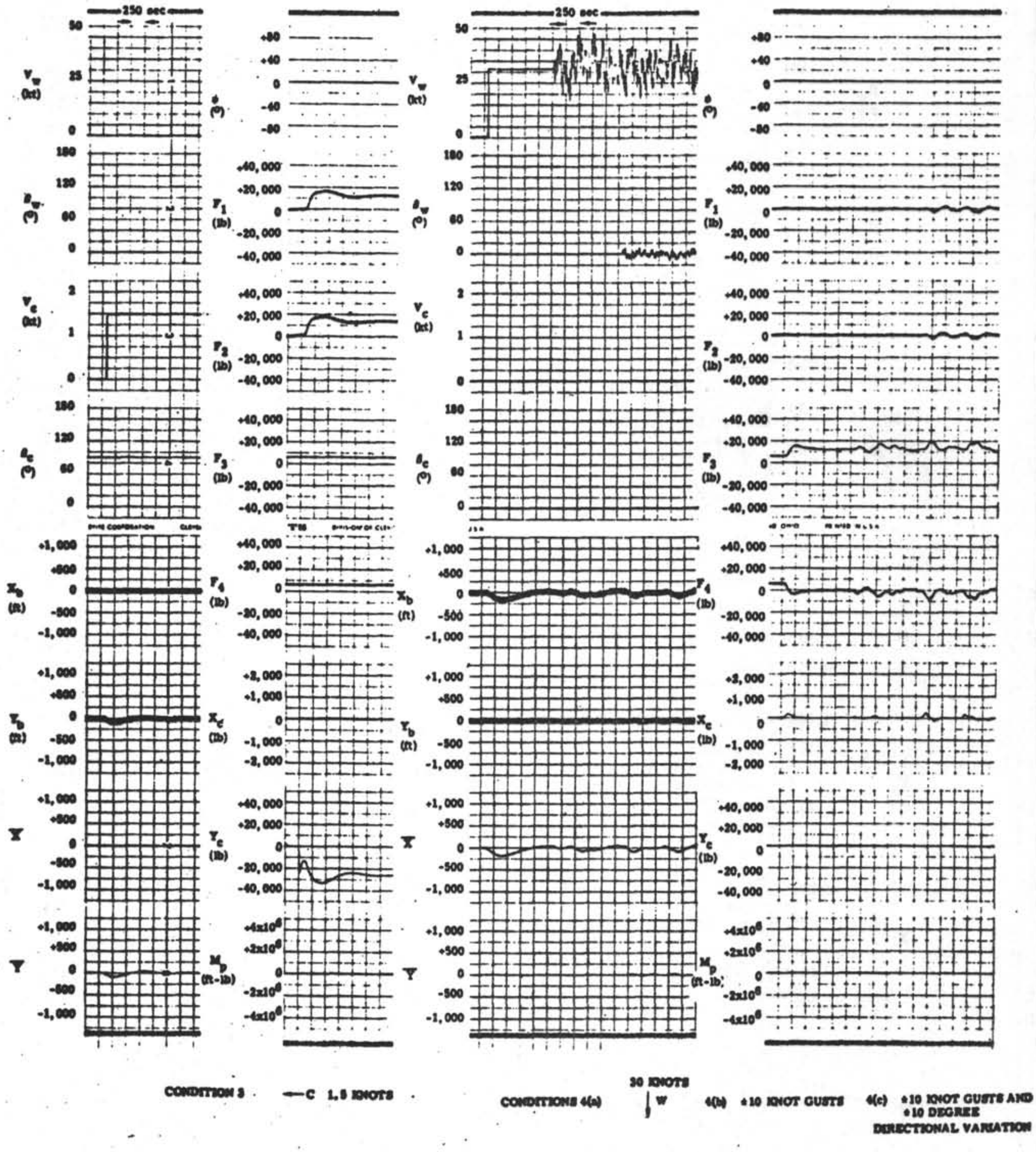
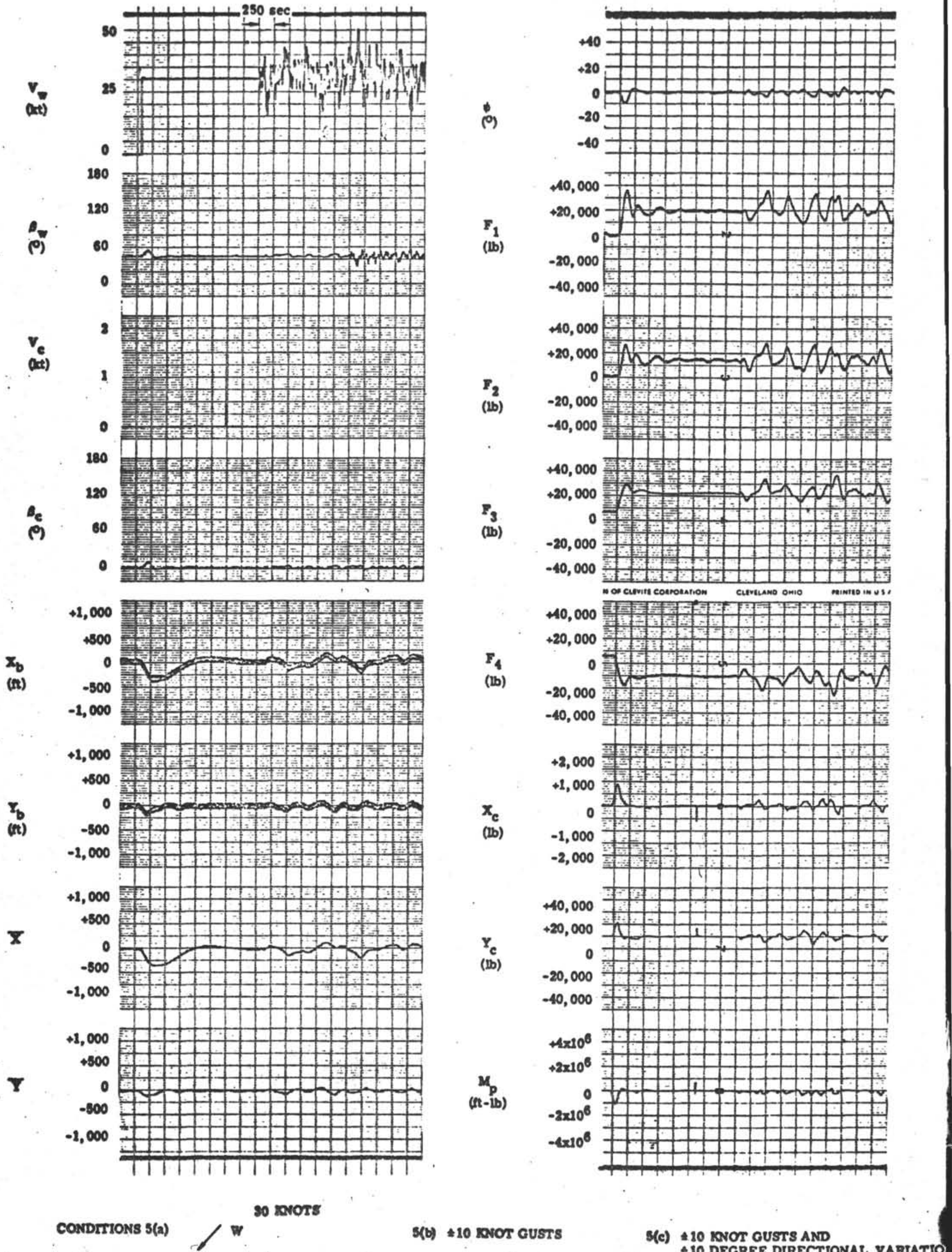


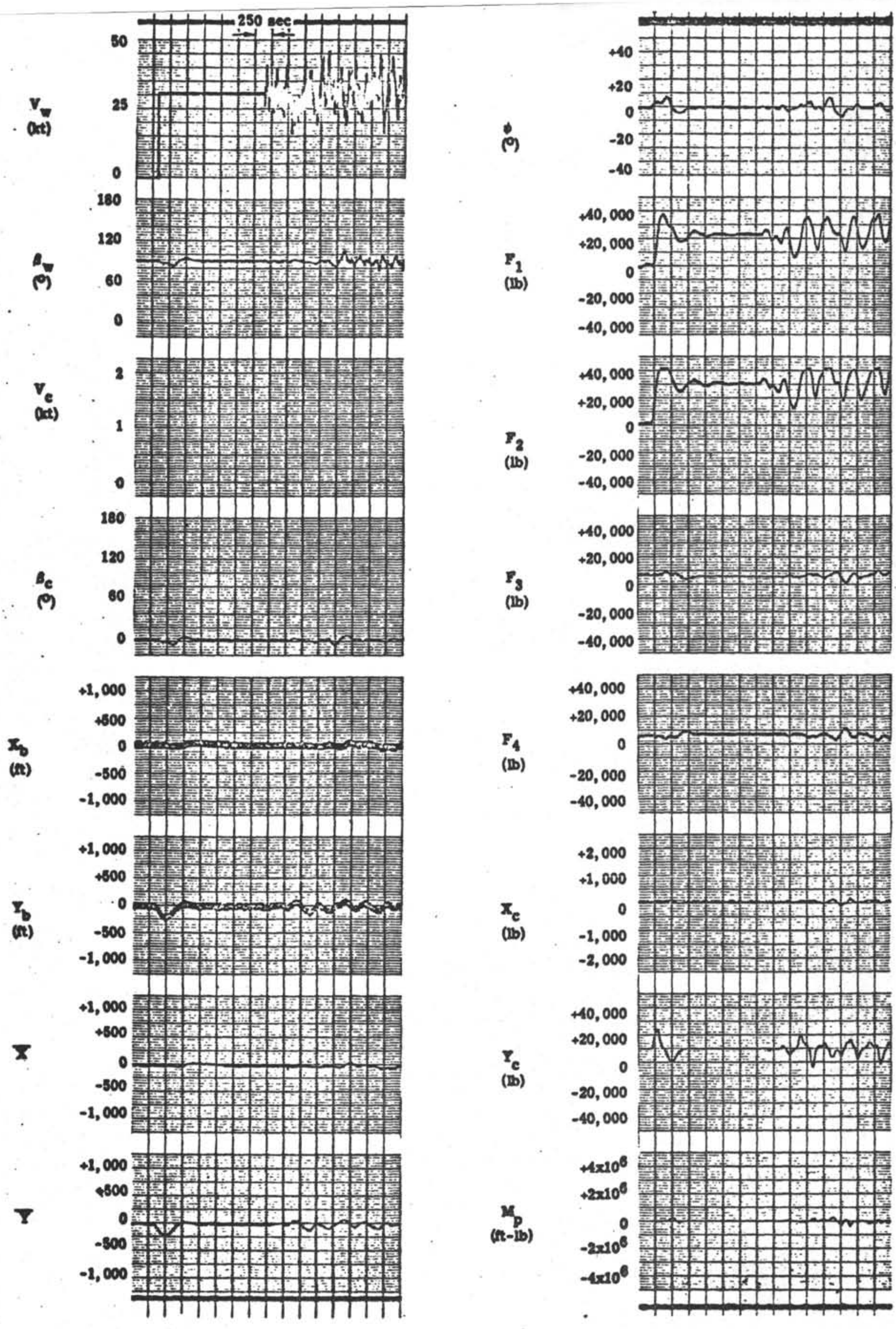
Figure 8 Performance of Recommended Ship Positioning System for Conditions 3 and 4

/62



/63

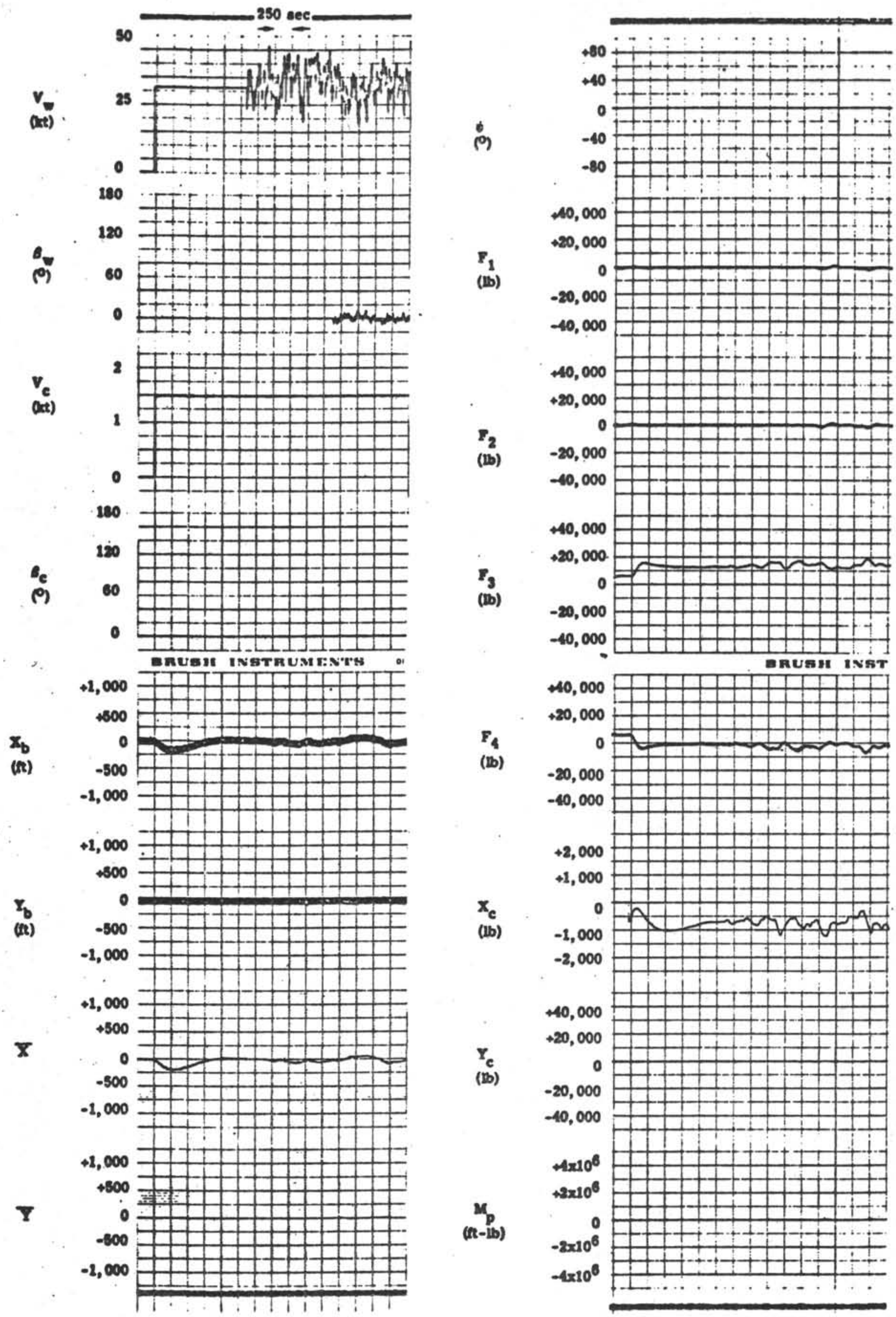
Figure 9 Performance of Recommended Ship Positioning System for Condition 5



CONDITIONS 6(a) →W 30 KNOTS 6(b) ±10 KNOT GUSTS 6(c) ±10 KNOT GUSTS AND ±10 DEGREE DIRECTIONAL VARIATION

Figure 10 Performance of Recommended Ship Positioning System for Condition 6

/64



30 KNOTS 1.5 KNOTS

CONDITIONS 7(a) ↓ W ↓ C 7(b) ±10 KNOT GUSTS 7(c) ±10 KNOT GUSTS AND ±10 DEGREE DIRECTIONAL VARIATION

/65

Figure 11 Performance of Recommended Ship Positioning System for Condition 7

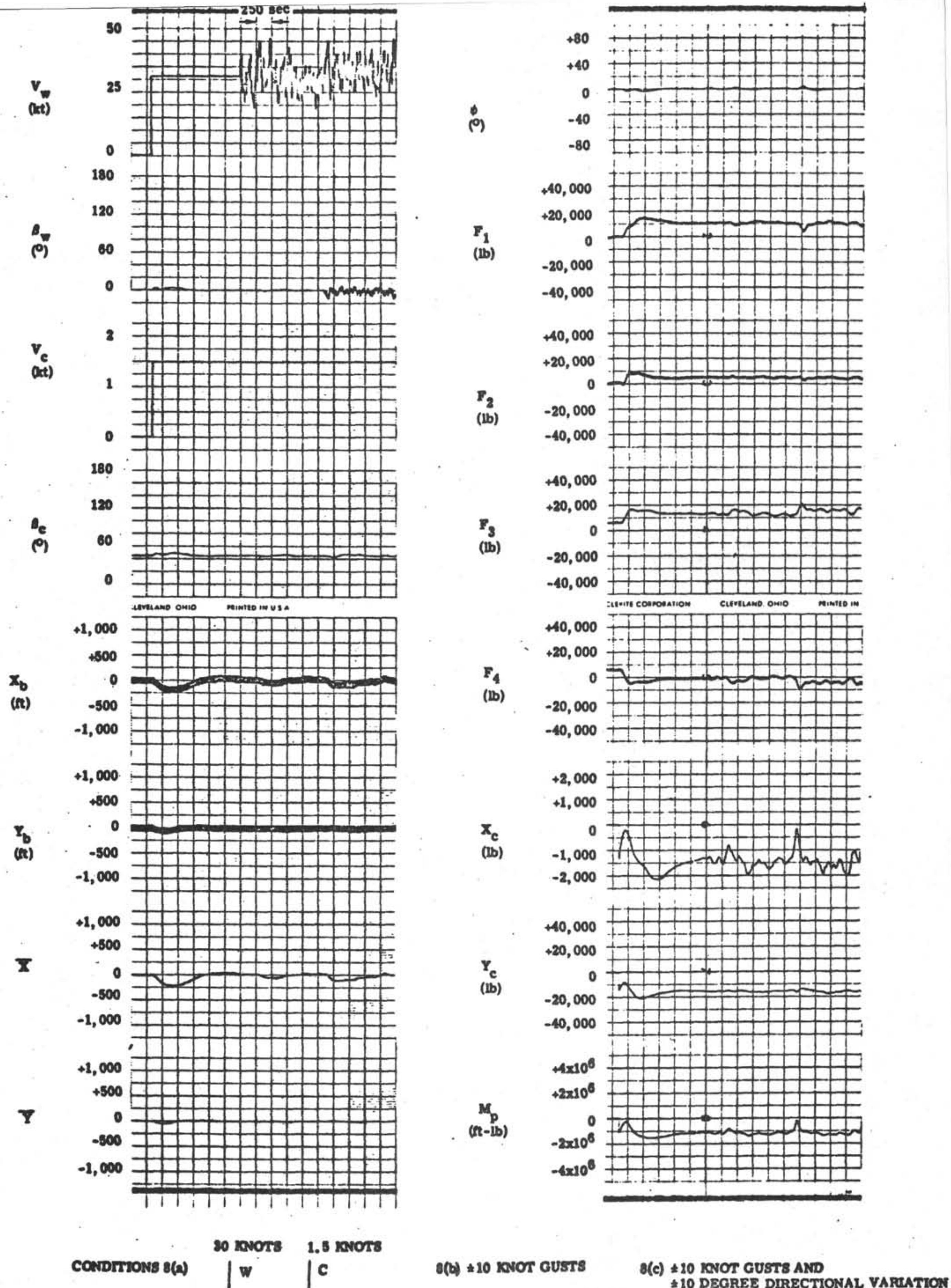
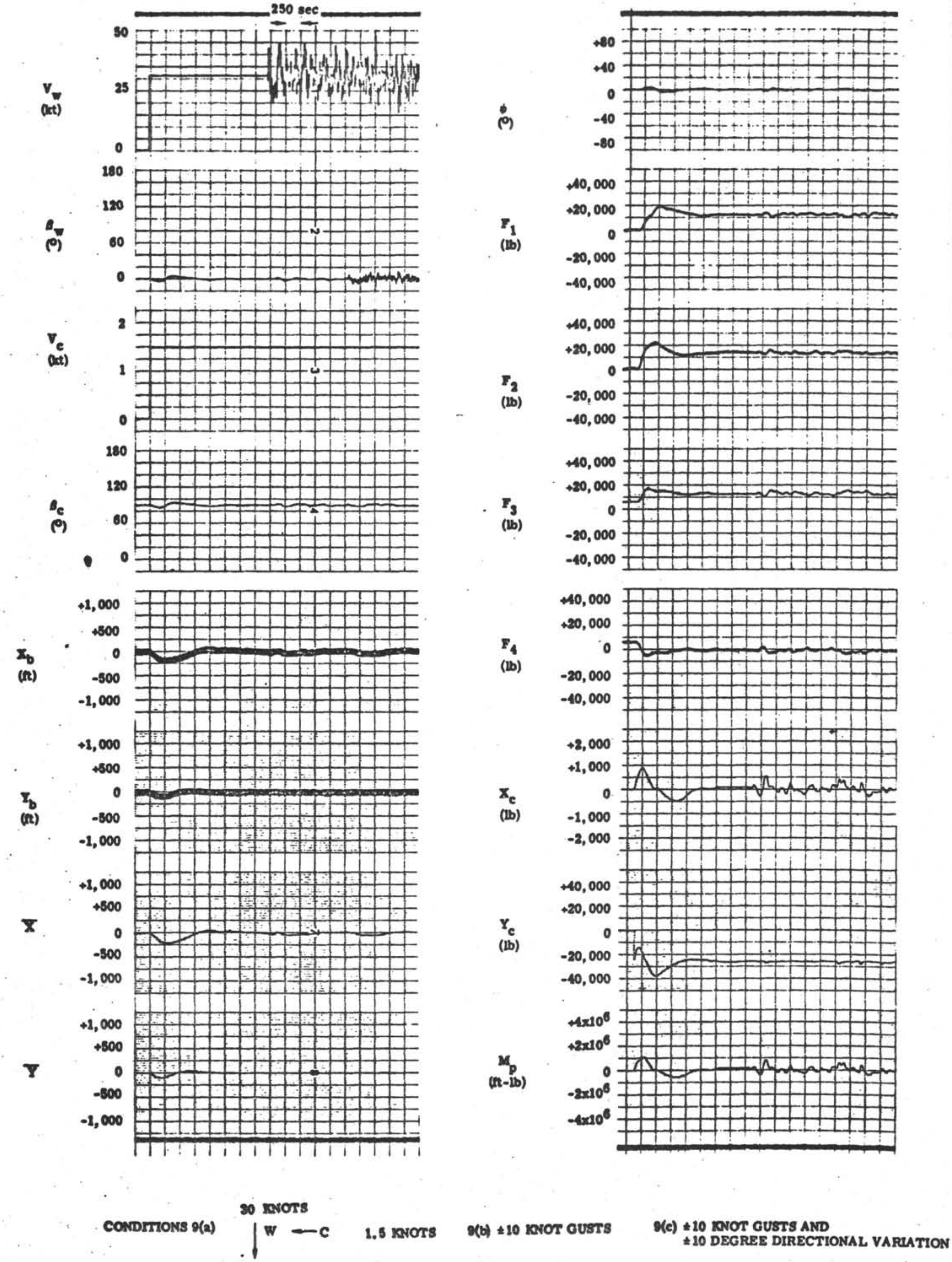
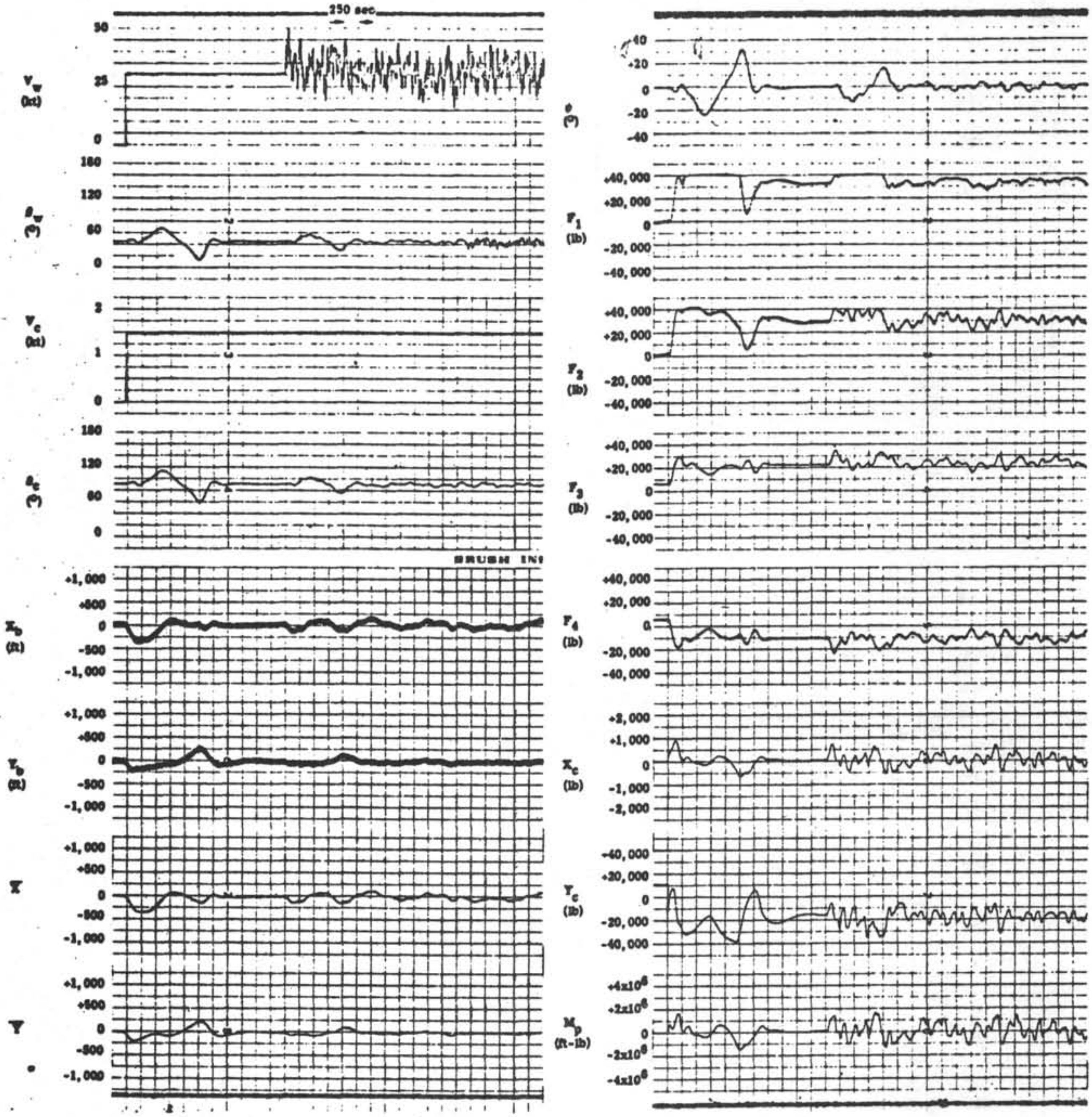


Figure 12 Performance of Recommended Ship Positioning System for Condition 8



/67

Figure 13 Performance of Recommended Ship Positioning System for Condition 9

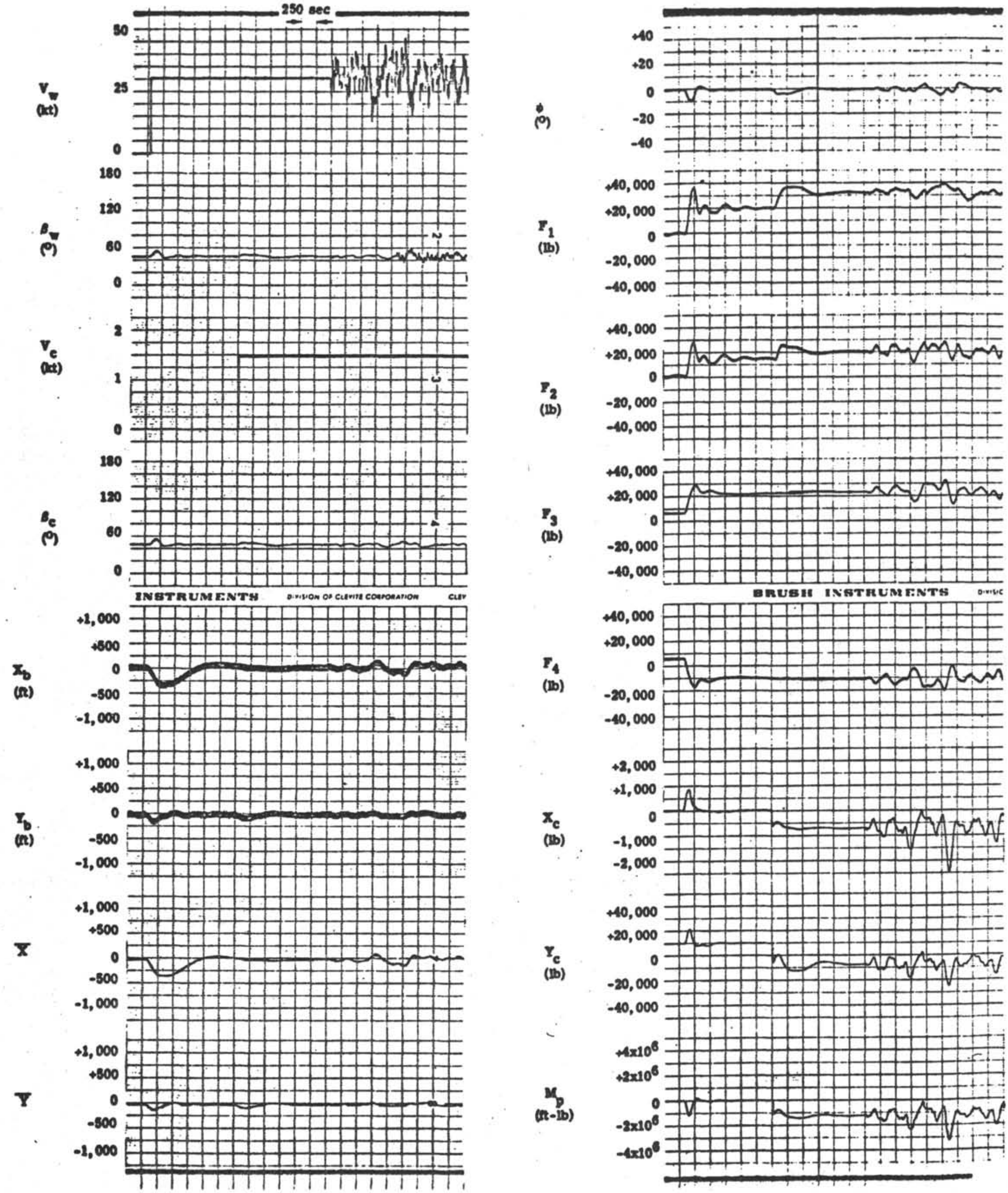


CONDITIONS 10 (a) 30 KNOTS W, C 1.5 KNOTS

10(b) ± 10 KNOT GUSTS

10(c) ±10 KNOT GUSTS AND ±10 DEGREE DIRECTIONAL VARIATION

Figure 14 Performance of Recommended Ship Positioning System for Condition 10



CONDITIONS 11(a) 30 KNOTS W 1.5 KNOTS C

11(b) ±10 KNOT GUSTS

11(c) ±10 KNOT GUSTS AND ±10 DEGREE DIRECTIONAL VARIATION

/69

Figure 15 Performance of Recommended Ship Positioning System for Condition 11

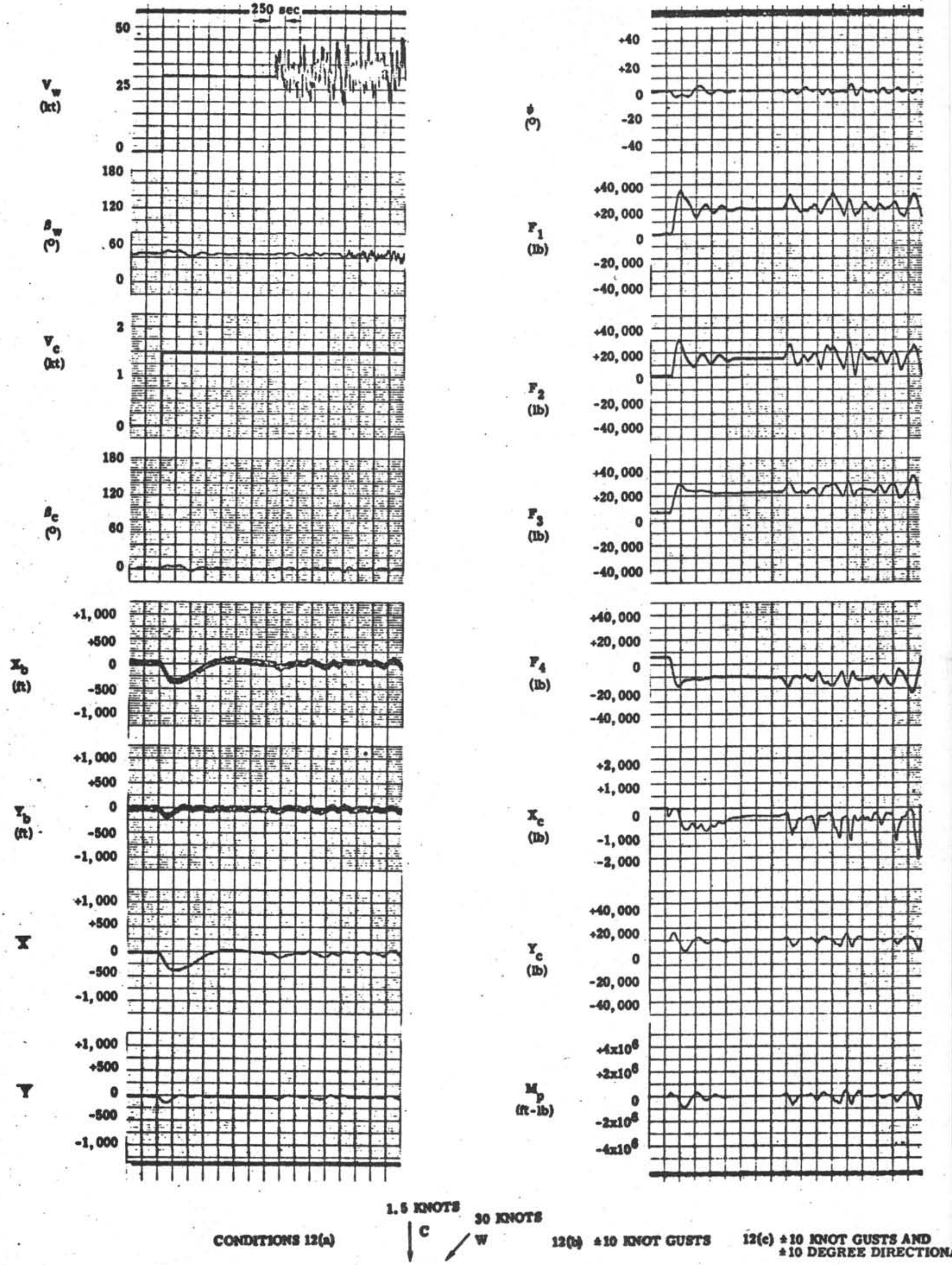
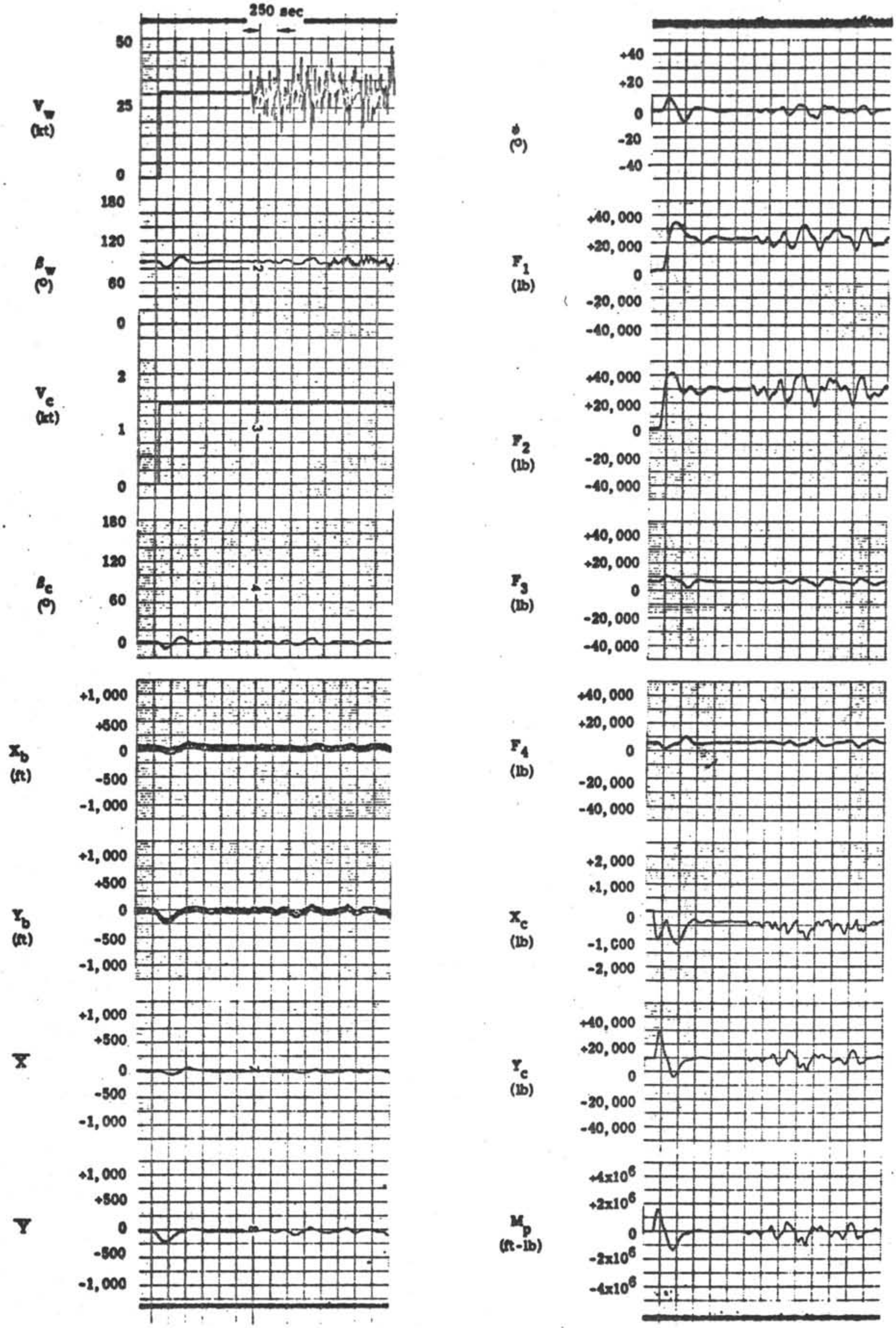


Figure 16 Performance of Recommended Ship Positioning System for Condition 12



CONDITION 13(a) 1.5 KNOTS C ← W 30 KNOTS

13(b) ±10 KNOT GUSTS

13(c) ±10 KNOT GUSTS AND ±10 DEGREE DIRECTIONAL VARIATION

/71 **Figure 17 Performance of Recommended Ship Positioning System for Condition 13**

