Technical Report CERC-93-20
December 1993

US Army Corps of Engineers
Waterways Experiment Station

Field Study on the Effects of Waves and Currents on a Distributed Explosive Array

by Jimmy E. Fowler, Judy H. Roughton
Coastal Engineering Research Center

Abron W. Deer, David Krivich
Department of the Navy, Indian Head Division

WES

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Prepared for Department of the Navy, Indian Head Division

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Final report

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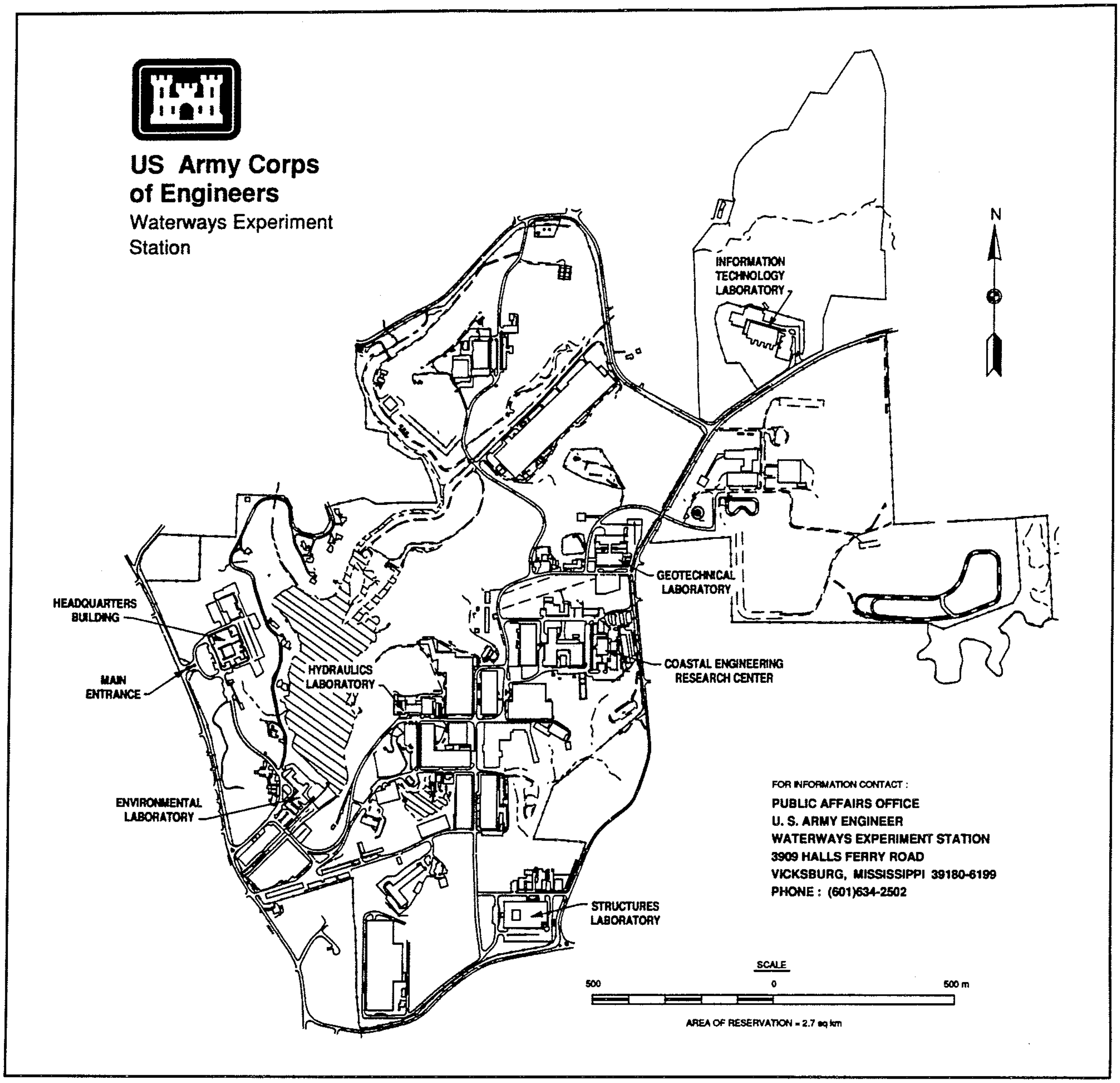

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Contents

Preface v

Conversion Factors, Non-SI to SI Units of Measurement vi

1—Background Information 1

Background 1
Objective 3
Organization of Report 3

2—Equipment, Materials, and Procedures Used in Field Test 4

Location of Field Tests 4
Compressed Air Gun 6
Inert Explosive Array 7
Marker Buoys 9
Shore-connected Tethers 9
Sensor Insertion System 9
Cameras and Videotapes 9
Deployment Sequence 10
Retrieval and Repair of Array Following Deployment 12

3—Results 14

Environmental Data 14
Nearshore Bathymetry 14
Array Deployment 17
Videotape Observations 17

4—Discussion and Summary 27

Array Stability Considerations 27
Limiting Conditions for Deployment 27
Other Deployment Considerations 28
Additional Comments 28

Appendix A: Details, Notes, and Observations A1

Appendix B: Summary of Videotape Resources B1

Appendix C: Nearshore Bathymetry of Test Site C1

Appendix D: Array Movement Analysis Drawings D1

Appendix E: Notation E1

SF 298

List of Figures

Figure 1. Artist's rendition of proposed deployment method 2

Figure 2. The Field Research Facility and location of the deployment zone 5

Figure 3. Photograph of the Coastal Research Amphibious Buggy 5

Figure 4. Photograph of the Sensor Insertion System 6

Figure 5. Photograph of compressed air gun used in FY93 tests 7

Figure 6. Inert explosive array and other payload components 8

Figure 7. Preparing the array in the compound area just prior to deployment 11

Figure 8. Launching of the array with the air gun 12

Figure 9. Cross-sectional plot of bathymetry in test area 17

Figure 10. Splashdown "footprints" for tests 1-4 18

Figure 11. Splashdown "footprints" for tests 5-8 19

Figure 12. Splashdown "footprints" for tests 9-12 20

Figure 13. Splashdown "footprints" for tests 13-14 21

Figure 14. Array movement diagram for test 2 23

Figure 15. Array movement diagram for test 13 24

List of Tables

Table 1. Summary of Video Camera Resources Used During Study . . . 10

Table 2. Environmental Data Obtained 15

Table 3. Summary of Array Movement Analyses 25

Preface

This report was prepared by the U.S. Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), and is the result of work funded by and performed for the Department of the Navy, Indian Head Division, Naval Surface Warfare Center (IHDIVNAVSURFWARCEN), Indian Head, Maryland, under the 6.2 Surf Zone Deployment Technology Project (RN155575). This research was authorized by Headquarters, U.S. Army Corps of Engineers and was conducted by Dr. Jimmy E. Fowler, Wave Dynamics Division (WDD), CERC; and Messrs. William A. Birkemeier and Eugene W. Bichner, both of CERC's Field Research Facility (FRF) Group, and Messrs. David E. Krivich and Abron W. Deer, both of IHDIVNAVSURFWARCEN. The work was carried out under the general supervision of Dr. James R. Houston, Director, CERC; Mr. Charles C. Calhoun, Assistant Director, CERC; Mr. C. E. Chatham, Chief, WDD; Mr. D. G. Markle, Chief, Wave Processes Branch; and Mr. Thomas Richardson, Chief, Engineering Development Division.

This report was prepared by Dr. Fowler, Ms. Judy H. Roughton, FRF, CERC, Mr. Krivich, and Mr. Deer. The authors acknowledge the contributions to this report of the following: Mr. J. E. Evans, Engineering Technician, CERC; and Ms. J. A. Denson, Contract Student, CERC. Assisting in the field work at the Field Research Facility were Messrs. C. F. Baron, K. K. Hathaway, P. R. Hodges, M. W. Leffler, B. L. Scarborough, C. R. Townsend III, H. Carl Miller, FRF full-time staff, and Walter E. Jones III, Jennifer L. Irish, and Guan Hong-Lee, Contract Students.

Director of WES during preparation and publication of this report was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or kelvins[1]
feet	0.3048	meters
feet per second	0.3048	meters per second
inches	2.54	centimeters
pounds (force)	4.4482205	newtons
pounds (mass)	0.4535929	kilograms
pounds (force) per square inch	1,422.0	kilograms per square centimeter

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32). To obtain kelvin (K) readings, use: K = (5/9) (F - 32) + 273.15.

1 Background Information

Background

Engineers and scientists associated with the Shallow Water Mine Countermeasures Program (SWMCM) are currently developing countermine systems to neutralize advanced and hardened mine threats in surf zone regions. One system currently under development consists of dual rockets, which deploy a large distributed explosive array. The distributed array is constructed from longitudinal detonation cord and lateral Kevlar members, dual rocket motors for deployment, and a waterborne launch platform such as the Navy's Landing Craft, Air Cushion (LCAC). Figure 1 is an artist's rendition of the proposed SWMCM system being deployed from an LCAC. Prior to the study reported herein, the dual-rocket deployment technique had only been flight tested over dry land. To investigate the effects of waves and currents on the distributed explosive system, SWMCM and engineers and scientists at the U.S. Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) participated in a two-phase research effort which began in May 1992. The initial phase consisted of a series of laboratory wave flume tests conducted at WES in Vicksburg, MS. The second phase was a series of tests using a helicopter, furnished by the Naval Air Warfare Center Aircraft Division, Patuxent River, MD, to simulate field deployments. The field tests were conducted at CERC's Field Research Facility (FRF) in Duck, NC, in accordance with SWMCM's test plan (Deer and Krivich 1993).[1] Test procedures, results, and other pertinent information for both phases of the 1992 effort are documented in Fowler et al. (1993).[2] This test series is a follow-on to the 1992 efforts and was designed to incorporate lessons learned from those efforts.

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[1] Deer, A., and Krivich, D. (1993). "6.2 Surf zone deployment, technology project in-water stability test plan," Indian Head Division, Naval Surface Warfare Center, Indian Head, MD.

[2] Fowler, J. E., Birkemeier, W., Denson, J. A., and Krivich, D. (1993). "Cooperative laboratory and field study to investigate effects of wave and current action on dual-rocket distributed explosive array deployment," Technical Report CERC-93-7, U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS.

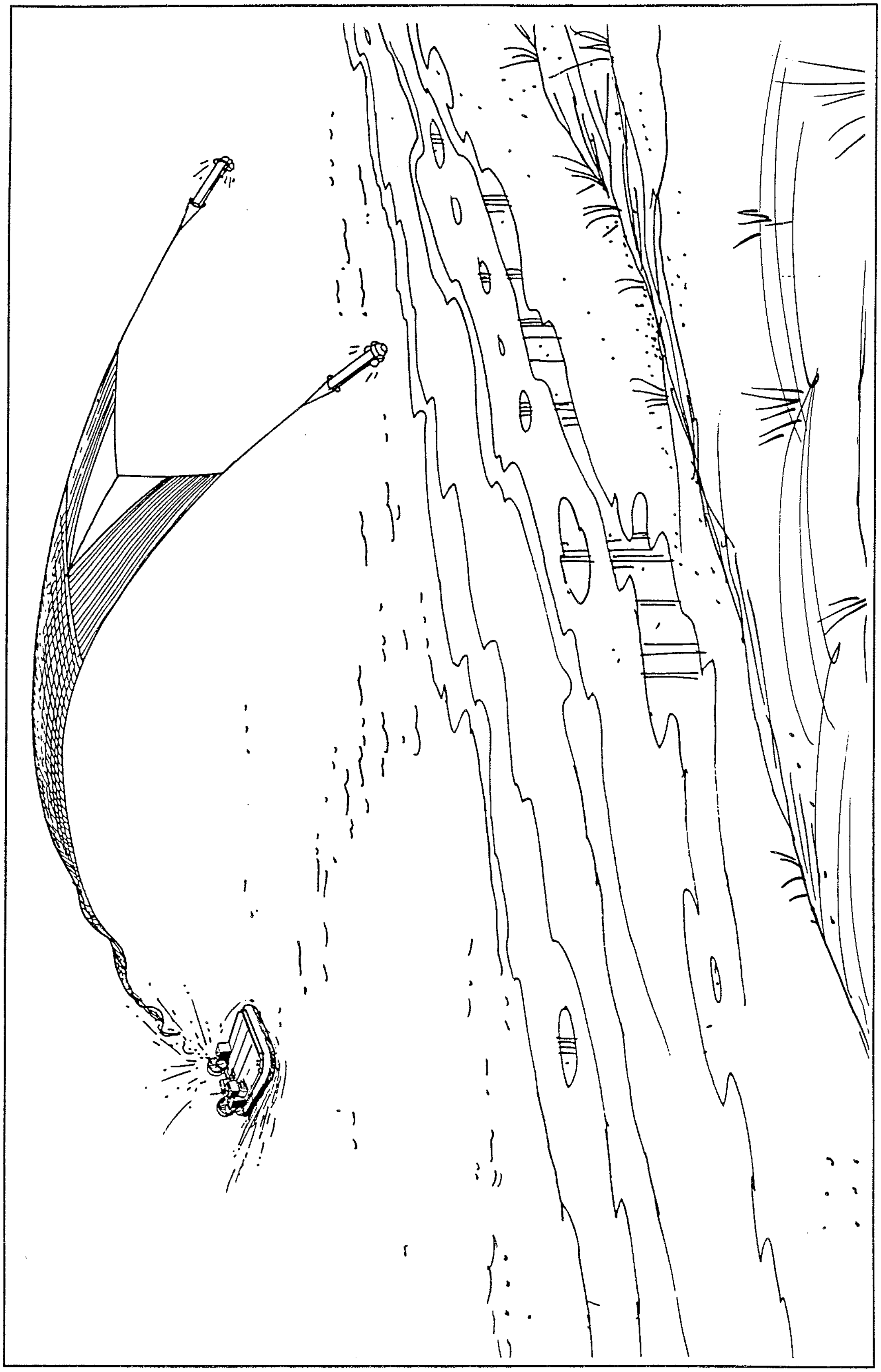

Figure 1. Artist's rendition of proposed deployment method

Objective

The objective of this project was to investigate effects of energetic sea state conditions and currents on an inert distributed explosive array.

Organization of Report

Chapter 1 contains a brief description of the project task with reference to the previous studies done in connection with this project. Materials, methods, and procedures used in the reported field tests are contained in Chapter 2. Chapter 3 presents results obtained by video, meteorological, and wave and current monitoring devices. Chapter 4 contains conclusions and recommendations regarding future studies and array deployment considerations. Notes, observations, and details relating to each of the test deployments are provided in Appendix A. Appendix B contains specifics regarding individual cameras and notes taken during each deployment. Appendix C contains bottom profiles for four survey lines that bracket the test zone for the pretest, mid-test, and posttest periods. A complete set of array movement analysis drawings is contained in Appendix D. Appendix E is a notation of the symbols and abbreviations used in this report.

2 Equipment, Materials, and Procedures Used in Field Tests

The field tests were designed to evaluate the performance of a distributed explosive array (inert) under wave and current conditions when deployed from the beach into the surf zone by a method that closely simulates the dual-rocket technique. The tests were conducted between 24 May and 4 June 1993 and used a compressed "air gun" to deploy the array. The following section describes equipment, materials, and procedures used in the study.

Location of Field Tests

The field tests were conducted at the FRF, which is located on the Atlantic Ocean in Duck, NC. The FRF facility is shown in Figure 2. This site was selected because the research pier and the observation tower offered good camera positions, instruments were available to measure appropriate environmental conditions, and the FRF is equipped to handle the deployed array. Specific FRF equipment required in the tests included a four-wheel-drive forklift, the Coastal Research Amphibious Buggy (CRAB), and a Sensor Insertion System (SIS) (Figures 3 and 4, respectively). The CRAB is a unique 35-ft-tall,[1] self-propelled tripod capable of operating in waves out to the 30-ft depth contour. The SIS is a track-mounted instrumentation support system that can be moved along the length of the pier. The SIS has a pivoting arm that can be maneuvered to position wave and current acquisition instrumentation at various depths and positions along the pier. It was used during the 1993 tests to obtain measurements of currents and waves in the surf zone near the test site. The CRAB was also used to survey the shape of the bottom across the deployment zone and to deploy reference marker placards.

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[1] A table of factors for converting non-SI units of measurements to SI units is presented on page vi.

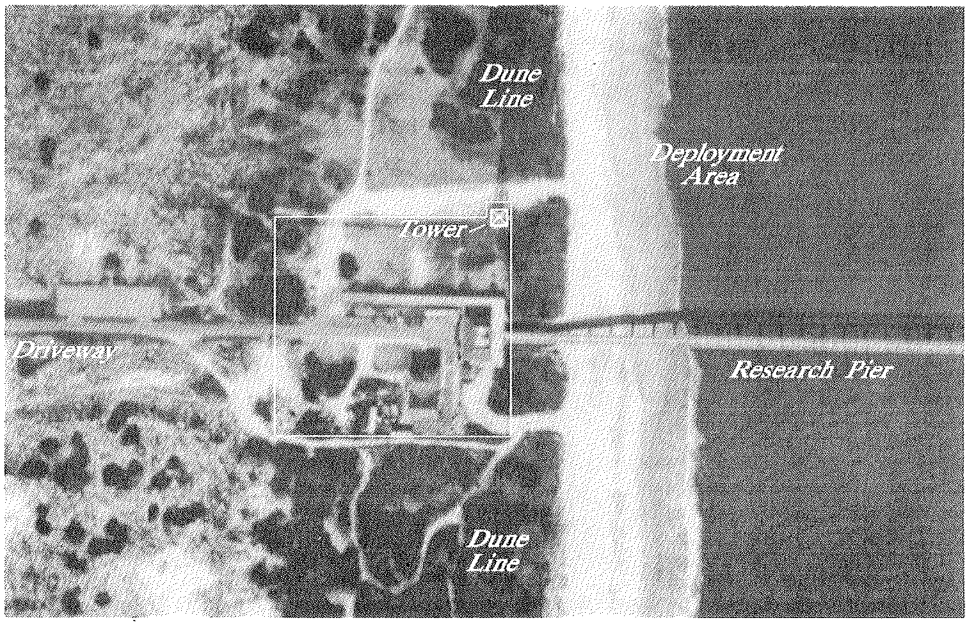


Figure 2. The Field Research Facility and location of the deployment zone

One attribute of the FRF is the long-term knowledge of the variation in the beach and nearshore bottom under changing conditions. At the FRF, the region of greatest variation extends from about the +0-ft elevation contour on the beach seaward to a depth of approximately -13 ft, a distance of 500 ft. Within this zone, the profile often is characterized by a steep bar/trough feature, which is highly mobile in the cross-shore. The natural variation of the bottom in this zone has significant implications to the performance of the distributed explosive array. Mines placed on a sandy bottom in this region can scour in and may be deeply buried as the bar develops and moves onshore or offshore. Although the bottom is less active offshore, seaward of this zone, heavy mines can scour into the bottom under the action of waves and currents. Once buried, mines will stay buried unless a deep trough develops, temporarily excavating the mines. Awareness of this variation must be accounted for in any shallow-water mine countermeasure program. Moreover, for a distributed explosive array to be most effective, it must be able to settle uniformly against the bottom and the mines. This includes settling into the trough, where buried mines are most likely to reappear, and where the longshore current is the strongest.

Figure 3. Photograph of the Coastal Research Amphibious Buggy

Figure 4. Photograph of the Sensor Insertion System

Compressed Air Gun

The air gun used in the field tests was designed and produced by the Aeroballistics Section, Wright Laboratory, Eglin Air Force Base. The double-barreled gun was designed to operate at 2,000 psi and produce a minimum muzzle velocity of 275 ft/s with each of two 100-lb_m projectiles. This velocity is necessary to simulate the pick-up velocity of the 1/3-scale Mk 22 Mod 4 Tractor Rocket Motors used in previously conducted overland flight tests. Primary components of the air gun are as follows:

- 2,000-psi pressure chamber
- Twin barrels having 30-deg angle between each
- One 100-lb_m projectile per barrel
- Bridle pick-up collars
- Compressed air tanks/cascade system
- 155-mm Howitzer trailer

The projectiles were designed to be captured by bridal collars as the projectiles exited the muzzle. The bridle collars in turn were attached to the array harness. Momentum from the projectiles provided the energy to deploy the array. The compressed air gun is shown in Figure 5.

