LABORATORY INVESTIGATIONS RELATED TO MICROWAVES

by

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INTRODUCTION

Research continues on the detection of the ocean surface properties by remote methods. Two frequently used microwave instruments are the radar and the radiometer. The radar backscatter cross section and the brightness temperature sensed by the radiometer are intimately related to the microstructure of the ocean surface. The exact nature of the dependence is not completely understood yet. An extensive study by Porter and Wentz (1971) explored the factors which influence the use of the radiometer for detection of ocean surface temperatures. Hollinger (1971) found that the brightness temperature increased with wind speed which suggests the possible use of the radiometer as an instrument for remote sensing of wind speed. The use of radar as a remote anemometer has received considerable attention by the Naval Research Laboratory and a number of their publications on this matter are available. A parallel investigation is conducted jointly by the University of Kansas and New York University and their results are documented in a series of publications. Complete agreement between the results of available investigations is not in hand yet and is perhaps the primary motivation for the initiation of the controlled laboratory investigation described herein.

An alternate method for estimating the wind speed is by evaluating the percentage of whitecaps area in aerial photographs of the ocean surface, and by correlating with wind speed. This method was explored by Ross, Cardone and Conway (1970). The available whitecaps data at different wind speeds exhibit an increasing trend although the large scatter in the data shown by Monahan (1969, 1971) cannot be ignored. The possibility of other factors which influence the whitecaps area such as sea state or swell need to be considered.

The present investigation was authorized by the Spacecraft Oceanography Project of the Naval Research Laboratory under Contract No. N62306-71-C0033 to study in a laboratory controlled environment the structure of the water surface and the immediate layers above and below the surface. The scope includes (i) the investigation of the capillary waves and their interaction with gravity waves, (ii) the formation of whitecaps at different wind speeds and the influence of gravity waves on whitecaps, and (iii) the wind generated spray under different wind and wave conditions. The comprehensive laboratory investigation was facilitated by the participation of Dr. R. J. Lai and Messrs. A. M. Reece and G. Tober. Only a brief description of the total study is described here and for more details the reader is referred to a report by Shemdin, Lai, Reece and Tober (1972).

DESCRIPTION AND APPARATUS

Wind and Wave Facility. - The wind and wave facility at the University of Florida was described in detail by Shemdin (1969). Briefly, the wave channel is 1.83 meters wide and 45.7 meters long, and is divided into two bays of equal width. The height of the facility is 1.93 meters. One bay is provided with a roof and is used as a wind channel. The water depth is maintained at 91.5 cm by a small water pump. The air intake is modified to simulate rough turbulent air flow in the wind channel as shown in Figure 1. The facility is equipped with a mechanical wave generator which can generate simple and random waves. A wave absorber beach is provided at the downwind end of the facility and is made of baskets filled with stainless steel turnings. The baskets absorb approximately 95% of the incoming wave energy of waves with frequencies greater than 0.8 HZ.

The velocity profiles above the water surface were investigated and found to follow a logarithmic distribution as shown by Lai and Shemdin (1971). These measurements were repeated for the present investigation to obtain a complete description of the wind field corresponding to the measured whitecaps area and spray.

Experiments were conducted in the wind and wave facility with both fresh well water and a prepared salt water solution with salt concentration equal to 35 parts per thousand. The surface tension of the well water was measured and compared to that of ordinary tap water. The surface tension of the prepared salt water was measured and compared to that of the ocean water. Figure 2 shows a comparison between the surface tension values of different samples. It was concluded that the prepared salt water solution was similar in physical properties to that of the ocean water.

Hot-film Anemometer System for Measuring Spray. - A technique using a hot-film anemometer was developed to measure spray above the water surface. A hot-film is cooled when hit by a drop which produces a change in the film resistence and consequently generates a voltage pulse. A calibration procedure was followed in which uniform droplets were generated and their diameters were recorded photographically. The droplets were allowed to hit the hot-film and the corresponding voltage heights were recorded. It was found that the height of the voltage pulse increased with increasing droplet diameter. The hot-film anemometer and calibration system is shown in Figure 3. The hot-film was placed in the air stream above the water surface and the calibration curve was used to determine the droplets size distribution under given wind conditions.

Laser-Optical Gage for Measuring Capillary Waves. - Capacitance gages are limited in studying the structure of high frequency waves because of the finite draining time of water along an insulated wire. Cox (1958) developed an optical gage to measure slopes of capillary waves. His technique, however, produces significant errors when the water surface displacements are large. A laser-optical gage was developed to study slopes of capillary waves in the presence of gravity waves. The gage is insensitive to the surface displacements produced by gravity waves generated in the wind and wave facility to within tolerable limits. A schematic of the facility cross-section and position of the laser and optical detector is shown in Figure 4. Details of the optical detector are shown in Figure 5. Simultaneous slope measurement in the downwind and crosswind directions are obtained by a beam splitter, two wedges filled with ink to produce spacial gradients of light intensities and two photo multiplier tubes. Changes in the surface slope correspond to variations in the voltage output from the photo multiplier tubes. A procedure was developed to linearize the voltage-spectral computations of capillary waves.

Whitecaps Area Measurement. - An overhead camera was used to obtain photographs of the water surface. The camera was mounted at an angle facing upwind. The distortion in the surface area was calibrated and used to obtain accurate estimates of the whitecaps area. For each wind, fetch and wave condition five photographs were averaged to arrive at an average whitecaps area.

Other Miscellaneous Equipment. - A Beckman Instruments salinometer, Model RS5-3, was used to detect salinity changes in the facility. A pitot static tube and sensitive pressure transducer were used to measure the wind velocity. A thermister probe and readout device, Model 431J, manufactured by Yellow Springs Instrument Company was used to measure the air and water temperatures. The humidity was obtained by measuring the wet and dry bulb temperatures with the same instrument.

EXPERIMENTAL PROCEDURE AND METHOD OF ANALYSIS

Two major experiments were conducted, one with fresh water and the other with salt water. In each case measurements of spray and capillary waves were obtained at three different wind speeds and at fetch 24.36 (i.e. 24.36 meters downwind of the air intake). At each wind speed measurements were obtained both in the presence and absence of mechanically generated gravity waves. The whitecaps areas were obtained under the above conditions and at two other fetches 9.15 and 15.3 meters to investigate their fetch limited properties. Spray and capillary wave measurements could only be obtained at one fetch in the available time. The scopes of the fresh-water experiment is shown in Table 1 and the saltwater experiment is shown in Table 2. A comprehensive description of tests, calibration and procedures is given in the report by Shemdin, et al (1972).

RESULTS AND DISCUSSIONS

Whitecaps Area. - The increase in whitecaps area with wind speed is shown in Figure 6 for both the fresh-water and salt-water. The whitecaps area increased from zero at 10 m/sec to approximately 10% at 15 m/sec and was consistant with the upper limit of field measurements given by Ross et al (1970). For a given wind speed the whitecaps area increased with fetch up to saturation at fetch 15.3. The whitecaps area remained constant thereafter.