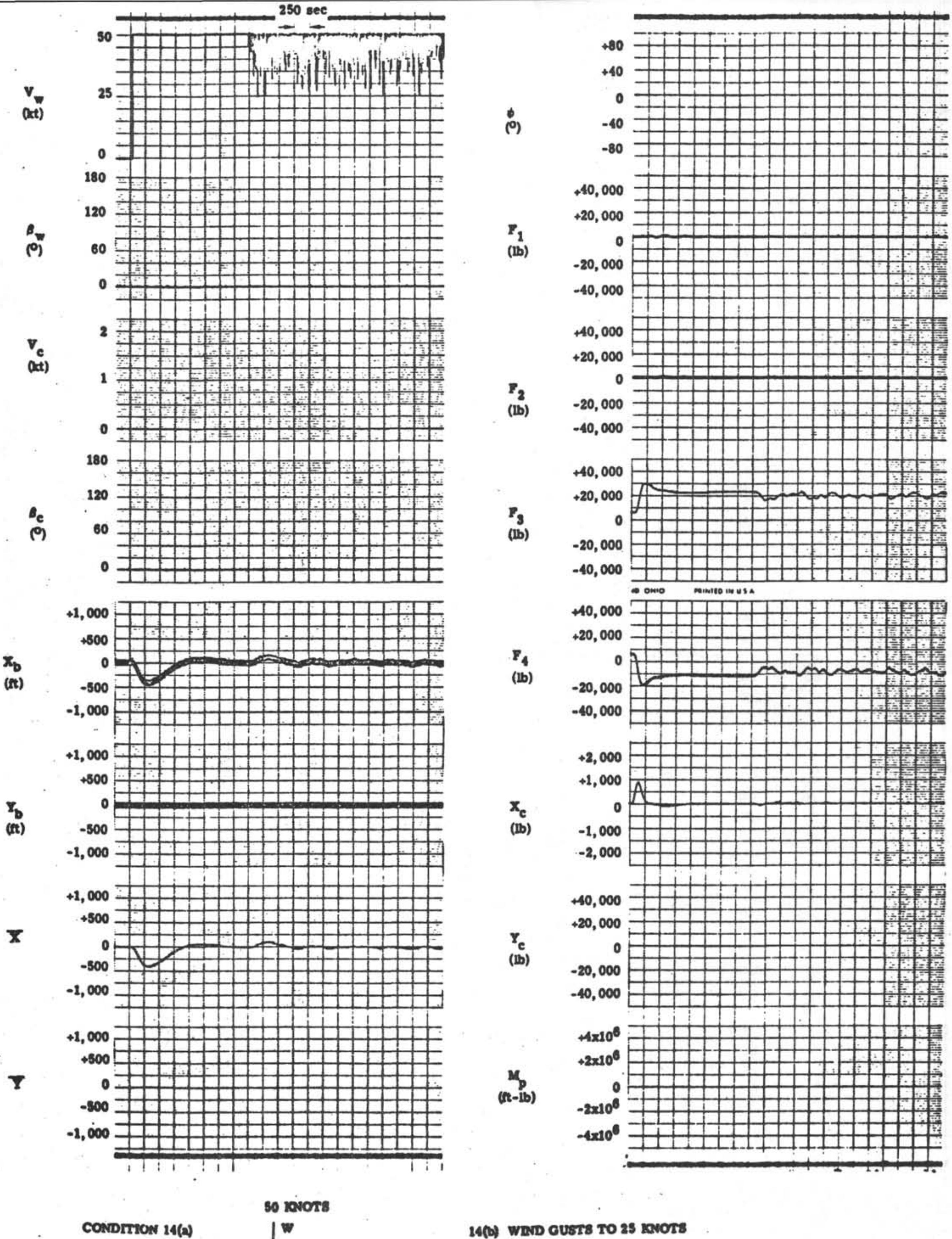
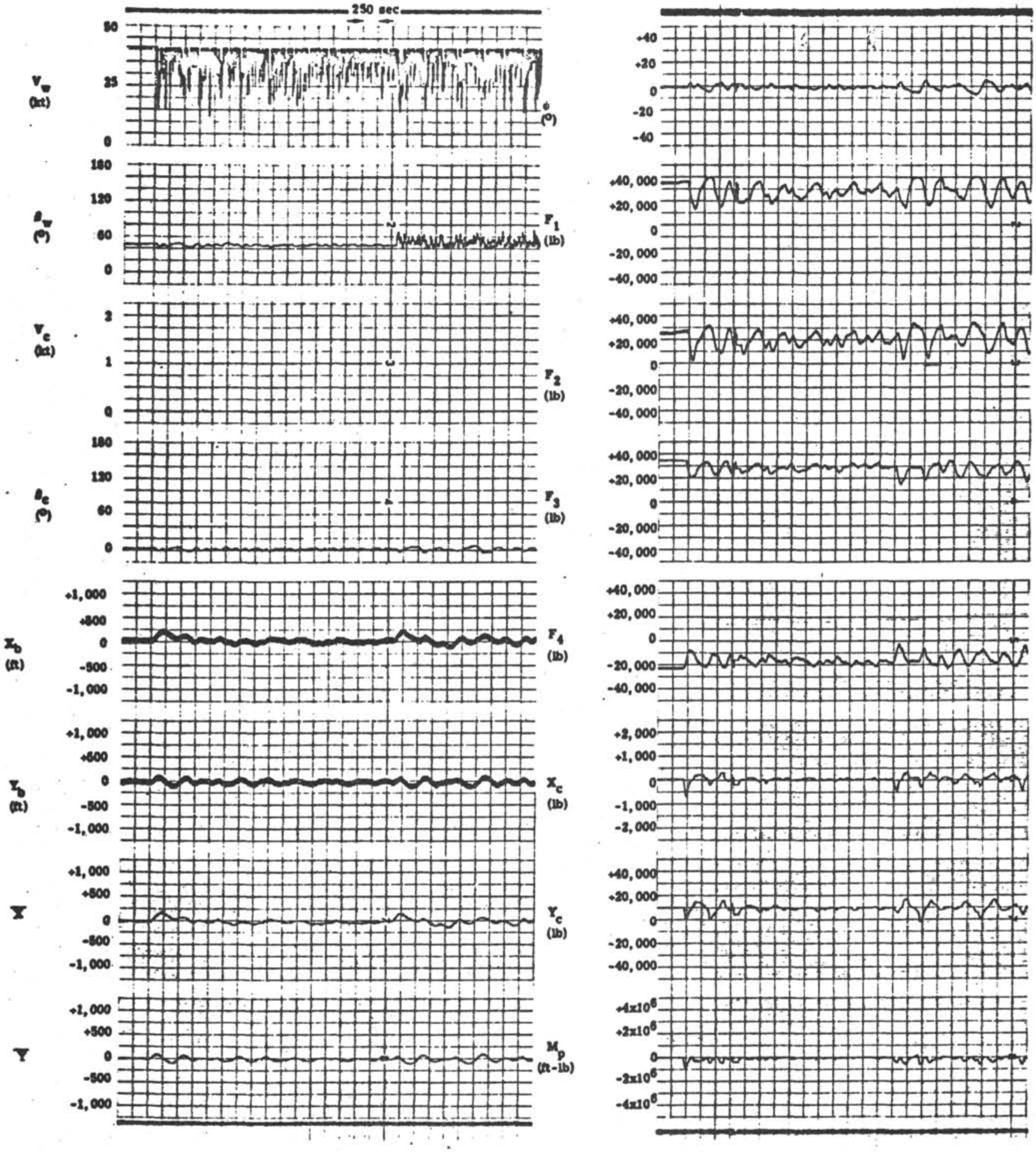


Figure 18 Performance of Recommended Ship Positioning System for Condition 14

/72



CONDITION 15(b) W 40 KNOTS, GUSTING TO 15 KNOTS

Figure 19 System Performance for Maximum Controllable Quartering Wind

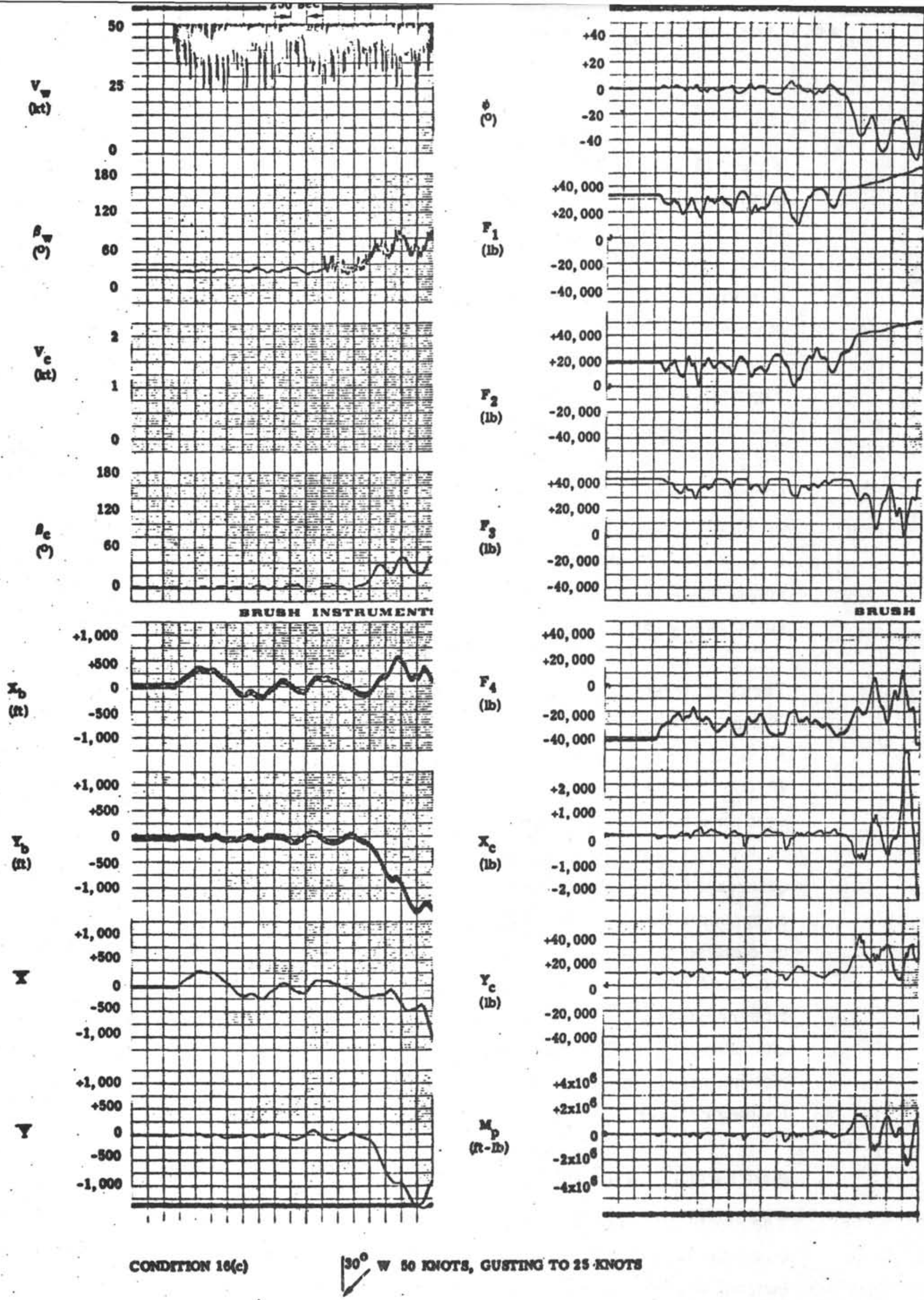


Figure 20 System Performance for 50 Knot Wind at Maximum Controllable Angle Off Bow

Figure 21 shows the axis system used in the simulation study, where $\overline{X}$ and $\overline{Y}$ represent inertial coordinates, and X_b and Y_b represent the positional data as obtained from the acoustic position measurement system. The X_b axis is aligned with the ship's longitudinal axis, and Y_b with the lateral axis. These inputs were modulated to represent the "leakage" as previously described. The positional inputs were filtered through simple 20-sec lags to provide smoothed error signals to the control system.

Figures 22—24 show simplified block diagrams of the X, Y, and ψ loops, respectively. Each loop uses derived rate, position, and integral feedback to give the desired stability and position-keeping characteristics. Gains were individually selected for optimum response time and minimum thruster demand. The thruster dynamics were each simulated by 10-sec first-order lags, and were assumed to have linear thrust-speed relationships, i.e., a given voltage command to the thruster results in a proportional thrust output. In actual practice, a compensating function is generated to account for a nonlinear thrust-speed relationship.

Thruster arrangements and assumed positive force directions are shown in Figure 25. The F_1 and F_2 forces each represent two thrusters for a total of four lateral thrusters. Each thruster was assumed to have a maximum thrust level of 20,000 lb, for a total of 80,000 lb of thrust available in the lateral or Y-axis. The F_3 and F_4 forces each represent thrusters having individual maximum thrust levels of 15,000 lb, for a total of 90,000 lb of thrust available in the X-axis. Under steady-state conditions, all thrusters have a quiescent thrust level (not necessarily as shown in Figure 25). The X-axis thrusters run in opposite directions at 6,000 lb thrust each, and the Y-axis thrusters operate at a level, as dictated by the control system, to counterbalance the moment generated by the X-thrusters (about 1,000 lb). The purpose of this quiescent level is to keep the motors running under power for minimized commutator buildup, as well as maximum response characteristics. Both thrusters in each axis receive equal thrust commands for any positional correction. The X-axis thrusters receive equal and opposite commands for heading corrections.

SIMULATION RESULTS

The simulation results for the various conditions listed in Figure 6 are shown in the computer traces of Figures 7—20. In each run the specified condition(s) (e.g., 1.5 kt current at 0°, 30 kt wind at 45°) are inserted simultaneously as a step function. The ship's position and the control system then undergo a transient phase while the control

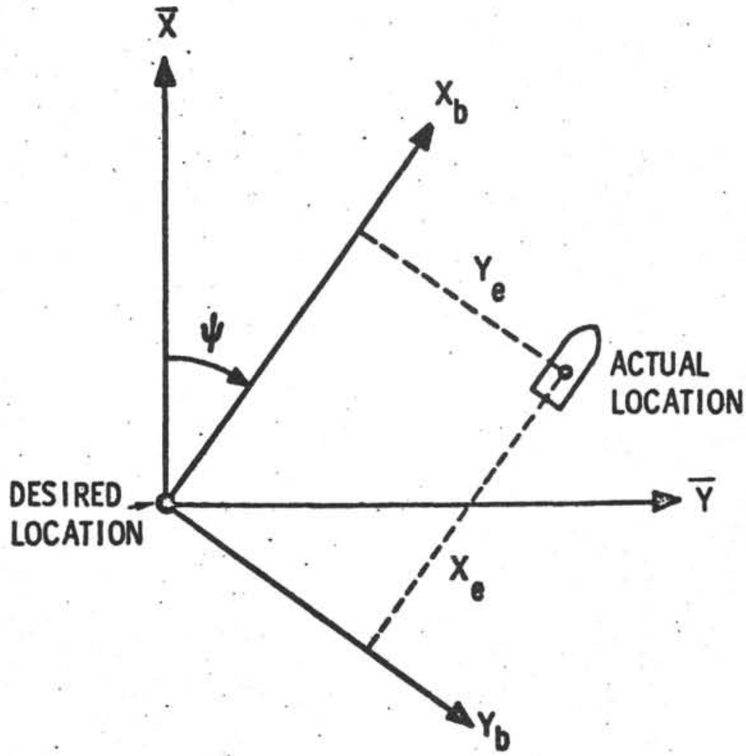


Figure 21 Axes System for Simulation

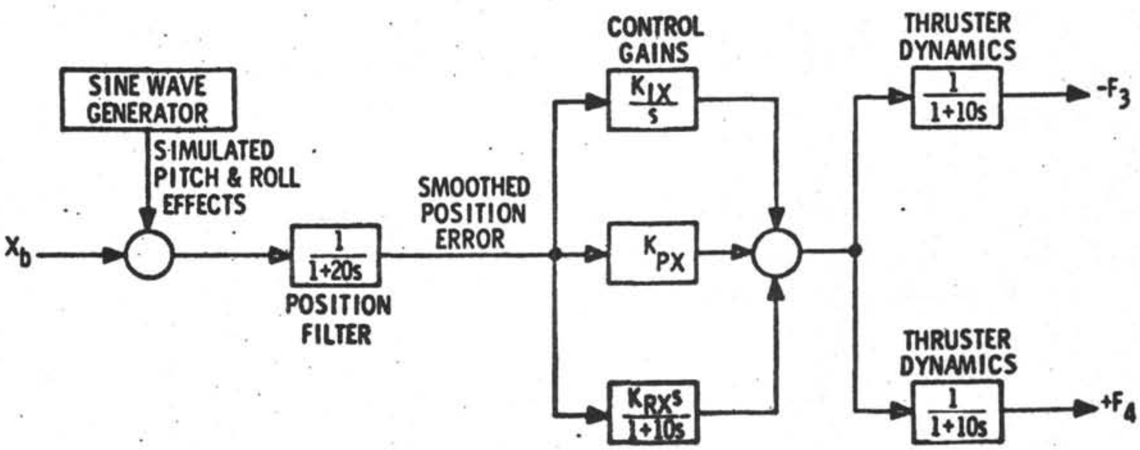


Figure 22 Simulated X-Axis Control Loop

/76

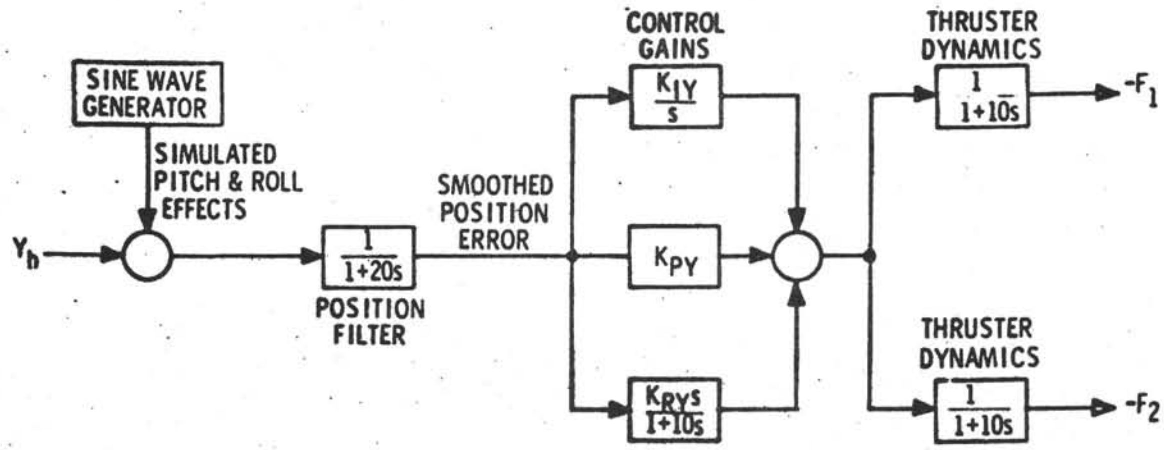


Figure 23 Simulated Y-Axis Control Loop

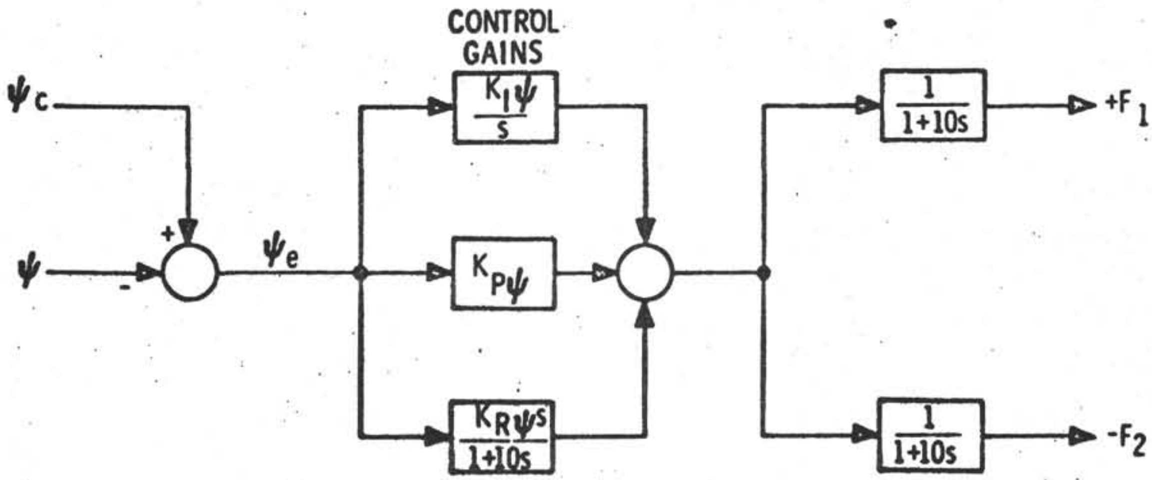


Figure 24 Simulated ψ-Axis Control Loop

/77

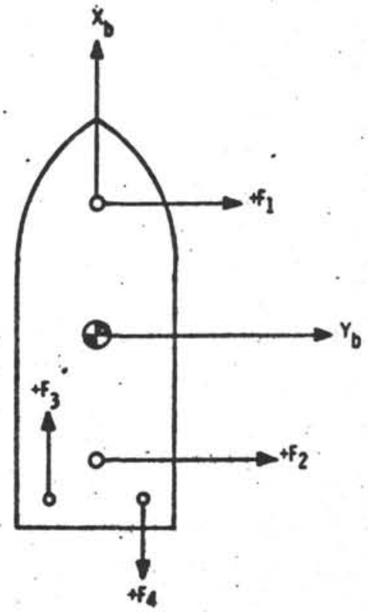


Figure 25 Thruster Arrangement and Force Convention

system is responding to the input disturbance, before settling out to a steady-state value. At that time, the random wind gusts were inserted, and later the random directional variations. The purpose of the step disturbance is solely to evaluate system stability at each position-keeping performance data. Deviations under the random wind conditions are the best indication of position-keeping performance.

For the random gusts and wind direction, the ship held position to within 200 ft in the worst case, and was generally within ± 100 ft. All results represent a "worst case" condition, i.e., the large amplitude error modulation (±70 ft) would occur only in very rough seas and deep water (to 12,000 ft). This requires a large lag (20 sec) in the control loop to filter out the low frequency error signal, and prevent unnecessary demands on the thrusters. In addition, a relatively long time constant (10 sec) was assumed for the thrusters. These lags add together to make a rather slow control loop, and performance would be markedly improved for smaller lags, as would probably be the case in the actual system. It should be noted that, under steady wind and current conditions, the ship always maintains a zero error position, once the initial transient has settled out.

The largest value of quartering wind for which the ship can maintain position is 41 knots (Figure 19). The maximum steady angle off the bow at which a 50-knot wind can be sustained is 30° (Figure 20). Under the varying angle condition at 30° nominal, the ship eventually lost position.

SECTION V
SYSTEM INSTALLATION

GENERAL

Proper installation of a dynamic positioning system is essential to its optimum performance; particularly the acoustic position measurement subsystem. Proper installation of the short baseline position measurement subsystem, especially the transducer array, cannot be over emphasized. Hydrophone mounting to assure repeatability of position, avoidance of ship mountings or locations which may "warp" the array, and avoiding noisy locations are all important. Accurate determination of hydrophone plane-gyroscope axis is pertinent.

ELECTRONIC EQUIPMENT

The electronic complement for the dynamic positioning system is contained in four basic groups:

- Control console
- Computer rack and teleprinter
- Position measurement racks (2)
- Local vertical reference unit.

These units should be installed in convenient locations in the ship. If a central area is available for electronics and instrumentation, all components except for the control console may be located there. Air conditioning ($+5^{\circ}C$ to $+35^{\circ}C$) is required for this equipment (except for the control console) and it must be protected from salt spray and splash. Figure 2 gives typical locations for equipment.

HYDROPHONES

The hydrophones, installed as an array on the ship, were designed by AC-DRL to mount on extender arms which place them below the noise sources. These arms were originally designed and manufactured by AC-DRL for Project Mohole. AC-DRL was directly responsible for mounting all of the short baseline position measurement hydrophones on the Project Mohole platform. The hydrophones are designed with high front-to-back ratio to reject surface and shipboard noise, and reflect a significant advance

/79

in the state of the art. Identical equipment has been successfully employed in newer systems installed by AC-DRL. Figure 26 illustrates the basic mounting technique.

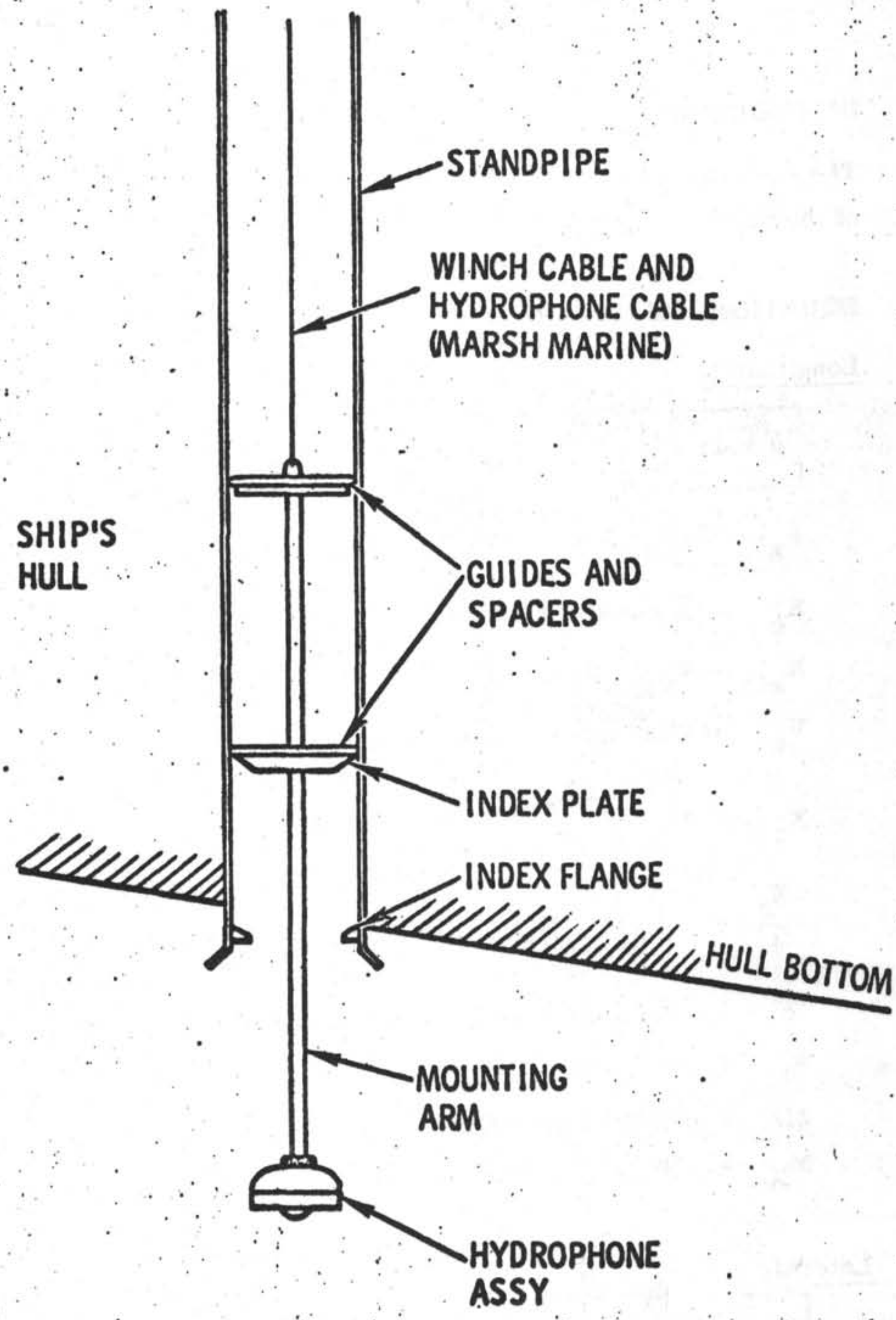


Figure 26 Basic Hydrophone Mounting Technique

pages 39 through 45 - deleted

APPENDIX
INPUT DATA FOR SIMULATION STUDY

INTRODUCTION

The equations of motion used in the simulation study are listed below along with values of the constants used.

EQUATIONS OF MOTION

Longitudinal

$$\boxed{\dot{\mu} = \dot{\psi} v + \frac{1}{M_x}\left[F_x + X_w + X_c\right]}$$

$F_x = (K_{XP} + K_{XR} + K_{XI})\, X_e$ (Control Force)

$X_e = \overline{X}\cos\psi + \overline{Y}\sin\psi$

$X_w = -V_w|V_w|\cos\beta_w \left\{\left|14.5\cos\beta_w + 57.5\sin\beta_w\right|\right\}$ (Wind Force)

V_w = Wind velocity in knots (ignore ship's velocity)

$X_c = 2L \text{ avg} \frac{dX_c}{dt}$ (Current Force)

$\frac{dX_c}{dt} = -(.835\, \mu_c|v_c| + .272\, \mu_c|\mu_c|)\frac{dx}{dt}$

$v_c = v + V_c' \sin\beta_c' + \dot{\psi}X$ (ft/sec)

$\mu_c = \mu + V_c' \cos\beta_c'$ (ft/sec)

$2L$ = Ship's length = 420'

$M_X = .793 \times 10^6$ slugs

Lateral

$$\boxed{\dot{v} = -\dot{\psi}\mu + \frac{1}{M_y}\left[F_y + Y_w + Y_c\right]}$$

$F_y = (K_{YP} + K_{YR} + K_{YI})\, Y_e$ (Control Force)

$Y_e = \overline{Y}\cos\psi - \overline{X}\sin\psi$

/81

$$Y_w = -V_w|V_w| \sin \beta_w \left\{ \left| 14.5 \cos \beta_w + 57.5 \sin \beta_w \right| \right\} \text{ (Wind Force)}$$

$$Y_c = 2L \text{ avg} \frac{dY_c}{dt} \text{ (Current Force)}$$

$$\frac{dY_c}{dt} = -(10\, v_c|v_c| + 2.1\, v_c|\mu_c|) \frac{dx}{dt}$$

$$M_y = 1.157 \times 10^6 \text{ slugs}$$

Moment

$$\ddot{\psi} = \frac{1}{J}\left[M + M_w + M_c + M_p\right]$$

$$M = (K_{\psi P} + K_{\psi R} + K_{\psi I})\, \psi_e \text{ (Control Moment)}$$

$$\psi_e = \psi_c - \psi$$

$$M_w = X_p\{\beta_w\}\, Y_w \text{ (Wind Moment)}$$

$$X_p\{\beta_w\} = 90 - 1.2|\beta_w| \text{ (feet)}$$

$$\beta_w = 90^o - (\psi + \gamma_w)$$

$$M_c = 2L \text{ avg} \left(X \frac{Y_c}{dt}\right) \text{ (Current Damping Moment)}$$

$$M_p = X_p\{\beta_c\}\, Y_c \text{ (Current Moment)}$$

$$\beta_c = \tan^{-1}\left(\frac{v_c}{\mu_c}\right)$$

$$J = 1.375 \times 10^{10} \text{ slug-ft}^2$$

List of Symbols

F1, F2, F3, F4	thrust from X and Y thrusters
F_x	X-axis control thrust $(F_3 - F_4)$
F_y	Y-axis control thrust $(F_1 + F_2)$
K_n	control gain coefficient
J	moment of inertia of ship
L	half length of ship

/82

M_x, M_y	mass of ship including added liquid mass in each axis
M	control moment from thrusters
M_c	current damping moment
M_p	current moment due to center of pressure shift
M_w	wind moment
s	LaPlace operator
V_c	current velocity (inertial)
V_w	wind velocity (inertial)
μ, v	body axis velocities (absolute)
μ_c, v_c	ship velocity relative to water
X_b, Y_b	body axes
X, Y	inertial axes
X_c, Y_c	current forces
X_w, Y_w	wind forces
β_c	angle of current off bow
β_w	angle of wind off bow
ψ	ship's heading angle
$X_P\{\beta_w\}$	wind center of pressure as function of angle of wind
$X_P\{\beta_c\}$	current center of pressure as function of current angle

/83

APPENDIX C

Station Keeping for Deep Sea Drilling

Printed in U.S.A.

69-WA/UnT-12

an ASME publication

Station Keeping for Deep Sea Drilling

A. R. McLERRAN

Assistant for Coring Operations,
Scripps Institute of Oceanography,
La Jolla, Calif. Mem. ASME

Operation of the "Glomar Challenger" has proved that a large ship can be kept within a few hundred feet of a station in the open ocean for extended periods of time under moderate weather conditions. Vessel size, wind, sea state, current, and method of application of thrust are very important considerations in developing power requirements for dynamic positioning. More important factors in systems design are the noise level of the ship and its thrusters and the relationship of hydrophones to the principal noise sources because these factors, together with maximum water depth, determine reference beacon source level. Systems redundancy is desirable, where risks are high, in case station is lost. Thoroughly trained personnel is vital to successful operation of the system.

Contributed by the Underwater Technology Division of The American Society of Mechanical Engineers for presentation at the ASME Winter Annual Meeting, November 16-20, 1969, Los Angeles, Calif. Manuscript received at ASME Headquarters July 30, 1969.

Copies will be available until September 1, 1970.

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, UNITED ENGINEERING CENTER, 345 EAST 47th STREET, NEW YORK, N.Y. 10017

Station Keeping for Deep Sea Drilling

A. R. McLERRAN

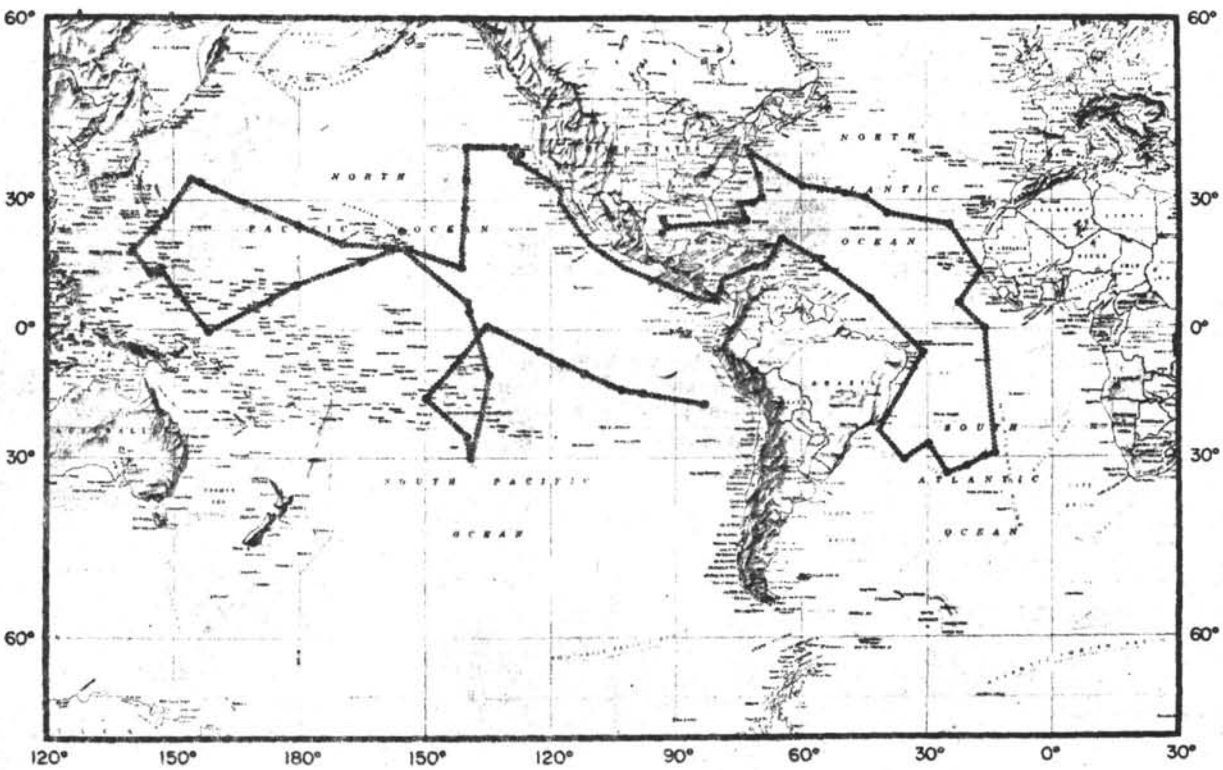
How do you keep a 10,000-ton ship stationary over a fixed spot on the ocean floor 20,000 ft below for days while drilling holes and taking cores from the ocean floor? This was one of the major problems facing engineers and scientists in 1966 when the National Science Foundation awarded a prime contract to Scripps Institution of Oceanography of the University of California to be Managing Operator for the Deep Sea Drilling Project as part of NSF's National Ocean Sediment Coring Program.

The scientific plans were developed with the assistance of the Joint Oceanographic Institutions for Deep Earth Sampling. This group is composed of Lamont-Doherty Geological Observatory, Woods Hole Oceanographic Institution, Institute of Marine Science, University of Miami, University of Washington, and Scripps Institution of Oceanography.

OBJECTIVES AND PLANS

The basic objectives of the Deep Sea Drilling Project are to gain insight into the history of the oceanic basins and to gain understanding of the processes that have lead to their formation and modification as well as to stimulate the technology needed for eventual economic benefits.

The plan called for recovering cores from the bottom of the ocean in water depths from 3000 up to 20,000 ft in the Atlantic and Pacific Oceans and for penetrating into the bottom to 2500 ft. The original contract provided for 18 months of drilling divided into nine legs of two months each; four in the Atlantic and five in the Pacific (Fig. 1). Conventional rotary oil well drilling methods were proposed using 5-in. OD drill pipe. Engineering studies and offshore drilling experience



DEEP SEA DRILLING PROJECT

ATLANTIC – PACIFIC TRACKS

Fig.1 Atlantic and Pacific tracks made during initial 18 months of Deep Sea Drilling Project indicated that the drill ship should hold station within a radius equal to 3 percent of water depth during dilling operations. Drilling operations were to be carried out on a 24-hr per day basis until coring on a given site was completed. It was estimated that as many as 12 days may be required to complete some coring sites and station must be maintained under all expected weather conditions. Design goals for the station keeping were selected as 30-knot steady-state winds with fully developed seas and $1^{1}/2$-knot current from any direction.

HISTORY OF SYSTEMS DEVELOPMENT

The dynamic positioning systems that have performed so successfully on the "Glomar Challenger" are the culmination of approximately 10 years of research which began with Phase I of Project Mohole. This National Science Foundation project was designed to determine the feasibility of drilling in the deep ocean from a dynamically positioned vessel. This project resulted in drilling 5 holes in 11,672 ft of water off Guadalupe Island from the Global Marine Vessel CUSS I in April 1961.

During this operation, a system of taut wire sub-surface buoys with sonar transponders attached and surface floats with radar reflectors were used as the position reference, and four large diesel powered Harbormaster outboard motors were utilized to hold the ship on station. While the limited objectives of this program were accomplished, it was recognized that much work was necessary in order to develop a more reliable position reference and station keeping system.

Phase II of Project Mohole, funded by NSF, undertook the development of a dynamic positioning system with the very high degree of accuracy, reliability, and systems response necessary for maintaining a drilling platform over a given station for periods up to three years in all except most severe hurricane conditions. A great deal of research was conducted by several companies, and a system was developed having one long base line sonar and two short base line sonar reference systems.

The long base line system consists of four transponders, each having a different response frequency, placed on the ocean floor in a square pattern with sides approximately equal to the water depth. The signals are received by a single hydrophone on the platform, and a change in range can be calculated by measuring change in arrival time of the four signals. The short base line

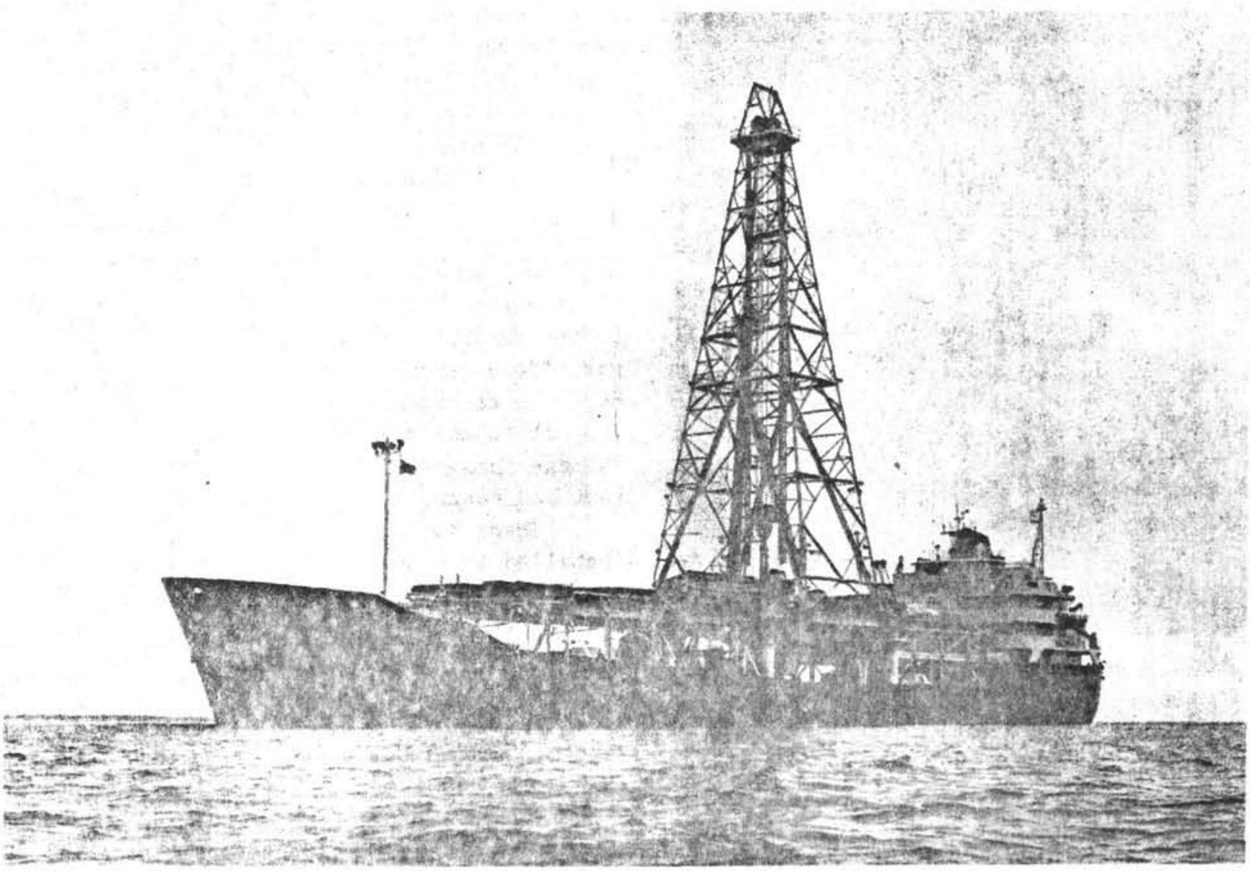


Fig.2 Port side of Deep Sea Drilling Project drill ship, "Glomar Challenger"

/87

systems each operate with one beacon on the bottom and four hydrophones mounted on the platform in a square pattern with the maximum spacing permitted by the platform configuration. In this case, the difference in time of arrival at the four hydrophones of a signal from a single source is used to calculate change in range.