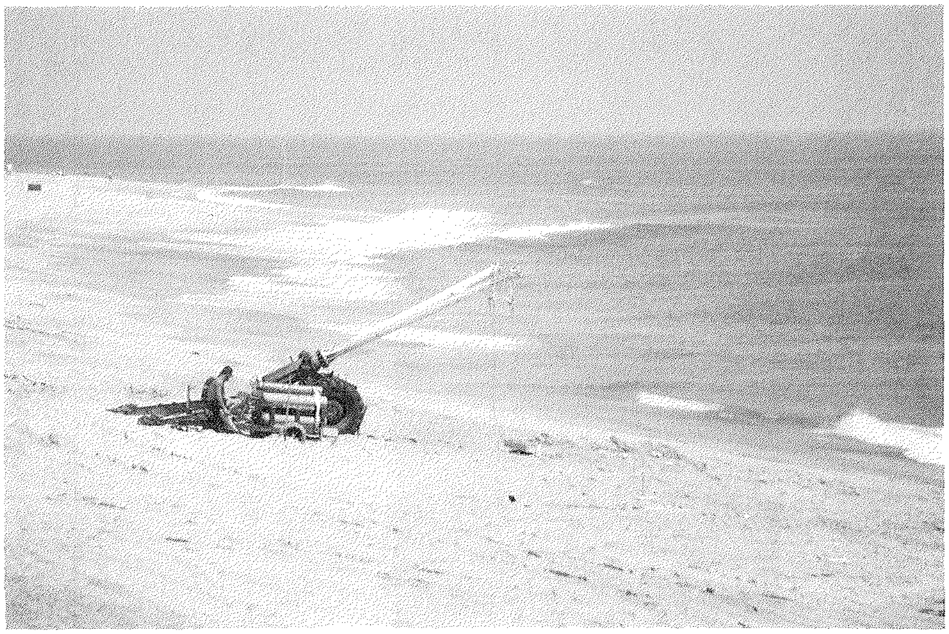


Figure 5. Photograph of compressed air gun used in FY 93 tests

Inert Explosive Array

The array tested at the FRF during FY 1993 was configured from individual panels, which measured 90 ft wide by 50 ft long. The panels were constructed by the Dahlgren Division, Naval Surface Warfare Center, White Oak Detachment. Longitudinal members of the array were made from inert 417-grain/ft SX-2 detonating cord having 0.377-in. diameter with Kevlar overbraid. Lateral members of the panels maintain 12-in. spacing between longitudinal members and are spaced at 24-in. intervals along the length of the array. Lateral members are 1/8-in.-wide Kevlar flat braid. Hot glue joints with resultant tensile strength of 1,200 lb_f were used to mate longitudinal and lateral members. Figure 6 shows the array and other payload components used in the deployments. The panels are designed such that they may be connected to each other by 1/4-in. steel spring hook chain connectors. Using this arrangement, varying sizes of arrays could be configured with 90-ft widths (e.g., 90 ft x 50 ft, 90 ft x 100 ft, or 90 ft x 150 ft). The towing bridle/harness arrangement consists of a dual 25-ft, 3/8-in., 7x19 steel wire ropes connected to each pick-up collar. The bridle is connected to the array by the harness's 19 distributed lines.

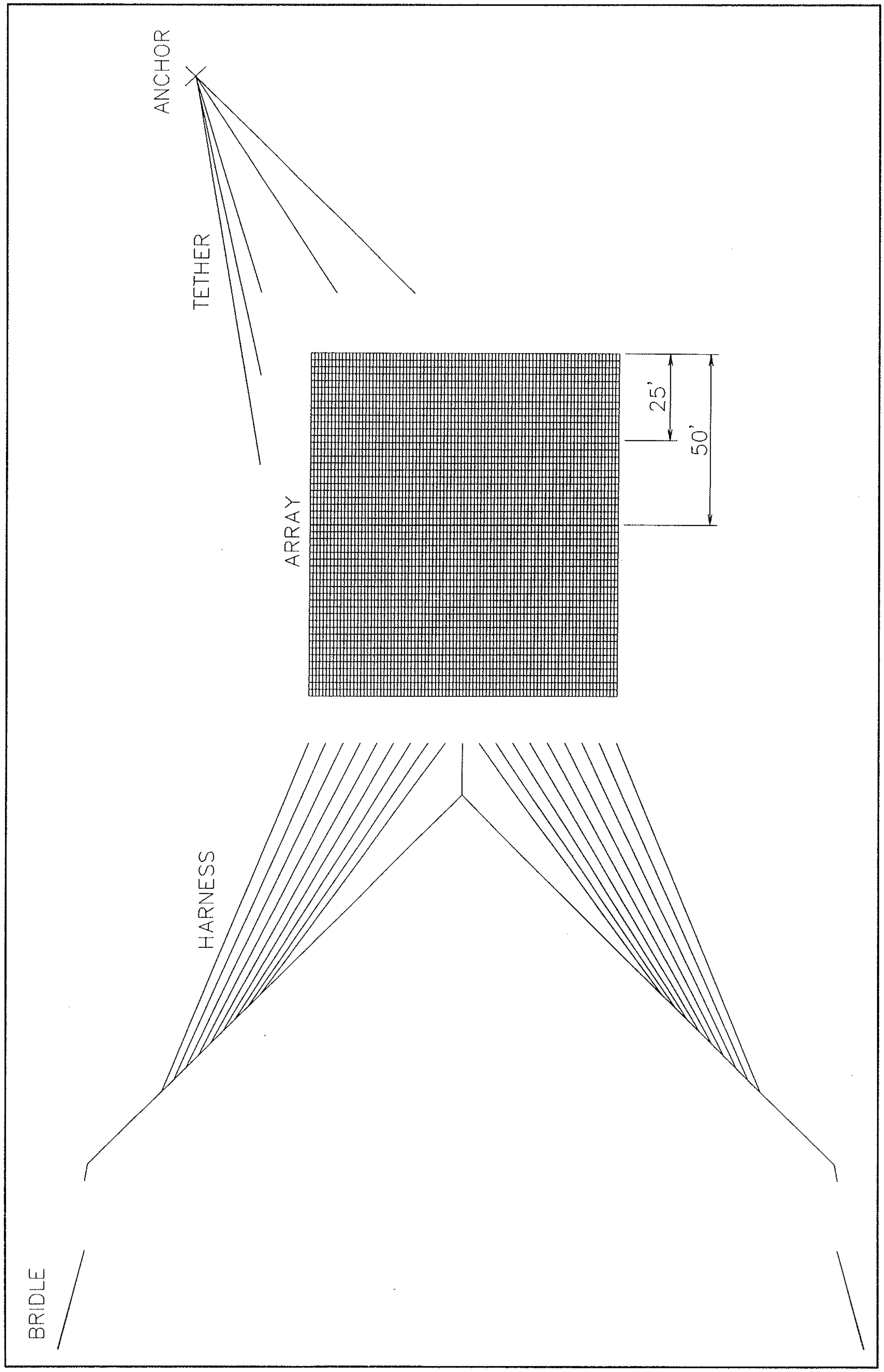


Figure 6. Inert explosive array and other payload components

Marker Buoys

Since a critical aspect of the field tests was observing the expansion and movements of the array immediately following deployment, a series of small buoys were attached along the shore-perpendicular perimeters of each panel. To be effective, the buoys had to be attached to the array such that they did not interfere with the deployment of the array. A number of different schemes were tried; however, the most effective technique was to use 6-ft × 4-ft white oval buoys attached to the array with 1/8-in.-wide Kevlar cord and 1/4-in. steel quick link chain connectors. The quick links were used for easy attachment and removal from the array. The length of the cord was adjusted to approximately twice the expected water depth. The buoy line was first hand-coiled around the perimeter of the buoy and then partially buried in the sand alongside the array. The buoys were attached after the array was reefed and ready for deployment. Care was taken to ensure that the buoys all lay to the outside of the array and that they would not interfere with the array as it was deployed. On average, 70 percent of the buoys successfully deployed without becoming entangled in the array.

Shore-connected Tethers

Results from the FY 92 test series indicated that a tethering/anchoring system was required to maintain stability under a combination of wave and longshore current conditions. In light of this, a tethering scheme was developed and tested during the FY 93 test series. For the 1993 tests, tethers were constructed from a combination of 1/2-in. nylon braid and 1/2-in. double esterlon lines and attached to the perimeter of the shore-parallel sides of the array as shown in Figure 6. The shore ends of the tethers were anchored on the beach with two 20-lb Danforth Sand Anchors.

Sensor Insertion System

The SIS was used to monitor nearshore current direction and magnitude as well as nearshore wave height and period. The SIS is a track-mounted device that can be positioned at any point along the length of the pier and has a pivoting arm/boom. This boom can be maneuvered vertically and horizontally to position wave and current acquisition instrumentation at various depths on either side of the pier.

Cameras and Videotapes

Videotapes were the primary method for monitoring and studying the deployments. A combination of S-VHS and VHS tape formats was used. Each test was recorded from several locations, including the observation tower

(S-VHS), the helicopter (S-VHS), the pier (VHS), and the dune immediately landward of the air gun (VHS). To provide reference points to assist in monitoring in-water movement of the array, a number of placards were placed at surveyed locations on the beach and on vertical pipes in the water, both north and south of the test area. Key positioning points on the compressed air gun were also surveyed for each deployment. The FRF's 125-ft-high tower provided a good vantage point for four cameras, which were operational during each deployment. One of the cameras was remotely operated and could be controlled from the FRF building by the test directors. It was used for close zooms of the array as it was deployed. Two black and white videos were also taken from the top of the tower, primarily for the image processing analysis method for tracking movement of the array. Another video camera provided views from additional angles, from the deck of the pier, the crest of the dune immediately behind the air gun, and from midway up the tower. An S-VHS video camera was used to tape deployments from the helicopter's perspective during all but three of the deployments. Table 1 is a summary of video camera resources used during the tests. Appendix B contains specifics regarding individual cameras and notes taken during each deployment.

Table 1
Summary of Video Camera Resources Used During Study

Camera ID	Location	Format	Availability
BWTEL	Top of tower	Black/white Super VHS	All tests
BWWIDE	Top of tower	Black/white Super VHS	All except 7
COLORPAN	Top of tower	Super VHS	All
COLORFX	Top of tower	Super VHS	All
HELO	Inside Helicopter	Super VHS	All except 12-14
FOWLER	Various positions - Mid-tower - Deck of pier - Dune crest behind air gun	VHS	

Deployment Sequence

Although considerable thought went into developing the deployment plan prior to the arrival at the FRF, the actual test procedure evolved during the test period. In this section details of the procedure ultimately adopted are described. The CRAB was used to survey the bottom across the test zone on 24 May 1993, 28 May 1993, and again at the end of the tests on 4 June 1993. At the start of each day, access to the FRF oceanfront was restricted by posting signs and fencing off the beach at the north and south property limits. Concurrently, a crew of people prepared the array for movement to and placement on the beach in its prelaunch configuration. At the same time, the SIS was readied for environmental data collection. The video camera crew also was getting ready, loading tapes and testing the cameras. Simultaneously, the Eglin Air Force crew prepared the air gun for movement to the beach area. This involved testing valves and electrical connections, pressurizing the tanks, and preparing the bridle collars. Once these preliminary tasks were accomplished, the air gun was towed to the beach and positioned in accordance with water level at the time of the deployment.

Within the compound area, the array was carefully reefed onto a 6-ft x 12-ft plywood platform as shown in Figure 7. This was done in such a method as to duplicate overland flight tests conducted earlier in FY 93. Once the air gun was in place, the array was transported to the beach and placed between the gun and the water line. Shore-based anchors were attached to the shore end of the array, extended, and buried. For Tests 4-14, the tethers, described on page 9, were attached to the array and the shore-based anchors to assist in stabilizing the array. The perimeter buoys were then coiled and attached to the array. When everything was confirmed ready (array, SIS, video cameras, and helicopter) by radio to the test directors, the helicopter was moved to an appropriate location above the test area. Once the helicopter was positioned, the gun crew cleared the beach and pressurized the air gun main pressure chamber. When the proper amount of pressure was obtained, the countdown sequence was begun and the slugs were fired (Figure 8). Near the end of the tests, it was discovered that placement of Visqueen sheets between the array folds significantly decreased damage to the hot glue connections.

Figure 7. Preparing the array in the compound area just prior to deployment

Figure 8. Launching of the array with the air gun

Retrieval and Repair of Array Following Deployment

Once the gun was fired and the array was deployed, the ground crew returned to the landward end of the array to check the anchor lines and make visual observations, particularly concerning marker buoy and array performance. Movement of the array was recorded by the video cameras. The retrieval process began with the beach crew releasing the array from the anchors and securing the landward end of the array with a single long line. The helicopter then landed over the landward end of the array and one of the crew members connected the line to the towing/release mechanism. As the helicopter took off, the array was lifted out of the water and flown to an open stretch of beach. Instead of simply lowering the array into a pile, the pilot was able to lay the array along the dry beach before releasing it and returning to the landing area. The array handlers then began their efforts, first removing the perimeter buoys and then loading the array onto a truck for transport back to the compound area. Once the array was returned to the FRF compound area, it was spread out on the pavement and examined for damages to the hot glue joints and the detonation cord. Damaged areas were repaired by installing new hot glue joints and wrapping damaged sections of detonation cord with electrical tape.

3 Results

Fourteen deployments were made during the test period. The following section is a presentation of the various data measurements and results obtained during each of the test deployments.

Environmental Data

Table 2 lists the primary environmental measurements that were obtained during the study. The first column gives the deployment or test number. The next column contains the date and the exact time of the deployment in terms of Eastern Standard Time. The third and fourth columns give the wind speed, in meters per second, and direction, respectively, as measured on the pier. Columns 5 and 6 give the current speed, in meters per second, and current direction, respectively, as measured by instruments on the SIS and timed float observations. Column 7 gives the wave height (H_{mo}) in meters as measured by a wave gauge on the SIS. Column 8 is the best estimate of the water depth at the seaward edge of the array, given in meters. Wave periods in seconds and wave directions given relative to True North may be obtained in Appendix B. Wave direction is the direction from which the wave is approaching. For reference, shore-normal waves at the FRF arrive from 70 deg. To augment SIS measurements, the movement of tossed floats was timed in the drop zone.

Nearshore Bathymetry

The CRAB was used to obtain bathymetric data just prior to, at the mid-point of, and just following the test sequence. This was accomplished using a Zeiss Elta-2 total station with reflectors mounted on the operator's platform of the CRAB. Profiles extend seaward from the established baseline behind the dune to a water depth of about 10 m. Figure 9 shows profiles measured in the vicinity of the test area. Appendix C contains profiles obtained at locations north and south of the test area.

Table 2
Environmental Data Obtained

Test Number	Date Time	Wind Speed m/s	Wind Direction	Current Speed, m/s	Current Direction	Wave Height, m	Approximate Depth at Seaward Edge, m
1	5-24-93 15:18	7.5	SSW	0.22 0.26	N	0.21	1.0
2	5-25-93 10:45	6.6	SW	0.12 0.02	N	0.22	1.8
3	5-26-93 09:05	5.7	NW	0.04 0.07	N	0.26	<1.0
4	5-27-93 09:22	3.5	NW	0.10 0.00	N	0.24	2.0
5	5-27-93 15:07	2.5	SE	0.12 0.10	N	0.22	2.0
6	5-28-93 10:35	5.9	SW	0.13 0.09	N	0.27	2.0
7	5-31-93 09:46	8.6	SE	0.26 0.20	N	0.30	0
8	6-01-93 10:02	8.09	NW	0.46 0.27	S	0.89	1.0
9	6-01-93 14:58	6.81	NE	0.75 0.32	S	1.52	0

(Continued)

Table 2 (Concluded)

Test Number	Date Time	Wind Speed m/s	Wind Direction	Current Speed, m/s	Current Direction	Wave Height, m	Approximate Depth at Seaward Edge, m
10	6-02-93 09:13	3.6	NW	0.19 0.03	S	0.50	1.0
11	6-02-93 14:40	3.1	SE	0.08 0.09	N	0.50	2.0
12	6-03-93 10:10	5.3	S	0.24 0.39	N	0.38	<1.0
13	6-03-93 14:30	5.3	S	0.56 0.59	N	0.56	2.0
14	6-04-93 11:52	0.8	NE	0.32 0.60	N	0.33	2.0

Note: Bottom values in Current column are SIS data; top numbers reflect beach current observations based on timed float measurements.

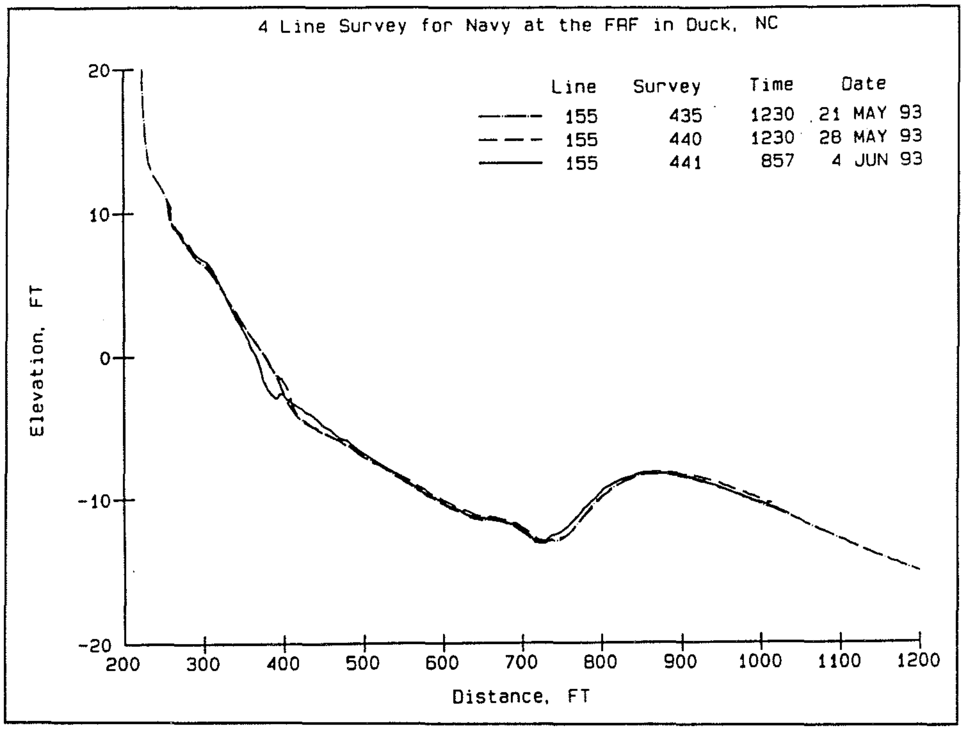


Figure 9. Cross-sectional plot of bathymetry in test area

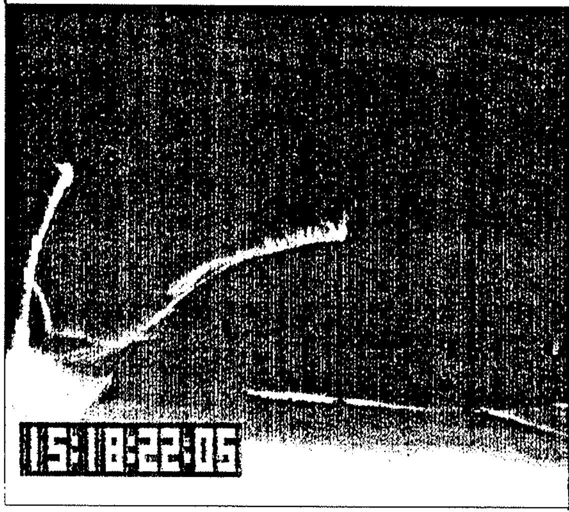
Array Deployment

Due to problems caused by failure of the bridle collars to seat tightly on the projectiles, only 7 of the 14 deployments were considered successful. The best method for judging whether a launch successfully simulated what might be expected with the dual-rocket method involved examination of the "footprint" left by the array as it impacted the water following the firing sequence. Figures 10-13 show the "footprint" for each of the 14 deployments. Based on examination of these footprints, deployments were judged as being either successful or unsuccessful.

