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**JUNGLE CANOPY
PENETRATION**

VOLUME III
LOGISTICS, INSTRUMENTATION,
AND DATA PROCESSING

 **SYSTEMS**
DIVISION
OF
THE BENDIX CORPORATION

JUNGLE CANOPY PENETRATION

(U)

FINAL REPORT

VOLUME III
LOGISTICS, INSTRUMENTATION,
AND DATA PROCESSING

PREPARED FOR

THE DEPARTMENT OF THE ARMY

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The Bendix Corporation gratefully acknowledges the cooperation and courtesies extended by the government of the Republic of Colombia during the Jungle Canopy Program. The operation of a program of this nature in a foreign country without the enthusiastic assistance from the government of that country would present insurmountable difficulties.

By working through the United States Department of State, the United States Embassy in Bogota, and the Inter-American Geodetic Survey with headquarters in Ft. Clayton, Canal Zone, arrangements were made with the Augustin Codazzi Instituto Geografico of Bogota, Colombia to allow the project to enter Colombia under an existing agreement between the United States government and the government of Colombia covering the survey work being done by the Inter-American Geodetic Survey.

Without this cooperation and the subsequent assistance rendered by Mr. James Haahr, the American Consul in Medellin, the Maderas del Darien Ltda., and the gratuitous assistance from numerous Colombians in Medellin, Turbo and Chigorodo the successful completion of the project would have been impossible.

It is appropriate to acknowledge those who participated in the several phases of the program. Workers in the field included Harold W. Baynton, Alan L. Cole, Gerald C. Gill, George J. Leszczynski, James W. Mair, Reinhardt Mittlestadt, Allan Ramrus, and G. H. Spence. In addition to these, W. Gale Biggs, Fred W. Brock, E. Wendell Hewson and Paul E. Sherr made major contributions to the data analysis and interpretation.

PREFACE

The Jungle Canopy Penetration study had as its primary objective, the investigation of the ventilation processes of rain forest. A standard aerosol tracer technique was used. The results of this phase of the study are presented in Volume I of this report. The two subsidiary investigations of the vegetation and the meteorology of the site are reported in Volume II. This volume presents a detailed account of the many preliminary activities and support functions that were an essential part of the data acquisition and their eventual interpretation.

TABLE OF CONTENTS

	<u>Page</u>
1. SITE SELECTION	1-1
1.1 CRITERIA FOR SITE SELECTION	1-1
1.2 COLOMBIAN SITE AND FIELD INSTALLATION	1-3
2. LOGISTICS	2-1
3. ERECTING THE TEST FACILITY	3-1
4. FIELD PROCEDURES	4-1
5. METEOROLOGICAL AND DIFFUSION INSTRUMENTATION	5-1
5.1 FLUORESCENT PARTICLE SAMPLERS	5-8
5.1.1 Millipore Filters	5-8
5.1.2 Rotorod Samplers	5-8
5.2 METEOROLOGICAL SENSORS AND RECORDERS	5-15
5.2.1 Lapse Rate Measurements	5-15
5.2.2 Beckman and Whitley Wind-Measuring System	5-23
5.2.3 Gelman-Gill Anemometer Bivane	5-25
5.2.4 Wind Monitor	5-39
5.2.5 Pemco Tape Recorder	5-41
5.3 LOW SPEED CALIBRATION FACILITY FOR THE PROPELLER AND SHAFT ASSEMBLIES OF THE ANEMOMETER BIVANES	5-43
5.3.1 Construction of the Test Facility	5-43
5.3.2 Operation of the Test Facility	5-47
5.4 RELIABILITY OF THE MEASURING EQUIPMENT AND THE RECORDED DATA	5-52
5.4.1 Fluorescent Particle Data	5-52
5.4.2 Meteorological Sensors and Recorders	5-56

TABLE OF CONTENTS (CONT.)

	<u>Page</u>
5.4.3 Anemometer Test Facility	5-63
5.4.4 Non-Linear Response of Anemometer Propeller to Very Low Wind Speeds	5-64
6. MACHINE PROCESSING OF ANEMOMETER-BIVANE DATA	6-1
6.1 OBJECTIVES	6-1
6.2 COMPUTER CIRCUITRY	6-4
6.2.1 Signal Conditioning	6-4
6.2.2 Vector Resolution	6-6
6.2.3 Mean Value	6-6
6.2.4 Standard Deviation	6-6
6.2.5 Final Mean Value	6-9
6.2.6 Sample and Hold	6-9
6.2.7 Output Recording	6-11
6.3 RESULTS	6-12

LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1-1	Profile Diagram of Primary Mixed Forest	1-2
1-2	Map Showing Eight Possible Site Locations in Central and South America	1-4
1-3	Site for Jungle Canopy Penetration Study, Chigorodo, Colombia	1-5
1-4	Tropical Rain Forest Looking South, Near the Mouth of the León	1-7
1-5	Tropical Rain Forest Between León and Atrato Rivers	1-8
1-6	Tropical Rain Forest (Close-up) Between León and Atrato Rivers	1-9
1-7	Aerial View of Forest Showing Rio León and Locations of Camp Site and Test Array	1-10
1-8	Detailed Map of Test Area	1-11
1-9	Typical Lower Growth in the Study Area Between Stations 6 and 14	1-12
1-10	A Typical Plank Buttressed Tree and Vines and Ferns Which Characterize the Tropical Rain Forest	1-13
2-1	Aircraft of the 403 Troop Carrier Wing Massed at Willow Run Airport Prior to Loading Operations of Jungle Project Equipment	2-2
2-2	Cargo Ready for Shipment on 403rd Aircraft	2-3
2-3	Cargo Being Loaded Aboard 403 Aircraft for Shipment to Panama, C. Z.	2-4
2-4	Sketch of Camp Layout	2-6
2-5	One of the Tents	2-7
2-6	Living Quarters for the Colombian Workers	2-8
2-7	Mess Tent and Kitchen	2-9
2-8	View of Camp Utilities	2-10
2-9	View of the Camp Complex From the Opposite Bank of the León	2-11
2-10	View of the Fiberglass Boat and Chalupa During the Wet Season	2-12
2-11	Steel Barge Arriving at the Camp Site With the Steel Towers	2-13

LIST OF ILLUSTRATIONS (CONT.)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
2-12	Electric Cable and Drums of Gasoline Being Pulled Through the Jungle by Tractor	2-14
2-13	Gasoline Generator and Other Heavy Equipment Being Transported to the Test Array	2-15
3-1	Surveyed Map of the Array in Relation to the Camp Site, to Scale	3-2
3-2	Set of Five 2.5-kw Generators Near the South Tower	3-3
3-3	Shelter Near North Tower, Under Construction	3-4
3-4	Completed Shelter at North Tower	3-5
3-5	Sketch of Principal Structural Features of the Forest	3-7
3-6	Waterlogged Condition of the Ground Near the South Tower After Some Heavy March Rains	3-8
4-1	Weather Log	4-3
4-2	Rotorod Performance	4-4
4-3	FP Release Record	4-5
4-4	Pilots' and Operators' Log	4-6
4-5	Operations Log	4-7
4-6	Coating Rotorods With Silicone Grease in Preparation for a Trial	4-10
4-7	Technician Performing Special Maintenance in the Shop	4-11
4-8	Facilities for Assaying Exposed Millipore Filters	4-12
5-1	Test Array Used for Jungle Canopy Penetration Study	5-2
5-2	Two-hundred Foot Steel Tower With FP Samplers and Meteorological Sensors	5-3
5-3	Log Raft Support for a 200-foot Steel Tower	5-4
5-4	The Use of a Large Tree as the Anchor for the Guy Wires on a 200-foot Steel Tower	5-5
5-5	Instrumentation of Level a (6.5 feet) for One of the 200-foot Towers	5-6
5-6	Tape Recorder (Left), L and N Recorder (Center) and E and A Recorder (Right), Shown in Instrument Shelter at North Tower	5-9
5-7	Sequentializer Schedule	5-10
5-8	Method of Supporting Rotorod Elevators on Cotibo Trees	5-12
5-9	Cotibo Tree, With Access Ladder, Used to Support Rotorod Elevator	5-13
5-10	One of the Rotorod Samplers, With Protective Cover and Elevator System	5-14

LIST OF ILLUSTRATIONS (CONT.)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
5-11	Schematic of the Rotorod Sequentializer Used to Control Polarity of Power to the Rotorod Motors	5-16
5-12	Thermocouple System for the Measurement of Lapse Rate	5-18
5-13	Constant Temperature Both Showing Heaters and Stirring Motor in Pyrex Water Jar	5-20
5-14	Thermocouple Radiation Shield and Aspiration System	5-21
5-15	Thermocouple Aspiration System	5-22
5-16	Block Diagram of Wind Measuring and Recording Equipment	5-24
5-17	Gelman-Gill Anemometer Bivane	5-26
5-18	Parts of the Anemometer Section of the Gelman-Gill Anemometer Bivane	5-29
5-19	Assembly Drawing of Anemometer Portion of the Gelman-Gill Anemometer Bivane	5-30
5-20	Details of Anemometer Propeller	5-31
5-21	Schematic Diagram of the Electronic Circuit for One Anemometer Bivane	5-32
5-22	The Amplitude Ratio for Elevation Angle, Azimuth Angle, and Propeller as a Function of Gust Wave Length for the Anemometer Bivane	5-35
5-23	Response Curve of the Anemometer Portion of the Bivane Anemometer as a Function of Wind Speed Less Than 1.5 ft/sec	5-37
5-24	Response Curve of the Anemometer Portion of the Bivane Anemometer as a Function of the Wind Speeds up to 36 ft/sec	5-38
5-25	Schematic of Wind Monitor Box	5-40
5-26	Test and Calibration Facility for Anemometer and Propeller Shaft Assembly	5-44
5-27	Cross-Section of Test Facility	5-45
5-28	Test Cart of Calibration Facility With Propeller and Shaft Assembly Mounted	5-46
5-29	Support Bracket for Cable at Motor Drive End of Test Facility	5-48
5-30	Cable Connectors for Stationary Cables and Pulley for Drive Cable of Test Facility	5-49

LIST OF ILLUSTRATIONS (CONT.)

