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UNIVERSITY OF CALIFORNIA, SAN DIEGO
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Principal Investigator
ADVANCED OCEAN ENGINEERING LABORATORY

Technical Progress Report

June 30, 1972

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13 ABSTRACT

This semi-annual report reflects the technical status of projects conducted within the Advanced Ocean Engineering Laboratory at the Scripps Institution of Oceanography. These projects are: (1) Stable Floating Platform - to conceive, design, build and demonstrate the feasibility of large stable floating platforms in the open sea. (2) Benthic Array - a program to develop and construct a quartz vertical accelerometer appropriately packaged and adapted for long term ocean bottom or perhaps sub-bottom use. (3) Advanced Studies in Nearshore Engineering - field studies of the water-sediment interface under wave action in and near the breaker zone, and laboratory investigation of the velocity field of breaking waves. (4) Electromagnetic Roughness of the Ocean Surface - utilization of radio signals scattered from the sea surface to determine the directional spectrum of ocean waves. ~~(5) Wave Breaking In Deep Water~~ - a projected two-year laboratory and field investigation of the factors controlling the breaking of mixed-frequency wave systems in deep water.

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Vibrotron-type pressure guages						
Three component accelerometer						
Acoustic wave measuring probe						
Radio telemetering float						
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Concrete structure						
Catamaran configuration						
Multiple-legged platform						
Barge-like structure						
FLIP						
Benthic Array						
Acoustic Command and Control System						
Capsule						
RUM						
DANA						
Seismic recording						
Data Logging System						
Nearshore Engineering						
Control of sand transport						
"Phase dependent roughness elements"						
Crater-sink sand transfer system						
Flow visualization procedures						
Vortex ripple interaction problem						
Electromagnetic Roughness of the Ocean Surface						
HF radio waves						
Doppler spectrum						
Bistatic geometry						
Monostatic geometry						
Bragg scatter						
LORAN						
Multifrequency Radar						
Wave Breaking in Deep Water						
Mixed-frequency wave system						
Wind-wave channel						
Digital wave staffs						
Orthogonal Array						

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Advanced Ocean Engineering Laboratory

TECHNICAL PROGRESS REPORT

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STABLE FLOATING PLATFORM

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Part I

STABLE FLOATING PLATFORM

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I. Project Summary

During the six months ending June 30, 1972 the SIO Stable Floating Platform program has moved along four distinct but closely related lines. The major effort has been to produce a specific, operationally satisfactory concept and general design for coupling two modules together at sea. Second has been the buildup of an instrumentation suit to support the eighth scale at-sea measurement program (to measure non-linear aspects of response, intermodular forces, coupling dynamics and slamming due to loading from very large waves). The third line originated with the receipt of the report of the review panel chaired by Tachmindji. This (in addition to points covered in items one and two above) raised a number of specific questions which are in the process of being answered. The fourth portion of the work has been on the development of a general concept for very large platforms and the relating of that concept to smaller components which might be buildable and useful in more immediate contexts.

II. Coupling

Early in the year decisions were made to shift our coupling design from one which only joined the tops of the modules and which left some degrees of freedom unconstrained over to one which would lock up all degrees of freedom and which would connect the modules at both top and bottom. These decisions were based on consideration of the possible needs of very large platforms in which it would be necessary to couple many modules together. Furthermore, it seemed attractive to explore the possibility of making initial connections deep in the water, where the relative motions of the two modules would be substantially less than at the top.

The approach taken was to design and test a coupling system to join two of our 1/8th scale, catamaran modules. While no attempt was made to consider the 1/8th scale coupling system as a detailed model of the full scale system the configuration was developed with an eye on its plausible scalability. The full scale design will be adapted from the 1/8th scale work upon its completion.

The basic scheme is shown in Figure 1. While the modules are in the horizontal attitude lines are rigged on module one from the living space out along the leg, through the hub of the rubber-tire cushioned coupling fitting and back to the living space. Two similar lines are rigged through the receivers on module two.

The modules are flipped to the vertical, platforms locked, and put in proper relative positions by the tending craft. With between one and two module length separation the outer ends of the lines are passed across and joined. The bitter ends of the lines on module one are fixed while on module two the slack is taken out and the lines secured to hand operated winches. The lines are then hauled in to pull the bottoms of the modules together. Although usual procedure is to keep the two units approximately square to one another it is not essential that both coupling units engage simultaneously. Ball joints just in back of each cushioned male fitting allow flexibility of alignment. Once both bottom fittings have been securely engaged a single fitting at deck level is coupled in and all degrees of freedom are constrained.

Initial trials of this technique have been carried out in the calm water of San Vicente reservoir near San Diego. These disclosed minor difficulties which have been remedied but primarily they demonstrated that this coupling technique is operationally feasible. Tests are scheduled to be conducted in the ocean off Coronado (San Diego) early in July to confirm operational feasibility in rough water conditions. The supporting structure, in addition to being designed with an eye toward scalability, is arranged in such a way that load cells can be inserted to allow measurement of coupling forces for comparison with calculated values during further tests to be conducted in early fall.

III. Instrumentation Development

Present schedules call for full tests this fall of the two module catamaran configuration as well as other geometries yet to be developed. These tests will be carried out with an instrumentation suit which will allow recording of six force components in the connecting struts, the motions of the vehicle (single and coupled modules) and the sea state at the time. These will be done to evaluate the validity of the force and motion calculations, forces during coupling (load cells will give continuous readings of joining line tensions) and forces during loading by large waves (which would interact with the upper portions of the platform).

The instrumentation system now under procurement is designed to provide basic capability for measurements on a full scale platform as well as 1/8th scale. It will utilize a PDP 8 computer as the data logging and processing unit, with appropriate analog to digital conversion of the necessary signals. This will allow us to do the first level data processing while data collection is in process, inserting calibration factors and making conversions to correct for geometric effects. The same computer will be able to produce power spectra and cross spectra immediately after conclusion of data collection runs.

Sensing elements will include eight load cells to measure forces between modules. Three will be inserted in the struts of one of the lower coupling units to measure tension-compression and two lateral force components. Two units will be inserted in the second deep strut assembly (one tension-compression and one lateral component). One unit will also be inserted in the single rod topside coupling and one attached to each of the hauling-in lines.

Platform motions will be measured using a three component accelerometer package placed in the upper portion of one module, with Vibrotron-type pressure gauges suspended below the units to measure their vertical displacements. An acoustic wave measuring probe will measure relative motion between platforms and sea surface while a small wave-following, radio telemetering float will provide independent wave height data.

At this time the acceleration package (instruments from FLIP studies) and the wave measuring float are in hand and the other elements of the system are on order for delivery and checkout during August.

IV. Review Report Questions

The review of last December raised a number of specific questions which are in the process of being answered. Mr. George Morgan, consulting engineer, is attacking two of these. One is the assembly of comparison information relating to floating platforms of the semi-submersible type which have been built by various offshore drilling companies. Emphasis will be on cost data and information relating to mobility and dynamic response to the waves. He is also assembling data taken in model tests of a multiple legged structure (Armstrong Seadrome test program of 1945-46) and analyzing it in relation to an appropriate computer model. These studies are progressing well and should be completed during July.

Two matters relating to concrete structures were raised. One of these is the question of water absorption in the types of expanded aggregate concrete which was the material proposed for the cylindrical legs. Specifications for the concrete mix and curing have been written and samples are being prepared from aggregate which would be used in three different geographic areas. Upon completion of sample fabrication the U. S. Navy Civil Engineering Laboratory will conduct the absorption tests. The other point relative to concrete design was the detailed analysis of key parts of the structure. Particularly important in the design as it existed at the time was the connection between each longitudinal hull and the large bridging cross-tube. A careful analysis has been made, although not in fine detail. It was realized that the principal difficulty lay, not in setting up the finite element analysis formalism (out concrete engineering consultants - Skilling, Helle, Christiansen, Robertson, already had the necessary computer programs), but in knowing what the loads should properly be. Load calculations, done for us by Alaa Mansour of Massachusetts Institute of Technology had given results based on extrapolations from model studies done in connection with design of the AGOR Hayes. It was determined that these might be significantly improved by carrying out model work on the catamaran-FLIP configuration at a large enough scale to allow valid force measurements. All of the problems in this case stem from loadings while the unit is in the horizontal mode;

thus this model work, although it might contribute usefully to the catamaran literature, was deemed to be too costly (cost estimates were obtained from three model basins) considering that the current concept (see below) does not utilize the catamaran configuration.

V. Concept Development

A major goal of the current year's effort is to give consideration to the problems of building very large stable platforms and within this framework to isolate some aspect which, if built at full scale, would contribute to technological advance and be a generally useful structure. If one focusses on large, column stabilized, platforms a number of problems appear. Most important, the large platform clearly will have to be assembled at sea from some component structures, thus we have concentrated significant effort on solution of the coupling problem in the 1/8th scale program.

The concrete catamaran configuration forces a number of compromises for reasons which are not truly relevant to the basic program goals. The legs are not far enough apart to be typical of some average leg spacing. The need to prevent the ship from breaking while horizontal in the seaway forced development of cumbersome details, some of which forced sacrifice of dynamic stability in the vertical. The use of concrete restricted weight distribution to the point at which it was difficult to achieve a safe air gap while in the vertical and prevented carrying some of the research payload which would have been desirable. Moreover, a number of risk areas (particularly the catamaran configuration, as noted above) were introduced which did not relate to the large platform problem.

Earlier consideration, however, had indicated that probably it was unlikely that any single module type would be found which could serve usefully in all contexts. It is not surprising, therefore, that the configuration now under consideration should combine two different types of units. Two aspects of the problem of assembling a multiple-legged platform are the logistic one of transporting many large spars to the working area and the structural one of wasting material (at least in terms of the final assembled structure) on providing structural strength so that the legs would not break while floating horizontal in the seaway or when flipping from horizontal to vertical. These problems and a number of other related considerations have led us to investigate the possibilities inherent in building a flippable barge-like structure which could carry a large number of individual legs to the area at good speed and flip with them to the vertical as the first step toward platform assembly. Studies of this concept are now underway starting from consideration of a simple ocean going barge design. This barge (built to transport pipe from Japan to Alaska for the Tramo-Alaska pipeline) has the stability and weight-handling capability to carry twelve FLIPS (900 tons, 20 ft. diameter each) while under tow at 8 to 9 knots with an ordinary ocean-going tug (3400 H.P.). Overall dimensions are quite similar to the envelope of the catamaran-FLIP (340 ft. long, 100 ft. beam, 15 ft. draft) already studied, thus much of the previous design data would continue to be applicable. It now appears quite feasible to produce a key element in the large platform complex, which can also be a very useful vehicle (in vertical or horizontal). Delineation of the configuration of this craft and its related satellite spar modules will be a major aspect of the program for the remainder of the current year.

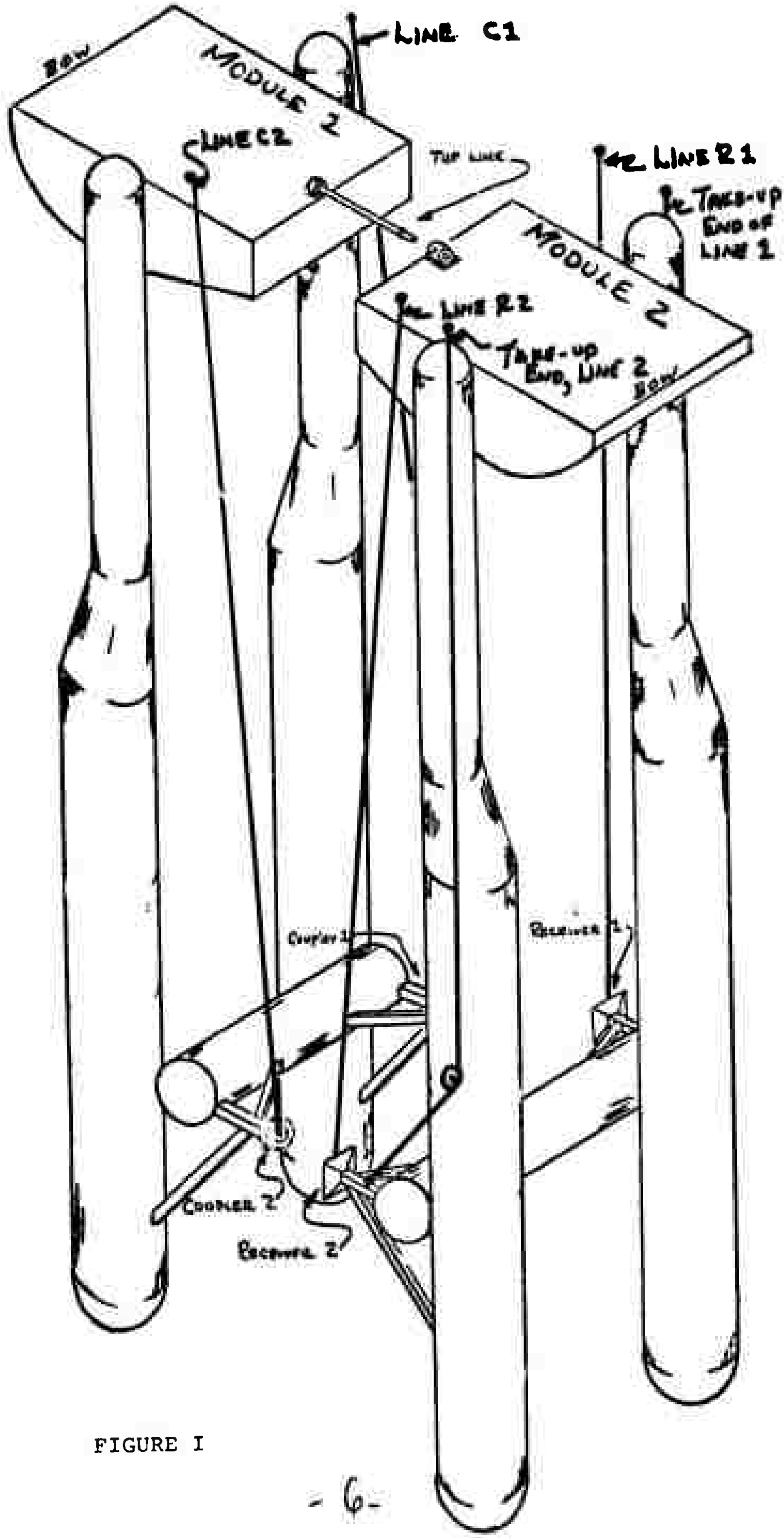
LINE C1
BOW
MODULE 1
LINE C2
TOP LINE
LINE R1
TAKE-UP END OF LINE 1
MODULE 2
LINE R2
TAKE-UP END, LINE 2
BOW
COUPLER 1
RECEIVER 1
COUPLER 2
RECEIVER 2

FIGURE I

Part II

BENTHIC ARRAY

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Part II

BENTHIC ARRAY

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Appendix I

Results of The First Ocean Test of The Ocean-Bottom Block-Moore Accelerometer Package

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I. SUMMARY

The work for the last six months has been to deploy the package in 4,000 feet of water near San Clemente Island and evaluate and modify the package in preparation for further ocean testing this summer.