Videotape Observations

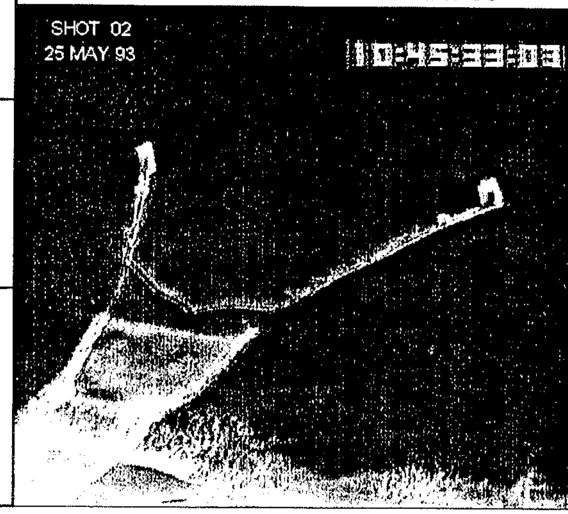
The primary method of recording and tracking in-water movements of the deployed arrays was video cameras placed as described previously on pages 9 and 10 and in Table 1. Movement rates were determined by deploying the array into a pre-defined zone marked by highly visible placards on the beach and mounted on pipes in the water. Coordinates of the placards are then related to movement of the perimeter buoys, which were attached to the array just prior to each deployment. The initial configuration of the array was determined by the "footprint" caused by the splash when the array first touched the

SHOT 01 — 24 MAY 93



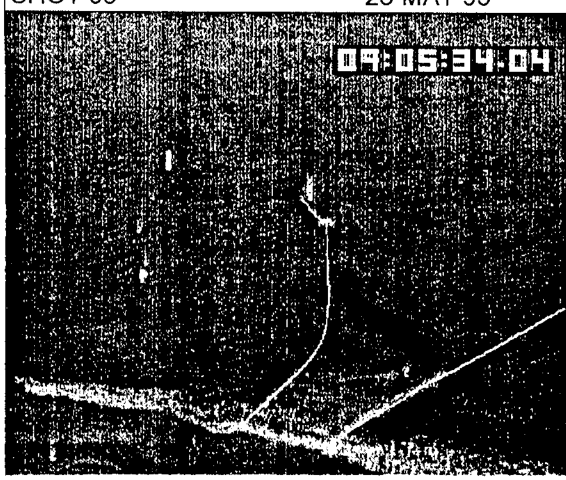
SHOT 01	
SIS DATA:	Hmo 0.21 m
CURRENT:	Speed 0.26 m/s Direction north
ANEMOMETER EOP:	Speed 7.48 m/s Direction SSW

SHOT 02 — 25 MAY 93



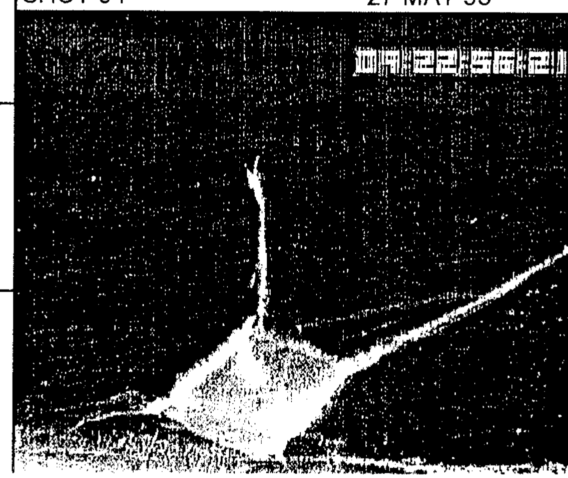
SHOT 02	
SIS DATA:	Hmo 0.22 m
CURRENT:	Speed 0.02 m/s Direction north
ANEMOMETER EOP:	Speed 6.61 m/s Direction SW

SHOT 03 — 26 MAY 93



SHOT 03	
SIS DATA:	Hmo 0.26 m
CURRENT:	Speed 0.07 m/s Direction north
ANEMOMETER EOP:	Speed 5.70 m/s Direction NW

SHOT 04 — 27 MAY 93



SHOT 04	
SIS DATA:	Hmo 0.24 m
CURRENT:	Speed 0 m/s Direction n/a
ANEMOMETER EOP:	Speed 3.54 m/s Direction NW

Figure 10. Splashdown "footprints" for tests 1-4 (tests 2 and 4 were judged to be successful)

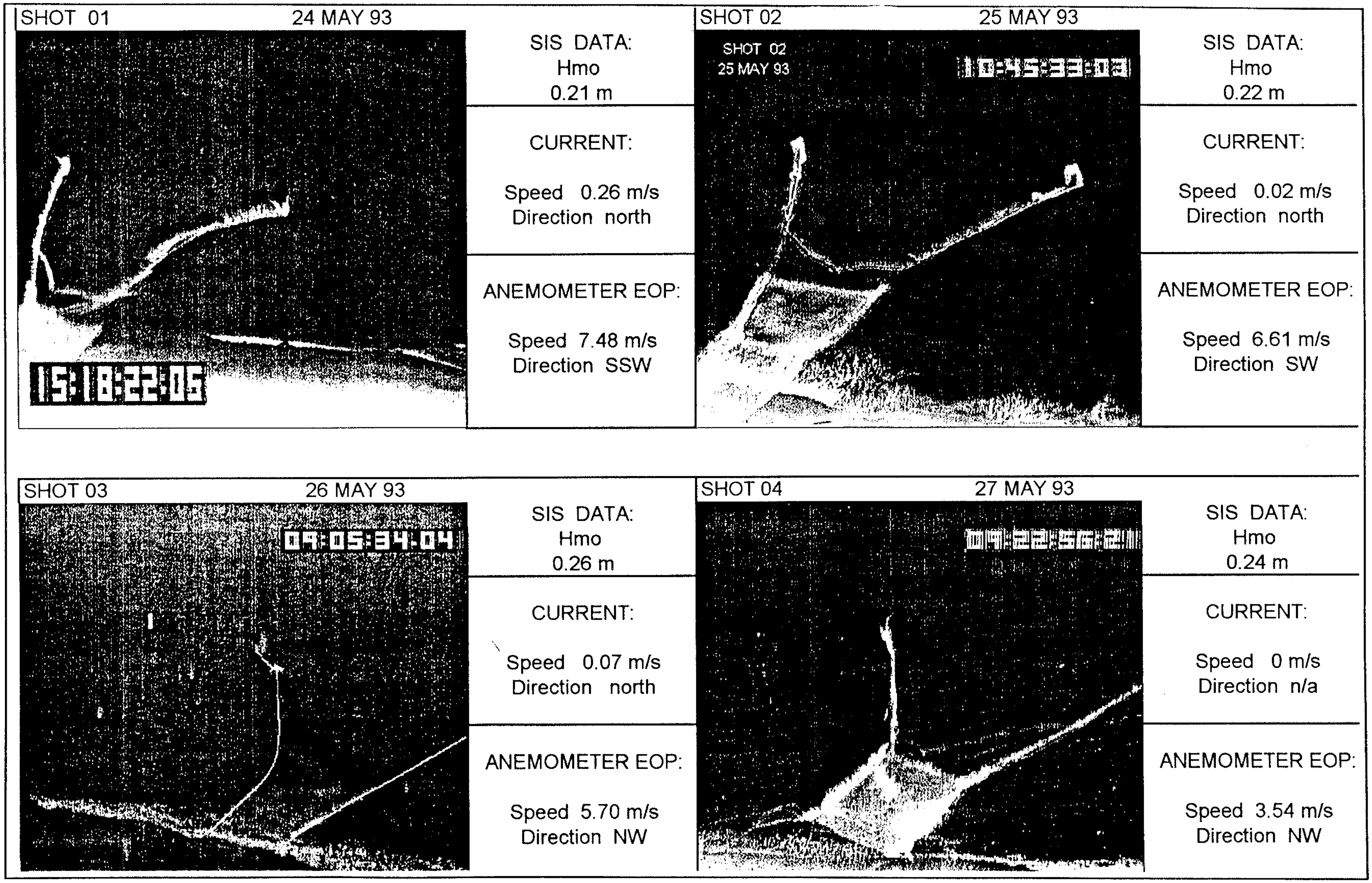


Figure 11. Splashdown “footprints” for tests 5-8 (tests 5 and 6 were judged to be successful)

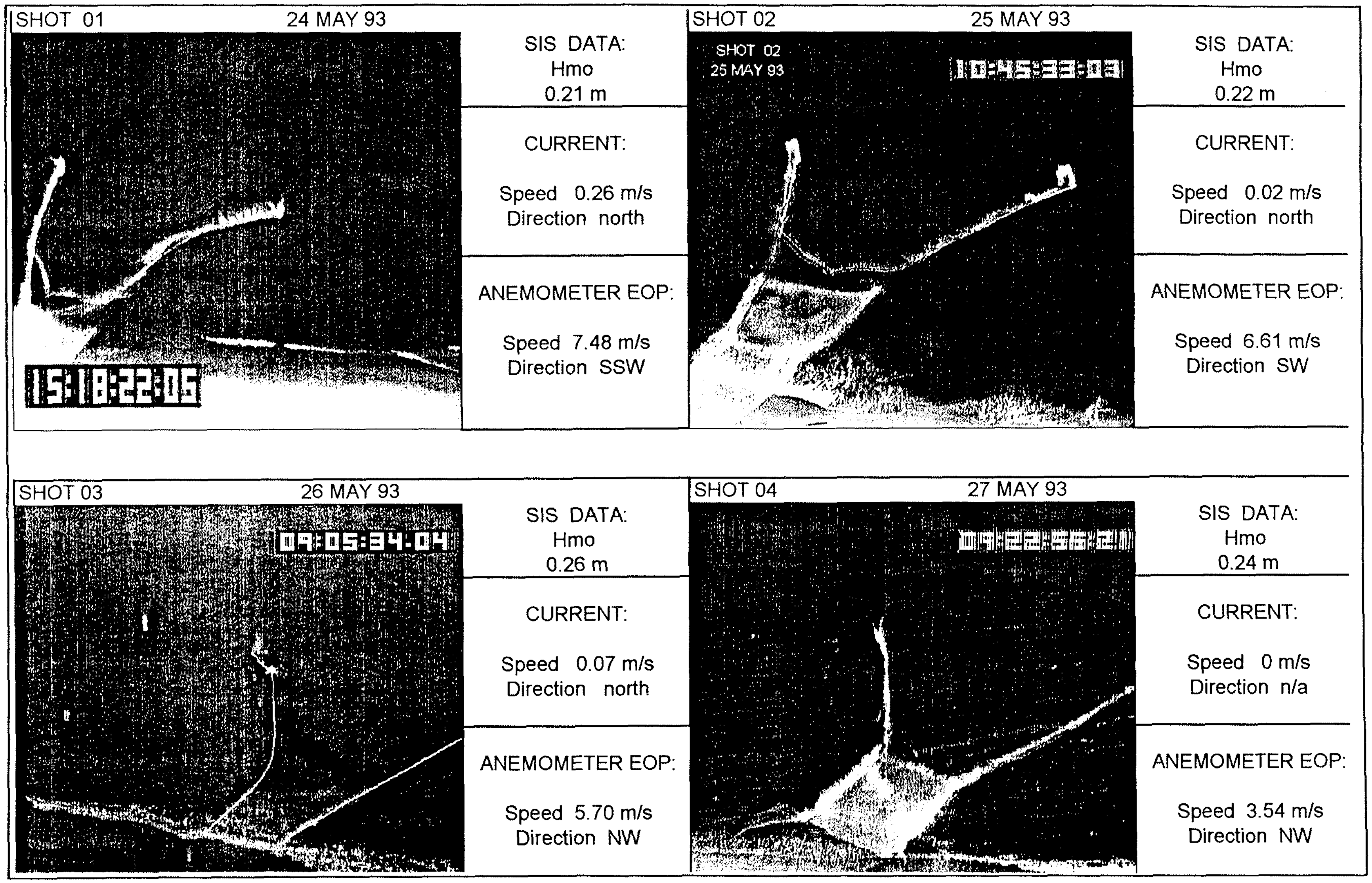


Figure 12. **Splashdown "footprints" for tests 9-12 (test 11 was judged to be successful)**

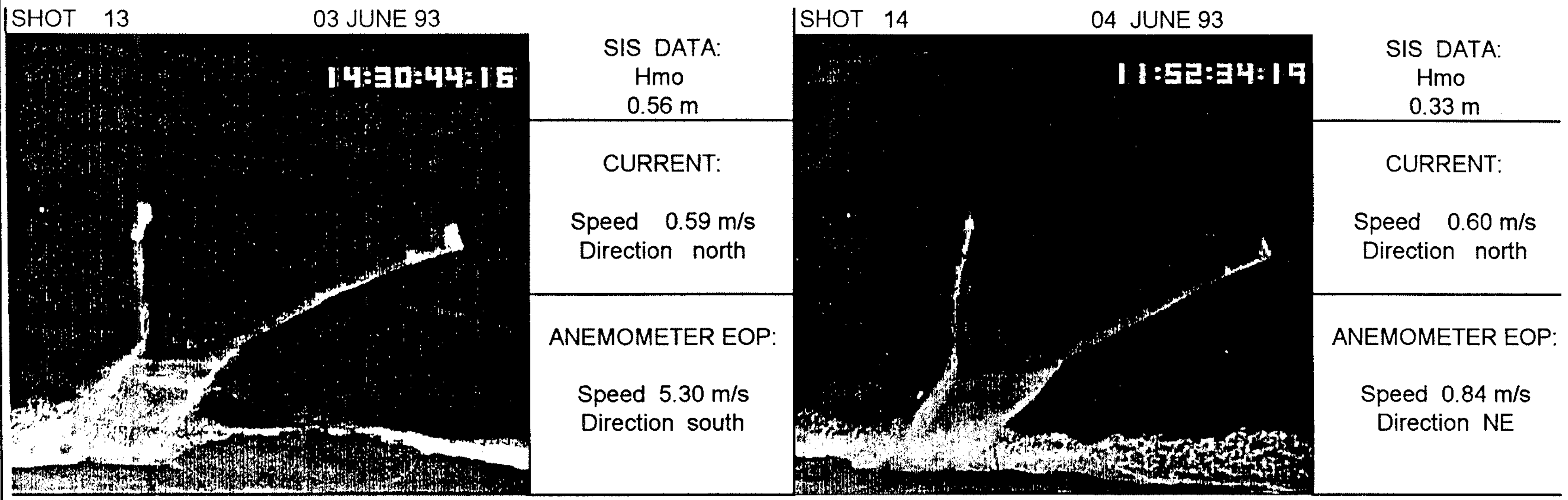


Figure 13. Splashdown "footprints" for tests 13-14 (tests 13 and 14 were judged to be successful)

water. The method involved use of a video image processing system and a clock superimposed on the screen to track movements of the perimeter buoys. Using this system, buoys that deployed correctly were digitized (located) at time intervals of 5, 15, 30, 60, and 90 sec after splashdown. Individual buoy movements are tracked in time by assigning symbols in the following manner:

5 seconds	- ○	60 seconds	- ▷
15 seconds	- ⫩	90 seconds	- ⌓
30 seconds	- □		

Examples of this analysis are given below in Figures 14 and 15. Figure 14 shows the analysis for test 2, a test which showed minimal array movement following deployment. This can be seen by examining temporal positions for each of the individual floats. As can be seen in Figure 14, very little movement was evident for the floats that deployed correctly, particularly beyond the swash zone. Figure 15 shows the analysis for test 13, which exhibited considerably more movement, particularly in the first 15 - 30 sec. As shown in the figure, the array moved northerly approximately 5 m during the 15 - 30 sec following splashdown, whereupon its movement was halted/stabilized by the tethering system. Splashdown configurations are shown with the dashed lines. Approximated "final" configurations of the array are shown with the solid heavy lines. The "final" configurations are based on best estimates made in consideration of measured currents and buoy movements. Table 3 presents a summary of results of this analysis for the array deployments with notations concerning success of deployment. A complete set of the figures used for this analysis is presented at Appendix D for all deployments considered to have been successfully launched by the air gun.

