THE UNIVERSITY OF MICHIGAN

COLLEGE OF ENGINEERING
Department of Meteorology and Oceanography

AN INVESTIGATION OF ATMOSPHERIC TURBULENT TRANSFER PROCESSES OVER WATER

Report Number One: Instrumentation
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by

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ABSTRACT

A facility for measurement of wind, temperature, and water vapor profiles over the surface of Lake Michigan has been established. The tower facility is located one mile from shore in 50 foot water depth. Instrumentation employed for measurement and recording of the above variables is described.

1. INTRODUCTION

In June, 1963, the U. S. Department of Commerce, Weather Bureau, contracted to the University of Michigan for an investigation of atmospheric turbulent transfer processes over water. The specific task included the design and construction or procurement of instrumentation to be installed on a tower in Lake Michigan to measure wind, temperature, and water vapor profiles, water temperatures and wave heights. Design, construction, and installation of the tower itself and associated cables from shore were accomplished by the U. S. Army Corps of Engineers. The ownership of the tower facility has been assigned to the U. S. Army, Corps of Engineers District, Lake Survey.

This report gives the design of the measurement system and presents specifications and descriptions of the individual system components. Schematic drawings of the electronic components are not presented; they are described only as to function. The tower structure is not described in engineering terms but is briefly discussed as required to present a concept of the measurement facility as a whole.

The tower was constructed and installed in Lake Michigan on July 12, 1963. The power cable was installed for transmission of 480 volt power to the tower on August 4, 1963. Current meters, supplied by the U. S. Public Health Service, were also installed at this time. Delay in establishment of the contract prevented installation of the permanent instrumentation during the contract period. However, temporary instrumentation was installed and first operated on a test basis on August 26.

2. DESIGN OF THE OVER-WATER FLUX MEASUREMENT FACILITY

The original proposal for the over-water flux measurement facility called for an instrumentation support extending 16 meters above water and located in water of sufficient depth to prevent bottom effects on surface waves. A location near Muskegon, Michigan, provided 50 foot water depth about 1 mile from shore. The tower facility was designed to be erected at this site.

2.1 Tower Structure

The tower structure was designed and constructed by the U. S. Army, Corps of Engineers, Detroit District. The tower is of braced construction having a triangular cross section 41 inches on a side. The tower itself is supported in a tripod base (See Figure 1) which is secured to 16 cubic foot concrete anchors at each leg. The tripod top is about 3 feet beneath the water surface when erected in 50 foot depth with the tower extending to a height of about 55 feet above the water surface. The upper sections of the tower are not shown in Figure 1.

The entire structure is self supporting and of open construction. Thus, water can flow through the structure with a minimum of resistance or interference. The portion of the tower above water is constructed of tubular steel and offers a minimum of interference to air flow consistent with the necessary strength requirements. The tower was designed to support a 200 lb. instrument load in a 50 knot wind or a 200 lb. person plus the instrument load in a light wind.

Electrical power for operation of the instrumentation and navigation beacon at the tower is supplied by a submarine cable from shore. Power consumption through cable resistance is reduced to a tolerable amount by use of 480 volt power transmission. A step-down transformer at the tower provides 117 volt AC as the basic power for instrumentation requirements. A second cable to shore provides 4 conductors for transmission of data to be recorded on shore.

The tower facility has not been designed to withstand the pressure of surface ice that will occur during the winter. It is, therefore, necessary to remove the tower before ice forms and re-install it the following spring.

2.2 Tower Instrumentation

The instrumentation of the off-shore tower for experimental measurement of turbulent exchange of heat, mass, and momentum between atmosphere and water has arbitrarily been divided into three separate systems. This division has been dictated by a desire to obtain maximum information during periods of relatively smooth water but yet provide for survival of instruments during

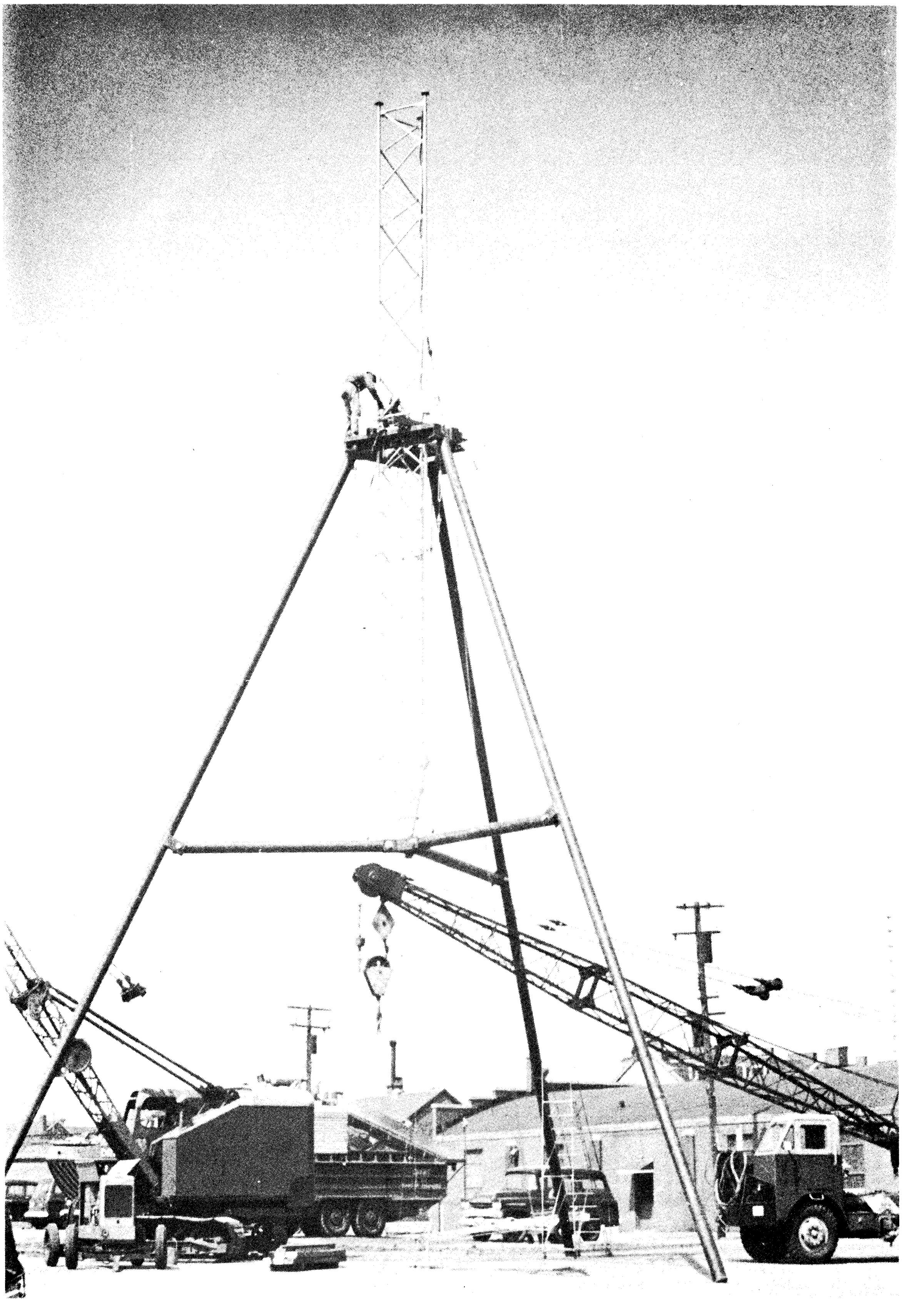

Figure 1. Tower facility showing structure both below and above water.

rough water. The systems are divided as follows.