II. TECHNICAL REPORT

The first ocean test was carried out with the help of Dr. Frank Snodgrass of the IGPP tide capsule group. Appendix I describes the test results and problems. The system performed extremely well for a first test. The main problem area was the acoustic system. Also a miswiring of the explosive cable cutters prevented a normal release and the instrument was retrieved by the line to the surface buoy. Detailed instrument checkout and calibration lists have been prepared which will insure proper release connections, so miswiring will not occur in the future.

Some of the system changes and additions which are being made for the next ocean test are as follows:

1. All sonar diagnostics are transmitted with one command.

2. All slow diagnostics are transmitted with one command.

3. An automatic accelerometer rezeroing circuit has been added.

4. Automatic release for leaks to sea water does not activate until a puddle 1/8 inch deep occurs in the capsule. A leak alert code is initiated as each drop of sea water passes over the leak detector conducting strips, however.

5. Extensive instrument check lists have been complied.

Changes 1 and 2 have been made to reduce the number of commands that must be initiated to get full diagnostic information. For one month deployments the accelerometer could go off-scale due to instrument drift or package settling, so some provision for automatic rezeroing must be made. A great deal of thought has been given to the sea water leak problem. During the last test where the package was down for four days, six to eight drops of water did enter the top flotation hemisphere during the third or fourth day. If the releases would have been wired correctly, a package release would have occurred. A normal deployment as anticipated in the future would include the drop plus a full day of acoustic monitoring to make sure the package is operating properly. An automatic release without the ship nearby could result in the loss of the package. Certainly, a severe leak could also result in loss, but a one or two drop per day leak could be tolerated for a month. If a 1/8 inch deep puddle occurs in the package, it then releases automatically because we believe that the package is better off lost on the surfact then lost on the bottom. We also expect almost all leaks to show up within the first hour when the capsule is still tethered and could be recovered even in the event of catastrophic flooding. Another safety check is that we require the pressure housings to hold vacuum at the surface, so except for a catastrophic connector failure, which we hope will never happen, leaks which do occur should be extremely small ones.

III. PLANS

1. June 9 - July 9; Vault testing of capsule. Cross-correlation with conventional instrument to determine instrumental noise levels.

2. July 24-25; tethered test of sonar and release, operational test of capsule systems, depth = 5000 ft.

3. August 7-?; one month untethered deployment. Observe emplantment using cabled sumersible RUM (no cost to us), determine bottom conditions using RUM, look for anomalous tilts due to ocean currents.

4. January; deep ocean test off California continental shelf. This is close enough to make logistics simple, yet provide a deep sea test. A desirable option here is to associate ourselves closely with DANA in some feasible fashion. Measure buoy-induced bottom noise (mooring line tension and acoustically coupled generator noise).

5. Spring or early summer; have the option of a North Pacific capsule deployment or make further buoy associated tests.

To date, progress with the instrument looks extremely hopeful. We have a well-engineered and sophisticated instrument that can be a basis for future developments. A major outgrowth of this work will be a determination of the need, or lack thereof, for instruments of this complexity. Some factors will be cost, capsule loss rates, deployments costs, bottom soil conditions, bottom noise levels, and type of information desired. A particularly important improvement in this instrument would be a considerable reduction in size and weight. Future designs will give considerable emphasis to this requirement. The new seismic knowledge that ocean bottom seismic recording will provide is extremely important for a complete understanding of the earth. Work on oceanic structure, seismicity, oceanic earthquake mechanisms, and lateral variations in the mantle will be aided immensely by these measurements. The present instrument work is an important step in these studies.

APPENDIX I

RESULTS OF THE FIRST OCEAN TEST OF THE OCEAN-BOTTOM BLOCK-MOORE ACCELEROMETER PACKAGE

The test occurred in 4,020 feet of water on the east side of San Clemente Island. The capsule was deployed Monday, March 13, 1972 and recovered Friday, March 17. The weather was excellent and the seas were glassy smooth the entire time. The entire capsule was tested, including the EDO acoustic command and control system, the digital capsule diagnostics, the accelerometer and tiltmeter and their associated electronics, the data logging system and the explosive releases. A line to a surface buoy was connected to the capsule in the event that the release failed. The gain of the accelermeter was 40 db lower than its intended operating value so that the accelerometer would stay on scale when the buoy pulled on it. The surface buoy will not be connected except for early tests where the release system is not yet trusted. The overall system performance was quite good for a first deployment.

Troubles occurred with the acoustic command system. A misconnection to the explosive cable cutters prevented a release of the package as intended and recovery was made with the line to the surface. The rest of the system worked perfectly and a number of possible improvements became apparent during the test. A detailed description and evaluation of the performance of each capsule subsystem follows.

The Acoustic Command and Control System

The acoustic system was purchased from EDO Western Corporation and arrived approximately ten days before the capsule was to be deployed. The system initiates a command from the surface by first sending a 30 millisecond pulse and responds by sending a 10 ms pulse at 13.5 khz. A command from the surface is then transmitted after a one second delay by a .5 second burst of 2 ms pulses of the 9.25 khz acoustical energy. The pulse rate is detected at the bottom and tuned filters select the proper command. During the one second delay which occurs between the 30 msec transpond pulse and the command burst, the bottom unit will disable the decode function if a command is received. Thus, the proper timing between the transpond pulse and command burst must be maintained or the system assumes that extraneous noise is the cause and will not accept the command.

During the test we found the system extremely difficult to command. A transpond could be initiated from greater than 6,000 feet horizontal distance but commands could only be initiated from certain locations. The best location seemed to be .3 miles east of the buoy on Thursday and Friday and south of the buoy on Monday and Tuesday. The transpond pulse travel time indicated that these locations were not over the capsule. At certain times, we were not able to command the capsule at all. We found that commands with higher burst frequencies could get through when others could not. Thus, the command range was considerably less than the transpond range. Also, spurious transpond pulses at 1.4 sec and 1.9 sec occurred consistently. We thought these transpond pulses were responses to echoes of the command signals. Later, after the capsule was recovered, we found that this behavior could be caused by increasing the command signal level above some threshold value. Apparently, the receiver can be easily overdriven and will then disregard the command signal. On the ship, the transmitter power was increased until the first transpond reply was heard from the capsule. At that level, commands still could not be initiated. A very slightly higher power setting would cause the echo behavior. Apparently some of the commands were initiated by true command echos though. I believe that this behavior is related to the difficulty in commanding the unit and that it will have to be modified to accept a wider range of input power levels.

Another possible problem was noted when the source level of the bottom projector hydrophone was measured. At the closest range of 1,340 yards, we measured a peak-to-peak amplitude of 5 microbars at the surface. The surface hydrophone and receiver combination had a gain of 0 db relative to one volt per microbar (receiver gain = 6). Correcting for spreading (63 db) and attenuation (4 db) at 13.5 khz, we have

$$L_s = 0 \text{ db} + 63 \text{ db} + 4 \text{ db} + 5 \text{ db} = 72 \text{ db re 1 ubar at 1 yd.}$$

The EDO specifications claim a source level of 86 db re 1 ubar at 1 yd., so there is a discrepancy here. In the unusually quiet sea, we measured -26 db re 1 ubar of acoustic noise over the 3 khz bandwidth of the receiver. This gives us a 31 db signal-to-noise ratio under these conditions. A sea-state of 1/2 and a bandwidth of 3 khz gives an ambient noist level of -33 db according to the EDO Sonar and Transducer Computer. A directivity index of 6 db lowers this to -39 db. It appears that the increased noise we measure is due to the proximity of the ship. There is probably a constant factor due to ship's generators, etc., and a factor which scales with sea state because of ship's roll, waves breaking against the ship and the usual sea state noise. In fact, one day the sea was rather choppy and small waves (6 to 10 inches high) were breaking but no increase in output noise was observed. Under deep ocean operating conditions, the water depth may be 18,000 feet. The minimum horizontal distance from the capsule which signals must be received from is 18,000 feet. So the range, attenuation and directivity of the hydrophones (45° angle) decrease the signal from bottom to surface by 53 db relative to that measured on our test directly over the package (spreading loss = 79 db, atten, = 23 db, beam pattern loss at 45° = 18 db). At present power level for comparable acoustical noise levels, our signal to noise becomes -22 db. If we assume that all the acoustical noise was from the ship and it doesn't scale with sea state, we achieve a signal to noise of one for a bottom unit source level of 94 db. This fits with the experience of Frank Snodgrass with his deep sea tide capsules, where he finds that the 94 db source level from his bottom projector hydrophones is barely adequate. Thus, it appears that the source level of our bottom acoustical projector will have to be raised to 94 db.

Another portion of the acoustic system is the digital diagnostic transmission. Transmission occurs by encoding 13.5 khz and 15.5 khz as zero and one logic levels. The surface receiver output is passed into a discriminator where output voltage is proportional to frequency. EDO uses a standard Airpax linear discriminator, which proved to be unsutiable for this purpose. First, the 3 khz bandwidth is much larger than necessary since we transmit data at 100 bits per second at only two discrete frequencies. In practice, the discriminator did not work well at signal-to-noise ratios below 10:1 and we got great improvement by lashing up tuned amlifier that detected ones and assumed that no signal out was a zero. Ideally, the discriminator shoudl consist of two tuned amplifiers at 13.5 khz and 15.5 khz whose outputs are rectified and subtracted. We plan on making this modification ourselves.

In spite of the discriminator problems, it was possible to get good diagnostics using this scheme. As the slant angle increased, we had some evidence of deterioration due to multipath effects, but when we were almost directly over the package, the transmission and decoding worked beautifully. I am very pleased that this has proven to be straight-forward as it makes diagnostic acquistion extremely simple. It also contributes to our experience in transmitting digital data by means of sonar in the event that it becomes desirable to recover actual data this way.

The Data Logging System

There were no problems with the data logging system. The data plots shown in the figures indicate that real data was recorded. There were no parity errors except where a start logger command was given. This causes the logger to write a record gap without the usual parity bit at the end, so this is expected.

The Acceleration, Tilt Sensors and Analog Electronics

The figures show the six data channels as recorded by the logging system. The two tiltmeter channels and the accelerometer show a 12 hour periodicity that is undoubtedly due to the buoy and line pulling at the instrument at different angles because of ocean currents driven by tides. Leveling and zeroing operations are shown on the figures. Both the recorded data and the diagnostics indicate that the accelerometer, tiltmeter, leveling system, electronics and temperature sensors are working perfectly. The GRAV-TEMP sensor was off-scale, so no data was obtained on the accelerometer temperature regulation. However, it can be inferred from the TIDE output that the regulation could not be worse than .02°C. This is not a very useful upper limit. For the next deployment, we will probably turn down the gain on this monitor to insure that it stays on scale.

The accelerometer gain was down 40 db from its intended operating value. This was a wise choice, in retrospect, as signals from the buoy would have been too large at higher gain settings.

The accelerometer seems to work fine and IGPP vault tests indicate that its intrinsic performance is excellent (ref. A.O.E.L. Report #26). I will be quite interested to see how it operates on the ocean bottom without a surface buoy attached. The next test will be directed toward this end.

Performance of the Parts Exposed to Sea Water

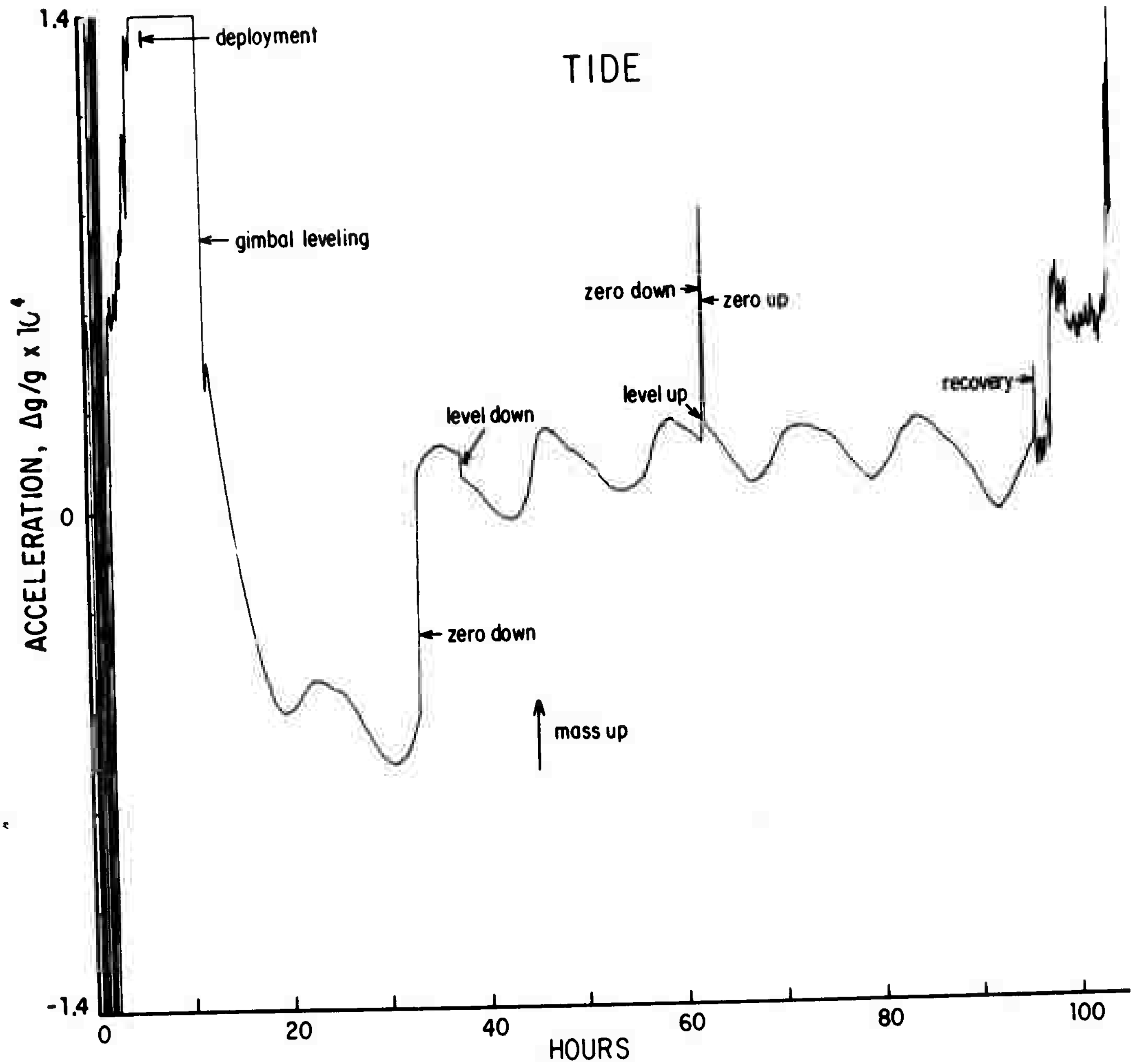
No apparent significant corrosive action was observed on the pressure housings, releases or aluminum structural members during the four day deployment. Some of the galvanized bolts were slightly corroded and will not be used in critical areas for longer drops.