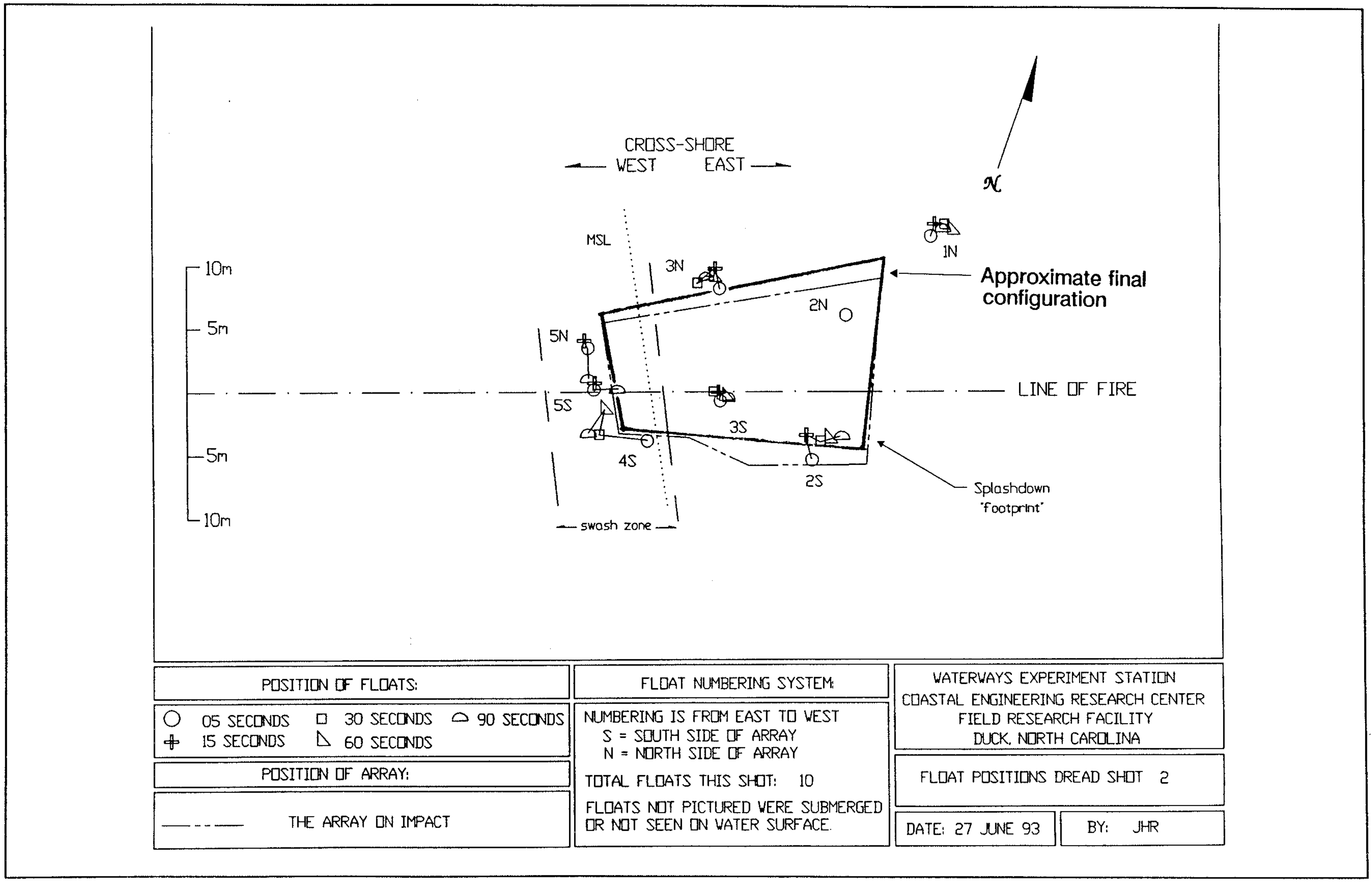


Figure 14. Array movement diagram for test 2

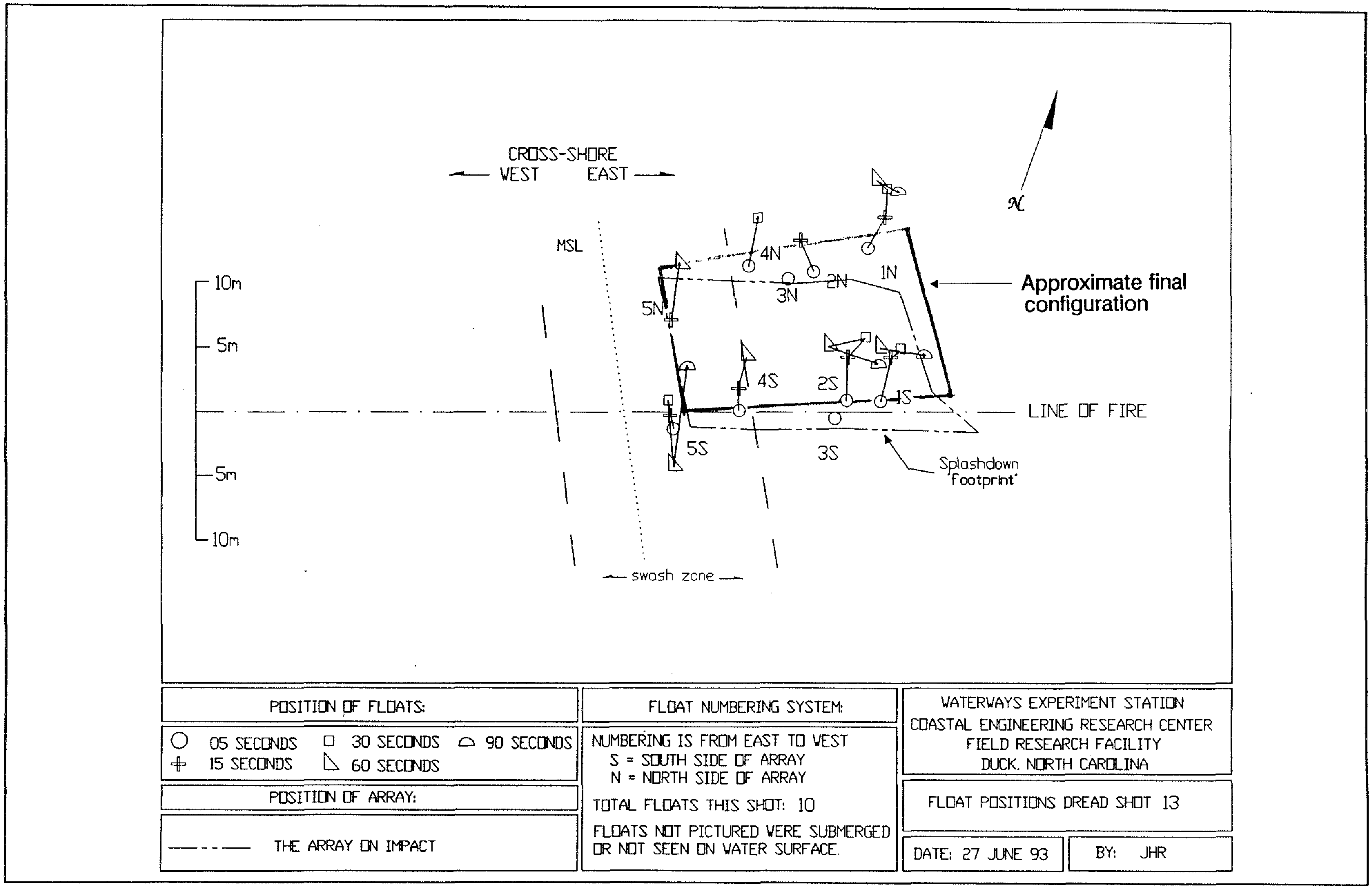


Figure 15. Array movement diagram for test 13

Table 3
Summary of Array Movement Analyses

Test Number	Success of Launch	Current speed and direction m/s	Movement of array meters	Remarks
1	Unsuccessful	0.22, N	N/A	Southern projectile lost, less than ⅓ of array made it into the water. Used 3 panels.
2	Successful	0.12, N	Minimal	Projectiles only pulled approximately 80 ft into the water. Some floats not visible. Used 3 panels.
3	Unsuccessful	0.04, N	N/A	Northern projectile lost, less than ½ of array made it into the water. Used 3 panels.
4	Successful	0.10, N	5	Used 2 panels vice 3 (100ftx90ft). Some floats became entangled in harness and array.
5	Successful	0.12 N	3	Some floats barely visible. Used 2 panels.
6	Successful	0.13, N	Minimal	Nearly all floats visible. Good deployment. Used 2 panels.
7	Unsuccessful	0.26, N	N/A	Both projectiles lost, none of array made it into the water. Used 2 panels. Tethers attached at 25 ft and 50 ft.
8	Unsuccessful	0.46, S	N/A	Southern projectile lost, less than ½ of array made it into the water. Deployment appeared to be affected somewhat by strong winds. Used 2 panels. Tethers attached at 25 ft and 50 ft.
9	Unsuccessful	0.75, S	N/A	Less than ⅓ of array made it into the water. Used 2 panels. Tethers attached at 25 ft and 50 ft.
10	Unsuccessful	0.19, S	N/A	Both projectiles lost, less than ½ of array made it into the water. Used 2 panels. Tethers attached at 25 ft and 50 ft.
11	Successful	0.08, N	5	Good deployment. Used 2 panels. Tethers attached at 25 ft and 50 ft.

(Continued)

Table 3 (Concluded)

Test Number	Success of Launch	Current speed and direction, m/s	Movement of array meters	Remarks
12	Unsuccessful	0.24, N	N/A	Southern projectile lost, less than ¼ of array made it into the water. Used 2 panels. Tethers attached at 25 ft and 50 ft.
13	Successful	0.56, N	5	Alternate panel was used at landward position. Panel was made of nylon jacket covering simulated det cord. Some floats tangled in array and harness. Used 2 panels. Tethers attached at 25 ft and 50 ft.
14	Successful	0.32, N	9	Alternate panel used in seaward position. Good deployment. Used 2 panels. Tethers attached at 25 ft and 50 ft.

4 Discussion and Summary

Array Stability Considerations

Generally, the objectives of this field test were satisfied. Although no successful deployments were made at higher sea states, sufficient deployments were made to assess the performance of the tethers and configuration of the array itself. Regarding stability in the water, the wider array tested in FY 93 was more stable in the water than the array tested in FY 92. Tests 1-6, conducted without the tethering lines and the three deployments judged successful, showed little movement. Unfortunately, waves and currents experienced during the 1993 tests were considerably less energetic than those experienced in 1992, and hard conclusions regarding stability of the 1993 version cannot be drawn. Tests 7-14 were conducted with tether lines fastened to the shore-perpendicular perimeter at points 25 ft and 50 ft from the landward edge. Even during the most energetic conditions tested (deployments 13 and 14) array movement was stabilized by the combination of the 100-lb_m projectiles and the tethering system (Refer to Appendix D for array movement analyses).

Limiting Conditions for Deployment

Experience gained in the laboratory study reported in Fowler et al. (1993),[1] based solely on wave action, indicates that sea state 3 is a limiting condition for use of the array without additional weights or anchors. Field tests conducted at Duck during 1992 and 1993 further reinforce this conclusion. The 1992 field tests provided eye-opening insight into the effects of longshore current on the proposed system. Extreme waves (upper sea state 2 and greater) and currents were not experienced during the tests conducted in 1993.

[1] Fowler, J. E., Birkemeier, W., Denson, J. A., and Krivich, D. (1993). "Cooperative laboratory and field study to investigate effects of wave and current action on dual-rocket distributed explosive array deployment," Technical Report CERC-93-7, U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Vicksburg, MS.

Other Deployment Considerations

Although rip currents are ephemeral features not consistently found on the world's beaches, they offer clear advantages for array usage. First, the offshore-flowing current would help extend the array seaward from the rocket anchors while reducing the longshore deformation. Moreover, rip current channels provide the deepest water access to the beach face and, if currents are not overwhelming, are ideal for an amphibious landing. Unfortunately, identifying the location of rip currents is difficult. Identification of rip channels and other nearshore features using remote sensing is a subject of ongoing ONR studies being conducted at the FRF and elsewhere.

Additional Comments

Based on observations during laboratory and field tests, additional items need to be addressed before distributed explosive arrays can be successfully deployed from sea to shore in a wave/current environment. Among these are:

a. Can tethers be used in the sea-to-shore deployment method? The tethers seemed to successfully handle effects of longshore currents.

b. Can point weights be added to the array and successfully launched by dual-rocket motors?

c. Can even wider arrays be used successfully? Field tests indicate that wider arrays might be more stable in the surf zone environment.

Items a., b., and c. must be addressed by further study (either in a laboratory or field environment) before the challenges of deploying a distributed explosive array in a Sea State 3 wave/current environment will be fully evaluated.

Appendix A
Details, Notes, and Observations

This appendix contains notes, observations, and details relating to each of the test deployments made during the 24 May 1993 - 4 June 1993 test series. Test number, date, location, and time of launch (EDST) are recorded at the top of each form. Test conditions, including air gun specifics, meteorological, and wave/current information also are noted. Finally, specifics relating to system setup and tethering arrangements are included as drawings or notations.

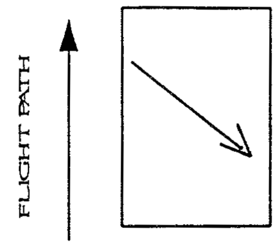
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 5/24/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

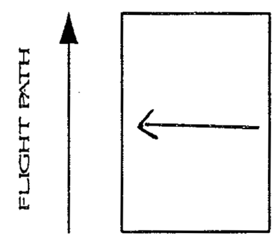
TIME OF FIRING: 1618
TEST NO: 1

TEST CONDITIONS

CHAMBER PRESSURE: 1700 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 30°
WIND SPEED: 3.13 mph
TEMPERATURE: 82° F
WEATHER CONDITIONS: Clear
WAVE HEIGHTS (DEEP/SURF): 1.48 ft
CURRENT SPEED (DEEP/SURF): 0.75 ft/s



WIND DIRECTION

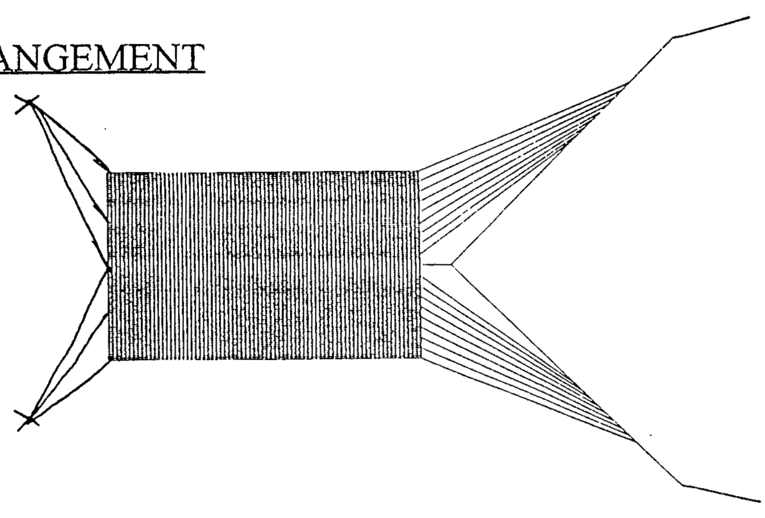


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 150'
NO. OF PANELS: 3
SYSTEM DESCRIPTION: 3 90' wide x 50' long inert det cord Panels. 6 tether lines on aft end of array attached landward to 2 anchors. Tether design #1.

TETHER ARRANGEMENT



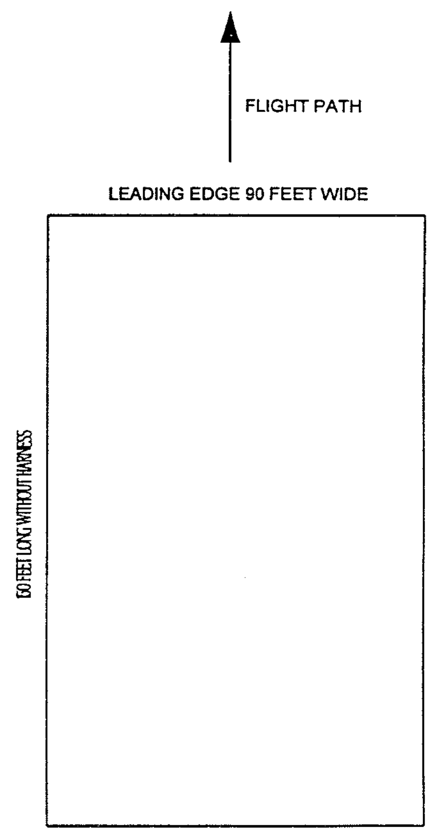
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min

NOTES: 1½ panels deployed: Lost south slug near tower on pier.



POST TEST CONFIGURATION

Test No. 1

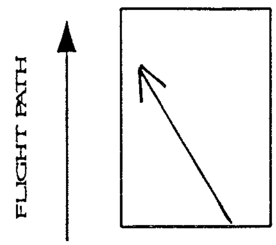
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 5/25/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

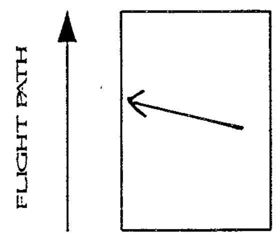
TIME OF FIRING: 1145
TEST NO: 2

TEST CONDITIONS

CHAMBER PRESSURE: 1700 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 30°
WIND SPEED: 3 mph
TEMPERATURE: 81° F
WEATHER CONDITIONS: Clear
WAVE HEIGHTS (DEEP/SURF): 1.5 ft
CURRENT SPEED (DEEP/SURF): 0.43 ft/s



WIND DIRECTION

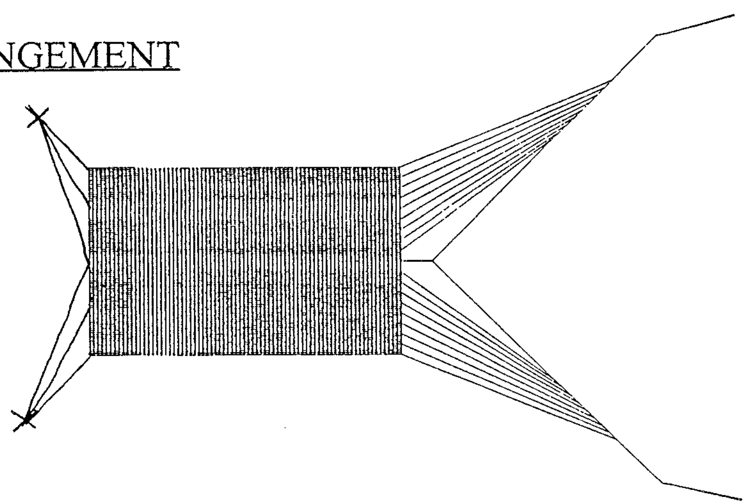


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 150'
NO. OF PANELS: 3
SYSTEM DESCRIPTION: Tether design #1 used on aft end.

TETHER ARRANGEMENT



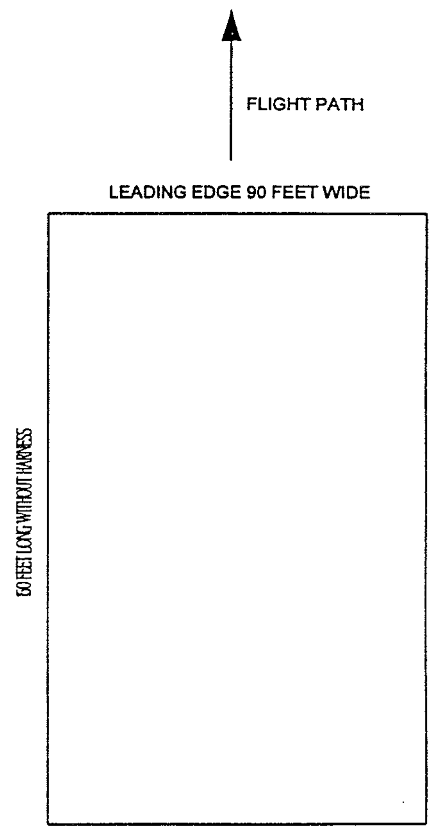
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min

NOTES: 1½ panels deployed: Low pressure valve leak on gun. Firing pressure reduced to approximately 1650 psi. Both slugs remained attached. Array remained stable under low current condition.



POST TEST CONFIGURATION

Test No. 2

6.2 IN-WATER STABILITY TESTS

PRE-TEST DATA SUMMARY

TEST DATE: 5/26/93

TEST LOCATION: FRF, DUCK, NC

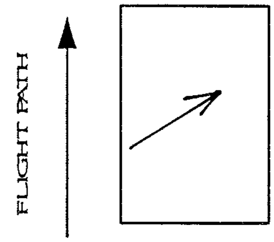
TEST DIRECTOR: B. DEER

TIME OF FIRING: 1005

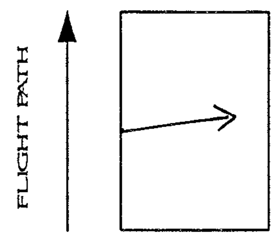
TEST NO: 3

TEST CONDITIONS

CHAMBER PRESSURE: 1800 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 30°
WIND SPEED: 3 mph
TEMPERATURE: 66° F
WEATHER CONDITIONS: Cloudy
WAVE HEIGHTS (DEEP/(SURF)): 1.5 ft
CURRENT SPEED (DEEP/(SURF)): 0.13 ft/s



WIND DIRECTION

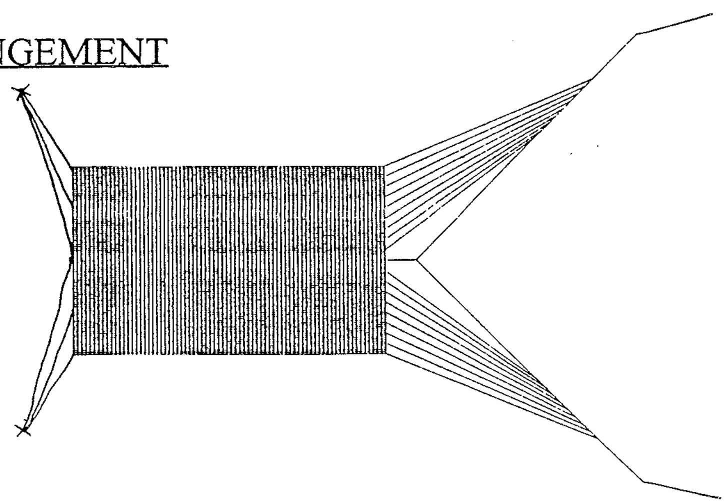


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 150 ft
NO. OF PANELS: 3
SYSTEM DESCRIPTION: Tether design #1 on aft end.

TETHER ARRANGEMENT



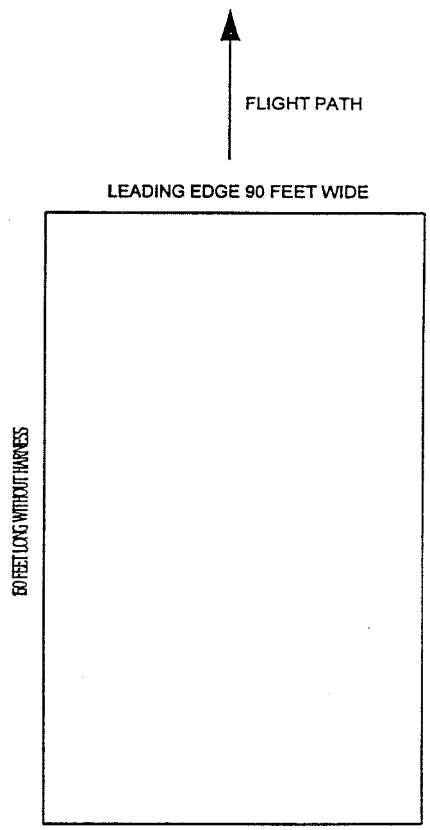
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min

NOTES: 1½ panels deployed: North slug lost. Gun misfired due to leak in seco valve.