A significant reduction in whitecaps area was effected by mechanically generated gravity waves as shown in Figure 7. Small amplitude gravity waves produced the highest reduction in whitecaps area for a given wind speed. The whitecaps area increased with increasing gravity wave amplitude up to an unstable amplitude whence the breaking of gravity waves increased the whitecaps area up to 45%. The influence of swell in the ocean, neglected by previous investigators, may well be the major reason for the data scatter shown by Monahan (1969, 1971).

Spray. - The drop size distribution was obtained by statistical analysis of pulse heights recorded on oscillograph paper. Drop size distributions are shown in Figure 8 from measurements at three elevations above the mean water level. The ordinate represents the number of drops per unit volume within a given drop diameter band width. The integral under a distribution curve represents the total number of drops per unit volume. The d^{-3} line is shown for comparison. An analysis of the relationship between drop size distribution and the surface shear stress is given by Shemdin et al (1972).

The total number of drops passing a unit vertical area per unit time, P, is found to decrease logarithmically with height as shown in Figure 9. Such a distribution is convenient and allows the construction of a simple analytical model for drops. The droplet factor P_* is a characteristic parameter similar in nature to the shear velocity U_* obtained from the logarithmic velocity distributions of rough turbulent shear flows. It is found from the experimental results that P_* increases exponentially with U_*.

Capillary Waves. - Slope records of the down-wind and cross-wind components of capillary waves are shown in Figure 10 and compared with a simultaneous water surface displacement record obtained by a capacitance gage. The optical records exhibit the presence of capillary waves up to 50 HZ whereas the capacitance gage does not respond to such frequencies. It can be observed that the capillary waves persist on the down-wind slope of the longer wind waves which demonstrates the importance of capillary waves and their interactions with longer waves.

In the presence of a long mechanically generated gravity wave the capillary wave records are shown in Figure 11 and exhibit an uneven distribution of capillary waves along the gravity wave profile. More capillary waves appear on the crests of the gravity waves compared to the troughs and are consistent with strong nonlinear interactions between the capillary and the gravity waves. Energy spectra of the gravity and capillary are given by Shemdin et al (1972).

The strong interaction between the capillary and the gravity waves offers an explanation for the decrease in the whitecaps area produced by the mechanically generated gravity wave. It is seen that the capillary waves transfer part of their excess energy to the gravity waves by nonlinear interaction.

The results of the present investigation amplify the importance of the capillary-gravity waves interactions in influencing the whitecaps area and in determining the ocean surface microstructure, both of which influence the radar backscatter and the brightness temperature sensed by a radiometer.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are derived from the present laboratory study:

1. Capillary waves generated by wind interact strongly with gravity waves generated mechanically.

2. The whitecaps area increases with wind speed from zero at 10 m/sec to approximately 10% at 15 m/sec. The long gravity waves reduce the whitecaps area significantly.

3. The size distribution of drops above the water surface has spectral features similar to field observations. The long gravity waves increase the total number of drops at a given elevation above the water surface. The total number of drops decrease with height according to a logarithmic distribution.

The effort up to date in this investigation was to develop the instrumentation and techniques to measure the capillary wave structure, whitecaps area and spray. With these objectives already accomplished and with sufficient experimental data in hand to asses the nature of the air-sea phenomena related to remote sensing the following recommendations are proposed:

1. Power spectra of capillary wave slopes need to be investigated under different wind, fetch and gravity wave conditions.

2. A radar mounted on the wind and wave facility can provide valuable information which can be interpreted in light of the measured microstructure of the water surface.

3. A radiometer mounted on the wind and wave facility can provide information on brightness temperature which can be related to the measured whitecaps area, surface temperature and microstructure of the surface.

4. Laboratory investigations of the radar and the radiometer as potential instruments for measuring, remotely, the wind speed is strongly recommended.

REFERENCES

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TABLE I

SCOPE OF FRESH-WATER EXPERIMENT
AT FETCH 24.36 m

Wave Conditions	Wind speed (m/sec)			
	10	15	17	18.7
Wind waves	3	4	5	6
f = 1.0 Hz, H = 5 cm	9	10	11	12
f = 1.0 Hz, H = 15 cm	15	16	17	18
f = 0.7 Hz, H = 10.5 cm	21	22	23	24

Whitecaps - Runs - 3 - 6, 10 - 12, 15 - 18, 21 - 24

Spray - Runs 3 - 6, 9 - 12, 15 - 18, 21 - 24

TABLE II

SCOPE OF SALT-WATER EXPERIMENT

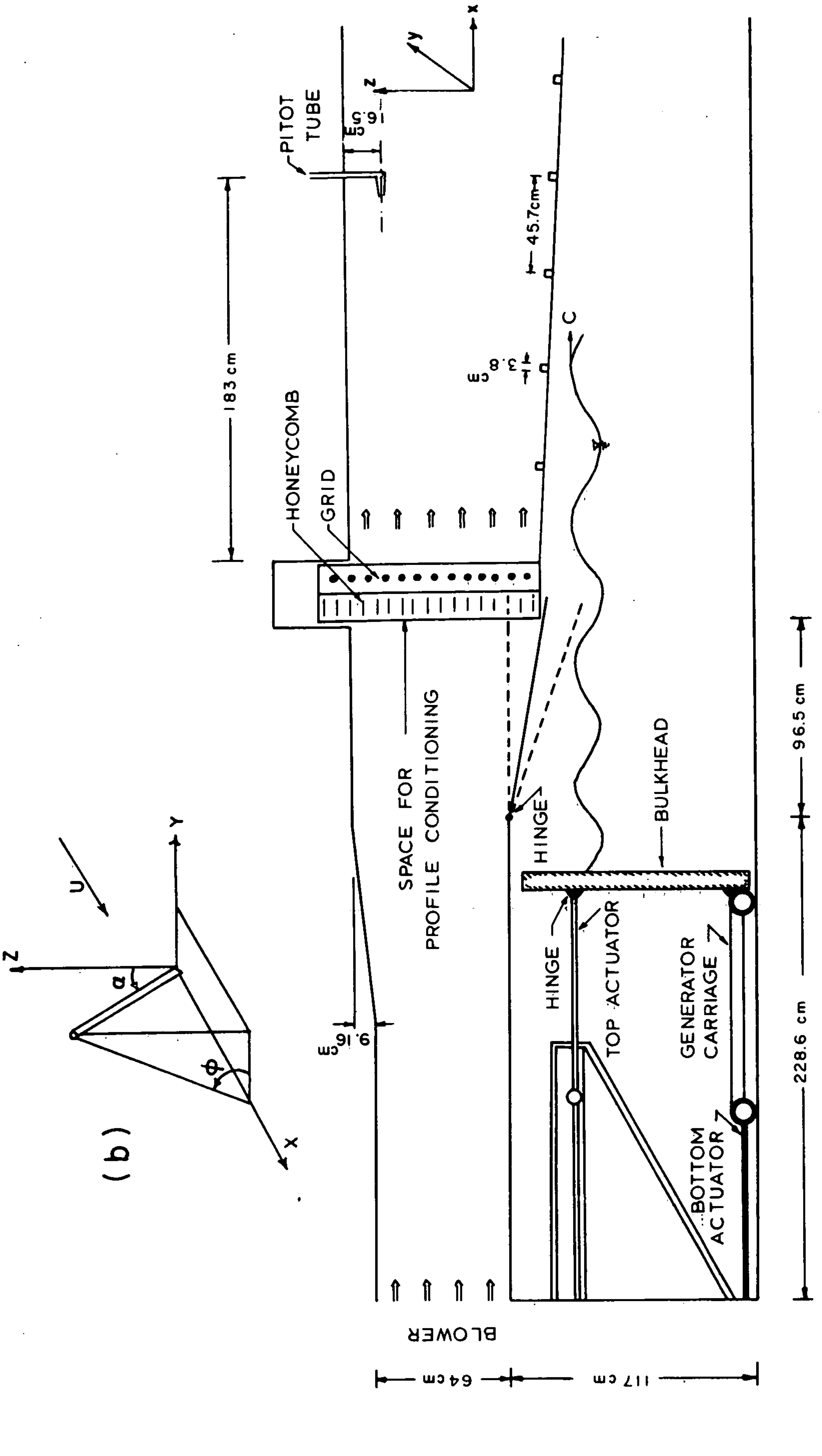
Wave Conditions	Wind Speed (m/sec)				
	5	10	15	16.7	18.1
Wind Waves	1	2	3	4	5
f= 1.0Hz, H = 5 cm F= 24.36 m	6	7	8	9	10
f= 1.0Hz, H = 15 cm F= 24.36 m	11	12	13	14	15
f= 1.0Hz, H = 20 cm F= 24.36 m	16	17	18	19	20
f= 1.0Hz, H = 25 cm F= 24.36 m	21	22	23	24	25
Wind Waves F = 15.3 m	26	27	28	29	30
Wind Waves F = 9.15 m	31	32	33	34	35