Components of this dynamic positioning system were under construction and nearly complete at the time Project Mohole was cancelled in 1966 due to lack of funds. The sonar reference systems were completed for possible use in future programs. The two short base line systems were eventually modified and used by Deep Sea Drilling Project.

THE GLOMAR CHALLENGER'S POSITIONING SYSTEM

A subcontract was awarded by Scripps to Global Marine, Inc., in November 1967 to furnish and operate a drilling ship to accomplish the objectives of the Program. The new dynamically positioned drill ship "Glomar Challenger" sailed from Orange, Texas for acceptance trials on July 20, 1968 (Fig.2).

Fig.2 shows "Glomar Challenger" as it set off on its 40,000-nautical mile voyage in the Atlantic and Pacific oceans on the most ambitious deep-sea drilling expedition ever attempted by U. S. scientists and engineers. The ship weighs 10,400 tons and is 400-ft long, and its drilling derrick towers 194 ft above the waterline. Forward of the derrick is the automatic pipe racker designed by Global Marine to hold 24,000 ft of 5-in. drill pipe.

In developing plans for the "Glomar Challenger," its owner chose to utilize one of these short base sonar reference systems as the primary position reference system. Since the system was still relatively unproven at this time, and due to the absolute necessity of having a reliable position reference, Scripps and NSF decided to have the second short base line system built for Project Mohole modified and installed on the "Glomar Challenger" in order to have complete systems redundancy.

These two position reference systems were installed in connection with the owner-supplied digital computer which automatically controlled the ship's propulsion system to keep the vessel in position without any external anchors or mooring system (Fig.3).

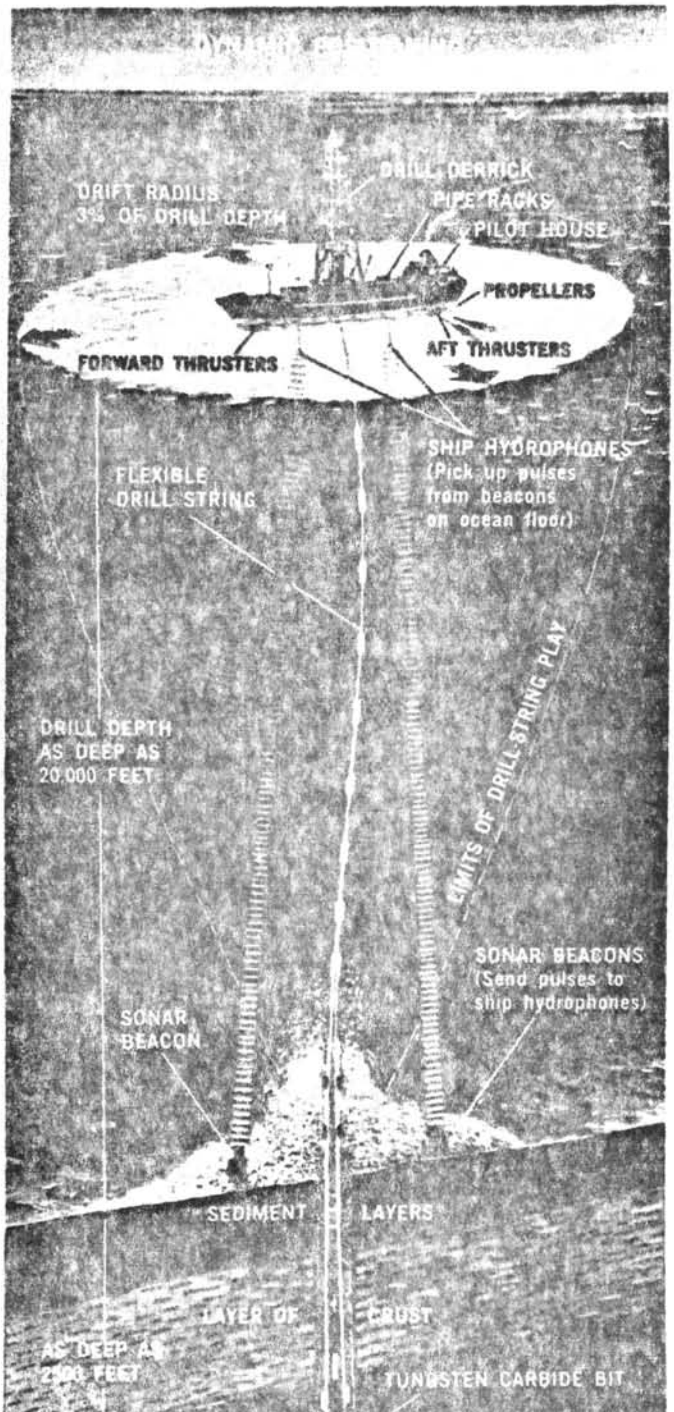


Fig.3 This illustration from Popular Mechanics Magazine shows dynamic positioning system that kept "Glomar Challenger" on station while working in water depths up to 20,000 ft, as well as flexibility of the drill string which weighs 400,000 lb at 20,000-ft depth

The dynamic positioning illustrated in Fig.3 used a computerized system of pulses, from acoustic beacons on the ocean floor, that are picked up by a ship-mounted hydrophone array, fed into a computer, and translated into corrective action by propulsion units (tunnel thrusters and ship propellers), which automatically keep the ship on station in depths up to 20,000 ft.

The "Glomar Challenger" is equipped with an unusual propulsion system which includes two forward and two aft tunnel thrusters (800 hp each) that combine with the two normal sterm screws (each with a 2250-hp d-c electric motor) and the computerized automatic ship positioning system to keep the ship on station in mid-ocean throughout drilling operations which often take several days (Fig.4).

The two position reference systems on the "Glomar Challenger" are a Pulse Position Measurement (PPM) system and a Phase Comparison System (PCS). Both of these systems determine range or distance from sonar beacons on the sea floor. The PPM System utilizes a 16 KHz pulse 4 msec in length at 2-sec intervals. Range is determined by measuring the difference in time of arrival of signals at the hydrophones. Since starting operations, the system has been modified to also permit operations on 13.5 KHz signal on a noninterference basis for additional systems redundancy. The PCS System utilizes a 10 KHz continuous wave signal from the sea floor beacon and determines change in range by measuring phase shift of the received signals.

Four hydrophones were mounted on extendable arms in a square pattern below the bottom of the vessel. Signals must be received by three of these hydrophones in order for the reference systems to compute the X and Y coordinates of the vessel's position with reference to the selected station. Input from two reference gyros near the center of the vessel permit compensation for the vessel's pitch and roll. The ship's gyrocompass is connected to the system to provide input on the ship's heading.

There are three possible modes of operations: Manual, Semi-automatic, and Automatic. In the Manual mode, the position reference system computes the position relative to the chosen reference and displays this as a dot on the PPI Scope on the ship's bridge. The mate in charge controls the main screws and thrusters manually to maintain station and desired heading. In case the computer is out of operation, the Manual mode would be used. In other words, the man is redundant to the computer.

In the Semi-automatic mode, a ship's heading is selected on the bridge and fed into the system. The heading is automatically maintained by the computer, and the mate on the bridge maintains X and Y position by manually controlling the main screws and the forward and aft thrusters. In early stages of operation, it was necessary to use the Semi-automatic mode frequently.

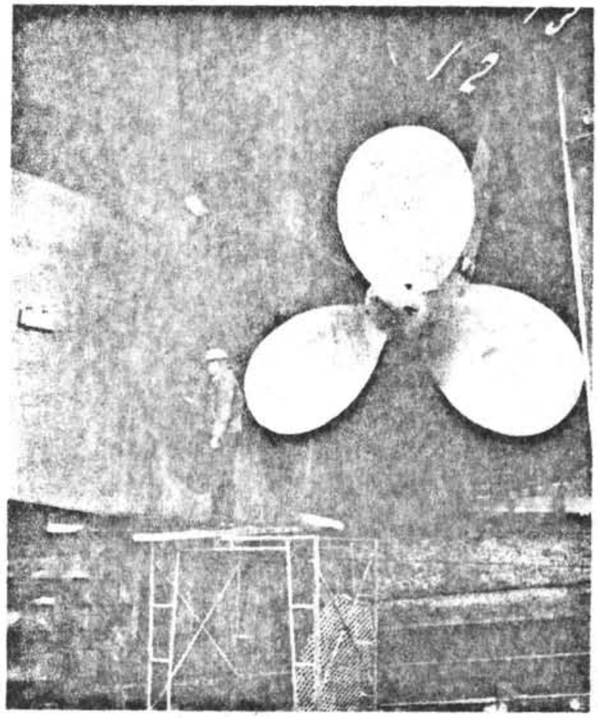


Fig.4 Starboard main propeller and two stern thrusters of "Glomar Challenger"

The system is intended to be operated in the Automatic mode during normal drilling operations. In this mode, once a station and heading are selected, they are maintained under automatic control by the computer. Ship's heading is selected by the bridge and may be changed from time to time as wind and current conditions change. A heading is usually selected so that station can be maintained with minimum thruster use.

SEA FLOOR SONAR BEACONS

The sea floor sonar reference beacons are a critical part of the positioning system. A study indicated that beacons having approximately 12 days' life could be procured at a low enough price so that the ship's time required to recover beacons would exceed their cost. Therefore, an early decision was made to consider the beacons expendable, and no attempt would be made to recover them.

Since there was no actual operating experience with these systems, it was decided that both a PPM and PCS beacon would be dropped at each location. These beacons were designed so that they could be dropped singly or bolted together and dropped as a single unit. Each beacon consisted of a battery package which served as an anchor, and electronics and a transducer mounted in a flotation unit. These were connected by a 20-ft power cable, and when implanted, the transducer and electronics unit floated approximately 20 ft above the bottom.

Based on estimated noise level of the ship and transmission losses between the beacon on the bottom and the hydrophones on the ship, an acoustic signal strength of 105 db was specified for the PPM beacon and 87 db for the PCS beacon.

ACCEPTANCE TRIALS

One of the conditions of acceptance of the "Glomar Challenger" was that the owners demonstrate its station-keeping ability by maintaining station for five days continuously.

The "Glomar Challenger" departed Orange, Texas, on July 20, 1969, with a full operating and scientific crew with the intention of completing acceptance trials within approximately seven days and then proceeding to the first drill site without returning to port. Murphy's law immediately became effective and everything that could happen, did happen. Acceptance trials were not completed until August 11 — 23 days later.

The first day at sea was spent in making ship's speed trials, thruster response tests, and other routine ship trials. During the second day, noise level tests were started after correcting the expected minor problems such as crossed wires and loose connections. These tests were conducted in approximately 1000 ft of water to avoid interference from bottom reflection. The test results indicated that the noise level received by the forward hydrophones was much higher than expected.

All four hydrophones were mounted to extend below the ship's bottom, forward of the drilling well which is located in the center of the ship. This placed the two forward hydrophones fairly close to the bow thrusters. It became evident that the noise generated by the bow thrusters, operating at maximum speed, would cause serious problems by overpowering the incoming signals from the sea floor beacons.

It was determined that the noise level at the hydrophones could be improved by changing their positions. By test, the position giving lowest noise level was determined, but this did not reduce the noise to a level that would permit fully automatic operation at design water depth with the available beacons.

It was decided to proceed to deeper water and implant beacons for actual systems test. On the fourth day at sea, two beacons (one PCS and one PPM) were implanted in 3447 ft of water, attached to a surface buoy so they could be retrieved after the test. After the beacons were implanted, the ship cruised over their indicated positions, and the strength of reference signals was measured. These tests showed that the main beam was extremely narrow — approximately 10 deg between the 3 db down points, and that the pulse shape did not remain constant over the projected area of the total beam at the surface. This indicated that the vessel would have to take up station essentially over the beacon, since a position offset from the beacon could cause the vessel to move into a lobe of the beam pattern where the signal was not useable.

It was determined from these initial tests that operation during early phases of the project would be limited to water depth less than the proposed 20,000 ft maximum due to higher than expected thruster noise and limited useable projected area of signal beam. It was estimated that the system could be expected to operate safely in 10,000 to 12,000 ft of water by taking up station directly over the beacon. It was believed that it would be possible to operate to 18,000-ft depth if the weather was very good so that the bow thruster speed could be limited to approximately 280 rpm or approximately 30 percent of maximum torque. Later experience proved that slightly higher speed could be used without serious interference. Normally only one thruster would be operated. However, the controls were arranged so that both thrusters could be operated together to increase available thrust.

During the fifth day of the test, the system was put into automatic operation. After several hours of satisfactory operation, a sudden command from the computer caused the ship to start to move rapidly off station. The operator on the bridge took control by switching to Manual operation. This occurred several times during the next two days while the technicians were attempting to pinpoint the trouble.

During this time, the ship's mates became quite proficient in keeping the ship on station in the Manual mode of operation. The problem was finally isolated as being in the computer program. The technicians and engineers aboard started a review of the program to identify and correct the deficiency.

After the 11th day at sea, the signals from the original beacons began to show signs of weakening, and it was decided to retrieve the beacons and install new ones. In attempting to retrieve the beacons, the mooring line parted below the sub-surface buoy, and only the buoys and a few feet of line were recovered. Since the two beacons on the bottom were still operating, it was necessary to move to a new site several miles away where a new beacon was implanted in 3627 ft of water.

During the initial 10 days of testing, some of the engineers felt that the beacon signal may have caused some of the erratic performance of the system. At the new test site, an experimental beacon furnished by the manufacturer of one of the reference systems was used. This beacon had lower signal strength but was adequate for the shallow water depth. This beacon has a 90-deg signal cone angle and a more uniform projected beam pattern than the beacon used during the initial test.

After only $2^1/2$ hr of automatic operation at the new test site, the computer gave an erroneous power demand signal, and the vessel was driven approximately 140 ft off station before the mate in charge on the bridge could take corrective actions.

Fortunately, during these acceptance trials, the "Glomar Challenger" was supported by a smaller vessel, the MV "Eureka," and it was possible to get the assistance of program specialists from shore. The program deficiencies were corrected, and the "Glomar Challenger" was finally accepted by the Prime Contractor on Aug. 11, 1968, the 23rd day after leaving port.

OPERATIONS EXPERIENCE

The "Challenger" immediately proceeded to Drill Site No. 1 where beacons were dropped on Aug. 11, 1968, to begin the highly successful Deep Sea Drilling Project. Water depth at the first site was 9226 ft, and during six days of operations, cores were recovered from 2528 ft below the ocean floor. The site was completed with only a few minor "bugs" in the positioning system. These were corrected by engineers aboard. Both PPM and PCS systems were operated with good correlation between indicated positions.

Site No. 2 was located over one of the many mounds known as the Sigsbee Knolls on the bottom of the Gulf of Mexico in 11,557 ft of water. This hole, drilled 472 ft below the ocean bottom, resulted in one of the most exciting discoveries of the Deep Sea Drilling Project, the recovery of oil saturated cores where many geologists thought oil could not exist. This hole was plugged with mud and cement before abandoning site. This site was subsequently named the "Challenger Knoll" by scientists aboard the ship.

Site No. 3 was drilled nearby on the surrounding plains in 11,992 ft of water. The first beacon failures occurred at this site. The PPM beacon signal failed shortly before reaching bottom, and a water leakage was suspected as the cause. After approximately 9 hr, the signal from the PCS System became erratic for unknown reasons, and the site was abandoned. A new position for Site No. 3 was selected approximately 2 miles away, and this site was completed in approximately four days operations with no unusual troubles.

The "Glomar Challenger" arrived at Site No. 4, east of the Bahama Islands, on August 27 and dropped beacons in 17,432 ft of water. Weather was very good and seas relatively calm for the area. Since this was approximately maximum water depth at which it was estimated the system could operate with the current 105 db max beacon power, a search pattern was run over the site to locate the point of maximum signal strength to take up station. At this depth and under existing conditions, it appeared that the PPM system could be used to maintain station. The PCS signal was very marginal at this depth and appeared to have considerable drift. The site was completed after $5^1/2$ days on station. Some heavy squalls were encountered that called for high levels of thrust which would drown out beacon signals. In the Automatic mode of operation, the computer would call for thrust at high level in attempting to return the vessel to the selected station. In cases where the acoustic signal from the beacon is lost, the computer command is based on the last verified signal and subsequently becomes "lost" if new signals are not received. By going to the Semi-automatic mode, the mate on the bridge controls the thrusters and can intermittently stop or reduce thruster RPM to the point where acoustic signals are received and verified by the signal processing equipment. In this manner, new position data can be obtained at desired intervals to maintain station by relying on the display on the PPI scope on the bridge.

Site No. 4 was completed on September 2 after $5^1/2$ days on station.

Site No. 5 was drilled in nearly 17,567 ft of water and was completed after 6 days on station without any new problems.

In view of the data taken and experience in operations, it was recommended that immediate action be taken to obtain beacons with minimum signal strength of 111 db with a beam width of 30 deg at the minimum 3 db down points. This represents an approximate doubling of the beacon signal power. Calculations indicated that this was the minimum beacon strength that would permit reliable auto matic operations in 20,000 ft of water.

A review of proposed drill sites indicated that none of the sites proposed during the next few months would be in water depths exceeding that of Sites 4 and 5. Therefore, it was decided that operations could safely proceed with existing beacons during the first three legs.

The first six months of operations were successfully completed when the "Glomar Challenger" arrived in Rio de Janerio on Jan. 25, 1969, after having drilled 38 holes at 22 different sites. Water depth for these sites ranged from 6928 to

17,567 ft. While drilling in the North Atlantic, the "Glomar Challenger" was able to maintain station in 40-knot winds and 12 to 15-ft seas.

A great deal of the credit for the success of these operations must be given to the training and dedication of the operating crews.

At Rio de Janerio new higher powered PPM beacons were placed aboard for Leg 4. One of the new beacons was dropped at the first site in 16,727 ft of water. The signal was very strong, with an indicated strength several times that of the original beacon. Tests indicated that the thrusters could be operated at maximum rpm without interference with the reference signal in maximum water depths of 20,000 ft.

Spirits were high for $3^{1}/2$ days until the signal strength began to fail. After 70 hr of operation, the beacon signal was unusable. Fortunately, coring operations had been completed at about the time that the beacon began to fail. The pipe was pulled and no time was lost.

Another new beacon was tried at the next site, and this beacon signal failed after 30 hr of operation. Operations were continued on the PCS system until coring operations were completed.

An investigation of these failures was immediately started, and it was soon determined that they were caused by a loss in buoyancy of the syntactic foam being used to support the transducer. Improvised flotation using glass spheres permitted use of remaining beacons aboard the "Challenger." The beacon manufacturer corrected the flotation failure by changes in material specifications and more stringent testing procedures.

During Leg 4, a site was drilled in 18,109 feet of water. The ship was on station for 5 days with moderate weather conditions. Maximum excursion recorded during this period was approximately 120 ft.

The "Glomar Challenger" successfully completed operation in the Atlantic area upon arrival in Panama on March 23, 1969, having investigated 31 sites. Operations are now proceeding in the Pacific Area where 5 legs are planned under the initial contract.

In addition to the Sonar position reference system, the "Glomar Challenger" is equipped with a satellite navigation system which gives the ship location with an accuracy of 0.1 mile or less. This equipment is used to determine accurate geographical locations so that drill sites can be pinpointed for future investigations. This system does not have the accuracy or frequency of fixes to be used for station keeping; however, a plot of 32 fixes taken over a 48-hr period fell within a circle having a radius of 200 ft.

CONCLUSION

The operation of the "Glomar Challenger" has proven that a large ship can be kept within a few hundred feet of a station in the open ocean for extended periods of time under moderate weather conditions. The majority of the time the ship was within 60 ft or less of the selected station. Reliable reference and control systems now exist with a systems accuracy sufficient for most conceivable uses of a vessel in the deep ocean such as drilling, conducting scientific experiments, salvage, missile tracking, etc.

The noise level of the ship and its thrusters and the relationship of hydrophones to the principal noise sources are very important factors in systems design. These factors, together with maximum water depth, determine reference beacon source level.

Vessel size, wind, sea state, current, and method of application of thrust are also very important considerations in developing power requirements for dynamic positioning. Operation experience to date testifies to the thoroughness with which Global Marine engineers have done their job.

Systems redundancy is desirable where risks are high in case station is lost. During initial operations of the "Challenger," serious loss of drilling tools was prevented by having redundant systems.

Thoroughly trained personnel is vital to successful operation of the system. As a result of a well-planned training program, the mates in charge were able to take over control of the vessel in several instances to prevent losses due to loss of signal, severe weather, or other equipment failures. Well-trained electronics technicians are essential for reliable systems performance.

/92

APPENDIX D

Emergency Methods of Maintaining "Hole" Position
During Casualty Failures to Components of
Ship's Computer-Positioning System.

EMERGENCY METHODS OF MAINTAINING "HOLE" POSITION DURING CASUALTY FAILURES TO COMPONENTS OF SHIP'S COMPUTER-POSITIONING SYSTEM.

CASUALTY #1 - "LOSS OF BEACON - SEAS & SWELL 6 FT OR LESS, WINDS 18 MPH OR LESS"

ACTION: A. IF WINDS ARE 18 MPH OR LESS AND SEAS AND SWELL 6 FT OR LESS LEAVE VESSEL IN AUTOMATIC MODE.

B. PULL UP 2 STANDS OFF BOTTOM.

C. CALL DRILLING SUPT. TO MAKE READY ALTERNATE FREQUENCY BEACON, i.e. 16.0 KHZ IF WE ARE USING 13.5 KHZ AND VICE VERSA.

D. INSURE THAT COMPUTER COMMANDS AT TIME OF BEACON LOSS ARE CLOSE TO THE LAST HOUR'S "MEAN" OF THRUST.

(1) IF COMPUTER COMMANDS AT TIME OF BEACON LOSS IS REPRESENTATIVE OF THE LAST HOUR'S "MEAN", THEN JUST LEAVE IN AUTOMATIC AND PROCEED TO ACTION E.

(2) IF THE COMPUTER COMMANDS AT TIME OF BEACON LOSS ARE NOT REPRESENTATIVE OF THE LAST HOUR'S AVERAGE, THEN IMMEDIATELY AVERAGE OUT THE THRUSTS FOR THE LAST HOUR BY REFERENCE TO 15 MINUTE LOG SHEETS, COMPARING THE MEAN ARRIVED AT WITH THE "MEAN" OF READINGS OF THE MICROAMPERES METERS, AND CRANKING THESE AVERAGES (MEAN) INTO THE FORE-AFT AND ATHWARTSHIP DIALS AND THEN SWITCH TO SEMI-AUTOMATIC MODE OF OPERATION. PROCEED WITH ACTION E.

E. TEST AND LET GO ALTERNATE FREQUENCY BEACON.

F. WHEN BEACON REACHES BOTTOM SWITCH TO ALTERNATE FREQUENCY (FOR A FEW SECONDS ONLY TO DETERMINE POSITION OF NEW BEACON RELATIVE TO OLD BEACON).

G. NOTE POSITION OF "NEW" BEACON AND PLACE OFFSETS TO REMAIN OVER OLD BEACON LOCATION WHILE POSITIONING OVER "NEW" BEACON.

(1) CHECK TO INSURE THAT VESSEL AT TIME OF PLACING OFFSETS IS IN RELATIVE LOCATION OF OLD BEACON BY ASSURING THAT DRILL STRING IS CENTERED IN ROTARY TABLE. IF NOT SO CENTERED THEN EASE VESSEL TO POSITION WHERE IT IS SO CENTERED. THEN PLACE IN OFFSETS TO CENTER NEW BEACON ON OSCILLOSCOPE.

H. SWITCH TO "NEW" BEACON AND RESUME DRILLING.

(NOTE: THE ABOVE PROCEDURE HAS BEEN USED ON NUMEROUS OCCASIONS SUCCESSFULLY, THE VESSEL REMAINING WITHIN 400 FEET OF THE BEACON IN AUTOMATIC MODE FOR WELL OVER ONE HOUR REQUIRED FOR THE ABOVE PROCEDURE IN 18,000 FEET OF WATER).

CASUALTY #2 - LOSS OF BEACON - SEAS 8-12 FEET, WINDS 18-35 MPH

ACTION: A. LEAVE VESSEL IN AUTOMATIC MODE WHILE "MEAN" OF LAST HOURS THRUST IS WORKED UP (APPROXIMATELY 2-3 MINUTES).

B. PULL UP 3 STANDS AND READY ALTERNATE BEACON.

C. CHECK "MEAN" OF READINGS WITH MICROAMPERES READINGS.

D. SWITCH TO SEMI-AUTOMATIC MODE OF OPERATION, AND PLACE IN REQUIRED PERCENTAGE OF THRUST FROM A COMBINATION OF "MEAN" OF READINGS AND MICROAMPERES.

E. PUT OVER AND TEST ALTERNATE BEACON.

F. PROCEED AS IN CASUALTY #1 F, G & H.

(NOTE: THIS ALSO HAS BEEN DONE SUCCESSFULLY WITH 8-12 FOOT SEAS AND SWELL AND 30 MPH WINDS WITH VESSEL MOVING ONLY 400 FEET IN ONE HOUR).

EMERGENCY METHODS OF MAINTAINING "HOLE" POSITION DURING CASUALTY FAILURES TO COMPONENTS OF SHIP'S COMPUTER-POSITIONING SYSTEM.

CASUALTY #3 - LOSS OF BEACON WHEN IT IS DECIDED TO PULL OUT AND ABANDON HOLE WHERE PENETRATION IS LESS THAN 1000 FEET.

ACTION: A. LEAVE VESSEL IN AUTOMATIC MODE OR SHIFT TO SEMI-AUTOMATIC MODE AS IN CASE #1 OR #2 RESPECTIVELY AND CONTINUE WITH PROCEDURES OUTLINED.

B. NOTE: WHEN MAIN SHAFT IS SHIFTED FROM PORT TO STARBOARD PROPULSION APPROXIMATELY 80% OF FORWARD THRUST REQUIRED BY PORT SHAFT IS NOW REQUIRED BY STARBOARD SHAFT.

CASUALTY #4 - LOSS OF BEACON WHERE IT IS DECIDED TO PULL OUT OF HOLE AND PENETRATION EXCEEDS 1000 FEET.

ACTION: A. WHERE BEACON IS COMPLETELY LOST AND PENETRATION EXCEEDS 1000 FEET THE PREVIOUSLY DESCRIBED METHODS OF OPERATING IN AUTOMATIC OR SEMI-AUTOMATIC MODSS AS IN CASUALTY #1 OR #2 SHOULD BE USED INITIALLY.

B. HOOK-UP THE "MARTIN DECKER" GAUGES AND PUT INTO OPERATION.

C. THEN USING A COMBINATION OF "MEAN" OF THRUST REQUIREMENTS, PLUS MARTIN DECKER READINGS, PLUS A PERIODIC CHECKING OF PIPE ANGLE BY VISUALLY INSPECTING PIPE IT IS FELT THAT VESSEL MAY BE HELD NEAR POSITION LONG ENOUGH TO PULL PIPE FROM ANY DEPTH CORRESPONDENT WITH OUR PRESENT OPERATING CAPABILITIES.

CASUALTY #5 - LOSS OF BEACON WHERE BEACON BECOMES TOO POOR TO OPERATE, HOWEVER SIGNALS ARE STILL BEING RECEIVED PERIODICALLY.

ACTION: A. IN THIS CASE ACTION SHOULD BE THE SAME AS IN CASES OF CASUALTIES #1 & #2 WITH THE EXCEPTION THAT VESSEL CANNOT BE OPERATED IN AUTOMATIC OR SEMI-AUTOMATIC AS DESCRIBED SINCE POOR SIGNALS WILL AFFECT HEADING AND "Y" COMPONENT THRUST EVEN IN SEMI-AUTOMATIC MODE OF OPERATION.

B. IF IT IS DECIDED TO CONTINUE WITH THE HOLE READY ALTERNATE BEACON.

C. "LOCK OUT" BEACON SIGNAL FROM COMPUTER AND OPERATE IN SEMI-AUTOMATIC MODE USING "MEAN" OF THRUST AS DESCRIBED IN CASUALTIES #1 & #2.

D. TEST AND LAUNCH ALTERNATE BEACON.

E. "LOCK IN" BEACON SIGNAL PERIODICALLY TO CHECK VESSEL'S POSITION WHILE ALTERNATE BEACON IS FALLING.

F. CHECK POSITION OF ALTERNATE BEACON AND PLACE IN REQUIRED OFFSETS AS DESCRIBED IN CASUALTY #1.

G. RESUME DRILLING OPERATIONS.

EMERGENCY METHODS OF MAINTAINING "HOLE" POSITION DURING CASUALTY FAILURES TO COMPONENTS OF SHIP'S COMPUTER-POSITIONING SYSTEM.

CASUALTY #6 - LOSS OF COMPUTER

ACTION: A. SHIFT IMMEDIATELY TO "MANUAL" MODE OF OPERATION.
B. SHIFT TO RELATIVE POSITION.
C. HOME OVER BEACON IN MANUAL MODE WHILE REPAIRS ARE MADE TO COMPUTER.
D. VESSEL CAN BE OPERATED IN THIS MODE UNTIL COMPLETION OF HOLE SHOULD COMPUTER REPAIRS REQUIRE SOME TIME.
E. IT HAS BEEN NOTED THAT WHEN SUBSTANTIAL FORWARD THRUST IS REQUIRED TO MAINTAIN POSITION (i.e. OVER 100 TURNS) PUTTING A HELMSMAN ON THE WHEEL AND STEERING IN A MANUAL MODE IS OF A GREAT DEAL OF ASSISTANCE IN MAINTAINING POSITION.

CASUALTY #7 - LOSS OF MASTER GYRO

ACTION: A. OPEN BACK OF CONTROL CABINET AND SWITCH "REPEATER COMPASS" SWITCH TO "OFF" POSITION.
B. LEAVE VESSEL IN AUTOMATIC MODE.
C. CALL A HELMSMAN TO THE WHEEL AND STEER DESIRED HEADING USING SHIP'S RUDDER AND "STANDARD" MAGNETIC COMPASS HEADING.
D. VESSEL WILL HOLD POSITION WELL IN THIS MODE OF OPERATION WHILE REPAIRS ARE MADE TO MASTER GYRO COMPASS.
E. THIS METHOD OF OPERATION REQUIRES THAT A "FORCE" OR VECTOR OF "FORCES" BE REQUIRED FROM AHEAD AS IS USUALLY THE CASE.
F. SHOULD THE VESSEL BE OPERATING IN THE AREA OF THE DOLDRUMS OR SHOULD THERE BE VERY LITTLE AHEAD THRUST REQUIRED THEN THE VESSEL SHOULD BE OPERATED IN A "MANUAL" MODE HOLDING HEADING BY USING "STANDARD" MAGNETIC COMPASS.

CASUALTY #8 - LOSS OF VERTICAL REFERENCE GYRO

ACTION: A. REGARDING VERTICAL REFERENCE GYRO IS IS EXTREMELY IMPORTANT THAT A "STANDARD" PROCEDURE OF SPUDDING IN BE TO INSURE THAT VESSEL IS ON AN EVEN KEEL. THE VESSEL SHOULD BE KEPT ON AN EVEN KEEL AT ALL TIMES.
B. VESSEL WILL OPERATE IN AN "AUTOMATIC" MODE RELATIVELY WELL WITHOUT THE USE OF VERTICAL REFERENCE GYROS IS THE VESSEL IS ON AN EVEN KEEL AND ROLL AND PITCH ARE NOT EXCESSIVE.
C. REPAIR OR REPLACE MAL-FUNCTIONING GYRO AS SOON AS POSSIBLE AND RESUME NORMAL OPERATIONS.

EMERGENCY METHODS OF MAINTAINING "HOLE" POSITION DURING CASUALTY FAILURES TO COMPONENTS OF SHIP'S COMPUTER-POSITIONING SYSTEM.

CASUALTY #9 -LOSS OF ALL POWER TO COMPUTER ROOM.

ACTION: A. PLACE VESSEL IN "MANUAL" MODE OF OPERATION IMMEDIATELY.

B. COMMENCE PULLING DRILL STRING ABOVE MUD LINE.

C. USE "MEAN" OF PROPULSION AND THRUST REQUIRED BY REFERENCE TO 15 MINUTE LOG SHEETS AND MICROAMPERES METERS.

D. IF DRILLING PENETRATION IS LESS THAN 1000 FEET CONTINUE OPERATING IN THE MANNER OF A AND C WHILE STRING IS PULLED ABOVE MUD LINE, CHECKING FREQUENTLY THE ANGLE OF PIPE IN THE ROTARY TABLE TO INSURE THAT VESSEL IS NOT FALLING OFF THE HOLE.

E. IF DEPTH OF PENETRATION EXCEEDS 1000 FEET HOOK UP MARTIN DECKER GAUGES (THESE GAUGES WORKED VERY WELL DURING TESTS AND ARE A DEFINITE VALUE WHERE VESSEL MUST BE OPERATED FOR RELATIVELY LONG PERIODS WITHOUT REFERENCE TO BEACON).

F. THEN USING A COMBINATION OF "MEAN" OF THRUST REQUIREMENTS, PLUS MARTIN DECKER READINGS, PLUS A PERIODIC CHECKING OF PIPE ANGLE BY VISUAL INSPECTION PULL UP TO MUD LINE AND AWAIT REPAIRS TO COMPUTER POWER.

THE ABOVE LISTED ACTIONS FOR CASUALTIES #1 THROUGH #9 ARE NOT MEANT TO BE ALL-ENCOMPASSING, NOR IS THERE ANY "PANACEA" IN METHODS OF OPERATIONS THAT ENABLE ONE TO SOLVE ALL PROBLEMS BY ANY ONE ACTION. HOWEVER, IT MAY BE READILY SEEN THAT WE HAVE A GOOD DEAL OF ALTERNATIVES IN METHODS OF OPERATION AND THAT WE HAVE THE ABILITY TO COPE WITH MOST CASUALTIES WE ARE LIKELY TO ENCOUNTER.

RESPECTFULLY SUBMITTED,

J.A. CLARKE, MASTER

APPENDIX E

Typical Acoustic Beacon Work Specifications

ACOUSTIC BEACONS - 13.5 KHZ WITH SYNTACTIC FOAM FLOATATION

SPECIFICATIONS: DSDP #AB-0101 March 18, 1970

1.0 Performance requirements for the electronics, acoustical projector, and power supply for the pulse type (short base line) expendable acoustic beacons.

1.1 Depth - All components shall be capable of operations as specified herein at ocean depths down to 20,000 feet.

1.2 Frequency - The operating frequency of the acoustic beacons shall be 13.5 ± 0.2 kHz.

1.3 Signal Output - The beacon's output shall be a train of acoustic pulses having rectangular pulse envelopes, with pulse shape and duration as shown in Fig. 1.

1.4 Pulse Duration - The pulse duration shall be 4 ± 0.2 milliseconds.

1.5 Pulse Repetition Rate - The pulse repetition rate shall be 1 pulse per $2 \pm .1$ seconds.

1.6 Operating Life - The operating life shall be a minimum of 260,000 pulses. A capability to increase the operating life with additional batteries shall exist.

1.7 Beam Pattern - The beam pattern of the beacon shall be as shown in Fig. 2.

1.8 Source Level - The on-axis acoustic source level of the beacon measured at one yard from the transducer shall be 111 db re 1 μ b - minimum.

1.9 Shelf Life - The shelf life of the beacon shall be such that a beacon can be implanted one year from delivery and meet all performance requirements.

1.10 Service - The design of the beacon shall be such that a beacon can be implanted within the required shelf life with minimum additional service to place it in operation.

1.11 Temperature - The beacon shall be capable of operating at the frequencies specified in the performance requirements (within the stated tolerance) at all temperatures from 0°C to 20°C inclusive.

2.0 Performance Requirements for Floatation Assemblies

2.1 Floatation Design and Performance - It shall be the Subcontractor's responsibility to design and furnish a syntactic foam floatation assembly suitable for operation with the acoustical equipment specified herein. Floatation shall be capable of operating under environmental conditions set forth in this specification.

2.2 Floatation design shall not incorporate inflammable substances such as gasoline.

2.3 Positive buoyancy (in lbs.) of the beacon floatation and attached containers at 20,000 feet implant depth shall be in excess of 10 pounds. This buoyancy shall decrease not more than 2% during 14 days immersion.

2.4 Vendor shall specify estimated weights and dimensions of the components of a complete acoustic beacon.

2.5 Floatation Tests

2.5.1 Pressure Test

2.5.1.1 Vendor shall, upon completion of the floats, extract a sample core from at least two floats (approximate core dimensions: 1" diameter by 10") from the body of the floats running from the top surfaces downward.

1a) These sample cores shall then be weighed to an accuracy of 1 gm and their displacement measured to 1 gm accuracy to determine their material densities.

2.5.1.2 The sample cores shall then be subjected to a hydrostatic pressure test in water for a minimum of 14 days at a maintained pressure of not less than 9000 psi.

2a) After the fourteenth day of pressure testing, the core samples shall be weighed to an accuracy of 1 gm and their displacement measured to an accuracy of 1 gm.

2.5.1.3 The difference between the two measured densities shall be used as a criteria to establish if the assembled units will exhibit a positive buoyancy of at least 10 pounds after 14 days at 20,000 ft. depth in sea water.

2.5.1.4 Upon completion of core testing, the remaining holes in the floats shall be plugged with similar material.

/100

2.5.2 Buoyancy Test

2.5.2.1 The vendor shall test all assembled units to establish that each will exhibit a minimum positive buoyancy of 10 lbs. when totally submerged in sea water.

2.5.3 Certification - A letter of certification is required for all floats. Include in the certification quantities and calculated values.

3.0 Tests Procedures - Acoustic Beacons

3.1 Vendor supplying a design which has not been proven in field usage aboard The Glomar Challenger shall construct two prototype units for shop and field testing.

3.2 Minimum Testing Required

3.2.1 Specify output voltage and currents and with transducer determine output power into dummy load including voltage output and current drain.

3.2.1.1 At room temperature.

3.2.1.2 At 0°C.

3.2.2 Check for excessive voltage. Determine output power into transducer as in 3.2.1.1 above. Advise if water or air loaded and % of rated input power used.

3.2.3 With dummy load connected determine (a) frequency, (b) repetition rate, (c) envelope rise and fall time (per Fig. 1).

3.2.4 Source Level - With standard hydrophone, measure minimum on-axis source level in db re 1 μ bar. measure beam pattern (ref. Fig. 2).

3.2.5 Pulse envelope shape with transducer operating in water photograph pulse envelope observed through the hydrophone (ref. Fig. 2).

3.2.6 Pressure Test - All sealed containers shall be pressure tested to 10,000 psi.

3.3 The Deep Sea Drilling Project will consider alternate proposals for testing, if sufficiently substantiated.

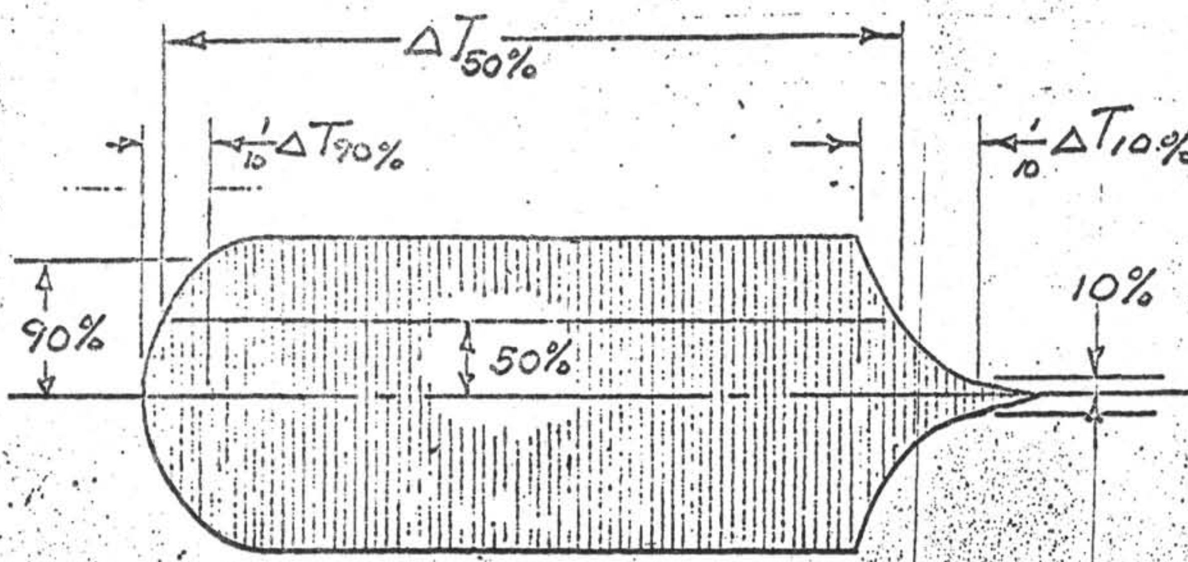
/101

4.0 Replacement in the Event of Non-compliance - In the event of purchase order award, if any of the items furnished do not perform in accordance with the specifications, then Subcontractor shall replace the defective item(s) at no cost to Prime Contractor with new items which satisfactorily meet with the performance requirements. Prime Contractor shall be responsible for furnishing Subcontractor with reasonable evidence in documentation or other similar data to support the fact of non-compliance of said item with the specifications.