POST TEST CONFIGURATION

Test No. 3

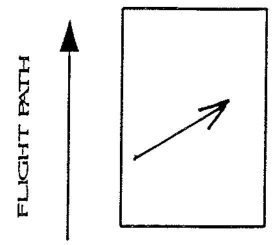
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 5/27/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

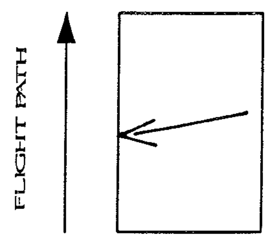
TIME OF FIRING: 1023
TEST NO: 4

TEST CONDITIONS

CHAMBER PRESSURE: 1700 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 25°
WIND SPEED: 3.35 mph
TEMPERATURE: 82.4°F
WEATHER CONDITIONS: Clear
WAVE HEIGHTS (DEEP/SURF): 1.48 ft
CURRENT SPEED (DEEP/SURF): 0.33 ft/s



WIND DIRECTION

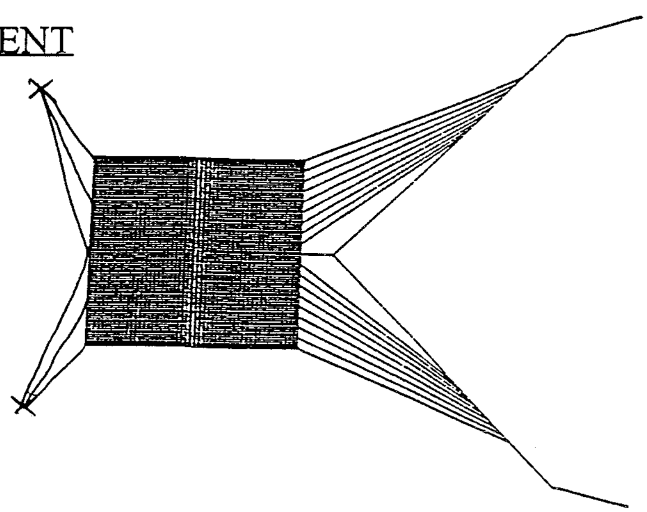


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #1 on aft end. System length reduced to 100. Basket added to collar ropes in order to attempt slug capture.

TETHER ARRANGEMENT



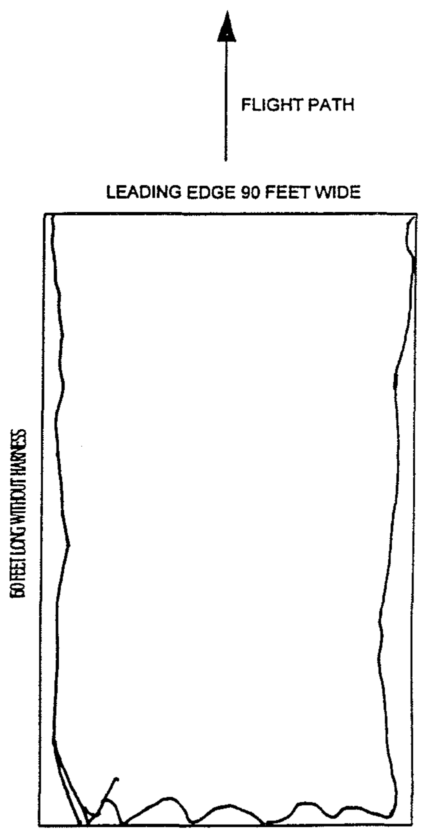
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min

NOTES: Full deployment of array. Tension achieved on rear tethers. Entire array entered water. North slug lost but recovered by FRF personnel.



POST TEST CONFIGURATION

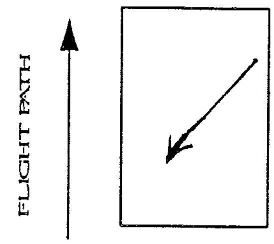
Test No. 4

6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 5/27/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

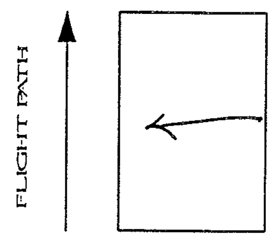
TIME OF FIRING: 1607
TEST NO: 5

TEST CONDITIONS



WIND DIRECTION

CHAMBER PRESSURE: 1700 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 25°
WIND SPEED: 1.34 mph
TEMPERATURE: 76.5° F
WEATHER CONDITIONS: clear
WAVE HEIGHTS (DEEP/SURF): 1.45 ft (SURF circled)
CURRENT SPEED (DEEP/SURF): 0.39 ft/s

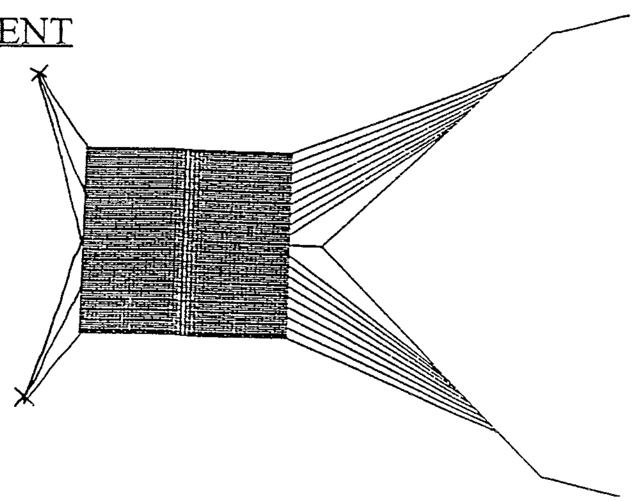


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #1 on aft end.

TETHER ARRANGEMENT

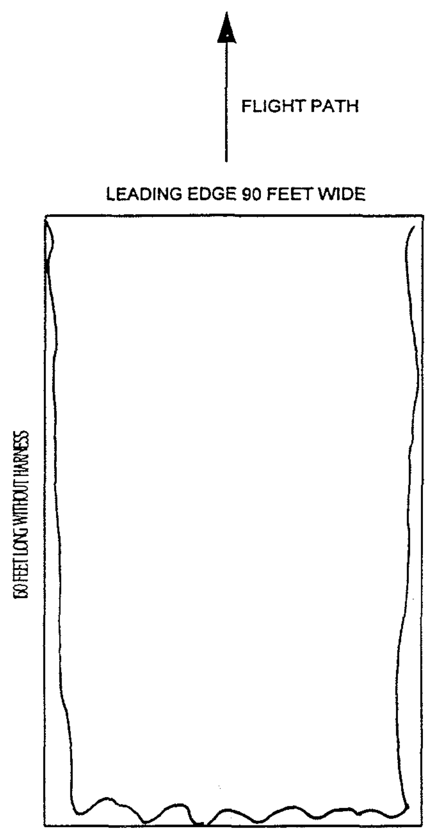


6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min



NOTES: Full array deployment. Tension on tethers. South shell lost, but recovered.

POST TEST CONFIGURATION

Test No. 5

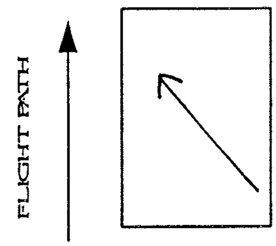
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 5/28/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

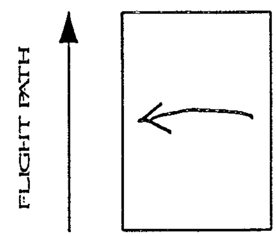
TIME OF FIRING: 1237
TEST NO: 6

TEST CONDITIONS

CHAMBER PRESSURE: 1800 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 25°
WIND SPEED: 2.5 mph
TEMPERATURE: 75-92°F
WEATHER CONDITIONS: Clear
WAVE HEIGHTS (DEEP/SURF): 1.54 ft
CURRENT SPEED (DEEP/SURF): 0.39 ft/s



WIND DIRECTION

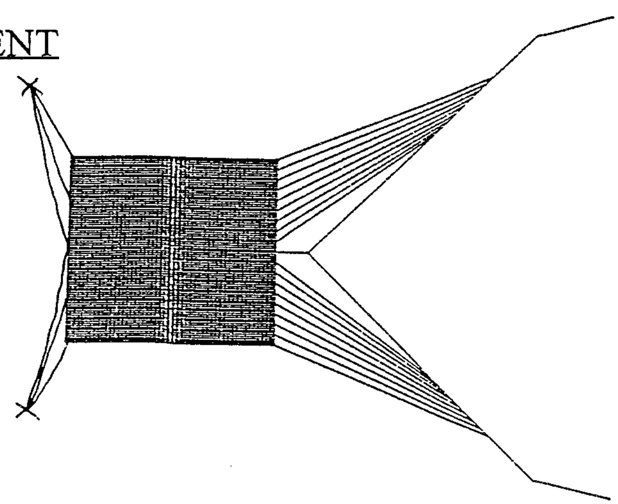


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #1 with anchors moved 5ft seaward of original launch position.

TETHER ARRANGEMENT



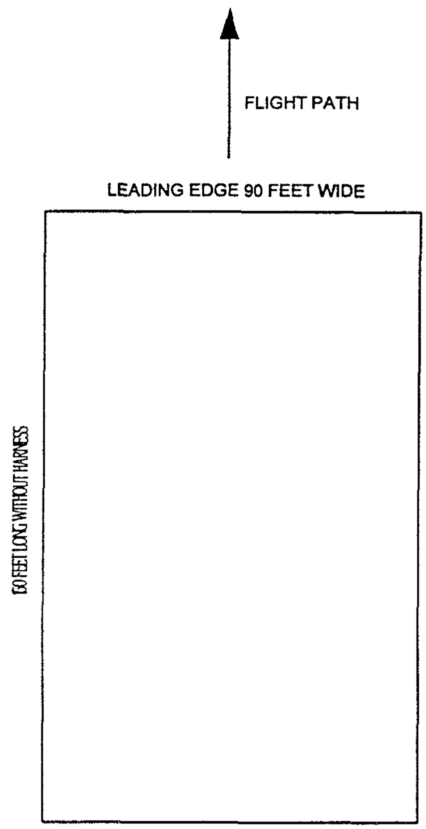
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min

NOTES: Full array deployment. Both slugs lost.



POST TEST CONFIGURATION

Test No. 6

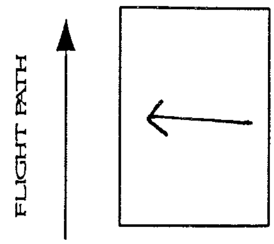
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 5/31/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

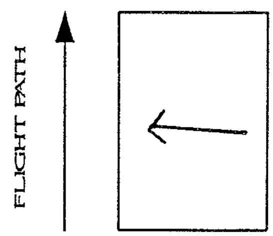
TIME OF FIRING: 1046
TEST NO: 7

TEST CONDITIONS

CHAMBER PRESSURE: 1800 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 25°
WIND SPEED:
TEMPERATURE: 62.06° F
WEATHER CONDITIONS: Cloudy
WAVE HEIGHTS (DEEP/SURF): 1.84 ft
CURRENT SPEED (DEEP/SURF): 0.85 ft



WIND DIRECTION

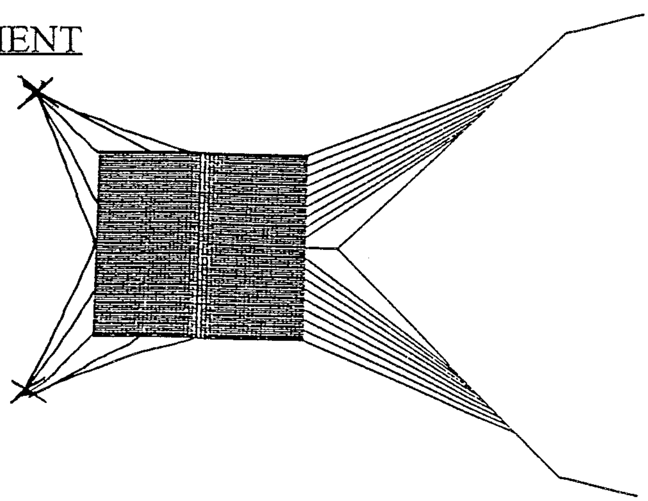


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #2. Aft end Tethered as with design #1 with tethers 25 ft. and 50 ft. from landward end attached to sides.

TETHER ARRANGEMENT



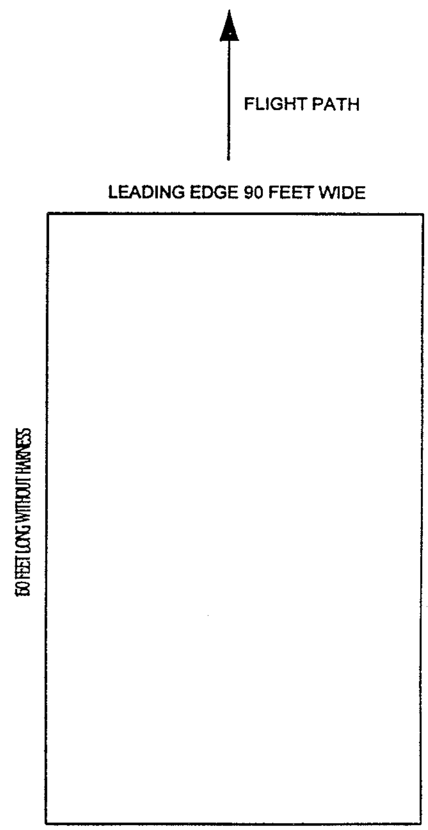
A14

6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER:



NOTES: 1½ panels deployed. Both slugs lost.

POST TEST CONFIGURATION

Test No. 7

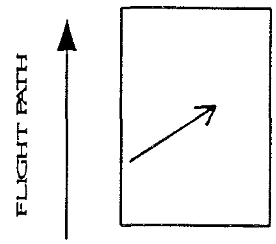
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 6/1/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

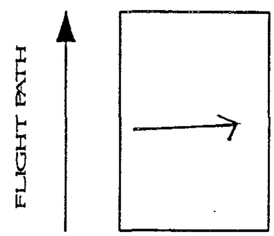
TIME OF FIRING: 1102
TEST NO: 8

TEST CONDITIONS

CHAMBER PRESSURE: 1500 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 30°
WIND SPEED: 3.62 mph
TEMPERATURE: 56.12°F
WEATHER CONDITIONS: Cloudy
WAVE HEIGHTS (DEEP/SURF): 3.25 ft
CURRENT SPEED (DEEP/SURF): 1.51 ft/s



WIND DIRECTION

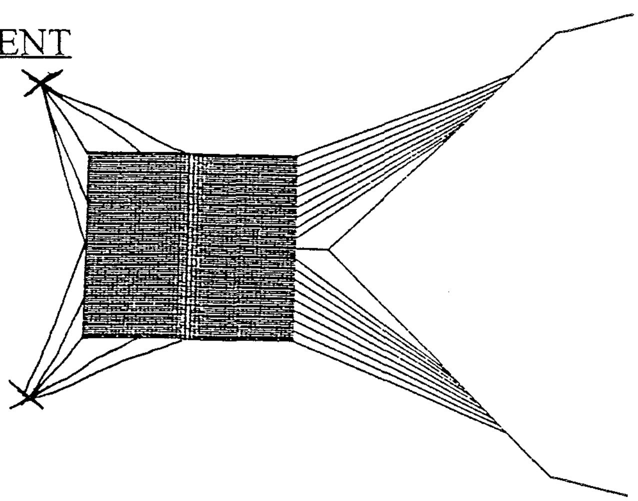


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #2

TETHER ARRANGEMENT



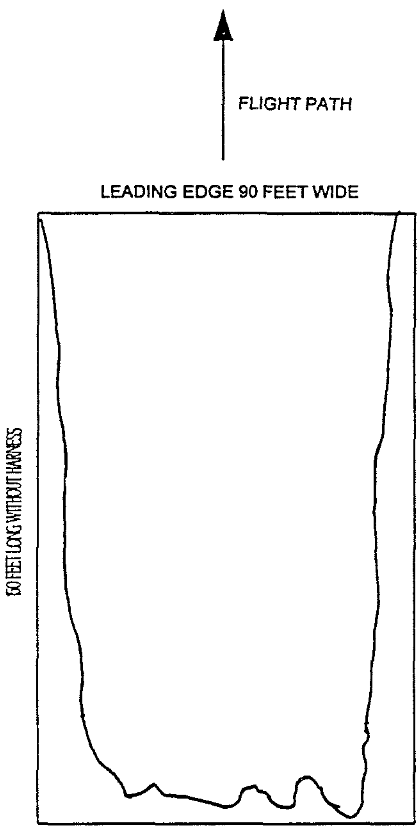
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min

NOTES: Full deployment of array. Tension on north tethers was greater than southern tethers. North edge was up-current.



POST TEST CONFIGURATION

Test No. 8

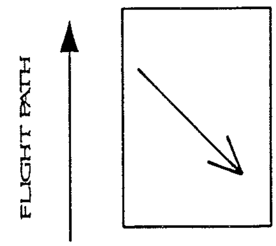
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 6/1/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

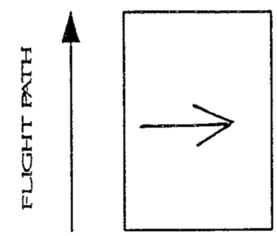
TIME OF FIRING: 1558
TEST NO: 9

TEST CONDITIONS

CHAMBER PRESSURE: 1500 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 30°
WIND SPEED:
TEMPERATURE: 60-62°F
WEATHER CONDITIONS: Cloudy
WAVE HEIGHTS (DEEP/SURF): 3.77 ft
CURRENT SPEED (DEEP/SURF): 2.46 ft/s



WIND DIRECTION

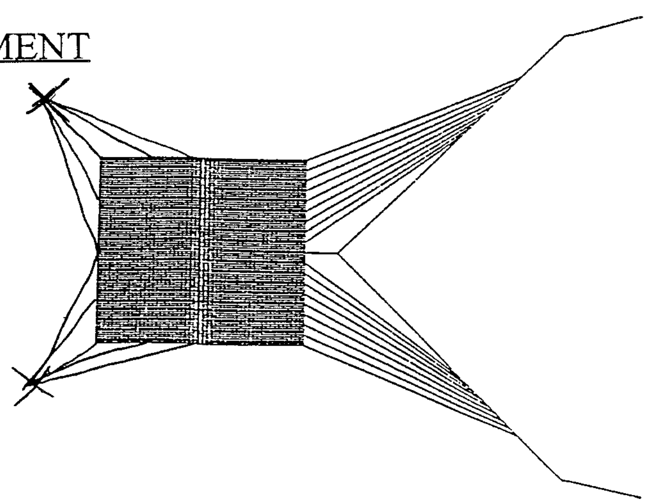


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #2. Harness taked to sides due to high water.

TETHER ARRANGEMENT

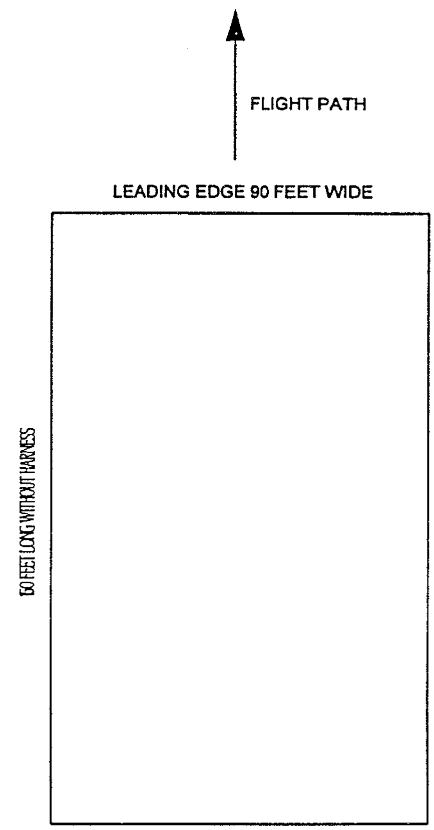


6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER:



NOTES: 1 panel deployed.
Both slugs lost.

POST TEST
CONFIGURATION

Test No. 9

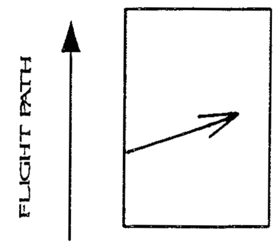
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 6/2/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

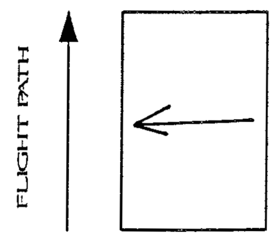
TIME OF FIRING: 1013
TEST NO: 10

TEST CONDITIONS

CHAMBER PRESSURE: 1500 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 32°
WIND SPEED: 1.79 mph
TEMPERATURE: 62.96°F
WEATHER CONDITIONS: Clear
WAVE HEIGHTS (DEEP/SURF): 2.13 ft
CURRENT SPEED (DEEP/SURF): 0.62 ft



WIND DIRECTION

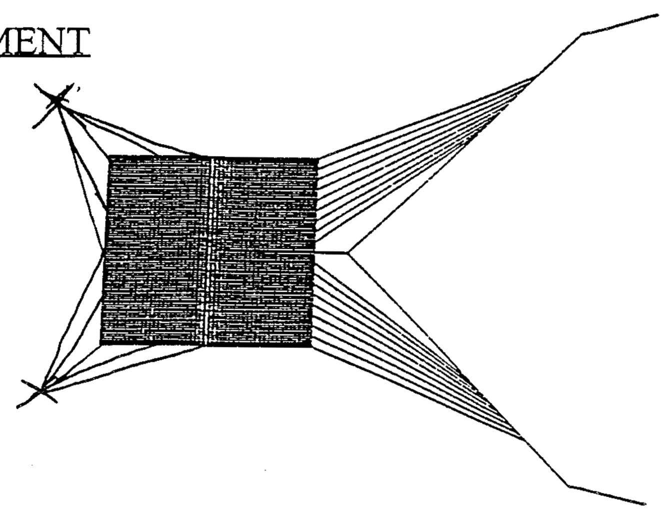


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #2.