<u>Figure</u>	<u>Title</u>	<u>Page</u>
5-31	Graham Variable Speed Transmission and Drive Pulley for Jungle Test Facility	5-50
5-32	Test Cart for Moving Propellers Through the Test Facility	5-51
6-1	Analog Computer Facility Used for Wind Data Reduction	6-2
6-2	Coordinate System Used in Reduction of the Wind Vector	6-3
6-3	Transformation From Magnetic Tape Playback Unit Output to Computer Variables	6-5
6-4	Computer Circuits: Signal Conditioning and Vector Resolution	6-7
6-5	Computer Circuits: Mean Value and Standard Deviation	6-8
6-6	Computer Circuits: Final Averaging and Sample	6-10

LIST OF TABLES

<u>Table</u>	<u>Title</u>	<u>Page</u>
5-1	Heights of Samplers and Sensors at Test Site	5-7
5-2	Relation Between Azimuth Angle and the Bivane Analog Voltage	5-27
5-3	Relation Between Elevation Angle and its Analog Voltage From the Bivane	5-27
5-4	Calibration Resistors and Their Equivalent Azimuth or Elevation Angles	5-33
5-5	Bivane Error Analysis	5-34
5-6	Constants for Bivane	5-36
5-7	Tape Recorder Channel Assignments and Calibration Voltages for 40% Modulation of FM Record Amplifiers	5-42
5-8	Particle Size Distribution of Zinc Cadmium Sulfide Used in Colombia	5-54
5-9	Number of Particles Per Gram of Zinc Cadmium Sulfide Used in Colombia	5-54
5-10	Frequency Response of Pemco FM Units to Zero and Full-Scale Voltage Inputs, Before and After Diffusion Testing, Station 1	5-61
5-11	Frequency Response of Pemco FM Units to Zero and Full-Scale Voltage Inputs, Before and After Diffusion Testing, Station 12	5-62
6-1	Format Used in Recording on the 8-Channel Sanborn Recorder	6-11
6-2	Survey of Data Processed	6-13

SECTION 1

SITE SELECTION

The first task under the program was the selection of a suitable field site which would permit the design of an experimental program to yield the necessary data.

1.1 CRITERIA FOR SITE SELECTION

Before a site could be selected for the field studies it was necessary to determine what type of vegetation is representative of a typical jungle and where such vegetation could be found. In arriving at a suitable answer to this question Bendix is indebted to the excellent cooperation received from Dr. Stanley A. Cain, Chairman of the Department of Conservation of The University of Michigan, Dr. Jesse Hobson, then director of research of the United Fruit Company, Dr. Vining C. Dunlap of the research department of the Tela Railroad of La Lima Honduras, who is a consultant to the United Fruit Company, Dr. Jose Cuatrecasas, of the United States National Herbarium, Washington, D. C., and Dr. Ross Pearson, Professor of Geography of The University of Michigan. With the help of these men who are personally familiar with tropical vegetation, the vegetation characteristics, illustrated in Figure 1-1, were selected as being representative of the jungle type vegetation required for the diffusion experiments.

This representative tropical forest vegetation is characterized by a main canopy formed by the crowns of the trees and having a top at about thirty meters. The canopy itself is about 10 meters thick. Below the main canopy are undergrowth trees mainly 5 to 9 meters high, with some trees extending as high as 15 meters. In a true rain forest there will be a scattering of emergent evergreen trees reaching heights of 50 meters. These trees are relatively scarce. Below the undergrowth is a layer of ferns and shrubs which can thrive with a minimum of light. From both the main canopy and the undergrowth trees, vines, and lianas hang, depending upon trees for support. Epiphytes are abundant on both the primary trees and the undergrowth.

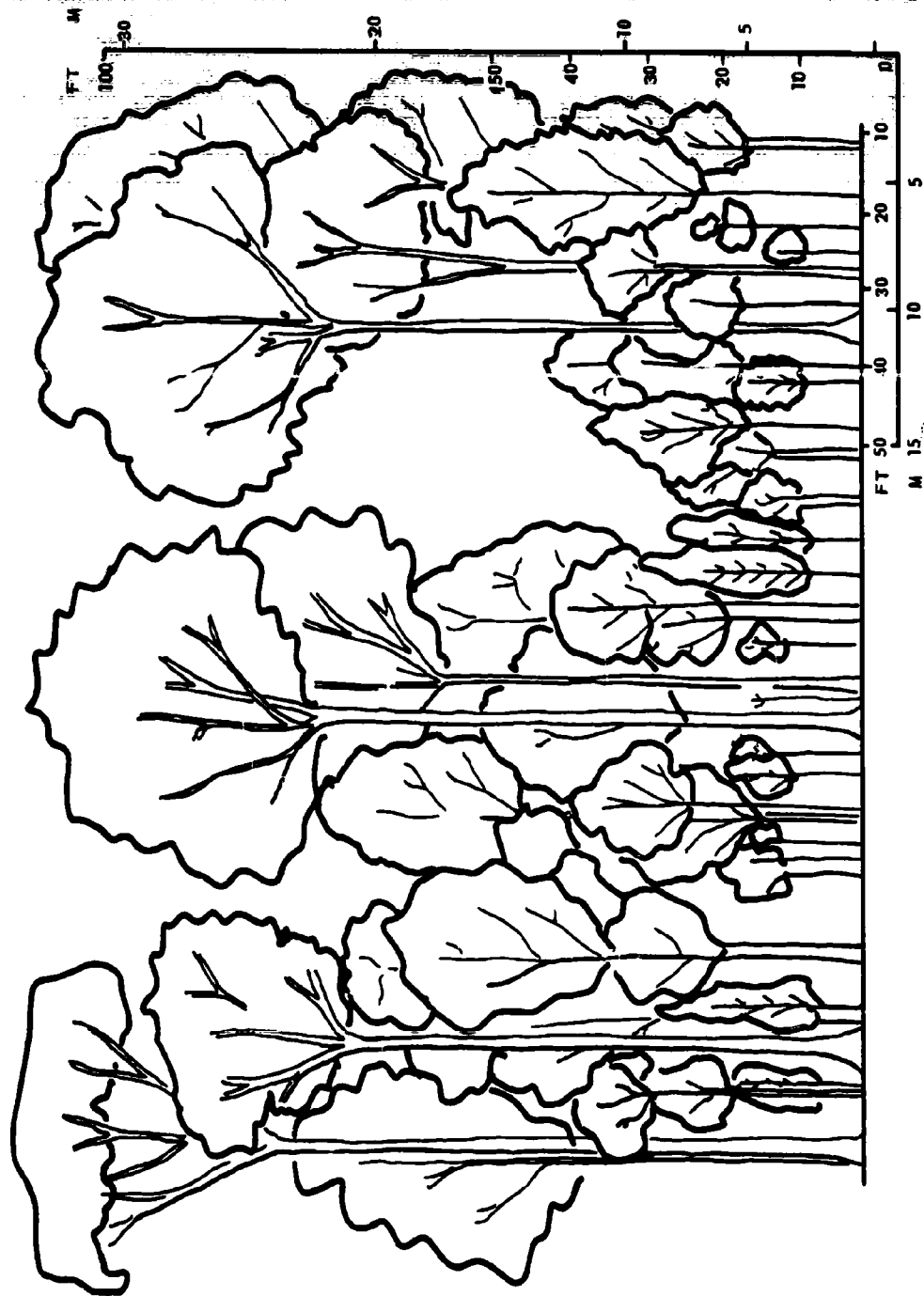


Figure 1-1 Profile Diagram of Primary Mixed Forest

In addition to the vegetation requirements, other requirements existed for the test site. These were established to simplify the analysis problems by removing uncontrollable variables. Level terrain was wanted in order to avoid the complications which might be introduced by slope winds or drainage effects. Rivers, lakes, swamps, and artificial holes in the jungle canopy were to be avoided in order that the analyst could be assured that tracer material had arrived at the sampling station through the canopy itself rather than by traveling horizontally beneath the canopy. Two climatological criteria were also important. The first of these concerned wind direction. The test plan was developed to provide for a long line of samplers parallel to the wind. In practice, because the line of samplers would be installed at any site, parallel to the prevailing wind, a more persistent prevailing wind meant more sampling opportunities. The second climatological criterion was that there should be a dry season of at least 3 months duration since it was required to conduct the penetration trials in the absence of rain. The scheduling of the field trials was in fact dictated by the occurrence of the dry season as revealed by climatological records.