Whitecaps - Runs: 2 - 5, 7 - 10, 12 - 15, 17 - 20, 22 - 25, 27 - 30, 32 - 35.

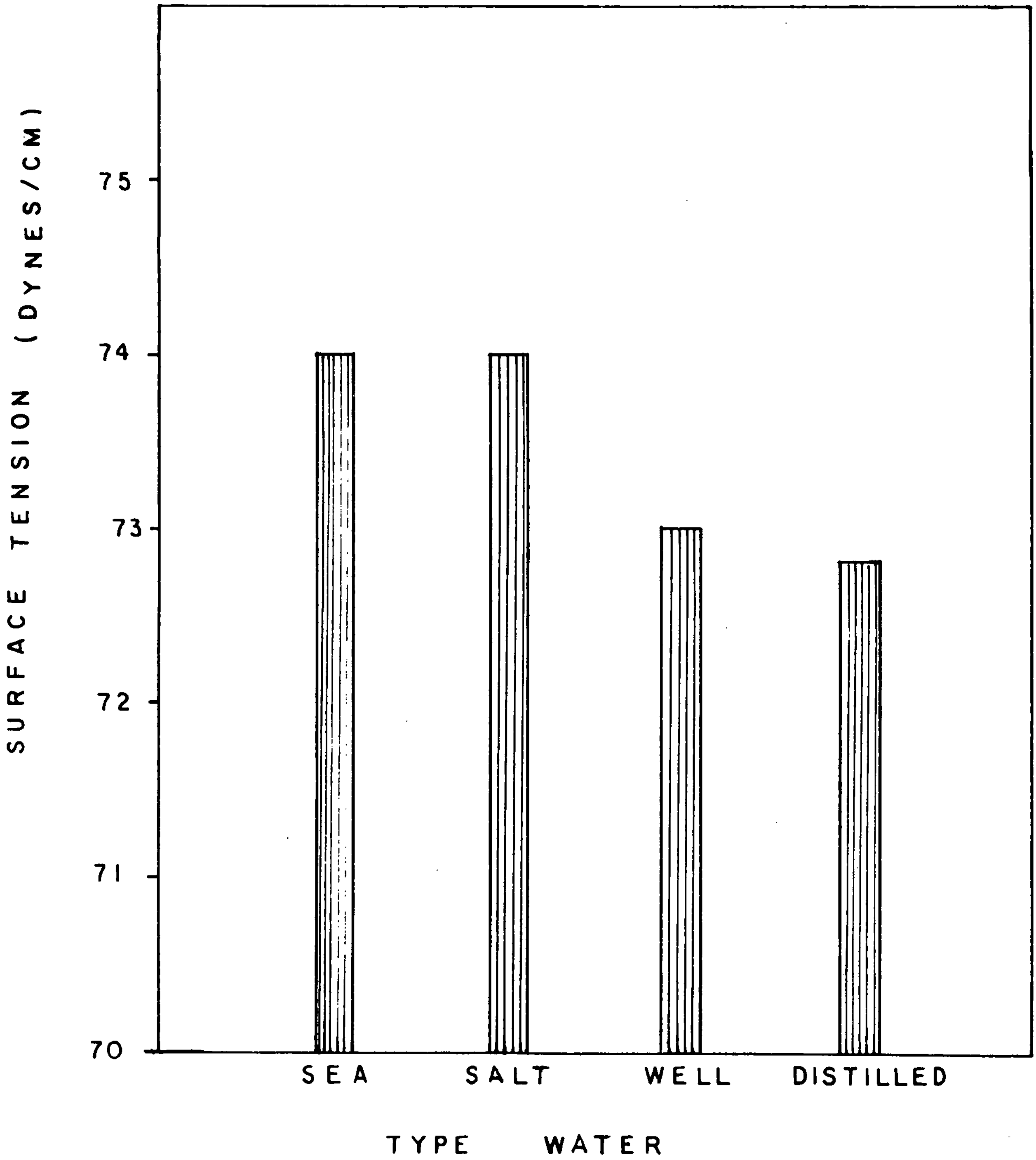
Spray - Runs: 2 - 5, 7 - 10, 12 - 15, 17 - 20, 22 - 25.