The package was evacuated to 5 psi prior to loading it on the ship and no water leaks occured at depth. Connectors, cabling and batteries functioned properly. Unfortunately, a misconnection to both explosive cable cutters prevented a normal release and the package was retrieved with the line to the surface. Upon examination, we found a defect in the vulcanizing of the leads to one of the cutters, causing a 3,000 ohm resistive leak. This kind of defect will not cause a failure unless the wires corrode through. The double firing circuits lessen the chance of this happening. A different kind of connector will be used in the future to make misconnection difficult. Also, the release checklist will include an item necessitating a continuity check through the cables actually used.

Internal Mechanical Structure

There were no mechanical failures inside the package. The gimbal clamping motors and leveling and zeroing motors worked perfectly. As shown by the data, the gimbal system levelled the accelerometer to better than 3×10^{-4} radians (.017 degrees), which is quite adequate for our purposes.

Ship's vibrations caused some electronics mounting bolts to be loosened and several actually dropped out. This could cause problems if they fall to the bottom and actuate the leak detector, causing a false release. This will be remedied by using castle nuts wherever possible and Lock-tite elsewhere. Also, the leak detector (parallel foil strips which become resistively coupled by the conductive water drops) will be protected so that any bolt or nut that might come loose cannot cause a leak indication. The accelerometer, gimbal and leveling motors showed no ill effects from the rough handling and ship vibration. Vibration isolation mounting pads will be constructed for package transportation in the future.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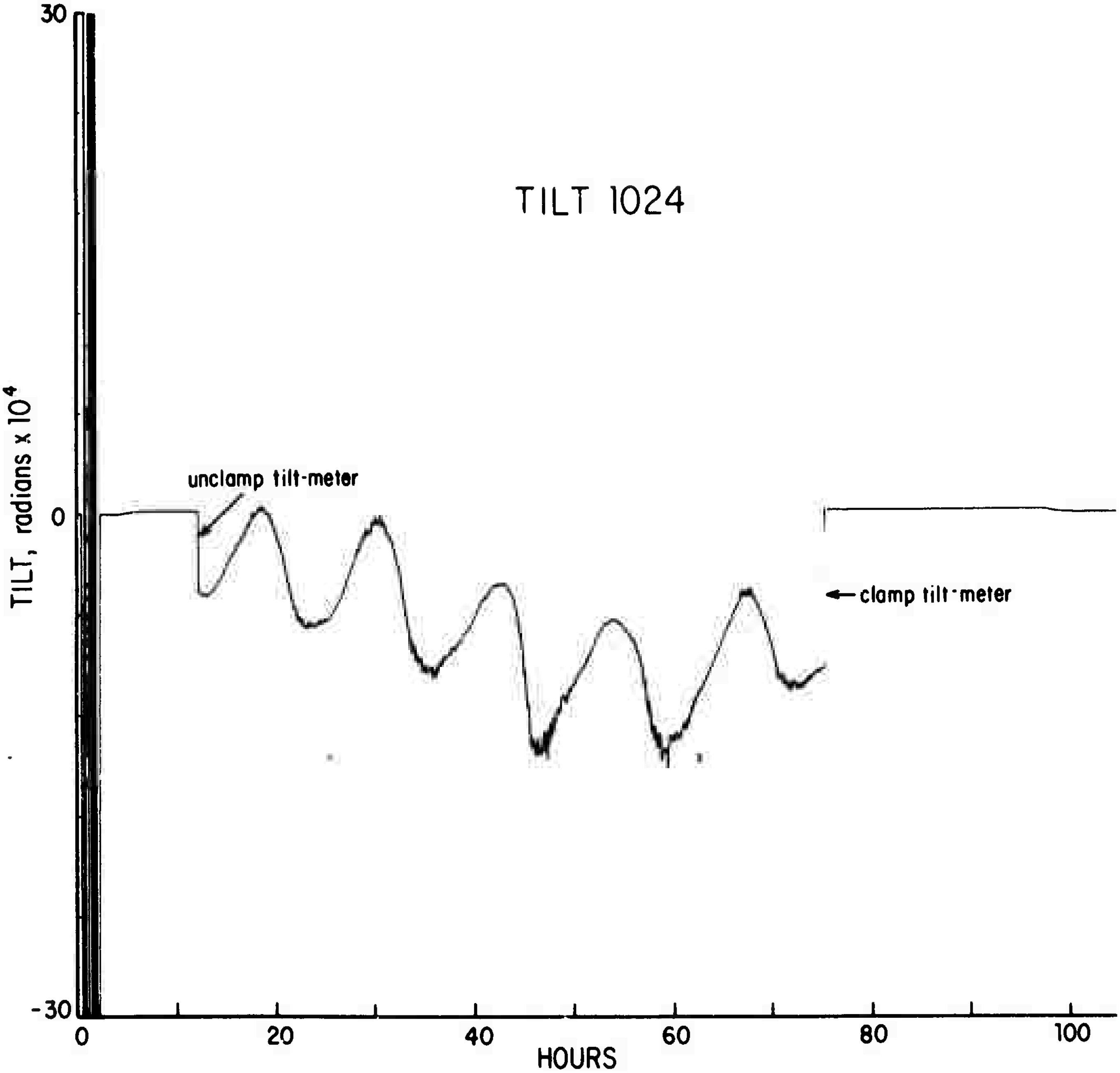
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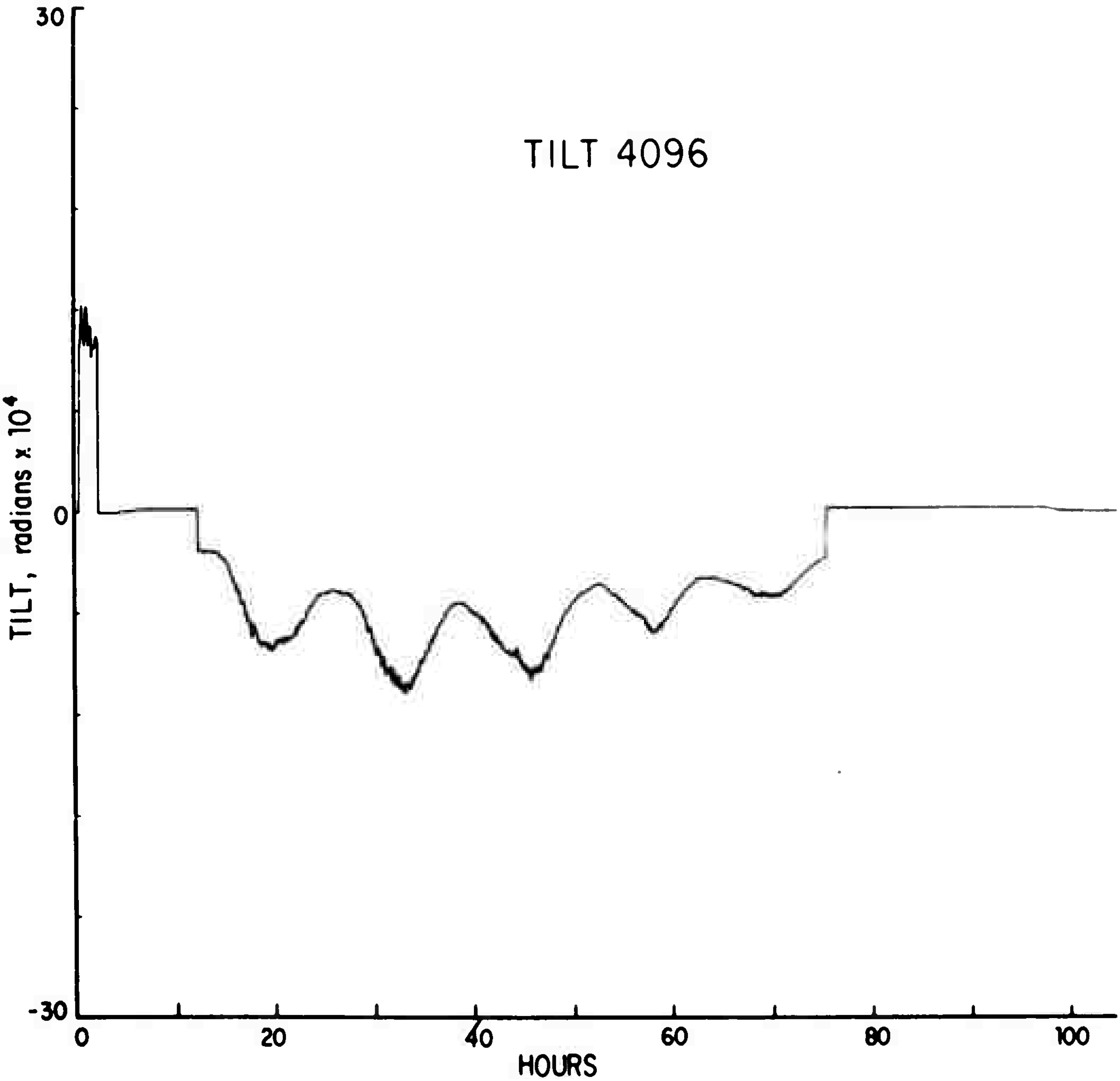
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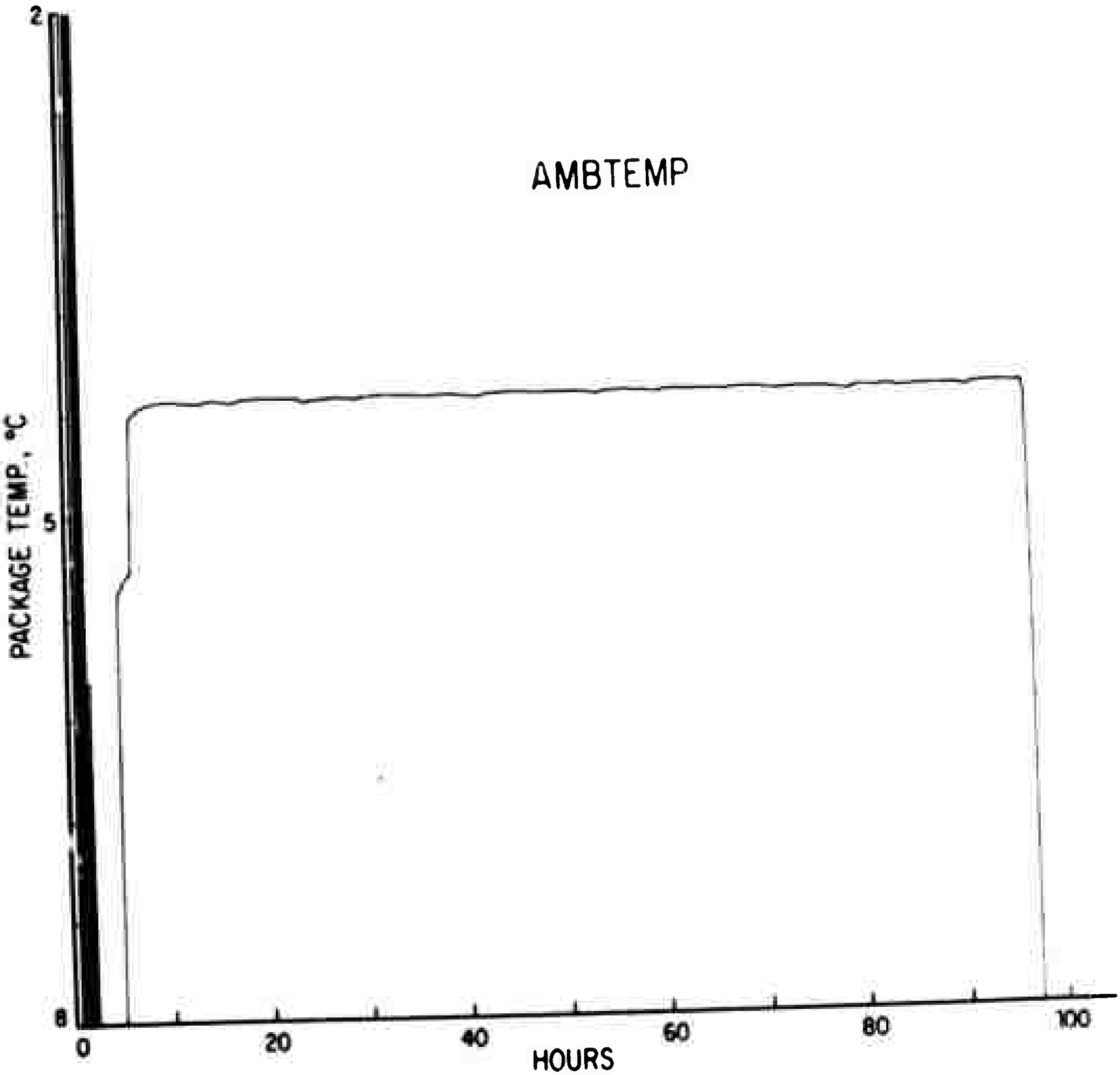
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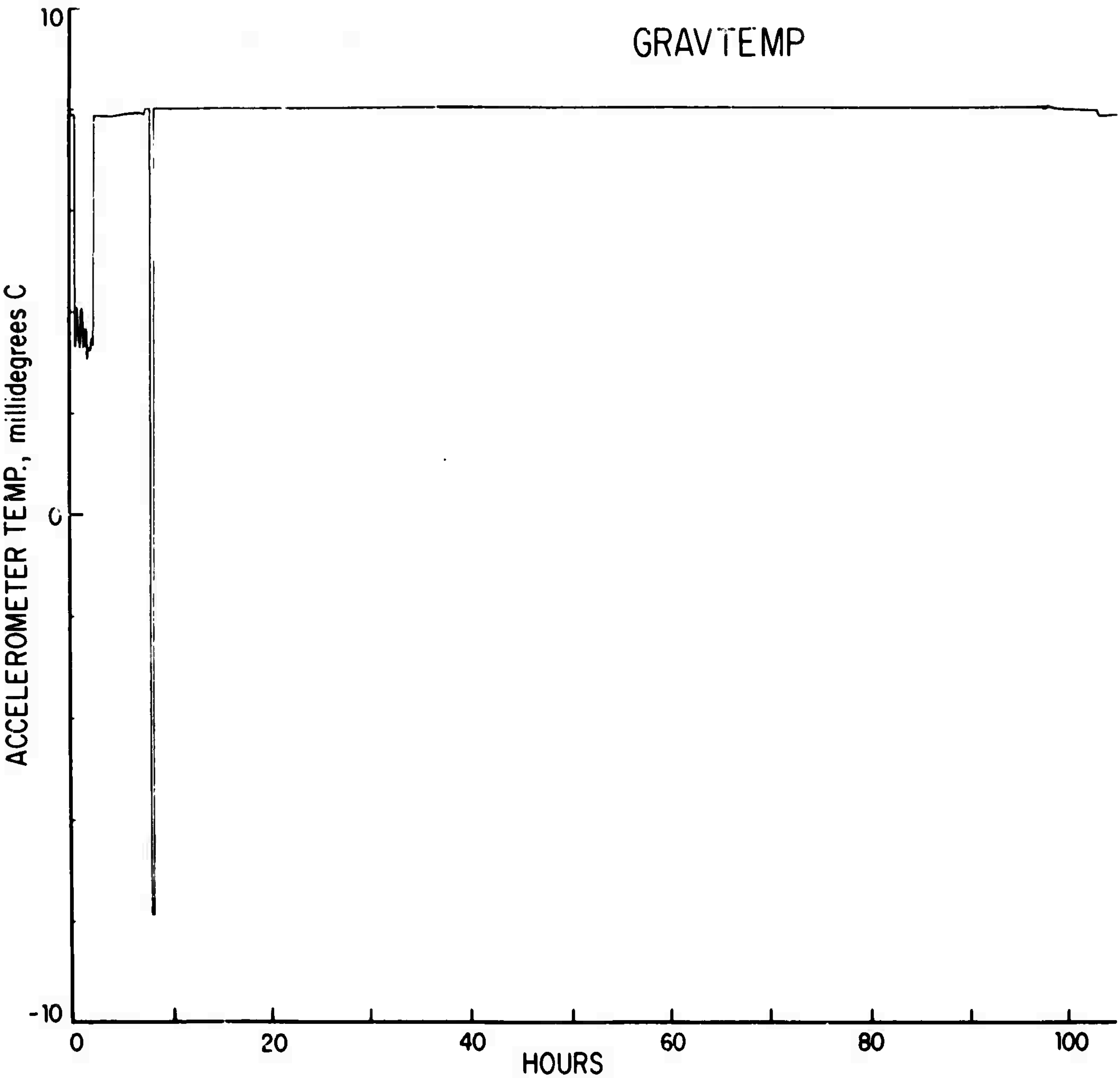
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ACCELEROMETER TEMP., millidegrees C
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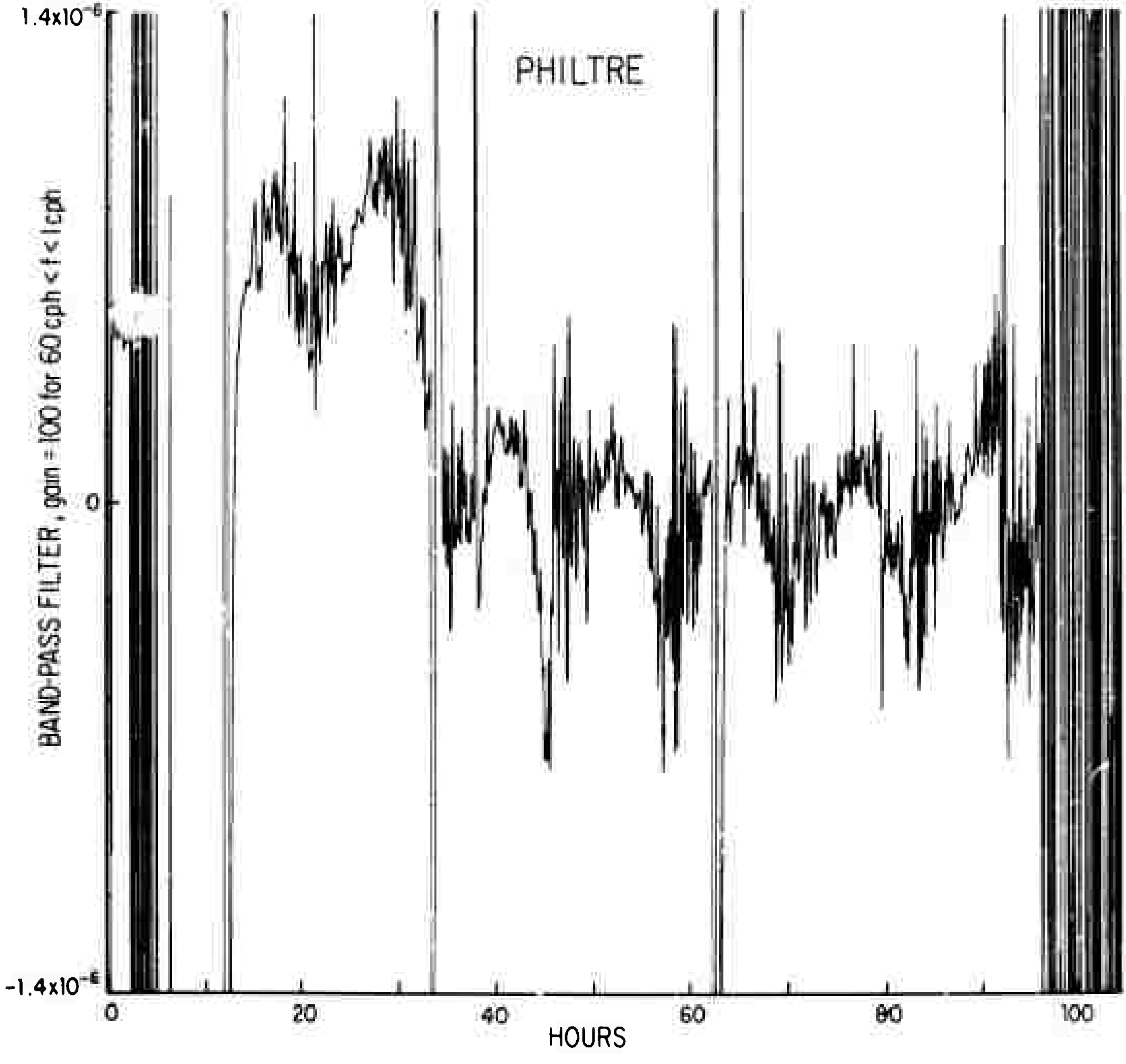