From a practical standpoint a final criterion for the test site was established. This required the area selected to be such that the field party could complete their mission without devoting a major portion of the effort to subsistence and logistics problems.

With the help of the experts mentioned above, in particular Dr. Dunlap who has spent some thirty years investigating the ecology of tropical America, eight areas were selected for further consideration. These areas are shown in Figure 1-2. As much information as possible was gathered for each of these sites and particular attention was paid to the climatology, especially the rainfall characteristics and the winds. Visits were actually made to the site near Coatzacoalcas, Mexico, the site near Ft. Sherman in the Panama Canal Zone, and the site near Turbo in Colombia. These three sites are numbered 1, 7, and 8 on the map in Figure 1-2. For one reason or another, in most cases poor terrain, lack of extensive continuous areas of forest, unfavorable meteorological conditions, or impossible logistics problems, all of the sites were eliminated except the one near Turbo in Colombia.

1.2 COLOMBIAN SITE AND FIELD INSTALLATION

The site selected in northwestern Colombia is shown in Figure 1-3. The area was located about 15 miles south of the Gulf of Uraba directly

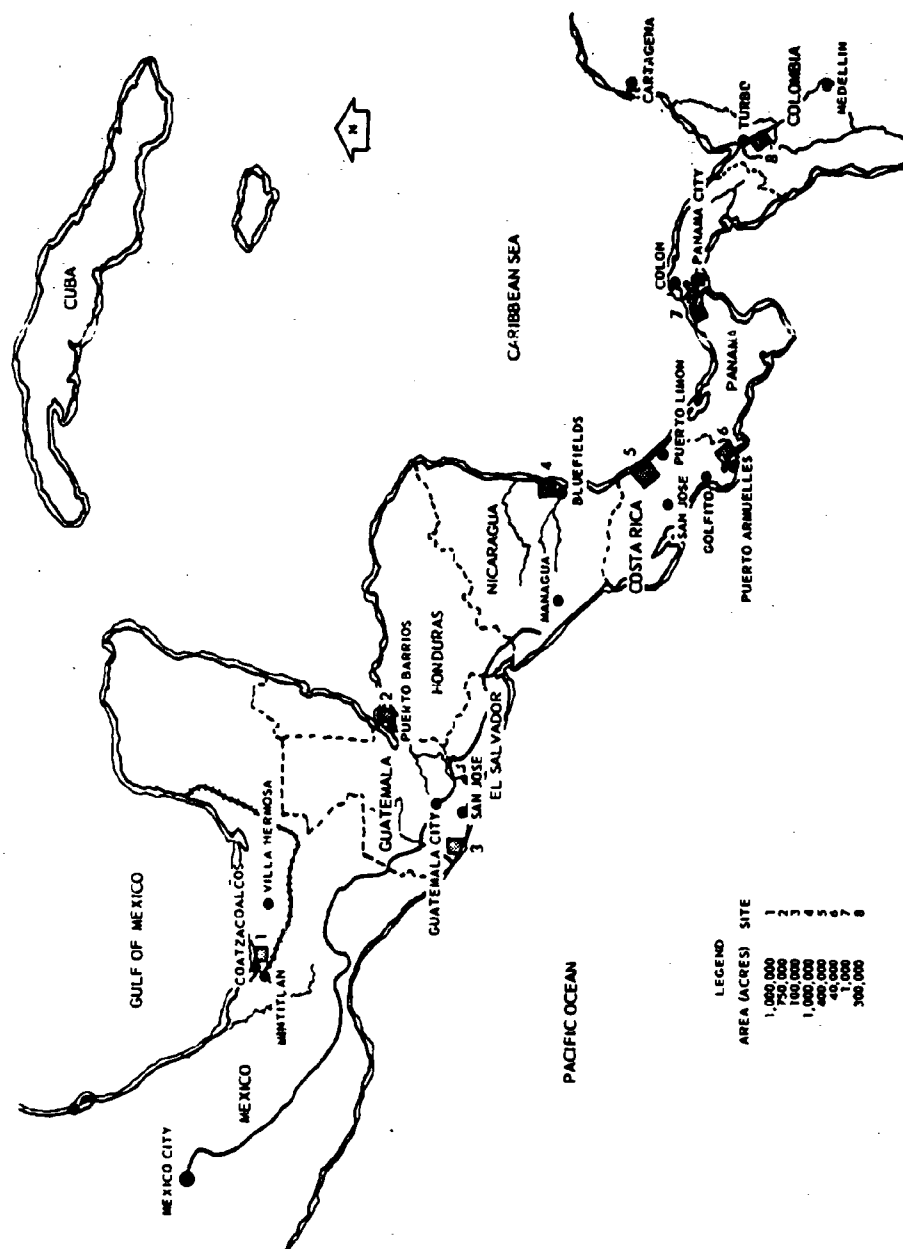


Figure 1-2 Map Showing Eight Possible Site Locations in Central and South America

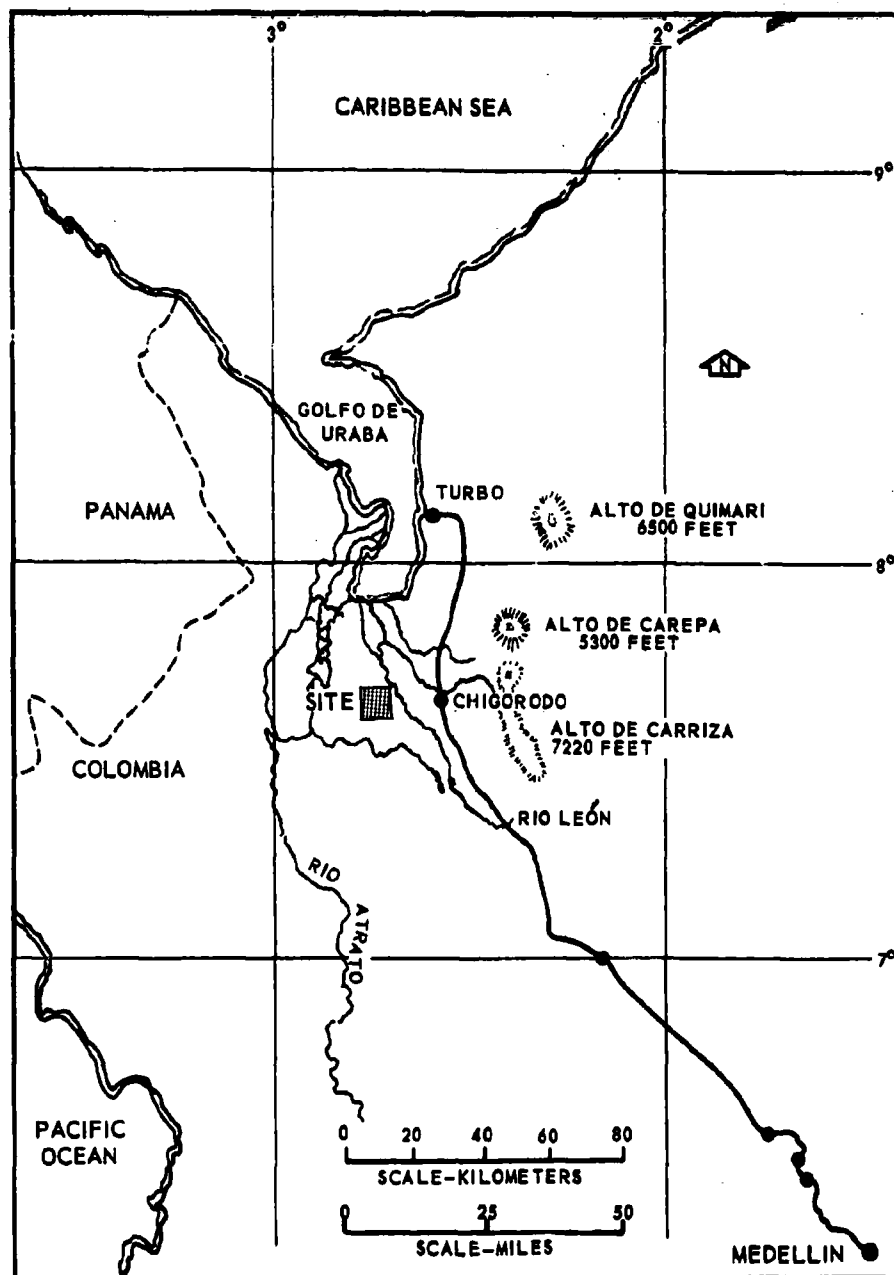


Figure 1-3 Site for Jungle Canopy Penetration Study Chigorodo, Colombia

west of the town of Chigorodo. The town of Turbo, about 30 miles north, was the most accessible settlement while Medellin, shown in the lower righthand corner of the map, was the city from which most supplies were obtained.