TETHER ARRANGEMENT



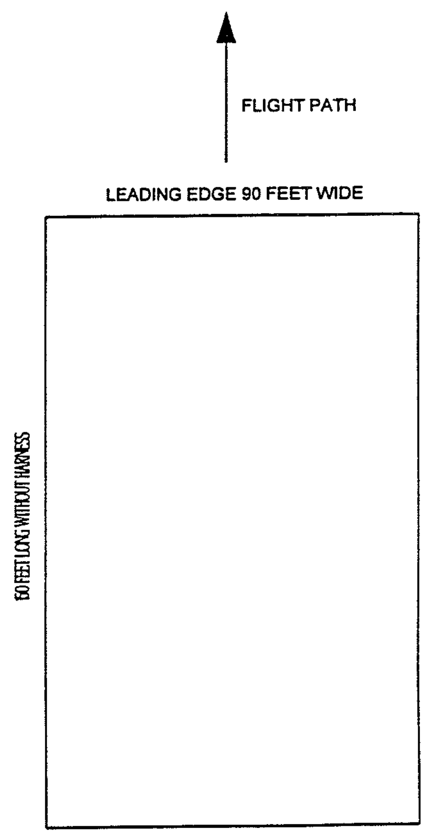
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min

NOTES: Full deployment of array 1/2 in water.



POST TEST CONFIGURATION

Test No. 10

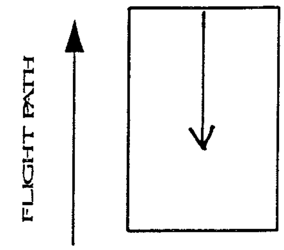
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 6/2/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

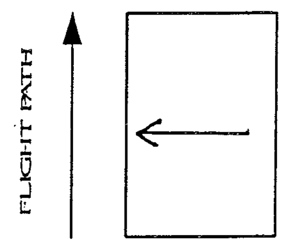
TIME OF FIRING: 1540
TEST NO: 11

TEST CONDITIONS

CHAMBER PRESSURE: 1500 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 32°
WIND SPEED: 1.65 mph
TEMPERATURE: 68.90°F
WEATHER CONDITIONS: Clear
WAVE HEIGHTS (DEEP/SURF): 2.26 ft
CURRENT SPEED (DEEP/SURF): 0.26 ft/s



WIND DIRECTION

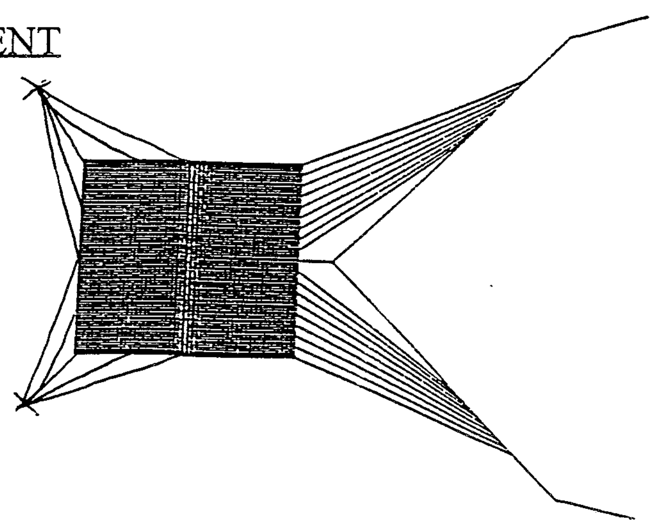


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #2. 4-mil-thick plastic sheets placed between every other layer of front panel.

TETHER ARRANGEMENT



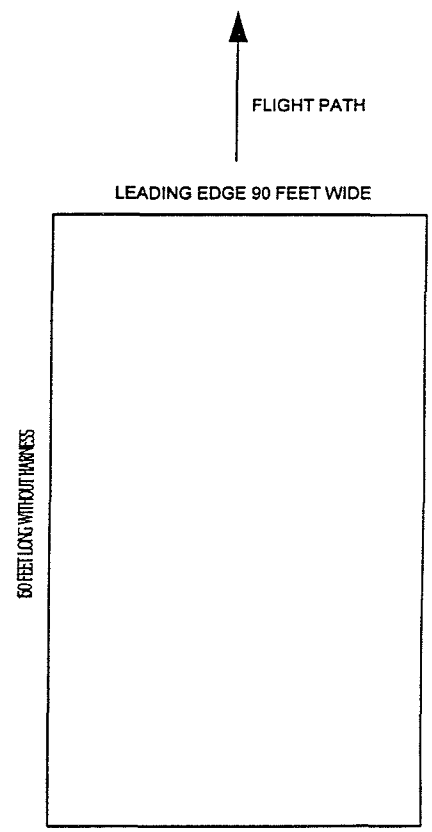
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min

NOTES: Full deployment of array. Majority of array in water. Good tension in all tethers.



POST TEST CONFIGURATION

Test No. 11

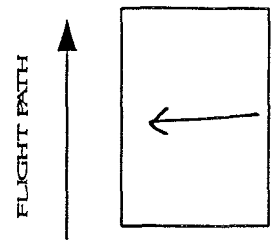
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 6/3/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

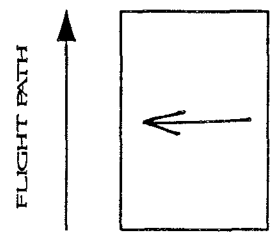
TIME OF FIRING: 1110
TEST NO: 12

TEST CONDITIONS

CHAMBER PRESSURE: 1500 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 32°
WIND SPEED: 2.37 mph
TEMPERATURE: 77°F
WEATHER CONDITIONS: Part. Cloudy
WAVE HEIGHTS (DEEP/SURF): 2.53 ft
CURRENT SPEED (DEEP/SURF): 0.79 ft/s



WIND DIRECTION

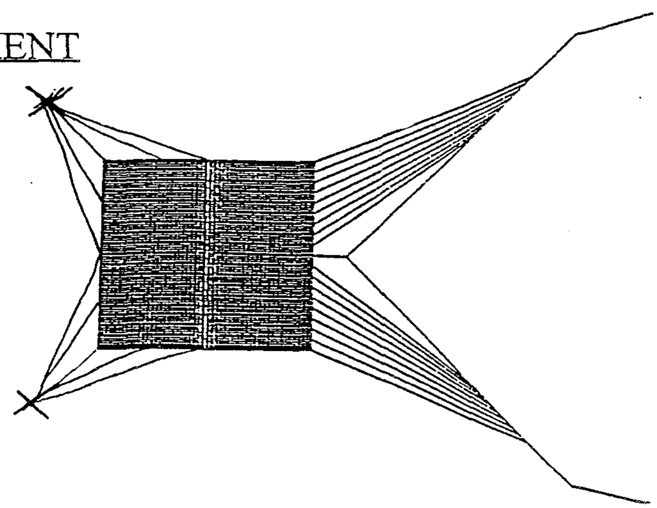


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #2. 4-mil plastic Sheets used between all folds of front panel.

TETHER ARRANGEMENT



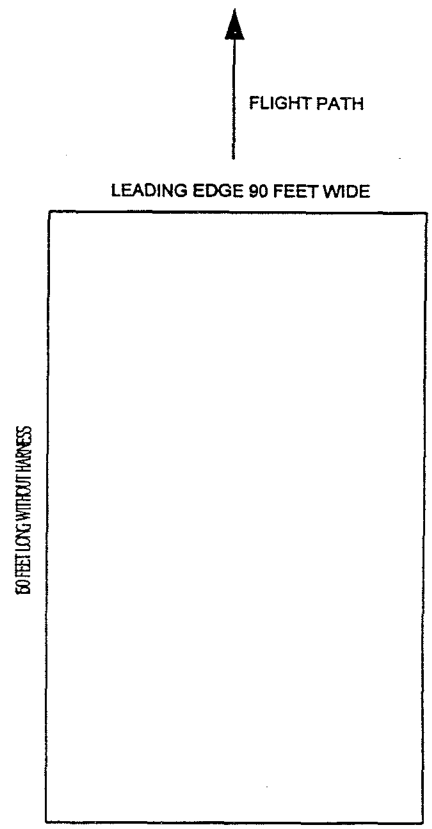
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER:

NOTES: Last 2' of array remained on platform after launch. Current then pulled it out. Array twisted with current to north. South slug lost.



POST TEST CONFIGURATION

Test No. 12

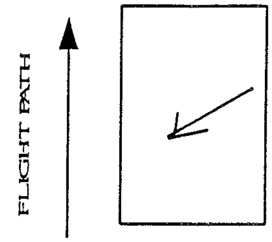
6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

TEST DATE: 6/3/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

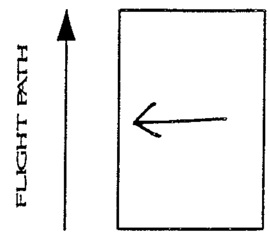
TIME OF FIRING: 1530
TEST NO: 13

TEST CONDITIONS

CHAMBER PRESSURE: 1500 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 32°
WIND SPEED: 3.89 mph
TEMPERATURE: 77.54° F
WEATHER CONDITIONS: Part. Cloudy
WAVE HEIGHTS (DEEP/SURF):
CURRENT SPEED (DEEP/SURF):



WIND DIRECTION

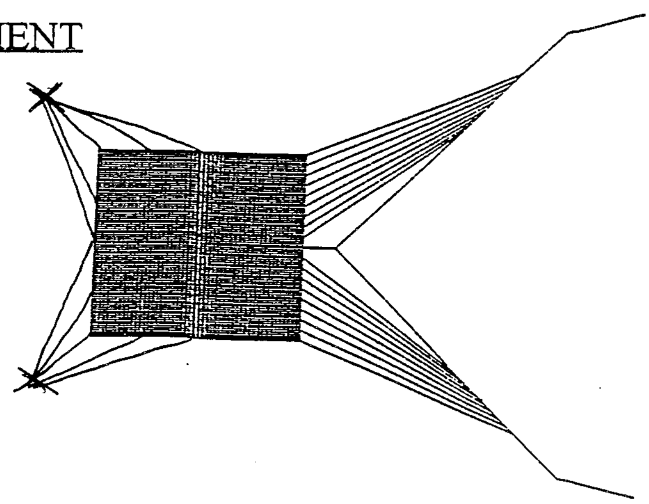


CURRENT DIRECTION

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #2. 4-mil plastic sheets between layers of front panel. alternate design panel placed as aft panel. Platform moved 5 ft seaward of original position.

TETHER ARRANGEMENT



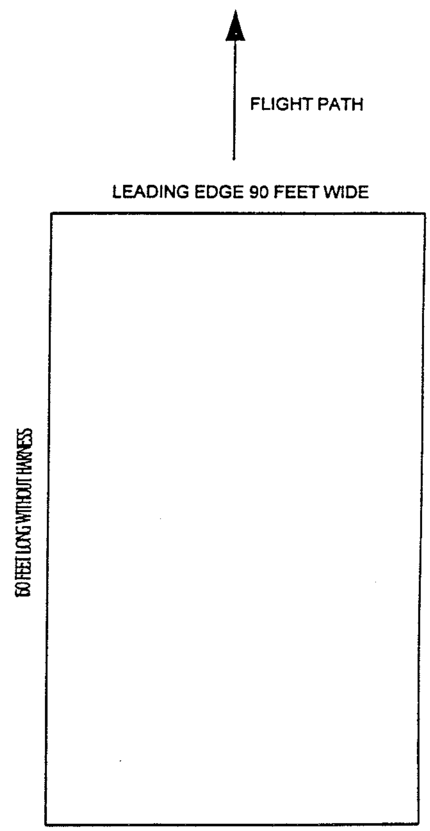
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min

NOTES: Full depoyment of array



POST TEST CONFIGURATION

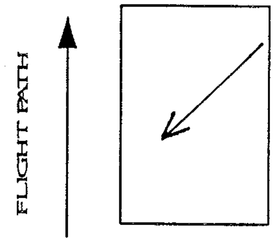
Test No. 13

6.2 IN-WATER STABILITY TESTS
PRE-TEST DATA SUMMARY

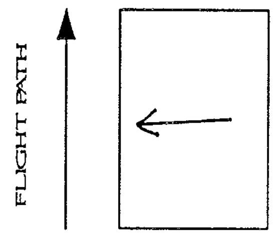
TEST DATE: 6/4/93
TEST LOCATION: FRF, DUCK, NC
TEST DIRECTOR: B. DEER

TIME OF FIRING: 1252
TEST NO: 14

TEST CONDITIONS



WIND DIRECTION



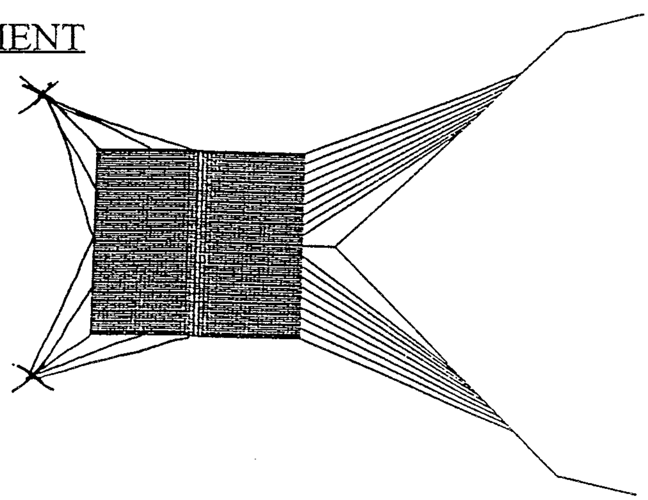
CURRENT DIRECTION

CHAMBER PRESSURE: 1600 psi
AZIMUTH ANGLE: 15°
LAUNCH ANGLE: 32°
WIND SPEED: 0.89 mph
TEMPERATURE: 76.62°F
WEATHER CONDITIONS: Clear
WAVE HEIGHTS (DEEP/SURF): 2.13 ft
CURRENT SPEED (DEEP/SURF): 0.98 ft/s

SYSTEM SET-UP

SYSTEM LENGTH: 100 ft
NO. OF PANELS: 2
SYSTEM DESCRIPTION: Tether design #2. Alternate design panel placed as 1st panel. 4-mil plastic sheets placed between folds of first panel. Platform 8 ft seaward of original position.

TETHER ARRANGEMENT



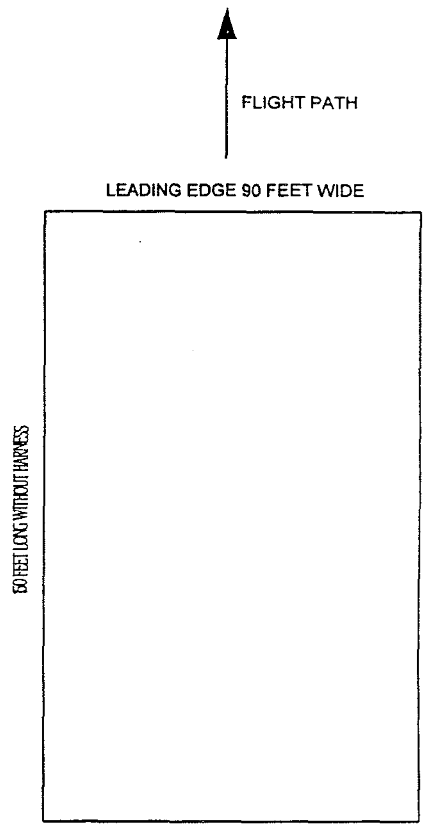
6.2 IN-WATER STABILITY TESTS
POST-TEST DATA SUMMARY

ARRAY MOVEMENT

DRIFT RATE:

TIME IN WATER: 5 min

NOTES: Full array deployment. Good tether tension.



POST TEST CONFIGURATION

Test No. 14

Appendix B Summary of Videotape Resources

This appendix contains notes, observations, and details relating to video coverage of each of the test deployments made during the 24 May 1993 - 4 June 1993 test series. Test number, date, and time of launch (EST) are recorded for each deployment. Camera name, tape ID, video elapsed time counter, and comments regarding test results and video quality are presented.

SWMCM VIDEO LOG		CAMERA NAME	TAPE ID	TAPE COUNTER	COMMENTS
SHOT NUMBER:	01	BWTEL	BWT 01	0:00:00 - 0:23:35	
3 - 50' panels 14 floats		BWWIDE	BWW 01	0:00:00 - 0:23:36	
DATE:	Monday	COLORPAN	CPN 01	0:00:00 - 0:06:18	post shot 1 - no footage prior to or during
	24-May-93	COLORFX	CFX 01	0:09:57 - 0:25:05	Only a portion of the array made it into water. South slug
TIME (EST):	15:18	FOWLER	FWL 01	0:03:59 - 0:11:45	was lost. This was essentially a shakedown run.
		HELO	HELO 01	0:00:00 - 0:01:58	
SHOT NUMBER:	02	BWTEL	BWT 01	0:23:35 - 0:42:16	Leading south and north floats are submerged. The
3 - 50' panels 10 floats		BWWIDE	BWW 01	0:23:36 - 0:42:23	landward most floats on both sides are not in the water,
DATE:	Tuesday	COLORPAN	CPN 01	0:06:18 - 0:22:07	but on the beach.
	25-May-93	COLORFX	CFX 01	0:33:00 - 0:51:44	Only 1 - 1/2 panels of the array made it into water.
TIME (EST):	10:45	FOWLER	FWL 01	0:15:53 - 0 :22:05	
		HELO	HELO 01	0:01:58 - 0:04:45	
SHOT NUMBER:	03	BWTEL	BWT 01	0:49:01 - 0:57:45	
3 - 50' panels 10 floats		BWWIDE	BWW 01	0:47:38 - 0:58:04	Picture is dark, iris was not adjusted
DATE:	Wednesday	COLORPAN	CPN 01	0:22:07 - 0:32:23	
	26-May-93	COLORFX	CFX 01	1:00:48 - 1:07:09	
TIME (EST):	09:05	FOWLER	FWL 01	0:23:20 - 0:28:25	Only a portion of the array made it into water.
		HELO	HELO 01	0:04:45 - 0:05:27	Lost north slug.
SHOT NUMBER:	04	BWTEL	BWT 01	0:57:46 - 1:15:46	2 panels were used, the entire array made it into the
2 - 50' panels 10 floats		BWWIDE	BWW 01	0:58:05 - 1:16:06	water. All video coverage looks great. 5 floats can be
DATE:	Thursday	COLORPAN	CPN 01	0:32:23 - 0:56:15	seen on the north side, but only 4 are visible on the
	27-May-93	COLORFX	CFX 01	1:07:09 - 1:25:00	south side of array. The SE leading float was tangled
TIME (EST):	09:23	FOWLER	FWL 01	0 :28:25 - 0:44:42	in harness and not seen on surface.
		HELO	HELO 01	0:05:27 - 0:06:24	