PHILTRE
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-1.4x10⁻⁶
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20
40
60
80
100
HOURS

Part III

ADVANCED STUDIES IN NEARSHORE ENGINEERING

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ADVANCED OCEAN ENGINEERING LABORATORY

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Part III

ADVANCED STUDIES IN NEARSHORE ENGINEERING

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Project Summary

Previous ARPA sponsored research has been concerned with the development of a system for the nearshore control of sand transport. The system utilizes the oscillatory nature of surface waves as a driving mechanism for strong vortex formation over the steep face of a rigid, asymmetrical ripple-like bed roughness. The asymmetrical roughness provides a method whereby the vortex generation may be enhanced on the steep face of the ripple form and degraded over the gentle face of the form. This differential vortex formation leads to differing amounts of sediment suspension and hence a preferred direction of sediment transport, the sediment being transported in the direction that is out-of-phase with the flow that causes the most intense vortex formation. Elements of this type that control the direction of sand transport are known as "phase dependent roughness elements".

Possible uses for such a system include the prevention of retardation of beach erosion, harbor entrance maintenance by prevention of sedimentation, and the directing of sand towards pumping systems such as the crater-sink sand transfer system (Inman and Harris, 1971).

Earlier research into the phase-dependent transport phenomenon has defined broad limits within which the mechanism was operational. These limits were given in terms of such wave parameters as orbital diameter at the water sediment interface, and the height and wavelength of the roughness elements. Limited tests were conducted in nearshore waters to test the validity of the method under natural conditions. The present study is concerned with better understanding of the mechanism, better definition of its limits, and full scale testing in the nearshore zone.

Present Research

One of the most interesting problems encountered during the earlier research was finding conditions where reversal of the direction of sediment transport occurred, i.e., transport in phase with the velocity which was thought to form the most intense vortex. In order to study the problem, flow visualization procedures were developed which utilized dye injection into the boundary layer above the elements, and hydrogen bubble generation from a fine wire. By employing this technique it is possible to mark the vortices at the time of formation and to study their subsequent growth, rotation and movement. Results of the flow visualization indicate that for ripple steepness above 0.15, where steepness is defined as ripple height/ripple wavelength, the higher velocities cause breakdown of the vortex on the steep side of the ripple form. This vortex breakdown causes a degradation in the amount of suspended sediment from the steep side and hence a reversal in the direction of net sand transport. This is illustrated in Figure 1, in which the solid dots correspond to out-of-phase transport and the X's correspond to in-phase transport.

In order to better understand the full range of the vortex ripple interaction problem, natural sand ripples were developed by placing a smooth layer of loose sand in a tray on the bottom of the wave tank and allowing the ripples to be generated by wave action. These ripples, formed on a tray, were then removed from the wave tank and artificially lithified by the application of an American Cyanamid product, "Aerospray 70". This long chain polymeric material somewhat resembles a white glue, and is sprayed onto the sand with a common garden sprayer. After spraying; the sand bed is then dried by the application of heat from below. Once these natural sand ripples were solidified, it was possible to reintroduce them into the wave tank and study the flow over the rigid surface.

Two different sand sizes were used for these tests, and the ripple parameters which were obtained are given in Table 1.

RIPPLE PARAMETERS			GENERATING WAVE PARAMETERS		
Sand Size Median Diam.	Ripple Height	Ripple Wavelength	Wave Height	Wave Period	Water Depth
177μ	2.1 cm	15.7 cm	25 cm	4.0 sec	170 cm
617μ	4.0 cm	30.0 cm	27 cm	4.0 sec	170 cm

With the ripples solidified; it became possible to not only study them under the generating conditions of wave height and wave period, but it was also possible to change these parameters without affecting the ripple shape. The flow over the natural ripples has been studied using both dye injection and hydrogen bubble generation flow visualization techniques. Using these methods it has been possible to investigate the size and rotational characteristics of the vortices. This data is currently being analyzed.

A set of roughness elements were cast of portland cement concrete and placed in the ocean to test the validity of the phase dependent roughness elements for use in the nearshore environment. The elements were held together by rods passing through the inside of the cast elements. These elements were placed in 6 meters of water and changes in the bed profile were monitored by the use of reference rods placed at both ends of the array as shown in Figure 2. When the elements were oriented so as to move sediment in an offshore direction, as shown in the top of the figure, a pit was formed on the onshore side of the array and a mound formed on the offshore side of the array. This result indicated that the elements were effective in decreasing the onshore movement of sediment which takes place at this time of year. When the elements were turned around and aligned so as to move sand in an onshore direction, as shown in the middle of Figure 2, pits formed on both ends of the array, with the offshore pit being some 2 cm deeper than the onshore pit. This indicates that the elements are still functional, but that the effect is being partially masked by the general onshore movement of sediment at the time.

Planned Investigations

Further tests on the full scale phase dependent roughness elements include dyed sand tracing studies to test the validity of the mechanism and its extension into the ocean environment; and flow visualization techniques to verify the hydrodynamics of the system in the ocean. If the foregoing full scale tests turn out as expected, the next logical step will be to construct larger arrays of the phase dependent roughness elements in order to test their effectiveness in the modification or maintenance of a particular shoreline feature.

One of the corollary dividends of this research has been the investigation of the size and structure of the vortices formed in the lee of ripples by oscillatory wave motion. Present work indicates that it will be possible to determine the amount of energy in this vortex field and hence its influence in terms of wave attenuation.

References

Inman, D. L. and R. W. Harris, 1971, "Crater-sink sand transfer system", Proceedings of the Twelfth Conference on Coastal Engineering, Amer. Soc. Civil Engin., New York, vol. 2, p. 919-933.

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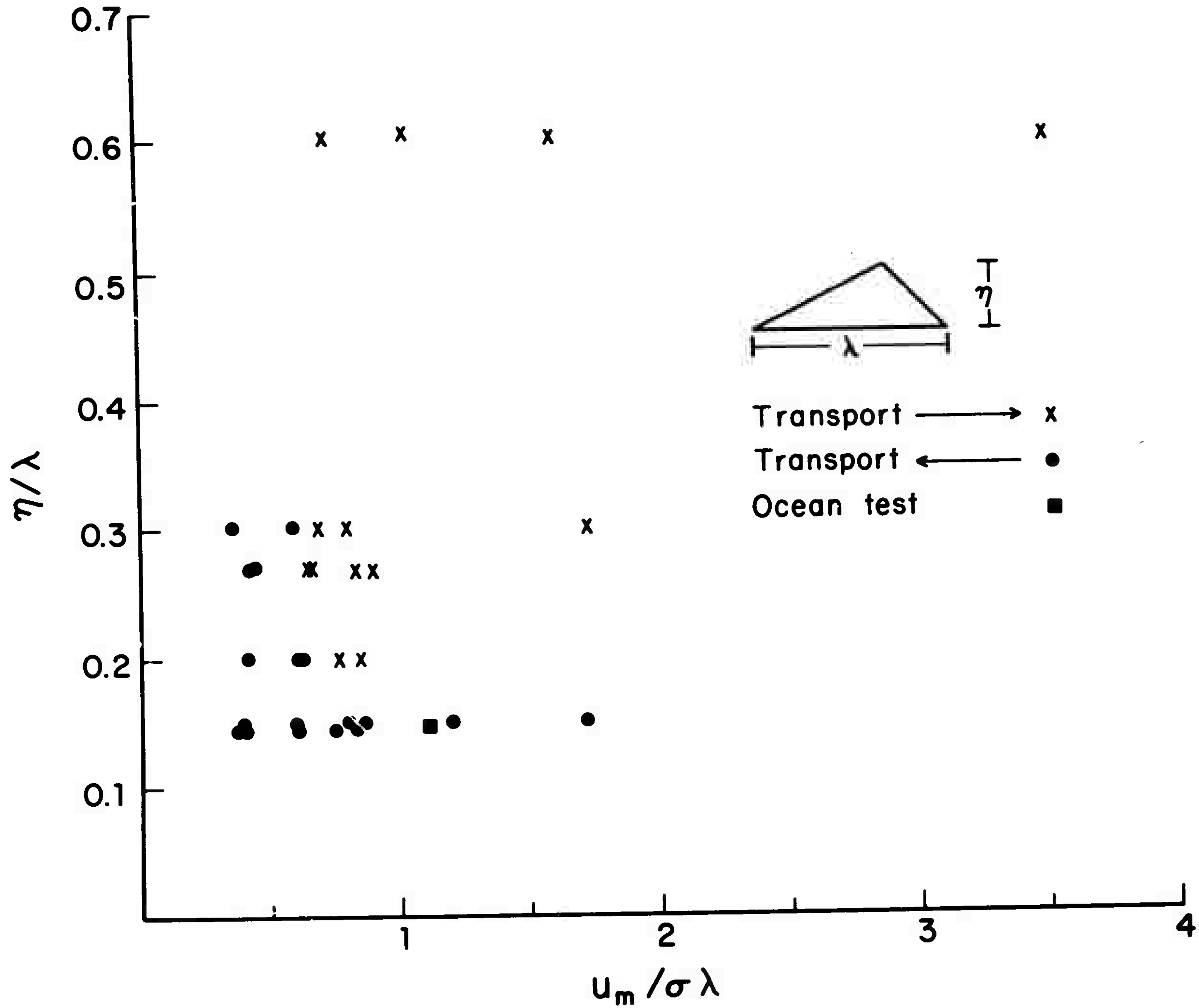

Figure 1. Transport behavior as a function of ripple steepness, η/λ, and wave parameters.