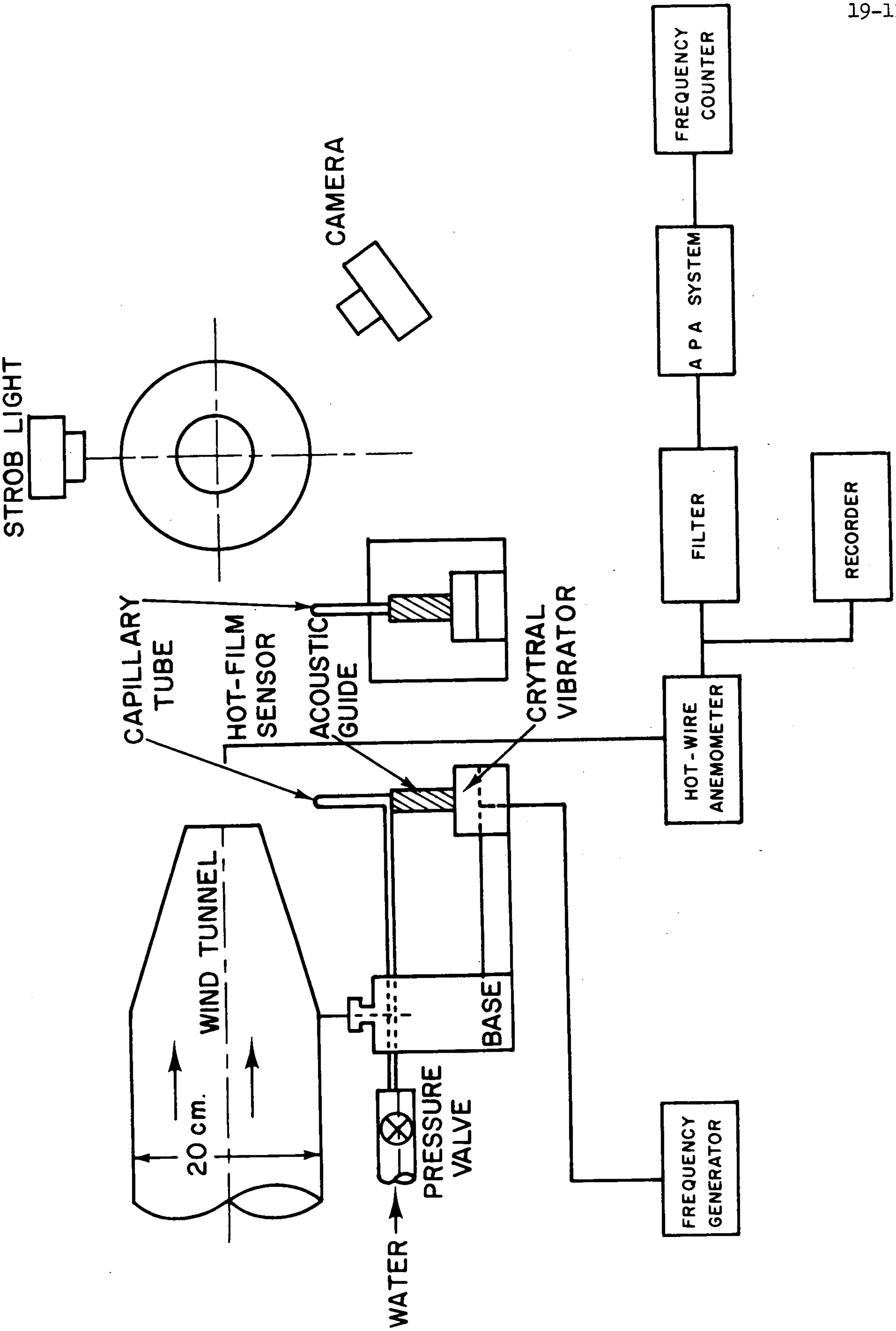
Capillary Waves - Runs: 1 - 3, 6 - 7, 11 - 13, 16 - 18, 21 - 23, 26 - 28, 31 - 33.