The test area was located in a broad alluvial valley formed by a complex of rivers and streams of which the Rio Atrato and the Rio León predominated. The Cordillera Occidental of the Andes formed a western boundary to the valley and the Serrania de Abibe formed an eastern boundary. The valley floor between these ranges is about 50 miles wide and between the Rio León and the Rio Atrato there is almost continuous forest. Between the test area and the Rio Atrato the broad level valley was disrupted by several peaks which rose to an estimated 1500 feet. These peaks were approximately 15 miles from the experimental area.

Figures 1-4 through 1-6 are representative of the forest area between the León and Atrato Rivers. Figure 1-7 is an aerial photograph of the test area showing the locations of the camp site and the test array. Both high altitude aerial photographs and maps of this region are extremely scarce. Figure 1-8 is a more detailed map of the test area compiled from several sources including sketches made by project members during the site selection survey. The detail east of the León River was obtained from the municipal engineer for the town of Chigorodo.

As shown in Figures 1-4 through 1-6, the forest in this area is extremely uniform. The area selected for the test site was approximately 15 miles south of the southern extremity of the Gulf of Uraba and about 16 miles west of the town of Chigorodo. Figures 1-9 and 1-10 show some typical views in the forest itself.



Figure i-4 Tropical Rain Forest Looking South Near the Mouth of the León

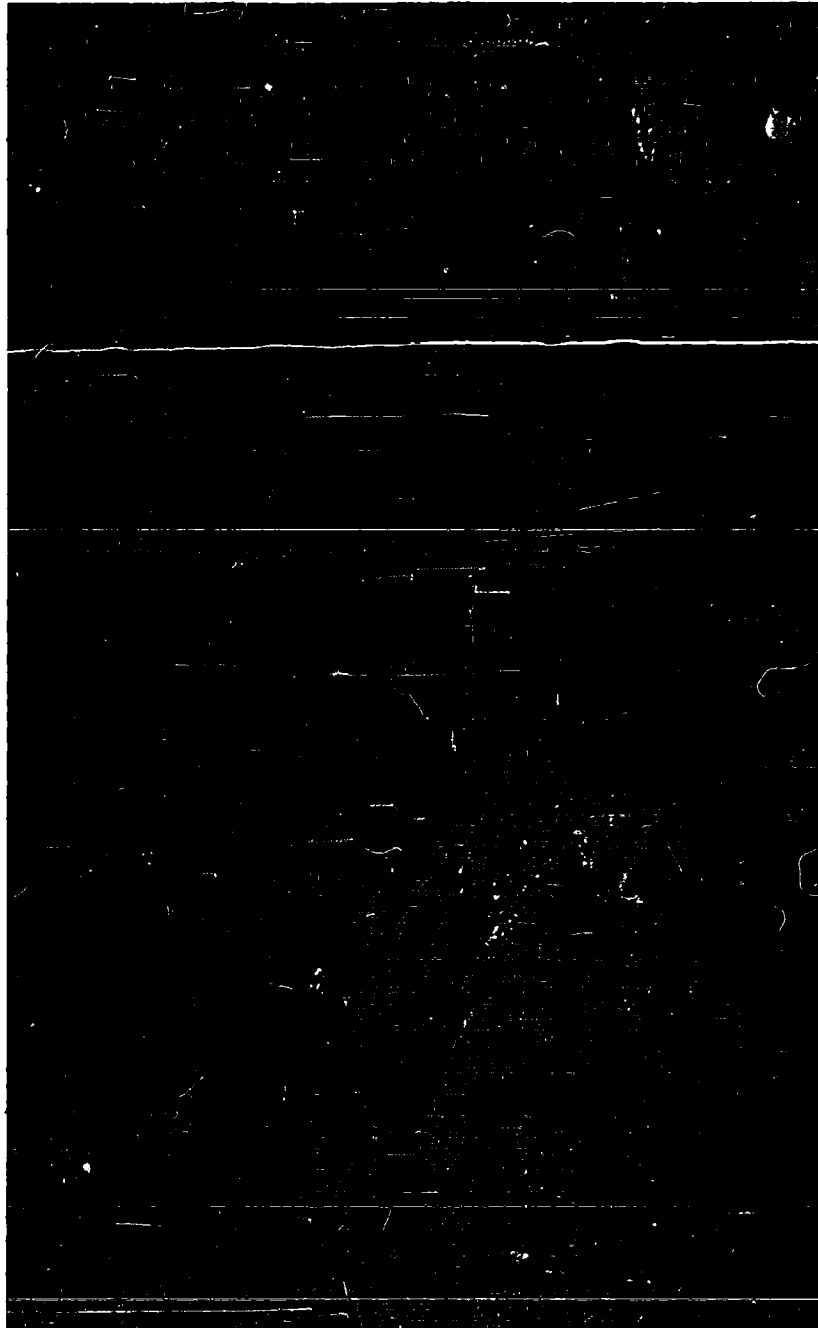


Figure 1-5 Tropical Rain Forest Between Leon and Atrato Rivers

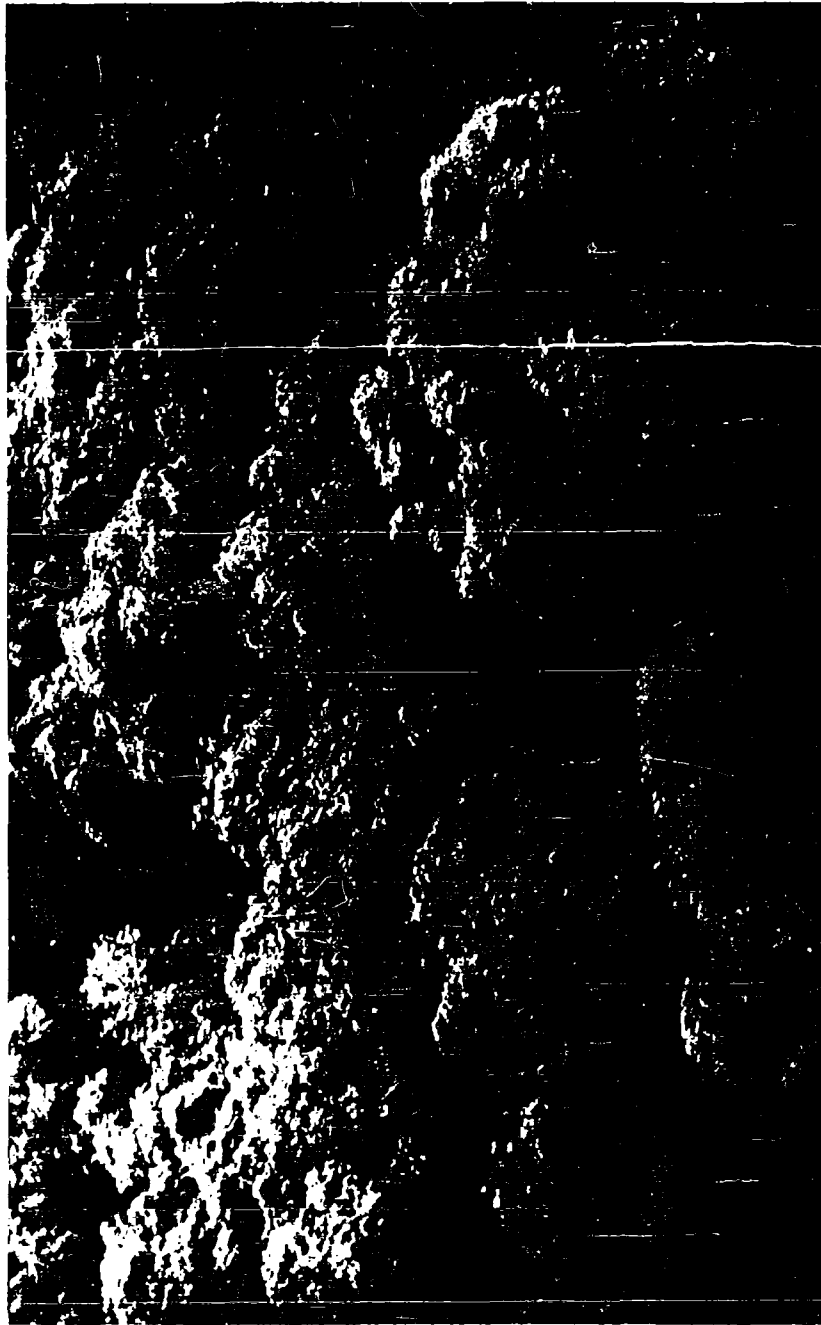


Figure 1-6 Tropical Rain Forest Between Leon and Atrato Rivers

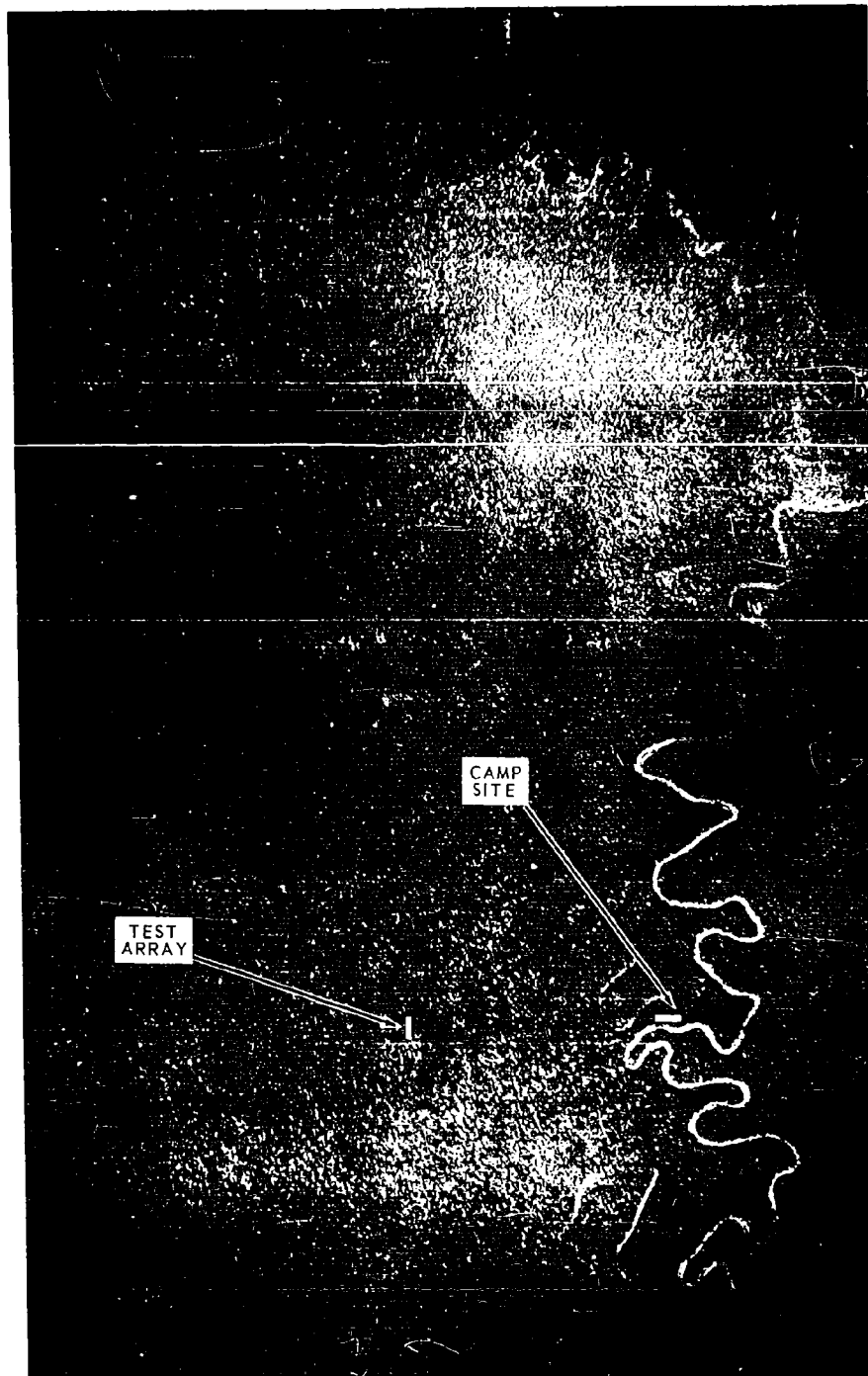


Figure 1-7 Aerial View of Forest Showing Rio León and Locations of
Camp Site and Test Array



Figure 1-9 Typical Lower Growth in the Study Area Between Stations 6 and 14



Figure 1-10 A Typical Plank Buttressed Tree and Vines and Ferns
Which Characterize the Tropical Rain Forest

SECTION 2

LOGISTICS

Since the schedule of the program revolved around the dates of the dry season, January through March, it was planned to erect the camp and install the instruments in December and early January. A shipping date from Ann Arbor, Michigan of 13 November 1961 was set to meet this schedule. All equipment was packed in reuseable wooden crates for air shipment.