Subcontractor shall immediately proceed to replace the defective item(s) claimed by Prime Contractor, but in no event shall said replacement item(s) be delivered later than 30 calendar days from receipt of Prime Contractor's claim of non-compliance.

If further information is required, please contact
R. E. Bates, Procurement Coordinator
Area Code (714) 453-2000 ext. 2261/2262

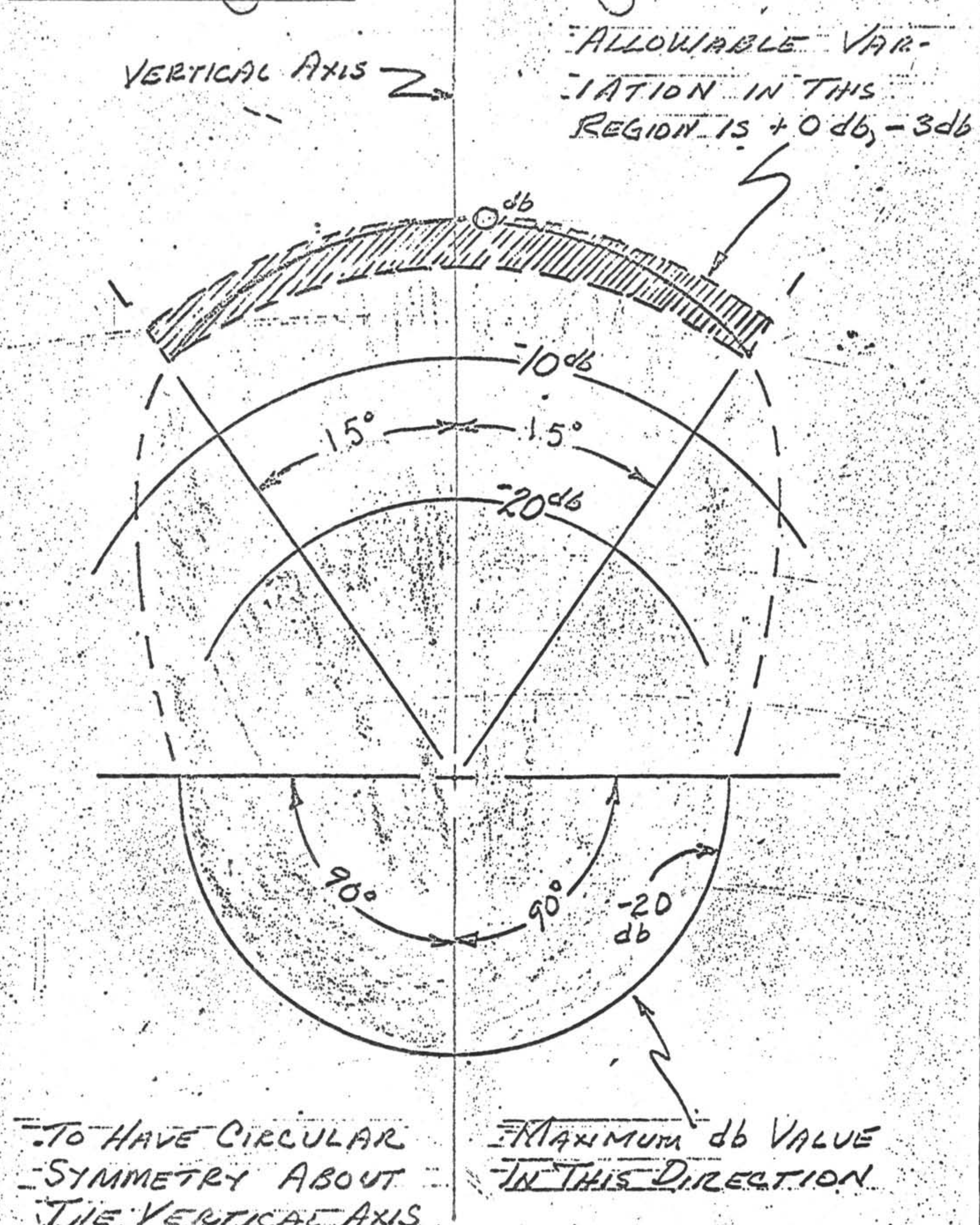
/102



ΔT = 4 MILLISECONDS

PULSE ENVELOPE - IN WATER - ACCOUST
P.P.M. BEACON DSDP /103

FIG 1



/104 ACOUSTIC BEAM PATTERN - PPM BEACON DSDP

FIG. 2

APPENDIX F

Beacon Drop Summary Through Leg 18

APPENDIX F

BEACON DROP SUMMARY

Legs 1 through 18

Site. No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
Acceptance:						August 11, 1968
	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
	ACDRL	16	PPM			100 db
						LEG 1
1	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
2	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
3	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
4	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
						August 31, 1968
5	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
6	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
7	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
						September 30, 1968
						LEG 2
8	ORE	16	PPM			erratic 105 db
	ORE	10	PCS			used to hold station 95 db
9	ORE	16	PPM			105 db
	ORE	10	PCS			95 db

Appendix F - Beacon Drop Summary contd.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
						October 31, 1968
10	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
11	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
12	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
						November 30, 1968
						LEG 3
13	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
14	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
15	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
16	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
						December 31, 1968
17	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
18	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
19	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
20	ORE	16	PPM			105 db
	ORE	10	PCS			failed during drop 95 db

Appendix F – Beacon Drop Summary contd.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
21	ORE	16	PPM			105 db
	ORE	10	PCS			95 db
22	ACDRL	16	PPM			failed – rep rate off 100 db
	ORE	10	PCS			failed during drop 95 db
	ORE	16	PPM			105 db
						January 31, 1969
						LEG 4
23	Burnett	16	PPM			lost signal after 70 hrs. (floatation) 111 db
	Burnett	16	PPM			dropped during test 111 db
24	Burnett	16	PPM			lost signal after 20 hrs. floatation 111 db
	ORE	10	PCS			95 db
25	Burnett	16	PPM			111 db
26	ACDRL	16	PPM			distorted signal held station 100 db
	ORE	10	PCS			95 db
27	ACDRL	16	PPM			distorted signal held station 100 db
						February 28, 1969
28	ACDRL	16	PPM			distorted signal held station
29	Burnett	16	PPM			111 db
	ORE	10	PCS			95 db
30	ORE	16	PPM }			lost beacon signal during drop – 105 db
	ORE	10	PCS }			2 knot current 95 db
	ORE	16	PPM			signal fluctuated – held station 105 db
31	Burnett	16	PPM			2 knot current. signal lost approximately 30% 111 db
						March 31, 1969
						LEG 5
32	Burnett	16	PPM			111 db
	ORE	10	PCS			95 db
33	Burnett	16	PPM			111 db
	ORE	10	PCS			95 db

Appendix F - Beacon Drop Summary contd.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
34	Burnett	16	PPM			111 db
						April 30, 1969
35	Burnett	16	PPM			111 db
35-1	Burnett	16	PPM			111 db
36	Burnett	16	PPM			111 db
37	Burnett	16	PPM			111 db
38	Burnett	16	PPM			111 db
39	Burnett	16	PPM			111 db
40	Burnett	16	PPM			111 db
41	Burnett	16	PPM			111 db
42	Burnett	16	PPM			
						May 31, 1969
43	Burnett	16	PPM			failed on impact 111 db
	Burnett	16	PPM			111 db
						LEG 6
44	ORE	10	PCS			95 db
45	Burnett	16	PPM			111 db
46	Burnett	16	PPM			111 db
47	Burnett	16	PPM			10% acceptable signal 111 db
	ORE	10				fluctuation in signal, held station 95 db
						June 30, 1969
48	ORE	10	PCS			95 db
49	Burnett	16	PPM			111 db
50	ORE	10	PCS			95 db
51	Burnett	16	PPM			111 db
52	Burnett	16	PPM			111 db
53	Burnett	16	PPM			111 db
54	Burnett	16	PPM			111 db
55	Burnett	16	PPM			111 db
56	Burnett	16	PPM			111 db

Appendix F - Beacon Drop Summary contd.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
57	Burnett	16	PPM			111 db
58	Burnett	16	PPM			111 db
59	Burnett	16	PPM			111 db
						July 31, 1969
60	Burnett	16	PPM			111 db
						LEG 7
61	Burnett	16	PPM			Note: All beacons after this date 111 db
62	Burnett	16	PPM			
63	Burnett	16	PPM			failed near surface
						August 31, 1969
		16	PPM			
	ORE	16	PPM			inoperative at surface
64	Burnett	16	PPM			
65	Burnett	16	PPM			(battery inoperative at surface)
66	Burnett	16	PPM			
67	Burnett	16	PPM			
						September 30, 1969
						LEG 8
68	Burnett	16	PPM			13.5 filters installed in positioning system
69	Burnett	16	PPM			
70	Burnett	13.5	PPM			weak signal (converted 16 kHz)
	Burnett	16	PPM			
						October 31, 1969
71	Burnett	16	PPM			erratic signal
		13.5	PPM			failed
		13.5	PPM			initially weak. failed after 4 hrs.
		13.5	PPM			weak signal but usable
72	Burnett	16	PPM			

Appendix F – Beacon Drop Summary contd.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
73	Burnett	13.5	PPM			
74	Burnett	16	PPM			failed
	Burnett	13.5	PPM			
75	Burnett	16	PPM			
						November 30, 1969
						LEG 9
76	Burnett	16	PPM			
77	Burnett	16	PPM			too long pulse rate (dropped)
		16	PPM			okay (moved location)
78	Burnett	16	PPM			
						December 31, 1969
79	Burnett	16	PCS			removed from Challenger all beacons PPM
80	Burnett	16				
81	Burnett	16				
82	Burnett	16				
83	Burnett	16				
84	Burnett	16				
						January 31, 1970
						LEG 10
85	ORE	13.5				not operating signal processing system out
	Burnett	16				not operating
	Burnett	16				return after repairs
86	Edo	16				distorted signal not usable
	Burnett	16				
						February 28, 1970
87	Burnett	16				
88	Burnett	16				
89	Burnett	16				
90	Burnett	16				

Appendix F - Beacon Drop Summary contd.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
91	Burnett	16				
92	Burnett	16				
93	Burnett	16				failed during drop
	Burnett	13.5				
94	Burnett	16				
95	Burnett	16				
						March 31, 1970
96	Burnett	16				held station intermittent signal
	Burnett	13.5				failed during drop
97	Burnett	16				failed
	Burnett	13.5				held station - erratic signal
						LEG 11
98	Burnett	16				
99	Burnett	16				
100	Burnett	16				held station signal erratic
101	Burnett	13.5				
						April 30, 1970
102	Burnett	13.5				failed on drop
	Burnett	16				
103	Burnett	13.5				
104	Burnett	16				
105	Burnett	16				signal fluctuation after 16 hrs. finished hole
106	Burnett	16				fluctuating signal
	Burnett	16				(1 mile move)
107	Burnett	16				
108	Burnett	16				
						LEG 11-C
109	Burnett	16				
110	Burnett	16	98			

Appendix F - Beacon Drop Summary contd.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
						LEG 12
111	Burnett	13.5	119			blurry pulse shape
						June 30, 1970 finished hole
112	Burnett	16	97			
113	Burnett	13.5				failed
	Burnett	16	102			
114	Burnett	13.5	121			
115	Burnett	16	108			
116	Burnett	13.5	122			failed
	Burnett	16	111			
117	Burnett	16	117			
118	Burnett	16	112			
						July 31, 1970
119	Burnett	16				lost signal after 14 hrs.
	Burnett	13.5				
						LEG 13
120	Burnett	13.5	124	97		
121	Burnett	16	125	122		
122	ORE	16				
123	Burnett	13.5	123	118		
124	ORE	16				
125	Burnett	16	134	118		
126	Burnett	16	103	115		
127	Burnett	16	113	121		
128	Burnett	16	109	124		
129	Burnett	13.5				
130	Burnett	16	142	149		
131	Burnett	16	142	149		
132	Burnett	16	142	147		
133	Burnett	16	105	141		
134	Burnett	13.5	104			

Appendix F - Beacon Drop Summary contd.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
						LEG 14
135	Burnett	16	104	504		
136	Burnett	16	106	115		
137	Burnett	13.5	150	114		lost strength after 3 1/4 hrs.
	Burnett	16	127	139		
138	Burnett	13.5	100			
139	Burnett	16	30	131		
140	Burnett	16	90	130		
141	Burnett	16	101	127		
142	Burnett	13.5	147	133		lost signal after 24 hrs.
	Burnett	16	140	134		lost signal after 23 hrs. , terminate location
143	Burnett	13.5	139	135		
144	Burnett	146	123			
						LEG 15
145	Inter Ocean	16.0	?	?		failed on pretest after prior satisfactory test terminated with cable damage
	Burnett	16.0	128	120	15	Okay - used three floatation rings & Inter Ocean acoustic release. Failed to release.
146	Burnett	16.0	144	125/126	1	Two batteries used in parallel circuit. Failed in first hour due weak signal.
	Burnett	13.5	154	143	151	Okay - weak signal after 151 hrs.. No failure since service exceeded six days.
	Burnett	16.0	141	128	144	okay - total of 295.5 hrs. on Site 146
147	Burnett	13.5	158	129	60	okay - half power beacon due to shallow water depth of 892 meters
148	Burnett	13.5	157	85	45	okay - half power beacon due to shallow water depth of 1232 meters
149	Burnett	16.0	138	132	100	okay
150	Burnett	13.5	152	136	50	okay
151	Burnett	16.0	139	137	34	okay
152	Burnett	16.0	133	145	99	Failed after 99.5 hrs. of service due to erratic signal strength. Site completed.

Appendix F - Beacon Drop Summary contd.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
153	Burnett	16.0	132	146	106	okay
154	Burnett	16.0	129	153	69	okay - functioned satisfactorily although pulse period was only 3.6 ml. sec.

Used nine 16.0 kHz beacon (1 Inter Ocean & 8 Burnett). One Inter Ocean and 2 Burnett beacons failed.
Used four 13.5 kHz beacons. All were Burnett beacons and all functioned satisfactorily.
Used fourteen batteries.
Used fourteen floatation rings.
End of leg shipboard inventory includes the following:

(a) Six 16.0 kHz Burnett beacons
(b) Twelve 13.5 kHz Burnett beacons
(c) Twenty Burnett batteries.
(d) Thriteen floatation rings.

LEG 16

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
155	ORE	16	124		57:45	vessel seemed to hunt within 50 feet of beacon
156	ORE	13.5	105		20:00	vessel seemed to hunt within 50 feet of beacon
157	ORE	13.5	106		93:45	vessel seemed to hunt within 50 feet of beacon
158	Burnett	13.5	138	155	54:30	Dropped to compare with ORE beacon. On site 157 vessel did not hold position very close. Suspected ORE beacon was moving . Burnett held vessel within 30 feet.
159	ORE	16	117		49:00	Beacon bridle restrung to make floatation unit float level. Secured transudcer gimbal. Swell and wind from different directions, 40° apart with a current 90° to swell. Positioning difficult. Lost acoustic for a period of two to three hours and had to position vessel in semi-automatic. Uncertain if beacon had any influence on positioning problems.
160	ORE	16	119		42:30	Dropped ORE 5-1445 March 71. Positioning erratic so dropped Burnett beacon to compare ORE and Burnett beacons under same conditions. Burnett dropped 5-200 March 71. Both beacons acted the same. Erratic positioning evidently due to sea and wind conditions.
	Burnett	13.5	162	144	37:15	

Appendix F - Beacon Drop Summary contd.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
161	ORE	16	107		49:45	Positioned better except vessel periodically drifted 100 plus feet along x-axis. Slow to return to position.
161A	ORE	16	107		53:45	same as 161
162	ORE	16	112		51:00	positioned same as site 161
163	Burnett	16	136	471	00:45	Dropped Burnett 16 kHz beacon with dual battery pack for use on re-entry site. Beacon failed in 45 minutes.
	Burnett	13.5	163	163	163:45	Dropped Burnett 13.5 kHz beacon after re-surveying site. Vessel positioned very well with no problem of drifting off along x-axis as experienced with ORE.
						LEG 17
164	Burnett	16.0	143	162	107 1/2	Gave unstable timing pulse - operated vessel in semi-automatic mode.
	Burnett	13.5	151	165		Failed immediately.
165	Burnett	16.0	135	164	90	Okay - unstable timing pulse for 1/2 hour but cleared up okay. Beacon dropped underway at 8 knots.
166	ORE	16.0	121		50 1/2	Beacon dropped underway at 8 knots. Failed after 50 1/2 hours.
	Burnett	13.5	153	169	33	okay
167	Burnett	16.0	137	158 & 160	328	Okay - Dropped underway at 6 knots. Two battery packs. Operated near perfect for 9.5 days.
168	ORE	16.0	122		42	Dropped underway at 8 knots. Failed after 42 hours. Unstable timing pulse.
169	Burnett	16.0	131	159	65 1/2	okay - dropped underway at 8 knots
170	ORE	16.0	118		64	okay - dropped underway at 8 knots
171	ORE	16.0	120		56	okay - dropped underway at 8 knots

Summary

4 - Burnett 16.0 kHz - 4 satisfactory, 0 failed
2 - Burnett 13.5 kHz - 1 satisfactory, 1 failed
4 - ORE 16.0 kHz - 2 satisfactory, 2 failed

Appendix F - Beacon Drop Summary concl.

Site No.	Make	Freq. kHz	Ser. No.	Batt. Ser. No.	Site Time Hrs.	Remarks
						LEG 18
172	Inter Ocean	16			5:00	after 5 hours beacon signal was too weak for positioning
	Burnett	13.5	170	157	35:00	beacon signal was good
173	Inter Ocean	16			76:75	used Burnett floatation, beacon was weak, but sufficient for positioning
174	Burnett	13.5	167	126	91:75	signal good, positioning was excellent
175	Burnett	13.5	156	86	42:75	signal good, positioning was excellent
176	Burnett	13.5	165	165	12:00	in 201 meters of water signal was very strong
177	Burnett	16	145	161	91:25	beacon was lost in storm, but was able to relocate and drill hole 177A
178	ORE	16	109		35:00	signal good, but floatation permits beacon to drift on the way to bottom
179	Burnett	16	130	158	44:75	Was run with releasing mechanism. Signal was excellent.
180	ORE	16	115		72:25	good signal, maximum excursion was 200; mostly plus or minus 40'
181	Burnett	13.5	171	148	90:50	strong signal, some excursions caused by tidal currents
182	Burnett	13.5	164	149	55:25	strong signal, erratic positioning because of strong winds and changing tides.

APPENDIX G

D/V Positioning Analysis Reports

By

William P. Schneider

VESSEL POSITIONING ANALYSIS

REPORT

for

National Science Foundation

Prepared by: PETROLEUM CONSULTANTS
William P. Schneider
Date: November, 1968

/119

CONTENTS

PREFACE

I. INTRODUCTION

A. General Control System
B. System Description

II. SYSTEM INSTALLATION

A. Interfaces
B. Dockside Noise Tests
C. Dockside Thrust Tests

III. SYSTEM CHECKOUT

A. Preliminary Operational Tests
B. Noise Tests
1. Hydrophone Changes
C. Thrust Response Tests
1. Positioning System Sea Tests

IV. SYSTEM OPERATION

A. Reference Systems
1. PPM
a. Beacons
b. Hydrophones
c. Signal Processing
2. PCS
a. Beacons
b. Hydrophones
c. Signal Processing
3. Heading
a. Gyro Compass
B. Controller
1. Computer
2. Pitch and Roll Compensation
C. Thrusters
1. Controllers
2. Noise
D. Total System Operation

V. CONCLUSIONS

APPENDIX

/120

PREFACE

This report covers the period from installation of the equipment on the vessel at the shipyard to the drilling at several sites. The report is a partial chronology of events as well as an analysis of the performance. The chronological sequence was preserved because it was felt that a full appreciation of the positioning system problems and its performance could only be obtained by knowing some of the historical events which preceded the ultimate decisions.

The positioning system operation performance includes the following sites.

Test Site #1	3480'	Water Depth*	27°-16'N Lat	94°-10'W Long
Test Site #2	3660'	" "	26°-59.4'N	94°-03.7'W
Site #1	9259'	" "	25°-51.5'N	92°-11'W
Site #2	11590'	" "	23°-27.3'N	92°-35.2'W
Site #3	12327'	" "	23°-01.5'N	92°-04.2'W
Site #4	17485'	" "	24°-28.67'N	73°-47.5'W

*Water depth measured from Rotary Table (33' Rotary Table to Sea Level)

I. INTRODUCTION

A. General Control System

The primary purpose of the vessel Glomar Challenger is to provide a platform from which to drill into the sea floor. To carry out this primary task of drilling requires that the vessel remain within a radius of approximately 5% of the water depth of the chosen reference; this positioning must be maintained throughout the total time that the drill pipe is in contact with the sea floor. Positioning of the vessel is accomplished by a control system which is composed of the basic components shown in Figure I. In control system terminology, it is an Automatic Feedback Control System or as is so obviously portrayed in the diagram, also known as an Automatic Closed-loop Control System.

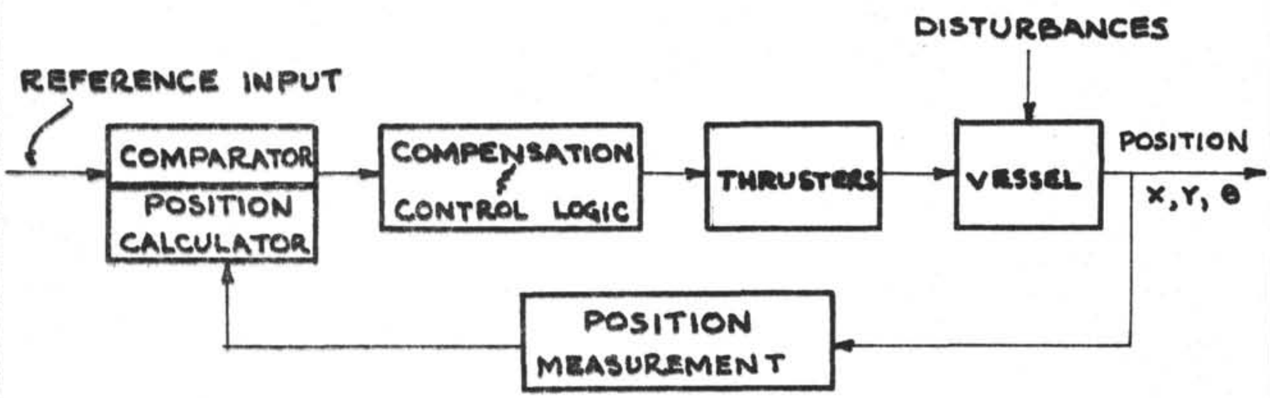


Figure 1

The selection of this type system becomes immediately obvious when it is realized that the vessel is dynamically positioned (free of any mechanical connection to the reference or sea floor*) and consequently a simple open-loop control system would be almost completely useless in view of the external disturbances to the vessel (wind, wave and surface current) which are both uncontrollable and unpredictable. It should be noted that under certain conditions of operation involving component failure, open-loop condition becomes the only positioning control possible and, as will be discussed later, can be of limited use

Providing automatic operation of the system is almost mandatory since continuous positioning is required for periods that can be as long as seven days. Automatic operation removes the man as an essential link from the control loop and his only requirement is to monitor the system operation. However, operation of the system with the man completing the feedback loop is possible and can be successfully used as will be discussed later.

In general, the system operates as follows: A reference position is selected and becomes the input signal to the system. This signal is compared to the calculated position of the vessel and the difference or error signal is processed to provide the proper logic to the vessel

* Obviously the drillpipe is a mechanical link to the sea floor but it is not used as a constraining member to assist in maintaining vessel position.

thrusters. As a result of the error signal, the thrusters move the vessel to reduce the error signal. Since the position of the vessel is continuously measured with respect to a fixed frame of reference (the sea floor and the earth's magnetic field), this measured position information signal is sent to the comparator where it is compared with the input reference signal. Any difference between the signals provides an error signal which continues to call for thrust and moves the vessel until the error signal is zero. At this time, the measured position of the vessel coincides with the selected reference position. If at this time, the vessel is moved due to an external disturbance, an error signal will result and the thrusters will be operated so that the vessel is moved back into position at which time the error signal again becomes zero. In actual operation, the vessel will seldom, if ever, reach an equilibrium condition (become motionless)but will be continually moving about the reference position due to the continuous external disturbances. The distance the vessel moves about the reference position depends on the parameters of the control system.* These parameters together with the vessel response characteristics determine the overall control system dynamics which include

* These parameters are essentially the system gains - the relationship between the thruster outputs vs error signal amplitude - and the time responses of the components making up the control loop.

the important aspect of system stability. Indeed, the overall system dynamics constitute the major consideration in the design of a control system.

It is essential to note that a control system as shown in Fig. 1 corrects for the external disturbing forces being applied to the vessel but it must be appreciated that the control system will also react to functional variations in any of the subsystem blocks involved in the control loop; these functional variations may be the result of disturbances that are either external or internal to the subsystem. For example, variations or errors in the position measurements appear as vessel errors in the control system and thrust corrections would be generated which would in this instance produce incorrect positioning. Therefore the accuracy of the positioning system depends not only on the control system logic and vessel characteristics but on the magnitude and frequency of the various errors generated by the subsystems.

B. System Description

The diagram shown in Figure I is highly diagramatic and is only meant to indicate the essential subsystems that make up the vessel positioning control system. At this time a more detailed description of the system is given so that the subsequent discussion of the system tests and operation will be more meaningfull. The description will not be highly detailed, but only sufficiently detailed to provide the necessary background for an appreciation of the problems encountered.

The vessel is essentially a conventional ship hull with the decks and internal structures modified to provide the necessary drilling functions.

Positioning thrust is provided by four tunnel thrusters (two forward and two aft) and the two main screws. Their locations are approximately as shown in Fig. 2. In normal operation, one bow thruster, one stern thruster and one main screw are activated. Because of the total power requirements and method of power division, simultaneous operation of all four thrusters cannot be obtained while performing the drilling operation. The thrusters and main screws are driven by DC motors which are controlled by DC generators. The generator output is varied by a semiconductor control unit. The thruster control system is shown schematically in Fig. 3. The motors are located adjacent to the thrusters and main screws and the generators and controllers are located in the engine room.

The signal to the generator controllers is the output of the digital computer which is a combination of the COMPENSATION AND CONTROL LOGIC, COMPARATOR, AND POSITION CALCULATOR blocks shown in Fig. 1. Actually, the control

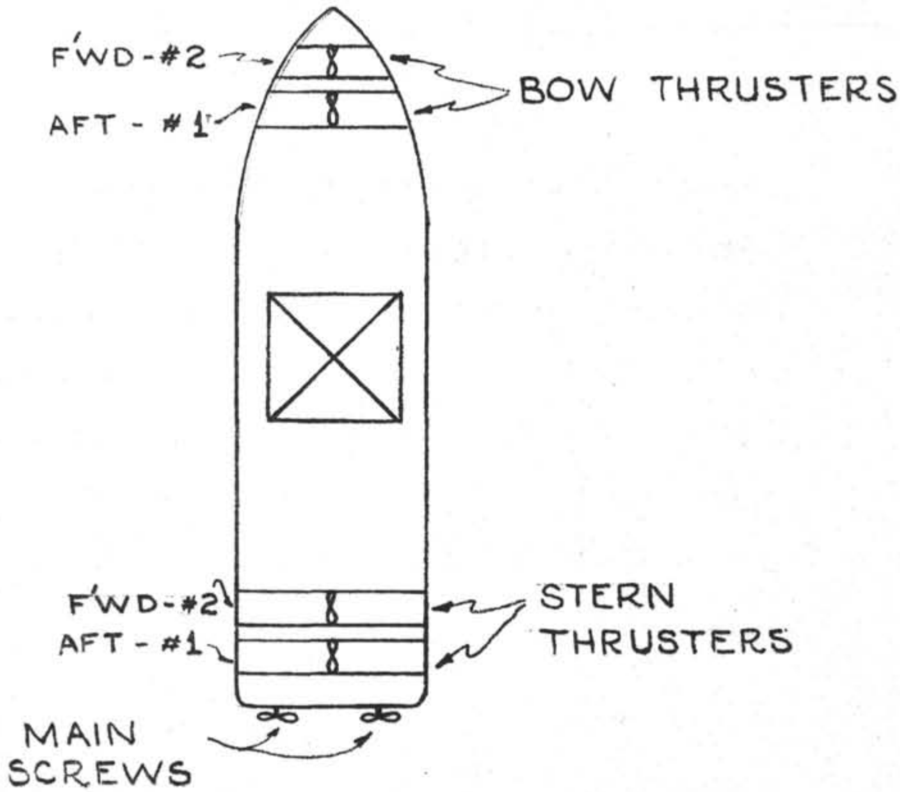


FIGURE 2

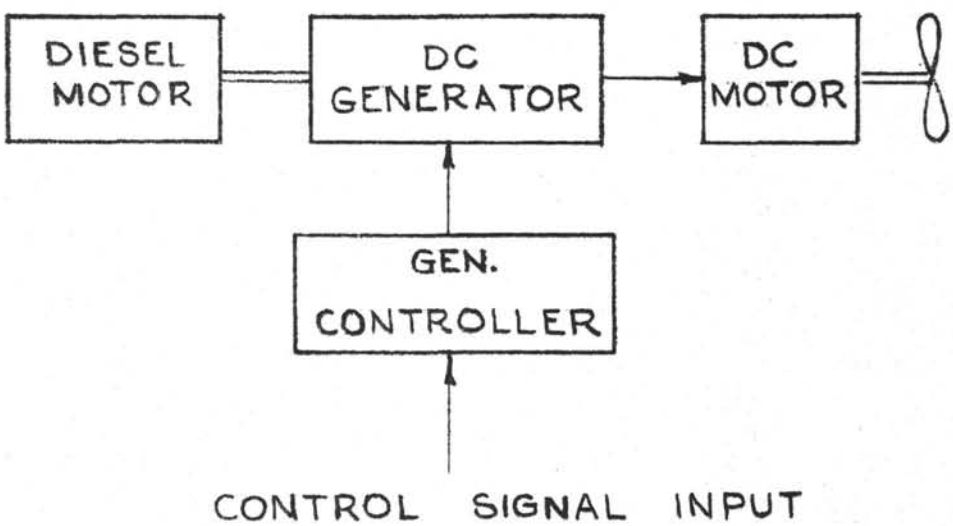
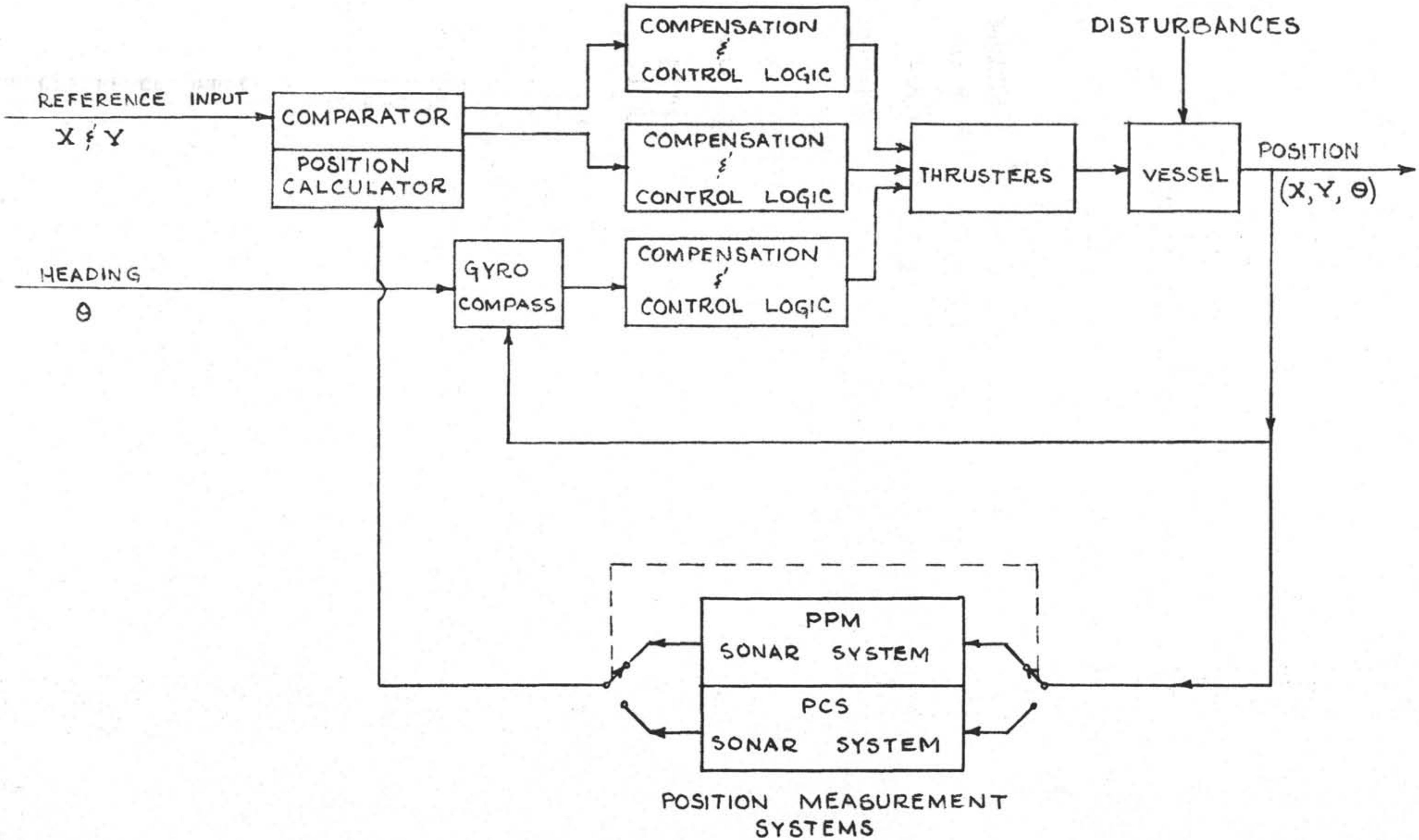


FIGURE 3

system is composed of three essentially independent loops - a heading loop, an "x" axis or for-and-aft position loop and a "y" axis or port-and starboard loop. This is shown in Fig. 4. An error signal in one or more of these loops is processed and directed to the proper generator controllers. The digital computer is located two decks below the bridge in the electronics room.

The heading measurement is taken from the ship's gyro compass. The information is obtained from a repeater located on the bridge. The vessel position with respect to a sea floor reference is measured by one of two independent sonar systems as indicated in Fig. 4. These systems with the exception of the receiving hydrophones and preamplifiers are located in the electronics room with the digital computer. The hydrophones are located at the bottom of the hull on arms which extend through tubes or wells that open on the main deck. The preamplifiers are located in junction boxes mounted adjacent to the hydrophone wells.

On the bridge is located the main control console from which the system is operated. Included on the control panel are meters and other visual displays for monitoring the control system performance. In particular, the vessel position is displayed with respect to the desired reference position; also the RPM and thrust direction



REFERENCE INPUT
X & Y
COMPARATOR
POSITION CALCULATOR
COMPENSATION & CONTROL LOGIC
COMPENSATION & CONTROL LOGIC
COMPENSATION & CONTROL LOGIC
DISTURBANCES
THRUSTERS
VESSEL
POSITION
(X, Y, Θ)
HEADING
Θ
GYRO COMPASS
PPM SONAR SYSTEM
PCS SONAR SYSTEM
POSITION MEASUREMENT SYSTEMS

/129

FIGURE 4

of the thrusters are displayed.

Additional extensive monitoring, recording and test equipment is located in the electronics room.

II. SYSTEM INSTALLATION

A. Interfaces

In general, the companies supplying the major subsystems also had the responsibility of providing the proper installation of the equipment. The supervision and responsibility of the interfacing between these subsystems was taken by G.M.I. As the systems were divided, the interfaces were relatively minor. However some problems were encountered, notable in the interface between the signal output from the digital computer and the input of the signal into the generator controllers. This is another of the many examples which point up the fact that interfacing between systems is a critical area in obtaining near optimum overall system performance and that even relatively simple interfaces must be critically examined.

B. Dockside Noise Tests

The design criteria used in the development of the system were for the most part firmly established from previous design and operation experience. One major exception was the level of the total background acoustic noise in which the sonar measurement systems would be operating. Since a noise-level figure had to be used to provide a basis from which to establish the general power levels in the measurement systems, a "best guess" figure was selected. This figure was based on data involving actual operating conditions but the data was limited in scope and did not involve conditions which would be similar to those on the Glomar Challenger. In particular, no useful acoustic-noise output levels generated by tunnel thrusters were available.

The actual background noise-level during vessel positioning is a very critical factor in proper system performance. The sea-floor acoustic-reference output-levels had been designed with respect to the "best guess" figure and consequently the usefull water depth range in which the vessel could be properly positioned depended intimately upon the actual noise-level. Because of the highly critical nature of the thruster noise-level output and the unavailability of any noise data involving tunnel thrusters, a decision was made to make some preliminary noise measurements on these thrusters with the vessel at dockside. These measurements were made with the clear understanding of the limited value of the data that would be imposed by these dockside tests; however the tests would indicate whether a potential noise problem existed.

The tests were made and the significant results were given in a letter report dated July 5, 1968, Subject: Preliminary Noise Measurement.

The basic conclusion resulting from this test is summarized by the following paragraph taken from the above report which states,

> "Under the conditions indicated, the measured noise levels due to the thrusters were extremely high and would indicate a potential operating noise level problem. That is, the ambient noise level in which the positioning system must perform may be much higher than the level assumed for design purposes."

In addition, the report stated,

> "---the measurements have indicated the importance of knowing the actual operating noise level and that the first test on the next sea trials must be noise levels."

As a result of the test, as many practical steps as possible were taken in an effort to reduce the thruster noise levels; this included dry-docking the vessel and checking and adjusting the thruster gears.

C. Dockside Thrust Tests

Another area critical to the position system performance was the actual available thrust output produced by the thrusters. The design figure was based on the most reliable data available, but to properly establish system performance, a measurement of the actual thrust is needed. It should be emphasized that reliable and accurate thrust measurements are extremely difficult if not impossible to make and that from the practical aspect, the test arrangement and conditions were about as reasonable as could be expected.

The thrust measurements after correction for test conditions, indicated that the available thrust from each unit was less than the 20,000 pound design goal. However, the thrust levels were considered high enough to provide for positioning the vessel in the environmental conditions under which positioning would be required. Also it became apparent from the tests that the bow thrusters were not producing the maximum available thrust and that by redesigning the propeller blades, notably the pitch, the full available output thrust could be obtained.

III. SYSTEM CHECKOUT

A. Positioning System Test Program

Prior to leaving the dock, a specific test program was developed. This test program was designed to provide a logical sequence in the testing such that any below-specification performance of a critical vessel positioning subsystem was immediately apparent and its effect on the total system performance could at that time be accurately evaluated. The outline used in the test program is given in the appendix and the paragraphs below are referenced to this document.

B. Dockside Tests (1.0)

Prior to leaving the dock, the electronics subsystems involved in the positioning system were tested and calibrated. In particular, the shipboard equipment of both sonar reference systems were extensively checked and calibrated and checks were made on as much of the control system loop as could be tested at dockside; the thrusters were not activated and no acoustic sound source was placed in the water: The water depth and physical location of the vessel at the dock made the use of an underwater sound source for system tests impossible.

C. Thruster Calibration and Response Tests (2.0)

As stated above, the actual operation of the thrusters by control signals from the computer could not be done dockside. Therefore, these tests were performed as soon as the vessel was in an area sufficient for running all thrusters at full power for several minutes.

Tests were performed to determine the actual relationship between control signal amplitude and thruster RPM; proper direction of the thrust was also checked at this time.

In addition, the important factor of "x" and "y" axis decoupling was measured. As was indicated previously, the control system is designed on the basis that the heading, fore-and-aft, and port-and-starboard vessel movements are independent. To obtain essentially independent control of these motions, the fore and aft tunnel thrusters must be commanded to produce a rotational torque on the vessel to counteract the torque produced when one of the main screws is commanded to provide fore or aft vessel movement.