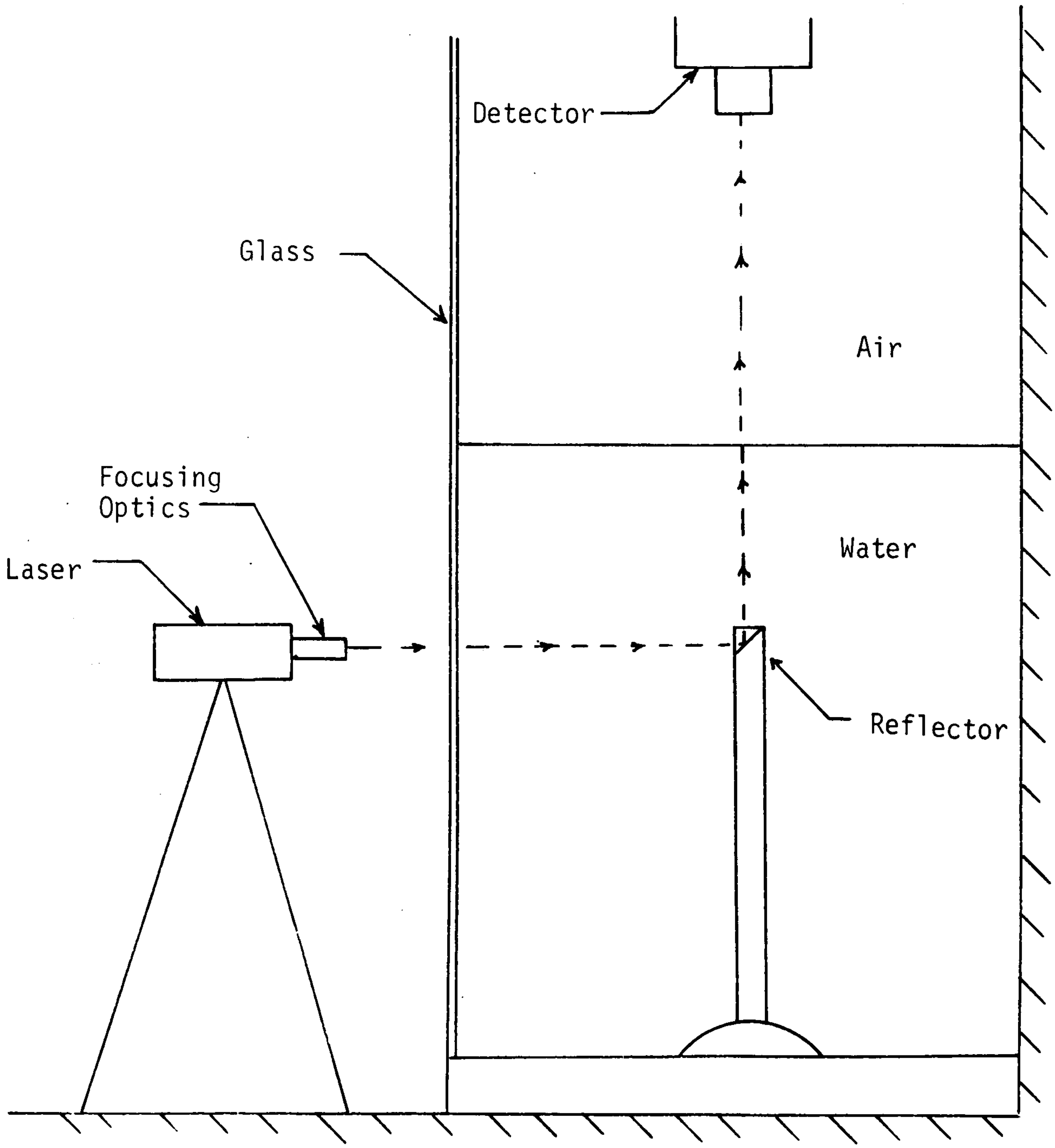
LIST OF FIGURES

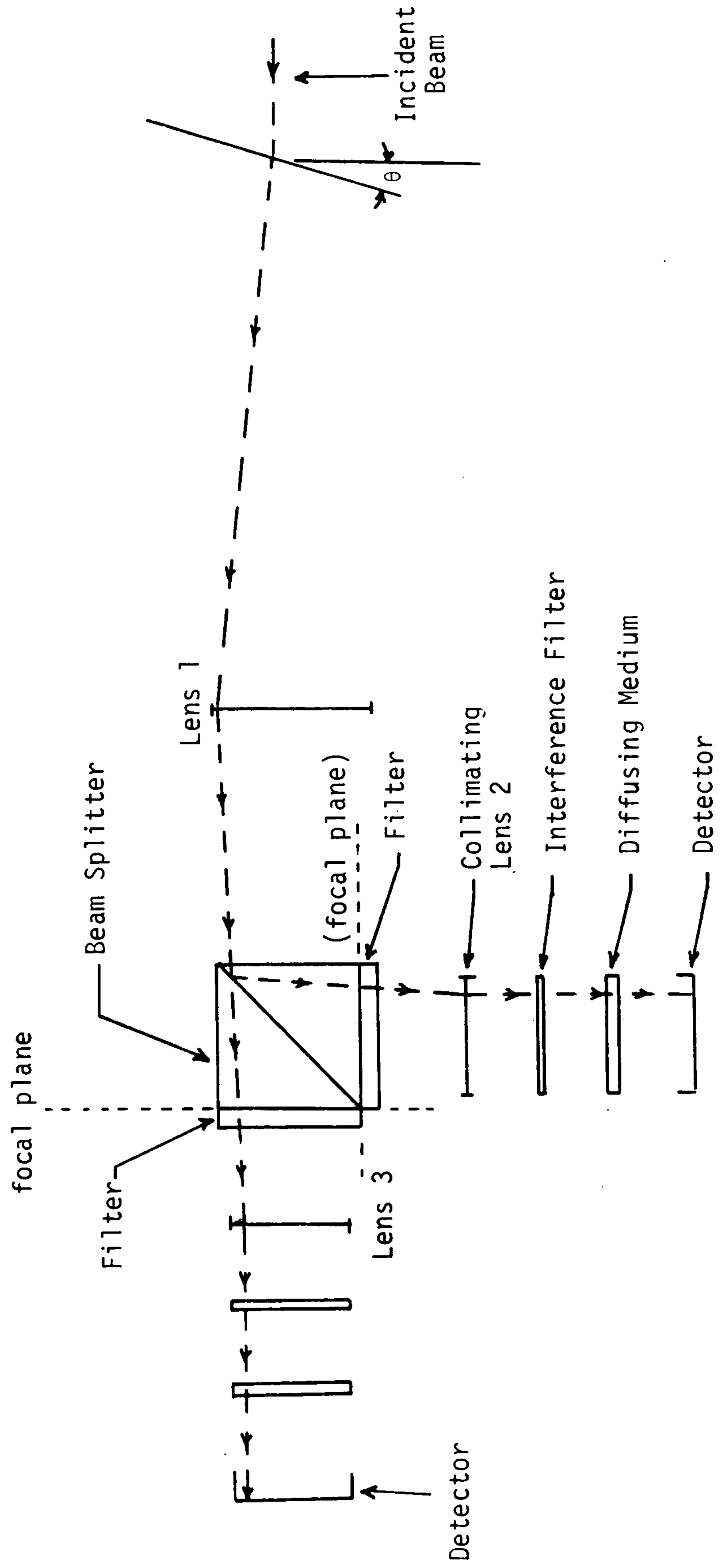


PITOT TUBE
16.5 cm
183 cm
45.7 cm
3.8 cm
C
HONEYCOMB
GRID
SPACE FOR PROFILE CONDITIONING
HINGE
BULKHEAD
HINGE
TOP ACTUATOR
GENERATOR CARRIAGE
BOTTOM ACTUATOR
96.5 cm
228.6 cm
9.16 cm
BLOWER
64 cm
117 cm
(a)
U
Z
Y
X
α
φ
(b)
x
y
z