I. Sensitive and accurate instrumentation designed to measure continually the mean profiles of interest and to be capable of operation during adverse weather.

II. A secondary system designed to supplement the instrumentation in System I to provide greater detail of the profiles near the air-water interface. This system can operate only during periods of relatively smooth water and must be attended to prevent wave damage to the sensors.

III. A rapid response system for recording direct measurements of the turbulent fluxes and wave statistics as continuous time series. This system can operate only during selected periods and only while carefully attended.

In addition to the three systems listed, other measurements of less direct concern to flux computations are to be made. These include measurements of water level, water current, and water temperature. Except for System III which will not be implemented under the present contract, instrumentation employed in all cases is described below in more detail.

2.2.1 Placement of Sensor Equipment on Tower

Figure No. 2 is a photograph of the tower showing the location of sensors as employed during the period of temporary operation during September 1963. The permanent installation will not differ in significant detail from the arrangement shown.

Placement of sensors was decided upon by consideration of the general characteristics of the profiles to be measured and with regard to the expected wave heights. It was decided that 3 meters above mean water level is the lowest height at which permanent instrumentation would not suffer frequent damage by waves. System I instrumentation is, therefore, limited to heights greater than 3 meters while System II instruments are mounted below that level on a removable mount. Mounting locations of sensors on the tower is summarized in Table No. 1. These locations will be changed if experience indicates a more desirable arrangement.

Temperature, wind, and dew point sensors are mounted on arms extending westward from the tower. This direction was chosen to avoid influence of the tower on the measurements since east (off-shore) air trajectories are of little interest. Wind sensors are supported on arms 60 inches in length while the temperature and dew point aspirators extended only 36 inches from the tower. It is believed that the tower will not exert significant influence on measurements when the air trajectory has any west component. The sensor elements and recording system is discussed in detail in the following sections.

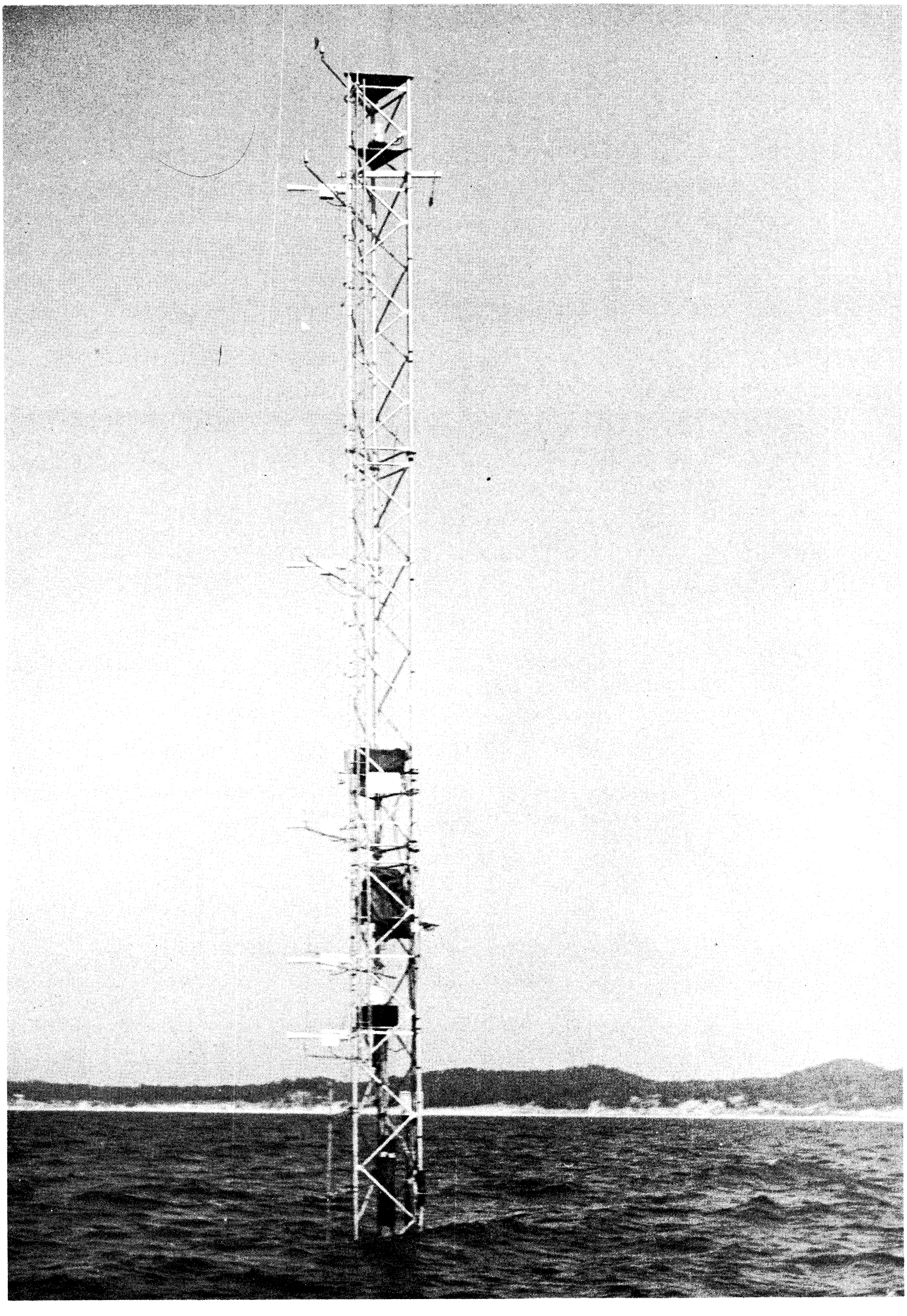

Figure 2. Off-shore tower showing location of sensors.

Table No. 1

Sensor Exposure on Off-shore Tower

Height Meters re sfc	Wind Speed	Wind Direction	Air Temp.	Dew Point Temp.	Water Temp.	Current Speed	Current Direction
16.0	X	X	X	X			
10.0	X		X	X			
6.0	X		X	X			
4.0	X		X	X			
3.0	X		X	X			
2.0	X		X				
1.0	X		X				
0.5	X		X				
Sfc.					X		
-2					X	X	X
-8					X	X	X
-16					X	X	X

3. RECORDING AND TELEMETERING SYSTEM

The method by which the measurements listed above would be recorded evolved from consideration of several factors. Some of the major considerations are listed.

a. All measurements should have errors of less than 1% of full scale values.
b. The recording system must be capable of operation during adverse weather to record the measurements from System I.
c. Any equipment to be operated at the tower must not exceed the weight limitations and power availability at the tower.
d. The output of the recording system should be of a form such that a minimum of time and effort are required in data reduction. Preferably, the output should be in a computer format.
e. Cost of the system must be within the limited budget of the contract.

Requirements "b" and "c" severely restrict the placement of a recording system on the tower. It was decided that a telemetering link to shore and subsequent recording of the data would be the most feasible approach. Consideration "a" placed stringent requirements on the telemetering system and eliminated direct transmission of an analog of each sensor output. The cost of a 32 channel data link would also have been prohibitive. It was, therefore, decided to provide for sequential commutation of the sensor outputs into a single channel data link for sequential recording on shore. The data transmission and recorder systems are described only in functional terms. Schematic diagrams of the electrical components will not be finalized until the system has undergone extensive testing and are, therefore, not included. This section describes the functions of the recording system; the sensors and associated transducers are described in later sections. Figure No. 3 is a block diagram of the functional components of the recording system.