Because of the interface problems that were discovered during installation and check-out, a time delay circuit had to be inserted at this point in the control loop and its effect on the control signal had to be analyzed. It was found that a recalibration of the control signal to the generator controller had to be made. This was accomplished by changing the part of the digital computer program which involved the control signal output command.

D. Acoustic Noise-Level Tests (4.0)

As indicated previously, the acoustic noise-level is a critical factor in the positioning system performance and an accurate determination of the vessel-produced acoustic noise had to be made. A copy of the pertinent data taken is given in the appendix. Before discussing the results of these noise tests, the general approach to the tests as well as the methods used should be considered.

The noise-level figure (-40 db/1μb/cps) used for design purposes was well above the generally accepted sea-state noise-levels that would be encountered during positioning and consequently it was obvious that the main source of noise energy would come from the vessel. One approach to the problem would have been to obtain by proper noise measurements an equivalent noise source representation of the vessel. This would have provided all the necessary information to determine the noise levels at the receiving hydrophones as well as provided sufficient information for possible design changes that would reduce the noise level. For example the effects of relocation of the hydrophones could have been calculated as well as the effect of a frequency change in the acoustic signal source. However, as attractive as this approach was, it would have been of more academic value than immediate engineering value and would have required a large number of rather sophisticated measurements that would have been time consuming and difficult to perform so as to yield reliable data.

On the other hand, the problem of immediate interest was the relationship between the acoustic reference signal and the noise signals at the detector. In essence, the question of concern was the total noise voltage appearing at the output of the band-pass filter prior to the signal detector as a result of acoustic noise energy received at the hydrophones; the block diagram of the essential components are shown in Fig. 5. The diagram shown is for the PPM system, however the same general philosophy is applicable to the PCS system as well. Therefore, the noise tests could consist of measuring with an averaging voltmeter the output voltage at this point resulting from acoustic-noise-producing vessel-operations. The noise test procedure would not only provide applicable data of immediate concern, but would also allow the use of the on-board equipment in taking the data; furthermore, all the measurements could be made aboard the Glomar Challenger.

The water depth in which the measurements would be made had to be such that any acoustic energy reaching the hydrophones due to reflection from the bottom would be attenuated sufficiently so as to produce a negligible effect on the direct noise measurements. The figure of 1,000 feet was chosen since this would provide sufficient attenuation of the reflected energy and could be reached in a reasonable sailing time from the point of departure; basically the noise measurements were made as soon as reliable data could be obtained.

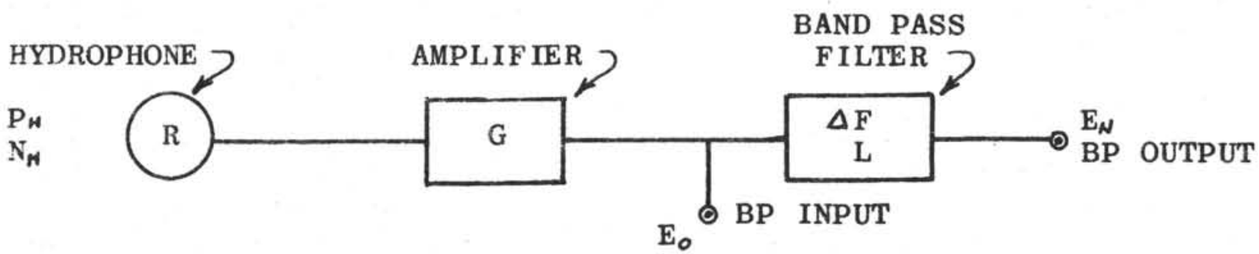
As a result of the data (given in the appendix) the following conclusions could be established:

1. The ambient noise-level produced by the sea-state in which the measurements were taken was

PPM BLOCK DIAGRAM

for

ACOUSTIC NOISE & SIGNAL LEVEL MEAS.



R = -(77+6) = -83 db = LOADED CONVERSION EFFICIENCY
G = VARIABLE - SEE GAIN CURVE
ΔF = 1.5 KC @ 16KC f_o
L = -8db (Filter Loss)
P_H = ACOUSTIC SIGNAL LEVEL AT HYDROPHONE/1 μb
N_H = ACOUSTIC NOISE POWER AT HYDROPHONE/1 μb
E_o = SIGNAL VOLTAGE OUTPUT
E_N = NOISE VOLTAGE OUTPUT (RMS)

Figure 5

negligible.

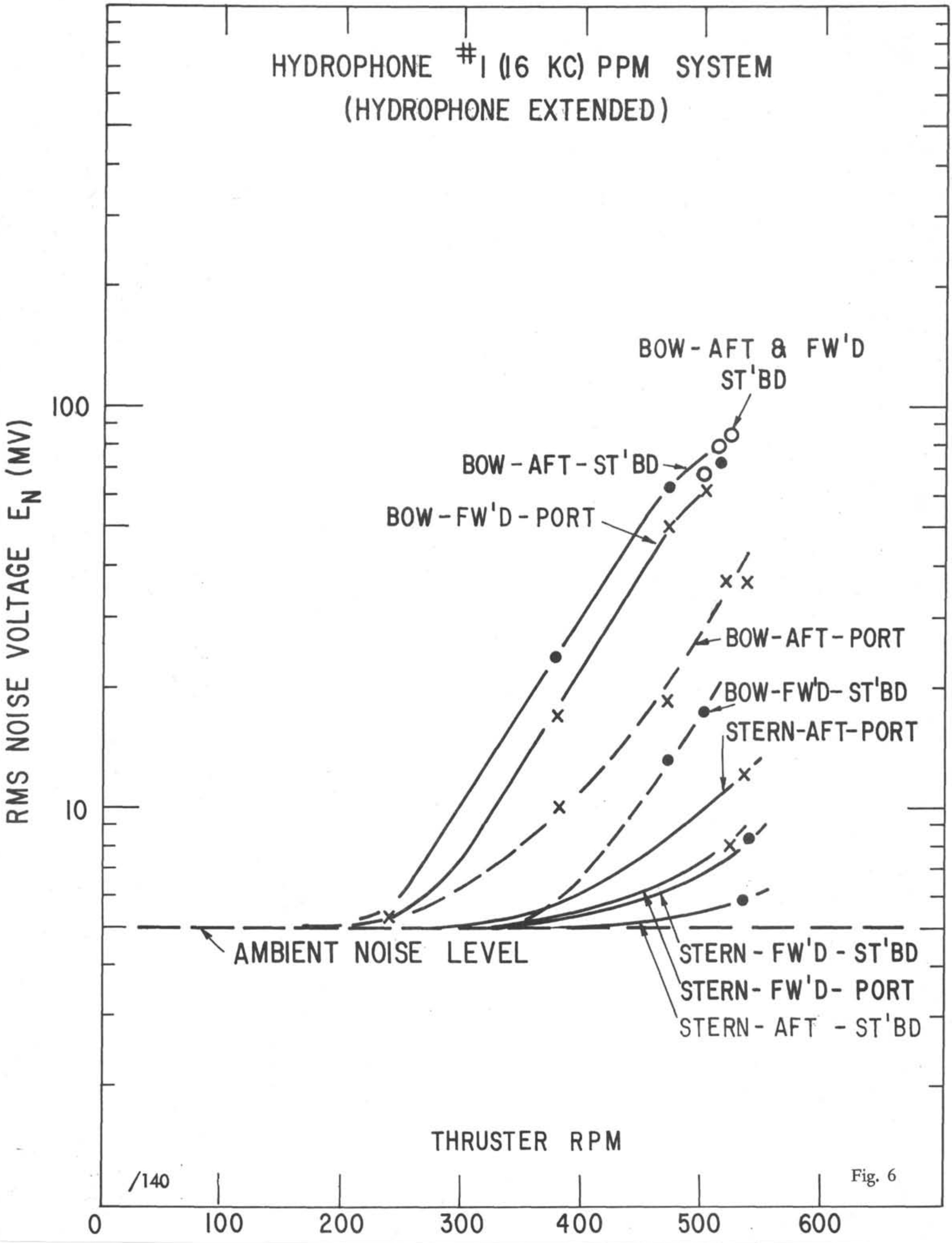
2. Motion of the hydrophones through the water - at least for vessel speeds up to three knots - did not produce a measurable increase in the ambient noise-level.

3. The major sources of noise energy coupled into the hydrophone receivers were the thrusters; in fact these were the only sources that were of any measurable consequence.

4. The noise-energy coupled into the hydrophones by the thrusters is a function of the thruster RPM and the direction of thrust - port or starboard. This relationship is shown in Figures 6 & 7. It should be noted that the output reading is the average of a randomly fluctuating voltage and consequently errors of approximately 20% in individual readings could be expected; these errors however, are well within the accuracy of interest.

5. The noise-energy coupled into the hydrophones by the thrusters depends upon the geometrical relationship between the given thruster and hydrophone. This is shown in Figures 8 & 9.

6. For the present hydrophone locations, the noise-level resulting from the operation of the stern thrusters is insignificant with respect to the noise-level resulting from the bow thrusters.


HYDROPHONE #1 (16 KC) PPM SYSTEM
(HYDROPHONE EXTENDED)
BOW-AFT & FW'D
ST'BD
BOW-AFT-ST'BD
BOW-FW'D-PORT
BOW-AFT-PORT
BOW-FW'D-ST'BD
STERN-AFT-PORT
AMBIENT NOISE LEVEL
STERN-FW'D-ST'BD
STERN-FW'D-PORT
STERN-AFT-ST'BD
RMS NOISE VOLTAGE E_N (MV)
100
10
THRUSTER RPM
0
100
200
300
400
500
600

/140

Fig. 6

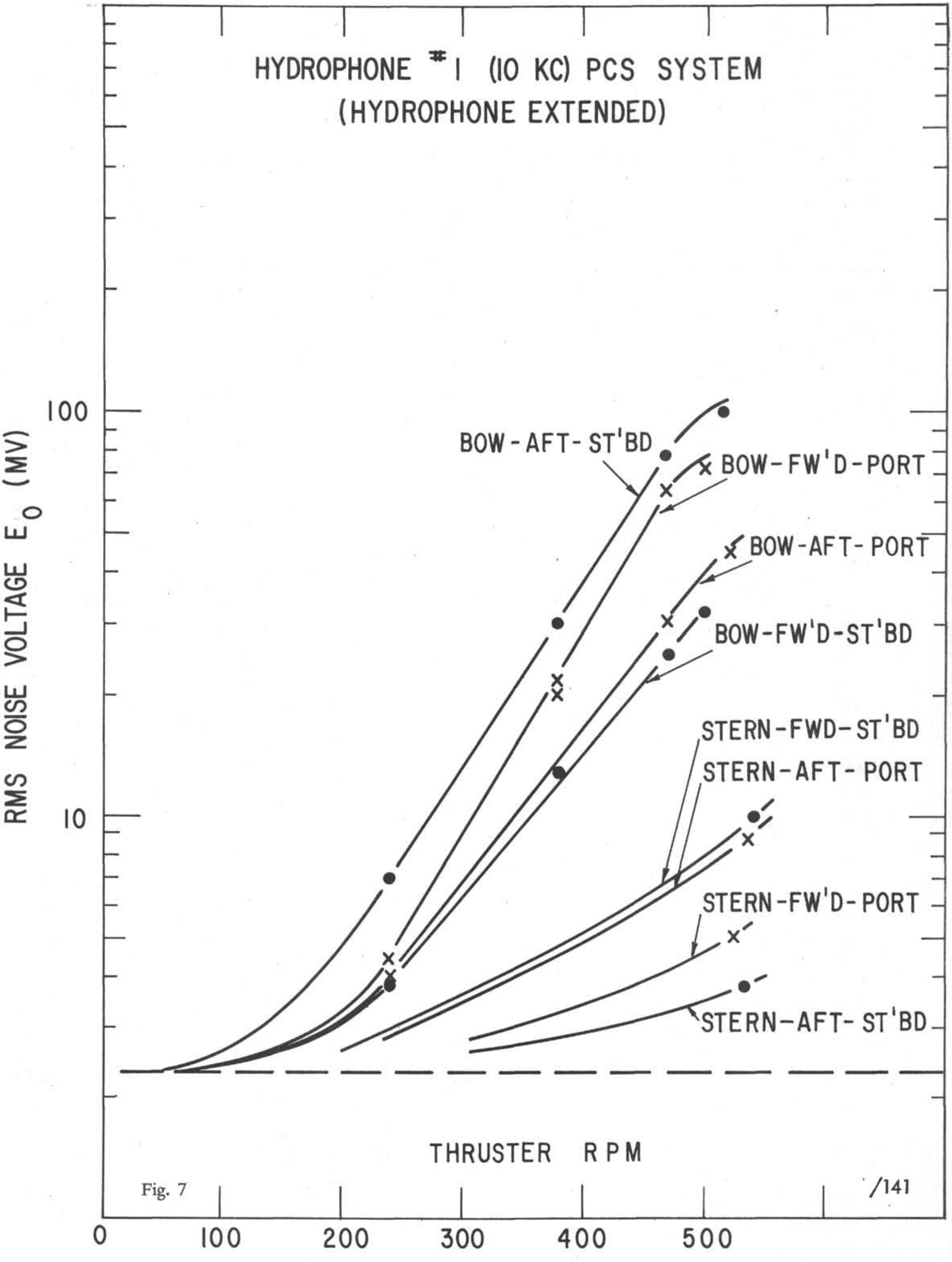
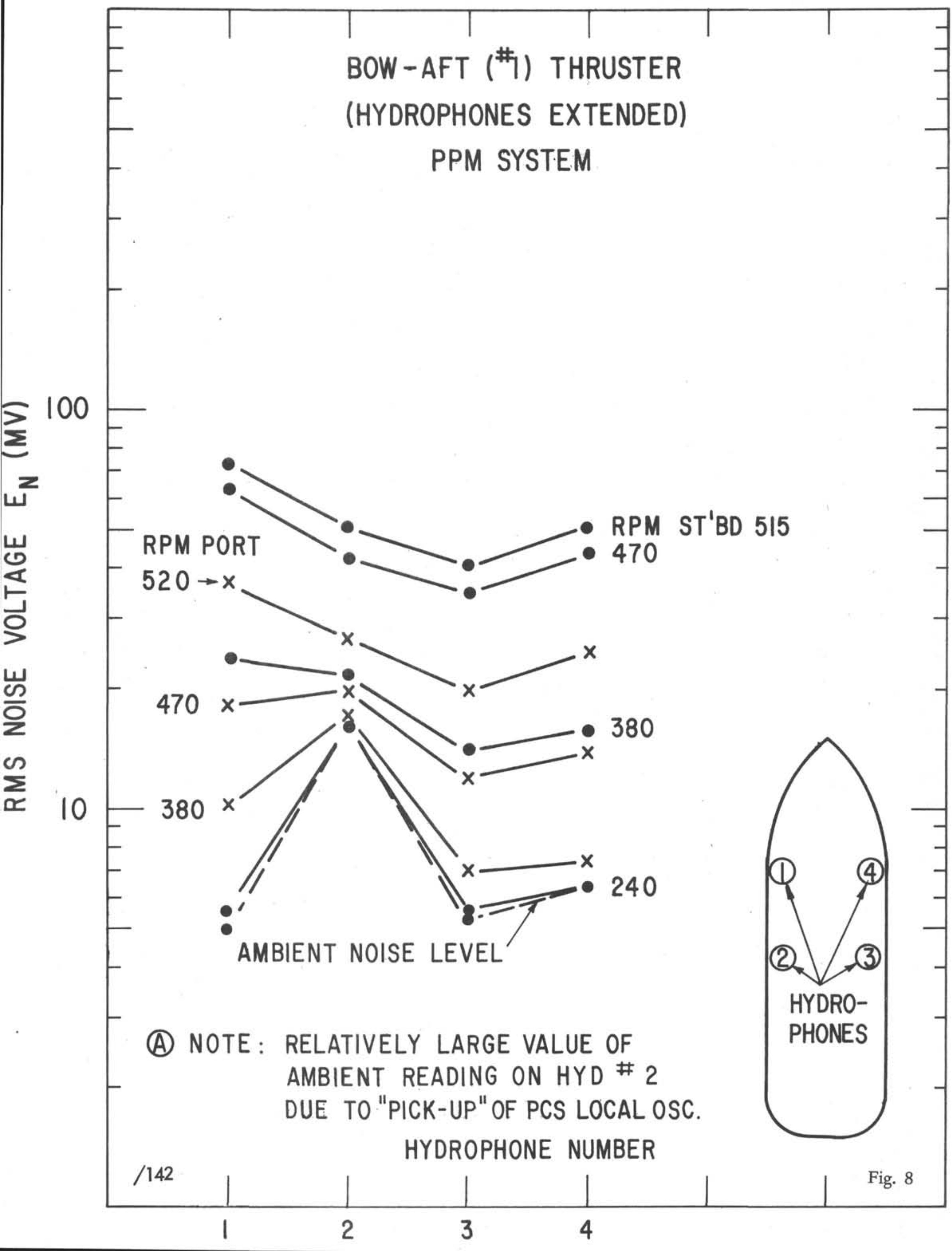
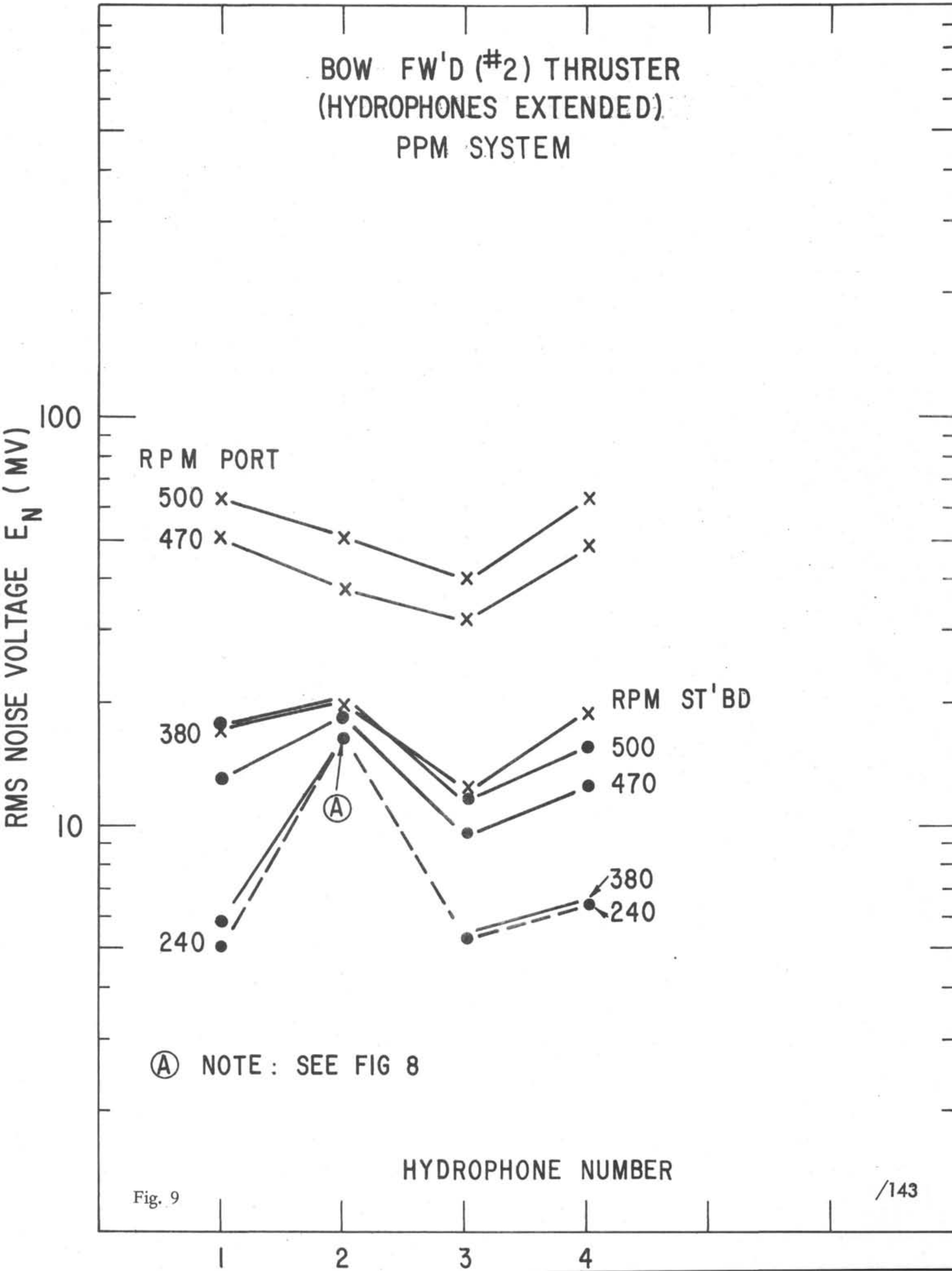

HYDROPHONE # 1 (10 KC) PCS SYSTEM
(HYDROPHONE EXTENDED)
RMS NOISE VOLTAGE E_0 (MV)
100
10
BOW-AFT-ST'BD
BOW-FW'D-PORT
BOW-AFT-PORT
BOW-FW'D-ST'BD
STERN-FWD-ST'BD
STERN-AFT-PORT
STERN-FW'D-PORT
STERN-AFT-ST'BD
THRUSTER RPM
0
100
200
300
400
500

Fig. 7


BOW-AFT (#1) THRUSTER
(HYDROPHONES EXTENDED)
PPM SYSTEM
RMS NOISE VOLTAGE E_N (MV)
100
10
RPM PORT
520
470
380
RPM ST'BD 515
470
380
240
AMBIENT NOISE LEVEL
Ⓐ NOTE: RELATIVELY LARGE VALUE OF AMBIENT READING ON HYD # 2 DUE TO "PICK-UP" OF PCS LOCAL OSC.
HYDRO-PHONES
1
2
3
4
HYDROPHONE NUMBER

/142

Fig. 8



BOW FW'D (#2) THRUSTER
(HYDROPHONES EXTENDED)
PPM SYSTEM
RMS NOISE VOLTAGE E_N (MV)
100
10
RPM PORT
500
470
380
240
RPM ST'BD
500
470
380
240
Ⓐ
Ⓐ NOTE: SEE FIG 8
HYDROPHONE NUMBER
1
2
3
4

Fig. 9

7. The maximum noise input at all hydrophones occurs when the aft Bow Thruster is operating at maximum RPM thrusting to starboard. With respect to the hydrophones, maximum energy is coupled into hydrophone #1, consequently, the noise-level figure obtained from this combination is the actual "worse-case" design and operating parameter.

8. The noise-level figure as previously defined above is high in comparison to the assumed noise level. The measured figure when translated to comparable units is approximately -23 db/1μb/cps which is 17 db higher than the original design value.

The real significance of the data was that the vessel thrusters produced a much higher noise-level than had been anticipated and consequently the positioning system operation would be marginal for the nominal water depth sites and essentially impossible* in the deep-water sites using the original sonar beacons.

For example, if it is assumed that the aft Bow Thruster will be operated at maximum thrust and that hydrophone #1 is used as part of the receiving array, the maximum water depth for which the required signal-to-noise ratio of 20 db is maintained would be 7,500 feet. Or if a water depth of 18,000 feet is

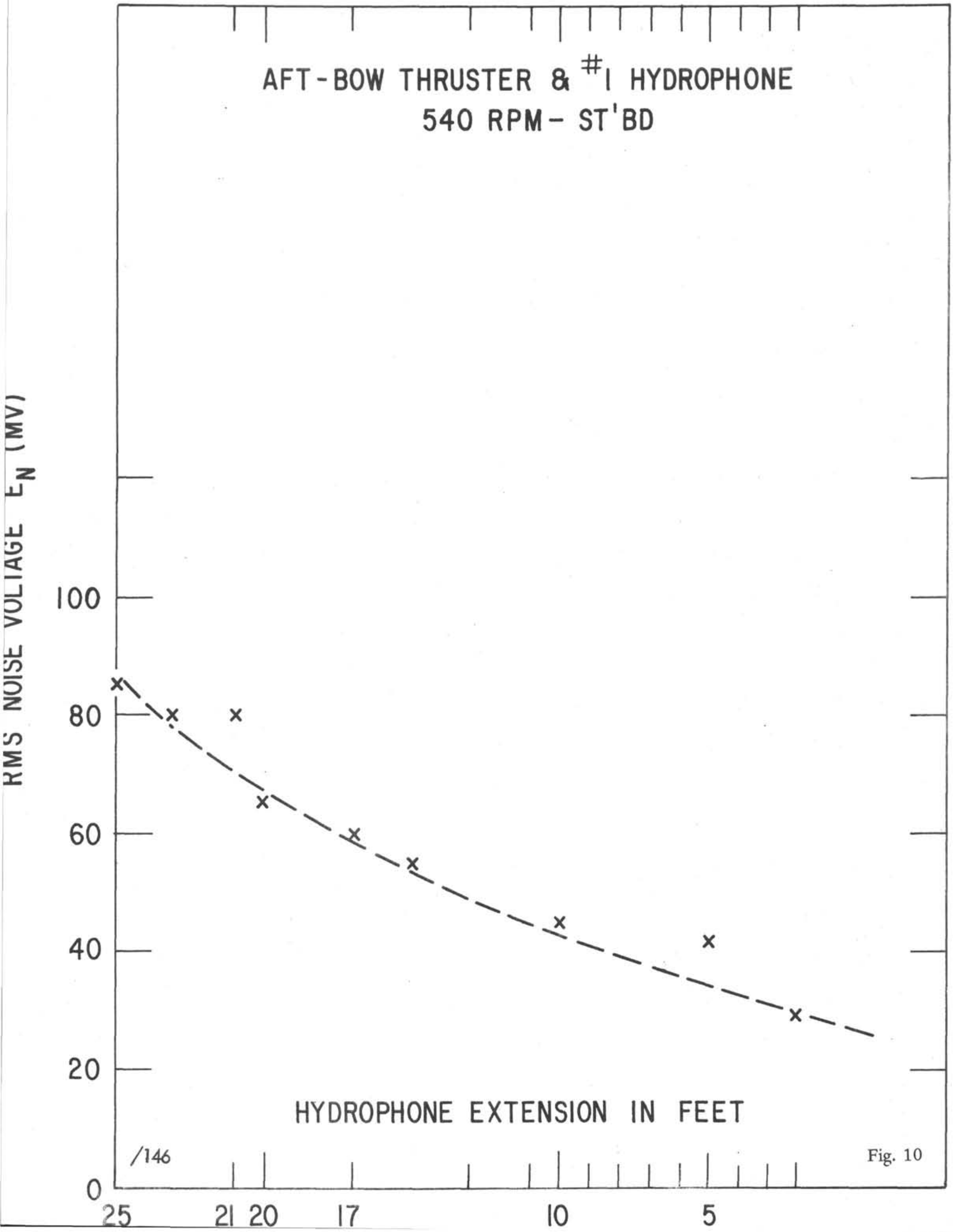
*Obviously, the operating performance would be highly dependent on the weather conditions for which positioning is required and conceivably under extremely good weather conditions the vessel could be maintained on station. However, since most sites would require several days of station keeping, it is improbable that the necessary weather conditions could be relied upon.

assumed, the aft Bow Thruster would be limited to approximately 280 RPM. Since the thrust output vs RPM is not linear, 280 RPM would produce only about 30% of maximum thrust. These figures are based on the assumption that the vessel is positioned directly over the beacon.

It was apparent that if dependable operation of the positioning system was to be obtained, either the noise-level at the hydrophones had to be reduced or the sonar beacon signal source had to be increased.

In an effort to obtain additional information about the noise-levels and beam-patterns produced by the thrusters, measurements were made with an omni-directional calibrated hydrophone. (4.21) These measurements indicated that the bow thruster beam-patterns had a rather large vertical angle and that a possible reduction in the noise-level at the hydrophones could be obtained by bringing the hydrophones closer to the hull. Tests were made using hydrophone #1; the data (given in Figure 10) indicated that a significant improvement would be obtained by raising the hydrophones into the recess in the hull; in this position the hydrophones are more completely baffled from the noise source (Thrusters). The data on hydrophone #1 indicated a 9 db improvement and additional tests on the other hydrophones indicated that an improvement factor of about 6 db was realistic.

With this improvement factor and the assumption that the



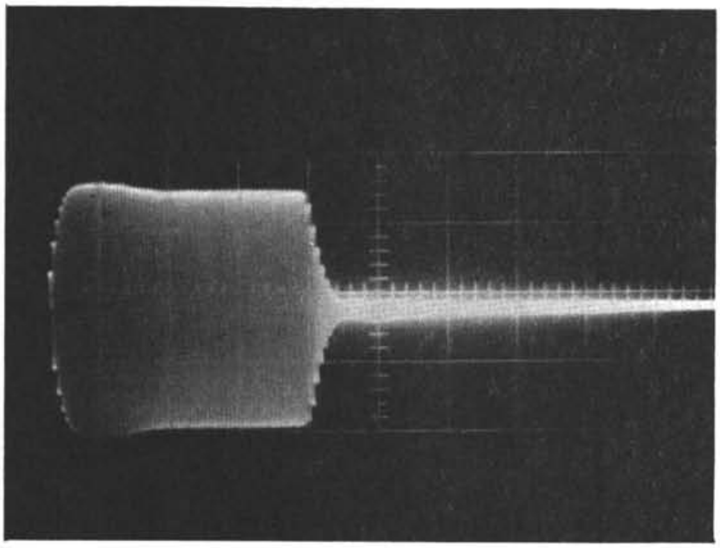
AFT-BOW THRUSTER & #1 HYDROPHONE
540 RPM - ST'BD
RMS NOISE VOLTAGE E_N (MV)
100
80
60
40
20
0
HYDROPHONE EXTENSION IN FEET
/146
25
21
20
17
10
5

Fig. 10

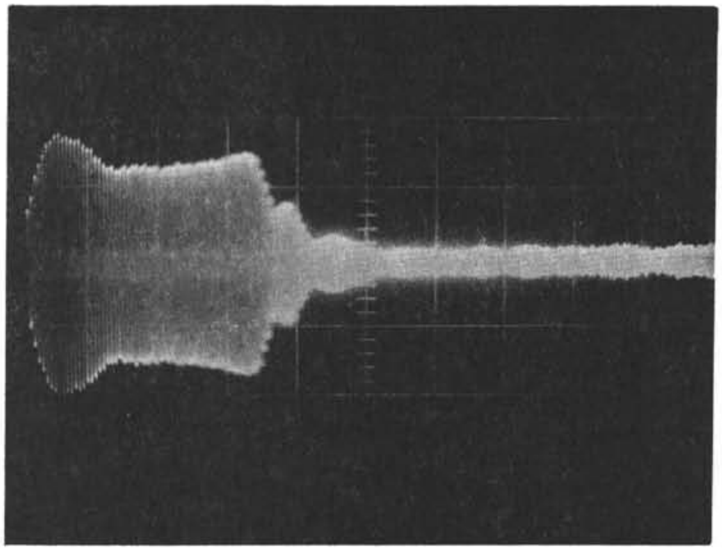
forward Bow Thruster would normally be used for positioning, the system would become marginal in operation only at the deep-water site - water depth greater than 17,000 feet.

E. Beacon Tests (5.0)

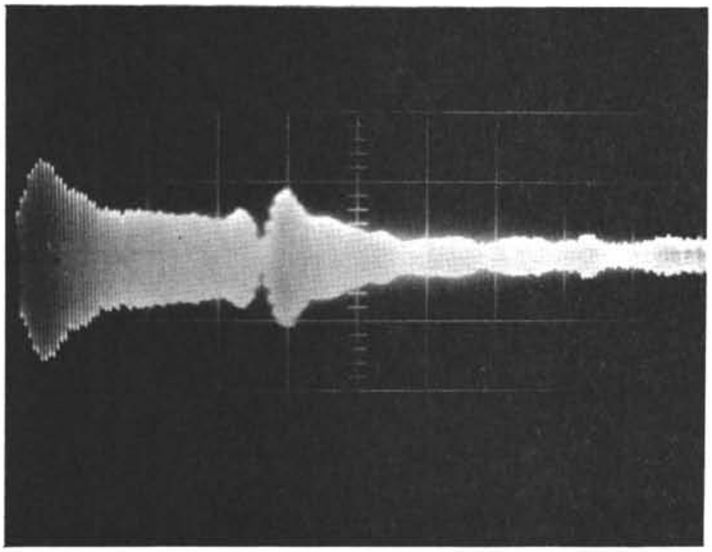
Measurements on the ORE beacons indicated that the beacons performed within specifications, but that the main beam was extremely narrow and that the pulse-shape did not remain constant over the projected area of the total beam on the surface. The main beam lobe had an angle of about 10 degrees between the 3 db points. However, what was of more significance was the fact that the pulse did not simply attenuate in level as a function of beam angle, but changed in shape. Some of the measured pulse shapes are shown in Figure 11. From the beam pattern measurements, it appeared that the resultant signal at the surface was composed of at least two pulses arriving at different times and that addition and cancellation of these coherent signals occurred. (See Fig. 11-e) Furthermore, it appeared that the beam lobes were distinct and separated by regions of essentially "no-signal" output. In normal operation, the vessel would be positioned essentially over the beacon and in all the water depths for which drilling would be performed, the main beam from the sonar beacon would cover a sufficient area to provide adequate signal strength and a constant pulse-shape. To be specific, the beam angle is such that the usable



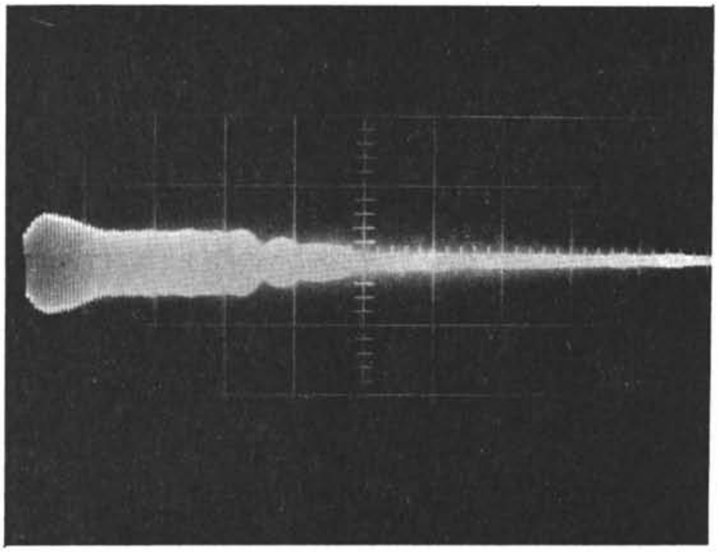
a.



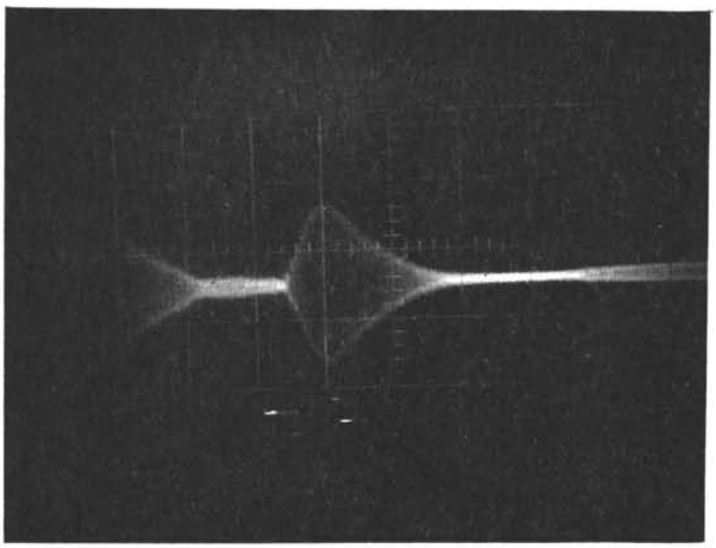
b.



c.



d.



/148

e.

Figure 11

portion of the beam covers a circular area having a radius of 8.7% of the water depth; since the vessel position must be maintained to within 5% the area is sufficient, providing the beacon transducer maintains a near vertical beam axis when implanted on the sea floor. It should be noted at this time that in the design of the sonar beacons, a trade-off was made between total beam-angle and maximum signal strength. While the beam angle might be considered inadequate for providing a sufficient operating margin, the additional signal strength obtained as the result of this narrow beam did pay off with respect to the higher-than-anticipated vessel noise output.

F. Reference System Sea Tests. (6.0)

During the beacon tests, both the PPM and the PCS systems were operated and the x - y coordinate readings from each system were compared. Both systems performed satisfactorily and the readings agreed within the expected error. Both systems were affected by the "holes" in the sonar beam pattern and the PPM system would not accept the pulse shape changes; this was as expected since the system was deliberately designed to discriminate against pulse shapes other than the specified one in order to reduce the affect of noise and other spurious signals on the reference measurements.

G. Semi-Automatic Positioning Tests (7.0)

For these tests a ships heading was selected and the vessel positioning system was switched to the Semi-Automatic mode. In this mode of operation the vessel heading is automatically maintained to the "set" heading and the vessel must be moved either fore-and-aft or port-and-starboard by manual control.

Tests of the heading loop were performed and the control system constants adjusted to provide the proper dynamic response.

Translation tests were performed in this mode and the results indicated that the vessel could be moved in any direction while maintaining within $\pm$ 2 degrees the "set" vessel heading.

H. Automatic Positioning System Control Tests (8.0)

At this point in the tests all the minor systems had been tested and adjusted and sufficient measurements had been made on these systems to indicate that the vessel positioning system should operate satisfactorily in the completely automatic mode.

The beacon which had been used for tests (Paragraph E) provided the reference signals. A set point was selected as close to the beacon axis as the surface bouy would permit and the system was placed in the automatic mode.

The initial results were excellent and it appeared at this time that the only changes that would be necessary would be changes in the constants of the x and y control loops to provide for the proper dynamic response of the overall control system.

The test program required that the vessel be maintained in this mode of operation for 5 days and that during this time emergency procedures and other operational techniques would be developed and tested.

During this time several major and minor problems were encountered. The minor problems included; cross-talk in various signal leads, breakdown of communications between the teletype and the digital computer and inadequate monitoring of the system between the bridge and the electronics room.

The major problems included; (1) The Beacon Pattern. While in normal operation, the beacon pattern would be sufficient as was indicated in Paragraph E above, at the shallow water depth (3000 ft.) at which the tests were being performed, the usable area was so restricted that if the vessel moved appreciably from its referenced location, a loss of acoustic information would occur which would compound the problems already existing. Furthermore, this beacon had attached to it a surface float to provide a visual reference and this further complicated the problem since the vessel could not be maneuvered freely over the beacon without the possibility of fouling the screws. As a result of this, the test location was moved and a GM-DRL beacon was implanted as the reference source. This beacon had a much larger beam angle and did not contain the "holes" and variations in pulse-shape and although its maximum signal strength was less than that of the original beacon, it was more than sufficient for the water depth in which the test was being performed; (2) The Digital Computer malfunctioned several times and in particular it would stop cycling for no apparent reason. In addition, power loss to the computer would wipe out the memory and it would be required to re-enter the complete positioning program in the computer. These problems were subsequently corrected; (3) Transient Runaway of the Thrusters. It was found that occasionally the system would suddenly call for maximum output from the thrusters and main screw for no apparent reason. In fact, prior to these transients, the vessel would be holding position very adequately and in many cases, had been holding this position for as long as 8 to 10 hours. It was determined that these transients resulted from a combination of several things. Among them were either a temporary loss in acoustical signal or signal verification, a subsequent verification of an erroneous pulse and a holding of this data from this erroneous pulse. This erroneous information was accepted by the computer and due to a program misapplication would call for maximum thrust. In essence, the vessel changes were being divided by zero which appeared as a very large vessel motion and consequently the control system would be called upon to correct for this apparent error. This problem was essentially solved by reprogramming the computer.

During this time tests were performed to determine the best gain figures to be used in the positioning system computer program. In fact, three different gain settings were determined to provide different dynamic responses of the system so that some selection could be made of the vessel response with respect to the operating weather conditions.

Both reference systems were tested in the control loop and it was found that if gain changes were made to take into account the additional lag in the system produced by the PCS reference, adequate positioning operation could be obtained with both reference systems.

After correcting the problems indicated above and other minor problems which inherently arise whenever a system of this complexity is first operated, the vessel positioning system performed exceptionally well. During the tests, the x and y coordinate information as well as the thruster and the main screw outputs were monitored on recorders. Because of the excellent agreement between the PCS and PPM reference information, it was unnecessary to use a third reference system to verify the positioning accuracy being maintained by the vessel. The records indicate that after the problems were eliminated, the vessel stayed well within the specified area of operation. In addition, it was demonstrated that after the personel on the bridge gained experience through practice, they were able to use the various modes - manual, semi-automatic and automatic - intelligently and sufficiently to provide emergency back up during drilling.