The 403rd Troop Carrier Wing, a reserve unit, transported the equipment to Panama as a training exercise. Figures 2-1, 2-2, and 2-3 depict the loading operation carried out at Willow Run Airport on 13 November. Eight planes were involved in the operation, one of which had proceeded directly to Tampa to pick up the steel towers. The total shipment, weighing 34,000 lbs was delivered to Panama on 14 November. From there it was transshipped by Avispa, a Colombian air carrier, to Medellin, and thence by truck to Turbo. Final transportation was by boat and barge to the camp by site on the Rio Leon.

Because of the remote location of the test area it was necessary that the field installation be self-sufficient from the standpoint of providing housing and messing facilities as well as office space, a shop, and an equipment storage area. These facilities accommodated a field complement of 14 Colombian workers and over some periods as many as 8 men from the United States.

During the last week of October 1961 an advanced party was sent to Colombia to purchase the necessary materials for the camp construction and equipment for housekeeping.

The advanced party, in addition to purchasing supplies, finalized arrangements with the Maderas del Darien lumber company for the use of the area tentatively proposed for the test site. This land was in Colombian National Forest and the Maderas del Darien lumber company held a concession for timber cutting in the region.

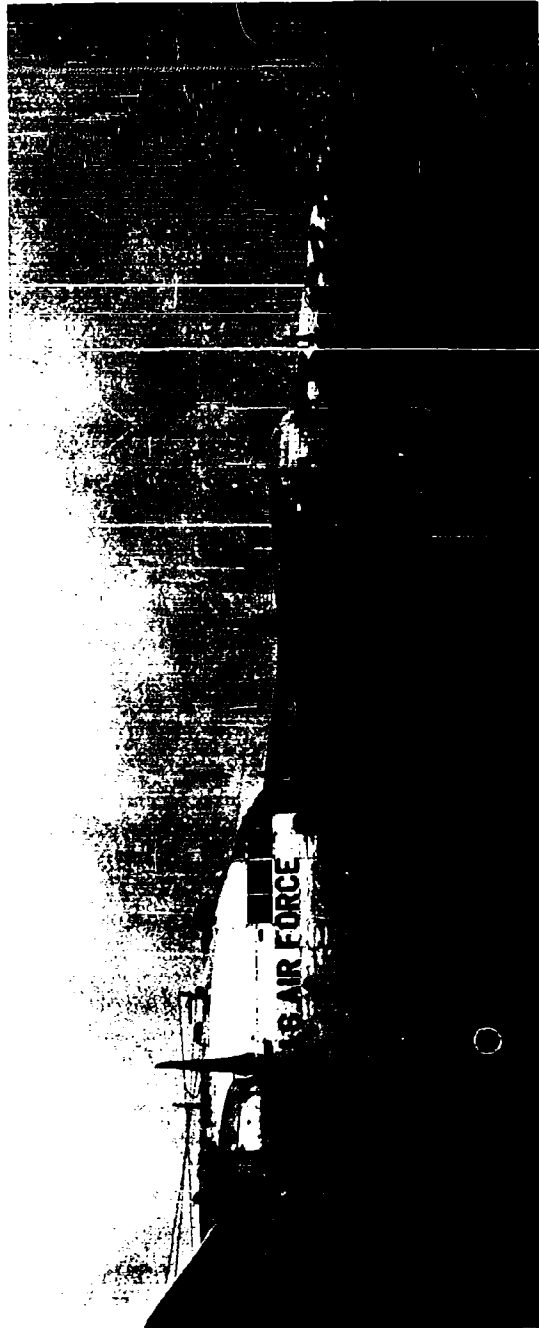


Figure 2-1 Aircraft of the 403 Troop Carrier Wing Massed at Willow Run Airport Prior to Loading Operations of Jungle Project Equipment



Figure 2-2 Cargo Ready for Shipment on 403 rd Aircraft



Figure 2-3 Cargo Being Loaded Aboard 403 Aircraft for Shipment to Panama, C. Z.

In addition to making these administrative arrangements, the advanced party undertook to make the final selection of the test site and to clear an area on the banks of the Leon River for the establishment of the project camp. The site selected for the camp was on the north bank of a section of the León River where the flow was from west to east. The cleared area had a frontage on the river of approximately 265 feet and extended approximately 150 feet into the forest. Figure 2-4 is a sketch showing the layout of the camp building. Figures 2-5 through 2-9 show the camp building and tents.

The León River served as the highway to camp and all personnel and supplies were transported by an outboard launch shown in Figure 2-10, or by an outboard powered dugout locally known as a chalupa. Most of the equipment was transported to the camp at the beginning of the project and from the camp at the end of the project on a steel barge belonging to the Maderas del Darien lumber company. This barge is shown in Figure 2-11 as it arrived with the steel tower sections. A comparison of Figures 2-9 and 2-11 shows dramatically the change in the water level in the river between the wet and dry seasons.