72.40-2

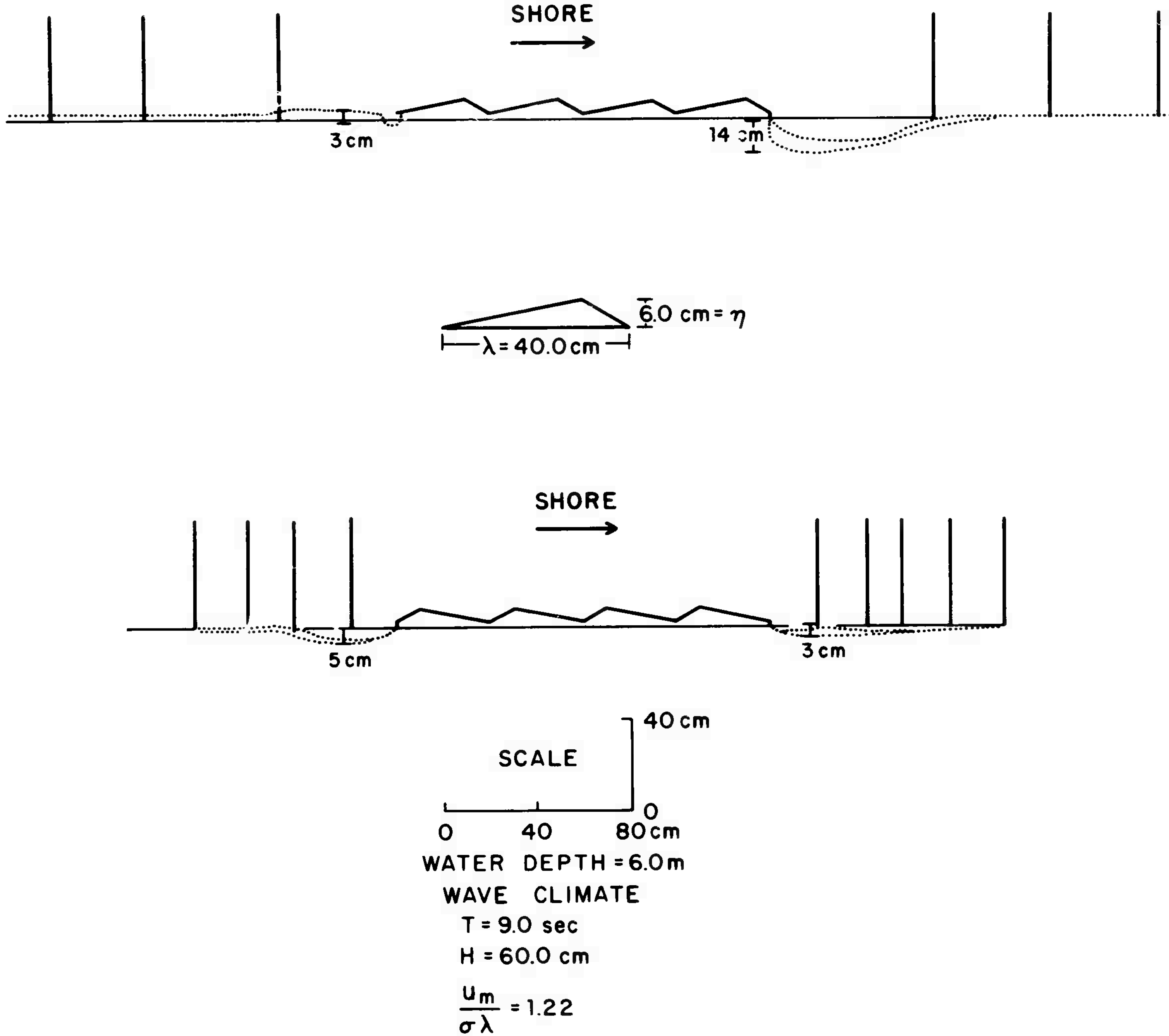

Figure 2. Results of preliminary ocean tests.

72-40-4

Part IV

ELECTROMAGNETIC ROUGHNESS OF THE OCEAN SURFACE

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Part IV

ELECTROMAGNETIC ROUGHNESS OF THE OCEAN SURFACE

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I. SUMMARY

The electromagnetic roughness studies are being conducted jointly by two groups, one at Stanford and one at Scripps Institution of Oceanography. The work uses HF radio waves scattered from the ocean surface to measure the statistical properties of this surface, particularly the ocean-wave directional spectrum.

The major proportion of our work for the third six months of the contract has been concerned with a series of experiments to measure the importance of the second-order scatter of radio waves from the sea. The work involved measuring the Doppler spectrum of 30MHz radio waves back-scattered from the sea off the California coast. These spectra indicate that, at this frequency, the radar scatter is strongly influenced by ocean surface currents, and to a lesser extent by second-order scattering. This information is important for the proper interpretation of data from multifrequency radio experiments when the radio frequencies extend above approximately 10MHz.

In addition to this work, we have analysed the data from the Hawaiian experiment described in our last report. The analysis indicates that the data recorded using a bistatic geometry and a shipborne receiver is strongly distorted by the ship's motion, and the effects of the distortion cannot be eliminated.

In order to extend the frequency range of our experiments we have begun the detailed design of a low power, easily portable, multi-frequency radar.

II. TECHNICAL REPORT

A. Introduction

The purpose of this contract, as stated in our proposal, is to use radio waves Bragg scattered from the sea as a tool to measure the statistical properties of the ocean surface. In particular, we are evaluating techniques for measuring the most important two-dimensional statistical property of the ocean surface, the ocean-wave directional spectrum. These techniques include situating the radar receiver and transmitter in 1) a bistatic geometry and using the range-Doppler spectrum of the scattered signal to determine the wave directions; 2) a monostatic geometry which uses a directional antenna to obtain the same information; and 3) a monostatic geometry with a moving receiver, where the motion of the receiver is used to synthesize a directional antenna.

Our first year's work has been described in two previous semi-annual reports, but can be briefly summarized. During the first part of the year a low-power, portable, LORAN A receiver; an antenna for the receiver; and a pitch-and-roll wave measuring buoy were designed and built. In September of that year, existing LORAN A radio signals (at 1.85MHz) were received by the receiver in a bistatic-geometry experiment to measure the directional spectrum of a fully-developed homogeneous sea. The receiver was placed on board a small ship located at a point north of the Hawaiian Islands such that the baselines from the receiver to the Hawaiian LORAN transmitters were at right angles, and aligned perpendicular and parallel to the wind. This geometry was chosen to give maximum coverage of the ocean-wave number spectrum. The one-dimensional ocean-wave spectrum was measured using a rented buoy since the pitch-and-roll buoy was not completed in time for this experiment. In addition, some radar data was recorded at locations on Oahu and Maui.

During the first six months of this year, the period covered by this report, we have analysed the Hawaiian data. This analysis has occupied less than half of our time, while the bulk of our effort has been concerned with several experiments to measure second-order scatter at [illegible]MHz. These experiments are described in the second half of this report.

B. Hawaiian Bistatic Experiment

The initial analysis of the data from the Hawaiian bistatic experiment showed that the data recorded on the ship was severely distorted by the ship's motion. This motion was primarily a constant but unknown velocity, on the order of 20-70 cm/sec, produced by surface currents, wind drift, and a slight forward motion needed to stabilize the yawing of the ship. However, by observing the distortion of the range-Doppler spectrum produced by this velocity it is possible to obtain a good estimate of its magnitude and direction.

We have attempted to account for this distortion to the range-Doppler data by deriving the equations which relate the ocean-wave directional spectrum to the observed range-Doppler data as recorded by a receiver moving at a constant velocity. We then seek a least-squares approximation to the inverse problem using highly redundant data from a number of separate experiments. This is necessary because the inversion of the data for a single experiment is not unique.

One way to obtain a solution to this problem is as follows:

We assume that the surface wave field is spatially homogeneous and temporarily stationary over the period of

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observation. The ocean surface can then be represented by a two-dimensional wave spectrum, S. Let s_i be a point in the numerical representation of S and d_j a data point in the set of all observational data, D. Then we can explicitly calculate the matrix element a_{ij} relating the two quantities:

$$d_j = \sum_i a_{ij} s_i$$

Typically, S contains several hundred points, D contains tens of thousands of points. The least-squares approximation to S is

$$S = [A^T A]^{-1} A^T D$$

Where A^T is the transpose of A, and $[A^T A]$ is a real, symmetric array that can be inverted using standard numerical techniques. Initial applications of this technique to the data yielded occasional negative values for S, even though S must always be positive; so we are now refining this analysis to obtain more realistic estimates.

The analysis for the data taken with a receiver on the shore is simpler, and we now have a complete set of programs to reduce the data and produce a contour plot of the ocean-wave directional spectrum given the range-Doppler data and pertinent experimental parameters. An example of such a plot for the data recorded at Hana (on Maui) is given in Figure 1.

C. 30 MHz Experiments

Three recent papers, by Barrick (1971), Hasselmann (1971), and by Stewart (1971), conclude that the second-order scatter of radio wave from the sea can be important when compared to the first-order Bragg scatter when the ocean waves scattering the radio waves are superimposed on much larger, longer-period, ocean waves. This second-order scatter may provide important information about the longer frequency ocean waves, but more importantly for our work, it may complicate the relationship between the radar cross-section and the ocean-wave directional spectrum, especially when the radar is operated in a bistatic or synthetic aperture geometry.

To determine the importance of the second-order scatter we performed a number of experiments off the California coast this spring. Each experiment consisted of measuring the range-Doppler spectrum of 30MHz radar signals back-scattered from the sea using a log-periodic antenna with a 60° one-half power beamwidth. The radar was operated at the shore 100-200 feet above the water; and data was recorded simultaneously from four ranges, each about 7.5 km wide, for 15 minute periods. In addition, for three of the experiments, the ocean-wave spectrum was measured in the scattering area using the pitch-and-roll buoy; on two occasions the surface current was measured using drogues, and on one occasion it was estimated from the drift of the wave buoy. For three other experiments the dominant wave period was estimated by observing the time between waves breaking on the beach.

A Doppler spectrum obtained during one of these experiments is shown in Figure 3. It shows a number of features common to the spectra obtained from the other experiments. First of all, the carrier frequency has been offset by 1.5hz so both positive and negative Doppler frequencies can be observed. The line in the spectrum at the carrier frequency is due to scatter from land, and the sharpness of this line is a measure of the stability of the radar. Secondly, there are two broad peaks near the expected position of the first-order Bragg scattered signal ($\pm f_B$). These peaks are not precisely at this frequency, but are both offset slightly in the same direction. Furthermore, they are not symmetric, and the peak at f_B does not have the same shape as that near $-f_B$. Thirdly, there are two weak lines, near 0.5 and 1.3hz. These small features appear from time to time at various positions and are probably due to scatter from ships. And fourthly, there is a continuum due to receiver noise. A line has been drawn by eye through this to indicate an average noise level for this spectrum.

The goal for the various experiments is to understand the cause of the broad peak near $\pm f_B$. We will first present the experimental data, and then discuss its implications, and its relation to second-order scatter.

We first note that the Doppler spectrum is independent of range. This is illustrated in Figure 4. Here, one side of the spectra from four ranges have been plotted together on an expanded frequency scale so that small details of the spectra can be observed. Note that even small peaks near the noise level appear to be correlated. The data from three ranges can then be averaged together to improve the signal-to-noise ratio. This has been done for the next plots.

If the averaged Doppler spectra are plotted as a function of time, the spectral peaks near $\pm f_B$ slowly evolve with time; the spectral intensity at a constant frequency can change at rates of approximately 10db/hr, as is seen in Figure 5. Finally, if the averaged spectra from differen days are plotted together as in Figure 6, there is no consistant pattern from day to day.

The data recorded to date are not sufficient to uniquely determine the cause of the broadening of the Bragg scattered peak in the spectra. The observed current of 50 cm/sec can cause a maximum broadening of 0.2hz, assuming the current is uniform, and that the sidelobes of the antenna are observing waves being carried toward and away from the receiver by the current. This broadening is indicated by the horizontal bar in Figure 3, and the broadening in excess of this limit is probably due to second-order scattering. Nevertheless, the separation between the sideband signal and the Bragg line, which characterizes this type of scatter, appears to be absent from much of the data; only the spectra from 6 December and 17 January have this distinctive feature.

The evolution of the spectra with time is probably due to changes in amplitude of the scattering waves. These waves have a group velocity of 2 km/hour, and could not propagate through the observed area in a few hours; and, although the structure of the current field in the top two meters of the ocean could change significantly on this time scale, it is likely the current would change throughout a greater depth than this, and its time scale for change would be more than a few hours.

To reduce the Doppler broadening of the Bragg scattered signals due to currents, we are planning future experiments using a much more selective antenna. A report on the data from the first three experiments has been published in Science (Tyler, et. al. 1972).

D. Multifrequency Radar

In order to extend the frequency range of our measurements, we began a detailed design of a multifrequency radar and its receiving antennas, and will construct the radar during the latter part of this year. Originally we had planned to use a borrowed Grainger Ionosounder for this work, but the available sounder requires repairs and modifications, and when operating properly would not be easily portable, and so would limit our ability to take data in oceanographically interesting areas. The new radar will operate on four easily-changed frequencies, will use a temperature-controlled crystal oscillator for a time base, and will be easily portable. The antennas will be broadband loops.

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Hasselmann, K. 1971, Determination of ocean wave spectra from Doppler radio return from the sea surface. Nature Physical Science, 220, p. 16-17.

Stewart, Robert H. 1971, Higher order scattering of radio waves from the sea. IEEE GAP International Symposium Digest, Los Angeles.

Tyler, G. Leonard; Faulkerson, William E.; Peterson, Allen M.; and Teague, Calvin C. 1972, Second-Order scattering from the sea: ten-meter radar observations of the Doppler Continuum. Science, 177, 349-351.