Basically, the recording system permits a single measurement from each of 32 sensors every two minutes. The 60 cps electric power is employed as a time reference. The time pulse generator produces a 15 cps square wave which serves as a pulse to cause the stepping motor to advance. At command from the two minute cycle timer the stepping motor rotates the double pole commutator through the 32 input points at a rate of 15 cps or 66.66 milliseconds per point. At the completion of a cycle, the stepping motor waits until the end of a two minute period for command to begin the next cycle.

The commutator output consists of a series of pulses, each of 66.66 milliseconds duration, and each having an amplitude equal to the value of the

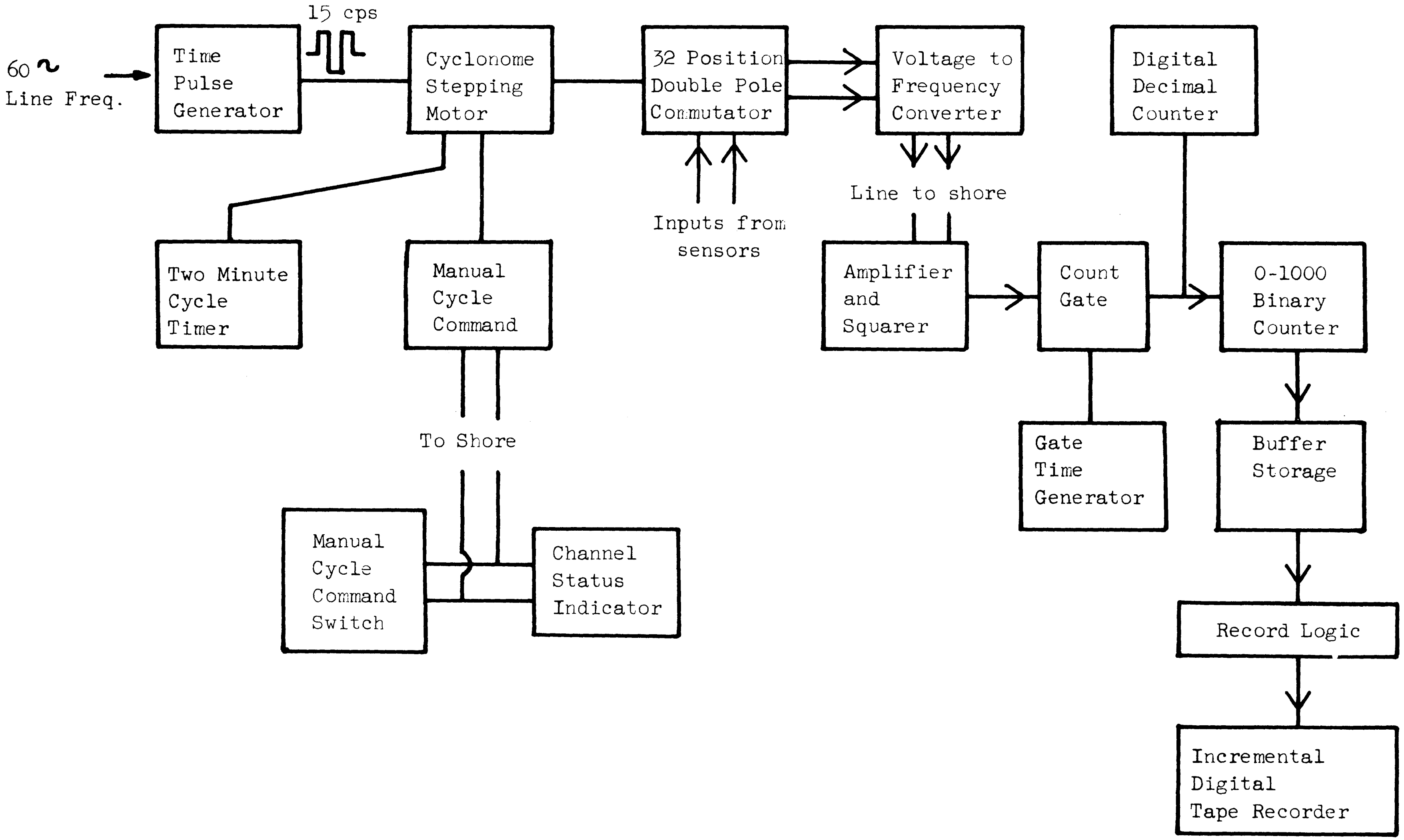

Figure 3. Block diagram of recording system.

analog input from the particular sensor. Thus, a 66.66 millisecond sample is obtained from each sensor every two minutes. All sensor outputs must be scaled to a 0-20 millivolt range and negative outputs are not permitted.

The low level voltage output of the sensors cannot be transmitted over the 1 mile cable to shore with the required accuracy. For this reason, a voltage to frequency converter is employed to provide a signal for transmission to shore in the form of frequency, variable from 1 to 31 Kcs in exact proportion to the applied voltage.

The variable frequency signal is amplified and converted to square wave pulses on shore. Because of the finite time required for the commutator switch to make contact to a new input and because of the time required for the voltage-to-frequency converter to stabilize at a new level, the entire transmitted pulse cannot be considered as valid information. The gate-time generator provides a gate pulse delayed about 10 milliseconds from the start of each new incoming signal pulse and having a duration of 33.3 milliseconds. Thus, only 33.3 milliseconds of each 66.6 milliseconds of information from each sensor is presented to the binary counter on each cycle.

The voltage-to-frequency converter produces an output signal which varies in frequency in a direct proportion to the applied voltage. The frequency range employed is 1 to 31 Kcs; the 1 Kcs offset is provided to avoid undesirable noise from inductive pick-up in the transmission line. The intelligence is obtained from the 33.3 millisecond pulse transmitted by the count gate to the binary counter. It is only necessary to count the number of cycles contained in the 33.3 millisecond pulse, allowing for the 1 Kcs zero offset, to obtain a 0 to 1000 part resolution of the applied voltage. The variables are, therefore, measured to a resolution of 1/1000 th of the scale chosen for any particular sensor.

The recorder employed cannot record directly at the rate that the commutator presents data. It is, therefore, necessary to store the output of the counter for approximately 60 milliseconds. This operation is accomplished in the buffer storage.

The record logic and incremental digital magnetic tape recorder* process and record the binary data in proper sequence and with checkbits to make it compatible with an IBM 727 or 729 tape transport and with the IBM 709 or 7090 computer. The logic and record system is a modified Meteorological Digital Data Logging System Model 293 produced by K. J. Law Engineers. A complete description of the system is contained in the instruction manual (Ref. 4). The recorder employed is a Honeywell Model 6151, Incremental Magnetic Tape Recorder.

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*The record logic and incremental recorder are supplied by the University of Michigan from another program.

The output tape format is shown in Figure No. 4. Data words are recorded in pure binary code, the recording being done in two parts for each data word of 10 binary bits. The first recording places the binary bits 2^6, 2^7, 2^8, and 2^9 in tracks 1, 2, 4 and 8 with odd parity check bit in track C. The second recording places bits 2^0, 2^1, 2^2, 2^3, 2^4 and 2^5 in tracks 1, 2, 4, 8, A, and B with the odd parity bit in track C.

Each data block will contain 30 complete cycles of the commutator system of 32 points each. Each 10 bit binary word requires .010" of space on the magnetic tape. A data block of 1 hour length will, therefore, require 9.60" of tape with a space block of 0.80" to separate blocks. The data blocks will be identified by sequential counts of 1 to 24 for purposes of time identification.

Successful recording of accurate data from a system of meteorological sensors requires frequent checks on sensor and recording system performance. Since the magnetic tape recording system provides no visible record, an auxiliary manual interrogation system is provided. Automatic cycling of the commutator is interrupted and the commutator switch is advanced one step upon each actuation of the manual cycle command switch. The channel status indicator will indicate the input channel being interrogated. While the system is under control of the manual command, a digital counter displays the output from the channel selected in decimal form.