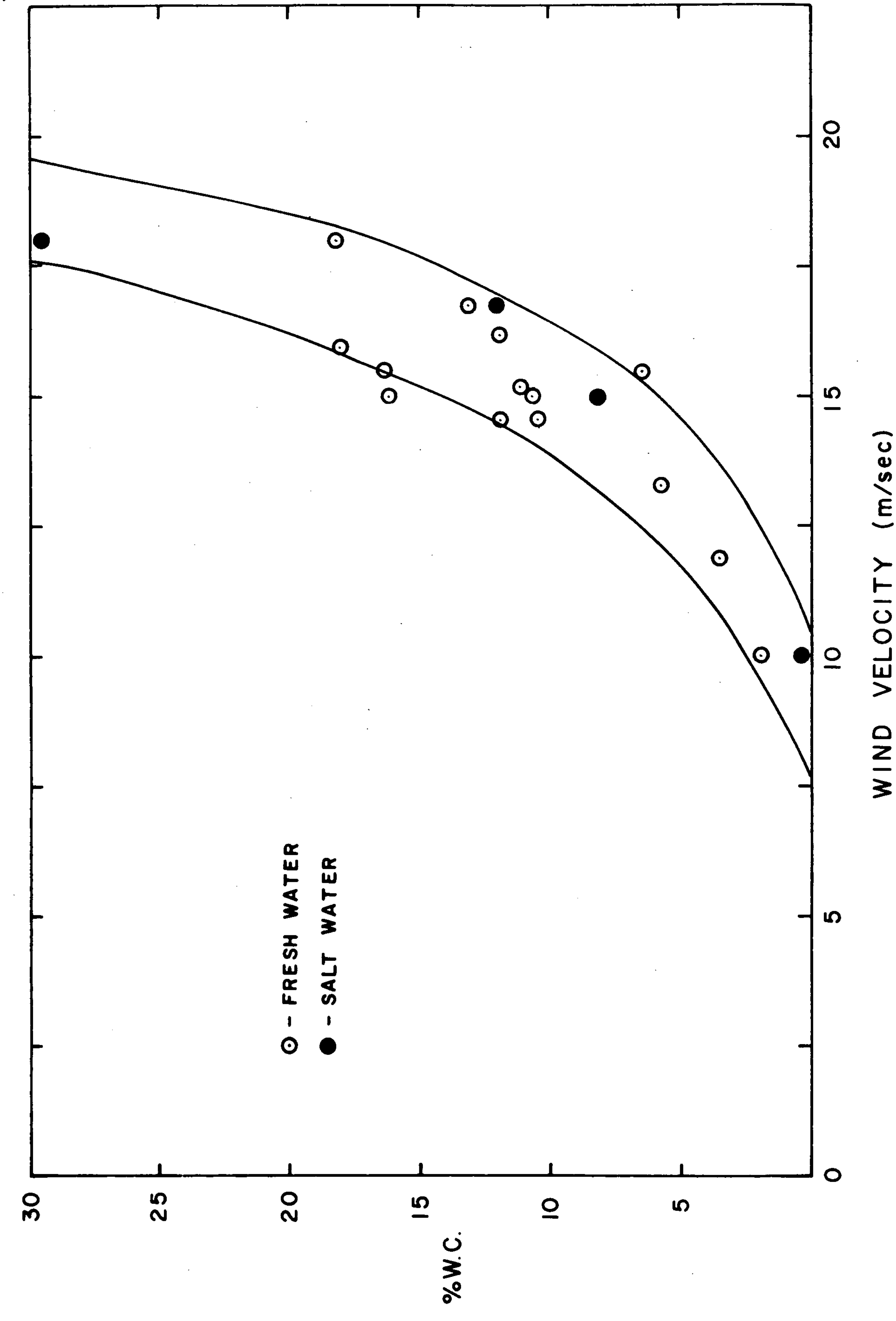

SURFACE TENSION (DYNES/CM)
75
74
73
72
71
70
SEA
SALT
WELL
DISTILLED
TYPE WATER


STROB LIGHT
CAMERA
FREQUENCY COUNTER
A P A SYSTEM
FILTER
RECORDER
CAPILLARY TUBE
HOT-FILM SENSOR
ACOUSTIC GUIDE
CRYTRAL VIBRATOR
HOT-WIRE ANEMOMETER
WIND TUNNEL
BASE
20 cm.
PRESSURE VALVE
WATER
FREQUENCY GENERATOR