In order to take full advantage of the January through mid-April dry season for conducting tests it was necessary to begin construction of the instrument array as soon as the equipment arrived in late November. Because the river was in flood stage and much of the area was inundated, the transporting of equipment to the experimental area presented considerable difficulty. The 20-ft sections comprising the two 200-ft and the one 140-ft steel towers were carried into the experimental area by the Colombian workers and the erection of the towers was completed by 12 December. By the end of December it was possible to use a caterpillar tractor procured from the Maderas del Darien lumber company for carrying fuel and heavy equipment into the experimental area. Figures 2-12 and 2-13 show the technique used in dragging the heavy material through the jungle. Even this mode of transportation proved difficult because of the poor trafficability. It was mid-January before all of the heavy equipment and supplies were at the experimental area.

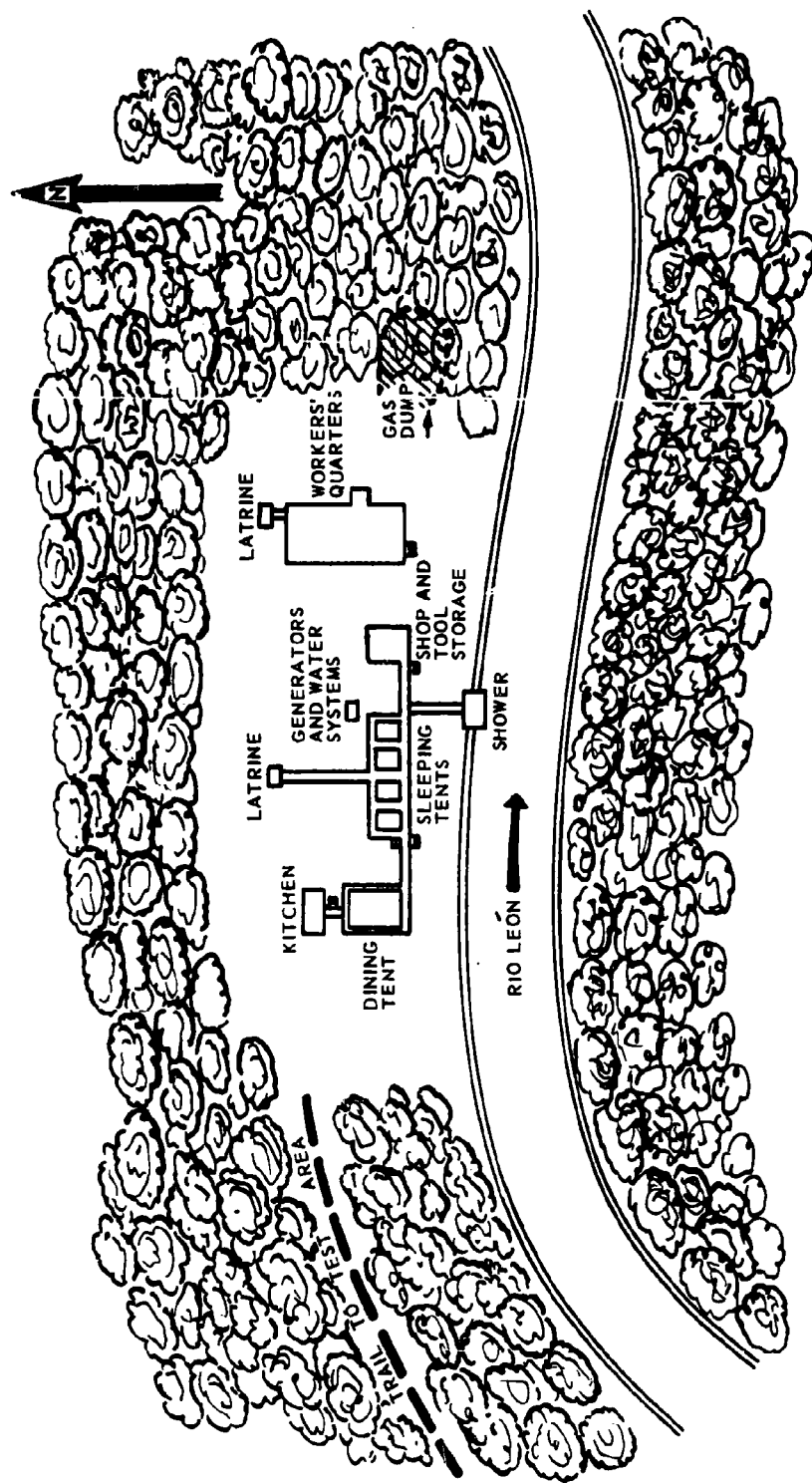


Figure 2-4 Sketch of Camp Layout



Figure 2-5 One of the Tents. The Platforms Were Protection From Water and Snakes,
the Straw Roof From the Sun



Figure 2-6 Living Quarters for the Colombian Workers



Figure 2-7 Mess Tent and Kitchen. Boxes of Coated Rotorods are Visible



Figure 2-8 View of Camp Utilities. Generator and Water Filter in Foreground, Shop and Tool Storage in Center Background



Figure 2-9 View of the Camp Complex From the Opposite Bank of
the León



Figure 2-10 View of the Fiberglass Boat and Chalupa During the Wet Season



Figure 2-11 Steel Barge Arriving at the Camp Site With the Steel Towers



Figure 2-12 Electric Cable and Drums of Gasoline Being Pulled
Through the Jungle by Tractor



Figure 2-13 Gasoline Generator and Other Heavy Equipment Being Transported to the Test Array

SECTION 3

ERECTING THE TEST FACILITY

A schematic of the test array is shown in Figure 5-1. The first task in the test area was to survey the array and select sites for the two 200-ft towers 1100 m apart on a north-southline and for the short tower to be erected at station 6. Since trees were to be used as supports for all other stations, it was necessary to pick the nearest large tree to the exact point on the surveyed line. Figure 3-1 shows the final choice of locations of the 14 sampling stations.

As indicated earlier, the towers were carried back to the test site in 20-ft sections and were erected by 12 December. Most of December was taken up with the erection of a good camp and it was well into January before the tractor was able to move cable, generators, gasoline, lumber, and other heavy equipment back to the test array. From then on the erection of the test facility moved more rapidly.

Generators were required at each end of the array to avoid excessive line losses. Their locations are shown in Figure 3-1. Sturdy platforms were erected for the generators about 200 yards from the array, and five 2.5 kw generators were mounted on each platform. Figure 3-2 shows the generators at the south tower. Three circuits were operated from each generator facility during trials and two generators were available as spares in the event of a power failure.

Power lines were run from the north generator facility to stations 1, 2, 3, 4, 5, 6, and 13 with the remaining seven stations being connected to the south generator facility. Field telephones were installed at the two 200-ft towers and also at every third station in the array.

An important part of the construction in the test area included the shelters which housed the recorders and timers, and served as a field headquarters during tests. Figures 3-3 and 3-4 portray the shelter at the north tower during construction and after completion.