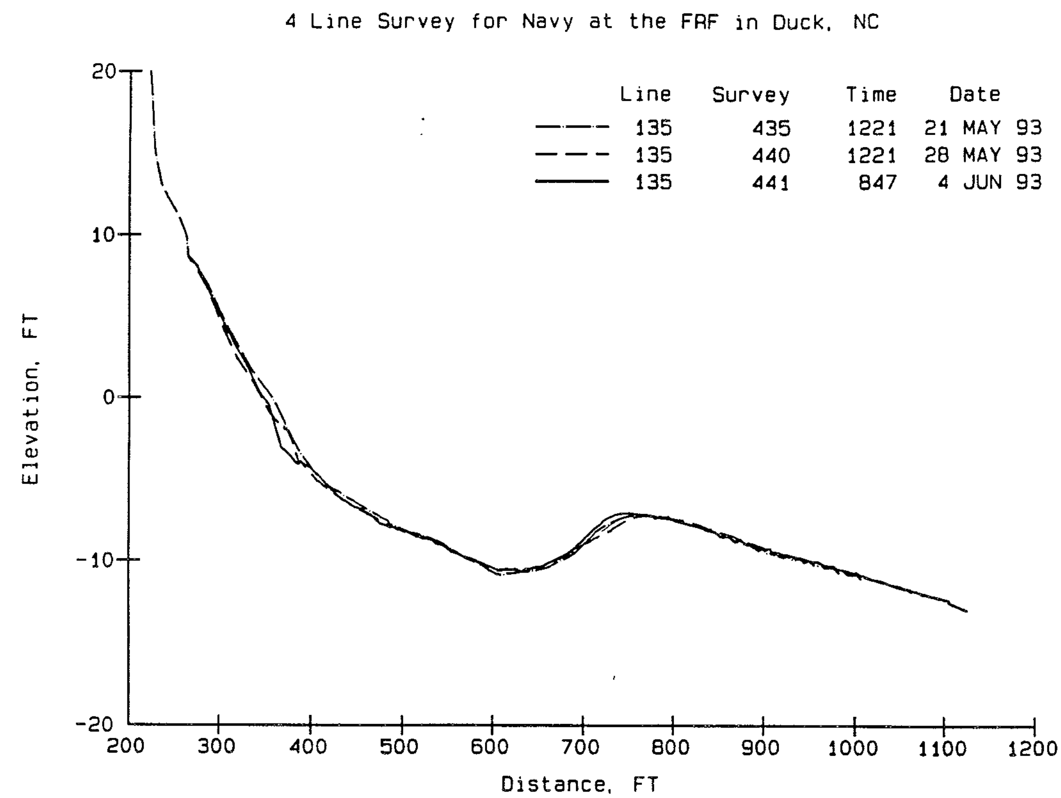
SWMCM VIDEO LOG		CAMERA NAME	TAPE ID	TAPE COUNTER	COMMENTS
SHOT NUMBER:	05	BWTEL *	BWT 01	1:15:48 - 1:31:34	All videos look good. The floats on western end
2 - 50' panels, 8 floats		BWWIDE *	BWW 01	1:16:07 - 1:31:55	of the array, 2 north, 3 south are clearly visible.
DATE:	Thursday	COLORPAN *	CPN 01	0:56:16 - 1:16:05	Others are barely visible just under water surface.
	27-May-93	COLORFX *	CFX 01	1:25:00 - 1:41:37	An unidentified floating object (UFO), crabpot float?
TIME (EST):	15:07	FOWLER	FWL 01	0:44:42 - 0:53:42	was floating midway between seaward array floats
*time code was not recorded		HELO	HELO 01	0:06:24 - 0:10:56	and the north pipe.
SHOT NUMBER:	06	BWTEL **	BWT 01	1:31:36 - 1:44:46	Video looks good. 7 of the 8 floats visible. float #2 south
2 - 50' panels, 8 floats		BWWIDE	BWW 01	1:31:57 - 1:45:13	or #3 south was caught in the array. North and south
DATE:	Friday	COLORPAN	CPN 01	1:16:05 - end	slugs lost in water on retrieval by the helicopter.
	28-May-93	COLORFX	CFX 02	0:00:00 - 0:16:14	
TIME (EST):	10:35	FOWLER	FWL 01	0:53:42 - 1:01:11	
**large gap on tape after shot 5		HELO	HELO 01	0:10:56 - 0:14:29	
SHOT NUMBER:	07	BWTEL	BWT 02	0:00:00 - 0:08:41	None of the array made it into the water.
2 - 50' panels, 8 floats		BWWIDE	BWW 02	N/A	BWW 02 shot #11 was taped over shot #7
DATE:	Monday	COLORPAN	CPN 02	0:00:00 - 0:8:24	Beginning with this shot, extra tether lines were added
	31-May-93	COLORFX	CFX 02	0:16:14 - 0:26:21	at 25' and 50' from the landward end of array.
TIME (EST):	09:46	FOWLER	FWL 01	1:01:11 - 1:08:59	These remained for duration of test series.
		HELO	HELO 01	0:14:29 - 0:17:59	
SHOT NUMBER:	08	BWTEL	BWT 02	0:08:41 - 0:26:39	Strong southerly current. Lots of foam from breaking
2 - 50' panels, 8 floats		BWWIDE	BWW 02	0:14:24 - 0:26:39	waves, floats are hard to see. Approximately 25' of
DATE:	Tuesday	COLORPAN	CPN 02	0:08:24 - 0:28:43	array remained on beach. 2 NW floats visible on beach.
	01-Jun-93	COLORFX	CFX 02	0:28:54 - 0:48:20	2 NE floats tangled under water. 2 SW floats visible on
TIME (EST):	10:02	FOWLER	FWL 01	1:08:59 - 1:16:31	beach, South #2 float in swash, SE lead tangled under
		HELO	HELO 01	0:17:59 - 0:21:10	water. Deployment appeared to be affected by winds.

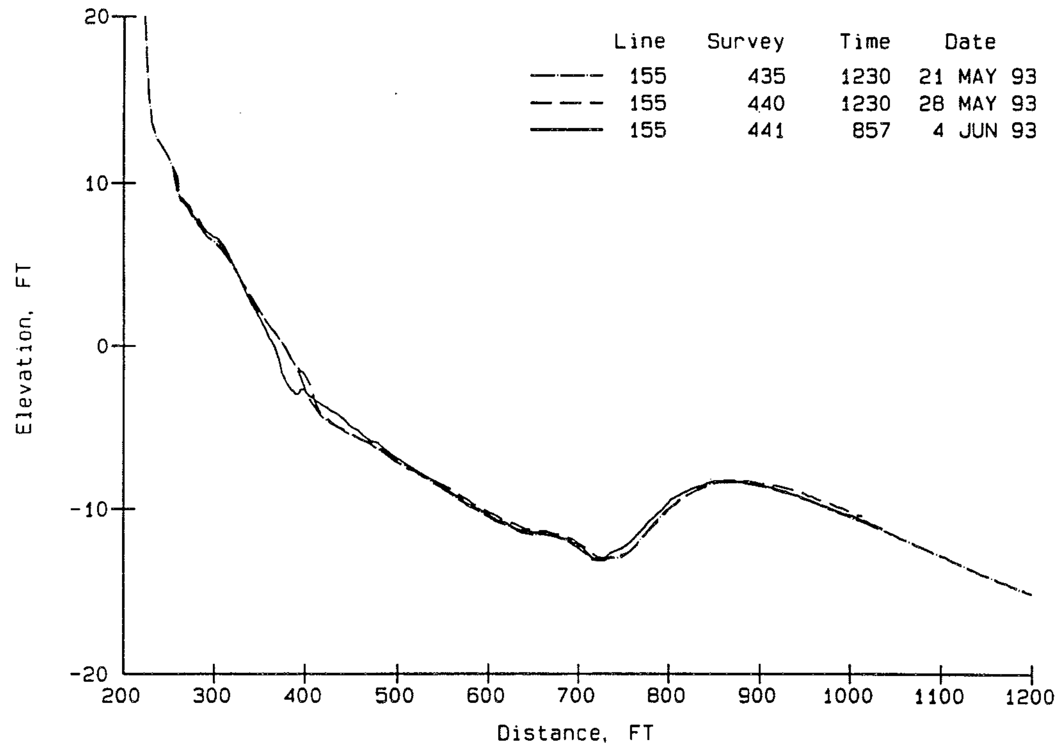
SWMCM VIDEO LOG		CAMERA NAME	TAPE ID	TAPE COUNTER	COMMENTS
SHOT NUMBER:	09	BWTEL	BWT 02	0:26:40 - 0:34:56	All video coverage looks good. The north pipe under
2 - 50' panels, 10 floats		BWWIDE	BWW 02	0:27:09 - 0:34:56	water at times. Flagging was attached to some of the
DATE:	Tuesday	COLORPAN	CPN 02	0:28:43 - 0:39:27	floats. Very little of the array made it into the water.
	01-Jun-93	COLORFX	CFX 02	0:48:20 - 0:58:26	
TIME (EST):	14:58	FOWLER	FWL 01	1:16:31 - 1:20:54	
		HELO	HELO 01	0:21:10 - 0:23:22	
SHOT NUMBER:	10	BWTEL	BWT 02	0:34:57 - 0:47:53	Video coverage looks good. Brightly colored Flagging was
2 - 50' panels, 8 floats		BWWIDE	BWW 02	0:34:58 - 0:48:38	placed on the 2 seaward floats. 8 floats are visible on the
DATE:	Wednesday	COLORPAN	CPN 02	0:39:27 - 0:51:30	surface. Both slugs broke free. Less than 1/2 of the array
	02-Jun-93	COLORFX	CFX 02	0:58:27 - 1:17:28	made it into the water.
TIME (EST):	09:13	FOWLER	FWL 01	1:20:54 - 1:29:55	
		HELO	HELO 01	0:23:22 - 0:29:37	
SHOT NUMBER:	11	BWTEL	BWT 02	0:47:55 - 1:02:17	Video coverage looks good. Majority of array made it
2 - 50' panels, 10 floats		BWWIDE	BWW 02	0:00:00 - 0:14:24	into the water. The south slug was lost during the
DATE:	Wednesday	COLORPAN	CPN 02	0:51:30 - 1:17:48	helicopter retrieval.
	02-Jun-93	COLORFX	CFX 02	1:17:29 - 1:39:54	
TIME (EST):	14:40	FOWLER	FWL 01	1:29:55 - 1:39:11	
		HELO	HELO 01	N/A	No video coverage from helicopter.
SHOT NUMBER:	12	BWTEL	BWT 02	1:02:17 - 1:10:57	Video coverage looks good. Flagging on the 2 seaward
2 - 50' panels, 10 floats		BWWIDE	BWW 03	0:00:00 - 0:08:41	floats on both sides. All floats are visible on surface.
DATE:	Thursday	COLORPAN	CPN 02	1:17:48 - 1:29:00	Only 25' of the array made it into the water. Both slugs
	03-Jun-93	COLORFX	CFX 03	0:00:00 - 0:12:59	were lost and not retrieved. Array platform located 5'
TIME (EST):	10:10	FOWLER	FWL 01	1:39:11 - 1:46:45	seaward of where it had been for previous shots.
		HELO	HELO 01	N/A	Helicopter unable to participate last 2 days.

SWMCM VIDEO LOG		CAMERA NAME	TAPE ID	TAPE COUNTER	COMMENTS
SHOT NUMBER:	13	BWTEL	BWT 02	1:10:57 - 1:23:09	Alternate panel was used in this shot. It was located in
2 - 50' panels, 10 floats		BWWIDE	BWW 03	0:08:41 - 0:20:54	the landward position. Array platform was 5' seaward of
DATE:	Thursday	COLORPAN	CPN 02	1:29:00 - end	Shot #11 position. 5 south floats were visible at first,
	03-Jun-93	COLORFX	CFX 03	0:12:59 - 0:32:40	then SE leading float became submerged. NE lead float
TIME (EST):	14:30	FOWLER	FWL 01	1:46:45 - 1:49:14	tangled and submerged with the 3rd north float. The
retrieval by forklift		HELO	HELO 01	N/A	Other 3 floats on north side are visible. Brightly colored
					Flagging placed on the 4 Eastern (seaward) floats.
SHOT NUMBER:	14	BWTEL	BWT 02	1:23:09 - end	Alternate panel was used in the seaward position. Array
2 - 50' panels, 8 floats		BWWIDE	BWW 03	12:20:55 - 0:33:12	platform 8' seaward of shot #13 position. 4 north floats
DATE:	Friday	COLORPAN	CPN 03	0:00:00 - 0:33:00	and 3 south floats are clearly visible on surface. The
	04-Jun-93	COLORFX	CPN 03	0:32:40 - 0:54:07	SE seaward float was tangled in harness but can be
TIME (EST):	11:52	FOWLER	FWL 01	1:52:07 - 1:57:29	seen below water surface. An unattached float was left
retrieval by forklift		HELO	HELO 01	N/A	on top of the array and lauched seaward. It can be seen
					floating just seaward of array. Flagging on 4 seaward floats

Appendix C Nearshore Bathymetry of Test Site

This appendix contains bottom profiles for four survey lines which bracket the test zone at the FRF in Duck, NC, during the 24 May 1993 - 4 June 1993 test series. Survey line 157 is approximately at the center of the deployment zone. Line 135 is 50 m north of line 155, which is 25 m north of line 157. Survey line 160 is 25 m south of line 157. Profiles are given for pre-test, mid-test, and post-test periods at each of these locations.


4 Line Survey for Navy at the FRF in Duck, NC
Line Survey Time Date
135 435 1221 21 MAY 93
135 440 1221 28 MAY 93
135 441 847 4 JUN 93
Elevation, FT
20
10
0
-10
-20
200 300 400 500 600 700 800 900 1000 1100 1200
Distance, FT


Line Survey Time Date
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Elevation, FT
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10
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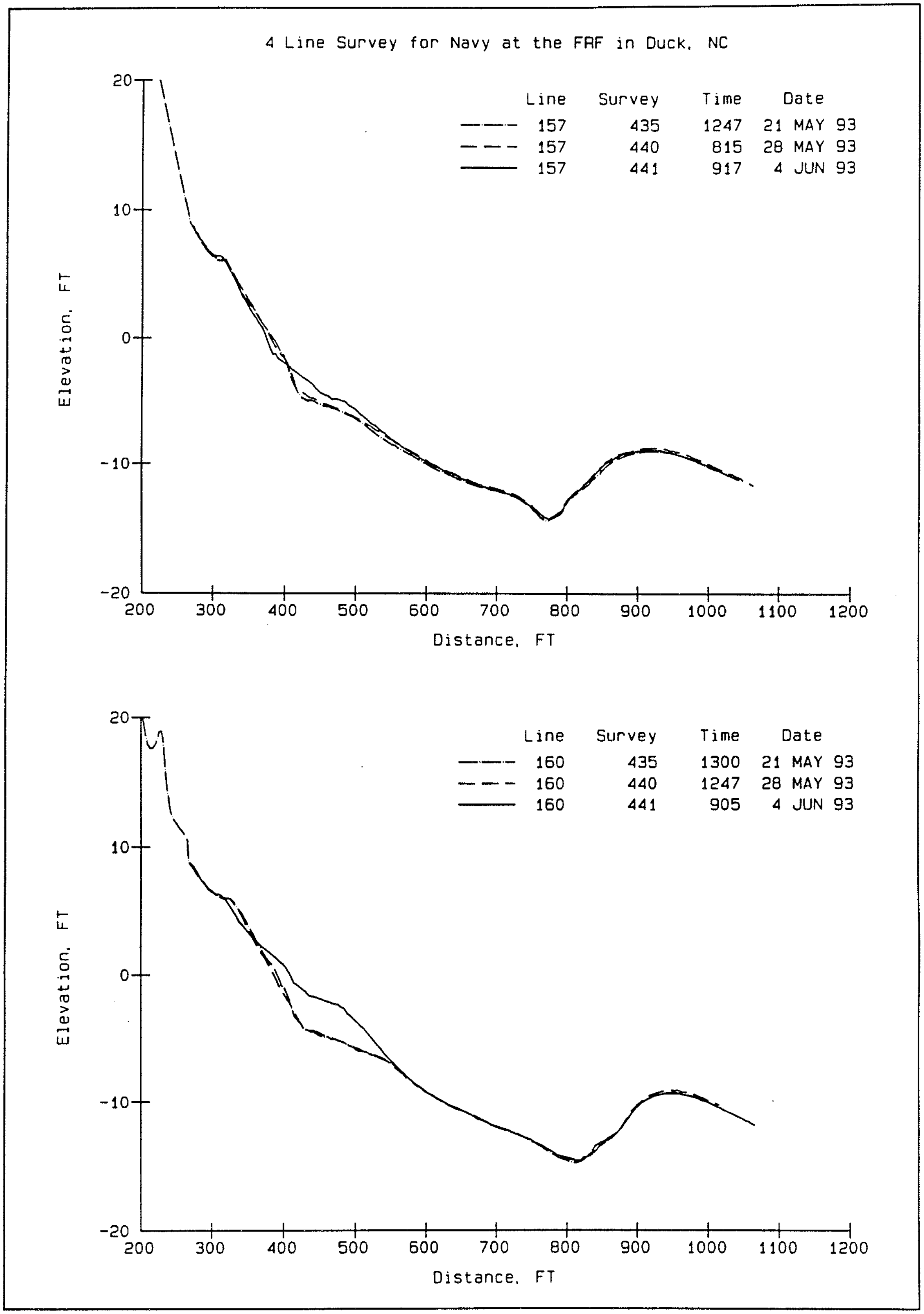
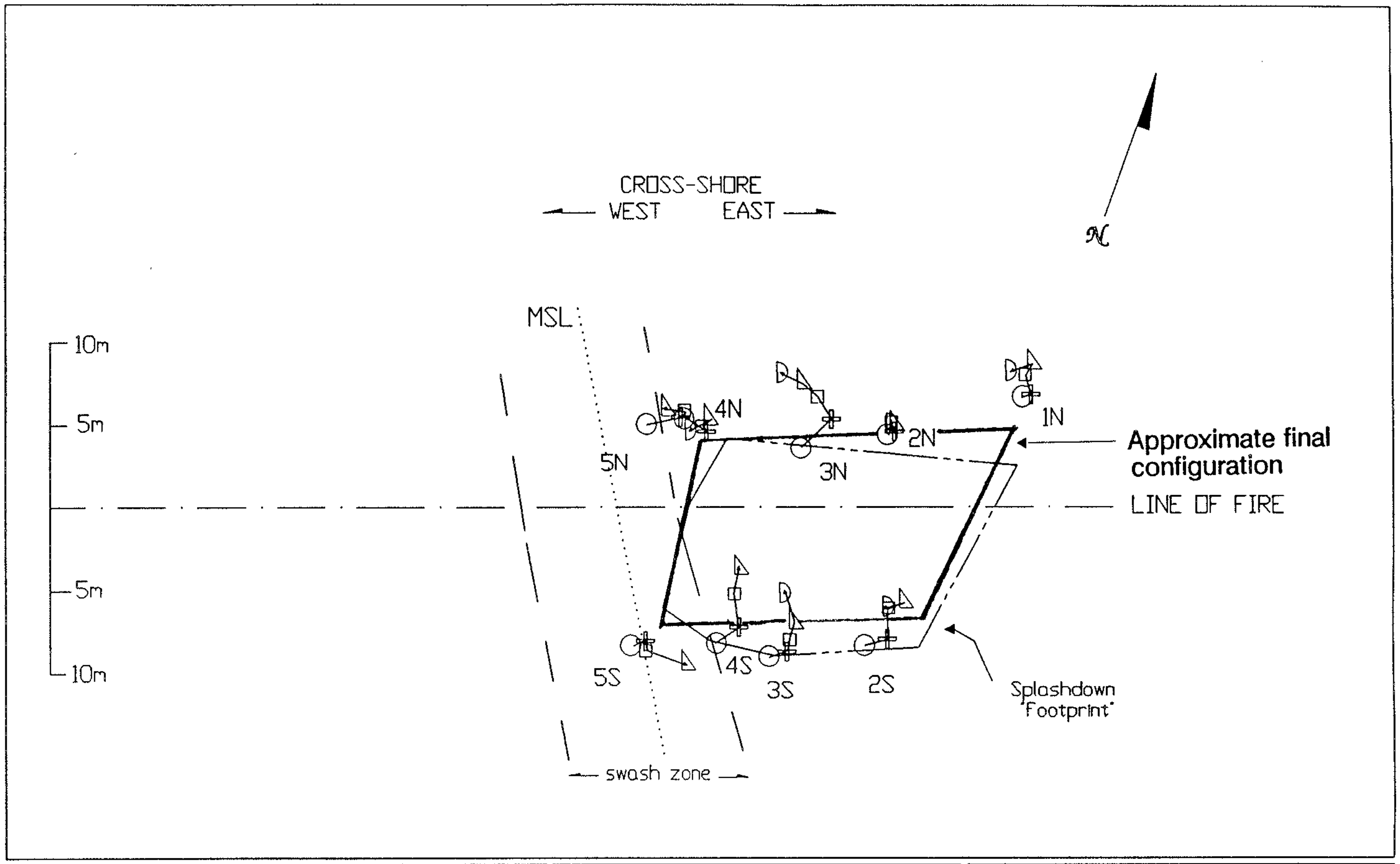
Distance, FT