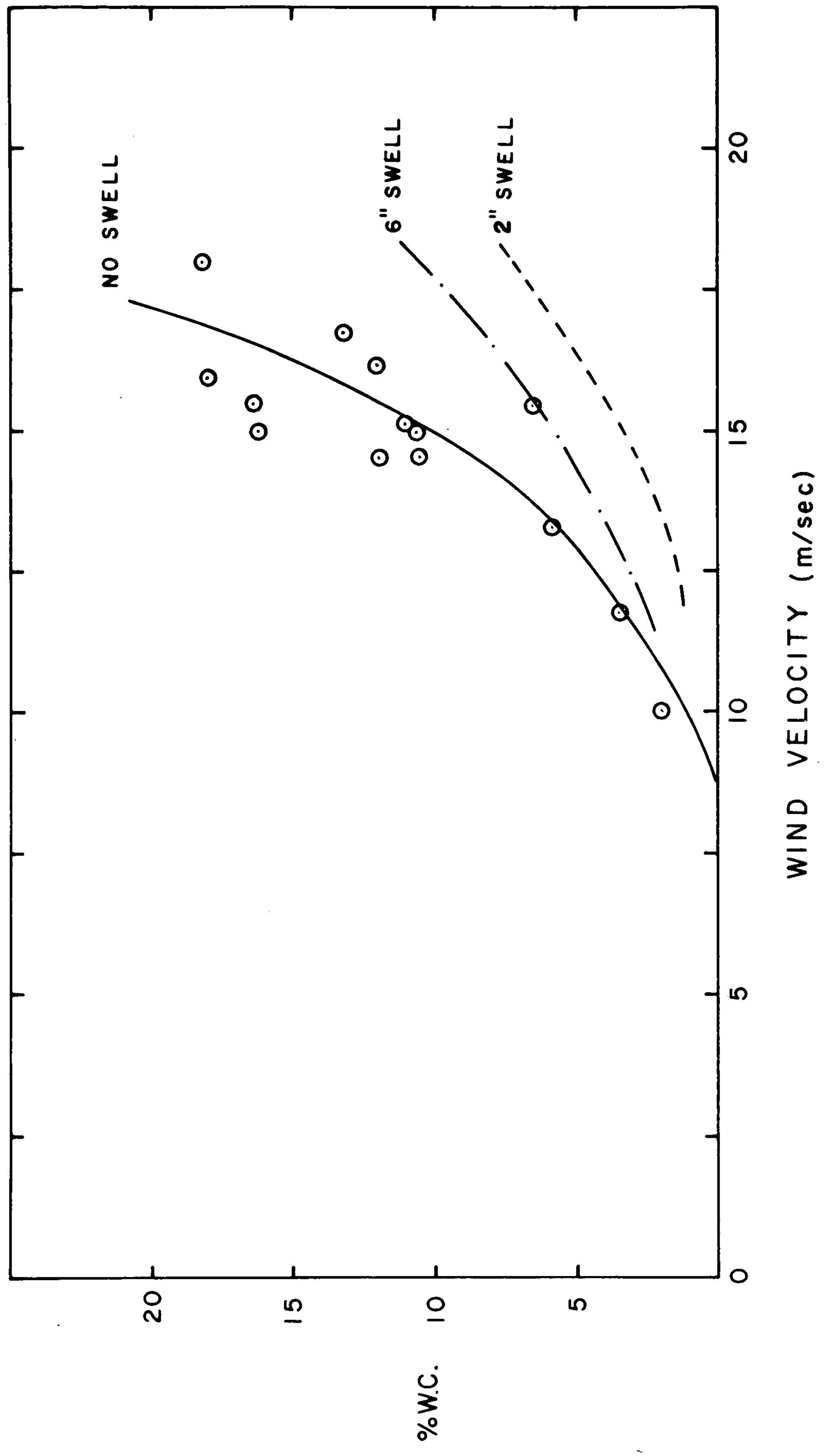

Detector
Glass
Air
Focusing Optics
Laser
Water
Reflector

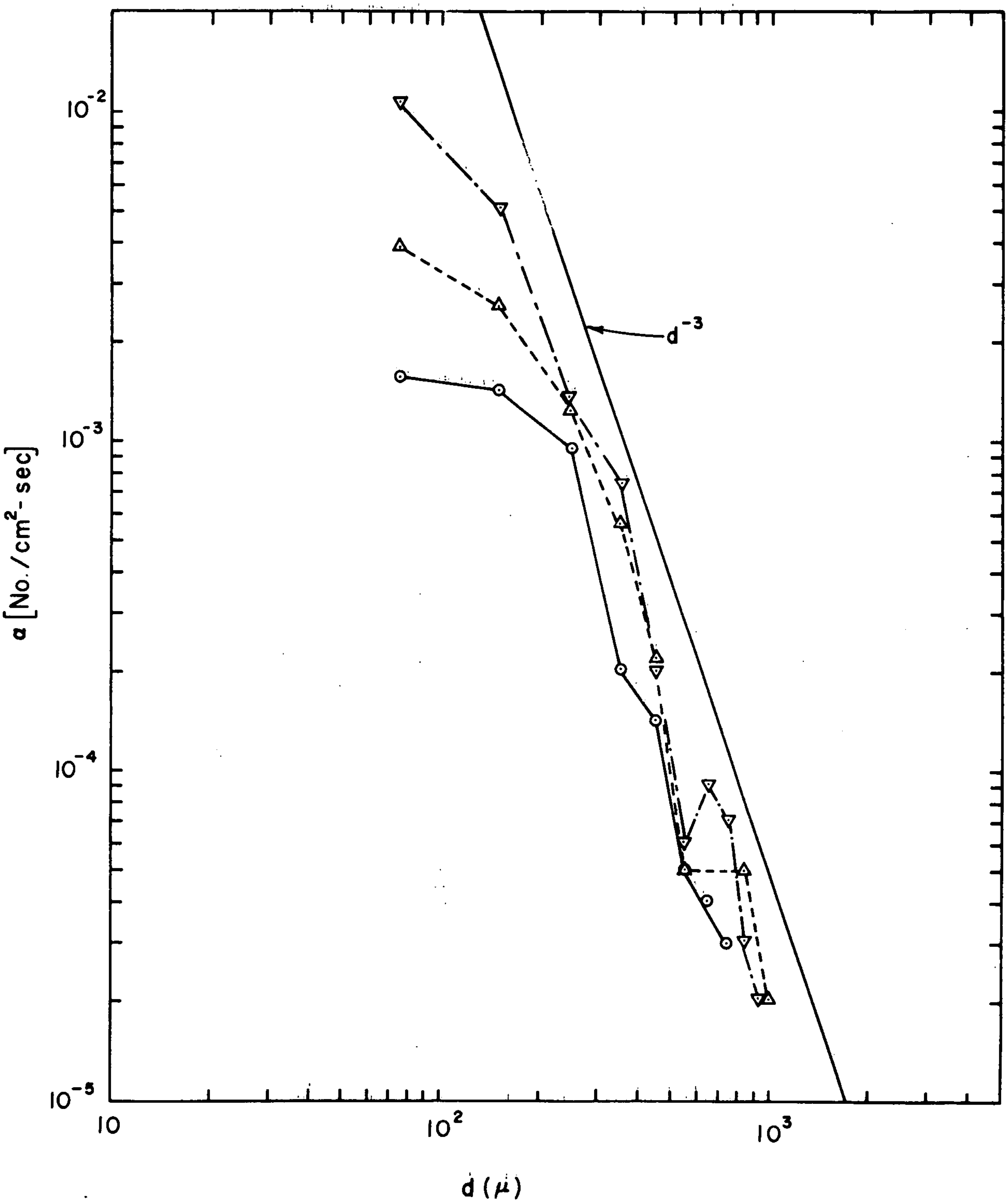


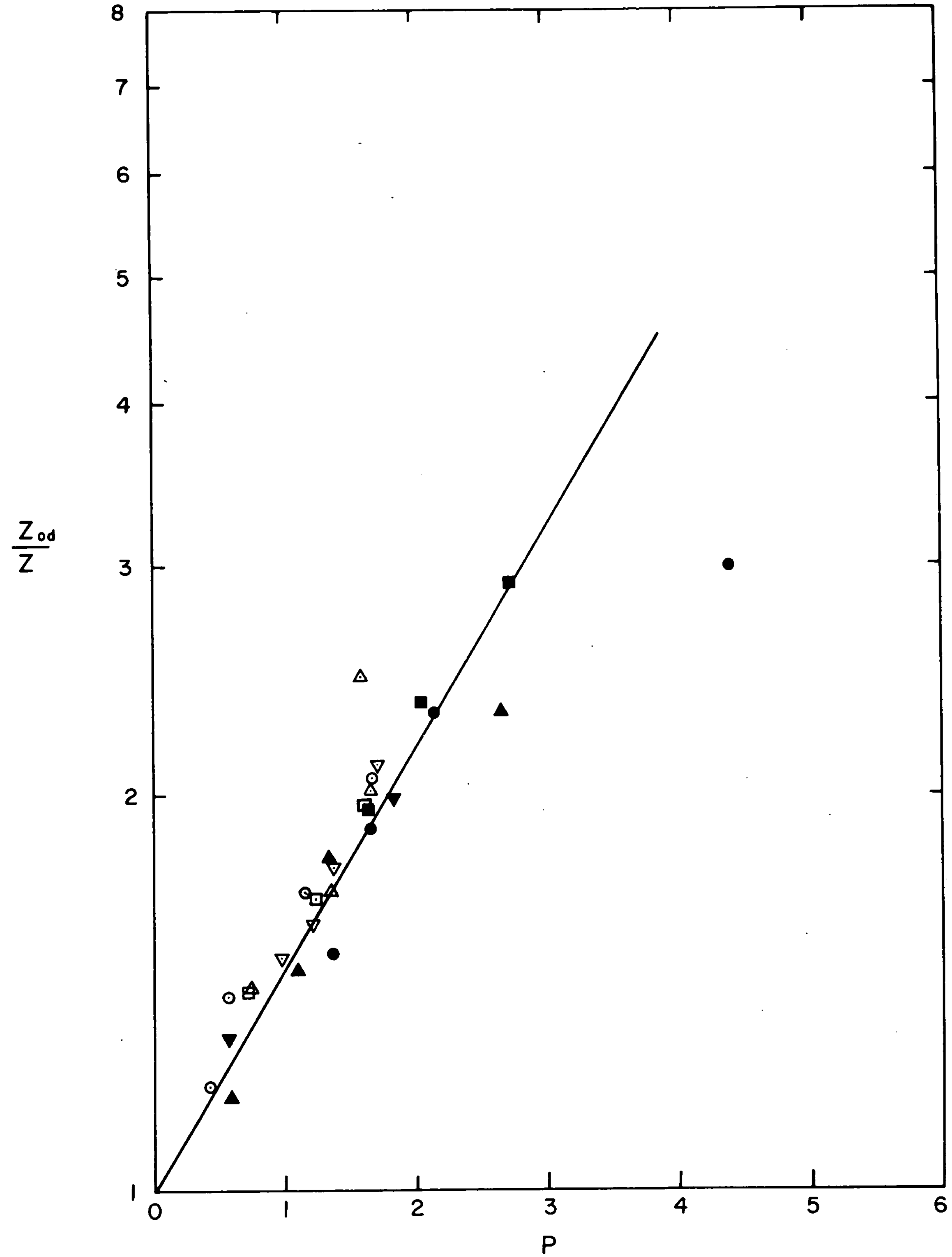
Incident Beam
θ
Lens 1
Beam Splitter
(focal plane)
Filter
Collimating Lens 2
Interference Filter
Diffusing Medium
Detector
focal plane
Filter
Lens 3
Detector