The manual cycle command permits an operator to obtain sequential readings from each of the sensors. He may thus determine if the various sensors and telemetering system are providing data that appear reasonable in his judgment.

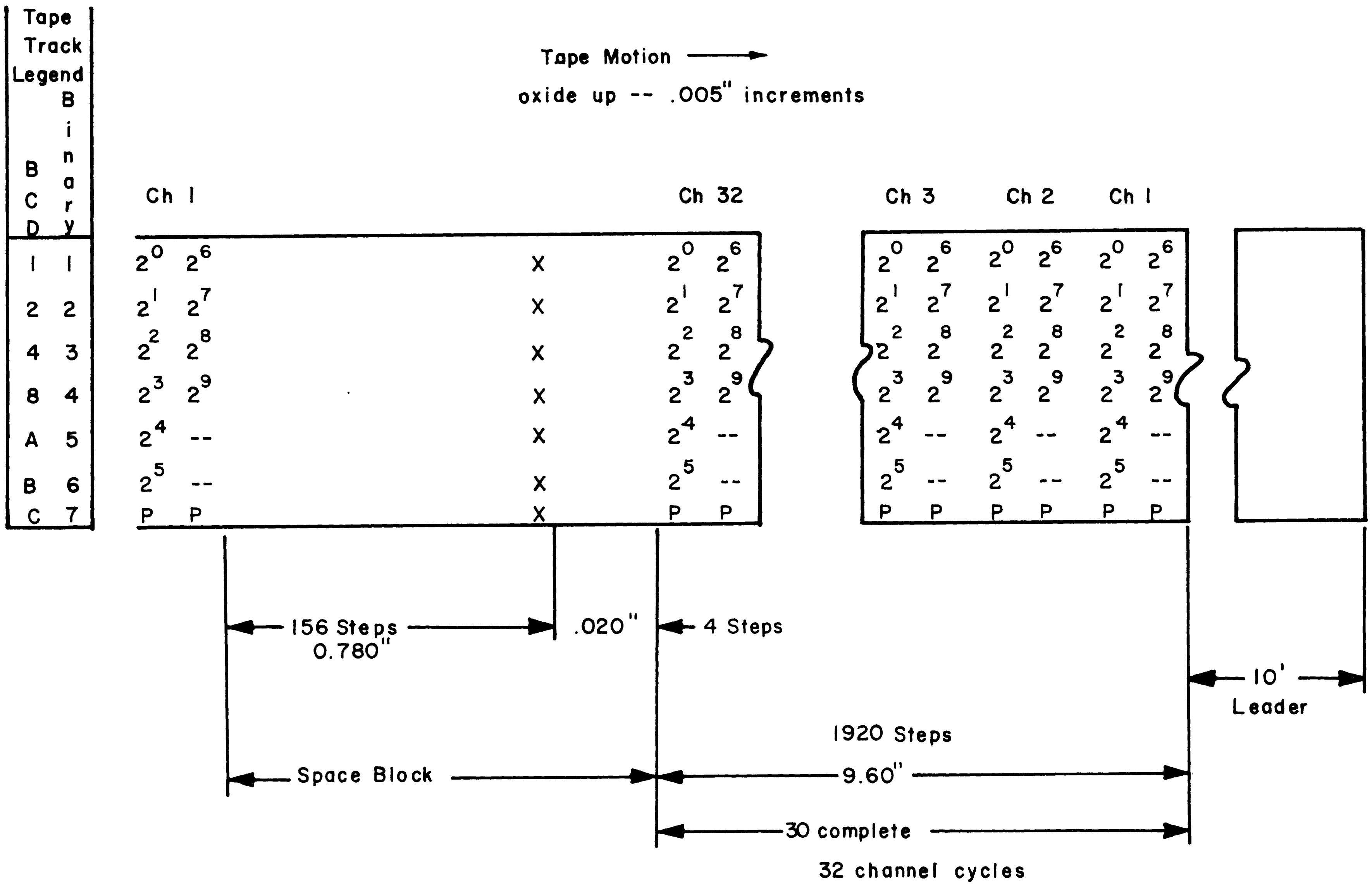

Figure 4. Magnetic tape recording format.

4. SENSOR SYSTEMS

The sensor systems described are those instruments that comprise System I and II as outlined under Section 2.2. The instruments for System III have not been procured under the present contract.

4.1 Wind Speed Sensors

The wind speed sensors are primarily required to provide a measure of the vertical gradient of wind speed over the vertical distance of the tower. The absolute accuracy of the sensors is, therefore, of less importance than the comparative accuracy of the different sensors although absolute calibration must also be known. Furthermore, Systems I and II above are for measurement of the mean wind speed profile rather than a continuous record of the instantaneous wind speed. The instantaneous speed need not be measured but an accurate measure of the time integral of the speed is essential.

The above factors and requirements of the recording system were considered in the choice of anemometers to be employed. Accurate and closely matched calibration of several anemometers is not easily achieved. Past experience indicates that a difference of calibration of less than 1% can be obtained among low inertia 3 cup anemometers if frequently calibrated and carefully exposed. At least three commerical units are available with specifications quoted to be within this limit.

The wind speed sensor chosen for the profile measurements of System I is the Climet Instruments Inc., Model 011-1 shown in Figure 5. The quoted specifications state a threshold of 0.76 mph and a calibrated range from 0-90 mph. The five units required for System I were procured with additional cups having calibrations matched to within ±1% so that lost or damaged cups could be replaced without loss of comparative accuracy within the system.

System II requires measurement of wind speed at closely spaced points near the water surface. The physical size of the Climet Instruments, Inc. anemometer make mounting difficult in this case. Interference of the mounting structure of one anemometer on the air flow measured by the sensor of the adjacent instrument could be possible. The anemometers produced by C. W. Thornthwaite Associates (shown in Figure No. 6) have a much smaller mounting and were, therefore, chosen for use at the lowest four levels. This anemometer has essentially the same characteristics as the Climet Model 011-1 but should not be exposed to wind speeds greater than about 30 mph.

In the case of both anemometers, the cup rotation produces one pulse per revolution through use of a photoelectric light "chopper." After suitable amplification and shaping, the pulse is applied to a Tunnel Diode Counter (Model 407, K. J. Law Engineers). The counters accumulate counts of anemometer revolutions until interrogated by the recording system, after which they are reset to zero.