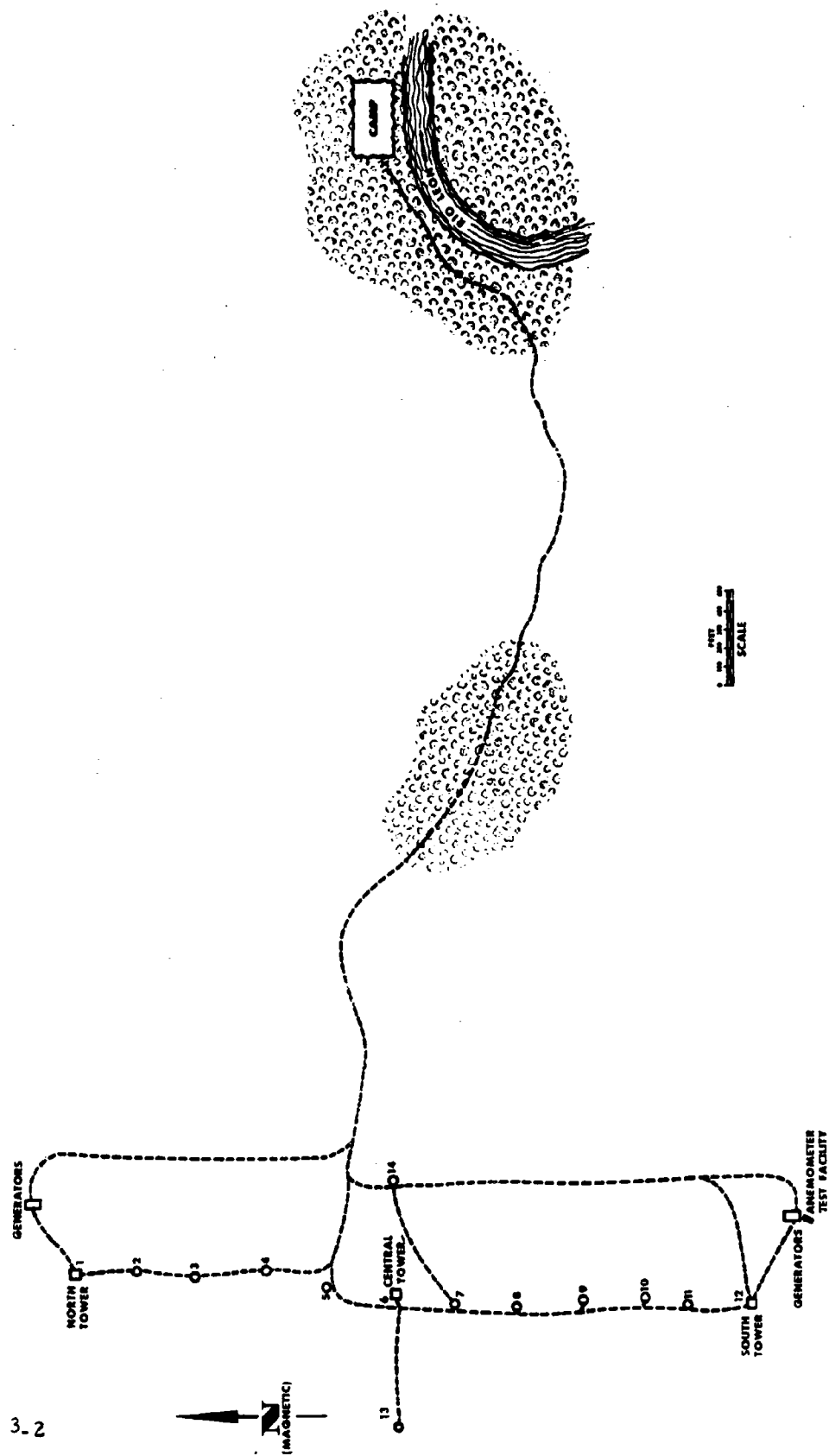


Figure 3-1 Surveyed Map of the Array in Relation to the Camp Site, to Scale

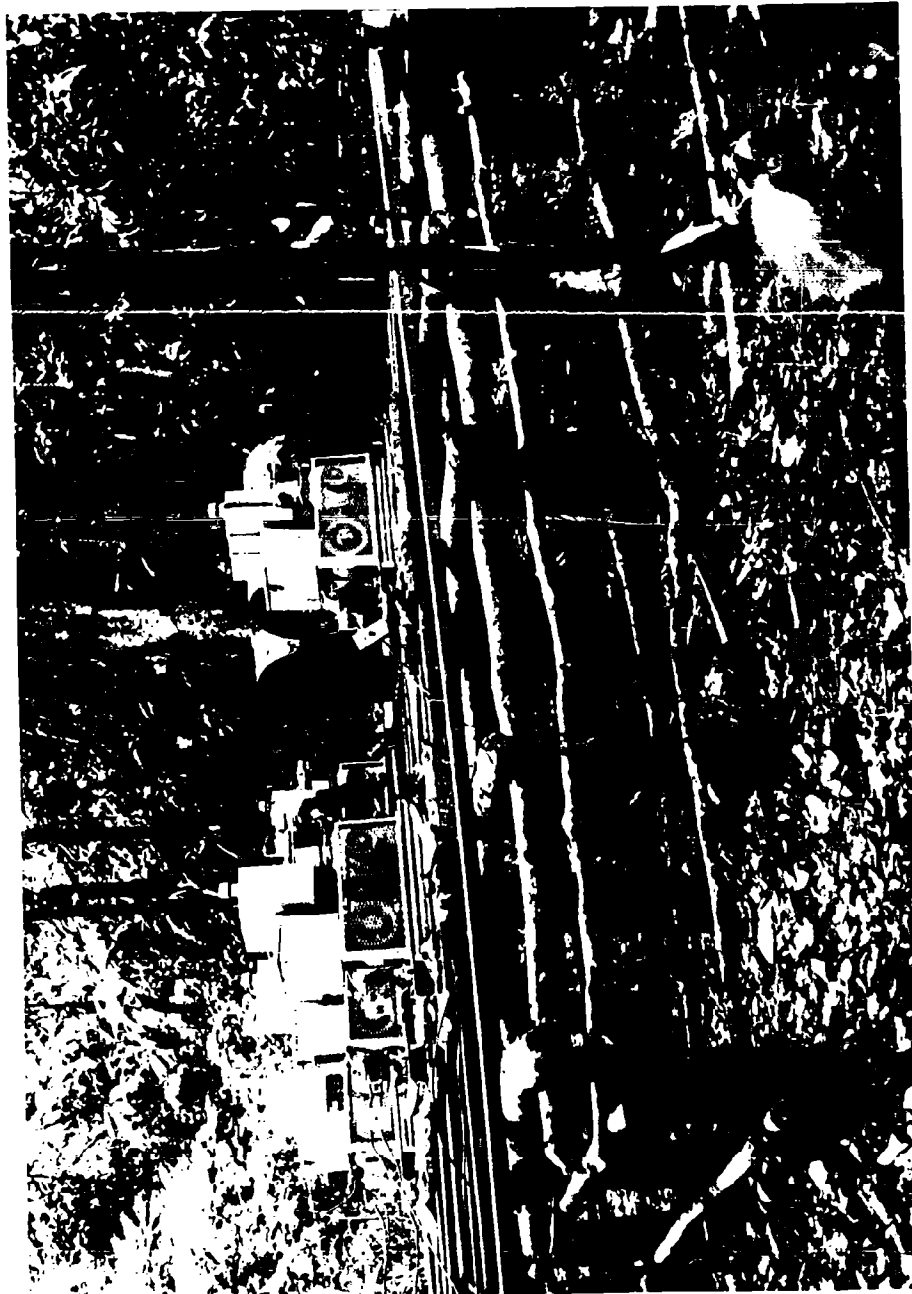


Figure 3-2 Set of Five 2.5-kw Generators Near the South Tower



Figure 3-3 Shelter Near North Tower, Under Construction



Figure 3-4 Completed Shelter at North Tower

After the towers were erected it was possible to visually survey the vegetation and select appropriate heights for the location of the meteorological sensors and the fluorescent powder samplers. Figure 3-5 has been made from a sketch completed in the field and shows the height selected for each instrumentation level.

The installation of the meteorological instruments on the two 200-ft towers, completion of the rotorod sampling network, and fabrication of some ancillary equipment for wind sensors required until the end of February for completion. Only a month of the dry season remained in which to conduct the penetration trials, and before they were completed the ground in the test area had become waterlogged again. Figure 3-6 depicts this condition as it existed at the south tower, toward the end of the field trials.