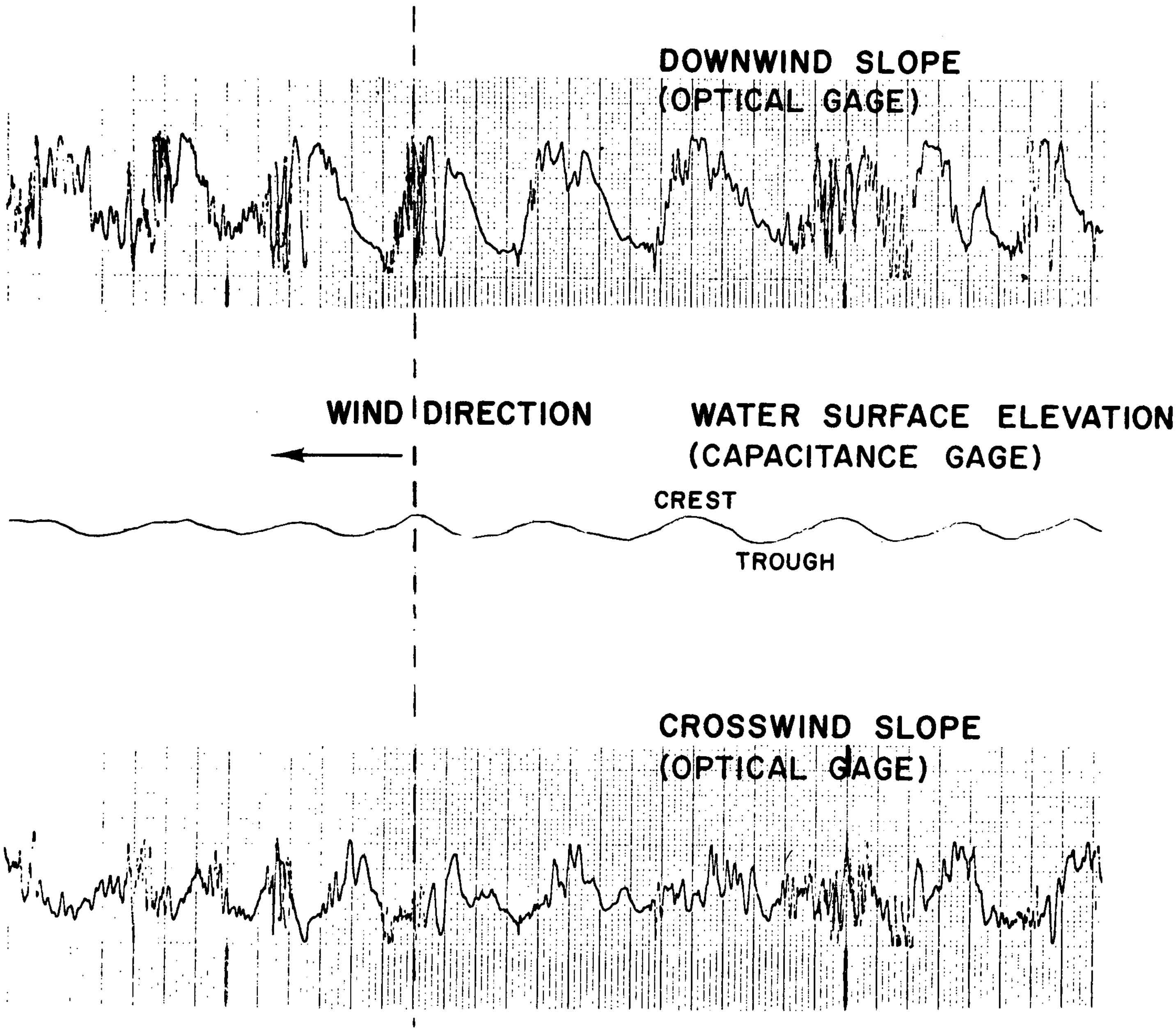
%W.C.
30
25
20
15
10
5
0
5
10
15
20
WIND VELOCITY (m/sec)
⊙ - FRESH WATER
● - SALT WATER

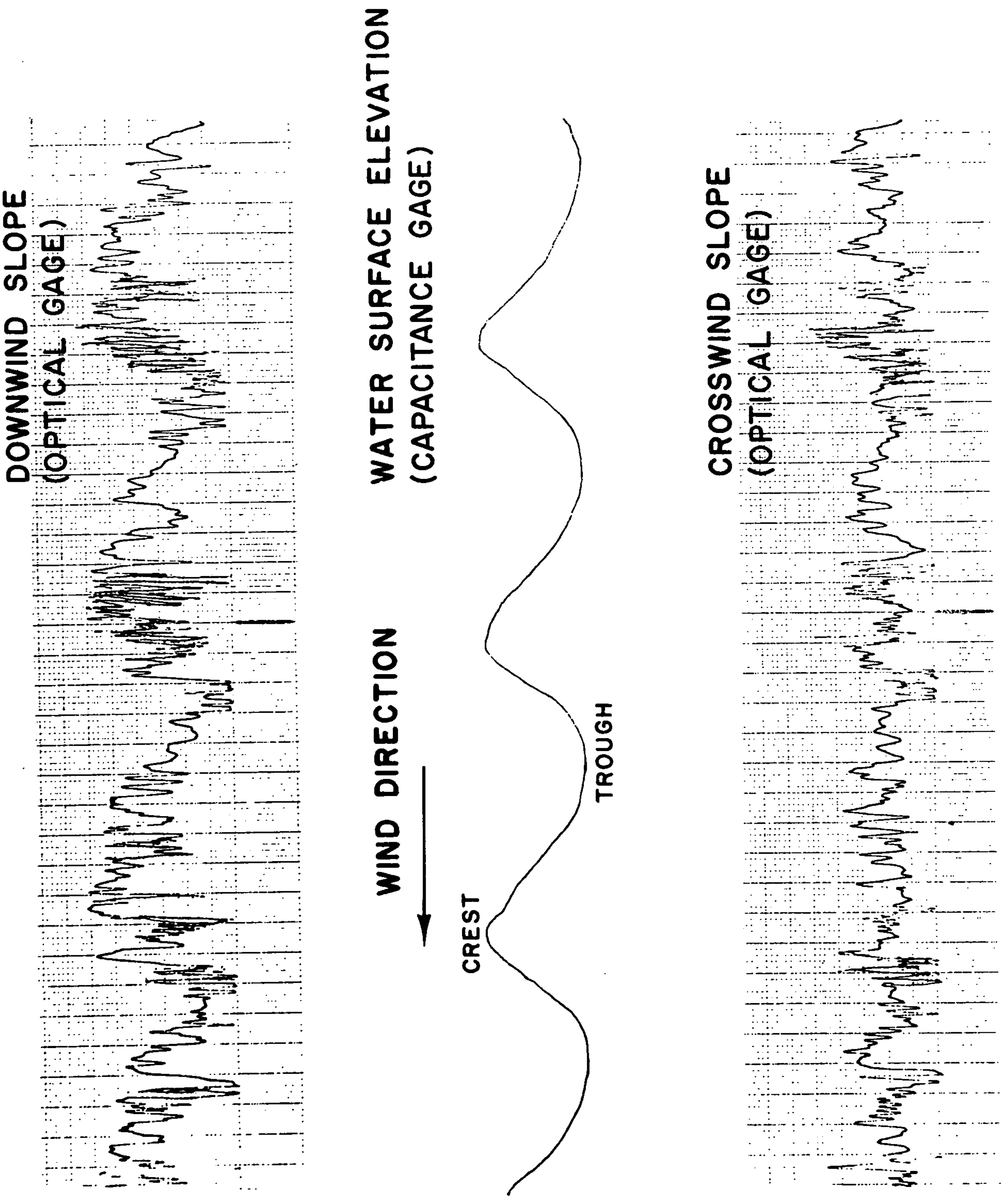

NO SWELL
6" SWELL
2" SWELL
WIND VELOCITY (m/sec)
%W.C.
0
5
10
15
20
5
10
15
20


a [No./cm²-sec]
10⁻²
10⁻³
10⁻⁴
10⁻⁵
d⁻³
10
10²
10³
d (μ)



8
7
6
5
4
3
2
1
$\frac{Z_{od}}{Z}$
0
1
2
3
4
5
6
$\frac{P}{P_*}$


DOWNWIND SLOPE
(OPTICAL GAGE)
WIND DIRECTION
WATER SURFACE ELEVATION
(CAPACITANCE GAGE)
CREST
TROUGH
CROSSWIND SLOPE
(OPTICAL GAGE)


DOWNWIND SLOPE
(OPTICAL GAGE)
WATER SURFACE ELEVATION
(CAPACITANCE GAGE)
CROSSWIND SLOPE
(OPTICAL GAGE)
WIND DIRECTION
CREST
TROUGH