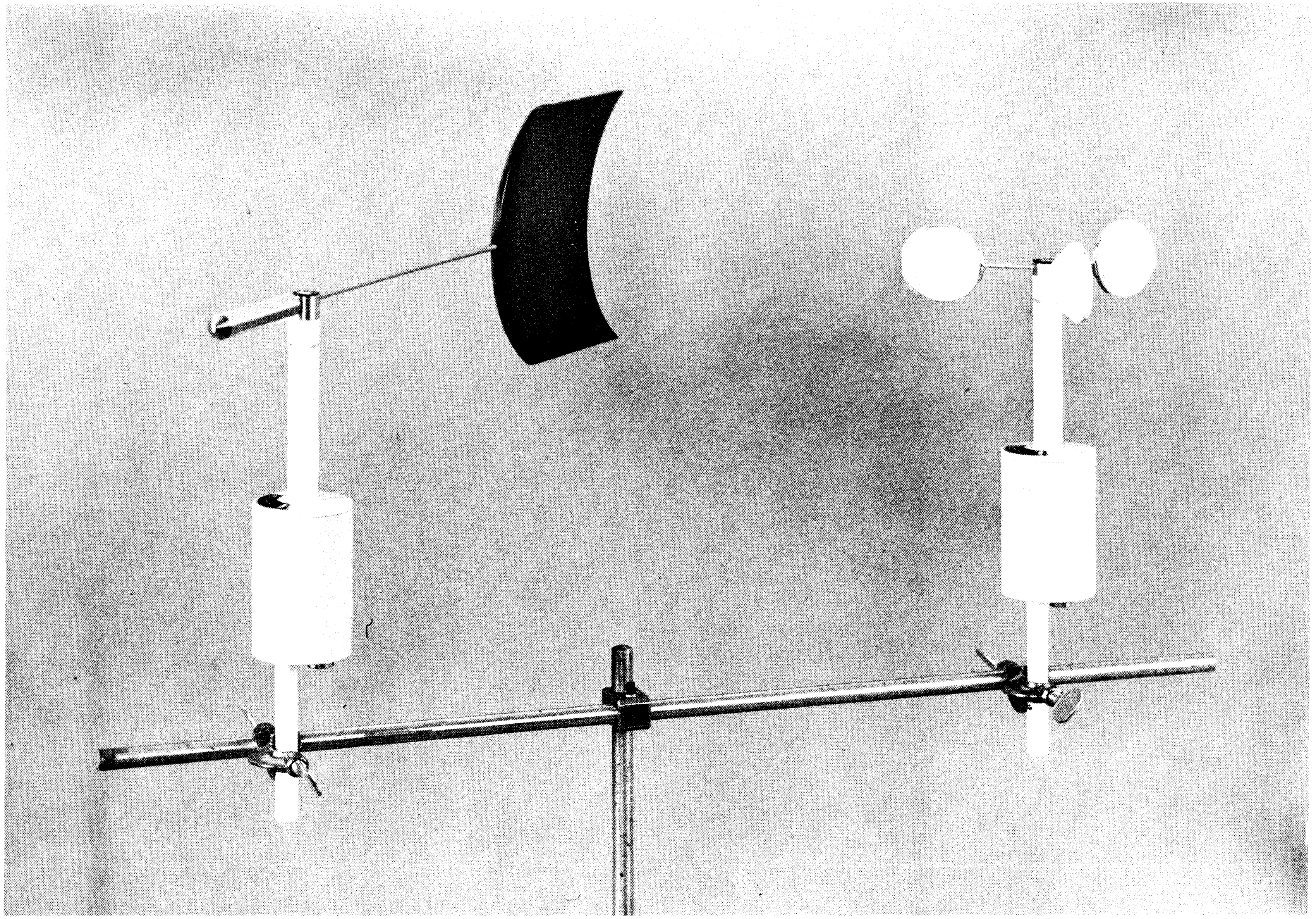

Figure 5. Climet Instruments, Inc., wind speed and wind direction sensors.

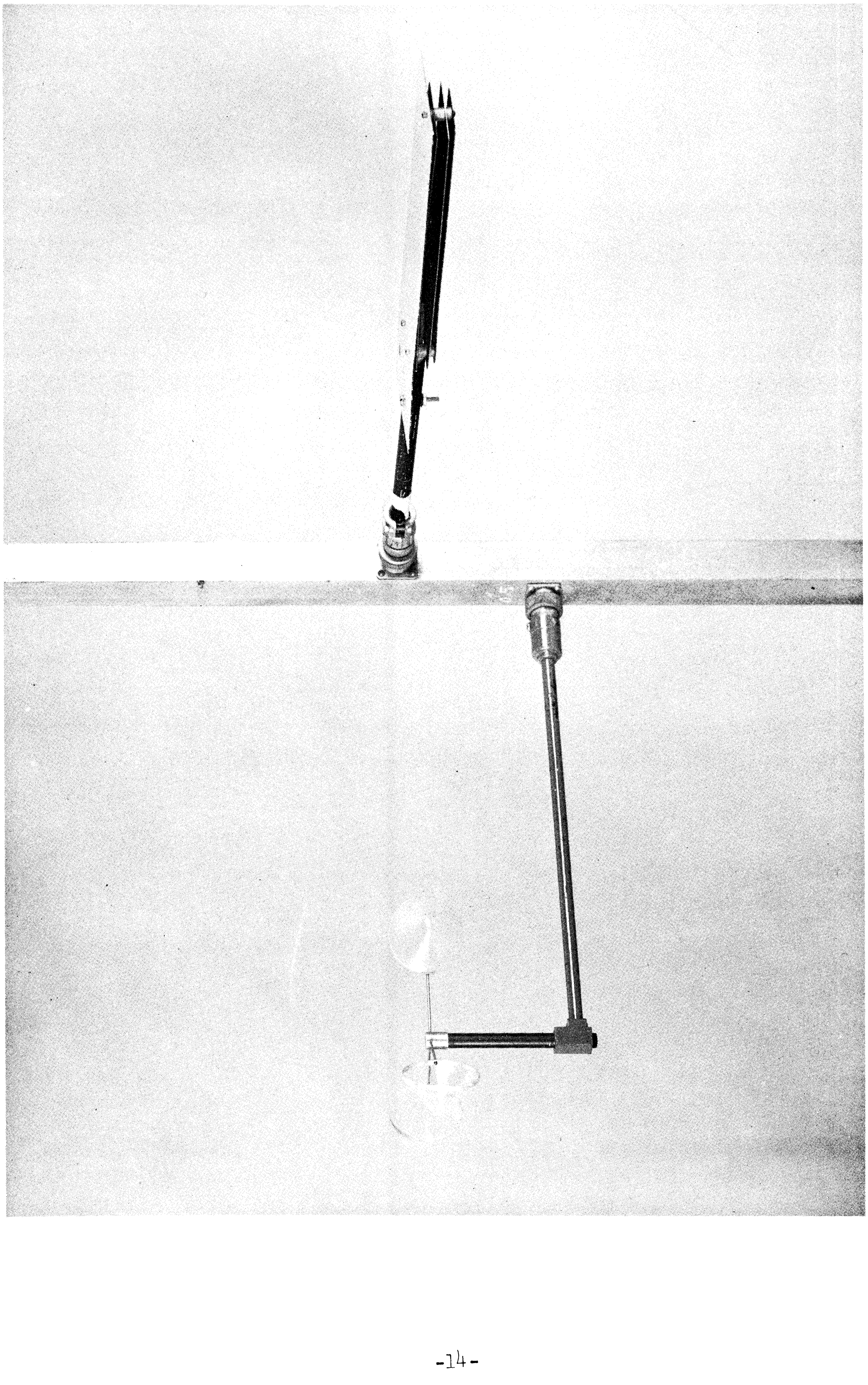

Figure 6. C. W. Thornthwaite Associates wind speed sensor and unaspirated radiation shield.

The recording system, as described in Sec. 3.0, provides for interrogation of each sensor once every two minutes. Thus, the measured value from each anemometer is an integral of the air movement for a two minute period to an accuracy of ± 1 anemometer revolution (about 5 ft of air). The integrals at successive levels are read sequentially with a time separation of 66.6 milliseconds. When eight wind speed measurements are employed, the maximum departure from simultaneous integrals at all levels is about 523 milliseconds. For practical purposes, the recorded data can be considered to be a simultaneous measure of air movement at all levels.

4.2 Wind Direction Sensor

Wind direction measurements do not enter directly into computation of the vertical fluxes but are required to determine the trajectory of the air and to obtain estimates of the equilibrium between air and sea movements. A single wind direction measurement can provide the required information.

The Climet Instruments, Inc., Model 012-1, wind direction transmitter, shown in Figure No. 5 was selected as a wind direction sensor. The instrument is exposed on the tower at a point near the 16 meter level in a location that does not influence the wind speed or temperature measurements. The wind vane actuates a potentiometer that provides a 0-20 millivolt signal for a 360° rotation of the vane. An instantaneous record of wind direction is obtained for every two minute period. Wind direction will be recorded to an accuracy of about one degree.