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Table 1: Summary of 30 MHz Experiments

DATE	PLACE	WAVE BUOY	WAVE VARIANCE	DOMINANT WAVE PERIOD	CURRENT
6 December 1971	Free Beach	no	Unknown	16 sec	Unknown
17 January 1972	Free Beach	no	Unknown	15 sec	Unknown
25 January 1972	Free Beach	no	Unknown	12 sec	Unknown
31 March 1972	Lobos Rocks	yes	880 cm^2	14 sec	50 cm/sec from NW/est.
1 May 1972	Lobos Rocks	yes	3800 cm^2	10 sec	50 cm/sec from NW
15 May 1972	Respini Creek	yes	1700 cm^2	6 sec	50 cm/sec from NW

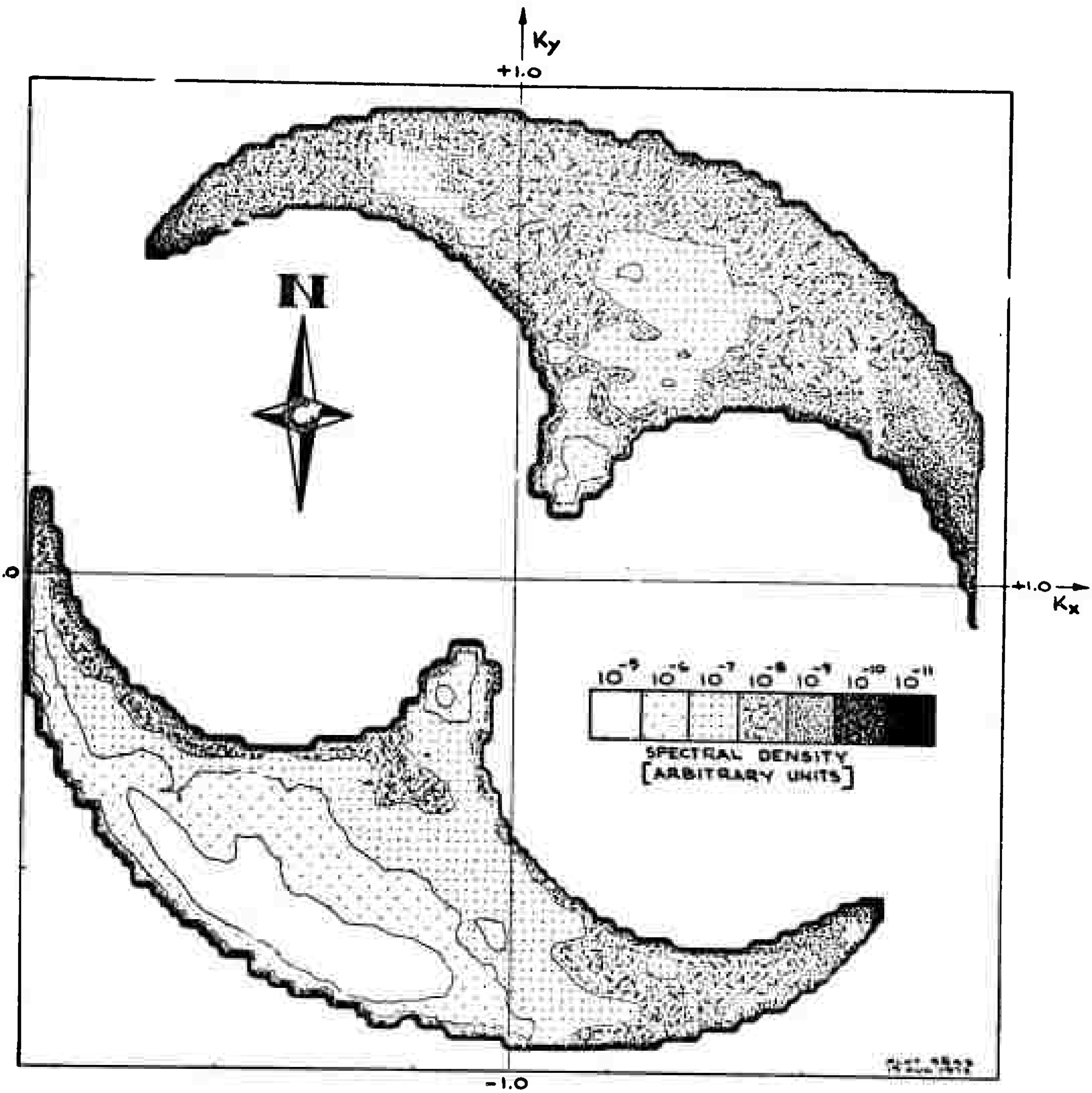

Figure 1. Dimensionless ocean wave number spectrum obtained from bistatic geometry measurements of a homogeneous, trade-wind sea near Hawaii. The length of the vector k is inversely proportional to the ocean wavelength, and its direction is the direction towards which the wave is moving. The length $\vec{k}$ = 1 corresponds to a seven-second ocean wave.

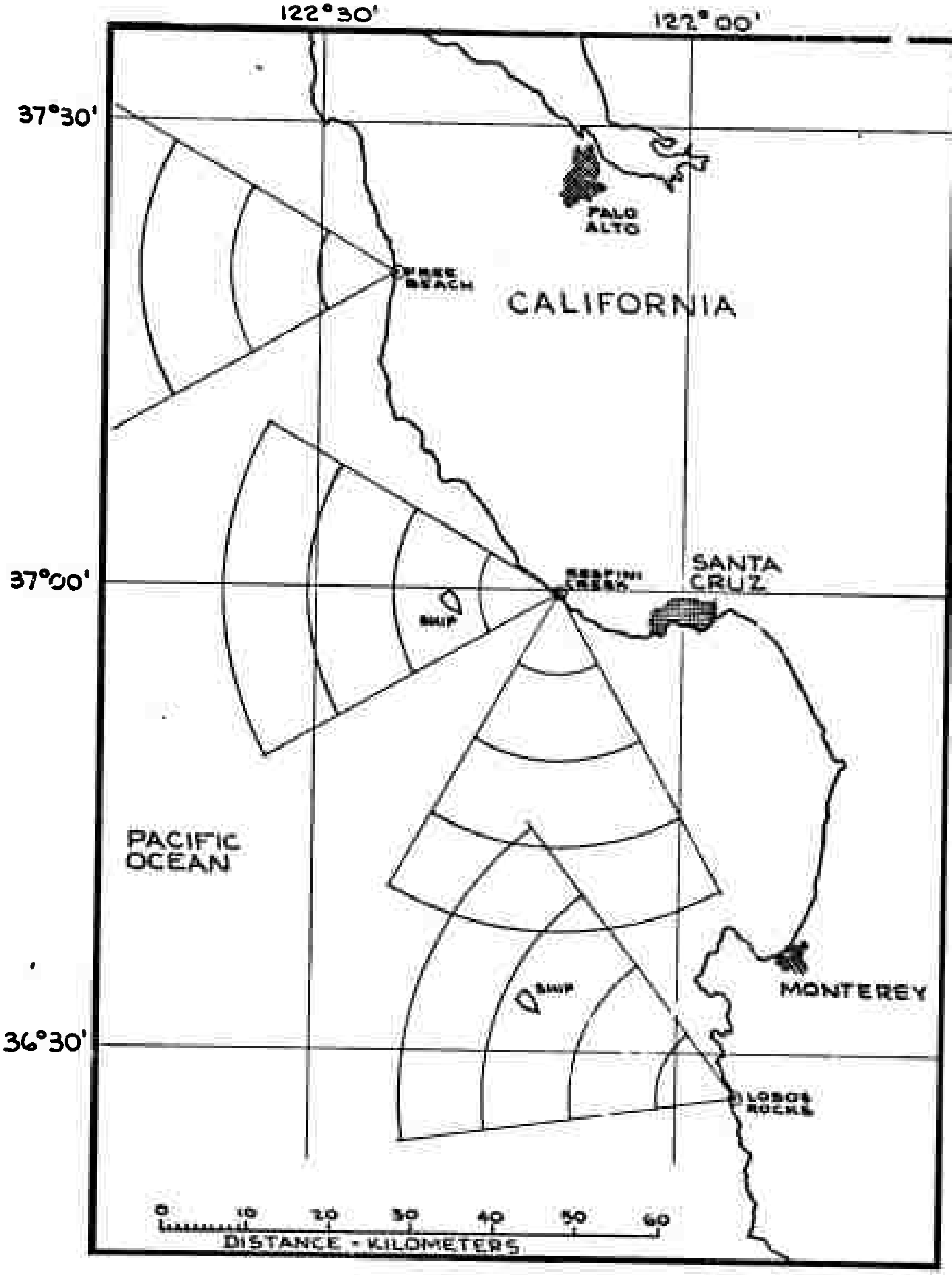

Figure 2. Experiment sites and scattering areas for 30MHz experiments. Bands in scattering area show ranges sampled by radar.

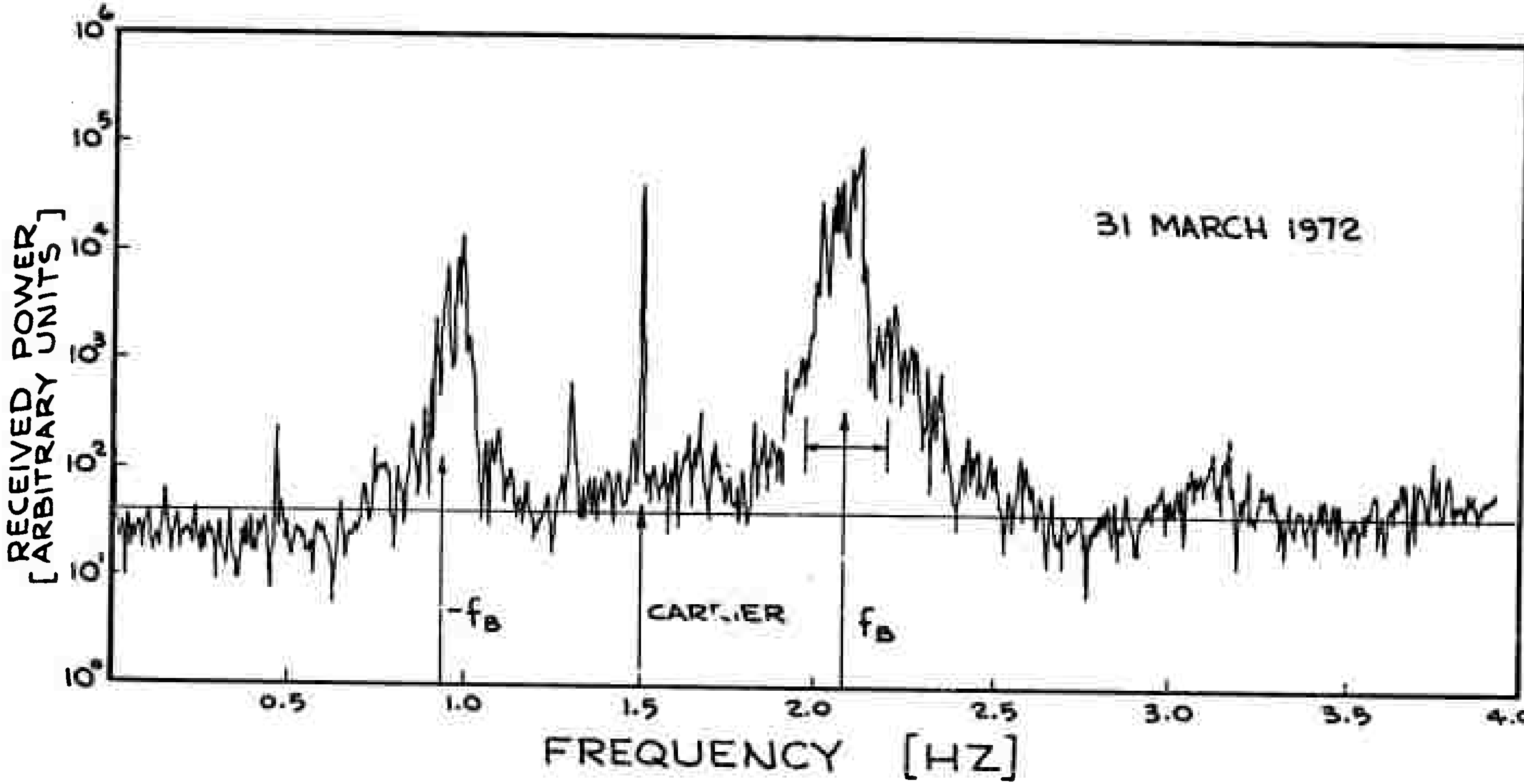

Figure 3. Doppler spectrum typical of those obtained from 30MHz experiments. The spectrum has been offset by 1.5Hz, the expected position of first-order Bragg scattered signals is indicated by $\pm f_B$. The bar centered at f_B indicates maximum broadening of this signal due to observed currents. The horizontal line is an estimate of system noise.

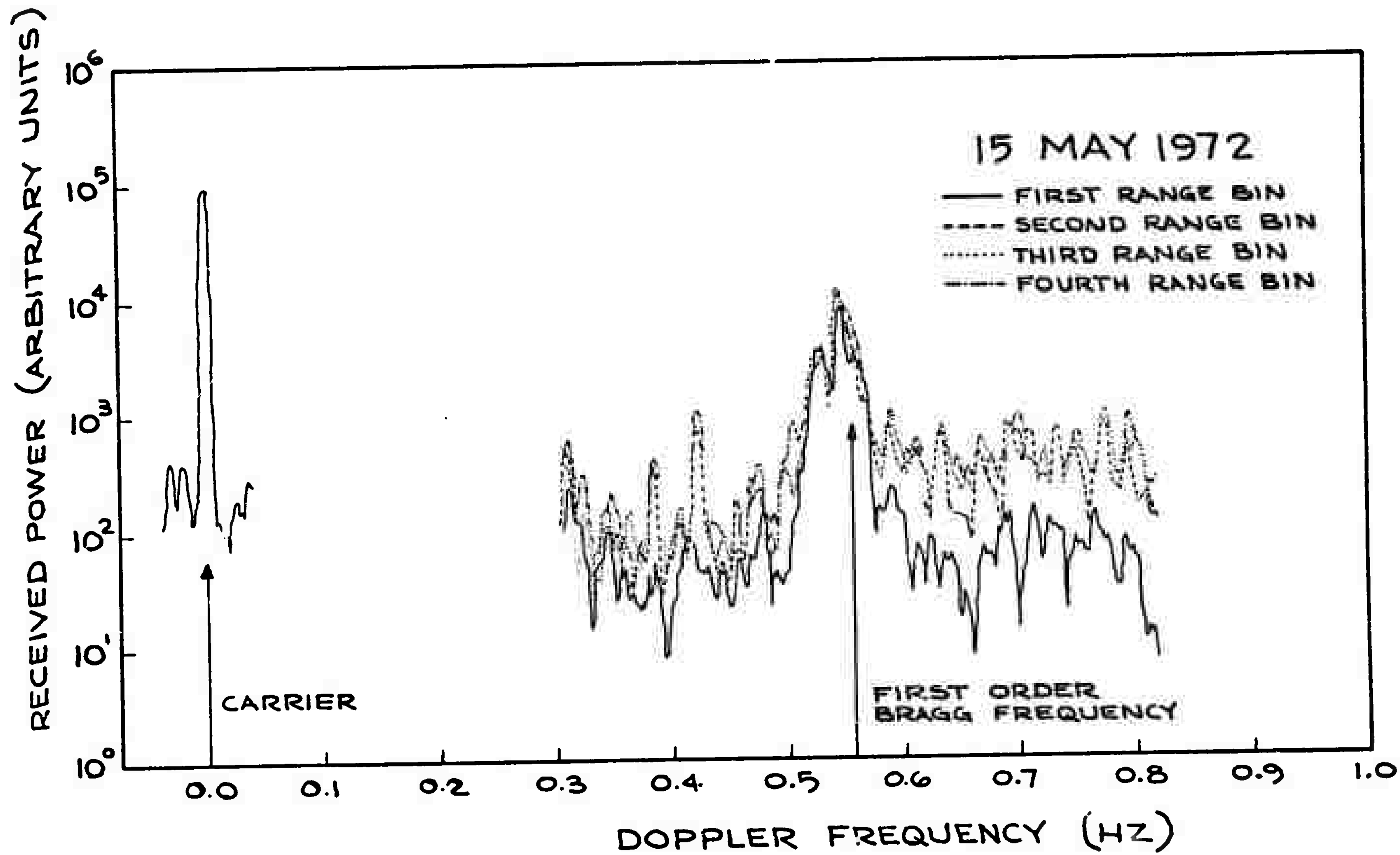

Figure 4. Range-Doppler spectra obtained from 30 MHz experiments. The observed spectra are independent of range. Only the positive frequency side of the spectrum is plotted here.