IV. SYSTEM OPERATION

A. Reference Systems

1. PPM

a. Beacons

To date, the beacon electronics has proven to be extremely reliable. Only one PPM beacon failed and that was during the implantation of the beacon. The beacon output signal was being monitored as it fell, and it appeared as if a leak had occurred in the connector between the battery pack and the electronic package which shorted out the power supply. The beacon output signal is stable and with the one exception, the unit provides an output for a time period well beyond the required seven days.

The one problem with the present beacons is the poor beam pattern, However, the beacons proved adequate for providing a reference signal for sites having water depths ranging between 9,000 and 17,500 feet. As discussed previously, the narrow main beam limits the area over the beacon in which reliable reference measurements can be made; however, unless the vessel must be off-set from the beacon reference - a situation that is normally not required - this is not a major problem. But, it should be noted that a broad smooth main beam is highly desirable, particularly when following the beacon during its free-fall to the bottom, and providing a safety margin for the event that, when on bottom, the beacon transducer did not float so that the beam axis was within one or two degrees of the vertical.

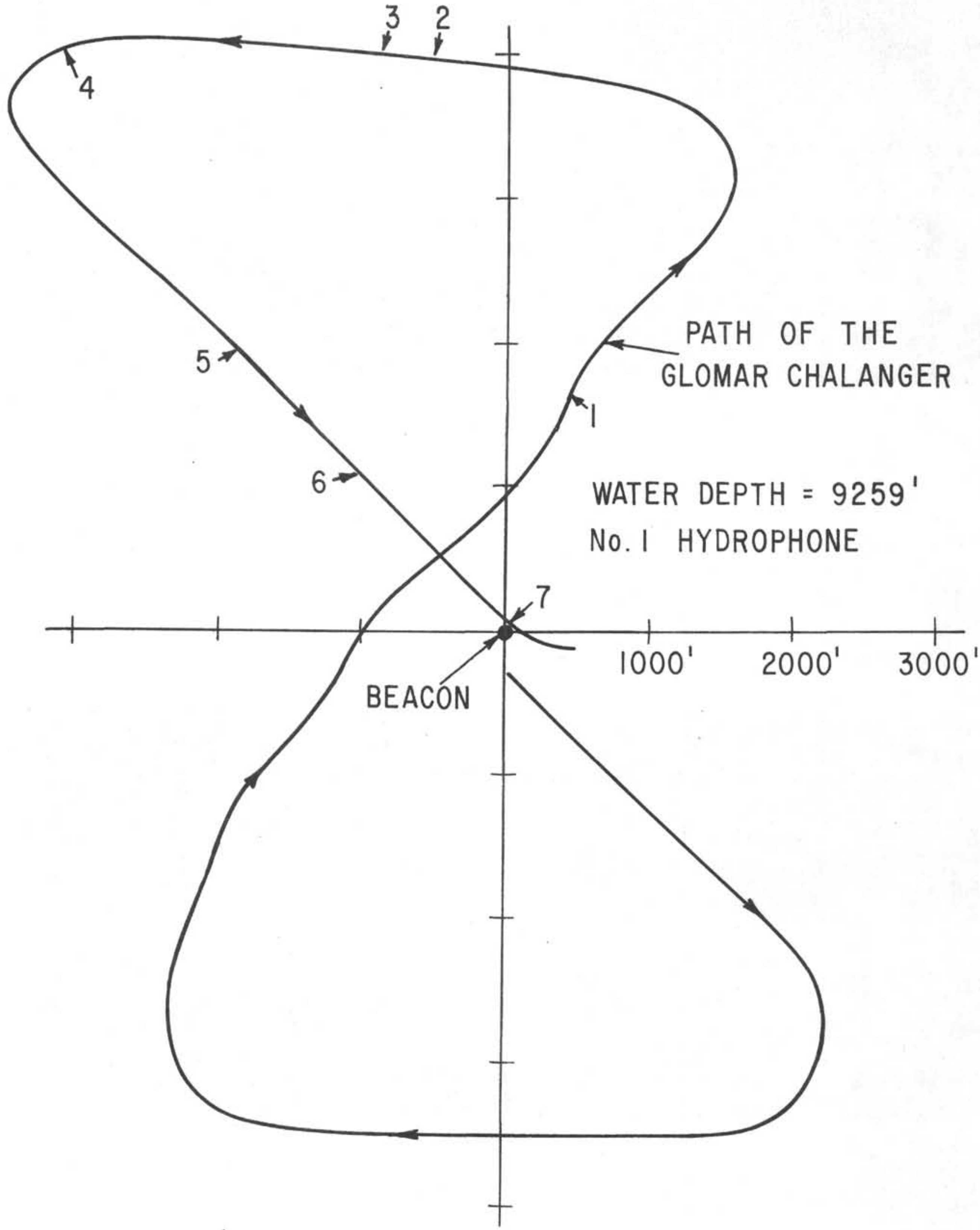
During the implantation of the beacons at the various sites, it was extremely difficult to follow the beacon all the way to the bottom because of the loss of acoustic information due to signal reduction and poor pulse-shape. Although the beacon was never actually "lost", it did require additional manuevering time to find the "optimum" point within the main beam from which to reference.

Figures 12, 13 and 14 show the pulse shape variation over the beacon used at site #1 in 9,217 feet of water. The photographs show the pulse-shapes for the upper path, however, the shapes are similar for the lower path and are essentially symetrical about the beacon.

In summary, once the beacons had been set and the vessel reference position chosen, no problems were experienced with the beacons for all sites drilled to date.

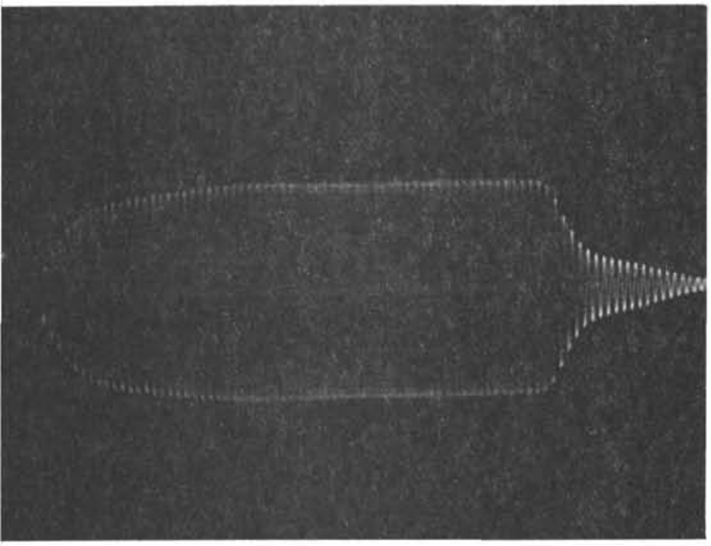
b. Hydrophones

The hydrophone array forms the vessel base line from which the x and y coordinates of the vessel relative to the beacon are measured. Since the coordinate axis is "fixed" to the vessel, these distances are relative to the vessel - the x-axis being fore-and-aft, fore positive, and the y-axis being port-and starboard, starboard positive. Four hydrophones are available, three are needed, therefore one can be considered as a spare. Provisions have been made for switching hydrophones so that any three of the four can be used.

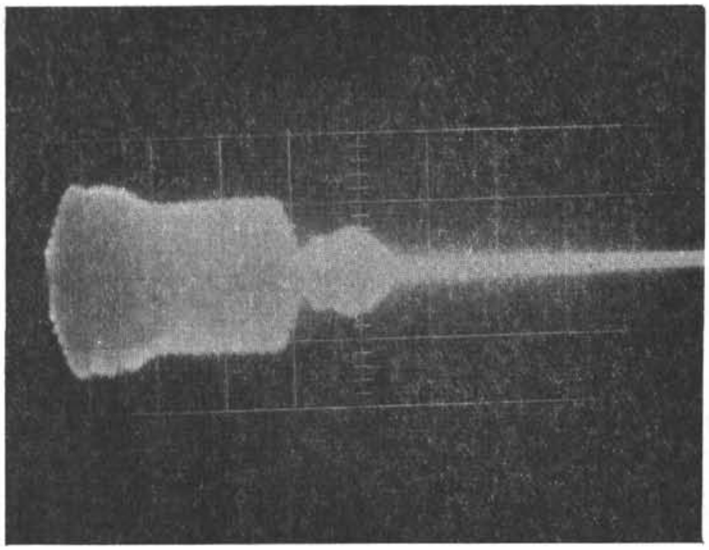


BEACON BEAM PATTERN
RUN SITE #1

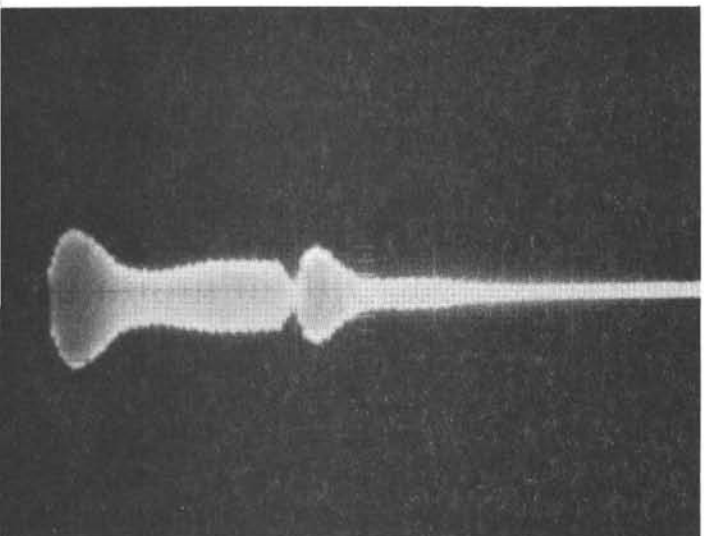
Fig. 12



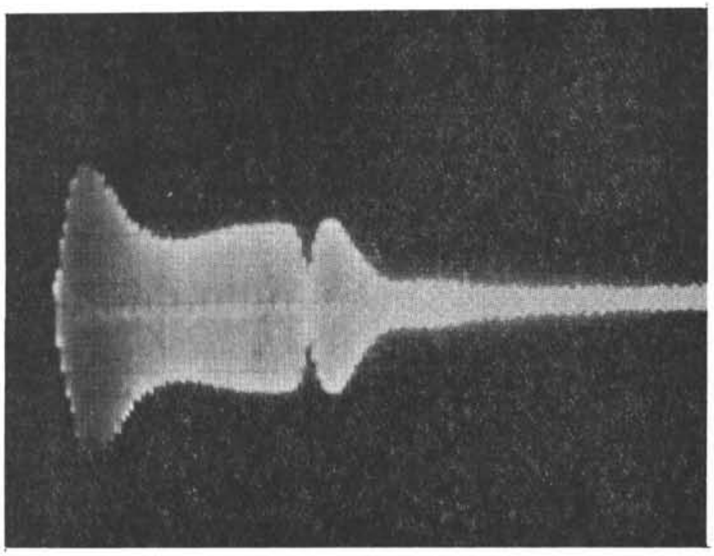
PRIOR TO LAUNCH
SEN: - SWEEP RATE:.5ms/cm
FREQ: 15,928 cps



NO. 1
SEN: 1v/cm SR: 1ms/cm
GAIN: 80 db re (HYDROPHONE INPUT)



NO. 2
SEN: 1v/cm SR: 1ms/cm
GAIN: 80 db

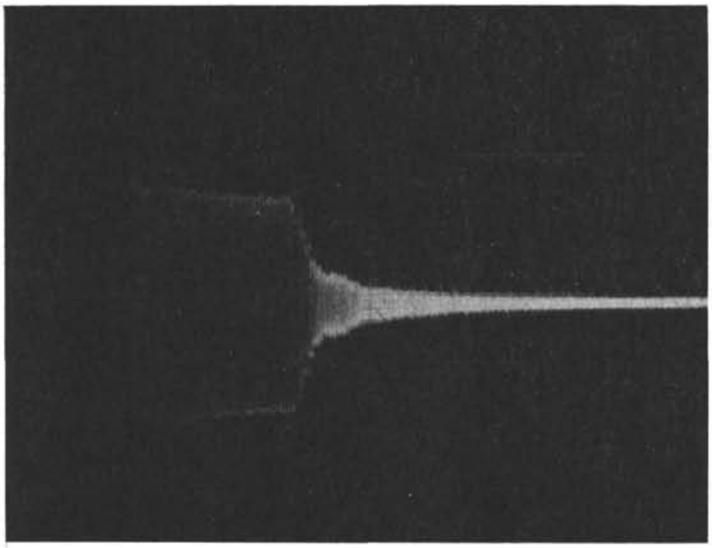


NO. 3
SEN: .5v/cm SR: 1ms/cm
GAIN: 80 db

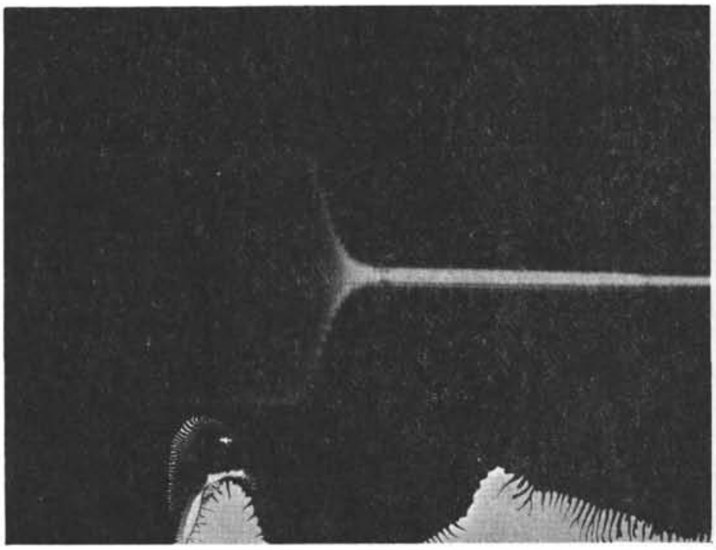
BEACON OUTPUT WAVE-SHAPES

/158

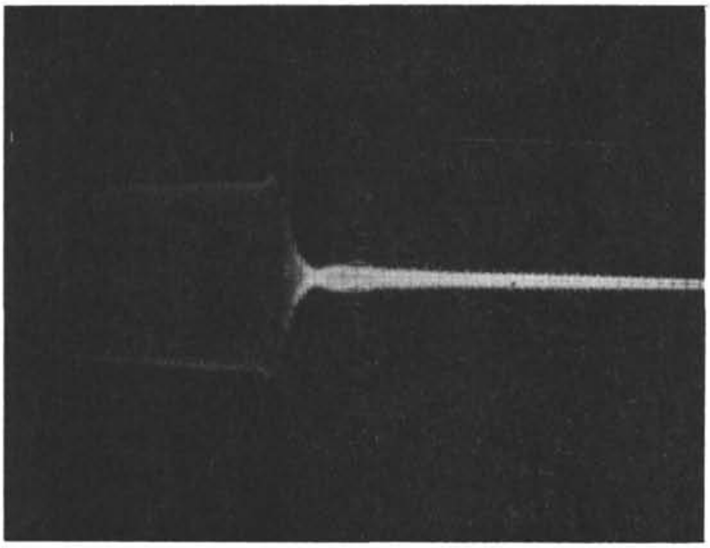
Figure 13



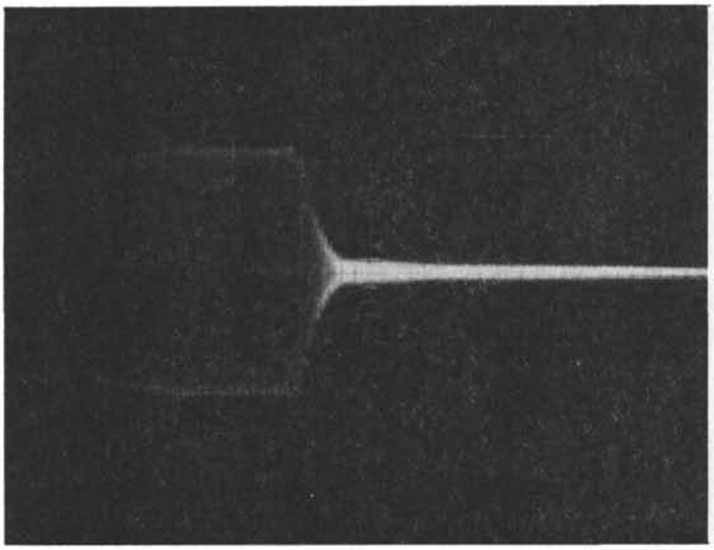
NO. 4
SEN: lv/cm SR: lms/cm
GAIN: 80 db



NO. 5
SEN: lv/cm SR: lms/cm
GAIN: 72 db



NO. 6
SEN: lv/cm SR: lms/cm
GAIN: 80 db



NO. 7
SEN: lv/cm SR: lms/cm
GAIN: 63 db

Figure 14

The operation of the hydrophones have to date been very satisfactory. The sensitivity of the transducers is sufficient and no problems were experienced with changes or instabilities in the characteristics.

The hydrophones were used in their "retracted" position which provided approximately 6 db of gain in the signal-to-noise ratio as compared with using them in the extended position as originally planned. Only one possible consequence resulted from the raising of the hydrophones; aerated water such as foam or cavitation wash from propellers tends to become trapped in the hydrophone baffle and stowage well and this aerated water surrounding the transducer produces a loss in acoustic energy reaching the hydrophone. This was noticed repeatedly during the system acceptance tests when another vessel came along side to transfer cargo or personel. Depending on the surface current and vessel heading, the condition would clear itself within approximately 2 minutes.

The hydrophone arms which extend through the well and up on the main deck can couple "noise" into the hydrophones. Consequently, they must be shock mounted and isolated from the main vessel structure. Several times during periods of vessel station keeping, noise signals were observed which were later traced to vessel-activity-produced noise coupled into the hydrophone arms. This noise was intermittent, random and normally of short duration and consequently did not cause any major problems during station keeping. However, it is a potential noise problem and should be kept in mind.

It might be well at this time to point out that the major effect of high noise levels* for short durations was surges on the output of the thrusters and main screw. The noise would cause erroneous x and y position information to be generated by the reference system and the controller - idiot like - would consider this data valid and call for high thrust levels to counteract this apparent discrepancy. In some instances maximum thrust output and reversal of thrust direction on all units would occur. Normally, however, the noise-level would drop sufficiently so that a few samples of valid data would be obtained which

*Noise levels for which the signal-to-noise ratio is less than 15 db.

would quickly provide proper controller action information and the output thrust would again be adjusted to the normal level; during this relatively short time period, the vessel would not move appreciably from the original position at which the trouble occurred and consequently the effect on station keeping was negligible.

There were cases, however, in the 17,485 foot water depth where "noise lock" would occur. This phenomenon occurred because the reference signal level at the hydrophones was such that the required 20 db signal-to-noise ratio was not obtained when the aft Bow Thruster was operating near maximum thrust output. Therefore, if a momentary high noise-level condition occurred which resulted in the controller erroneously calling for maximum or near maximum thrust from the Bow Thruster, the additional noise output due to the operating level of the thruster would prevent the signal processer from obtaining valid data when the original noise disturbance disappeared. Consequently the controller would continue to operate with erroneous data "locked" in by the noise-level from the high thruster output called for by the erroneous data.*

*This "noise lock" condition will remain unless deliberate action is taken to open the loop.

When this happened it was necessary to drop out of automatic operation so that the thruster outputs would all drop to zero reducing the noise-level so that valid data would be received. With the reception of valid data, the system was then placed back in the Automatic Mode which would then call for the normal thruster outputs based on the valid reference data. If the "noise lock" condition was recognized soon enough, the vessel had not moved too far from the reference position and the thrust level required from the valid reference data would not produce noise problems; however, there were cases in which the vessel had moved sufficiently far from the reference position so that when the system was again placed in the Automatic Mode, the required output level of the Bow Thruster called for by valid data would introduce sufficient noise to send it back into the "noise lock" condition. In these instances, the vessel was controlled in the Semi-Automatic Mode and moved sufficiently close to the reference location so that the required thruster level due to the error would be substantially reduced. At this time automatic operation could again be performed.

c. Signal Processing

The signal processing equipment proved to be extremely reliable. No trouble was experienced with the equipment during the total time covered by this report.

The performance of the system was very good and the system philosophy proved to be well founded. The system was capable of rejecting noise signals that were within the specified limits, that is a 20 db signal-to-noise ratio. Furthermore it proved capable of rejecting pinger signals and signals from the water-depth measuring devices such as the PDR.

In operation the system is relatively simple to set up and adjust. One possible weak point is the lack of automatic gain control. Changes in acoustic signal strength must be compensated for by manual adjustment of gain controls. Normally there is a limited range of signal levels that can be accepted and this would normally be sufficient. However, for conditions in which the noise level approaches and exceeds the specified limits, the gain settings become critical and must be frequently adjusted.

In summary the equipment was very reliable and, when the operating and environmental conditions were within the specified limits, the equipment performed extremely satisfactorily. Normally, the system performed well under conditions where the operating environment was worse than the specified limits; the major exception is the conditions under which "noise lock" would occur.

2. PCS

a. Beacons

The PCS beacons also proved to be extremely reliable. No trouble was experienced with instability or signal drift and the beacon life was well above that required. As with the PPM beacon, the one problem with the beacon is the narrow beam pattern. The same arguments apply for a smoother and broader beam pattern as were given in 1-a above.

b. Hydrophones

The same hydrophones are used in both the PPM and the PCS systems. No problems were experienced in cross-talk because of this common usage. The transducers were stable and no detrimental effect was observed due to possible phase variations in the hydrophone transducers. The sensitivity and band-width were sufficient for proper system performance. The same caution with respect to the potential noise source should be observed as noted in 1-b.

c. Signal Processing

In general the signal processing equipment was reliable. Trouble did occur in the equipment sometime after the third site. The exact nature of this problem was not determined.* When the equipment was operational it provided reliable position data. The major problem with this equipment is in the servo modules. These units are prone to drift and have a long time constant. Normally the drift amplitudes are within usable limits and the long time constants can be compensated by the positioning system CONTROLLER. Satisfactory station keeping was performed using this reference system and the system provides an excellent back-up to the PPM system.

3. Heading

The heading reference system is the gyro compass which in itself is a well tested and highly reliable

*Subsequently this problem was traced to a broken connection and was repaired and the system was used for positioning during the second leg.

piece of equipment. In providing the data to the CONTROLLER, the analog signal from the gyro compass must be converted to digital information. Trouble was experienced in this analog-to-digital conversion unit and the original equipment had to be replaced. Additional trouble occurred in the replacement unit. At this time sufficient information is not available to indicate whether this is an inherent weakness in the component or a misapplication of the component in an overall system. This point should be checked. In general the heading reference system had sufficient reliability to provide station keeping for all the necessary sites to date and when operating, performed exceptionally well.

B. Controller

1. Computer

Probably the most critical component in the positioning system is the digital computer.* In operation, the computer receives the x and y coordinate data, converts this to vessel position, considers this data with respect to previous process data and computes the necessary thrust orders.

The computer is programmed to take the position information, which is sampled every two seconds,

*This is also the only major positioning system component that is not redundant or for which any installed spare is not available.

compensate it for the pitch and roll of the vessel, compare it to the "set" position, calculate the present position with respect to the previously sampled position and calculate the vessel velocity. From this information, the proper thrust output and direction are computed to direct the vessel toward the referenced position if an error exists. The mathematical operations performed with position information determines the dynamics of the control system and hence the vessel response during station keeping.

Obviously the importance of this component is two-fold: 1) it must operate, that is the hardware must be reliable and capable of continuous operation during the station keeping periods; 2) the computer program or software must be correct so that proper manipulation of the input data is performed.

Some problems were experienced with the computer hardware and component changes and circuit card replacements had to be made. Although there were several malfunctions, the computer, when used for actual station keeping, performed without trouble. It appears that the computer has been "checked out" by competent factory personel and that it should be sufficiently reliable for its intended use.

Problems were also experienced in the programming of the computer, but unlike the hardware troubles, once the program has been "de-bugged" it is "permanently" corrected and reliability per se is not questionable. There is some question concerning the need for keeping the capability of changing the program at sea and the capability of communicating with the computer so that the programmed constants can be determined and diagnostic tests performed. To be completely versatile, a 12 K memory capacity is required and the teletype equipment is needed. From the operating experience to date, it appears that this versatility should be maintained. In particular, there were several instances where the control system constants were adjusted with respect to the weather conditions. It should be noted that a single set of constants can be programmed which will provide satisfactory station keeping performance but under certain weather conditions, it would require the thrusters to work rather vialently; at this time, a change in the control loop constants would permit the vessel to be maintained within the perscribed limits while requiring the thrusters to be operated less actively.

In summary the computer appears to have satisfactory reliability. However, this is based on limited operational experience. It is a critical part in the positioning system and its failure during station keeping would leave the position control system operable only in the Manual Mode. In addition, only the PCS sonar reference system would be available for providing the pilot with the vessel position information. The program philosophy provided excellent vessel control and sufficient stability margin existed so that a relatively large change in constants and system dynamics could be obtained if needed.

2. Pitch and Roll Compensation

Since the x and y vessel position coordinates are calculated essentially from the angle at which the acoustic energy arrives at the hydrophones, angular changes of the vessel would appear similar to vessel motion. Consequently, the signals from the reference beacon must be compensated for the pitch and roll of the vessel before the position data can be correctly calculated. Compensation of this pitch and roll is accomplished by electrical signals from a gyro aligned with the x and y axis of the vessel.

The gyros used are small high speed aircraft type and have a relatively short operating life. Trouble was experienced in two of the three gyros aboard and hence the reliability of these components is questioned.

The normal pitch and roll of the vessel was approximately 2 degrees with periods in the order of about 6 seconds. Actually, unless the vessel lists or takes a trim fore and aft, the average of this angular motion about the pitch and roll axis is zero and since the period is short compared to times required to get the vessel in motion, compensation is not necessary. However, the vessel x and y position information is displayed on an oscilloscope on the bridge and is used by the man on watch to monitor the vessel location during station keeping. This display data is affected by pitch and roll and the result is that the oscilloscope spot jumps back and forth across the screen as it follows the pitch and roll action of the vessel. For small angles, this spot jitter is not serious. However, when the angles become greater than about 1 degree, the spot motion is very disconcerting. It was found that even with the pitch and roll compensation a sufficient error remained to produce intolerable jitter in the scope presentation for angular motion of 3 degrees or greater. This was corrected by filtering the signals. After the filters were inserted, the monitoring system proved to be highly satisfactory.

It should be noted that although pitch and roll per se does not actually have to be compensated, this should not be construed to mean that a pitch and roll axis gyro system is not necessary. Correction must be made for long term changes in the vessel attitude which do occur when the pipe is handled in the derrick. In these cases, the angular changes remain at a given value long enough for the vessel to actually change position due to the apparent change in reference location.

C. Thrusters

1. Controllers

As indicated in Figure 3, output signals from the computer are directed to the DC generator controller. Problems were experienced with the semiconductor generator controllers and several times proper control of the generators and hence the thrusters could not be obtained. When this occurred, reassignment of the thrusters was made. Insufficient data and operating experience exists with respect to the controllers to determine the reliability of the units. It should be pointed out that interfacing problems were experienced in this area and it would be reasonable to state that optimum interfacing between the control signal generating equipment and the controllers does not exist.

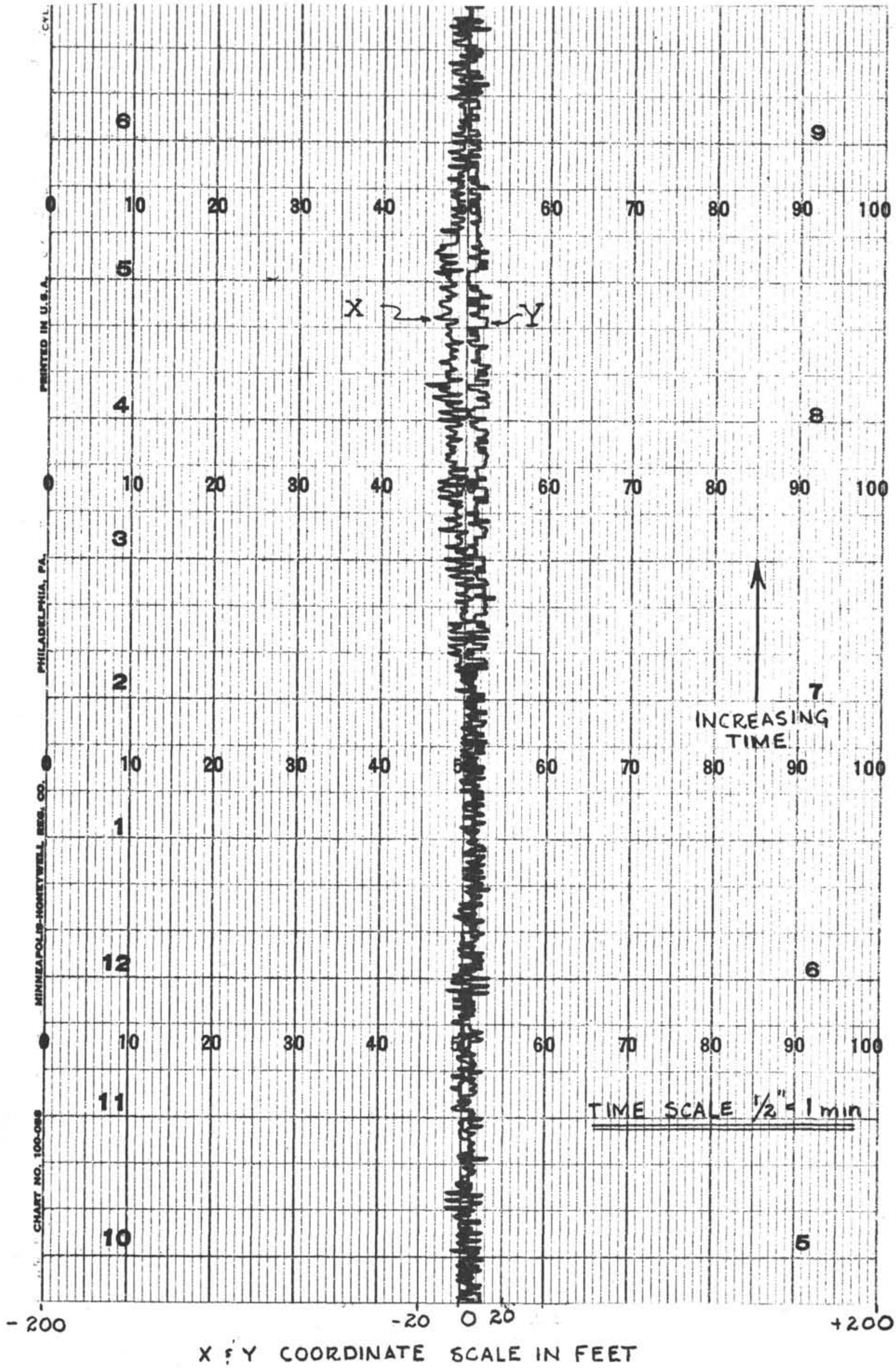
In general, the thrusters performed reasonably satisfactorily and the ability of reassignment of the thrusters during station keeping is extremely useful as was proven on several occasions.

2. Noise

The noise data taken and described in paragraph III-D proved to be valid and the conclusions based on this data were verified during the station keeping operation at the various sites. The major problem was noise from the Bow Thrusters and in the deep-water site, "noise lock" was experienced as described in detail in IV-A-1-b.

D. Total System Operation

The overall behavior of the positioning system was excellent. In calm weather the vessel was maintained extremely close to the selected reference. Variations of less than 20 feet were normal. An example of this is shown in Figure 15. While the total time shown is approximately 20 minutes, the record is typical of what occurred for many hours. Perhaps a more "normal" record is shown in Figure 16. The total variation of the vessel around the set point is well within the required area of operation. It should be noted, however, that there are some apparent motions shown that are not fully explained. These are the approximately 40 foot sinusoidal motions with periods of about 90 seconds in both the x and y directions. There are several possible causes but as of this time,



X
Y
INCREASING TIME
TIME SCALE 1/2" = 1 min
- 200
-20
0
20
+200
X & Y COORDINATE SCALE IN FEET
PRINTED IN U.S.A.
PHILADELPHIA, PA.
MINNEAPOLIS-HONEYWELL REG. CO.

Figure 15

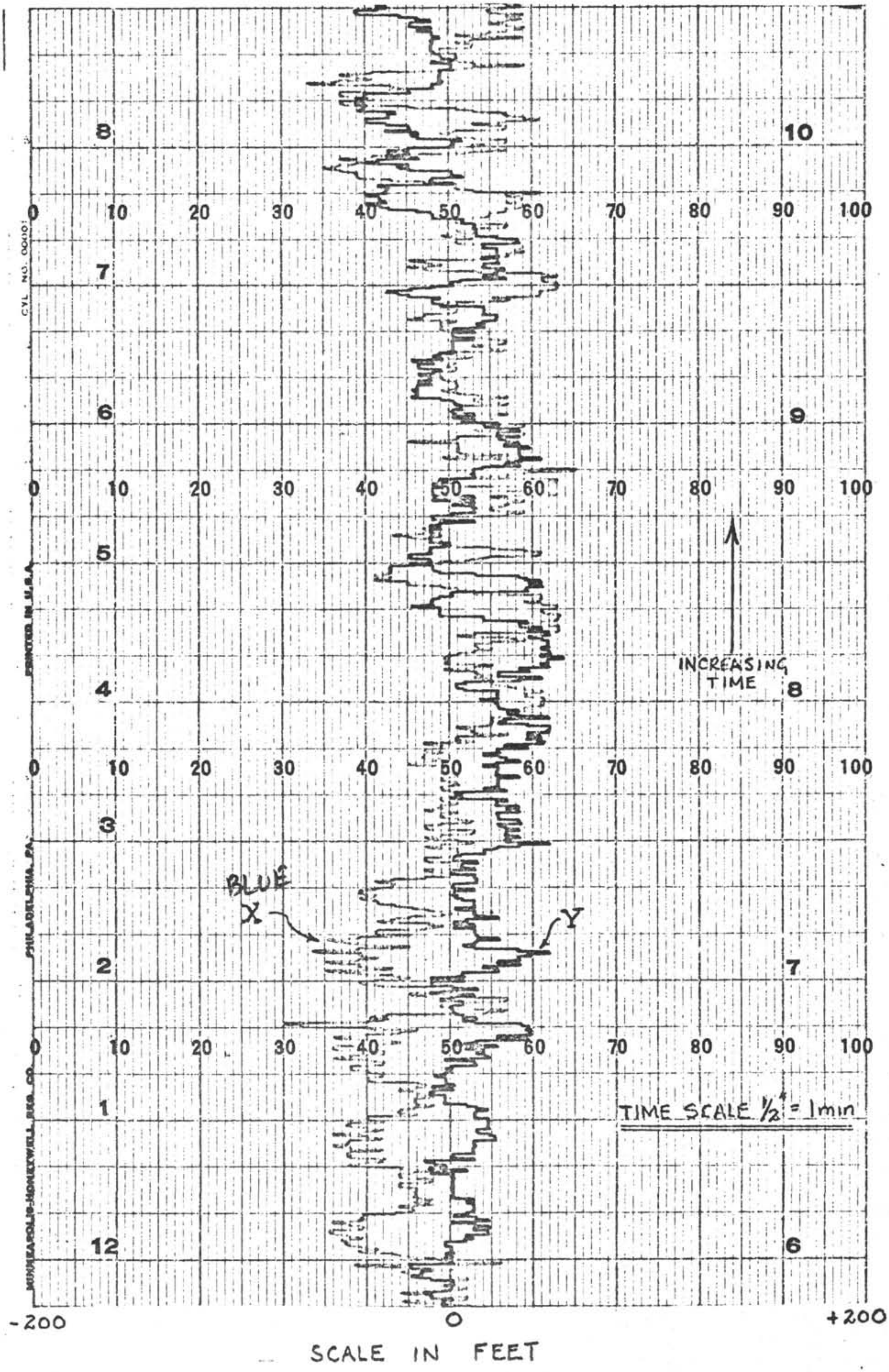

8
10
0 10 20 30 40 50 60 70 80 90 100
7
6
9
0 10 20 30 40 50 60 70 80 90 100
5
INCREASING TIME
4
8
0 10 20 30 40 50 60 70 80 90 100
3
BLUE X
Y
2
7
0 10 20 30 40 50 60 70 80 90 100
1
TIME SCALE ½" = 1min
12
6
-200
0
+200
SCALE IN FEET

Figure 16

no definite or satisfactory conclusion has been reached. The short time variations which appear riding on the overall records are due to the pitch and roll of the vessel. As mentioned previously, even though pitch and roll correction to the signal is applied, some feed-through due to incomplete cancellation occurs. That shown in Figure 16 was due to relatively small angles. For larger angles the record appears as shown in Figure 17. It is apparent that the position of the vessel with respect to the reference can be determined through this "noise". However, it can be appreciated that the scope trace which would be following this variation would be hard to analyze and that the integration that must be performed to determine the true vessel motion would be difficult to accomplish mentally.