4.3 Air Temperature Sensors

The measurement desired from Systems I and II is a true mean value of the air temperature at the level of sensor exposure. To accomplish such a measurement, the sensor must be exposed so that it is not influenced by solar or terrestrial radiation and its temperature must be representative of the air at the level at which it is exposed. The recording system provides for a temperature measurement at each level once every two minutes. Therefore, if the recorded value is to be a true mean the sensor itself must not respond to fluctuations appreciably shorter in period than the sampling period. The electrical output signal from the sensor must be sufficient to provide for the desired 1% accuracy in recording.

Consideration of the above factors led to selection of different sensor elements for System I and II. System I consists of permanent equipment that must withstand exposure to severe weather. The location of the sensors is distant from the water surface in the region of smaller gradients of temperature. System II sensors are near the surface and in the region of larger gradients. It was decided to employ radiation shields with artificial aspiration in System I while the requirement of small size and precision in height specification dictated a naturally ventilated sensor for System II. The requirement for a higher voltage signal for the recording system indicated the desirability of a resistance element rather than a thermocouple as the basic sensor.

Several types of aspirated radiation shields have been described in the literature and at least three are commercially available. The unit selected for use in System I is the Climet Instruments, Inc., Model 016-1 Motor Aspirated Temperature Shield. The unit is constructed to provide convenient mounting and employs sound principles in radiation shielding. The manufacturer's specifications state a radiation error less than 0.2°F under maximum solar radiation. The modified units are shown assembled for tests in Figure 7.

The Honeywell Model 921A3, Nickel A resistance bulb is employed as the temperature sensor. This unit consists of a 5/16" x 6" stainless steel housing over the nickel resistance element. The thermal mass of the protective housing also provides the longer time constant desired. The stated accuracy of calibration is ± 0.5°F so that calibration of each unit was required.

The calibration was performed by comparison of the individual resistance elements with a National Bureau of Standards calibrated, mercury in glass thermometer in a stirred water bath. The elements were found to differ from the published calibration by about 0.5°C. However, five of the nine elements purchased were found to match within ± 0.05°C. These elements were selected for use and assumed to have a common calibration.

The response rate of the elements to changes in air temperature is important because of the two minute sampling rate employed. The time constant of the element was determined by rapid transfer of the element from a warm to cool air stream having a velocity nearly equal to that of the aspirated shield. The aspiration velocity of the shield, as stated by the manufacturer, is about 22 ft/sec. The time constant of the element was determined to be 56 seconds at a ventilation rate of 1250 ft/min. While it would be desirable that the time constant be more nearly equal to the sampling period, it is probable that measurements averaged over several readings cannot depart significantly from the true mean value. If a temperature fluctuation of 1 cycle per minute were to occur, the error in mean value computed from the two minute sample could be as great as 16%. This would be the extreme case and is not likely to occur.

Errors in temperature measurement due to radiation are difficult to determine. An effort was made to determine the maximum possible error that could occur. An aspirated shield was exposed to both natural sunlight and to infrared heat lamps in an effort to determine effects of radiation. The heat lamps produced a radiation level of 6 cal cm^{-2} min^{-1} as measured by a Beckman and Whitley Thermal Radiometer. The sunlight exposure was a clear day on May 31, 1963 and the radiation level probably reached nearly 2 cal cm^{-2} min^{-1} but was not measured. In both cases, the shielded element was alternately exposed and shielded from the radiation source at about 5 minute intervals.

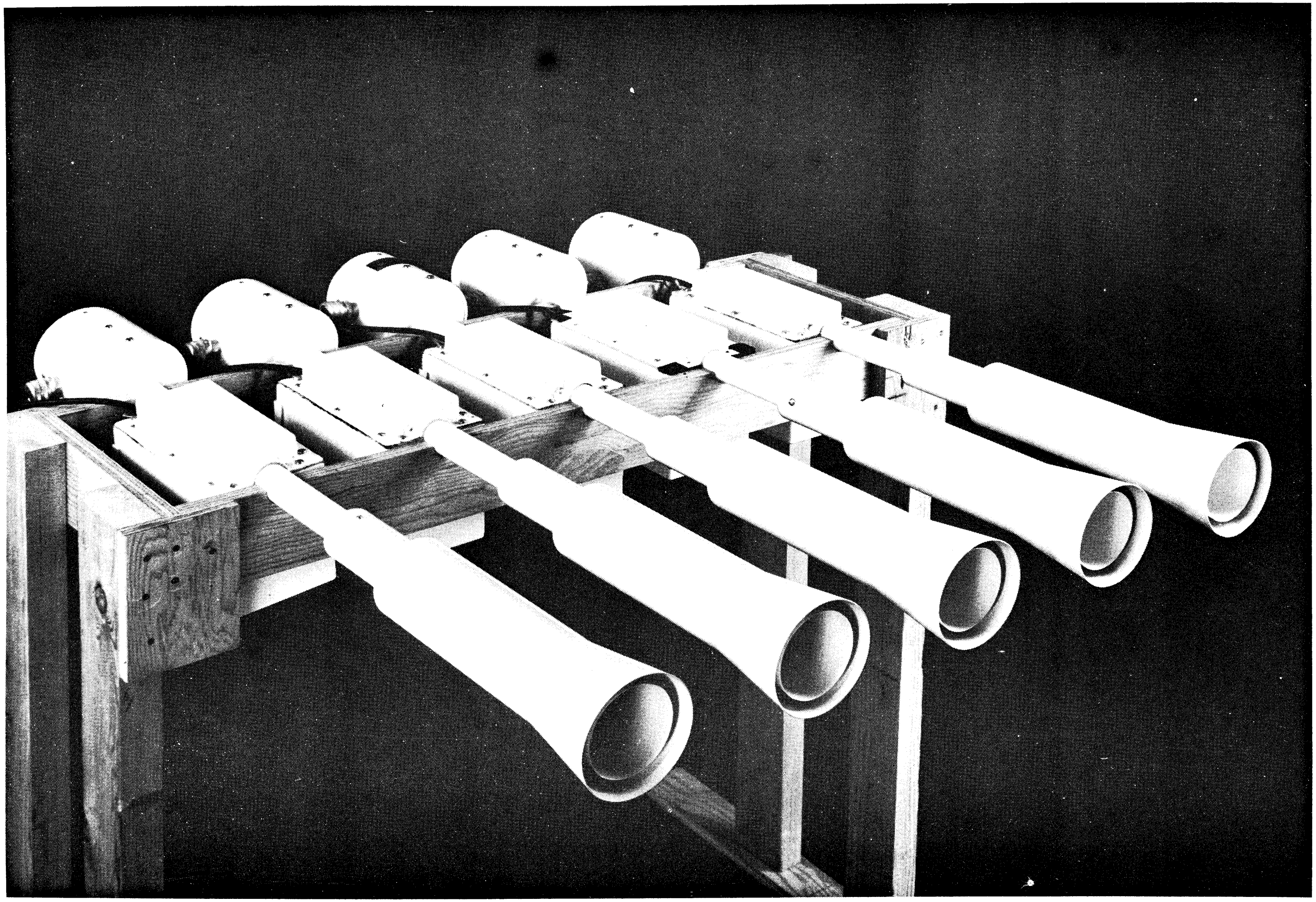

Figure 7. Aspirated radiation shields including Dew Probe mounting.

The radiation effect on the recorded air temperature was not detectable in any case. It was concluded that the limit of error due to radiation is probably within the values stated by the manufacturer.