4 Line Survey for Navy at the FRF in Duck, NC
Line Survey Time Date
157 435 1247 21 MAY 93
157 440 815 28 MAY 93
157 441 917 4 JUN 93
Elevation, FT
Distance, FT
Line Survey Time Date
160 435 1300 21 MAY 93
160 440 1247 28 MAY 93
160 441 905 4 JUN 93
Elevation, FT
Distance, FT

Appendix D
Array Movement Analysis Drawings

This appendix contains the array-tracking drawings for the 24 May 1993 - 4 June 1993 test series. These drawings were generated using the data method developed at the FRF. This method involved use of a frame grabber system and a clock superimposed on the screen to track movements of the perimeter buoys. Using this system, buoys which deployed correctly were digitized (located) at time intervals of 5, 15, 30, 60, and 90 sec after splashdown. Individual buoy movements are tracked in time by assigning symbols in the following manner:



POSITION OF FLOATS:

○ 05 SECONDS □ 30 SECONDS ⌓ 90 SECONDS
✢ 15 SECONDS ◿ 60 SECONDS

POSITION OF ARRAY:

– – – – THE ARRAY ON IMPACT

FLOAT NUMBERING SYSTEM:

NUMBERING IS FROM EAST TO WEST
S = SOUTH SIDE OF ARRAY
N = NORTH SIDE OF ARRAY

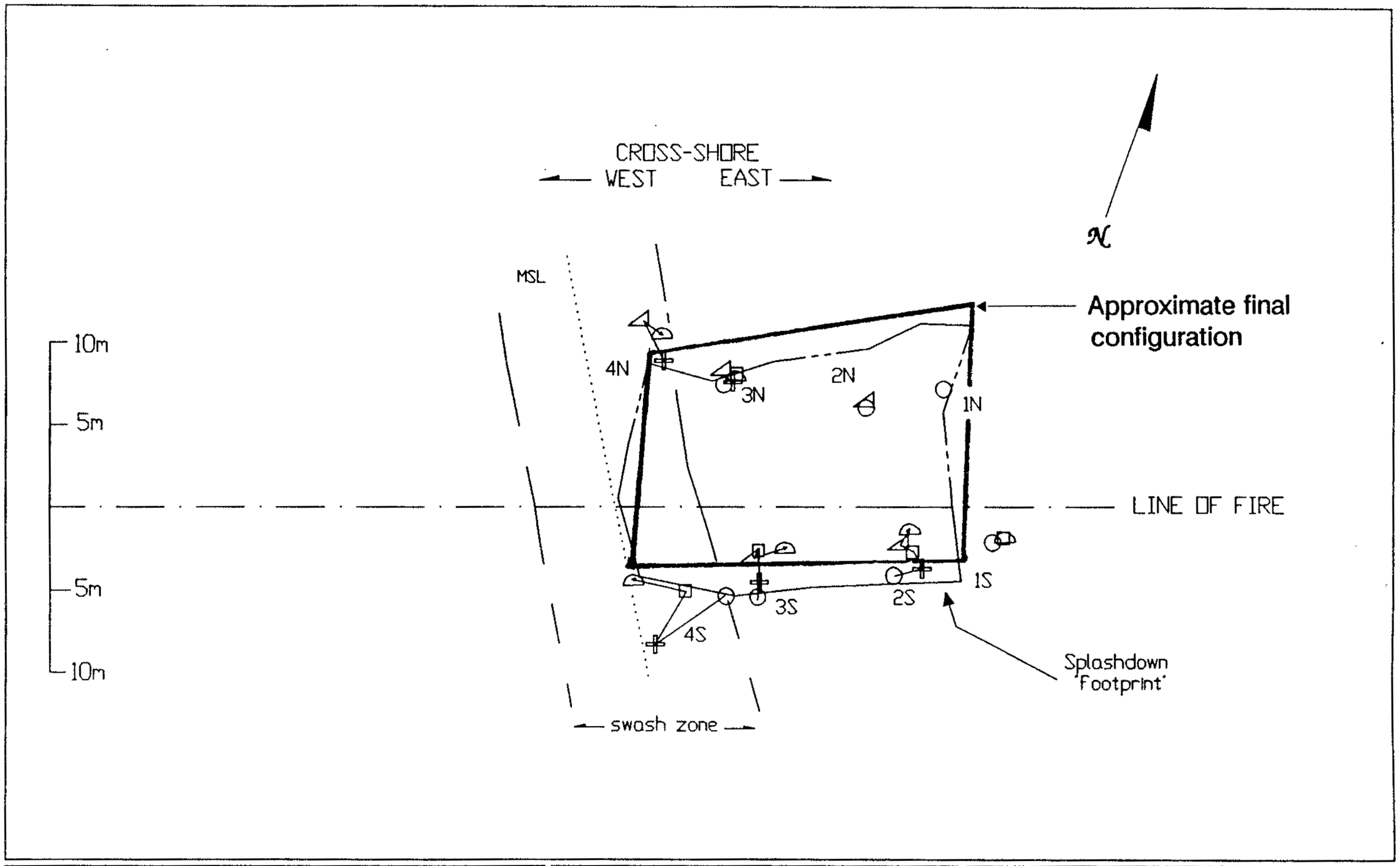
TOTAL FLOATS THIS SHOT: 10

FLOATS NOT PICTURED WERE SUBMERGED OR NOT SEEN ON WATER SURFACE.

WATERWAYS EXPERIMENT STATION
COASTAL ENGINEERING RESEARCH CENTER
FIELD RESEARCH FACILITY
DUCK, NORTH CAROLINA

FLOAT POSITIONS DREAD SHOT 4

DATE: 27 JUNE 93 | BY: JHR



POSITION OF FLOATS:

○ 05 SECONDS □ 30 SECONDS ⌓ 90 SECONDS
+ 15 SECONDS ◺ 60 SECONDS

POSITION OF ARRAY:

—·—·— THE ARRAY ON IMPACT

FLOAT NUMBERING SYSTEM:

NUMBERING IS FROM EAST TO WEST
S = SOUTH SIDE OF ARRAY
N = NORTH SIDE OF ARRAY

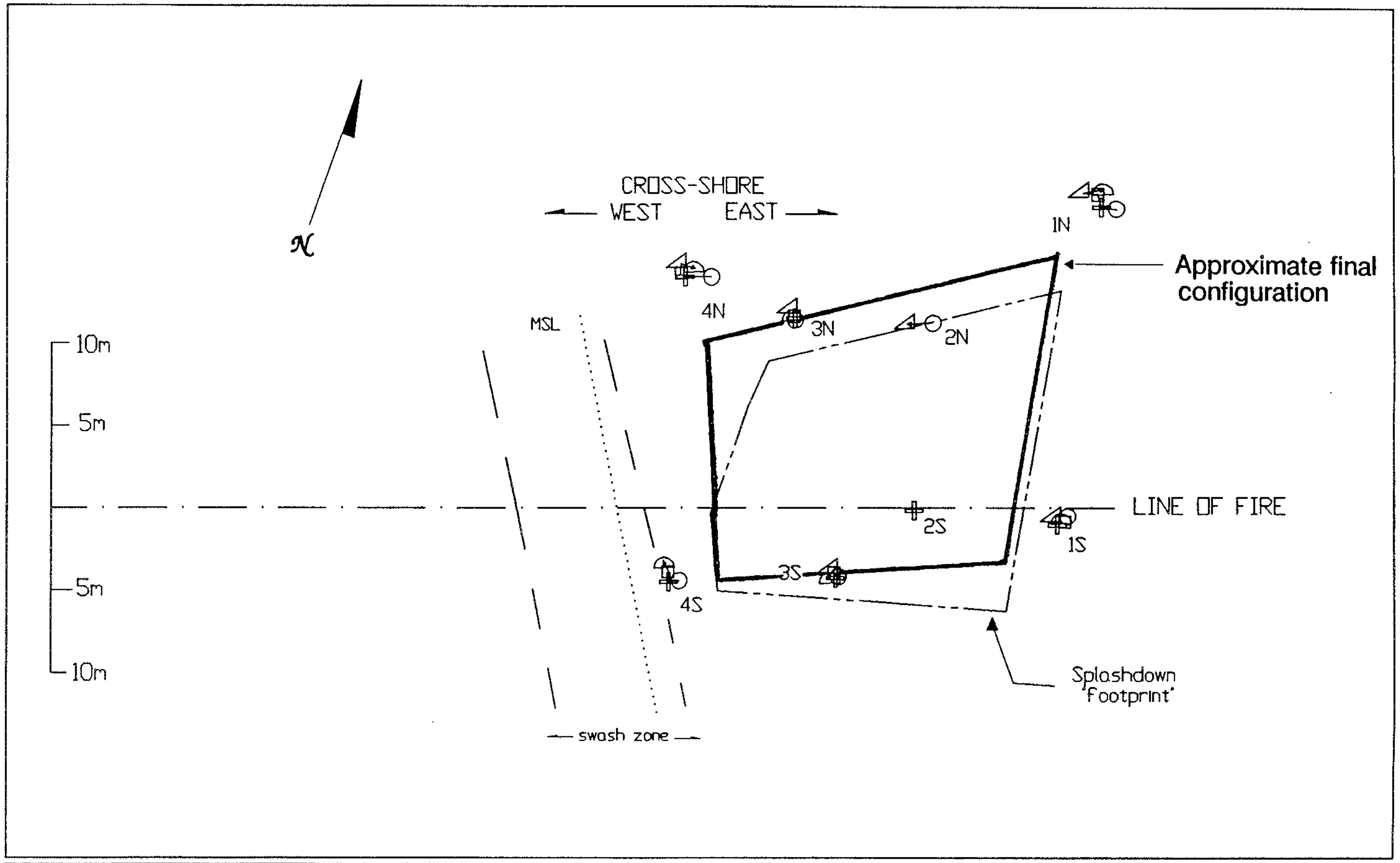
TOTAL FLOATS THIS SHOT: 8

FLOATS NOT PICTURED WERE SUBMERGED OR NOT SEEN ON WATER SURFACE.

WATERWAYS EXPERIMENT STATION
COASTAL ENGINEERING RESEARCH CENTER
FIELD RESEARCH FACILITY
DUCK, NORTH CAROLINA

FLOAT POSITIONS DREAD SHOT 5

DATE: 27 JUNE 93 BY: JHR



POSITION OF FLOATS:

○ 05 SECONDS □ 30 SECONDS ⌓ 90 SECONDS
+ 15 SECONDS ⊿ 60 SECONDS

POSITION OF ARRAY:

— - - — THE ARRAY ON IMPACT

FLOAT NUMBERING SYSTEM:

NUMBERING IS FROM EAST TO WEST
S = SOUTH SIDE OF ARRAY
N = NORTH SIDE OF ARRAY

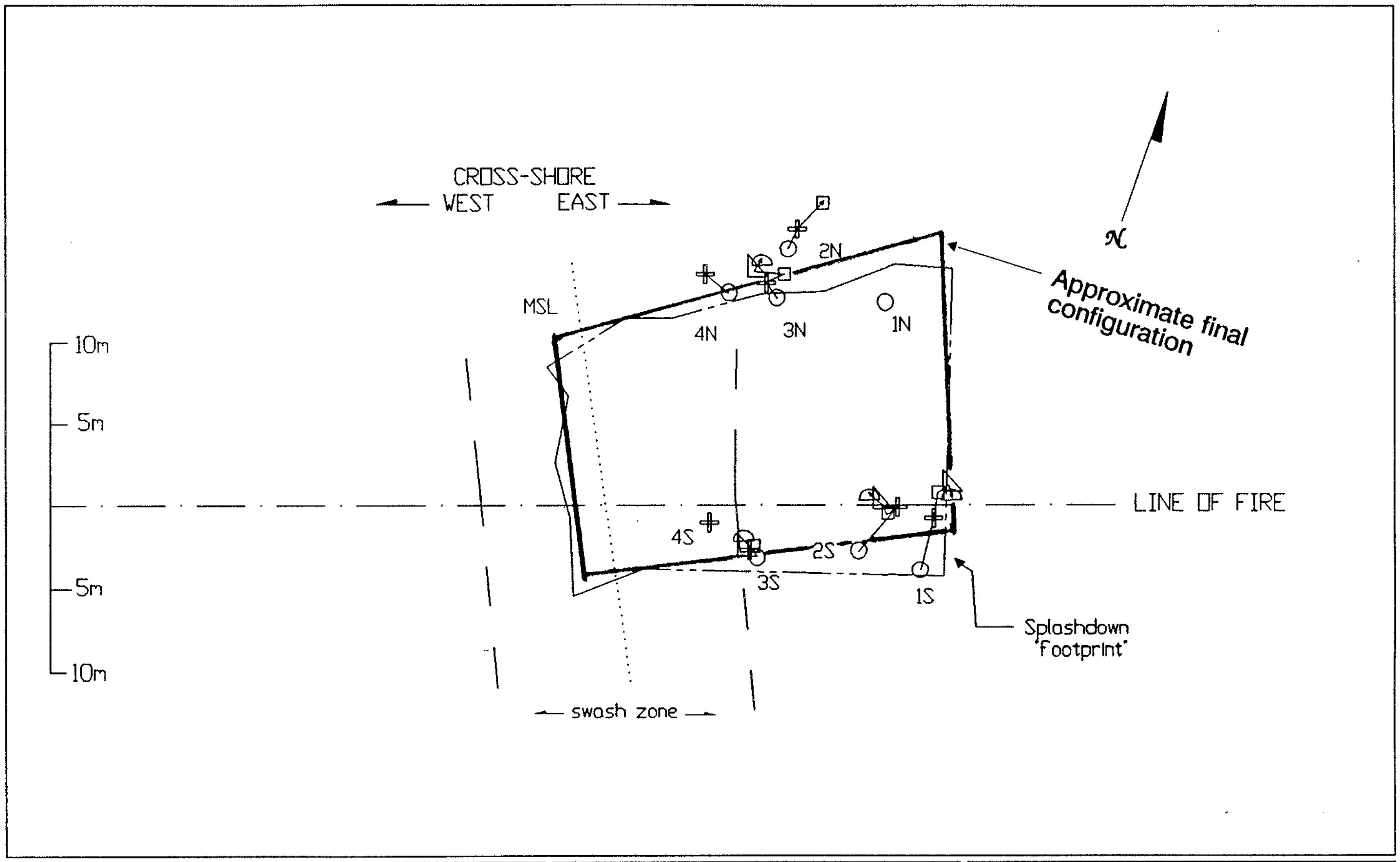
TOTAL FLOATS THIS SHOT: 8

FLOATS NOT PICTURED WERE SUBMERGED OR NOT SEEN ON WATER SURFACE.

WATERWAYS EXPERIMENT STATION
COASTAL ENGINEERING RESEARCH CENTER
FIELD RESEARCH FACILITY
DUCK, NORTH CAROLINA

FLOAT POSITIONS DREAD SHOT 6

DATE: 27 JUNE 93 BY: JHR



POSITION OF FLOATS:

○ 05 SECONDS □ 30 SECONDS ⌓ 90 SECONDS
+ 15 SECONDS ◺ 60 SECONDS

POSITION OF ARRAY:

—·—·— THE ARRAY ON IMPACT

FLOAT NUMBERING SYSTEM:

NUMBERING IS FROM EAST TO WEST
S = SOUTH SIDE OF ARRAY
N = NORTH SIDE OF ARRAY

TOTAL FLOATS THIS SHOT: 10

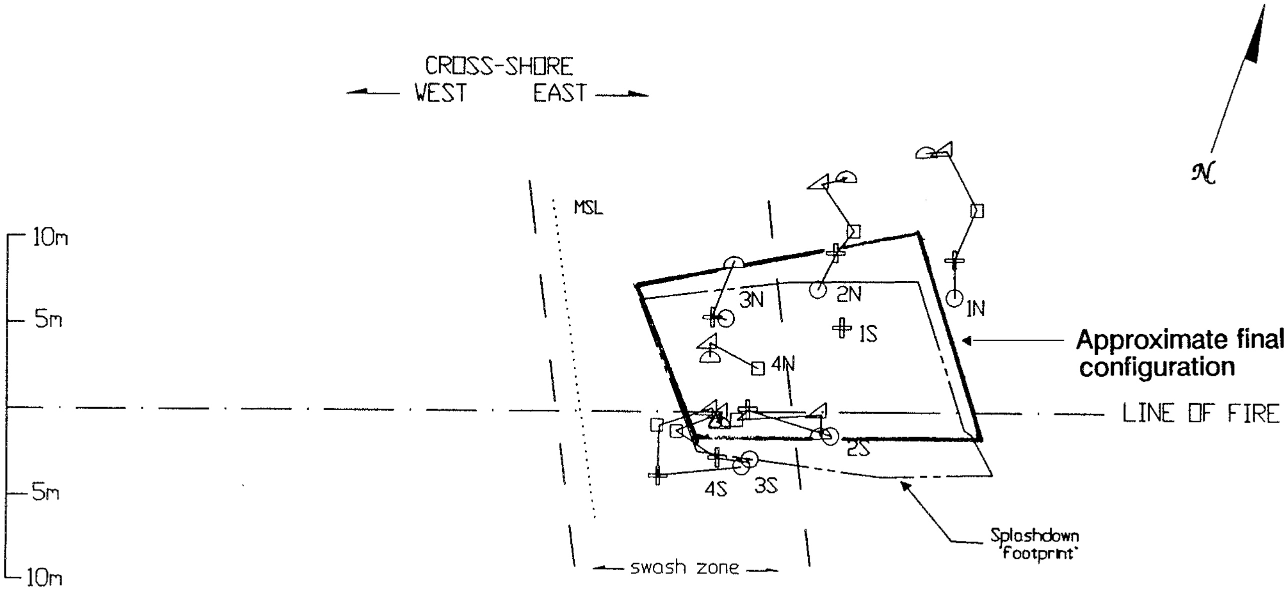
FLOATS NOT PICTURED WERE SUBMERGED OR NOT SEEN ON WATER SURFACE.

WATERWAYS EXPERIMENT STATION
COASTAL ENGINEERING RESEARCH CENTER
FIELD RESEARCH FACILITY
DUCK, NORTH CAROLINA

FLOAT POSITIONS DREAD SHOT 11

DATE: 27 JUNE 93

BY: JHR



POSITION OF FLOATS:	FLOAT NUMBERING SYSTEM:	WATERWAYS EXPERIMENT STATION COASTAL ENGINEERING RESEARCH CENTER FIELD RESEARCH FACILITY DUCK, NORTH CAROLINA
○ 05 SECONDS □ 30 SECONDS ⌓ 90 SECONDS + 15 SECONDS ◿ 60 SECONDS	NUMBERING IS FROM EAST TO WEST S = SOUTH SIDE OF ARRAY N = NORTH SIDE OF ARRAY	FLOAT POSITIONS DREAD SHOT 14
POSITION OF ARRAY:	TOTAL FLOATS THIS SHOT: 8	
- - - - - THE ARRAY ON IMPACT	FLOATS NOT PICTURED WERE SUBMERGED OR NOT SEEN ON WATER SURFACE.	DATE: 27 JUNE 93 BY: JHR

Appendix E
Notation

H_{mo}	Zeroth moment wave height
N	North
S	South

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

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13. ABSTRACT *(Maximum 200 words)*

Field tests to assess the effects of waves and currents were conducted during the summer of 1993 at CERC's Field Research Facility (FRF) in Duck, NC. This test series is a follow-on to similar efforts accomplished in 1992 and was designed to incorporate lessons learned from those efforts. Major differences between the 1993 tests and those conducted in 1992 involved the use of a wider array, a compressed "air gun" to simulate the dual-rocket deployment technique, and shore-based tethers to stabilize the deployed array. Results of the 1993 field tests generally supported 1992 findings, which indicated that both waves and longshore currents have significant effects on the explosive array deployment system and must be considered in the final design. The tests also indicated that wide arrays used in conjunction with the tethers proved to be quite stable under the environmental conditions tested.

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Coastal Engineering Research Center
DRDEAD
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Duck, North Carolina
Explosive array
Explosive array deployment
Field tests
IHDIVNAVSURFWARCEN
Indian Head Division
Landing craft, air cushion
LCAC
Longshore currents
Sea state
Shallow Water Mine Countermeasures Program
SWMCM
Waterways Experiment Station
Waves