The thruster action, particularly reversals of direction, depended intimately on the vessel heading with respect to the weather and sea conditions. In cases where a heading was taken, so that a constant torque in the same direction was required to maintain heading, the thrust behavior would essentially be as shown in Figure 18. However, a change in heading of approximately 30 degrees could produce thruster operation as shown in Figure 19. Obviously, for a given set of environmental conditions there exists an optimum heading such that minimum thrust variations and thrust direction changes are required. This point is

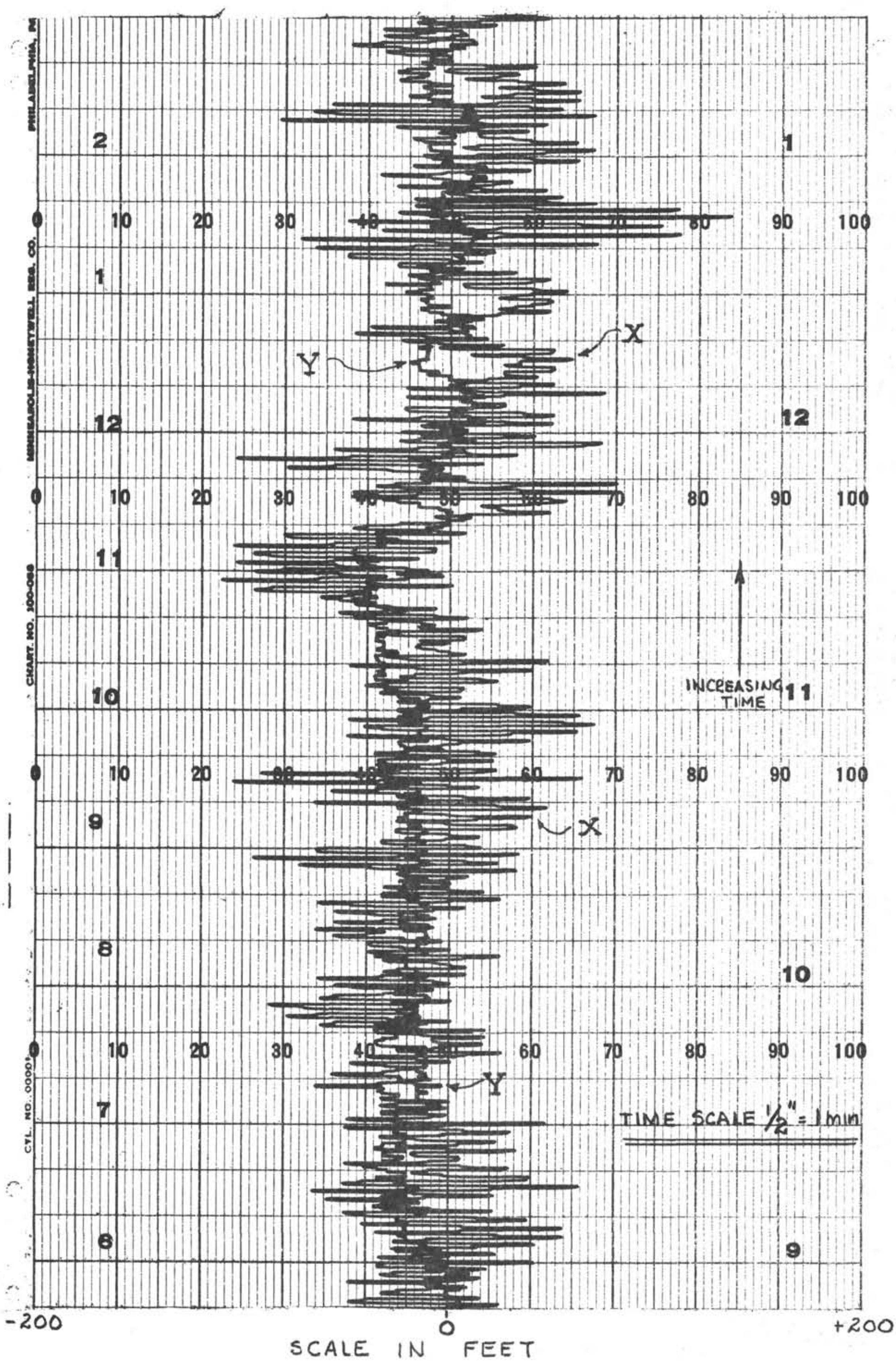


Figure 17

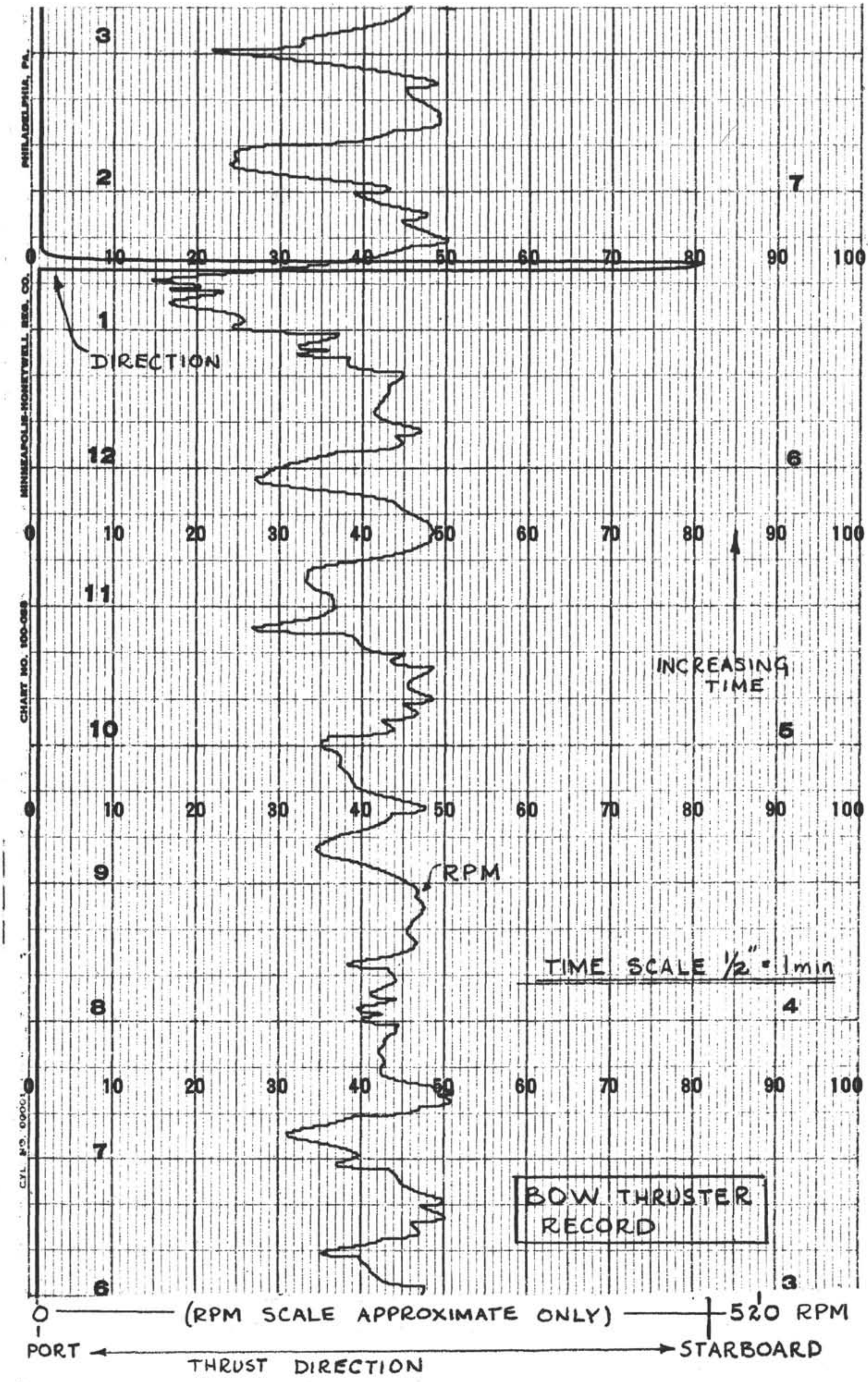
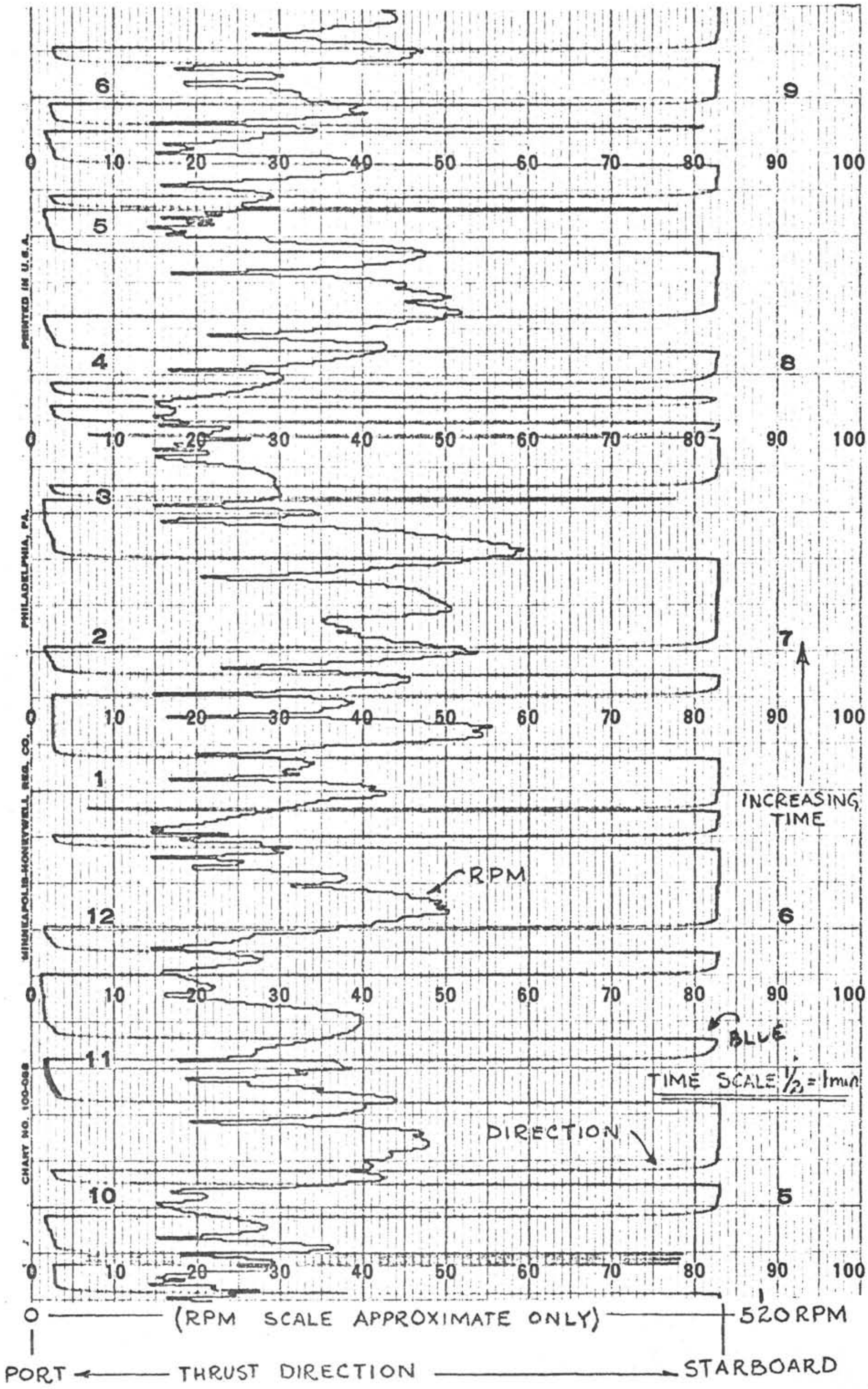

DIRECTION
INCREASING TIME
RPM
TIME SCALE ½" = 1min
BOW THRUSTER RECORD
0
(RPM SCALE APPROXIMATE ONLY)
520 RPM
PORT
STARBOARD
THRUST DIRECTION

Figure 18



PRINTED IN U.S.A.
PHILADELPHIA, PA.
MINNEAPOLIS-HONEYWELL REG. CO.
CHART NO. 100-088
0 10 20 30 40 50 60 70 80 90 100
6
9
5
4
8
3
2
7
1
INCREASING TIME
RPM
12
6
BLUE
11
TIME SCALE 1/2 = 1min
DIRECTION
10
5
0 (RPM SCALE APPROXIMATE ONLY) 520 RPM
PORT ← THRUST DIRECTION → STARBOARD

Figure 19

of importance since it reduces the mechanical strain imposed on the thrusters and should also provide minimum fuel consumption. It appears that a study of this optimization would be highly informative and of considerable value. As a measure of the environmental conditions under which the vessel was maintaining position, drift runs were made after the drill pipe was removed from the sea floor; i.e. all power to the thrusters and main screw was turned off and the vessel was allowed to drift free. During this time the heading and the x and y coordinates were measured. A plot of two of these curves are given in Figures 20 and 21. From Figure 20, it can be seen that the vessel would have exceeded the 5% water depth limit in less than 8 minutes. Note also the heading change in the vessel due to the surface wind. In Figure 21 the conditions were much calmer; the vessel stayed within the 5% water depth range for almost 24 minutes. In this instance the drift was due almost entirely to surface currents and the vessel heading changed very slightly. Using the vessel as a current measuring device, the current was approximately 0.37 knots.

As was pointed out previously, the PCS did perform reasonably well. Figure 22 shows a portion of the recorded x and y data obtained from the PCS system while in Automatic Mode. The vessel was positioned, in this particular case, for 7 hours with no problems. At a subsequent site, trouble occurred in the PCS system and it became impossible

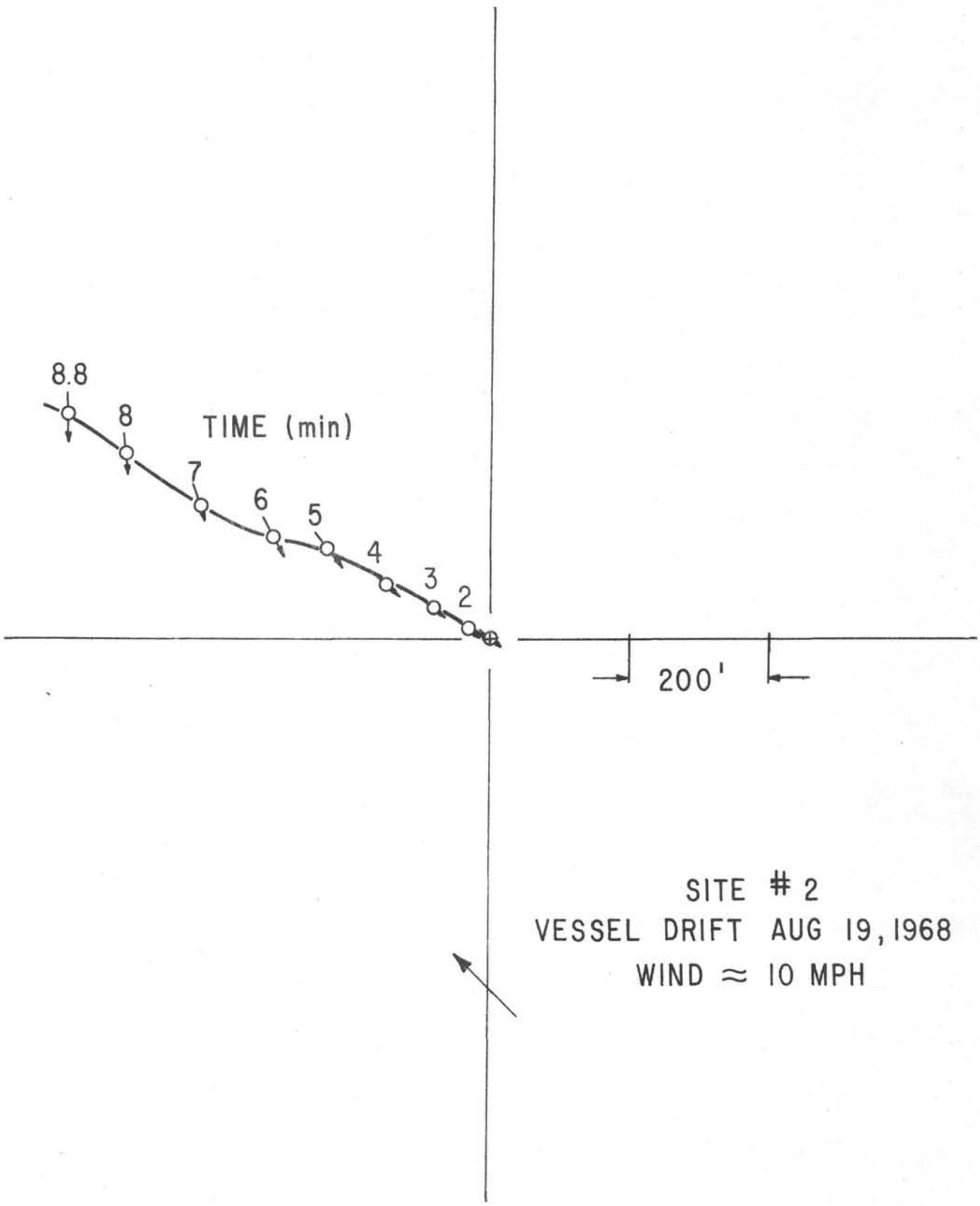

8.8
8
TIME (min)
7
6
5
4
3
2
200'
SITE # 2
VESSEL DRIFT AUG 19, 1968
WIND ≈ 10 MPH

Fig. 20

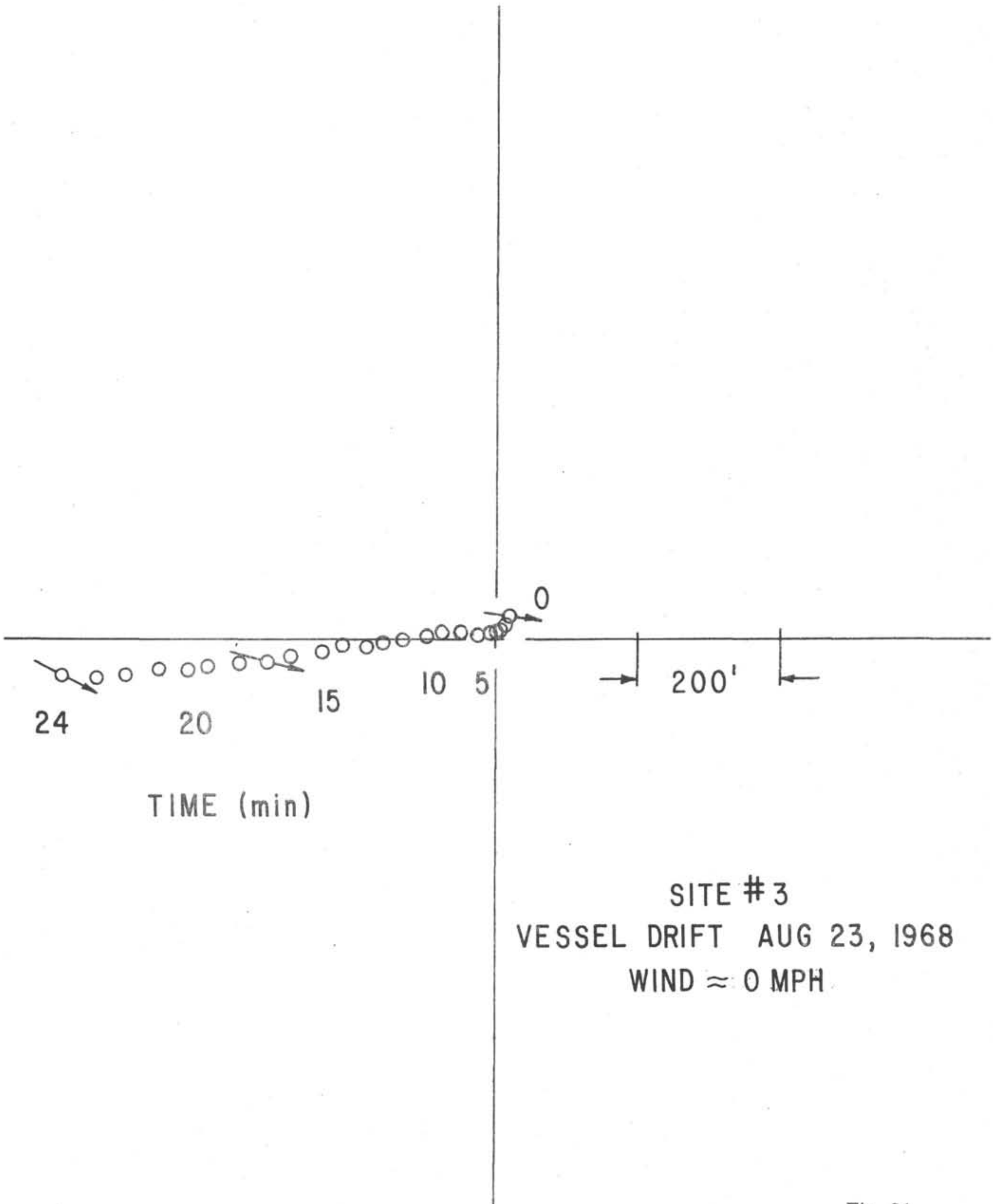
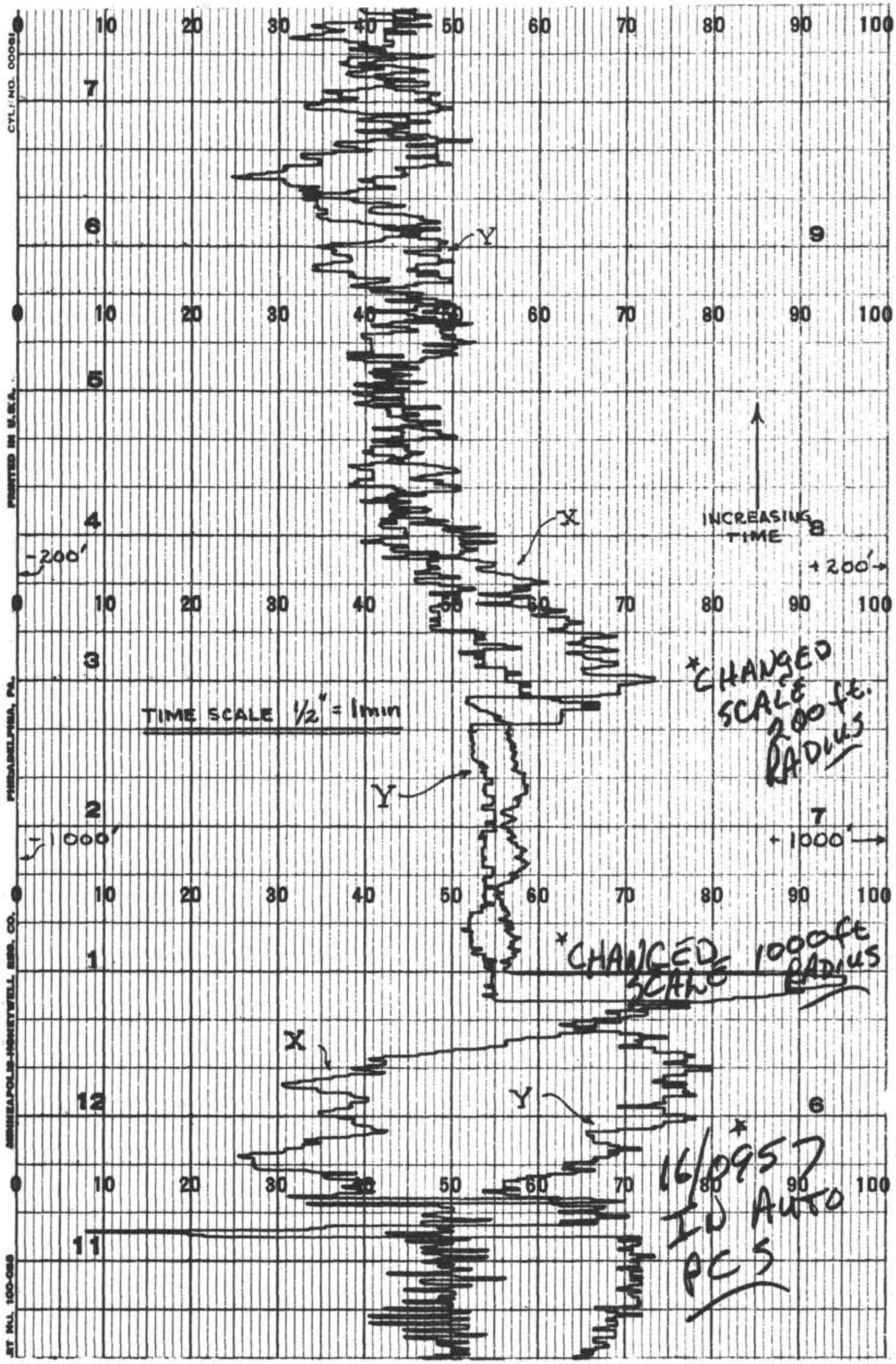

0
24
20
15
10
5
200'
TIME (min)
SITE #3
VESSEL DRIFT AUG 23, 1968
WIND ≈ 0 MPH

Fig. 21



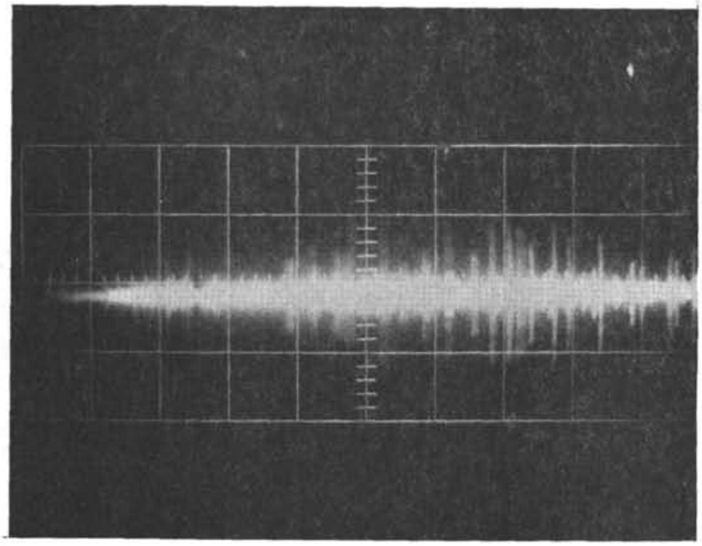
PCS X & Y COORDINATES RECORD

Figure 22

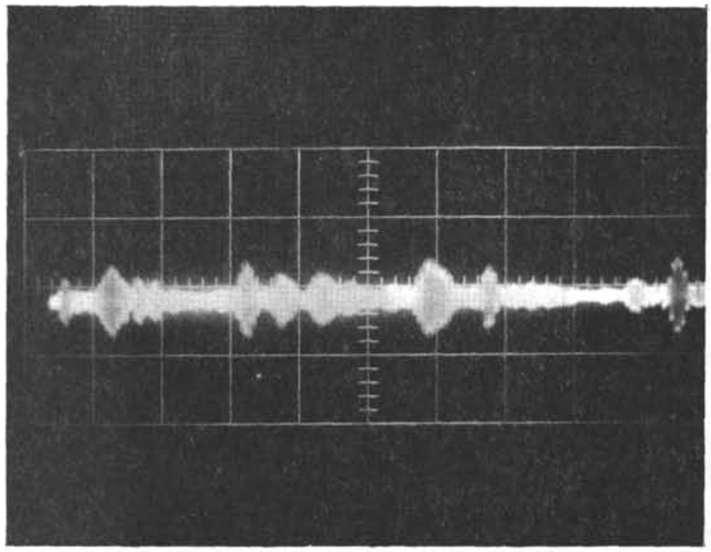
to maintain position with the PCS. However, no real effort was made to determine the cause and to objectively determine the positioning performance using the PCS system. During the time covered by this report, the PPM system was considered the primary reference and because of its excellent performance and the fact that it was considered the primary equipment, little time and effort were allowed for analyzing, testing and operating the PCS system. This is regrettable considering the importance of this back-up system.

The major noise source as indicated previously resulted from the thrusters and except for occasional noise being coupled into the hydrophones through the hydrophone arms, normal vessel operation and normal drilling operation produced no noise problem. However, one phenomenon was noticed which because of its time sequence did not cause major problems in drilling but was a major problem in accurate reference position measurements. This phenomenon is the noise generated by zinc coating flaking off the drill pipe. It was observed that after the drill pipe had been on bottom in deep water (greater than 10,000 feet) for several hours, the zinc coating would flake off as the pipe was raised. The pressure entrapment behind the coating appears the most likely cause. A photograph of the pipe and the zinc coating is shown in Figure 23. The noise pulse-shapes are shown in Figure 24. The

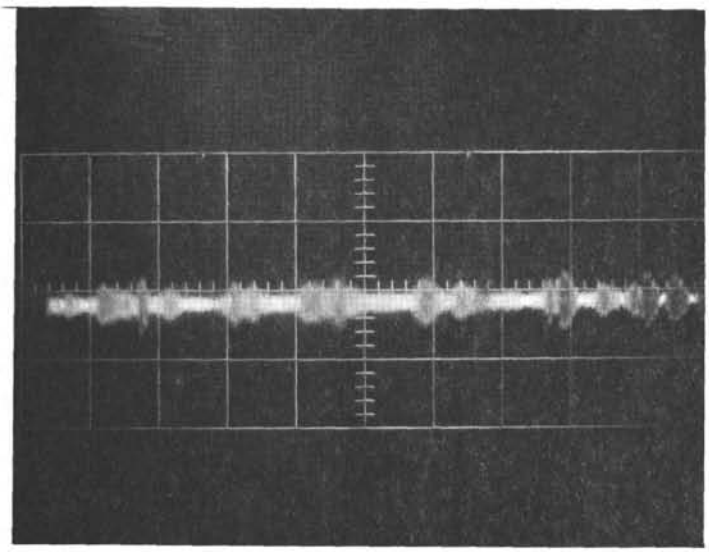
Figure 23



a. SENSITIVITY: 1 v/cm
SWEEP RATE: 20 ms/cm
GAIN: 65 db



b. SENSITIVITY: 1 v/cm
SWEEP RATE: 1 ms/cm
GAIN: 65 db



c. SENSITIVITY: 1 v/cm
SWEEP RATE: 1 ms/cm
GAIN: 65 db

NOISE PULSES PRODUCED BY THE ZINC COATING FLAKING OFF DRILLPIPE

Note: These measurements were taken at the input to the Bandpass Filter - See Figure 5.

energy level of these noise pulses exceeded the reference signal energy ($S/N < 0$db) and therefore inaccurate x and y data would be obtained during the time that this flaking occurred. An example of the effect on the x and y data is shown in Figure 25. The drill pipe was being raised to remove a stand during the record and it is quite apparent that the noise activity had increased during this time interval. The noise level would increase immediately after the pipe was raised; during the time the stand was being removed and the pipe was hanging from the rotary table, the noise pulses would effectively disappear. Since this phenomenon occurred while the pipe was being retrieved and maintaining position was not mandatory, the effect was not disastrous.

V. CONCLUSIONS

The conclusions that follow are based on the experience gained to date from actual station keeping and hence must be qualified. The water depths ranged from 3,480 feet (system check out) to 17,485 feet. The weather conditions were essentially mild; the average wind velocity was approximately 10 knots; some squalls were experienced that had peak winds of approximately 40 knots. The usual sea conditions during station keeping was about sea state 1 and the maximum sea conditions experienced was about sea state 3. Pitch and roll angles were usually less than $\pm$ 2 degrees with occasional 3 to 4 degree half angle rolls. From these conditions, it is obvious that the positioning system and the vessel station keeping

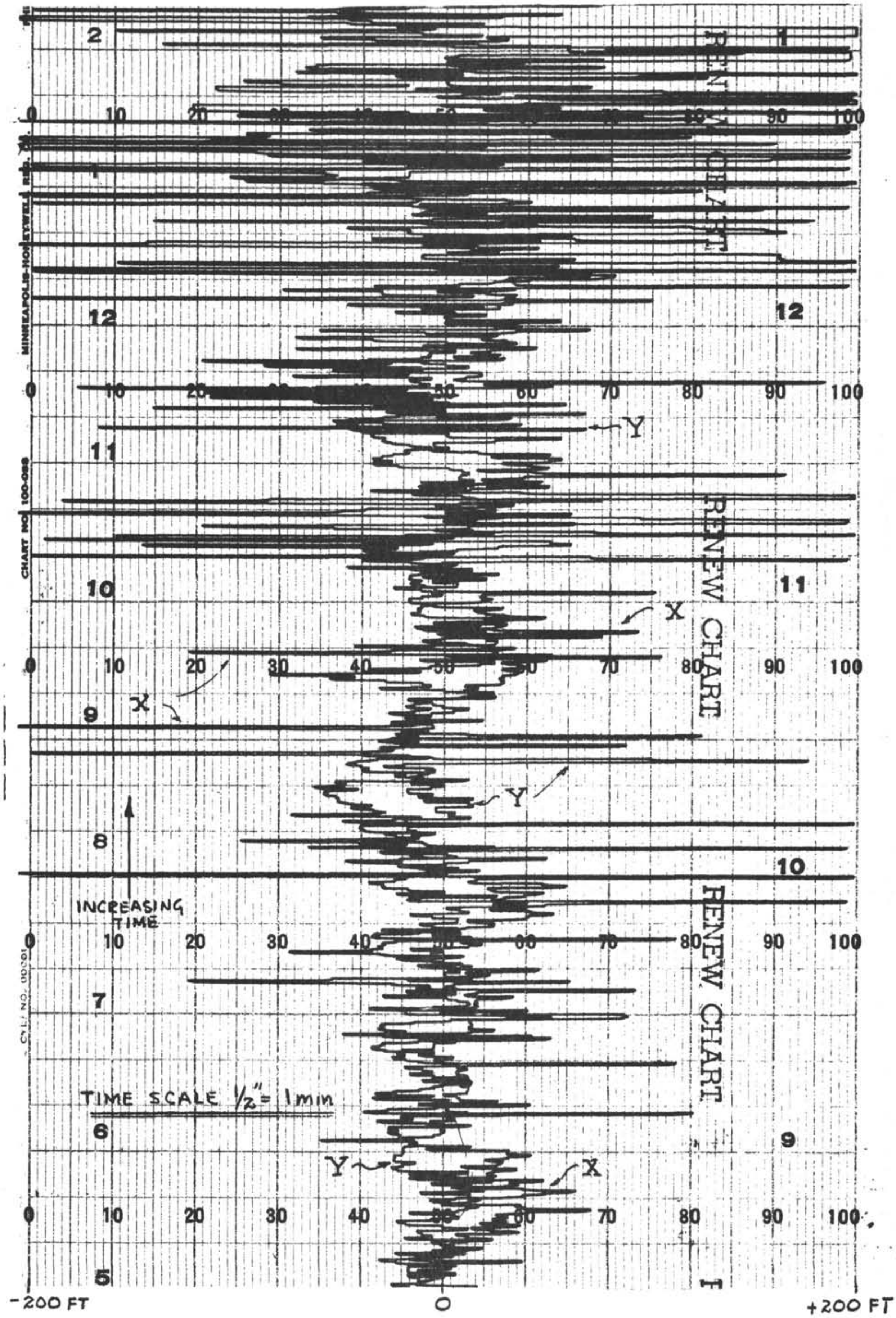

RENEW CHART
RENEW CHART
RENEW CHART
MINNEAPOLIS-HONEYWELL REG. CO.
CHART NO. 100-088
0 10 20 30 40 50 60 70 80 90 100
2
1
12
11
10
9
8
7
6
5
Y
X
INCREASING TIME
TIME SCALE ½" = 1 min
-200 FT
0
+200 FT

Figure 25

ability has not been thoroughly tested. However, sufficient data has been gathered to indicate that reasonably good overall performance can be expected in all weather conditions in which drilling can be performed.

With respect to weather conditions, the major question of concern is the adequacy of the total thrust available for station keeping; this question arises because of the fact that the thrust output is less than the design maximum and only a single bow and stern thruster are normally used with the limited capability of using either an additional bow thruster or stern thruster in severe conditions. Performance of the system in near maximum and maximum weather conditions can only be determined under actual experience.

To date open loop operation of the control system was not required. However, if this type operation becomes necessary, maintaining station is virtually impossible and the best that can be hoped for is that the vessel can be kept close enough to the reference position for a long enough time period to allow the drill pipe to be removed from the sea floor. Reasonably this may be expected in relatively calm weather and after the vessel has reached a stable equilibrium so that thruster levels can be maintained at their values prior to open loop operation. Conditions which would force operation in the open loop mode are; 1) loss of computer with only the PPM sonar reference system in use, 2) loss of both sonar reference systems. Therefore, it is obvious that the PCS sonar reference system or its equivalent is mandatory.

Semi-automatic operation is a valuable and highly satisfactory mode of operation. In this mode the pilot on the bridge becomes a part of the x and y feedback loop. After the crew gained experience, keeping the vessel within the required radius of operation was performed with relative ease. However, the weather conditions were not really severe and so some reservations must be made. In any case, it became readily apparent that manual operation of the vessel without automatic heading control was extremely difficult. Therefore, in general, it could be said that a primary operations rule would be "always maintain automatic heading control of the vessel unless equipment malfunction makes this impossible."

During the course of station keeping at the various sites, the deficiencies in monitoring techniques on the bridge and communications between the bridge and the electronics room became evident. Many of these deficiencies were corrected and the solutions proved to be very satisfactory. However, the value of recording the x and y data became apparent and this facility is not available on the bridge. The scope presentation is sufficient to indicate the immediate behavior of the vessel; long term trends which are readily apparent in the recordings and useful for corrective action to prevent difficulties should also be available on the bridge.

A standard bouy implantation procedure should be incorporated so that adequate and reliable reference information is obtained. A general procedure for optimizing the chances of obtaining a satisfactory and reliable reference is:

1) Pre-soak the beacons for approximately 30 minutes prior to free-falling. The beacons should be monitored at this time and output levels closely observed. This will detect connector leaks and early pressure seal failures.

2) The beacon should be followed in its free fall using the Semi-Automatic Mode. In this manner the vessel position can be altered so as to stay within the beam pattern of the beacon.

3) When the beacon is on the bottom, a simple but adequate search pattern should be made to locate the area of maximum energy and to determine the approximate sonar beam cross-section. This will provide the area & energy level of the usable sonar signal and will allow time for high pressure initiated failures to appear; a beacon operating satisfactorily at this time will have an excellent chance of surviving for the desired time limit.

APPENDIX

NOISE VOLTAGE OUTPUT VS. THRUSTERS -
THROUGH VESSEL HYDROPHONES

All Measurements Were Taken as Follows:

1. PPM System Gain Setting = 1
2. BP Output
3. HP 3400A True RMS Voltmeter

A. Hydrophones Extended

Aft-Bow Thruster - Thrust to Star'b

RPM	HYDROPHONE NUMBER			
	1	2	3	4
0	5.0	17	5.3	6.4
240	5.5	17	5.6	6.2
380	24	22	14	16
470	63	42	35	44
515	73	50	40	52

Note: All readings given in milivolts

ACCEPTANCE TEST

NOISE MEASUREMENT TEST DATA

AUGUST 11, 1968

USF ...

NOISE MEASUREMENTS THROUGH VESSEL HYDROPHONES

AFTER NOISE MEASUREMENTS TAKEN ON FORMS 4.11, 4.12 & 4.13 THE HYDROPHONES WERE RETRACTED AND THE NOISE WAS AGAIN MEASURED. FROM THIS DATA IT APPEARS THAT A SIGNIFICANT REDUCTION IN NOISE INPUT TO THE HYDROPHONES WAS OBTAINED. THE FOLLOWING DATA WAS TAKEN WITH THE HYDROPHONES EXTENDED 8" FROM THE FULLY RETRACTED POSITION. ALSO THE CONNECTION OF THE PCS SYSTEM WAS CHANGED SO THAT THE PCS INPUT IS TAKEN AFTER THE PPM PRE-AMPLIFIER. THIS REDUCED THE LOADING EFFECT ON THE HYDROPHONE SO THAT AN INCREASE OF APPROXIMATELY 2db IN OVERALL HYDROPHONE SENSITIVITY IS OBTAINED.

NOISE DATA

PPM SYSTEM GAIN SETTING = 1.0

VOLTAGE MEASURED AT BP OUTPUT

VOLTAGE MEASURED WITH HP 3400A RMS VOLTMETER

ALL VOLTAGE READINGS ARE GIVEN IN MILLIVOLTS

DATA TAKEN AUG. 11, 1968 0550 + 0645

WATER DEPTH 9226 FEET

THRUSTER RPM	HYDROPHONE NUMBER 1	2	3	4	
0	2.6	1.9	2.2	2.0	AMBIENT NOISE LEVEL
	BOW-AFT (#1) THRUSTING STARBOARD				
520	44	5.8	5.2	53	
	BOW-AFT (#1) THRUSTING PORT				
520	20	13	4.7	14	
	BOW-FW'D (#2) THRUSTING STARBOARD				
490	8.0	2.6	2.6	18	
520	10	3.2	2.9	20	
	BOW-FW'D (#2) THRUSTING PORT				
500	27	4.8	5.0	33	
540	30	19	16	50	
	STERN-FW'D (#2) THRUSTING STARBOARD				
530	8	14	11	9.5	
	STERN-FW'D (#2) THRUSTING PORT				
520	4	4.2	3.8	2.6	
	STERN-AFT (#1) THRUSTING STARBOARD				
540	3.1	2.7	3.1	2.4	
	STERN-AFT (#1) THRUSTING PORT				
550	5.0	6.5	6.5	5.4	

William P. Schneider
J. G. Reed III

FORM 4.11

AMBIENT NOISE MEASUREMENT THROUGH VESSEL HYDROPHONES

DATE: 7-21-68

SYSTEM	PPM				PCS				REMARKS
HYDROPHONE	1	2	3	4	1	2	3	4	PPM. READINGS TA AT BP OUTPUT
INPUT SHORTED	4.5	5.5	5.3	4.3	2.0	2.9	2.8	2.3	PCS READINGS TA
NOISE VOLTAGE	5.0	16.6	5.3	6.4	2.3	4.6	3.	3.3	BEFORE FILTER-INPUT AF@ 160KC
EQUIVALENT GAIN OR SET.	1.0	1.0	1.0	1.0	35db	35db	35db	35db	HYDROPHONES FULL EXTENDED
VOLTMETER DESCRIPTION	HP 3400 A True RMS Voltmeter				HP 3400 A True RMS Vol				

MAJOR EQUIPMENT RUNNING: one AC Generator, Radio

SEA STATE: one to two feet, No white caps

VESSEL CONDITIONS: Steady

MRL

JWR

FORM 4.12.

WATER VELOCITY NOISE MEASUREMENTS

DATE: 7-21-68

SYSTEM	PPM				PCS				REMARKS
HYDROPHONE	1	2	3	4	1	2	3	4	Gain same as 4.11
NOISE VOLTAGE AT TIME V=26.	5.0	16.7	5.3 ~~3.3~~	5.4 ~~3.2~~	2.8	4.8	3.3 ~~9.3~~	3.3 ~~5.4~~	
T= 0 V=									
T= V=									
T= V=									
T= V=									

VELOCITY MEASURED BY: Pittometer Log. (Hastings Raydist)

VOLTMETER DESCRIPTIONS: Same as 4.11

[illegible signature/initials]

NOISE VOLTAGE OUTPUT VS THRUSTERS — THROUGH VESSEL HYDROPHONES

DATE: 7-21-68

THRUSTER (S): BOW-AFT (#1) DIRECTION OF THRUST: STAR'B

SYSTEM	(PPS) CHAN 1				(PCS)			
HYDROPHONE	1	2	3	4	1	2	3	4
NOISE VOLTAGE — RPM = 0								
RPM = 240	5.5 MV.	16.8 MV.	5.6 MV.	6.2 MV	7. MV	6 MV	3.4 MV	7.0 MV
RPM = 380	24. MV	22 MV	14 MV	16 MV	30. MV	20. MV	13. MV	30 MV
RPM = 470	63 MV	42	35	44	80 MV	40 M	28	80
RPM = ~~520~~ 515	73 MV	50	40	52	100 MV	50 MV	35	90
RPM = 550								

THRUSTER(S): BOW-AFT (#1) DIRECTION OF THRUST: PORT

RPM = 0								
RPM = 240	5.3	16.8	5.5	7.	4.	5.	3.	4.5
RPM = 380	10.0	17.5	7.0	7.5	20.	12.	8.0	24.
RPM = 470	18.5	20	12	14.	30.	17	11	30
RPM = 520	37	27	20	25	45	24	18	45
RPM = ~~550~~ 535	36	28	20	24	45	25	18	47

NOTE! REMARKS ON FORM 4.11 APPLY TO ALL MEASUREMENTS ON FORM 4.13

[illegible] VOLTAGE OUTPUT VS THRUSTERS — THROUGH VESSEL HYDROPHONES

DATE: 7-21-68 All readings in M.V.