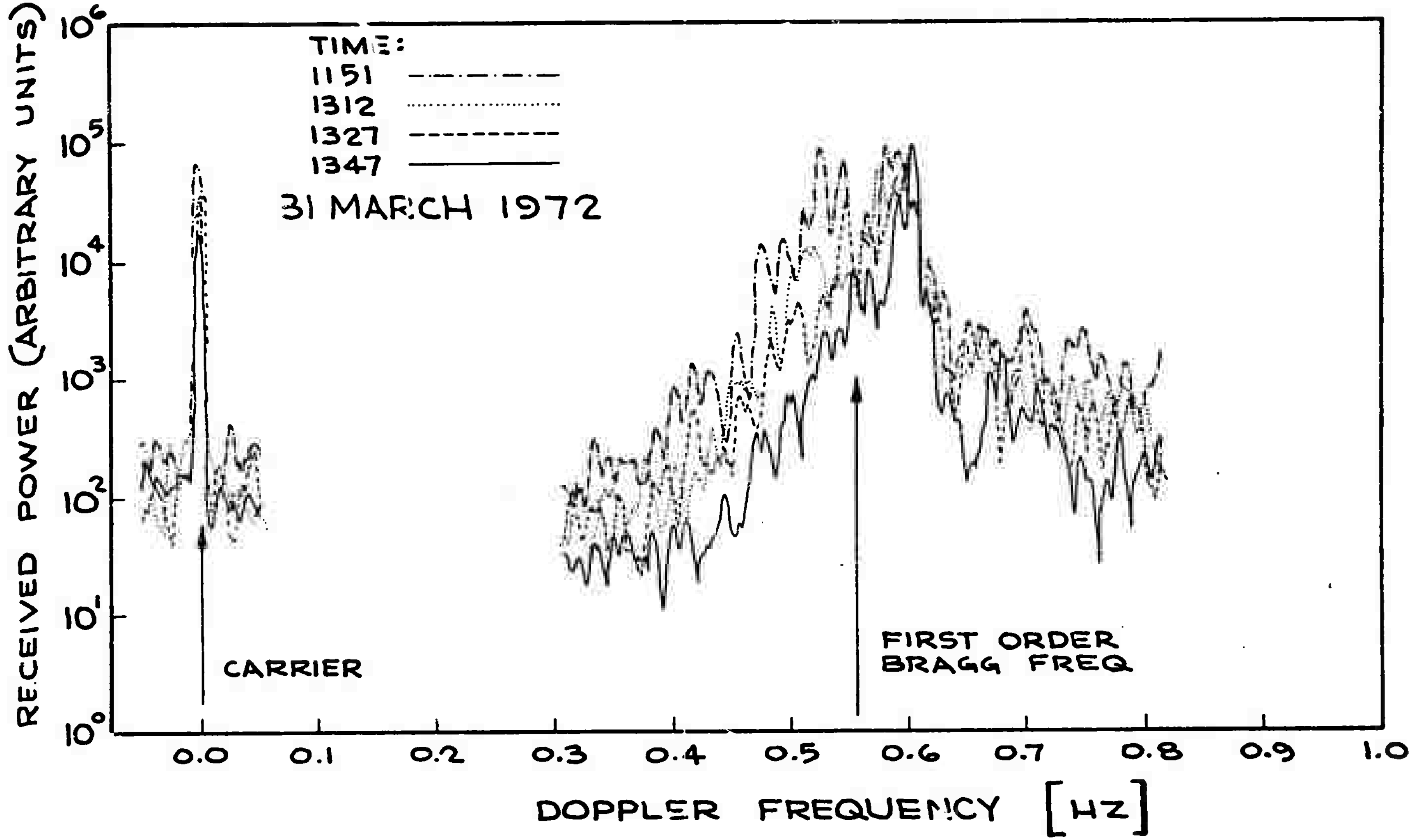

Figure 5. Averaged range-Doppler spectra obtained from 30MHZ Experiment showing evolution of spectra with time. Only one half of the spectrum is plotted here.

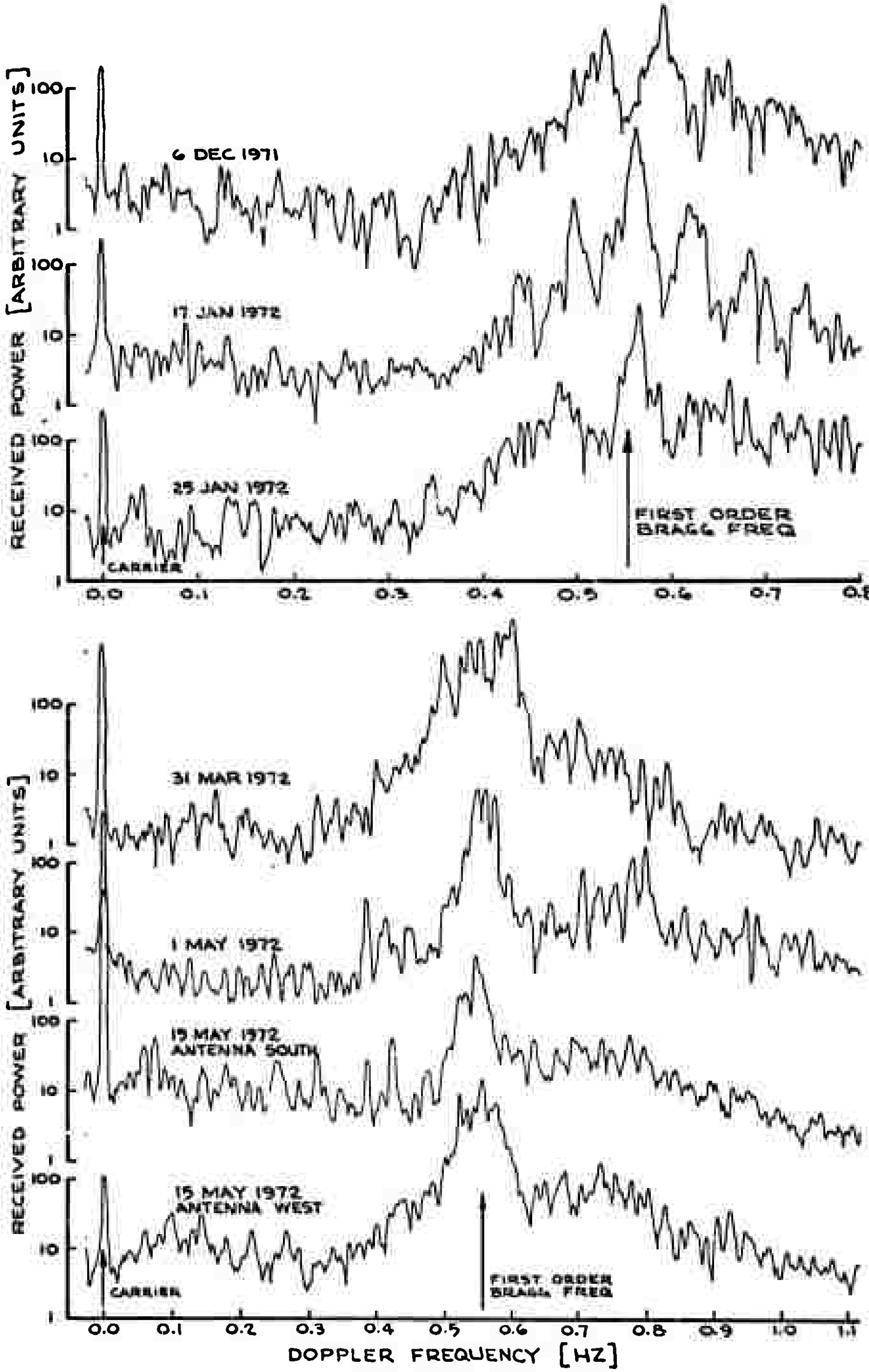

Figure 6. Averaged Doppler spectra from 30MHz experiments for various days or antenna directions.

Part V

WAVE BREAKING IN DEEP WATER

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Part V

WAVE BREAKING IN DEEP WATER

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I. SUMMARY

This report summarizes results of the first six months of a projected two-year laboratory and field investigation of the factors controlling the breaking of mixed-frequency wave systems in deep water, such as occur under storm conditions in the open sea.

Because the first year (laboratory phase) of our study closely parallels that of our previous study of wave breaking in shoaling water, carried out during the past two years under ARPA sponsorship, similar measurement techniques are being employed. The former study was concerned with waves about 20 cm high, breaking in water of similar depth, and was conducted in a 0.5m x 1.2m x 30m wave channel. The present study involves waves up to 1m high, breaking in 2m of water, and is being conducted in the 8' x 8' x 150' wind-wave channel at the SIO Hydraulic Facility. This scale increase has required considerable revision of instrumentation, to which our efforts have been largely directed during the last six months. Work has included:

1. Construction of four 1m digital wave staffs and logic circuitry

2. Reconfiguration and calibration of orthogonal arrays of hot-film velocity probes for measuring fluid velocity and direction

3. Construction of an 80' x 8' converging section for the wave channel, so that smaller waves can be amplified to the breaking point in deep water

4. Assembling an analogue tape-drive for the servo-controlled wave generator so that arbitrary wave programs can be digitally generated and pre-recorded for multiple playback.

5. Writing computer programs for:

    a. Convoluting wave generator amplitude and frequency to produced arbitrary wave forms,

    b. Semi-automatic digital calibration of velocity probes, and computer processing to directly obtain wave orbital velocity and direction,

    c. Analogous processing of wave height and pressure data.

In addition to the above, the remainder of our time has been devoted to completing a (voluminous) special technical report of results of our previous study of wave breaking in shoaling water. This report should be finished by September, 1972.

II. TECHNICAL REPORT

1. Introduction

Most human activities at sea are to some extent inhibited by wind waves. The degree of inhibition increases with sea state, is aggravated by whitecapping, and becomes severely limiting when the larger waves begin to break. These circumstances notwithstanding, wave breaking in deep water has received little scientific or engineering attention heretofore. At present, there is no theory--nor even a prescription--for the mechanism whereby deep water waves become unstable and break, nor are there observational data that permit estimates of the statistical probability of breaking as a function of wind speed or sea state. Yet, it is generally assumed that breaking limits the ultimate growth of sea state under a given wind condition.

At the same time, it is evident that many practical applications of sea state information would benefit from an understanding of breaking dynamics and breaking statistics:

a. Much, if not most, non-collision ship damage in the open sea is caused by breaking waves;

b. Ship operations of all kinds are often limited more by wave breaking than by wave height or steepness, per se;

c. Present aerial, and proposed satellite, observations of sea state employ X-band radar, whose scatter return is heavily weighted by small ripples. The correlation of breaker indices with radar return might provide important clues for their proper interpretation;

d. Ambient sonar surface noise above 1-KHz increases rapidly with sea state. The distinction between breaker noise and other surface effects, even such as mild turbulence, remains obscure, but the former contribution is undoubtedly significant. Both ambient noise and sonobuoy dynamics in breaking waves have obvious ASW-1 implications.

e. Optimum engineering development and operation of all classes of interfacial and surface-piercing vehicles and devices require a better knowledge of peak accelerations and forces than can be obtained from statistical studies of sea state.

Our present study is predicated upon certain observational characteristics of breaking storm waves that lead us to believe that carefully designed laboratory experiments, coupled with appropriate open-sea measurements, might provide a more deterministic picture of breaking dynamics:

a. There is ample photographic evidence that large storm waves break in much the same manner as swell breaks in shoaling water. This similarity can be checked by causing deep water waves to break in a convergent laboratory channel.

b. The average energy and short life span of a storm wave, compared with reasonable estimates of the rate of energy input by wind, and the fact that large waves continue to break for some hours after the wind dies, suggest that local wind conditions dominate only the breaking of smaller waves. The influence of wind on breaking can also be checked in our laboratory channel on a meaningful scale.

c. Breaking of storm waves is quite directional and parallel to the prevailing wind field, indicating that it is basically a two-fimensional process, and might be meaningfully simulated by two-dimensional experiments.

Taken together, these observations suggest that waves break by some instability associated with the dynamics of the region near a wave crest. Observations of single wavetrains indicate that the criteria of breaking is more nearly related to wave steepness than wave length. No information is available concerning the breaking of more than one wavetrain. It seems likely that both the steepness of the various wave components and their relative phase velocities, which determines the duration of the constructive interference and which produces large steep crests, will affect the onset and extent of breaking.

2. Objectives

Briefly stated, the objectives of our study are threefold:

a. In the laboratory, to generate a variety of tape-controlled, reproducible wave fields, whose harmonic components interact to produce "deep water" breaking. Measure the time-dependent surface elevations, subsurface pressures and orbital velocities so as to fully define the flow fields in near-breaking and breaking waves, with view to establishing breaking criteria. Explore the effect of wind on wave breaking.

b. At sea, to compare our laboratory results with similar--or additional--observations of breaking waves at various sea states, using the SIO vessel R/V FLIP as a reference platform.

c. Prepare a set of wave breaking indices as functions of sea state, from which the statistical probability of breaking can be predicted, together with the range of magnitudes of important variables; such as, orbital velocities, accelerations, and impact forces.

3. Methodology (laboratory phase)

We are proceeding simultaneously with two different types of experiments:

a. Convergent breaking: In these experiments, periodic waves are converged laterally to the point of breaking by an 80-ft. oblique barrier (Fig. 1). The terminal 20-ft. section of the barrier is hinged, so that the degree of convergence can be adjusted to control breaking intensity and duration. Breaking inception is determined by the initial height and frequency, which can also be adjusted to occur at the desired position on the channel. With a maximum operating depth of 1.8m, breaking waves as high as 1.5m meters can be accommodated, although the practical range of "deep-water" conditions restricts us to wave periods of about 2.2 sec, and heights of about 1m. Because of terminal reflections, we will also be limited to experiments whose duration does not exceed two or three wave periods.

b. Coincident breaking: Without the convergence, breaking can also be produced by tape-controlling the generation of consecutive waves of progressively lower frequency, such that two or more sub-critical waves coincide to produce a super-critical (braking) wave within the measurement section of the channel.

In both experiments, the effect of wind can be studied, since the channel is equipped with a 45-hp, 78" aspirating fan, capable of generating surface wind speeds of 30 ft/sec.

Random coincidence of a relatively narrow directional waves" spectrum is the basic assumption underlying stochastic theories of sea state. Within the constraints imposed by channel dimensions and the mechanical limitations of the wave generator, we can simulate deep-water sea states corresponding to prototype waves as high as 50 feet within the period range 3.5 - 17.5 sec.