The resistance elements are employed in one arm of an unbalanced Wheatstone Bridge circuit that produces a 0-20 millivolt signal for a 20°C temperature change. The 20° span is adjustable from -10 to +30 degrees centigrade. The current through the temperature element should produce a self-heating of less than 0.02°C at the aspiration rate employed.

Non-aspirated radiation shields of the type described by Portman (1947) were chosen for use in System II. If air speed is significant, radiation error resulting from use of such shields has been shown to be small except at very low sun angle. (Portman, 1961). Figure 6 shows a shield of the type employed. It can be seen that the shield and support have a small vertical dimension and offer a minimum of interference to air flow.

The sensor element employed in the non-aspirated shield is a Victory Engineering Corporation type 32A84 thermistor. The element is necessarily small to facilitate mounting in the radiation shield. The fast response of the element could lead to some error in the measured mean temperature due to the sampling period. All elements were individually calibrated in the same manner as were the resistance thermometers.

The thermistors were also mounted in one arm of an unbalanced Wheatstone Bridge. A circuit was employed to provide an output signal linear with applied temperature. The scale span of 20°C was employed as with the System I sensors.

4.4 Humidity Sensors

Devices that can accurately obtain a direct measure of atmospheric moisture at a remote location on a continuous basis and provide an output that can be recorded remotely from the sensor are available only at costs prohibitive to this project if, indeed, they exist at all. Operation of the System I sensors unattended for extended periods and at wet bulb temperatures that may be below freezing prohibited use of a direct wet bulb device.

The only device known to be available (1) within the cost limitations of the contract, (2) that provides a direct electrical analog of the atmospheric moisture content and (3) that can be remotely recorded in a recording system such as that described in Section 3 is the lithium-chloride heated electrical hygrometer. Devices of this type have been subjected to extensive evaluation as reported by Conover (1950), Tanner and Suomi (1956), Acheson (1963) and Hedlin and Trofimenkoff (1963). These reports all indicate serious deficiencies in the heated lithium-chloride element for use as an accurate humidity indicator. However, Tanner and Suomi (1956) showed that meaningful measures of moisture profiles could be obtained if the proper precautions were observed in application.

At least two commercial versions of the lithium chloride heated electrical hydrometer are now available. The Dewcel made by the Foxboro Company and the Dew Probe made by Honeywell were both considered. One unit of each model was obtained for testing.

A small humidity controlled chamber was constructed to calibrate and test the moisture sensors. A schematic diagram of the chamber is shown in Figure 8. A Gelman Instrument Co. pump circulates air in the closed system. Valves are available for the operator to regulate the air flow passing through both the drying and humidifying chambers. The two air streams enter a mixing chamber before passing into the observation chamber. The humidifier causes air to pass over open water surfaces and produces air saturated at the water temperature. Silica gel was employed in the drying chamber after it was learned that calcium chloride produced contamination of the lithium chloride cell. It was found that this simple chamber would provide a stable calibration environment over a range of about ± 5°C relative to the ambient dewpoint. A carefully matched wet and dry bulb psychrometer is employed as a standard.

Early tests showed very little difference between the performance of the Foxboro Company and the Honeywell units. It was also observed, as indicated by the work of Suomi (1956), that the instrument calibration is strongly influenced by the rate of aspiration. It was decided to use the Honeywell Dew Probe and, because of the dependency of calibration upon exposure conditions, to conduct all tests and calibrations in the manner in which the instrument would be employed in practice.

Since the measure of dew point is desired at the same levels as that at which temperature is measured, it was decided to mount the Dew Probe on the same aspirator as that employed to aspirate the temperature element. Figure 9 shows an exploded view of the aspirator and Dew Probe unit. Two 3/8" holes and two venturi orifices in the shaft of the main aspirator cause a small ventilation of the box housing the Dew Probe. The rate of ventilation is not measurable and, therefore, is not known. The units were tested for response rate and calibration while aspirated in this manner.

A limited amount of testing provided a stable calibration curve that differed somewhat from that furnished by the manufacturer. The results indicate that the absolute accuracy of the dewpoint measurement may not exceed ± 0.5°C. However, comparative accuracy between two or more units employed in profile measurements may exceed this value. Further tests are planned after this season of operation.

The time constant of the Dew Probe is strongly dependent upon the aspiration rate. Measurement of the response rate was, therefore, necessary while the Dew Probe was mounted in the modified aspirator. The entire unit was exposed in the humidity chamber at a dew point above the ambient value.

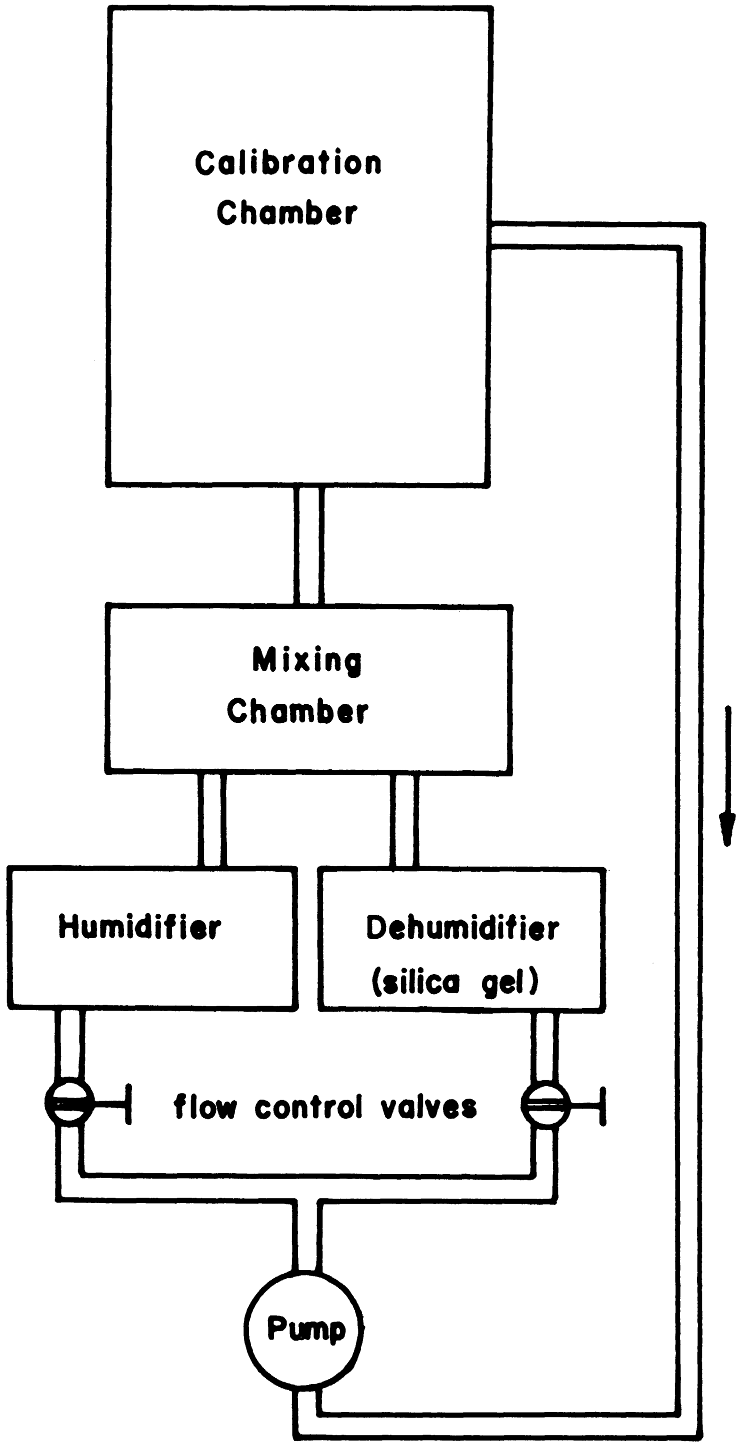

Figure 8. Schematic diagrams of humidity test chamber.