THRUSTER(S): BOW FW'D (#2) DIRECTION OF THRUST: STA[illegible]

SYSTEM	(PPS) GAIN 1				PCS			
HYDROPHONE	1	2	3	4	1	2	3	4
NOISE VOLTAGE AT RPM = 0	~~4.6~~				~~3.8~~			
RPM = 240	4.6	16.	4.7	6.7	3.8	5.0	3.0	4.5
RPM = 380	5.8	16.	5.2	5.5	13.	8.0	6.0	15.0
RPM = 470	13.0	18.5	9.5	12.5	25	12.5	9.5	27. ~~8.5~~
RPM = 500	17.5	20.5	11.5	15.5	32	16.	12.	30.
RPM = 550								

THRUSTER(S): BOW FW'D (#2) DIRECTION OF THRUST: PORT

RPM = 0								
RPM = 240	4.6	16.	4.7	6.8	4.5	5.5	3.5	5.5
RPM = 380	17.	20	12.	19.	22	12.	9.	24.
RPM = 470	50	38	32	48	65	33	30	78.
RPM = 500	62	51	40	63	72	38	30	78
RPM = 550								

NOISE VOLTAGE OUTPUT VS THRUSTERS — THROUGH VESSEL HYDROPHONES

DATE: 7-21-68 ALL Readings in MV

THRUSTER(S): STERN FW'D (#2) DIRECTION OF THRUST: STAR'D

SYSTEM	(PPB) GAIN 1				PCS			
HYDROPHONE	1	2	3	4	1	2	3	4
NOISE VOLTAGE AT RPM = 0								
RPM₁ = 240 ~~RPM₂~~ =	4.5	16	4.7	5.6	2.2	5.	2.6	3.0
RPM₁ = 380 ~~RPM₂~~ =								
RPM₁ = 470 ~~RPM₂~~ =								
RPM₁ = ~~___~~ ~~RPM₂~~ = 540	8.5	21.5	16	11	10	25	18	16
RPM₁ = 550 ~~RPM₂~~ =								

THRUSTER(S): STERN FW'D (#2) DIRECTION OF THRUST: PORT

RPM = 0 ~~RPM~~ =								
RPM = 240 ~~RPM~~ =								
RPM = 380 ~~RPM~~ =								
RPM = 470 ~~RPM~~ =								
RPM = ~~___~~ RPM = 525	8.3	27.5	9.2	8.8	5	11.5	8	6
RPM = 550 ~~RPM~~ =								

7/1/71 Jus

NOISE VOLTAGE OUTPUT VS THRUSTERS — THROUGH VESSEL HYDROPHONES

DATE: 7-21-68 ALL READINGS in M.V.

THRUSTER(S): STERN AFT (#1) DIRECTION OF THRUST: STAR'B

SYSTEM	(PPS) GAIN 1				PCS			
HYDROPHONE	1	2	3	4	1	2	3	4
NOISE VOLTAGE RPM = 0	4.5	15	4.6	4.4	2.2	4.8	2.8	2.8
RPM₁ = 240 / RPM₂ =								
RPM₁ = 380 / RPM₂ =								
RPM₁ = 470 / RPM₂ =								
RPM₁ = 5 / RPM₂ = 535	5.8	17.6	10.5	8.8	3.8	8.5	7.8	5.3
RPM₁ = 550 / RPM₂ =								

THRUSTER(S): STERN AFT (#1) DIRECTION OF THRUST: PORT

RPM = 0 / RPM =								
RPM = 240 / RPM =								
RPM = 380 / RPM =								
RPM = 470 / RPM =								
RPM = 5 / RPM = 535	12.5	37	19	15	9	23	19	10
RPM = 550 / RPM =								

7/21/68 [signature]

NOISE VOLTAGE OUTPUT VS THRUSTERS — THROUGH VESSEL HYDROPHONES

DATE: 7-21-68

~~THRUSTER(S)~~: MAIN DIRECTION OF THRUST: FWD

SYSTEM	PPM GAIN = 1				PCS			
HYDROPHONE	1	2	3	4	1	2	3	4
NOISE VOLTAGE AT RPM =								
PPM = RPM =								
RPM = RPM =								
RPM = RPM =								
RPM = RPM = 185	4.7	16			3.8			
RPM = RPM =	← AMBIENT →							

~~THRUSTER~~(S): MAIN DIRECTION OF THRUST: AFT

RPM = RPM =								
RPM = RPM =								
RPM = RPM =								
RPM = RPM =								
RPM = RPM =	5	2	5.4	0.8	11	25	14	13
RPM = RPM =								

WJB
[illegible]

NOISE VOLTAGE OUTPUT VS THRUSTERS — THROUGH VESSEL HYDROPHONES

DATE: 7-21-68

THRUSTER(S): BOW #1 & #2 DIRECTION OF THRUST: STAR'

SYSTEM	(PPS) GAIN 1				PCS			
HYDROPHONE	1	2	3	4	1	2	3	4
NOISE VOLTAGE AT RPM = 0								
RPM(1) = 550 RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = 500 RPM(2) = 500	68	50	38	48	100	48	38	95
RPM(1) = 510 RPM(2) = 495	80	55	43	58	110	55	43	100

THRUSTER(S): BOW #1 & #2 DIRECTION OF THRUST: PORT

RPM(1) = 0 RPM(2) =								
RPM(1) = 550 RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = 510 RPM(2) = 505	64	38	40	64	75	40	35	95

/204

JAR

NOISE VOLTAGE OUTPUT VS THRUSTERS — THROUGH VESSEL HYDROPHONES

DATE: 7-21-68

THRUSTER(S): STERN #1 & #2 DIRECTION OF THRUST: STA[illegible]

SYSTEM	(PPS) GAIN 1				PCS			
HYDROPHONE	1	2	3	4	1	2	3	4
NOISE VOLTAGE AT RPM = 0								
RPM(1) = 550 RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = 535 RPM(2) = 540	17,5	38	30	16,5	14	26	22	12

THRUSTER(S): STERN #1 & #2 DIRECTION OF THRUST: PORT

RPM(1) = 0 RPM(2) = 0								
RPM(1) = 550 RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = RPM(2) =								
RPM(1) = 540 RPM(2) = 530	8,2	18,5	9,5	9,8	11	22	18	14

/205 7/1/4 Jan

NOISE VOLTAGE OUTPUT VS THRUSTERS THROUGH VESSEL HYDROPHONES

DATE: ____________

BOTH THRUSTER(S): (Bow & Stern) (BOTH BOW / BOTH STERN) DIRECTION OF THRUST: STBD

SYSTEM	PPS GAIN=1				PCS			
HYDROPHONE	1	2	3	4	1	2	3	4
NOISE VOLTAGE AT RPM=								
RPM #1 = 490 RPM #1 = 535								
RPM #2 = 500 RPM #2 = 530								
RPM = RPM =								
RPM = RPM =								
RPM = RPM =	72 68	58	43	53	90	55	45	100

THRUSTER(S): BOTH BOW / BOTH STERN DIRECTION OF THRUST: PORT

RPM #1 = 510 RPM #2 = 510								
RPM #1 = 535 RPM #2 = 530								
RPM = RPM =								
RPM = RPM =								
RPM = RPM =	75 ~~62~~	62	52	75	85	50	42	95
RPM = RPM =								

Jan

POSITION SYSTEMS SEA TEST DATA

ACCEPTANCE TEST

JULY 20 TO AUGUST 11, 1968

POSITIONING SYSTEM SEA TESTS

1.0 DOCKSIDE TESTS

1.1 Calibration And Operational Check of Both Reference Systems

1.11 PCS system.
- Test Procedure: See Form 1.11
- Test Stations: Computer Room

1.12 PPM system.
- Test Procedure: See Form 1.12
- Test Stations: Computer Room

1.2 Positioning System Controls and Monitoring System Test.
- Test Procedure: See Form 1.20
- Test Stations: Bridge (TC); Computer Room; Engine Room.

Dockside Tests completed: OK KBH; No______; Remarks________

2.0 THRUSTER CALIBRATION AND RESPONSE TESTS

- Vessel Location: At sea in sufficient water depth and area to run all thrusters to max output.
- Test Procedure: See Form 2.0
- Test Stations: Bridge (TC); Engine Room

Thruster calibration and response tests completed: OK KBH; No______; Remarks ADJUSTED COUPLING COEFFICIENTS ON THRUSTERS & MAIN SCREWS. ALSO SCALE FACTORS.

3.0 SPEED TESTS

- Test Procedures: See Form ______.
- Test Stations: See Form ______.

Vessel Speed Tests Completed: OK KBH; No________;
Remarks 11.9 KTS @ SHAFT RPM 225 WITH 17.7' WATER UNDER KEEL. SET SPEED LOG TO CORRESPOND.

4.0 NOISE TESTS

- Vessel Location: At sea in a minimum of 1000 ft. of water.

4.1 Noise Power Level at Vessel Hydrophones.

4.11 Measure the ambient noise level.

- Test Procedure: For these measurements the ship should be as near to "dead ship" conditions as possible. The captain shall determine the actual equipment left running at the time and location of test. - Fully extend the hydrophones and check for proper seating. - When minimum vessel operating conditions have been established and attained, the data outlined in Form 3.11 will be obtained.
- Test Stations: Bridge; Hydrophone Winches; Computer Room (TC).

4.12 Measure noise level through hydrophones for a maximum vessel velocity through the water of 3 knots.

- Test Procedure: With the vessel conditons as established in 3.11, only the necessary additional equipment will be operated for bringing the vessel to a maximum velocity of 3 knots with the main screws. - When 3 knots is reached, the equipment will be shut down. - The data outlined in Form 3.12 will be taken during the time that the vessel is loosing headway.
- Test Stations: Bridge; Computer Room (TC); Stern after steering.

4.13 Measure noise level vs. each thruster (including the main screws).

- Test Procedure: With the vessel conditions as established in 3.11, only the necessary additional equipment will be operated to provide maximum thrust output from either both forward thrusters, both rear thrusters, or both main screws.
- Test Stations: Bridge; Computer Room (TC); Stern after steering; Engine room.

4.2 Noise Level Measurement with Calibrated Hydrophone

4.21 Noise vs. Depth

- Test Procedure: With the vessel condition as established in 3.11, lower calibrated hydrophone through "moon Pool" Measure the noise input at hydrophone for maximum thruster output and for several hydrophone depths. For remaining procedures see Form 3.21.
- Test Stations: Computer Room (TC); Bridge; "Moon Pool" Engine Room; Stern after steering.

4.3 Noise Spectrum Measurement of Vessel "Noise Sources" Other Than Thrusters

- Test Procedure: Starting with the vessel condition as established in 3.11, operate major equipment of potential acoustic noise generation, and measure noise level through vessel hydrophones. For remaining procedures see Form 3.3.
- Test Stations: Derrick Floor (TC); Bridge; Computer Room; Radio Room.

Noise Tests Completed: OK ____; NO _____; Remarks SET OPTIMUM HYDROPHONE DEPTH @ 8" DOWN FROM ____. /209
STOWED POSITION. SKIRT ? BAFFLE EXTENDS 5" BELOW HOLE. -2- THIS GAVE MINIMUM ? [illegible]

5.0 BEACON TESTS

5.1 On Board Tests

- Test Procedure: The selection of the PPM beacon to be used in the remaining sea tests will be made using the results of 3.0 - Measure the frequency and wave-shape of the output of both beacons, PPS and PCS. Rig up both beacons and test for proper suspension.
- Test Stations: Main Deck.

5.2 In-water Tests

- Vessel location: At sea in a minimum of 3000ft. of water.
- Test Procedure: Fully extend and properly seat the hydrophone arms - Connect tether line to beacon assembly in 4.1 - Measure the signal level, frequency and wave-shape of beacon outputs vs. depth below surface. - Turn on the positioning system equipment and monitor the beacon output - See Form 4.2 for remaining procedure.
- Test Stations: Computer Room (TC); Bridge; Main Deck.

5.3 Beacon Pattern Measurements

5.31 Set Beacons on Bottom

- Test Procedure: Rig up beacons assembled in 4.2 attach surface marker buoy - Turn on positioning system equipment - Monitor outputs while the beacons are being lowered. Measure signal output of beacons after being on sea floor a minimum of 30 min. (During this period the vessel should be maintained as nearly as possible directly over beacons using the surface buoy as a reference).
- Test Stations: Main deck; Bridge; Computer Room (TC)

5.32 Cross-Axis Measurements

NOTE: Since the hydrophones are extended, the relative velocity of the vessel through the water must be limited to a maximum of 3 knots.

- Test Procedure: Measure the signal level at the vessel hydrophones for at least two passes of the vessel over the beacon location - Each pass should start at a minimum of 1000 ft. plus the water depth from the projected beam axis and end 1000 ft. plus the water depth past the projected axis. The vessel speed should be approximately 2 knots and the angle between the two courses should be approximately 90°.
- Test Stations: Bridge; Computer Room (TC); Stern after steering.

5.33 Constant radius Measurements

NOTE: Since the hydrophones are extended, the relative velocity of the vessel through the water must be limited to a maximum of 3 knots.

- Test Procedure: Measure the signal level at the vessel hydrophones as the vessel moves at a constant radius of 2000 ft. about the projected beacon axis. The vessel speed should be approximately 2 knots and should cover a circular course over a minimum of 450°.
- Test Stations: Bridge; Computer Room (TC); Stern after steering.

BEACON TESTS COMPLETED: OK [initials]; No_____; Remarks WAVE SHAPE ON ONE BEACON GOOD IN MAIN LOBE - LARGE VARIATION IN SIGNAL LEVEL MEASURED IN SIDE LOBES. BEACON IN CONTINUOUS USE FOR 14 DAYS.

6.0 REFERENCE SYSTEM SEA TESTS

NOTE: These measurements will be obtained during tests 5.31, 5.32 and 5.33.

- Test Procedure: The vessel position information read-outs from the PPM and the PCS reference systems will be plotted, analyzed and compared during the beacon tests 5.31, 5.32 and 5.33.
- Test Stations: Computer Room (TC); Bridge

Reference system sea tests completed: OK [initials]; No_____;
Remarks COMPARISONS WERE SUFFICIENTLY ACCURATE TO ELIMINATE NEED FOR 3RD REFERENCE.

7.0 SEMI-AUTOMATIC POSITIONING TESTS

- Vessel Location: Approximately over beacons. The Vessel must be maintained within a 1500 ft. radius from the beacon axis during these tests so that the vessel movements may be monitored by the reference systems.

7.1 Hold Given Heading

- Test Procedure: Set the positioning system to the Semi-Automatic Mode to hold a heading selected by the captain. Hold this heading for a minimum of 30 min. or until it is firmly established that the given heading is being maintained.
- Test Stations: Bridge (TC); Computer Room; Engine Room.

7.2 Heading Dynamics

- Test Procedure: Select several headings and maintain each selected heading for sufficient time to allow transients to die out and establish that the given heading is being held. See Form 7.2 for additional procedures.
- Test Stations: Bridge (TC); Computer Room; Engine Room.

7.3 Vessel Translations

NOTE: Since the hydrophones are extended, the relative velocity of the vessel through the water must be limited to a maximum of 3 knots.

- Test Procedure: Using the controls on the control console, translate the ship fore-and-aft, port-and-starboard, and in a direction requiring both fore-and-aft and port-and-starboard movement. See Form 7.3 for additional procedure.
- Test Stations: Bridge (TC); Computer Room; Engine Room

Semi-Automatic positioning tests completed: OK MM; NO ____;

Remarks ON LOSS OF ACOUSTIC SIGNAL TRANSIENT THRUSTER OUTPUTS WERE EXPERIENCED DUE TO PROGRAM ROUTINE WHICH ROUTINE HAS NOW BEEN CORRECTED.

8.0 AUTOMATIC POSITIONING SYSTEM CONTROL TESTS

NOTE: This portion of the tests will constitute the beginning of the 5 day test 1.7.10 of the Sea Trial Agenda.

- Vessel Location: Approximately over beacons.

8.1 Establishment of Position Keeping

- Test Procedure: Bring vessel approximately over beacons and set positioning system to Automatic Mode using the PPM reference system. Establish position keeping and maintain this automatic positioning for a minimum of four hours to firmly establish proper system operation - Switch to PCS reference and continue to maintain automatic positioning for a minimum of 2 hours. At the end of this time, set up the Baylor Taut Line reference system. See Form 8.1 for further procedures.
  NOTE: At this time limited drilling equipment tests may be started.
- Test Stations: Bridge (TC); Computer Room; Engine Room.

8.2 System Dynamics Tests (step response)

- Test Procedures: Switch to PPM reference system operation-Switch to Semi-Automatic Mode and move vessel a specified distance from "zero" reference - Switch to Automatic Mode and monitor the vessel motion until transients have decayed sufficiently to determine that the "zero" reference is being maintained. The detail distances and data to be monitored are given in form 8.2 - Repeat tests using the PCS reference system.
- Test Stations: Bridge (TC); Computer Room; Engine Room.

8.3 Emergency Procedures

8.31 Loss of Reference System

- Test Procedures: Simulate loss of reference system being used for positioning and take the necessary action to switch over to the standby reference system as quickly as possible. Detail procedures are given in form 8.31.
- Test Stations: Bridge (TC); Computer Room; Engine Room.

/212

8.32 Loss of Computer
- Test Procedures: Simulate Loss of Computer and take the necessary action to hold position in the Manual Mode. Detail procedures are given in form 8.31.
- Test Stations: Bridge (TC); Computer Room; Engine Room.

8.33 Power Failure to on-line Thruster:
- Test Procedures: Simulate loss of power to an on-line Thruster and take the necessary action to get Thruster back on-line. - Detail procedures are given in form 8.33.
- Test Stations: Bridge (TC); Computer Room; Engine Room.

8.34 Establishment of Dynamic Positioning For Reliability and Operational Checks.
- Test Procedure: Set Positioning system in Automatic-Mode with all redundant systems in stand-by condition.
- Test Stations: Bridge (TC); Computer Room; Engine Room.

Automatic positioning system control tests completed: OK KB/RWR
No _______; Remarks EMERGENCY PROCEDURES OUTLINED & DISTRIBUTED TO CREW.

9.0 FULL SHIP SYSTEM OPERATION PERFORMANCE

Personnel training in all modes of operation and in emergency prodedures will be conducted during the next 48 hours. The ship will normally be maintained on position using the automatic positioning control mode. Drilling equipment will be operated to take cores of the ocean floor, no deeper than 50 feet penetration, using coring amemblies specified by Scripps. To avoid loss of drilling assemblies while conducting emergency-procedure drills, the drilling assembly will be raised clear of the ocean floor pior to conducting emergency drills.

• • NOTE • •

The vessel positioning system will be continuosly monitored by instruments and personnel at all times during the training periods to ascertain that no malfunction of the equipment has occured; and to establish that if the system had been in the Automatic Mode during this time the vessel would have been properly positioned.

9.1 Training of Personnel in Operation Modes

Commencing with the first watch after completion of test 8.3 Emergency Procedures, the following cycle of events will be conducted during each watch, until two (2) days of watch standing has been completed, or personnel have shown sufficient operational proficiency.

9.11 Emergency Operating Performance

- Operation procedure:

  A. Relieve watch with positioning system satisfactorly operating in Automatic-Mode.

  B. On the first watch move to selected site to take a shollow core using the Manual Mode, Semi-Automatic Mode, ending in the Automatic Mode.

  C. During this period operate all drilling equipment possible with the rotary power sub. Keep all tools clear of ocean bottom.

  D. Conduct emergency procedures as described in test 8.3 for one cycle.

  E. Resume normal operations (Automatic Mode) for 2 hours and take a core during this time.

  F. Repeat step D., Emergency Procedures, for one cycle.

  G. Return to reference position if off and maintain position in manual mode until 20 minutes pior to end of watch. At this time resume automatic positioning control.

- Test Stations: Bridge; Computer Room, Derrick Floor.

9.2 Regular Operating Performance

- Operation Procedure: Maintain the vessel in the Automatic Mode, and for the next 24 hours conduct regular coring operations using different drilling assemblies as specified by Scripps. During this period, operate all necessary and stand-by equipment. - Change Rotary Power Sub out for Kelly Drive leaving Ideco double elevator system in place. - Run a deviation survey. - Change back to power sub.
- Test Stations: Bridge; Computer Room; Derrick Floor

9.3 Reliabilty Test

- Test Procedures: Operate positioning system in the Automatic Mode and maintain proper station-keeping for the necessary time to complete five (5) continuous days of satisfactory perfomance. Unless a major system malfunction occurs, the total time will be measured from the time satisfactory operation is obtained in 8.1
- Test Stations: Bridge (TC); Computer Room; Engine Room

Full Ship Positioning System Operation Performance Test Completed:
OK ✓; No_____; Remarks DEBUGGED SYSTEM OVER A 23 DAY PERIOD. LAST 48 HRS WERE OPERATED IN AUTOMATIC MODE WITH VERY MINOR (10'-20') EXCURSIONS. [signature]

/214

NOISE MEASUREMENT TEST DATA

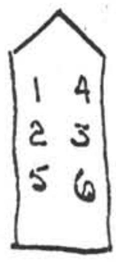
AFTER MODIFICATION OF BOW THRUSTORS
AND ADDITION OF TWO ADDITIONAL HYDROPHONES

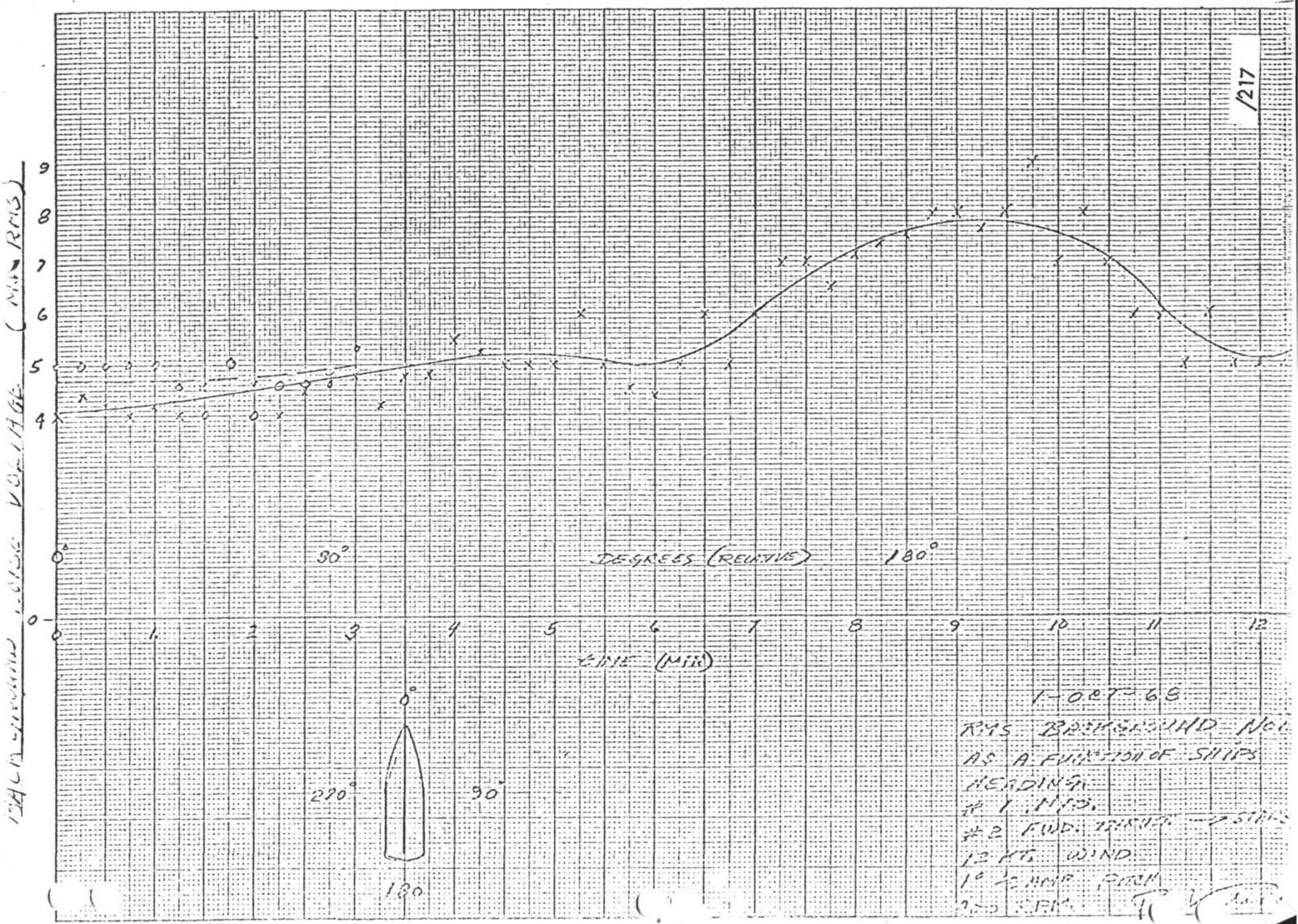
OCTOBER 1, 1968

NOISE TESTS OCT 1, 1968
1300 FATHOMS

THRUSTER	DIRECTION OF THRUST	RPM	HYDROPHONES 1	2	3	4	5	6	REMARKS
AMBIENT			2.7	1.7	2.7	2.5	2.4	2.9	A.C. GEN. ONLY
AFT-BOW #1	STB'D.	500	23	6.0	5.8	40	6.2	4.7	
		540	30	6.0	5.5	27	8.5	5.0	
		550	25	6.2	6.0	35	4.1	4.0	MAX. RPM
AFT-BOW #1	PORT	500	10	3.0	3.0	8.0	3.0	2.8	
		540	9	3.0	4.0	6.0	3.6	5.5	MAX. RPM
FWD BOW #2	STB'D.	500	7.0	3.0	3.2	6.5	3.0	4.5	1ST RUN
		500	5.0	2.6	3.7	7.5	2.8	3.0	REPEAT RUN
		520	4.2	3.5	3.5	7.0	2.2	3.0	MAX RPM.
		520	3.8	2.5	3.0	7.0	2.6	3.0	REPEAT RUN.
FWD BOW #2	PORT	500	12.0	5.0	5.0	16.0	4.2	4.5	
		530	25.0	4.8	5.0	15.0	4.0	5.0	MAX RPM.
STERN FWD #2	STB'D.	500	4.5	4.2	4.8	4.6	4.8	10.0	
		565	5.0	6.0	7.0	4.0	5.5	18.0	MAX RPM
STERN FWD #2	PORT	500	5.0	4.0	5.0	4.2	4.0	4.0	
		560	3.0	2.8	3.0	3.0	4.0	4.5	MAX RPM
STERN AFT #1	STB'D.	500	3.6	3.0	3.6	3.0	3.6	4.0	
		530	3.0	3.6	4.0	2.6	2.8	4.0	MAX RPM
STERN AFT #1	PORT	500	4.8	7.0	7.0	6.0	8.0	8.0	
		550	5.0	5.0	4.8	5.0	6.0	5.0	MAX RPM

PPM SYSTEM GAIN SETTING = 1.0
RDGS. IN MV MEASURED @ B.P. OUTPUT




BACKGROUND NOISE VOLTAGE (MV RMS)
9
8
7
6
5
4
0
1
2
3
4
5
6
7
8
9
10
11
12
TIME (MIN)
0°
90°
DEGREES (RELATIVE)
180°
0°
270°
90°
180
1-OCT-68
RMS BACKGROUND NOI
AS A FUNCTION OF SHIPS
HEADING.
#1. MID.
12 KT. WIND

REPORT ON NOISE DATA TEST MADE

OCTOBER 1, 1968

PETROLEUM CONSULTANTS
ENGINEERING AND GEOLOGY
NIELS ESPERSON BUILDING
HOUSTON, TEXAS 77002

October 31, 1968

National Science Foundation
Deep Sea Drilling Project
Scripps Institution of Oceanography
La Jolla, California 92037

Attention: Mr. A. R. McLerran

Dear Arch:

I have reviewed the data from the noise tests performed October 1, 1968. However, before making any conclusive statements with respect to the results of these tests, I would like to point out several factors that must be qualified before any absolute conclusions can be made.

It should be appreciated that if the sensitivity of the hydrophones is changed then the value of the noise measurements will be changed accordingly, but the signal-to-noise ratio which is the crucial factor does not change. Therefore, since no measurements have been supplied to determine these sensitivities, it must be assumed that the hydrophone sensitivities did not change. This, I feel is a reasonable assumption unless some physical changes were made on the hydrophone and baffle assemblies.

Also, in evaluating the behavior of the new hydrophones, this same consideration must be made; that is, it must be assumed that the sensitivities of the two (2) new hydrophones are approximately the same as the four (4) original ones. This also is a reasonable assumption since I have examined copies of the recorded sensitivities of these 6 hydrophone assemblies and they all show fairly close agreement. These were made, incidentally, during the Mohole Program. Therefore, under the assumption that (a) the hydrophone sensitivities have not changed since the noise measurements taken in August and (b) the two (2) new hydrophones have approximately the same sensitivities as the previously installed hydrophones, the following conclusions can be drawn.

1. The noise level measurements were reasonably consistent, that is, the same general trend was obtained between hydrophones for essentially similar conditions. See Figs. 1 & 2.

2. The general trend is essentially similar to the measurements made previously - August 11, 1968. See Figs. 1 & 2.

3. The variations in repeat runs were considered and the recorded differences fall within the statistical variation one would expect in making measurements of random signals under these conditions.

4. The noise input to the two new hydrophones (nos. 5 & 6) appeared to be in the proper relationship to the other four. For example, the noise level measured on these hydrophones due to the bow thrusters is approximately the same as hydrophones 2 and 3. While theoretically they should be less, the ambient noise level is significant for the low signal levels and as mentioned previously, the variation due to the randomness of the input signal is large enough to mask out the slight difference in level that would be expected. Noise levels due to the stern thrusters have the proper relationship with respect to the new hydrophones. See Figs. 1 & 2.

5. Considering the possible variations in making these noise measurements, the noise levels obtained on these tests are generally less than those made in August, considering comparable RPM's.

6. It is rather obvious that a significant improvement in the signal-to-noise ratio for positioning information can be obtained by using hydrophone array 2, 3, 5, and 6.

I have looked over the background noise data accompanying the hydrophone measurements and I am unable to draw any definite conclusions as to the significance of this data and its possible effect. It does indicate that the ambient or background noise was not omnidirectional and that the hydrophones are not omnidirectional in a horizontal plane. It appears reasonable to assume that most of the background noise resulted from surface action and consequently was probably related to the wind and wave direction. This might account for the apparent directivity of the ambient noise. Also, it would be reasonable to assume that most of the noise was being received by the hydrophones from angles near the horizontal and with the hydrophones being partially recessed into the hull, they would not be omnidirectional in a horizontal plane for these receiving angles. However, since most of the beacon energy comes from angles close to vertical, this horizontal directivity should not present any serious

PETROLEUM CONSULTANTS
HOUSTON 2, TEXAS

problem. However, it is worth considering that the surface noise received by the hydrophones could possibly be reduced by selecting a particular ships heading, unless of course this requires the vessel to be broadside to the forces. This fact is impossible to determine from the accompanying data since the direction of the wind and waves is not indicated.

Sincerely,

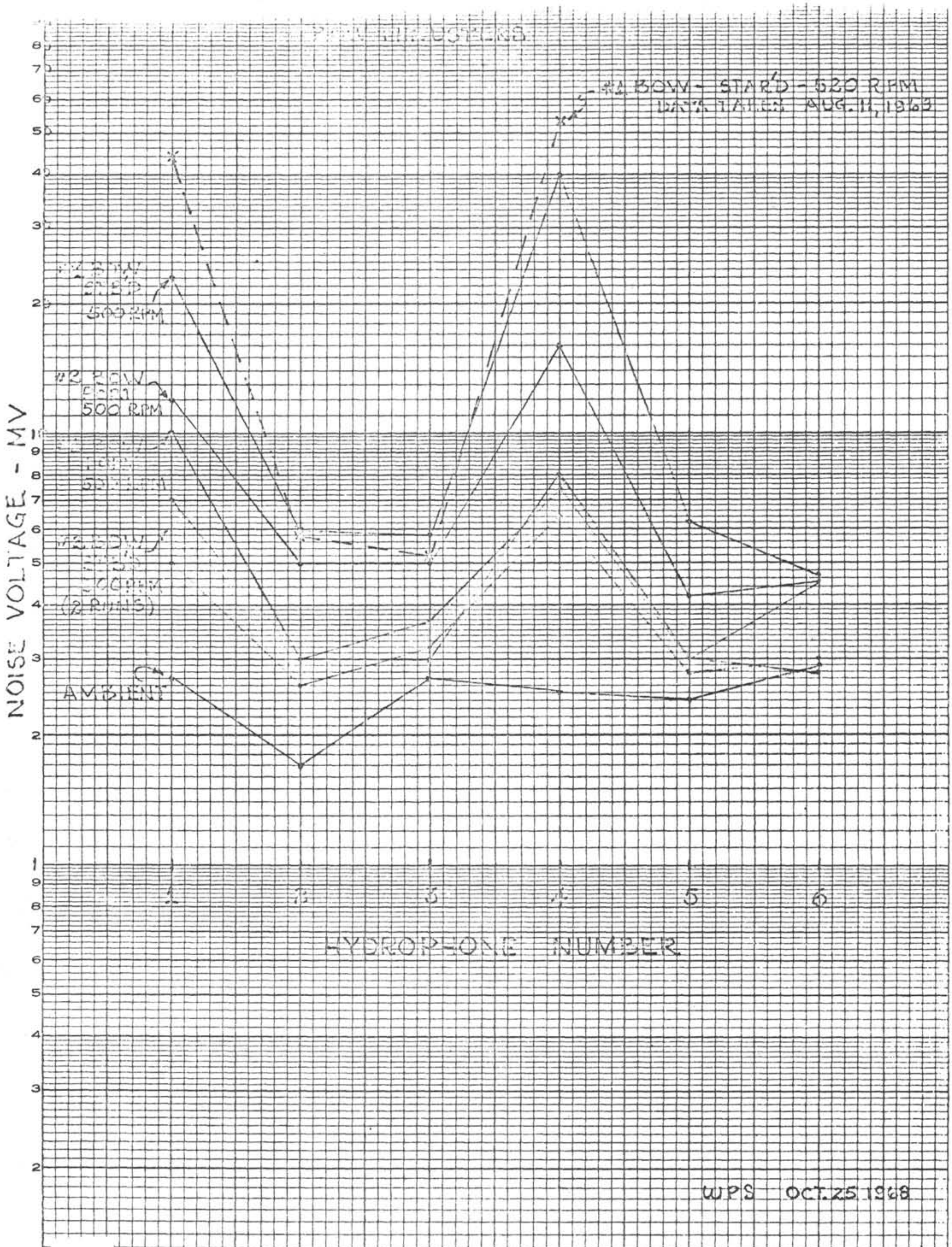
PETROLEUM CONSULTANTS

William P. Schneider

William P. Schneider

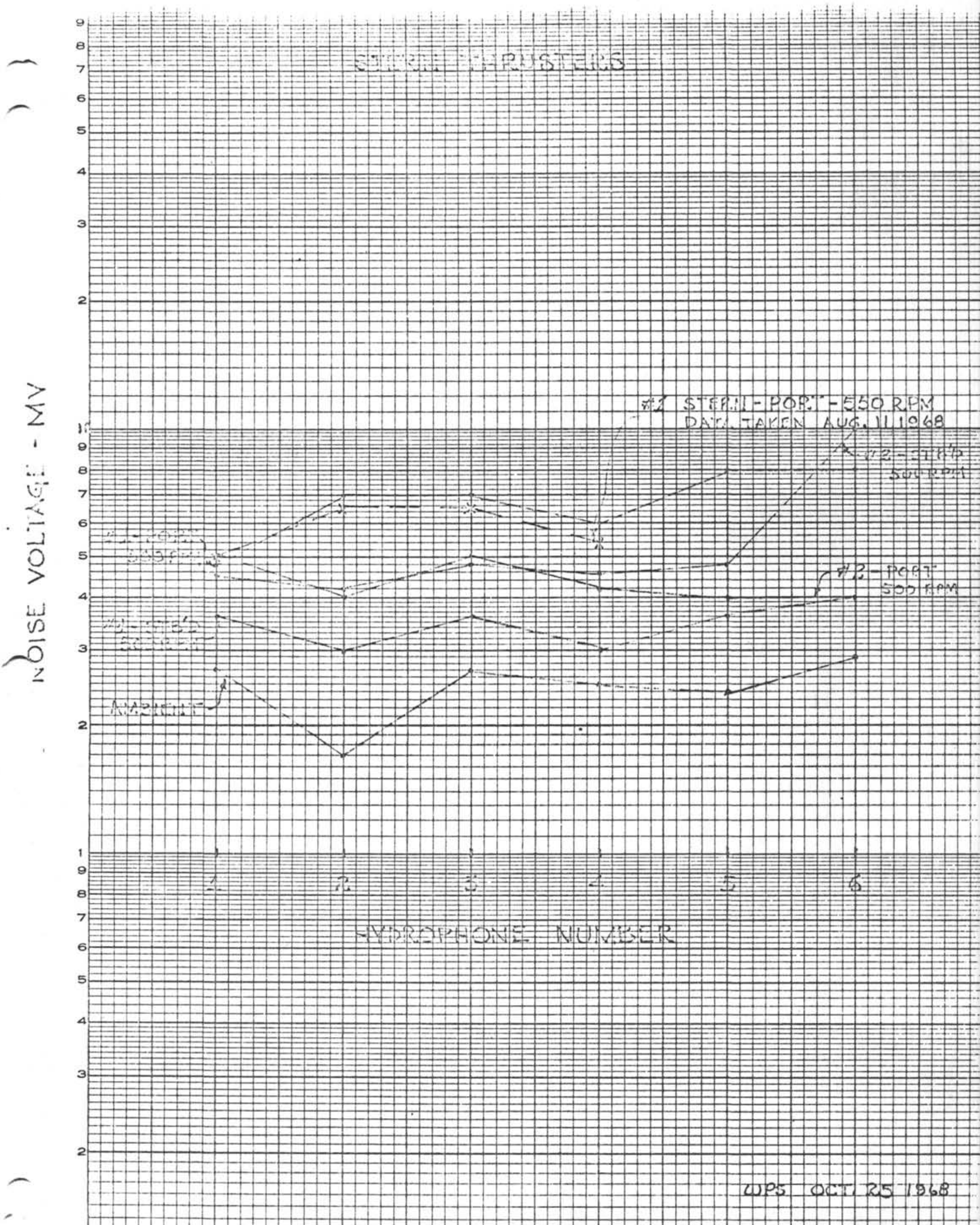
WPS/jd

Enc.


#1 BOW - STAR'D - 520 R.P.M.
500 RPM
#2 BOW
500 RPM
AMBIENT
NOISE VOLTAGE - MV
HYDROPHONE NUMBER
1
2
3
4
5
6
WPS OCT. 25 1968

/222

FIG. 1



STERN THRUSTERS
#1 STERN - PORT - 550 RPM
DATA TAKEN AUG. 11 1968
#2 - STB'D
500 RPM
#2 - PORT
500 RPM
AMBIENT
1
2
3
4
5
6
HYDROPHONE NUMBER
NOISE VOLTAGE - MV
WPS OCT. 25 1968

FIG. 2

BIBLIOGRAPHY

1. Experimental Drilling in Deep Water at La Jolla and Guadalupe Sites. NAS NRC-914.

2. Stage A Report, Vessel Positioning System. NSF Contract C-260.

3. Cruise Operations Manager's Resumes, Legs 1 through 18.

4. Global Marine Inc., daily drilling reports.

5. Global Marine Inc., daily deck reports.

6. Global Marine Inc., Subcontract.

7. Deep Sea Drilling Project, press releases.

8. Global Marine Inc., press releases.

9. ACDRL, press releases.

10. Test Report ACDRL. Results of an experiment to measure phase characteristics of the Mohole-type hydrophones at frequencies centered around 10 kHz.

11. Transdec Report No. 5984. Calibration of PCS Hydrophones.

12. Operation and Maintenance Manual for the SBS Position Measuring System. General Motors Corporation.

13. Honeywell Aerospace and Defense Group. A Technical Manual for Vessel Positioning System.

14. Honeywell - Proposal for Phase-Computer Improvement and Provision of Re-entry Mode Capability for PCS Positioning Reference System Aboard Glomar Challenger. Document J39-69.

15. Honeywell - Proposal - Deep Ocean Automatic Station-Keeping Equipment for the Deep Sea Drilling Project (DSDP) Positioning System. Document W23 - 1/67.

16. A Proposal for Deep-Ocean Automatic Station Keeping Equipment for the Deep Sea Drilling Project (DSDP) Positioning System. (all bidders).

17. Honeywell Acoustic Position Reference System Document 1812.

18. The Meaning of Error in a Short Base Underwater Navigation System. Frank A. Andrews.

19. Operating Specifications and Requirements for Position Keeping for the Mission Capistrano. H.C. Beck. Tag 162. Columbia University Hudson Lab.

20. Mission Capistrano Position-Keeping System Primary Evaluation. B.B. Adams. Tech. Memo. #81. Columbia University Hudson Lab.