4. Present Status

Most of the past six months has been devoted to instrument revision and generation of computer codes for real-time data processing. Although we are employing the same measurement techniques used in our previous study of shallow water wave breaking, (Ref. 1), the length scale of our current experiments is now some 5 - 6 times larger than before, and the time (velocity) scale more than twice as large. Accordingly, larger fixtures, and extended-range calibrating techniques are required. Progress during this period has included:

a. Construction of the 8' x 80' convergent barrier for the wave channel, with provisions for adjusting the terminal 20' hinged section. Because of high demand for channel use by others, the convergence is constructed in sections, and can be installed or removed in one working day.

b. Construction of a pivoting strut and turret head for fluid velocity measurements (Fig. 2). The turret holds two orthogonal hot-film probes. In a fixed position, the probe outputs can be interpreted as fluid velocity and direction within a 90-degree azimuth. By rotating the turret and repeating any experiment, all azimuths in a vertical plane can be covered. By pivoting the strut to a horizontal position, both probe tips inpinge on the discharge stream from the calibrating cylinder. The cylinder is equipped with contact points, such that, by recording probe output voltage and water elevation as a function of time, a complete dynamic flow calibration can be made within one minute, covering the velocity range 0.5 - 6.0 m/sec.

c. The directional response of the orthogonal probe head was independently calibrated over the same flow range in the 600-ft. Lockheed towing tank (San Diego). Directional response depends upon individual probe characteristics, as well as upon water temperature. All calibration data are stored on tape, and computer programs have been written for converting the outputs from any pair of orthogonal probes into vector velocity and direction.

d. In order to be able to generate and reproduce arbitrary input wave signature, an FM amplifier-demodulator, and a high-fidelity tape deck were purchased, and interfaced with the IBM 1130 computer. Periodic wave characteristics as functions of generator frequency and stroke were determined experimentally, and a computer algorithm written that allows us to determine in advance what complex wave systems will be generated for known input instructions, whether analogue or digital.

e. An instrument cart was fabricated to ride on rails above the wave channel. This cart (Fig. 3) carries all moveable sensors and calibrating equipment, and can be positioned at any point along the channel. All sensors are cable-connected to a Varian Statos III, eight-channel strip-chart recorder, that also can be rolled along a catwalk beside the channel. Analogue outputs are also cabled to the IBM 1130 computer, where they are multiplexed through an A/D converter and tape recorded for digital processing.

f. Four 1m digital wave staffs and associate logic circuitry were fabricated for the purpose of monitoring surface elevation as a function of time. By spacing these staffs sequentially along the wave channel, phase velocity can also be determined. We have also modified our subsurface pressure sensors to accommodate larger waves.

As of this writing, all of the foregoing equipment programs have been completed, and we expect to commence the measurement program within the next month. Because they are more straightforward, we will commence by measuring the characteristics of convergent wave breaking, as functions of frequency and initial amplitude. These completed, we can remove the barrier and study the behavior of multi-component wave systems. The duration of these experiments is somewhat contingent upon other demands for use of the wind-wave channel (mostly for other ARPA-funded projects), but, judging from present experience, it will extend into 1973.

5. Reporting of Previous Work

All analysis of experimental results from our previous study of breaking wave dynamics in shoaling water is now complete. The special project report of this work is now underway, and should be available for distribution by October, 1972.

III. FUTURE PLANS

In line with our long-term objectives, future plans call for comparison of the foregoing laboratory results with contemporary sea state theories and with ongoing sea state measurements by Prof. Davis (Co-investigator). From the work of Pierson (Ref. 2), among others, surface slope and height distributions are fairly well established for random seas from a single source disturbance. If we can determine breaking parameters as functions of these same variables, and correlate them with experimental observations in the open sea, we should be able to put a deterministic limit on sea state growth, without necessarily considering growth factors per se. In the latter context, it may be necessary to augment present field experiments of surface elevation and breaking incidence with additional measurements of orbital velocities. Accordingly, we are giving some thought to techniques for making velocity measurements from FLIP, consistent with her projected operation schedules in the spring and summer of 1973.

REFERENCES

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2. Pierson, W. J., Models of random seas based on the Langrangian equations of motion, NYU Col. of Eng. Res., prepared for the Office of Naval Research under Contract NOnr-285 (03), April, 1961.

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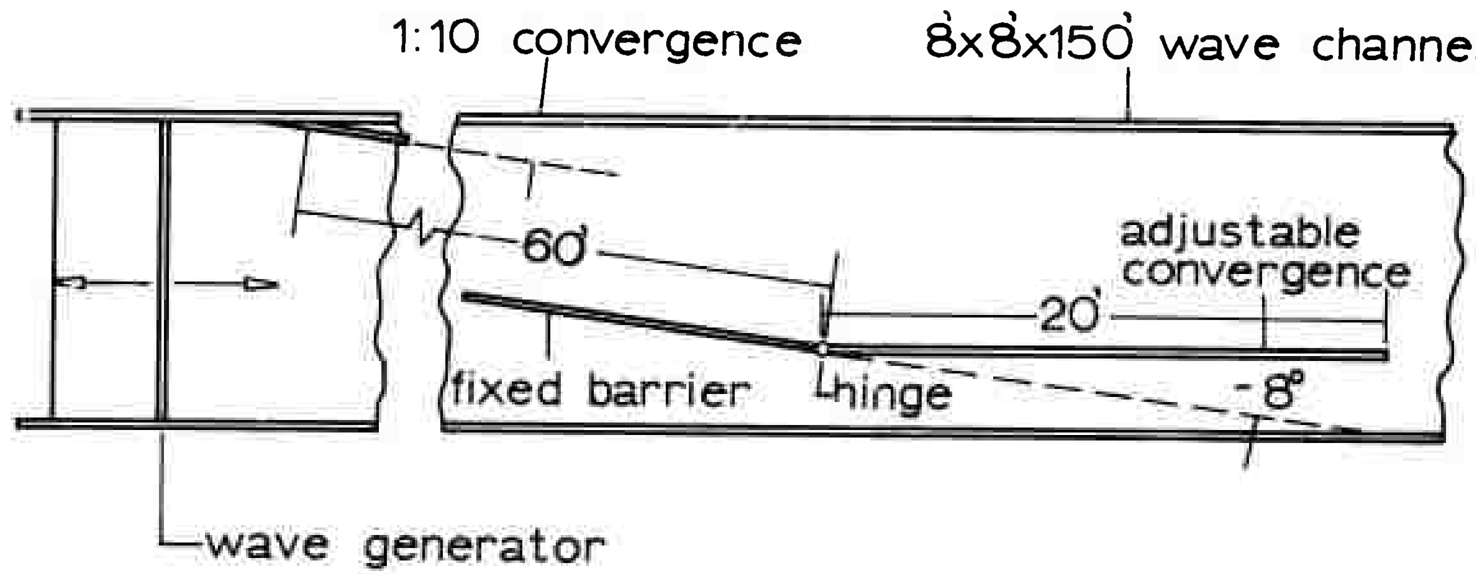

Fig. 1
Top view of 8' :: o' x 150' wave channel, showing installation of 80' barrier for converging periodic waves to the breaking point. Terminal 20' section of barrier is hinged to permit adjustment of convergent angle.

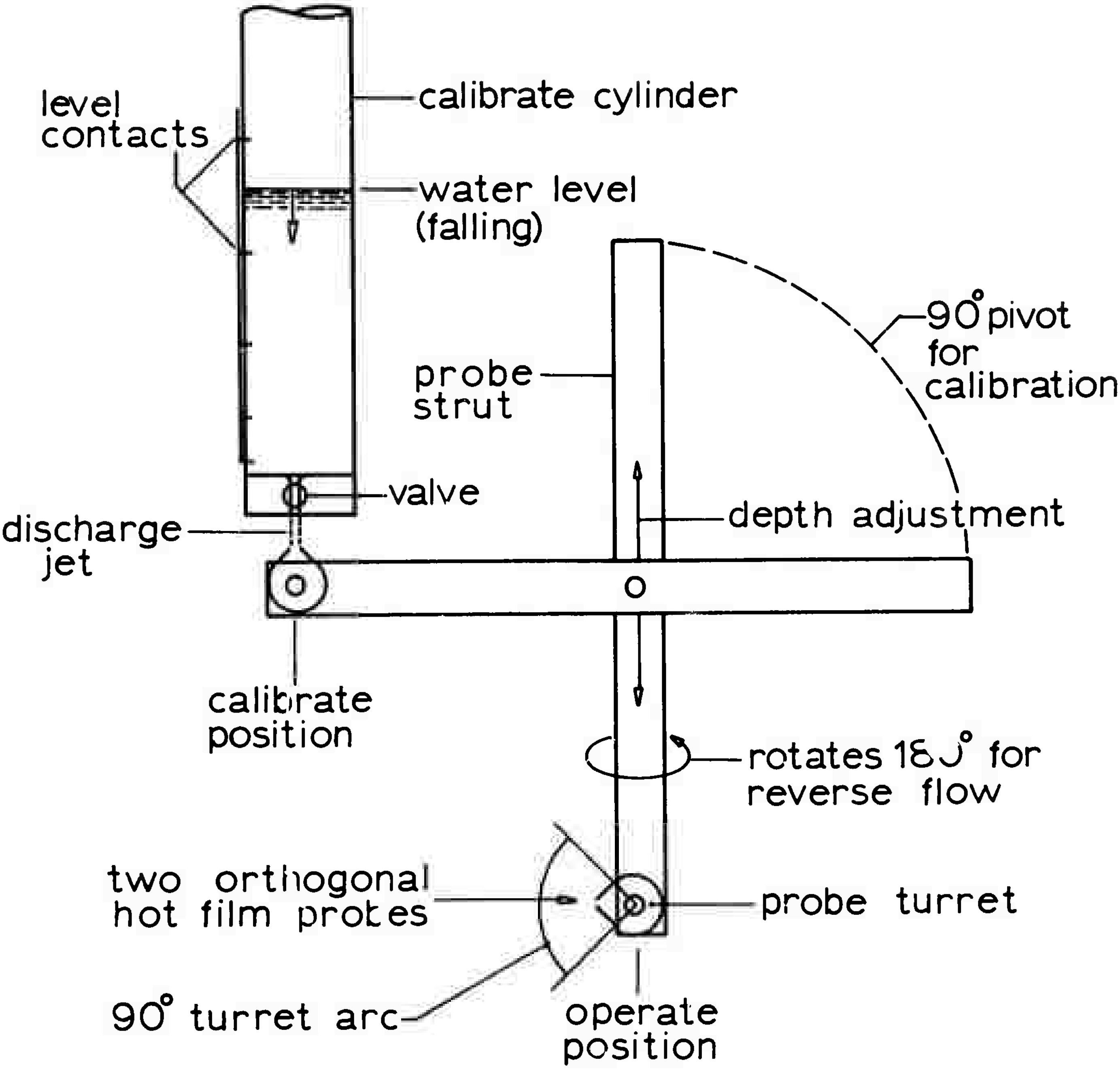

Fig. 2
Method of mounting strut for hot-film velocity probes for elevation, reversal, and calibration.

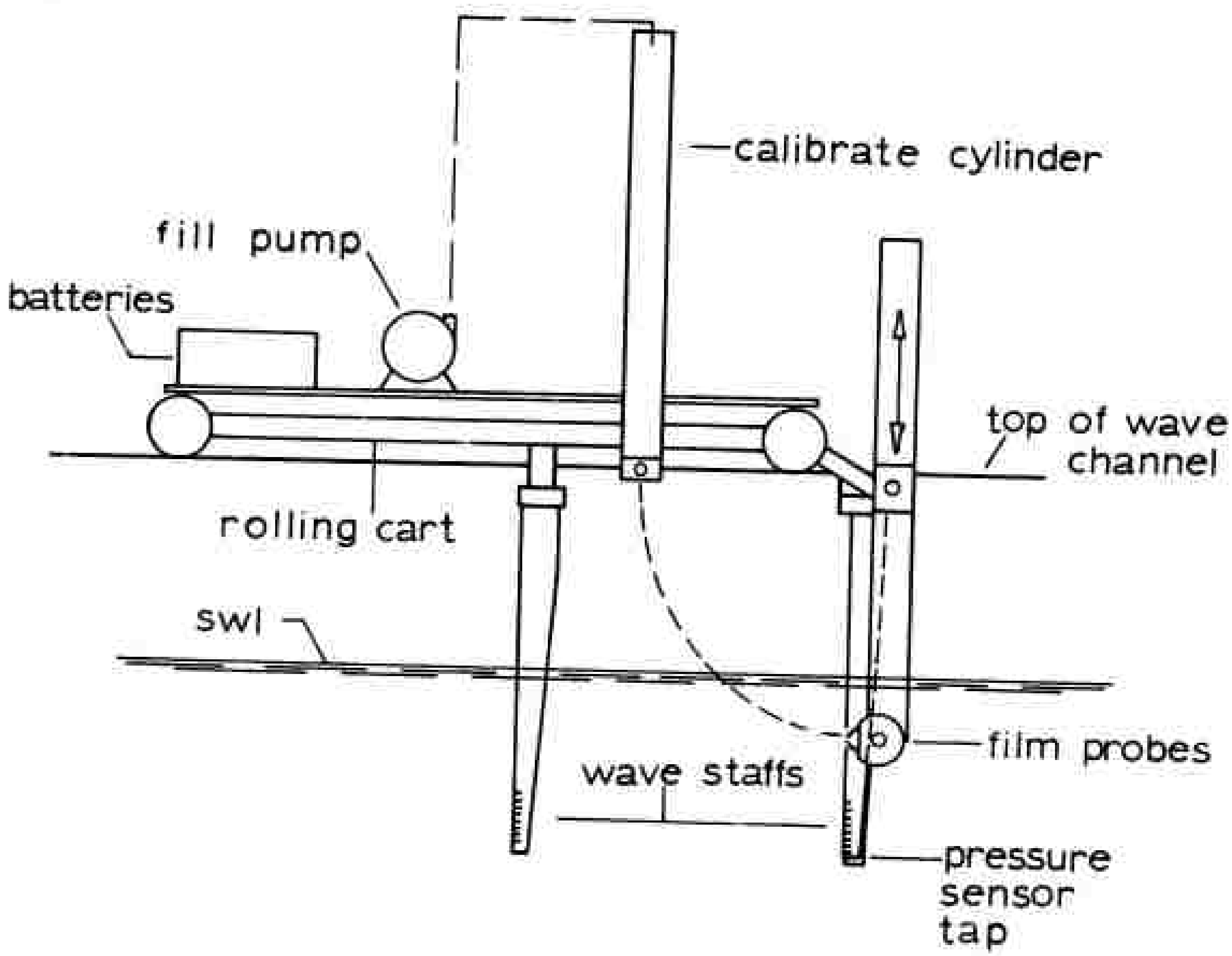

Fig. 3
Rolling cart atop wave channel carries all sensors and calibrating equipment.