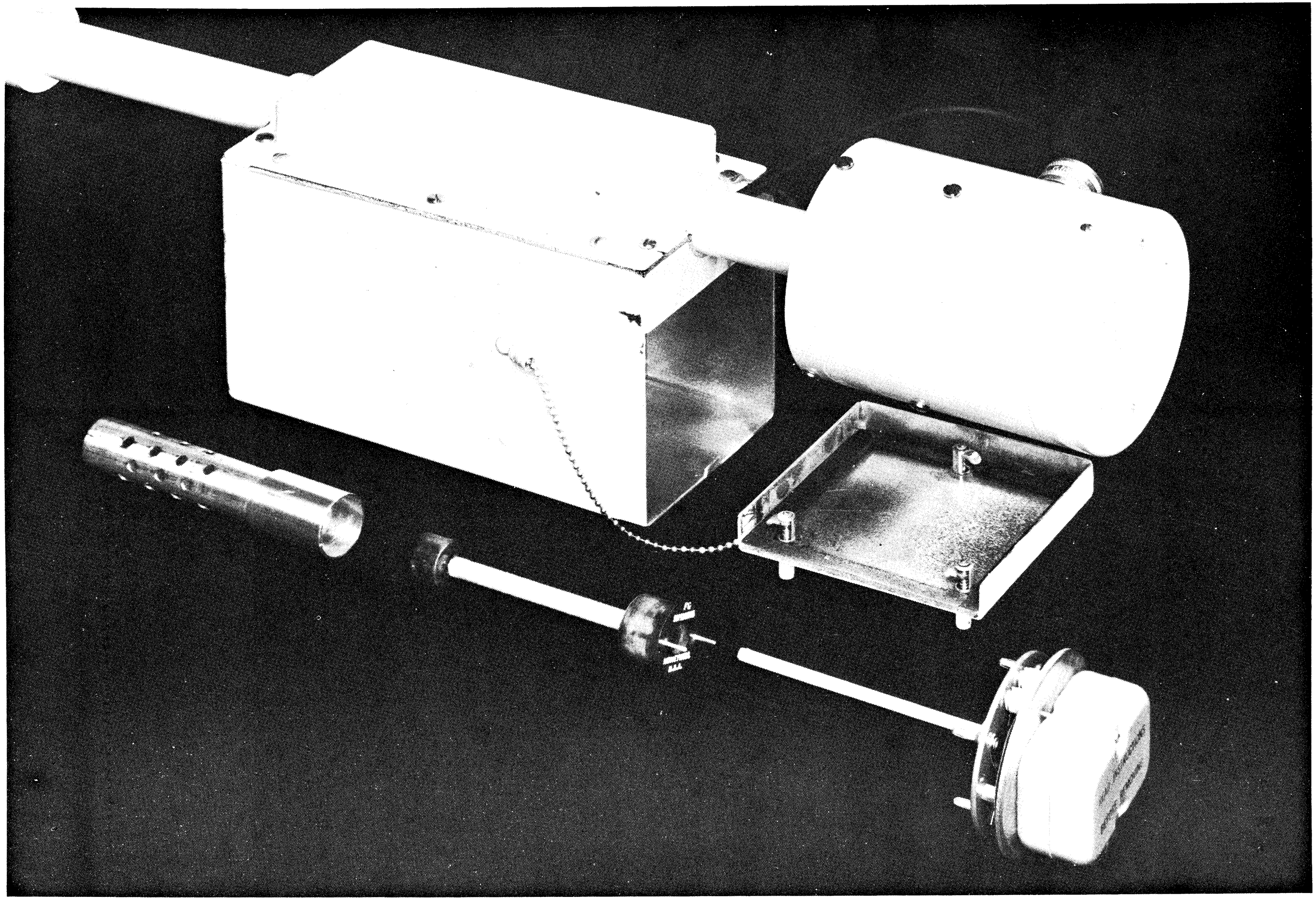

Figure 9. Aspirator and Dew Probe showing element disassembled.

It was quickly removed and the return to equilibrium noted. The time constant was determined to be about 2.8 minutes for decreasing values of dew point at an ambient dewpoint of 13°C. It is probable that a somewhat more rapid response would be observed for increases in dew point although such measurements were not made. This value of response time must not be considered a constant but indicates that the instrument will have only a limited response to fluctuations more frequent than the sampling rate.

The Dew Probe is considered to be the most appropriate instrument available for the System I measurements. However, it has not yet been shown that water vapor profiles of sufficient accuracy for flux computations can be achieved by use of the Dew Probe type of instrument. Analysis of data obtained during this season may yield information from which a more complete evaluation may be obtained.

4.5 Water Temperature Sensors

Water temperature measurements are of direct concern to flux computations because the surface temperature determines the surface vapor pressure. Also, the water temperature provides a measure of the air-water temperature difference at the interface. Only surface temperature is of direct concern but, since water temperature profiles can be obtained at small additional effort, provisions were made for three additional temperature measurements at depths indicated in Table No. 1.

Past experience (see Portman, et. al., 1961) indicates that water surface temperature can be successfully obtained from a floating sensor only during small wave conditions. Recent improvements in thermal radiometers have provided instruments that can measure the radiation temperature of a black body with good accuracy at an acceptable cost. An Infrared Thermometer Model IT-2, manufactured by Barnes Engineering Company is available from another program for use during the fall of 1963. This instrument will be employed to measure water surface temperature and if found to be satisfactory will be considered for use in the permanent instrumentation.

Water temperature at 2, 8 and 16 meter depth will be measured by Honeywell Model 921A3, Nickel A resistance elements identical to those employed in the aspirated air sensors. The water temperatures will be recorded once every two minutes in sequence and to the same accuracy as air temperature measurements.

4.6 Water Level and Wave Height Measurements

Mean water level and wave height sensors and recording systems will be provided by the U. S. Army Engineer District, Lake Survey. The wave height sensor and recording system was designed and constructed by the Corps of Engineers, U. S. Army, Beach Erosion Board. The water level recorder employs a stilling basin and float that actuates a Fischer and Porter digital recorder. Technical specifications on both of these instruments are lacking at this time.

4.7 Water Current Measurements

The tower facility provides a well exposed support for measurement of water current. While water current is of a secondary interest for the measurement of the turbulent fluxes, the data obtained could be valuable in relating the shear stresses to water transport. This use of the data could justify the small effort required to obtain the measurements.

During the summer of 1963, the U. S. Public Health Service made available three Woods Hole Current Meters manufactured by the Geodyne Corporation. These meters were installed during August at approximately 2, 8 and 16 meters depth. They will record current speed and direction throughout the period until removal of instrumentation. A self-contained recording system permits a one-minute sample of data to be recorded every 20 minutes for up to 125 days. The records will be returned to the U. S. Public Health Service for analysis.

ACKNOWLEDGMENTS

Much of the actual planning and design of the measurement facility described in this report were done by other members of the Meteorological Laboratories. The design and testing of the temperature and dew point measuring systems were largely accomplished by Francis Yockey and Larry McMillin. Actual construction of much of the instrumentation was done by John Casey. Advice and consultation of Dr. D. J. Portman, Project Director, and Edward Ryznar were important contributions throughout the program. Mrs. Joy Beil typed the report and assisted in other aspects of its preparation.

The contribution of personnel of the U. S. Army Corps of Engineers in design, construction, and installation of the tower was, of course, essential to the entire program. Assistance of personnel of the U. S. Lake Survey, U. S. Public Health Service, and U. S. Weather Bureau is also acknowledged.

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