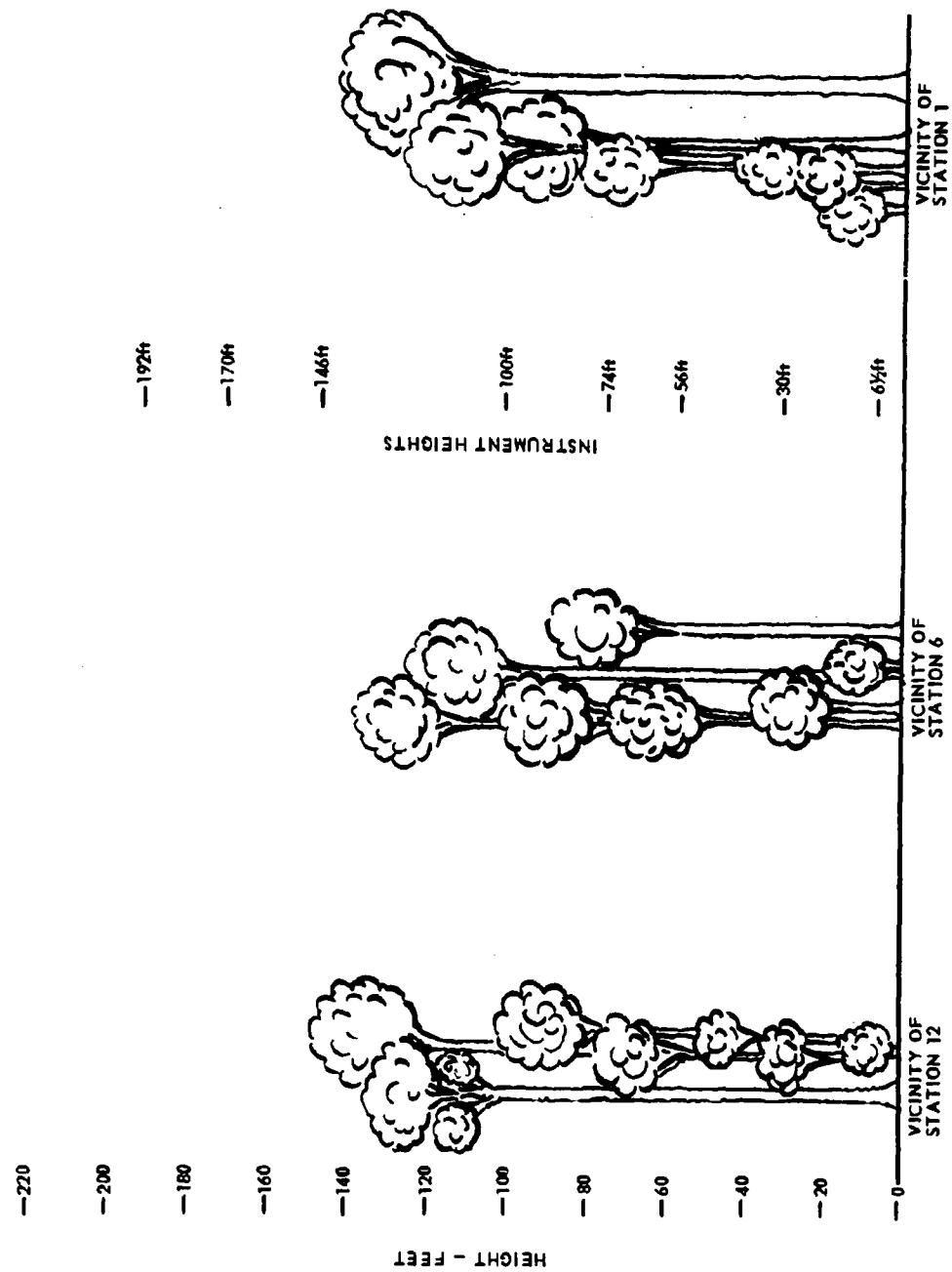


Figure 3-5 Sketch of Principal Structural Features of the Forest



Figure 3-6 Waterlogged Condition of the Ground Near the South Tower
After Some Heavy March Rains

SECTION 4

FIELD PROCEDURES

The standard time used was 75th Meridian (i. e. , Eastern Standard) which is also the local standard. Time checks were obtained via short wave radio from the Dominion Observatory in Ottawa. All day trials began at 0700 except for trial 3 which began 30 minutes later. All night trials began at 1700; the release of FP began 2 hours after the start of each trial. Each trial consisted of twenty half-hourly sampling intervals.

The decision to schedule a field trial was made by the test director several hours in advance so that the flight crew, based at Turbo, could be contacted and advised of the desired flight plan. In accordance with the test plan, sampling began 2 hours before the scheduled drop of FP to establish the background. The test criteria included winds parallel to the test array and no rain. Since there was no wind vane at the campsite above the tops of the trees, it was impossible to tell if the wind criteria were being met without walking to the test array. Once at the test array radio communication with the aircraft was possible only when the aircraft was directly overhead. As a result there were occasions when a trial was aborted after the aircraft arrived overhead to begin the drop.

The assignment of manpower was as follows. Two Americans and one Colombian were stationed at the 200-ft towers where they were responsible for operation of the generators, operation of meteorological sensors and recorders, operation of the timers which cycled all rotorod samplers every 30 minutes, and changing of rotorods at eight levels. The remaining twelve stations were manned by Colombians, who worked in pairs, each pair being responsible for the changing of rotorods at three stations. All rods had been coated in advance, and labels had been prepared and stored in the rotorod boxes for sequential use.

Two sets of rotorod samplers were installed at each station, one to the west of the supporting tower or tree, and the other to the east. Timing switches were set so that the first sample of each trial was collected by

the westerly sampler and so that all odd numbered samples were collected during rotation that was clockwise as viewed from the rod toward the sampler. The sequence of samples, achieved by timing switches and appropriate wiring, is summarized in the table below.

<u>Westerly Sampler</u>		<u>Easterly Sampler</u>	
<u>Clockwise Rotation</u>	<u>Counterclockwise</u>	<u>Clockwise Rotation</u>	<u>Counterclockwise</u>
Sample 1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20

In an attempt to assure that all required information would be available for analysis purposes, five forms were designed to standardize documentation procedures. These forms are reproduced as Figures 4-1 through 4-5.

Of the two forms designed for use in connection with the aircraft operations, only Form BS-99 was of use. Due to the uncertainty of the communications between the campsite and Turbo, it was not feasible to transmit the detailed information needed to complete Form BS-98. Form BS-99 was completed by Avispa personnel and mailed to the campsite. Because of the extreme consistency of the wind direction, adjustment of the position of the release line proved unnecessary and Form BS-98 was eliminated.

The remainder of the forms, however, proved to be essential during the analysis portion of the program. Form BS-97, originally designed simply to show missing rotorods but actually used to document any inconsistencies in the positioning of exposed rotorods in their storage boxes, proved to be invaluable. Its use in this manner required that each rotorod had to be checked after the tests had been completed. This was a time-consuming procedure but enabled the analyst to correctly interpret many of the apparent inconsistencies in particle count tabulations.

[illegible]

SYSTEMS DIVISION
OF THE RETECOR CORPORATION

TRIAL NUMBER _____

DATE _____ MONTH _____ DAY _____

FIRST SAMPLING INTERVAL BEGINS
DATE _____ HOURS _____ MINS _____

FP RELEASE
BEGINS _____ HOURS _____ MINS _____
ENDS _____ HOURS _____ MINS _____

FORM COMPLETED BY _____

ROTOROD PERFORMANCE
(ALL TIMES 75h MERIDIAN)

MAJOR AXIS ARRAY

MINOR AXIS ARRAY

INSTRUCTIONS
SAMPLE OBTAINED-ENTER X
SAMPLE MISSING-ENTER O

STATION LEVEL	SAMPLING INTERVAL													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														

Figure 4-2 Rotorod Performance

**SYSTEMS DIVISION**

OF THE BENDIX CORPORATION

FP RELEASE RECORDTRIAL NO. 162 MONTH DAY DATE

ALL RELEASE LINES ON W-E BEARING
FIRST CHECK POINT IS INTERSECTION OF RELEASE LINE WITH ROAD
POINT A-POINT AT WHICH RELEASE LINE CROSSES R. LEON AND RELEASE BEGINS
POINT B-POINT AT WHICH RELEASE OF FP ENDS
SECOND CHECK POINT IS INTERSECTION OF RELEASE LINE WITH TUMARADÓ RIVER

RELEASE LINE DATADISTANCE STATION 1 TO RELEASE LINE MILESFIRST CHECK POINT TO A MILES, MINS SECS IN STILL AIR AT MI/HR TASA TO B MILES, MINS SECS IN STILL AIRFIRST CHECK POINT TO SECOND CHECK POINT MILES, MINS SECS IN STILL AIR**FLIGHT PLAN**

TAKE OFF	<u> </u> HOURS <u> </u> MINS	FLIGHT LEVEL	<u> </u> FT ABOVE MSL
TEMPERATURE AT FLIGHT LEVEL	<u> </u>	WIND AT FLIGHT LEVEL	<u> </u> DEG <u> </u> MI/HR
TRUE AIRSPEED	<u> </u> MI/HR	INDICATED AIRSPEED	<u> </u> MI/HR
COURSE	<u> </u> DEGREES	TRUE HEADING	<u> </u> DEGREES
MAGNETIC HEADING	<u> </u> DEGREES	FIRST CHECK POINT	<u> </u> MI N OF STA 1 ON ROAD
TIME OVER FIRST CHECK POINT	<u> </u> HOURS <u> </u> MINUTES		
FLIGHT TIME FROM CHECK POINT TO BEGIN RELEASE	<u> </u> MINS <u> </u> SECONDS		
DURATION OF RELEASE	<u> </u> MINUTES		
LENGTH OF RELEASE LINE	<u> </u> TRUE A.S. <u> </u> X <u> </u> DURATION OF RELEASE <u> </u> MILES		

ACTUAL FLIGHT LOG

TAKE OFF <u> </u> 75th MER	FIRST CHECK POINT	POINT A RE-LEASE	TIME IN MINUTES AFTER BEGINNING OF RELEASE						POINT B END RE-LEASE	SECOND CHECK POINT
LAND <u> </u> 75th MER			1	2	3	4	5	6		
TIME										
ELEVATION ABOVE MSL										
TEMPERATURE										
INDICATED AIR SPEED										
TRUE AIR SPEED										
MAGNETIC HEADING										
TRUE HEADING										
DISSEMINATOR										
AIR PRESSURE										

FP RELEASELOT NO.

	WEIGHT OF CARTON FULL	WEIGHT OF CARTON & FP REMAINDER	WEIGHT OF FP RELEASED
TOP SCALE	LBS	LBS	
BOTTOM SCALE	LBS OZ	LBS OZ	
TOTAL			LBS OZ

RATE OF RELEASE LBS/MI**SEQUENCER PROGRAM**

SEQUENCER	ORIFICE L/MIN	SAMPLE DURATION IN MINUTES									
		1	2	3	4	5	6	7	8	9	10
1a											
1f											
12a											
12f											

SEQUENCER FIELD COUNTS

RESIDUAL FEED COUNT													
SEQUENCER		PARTICLES PER LITER											
		VACUUM		FILTER 1	2	3	4	5	6	7	8	9	10
		BEFORE	AFTER										
1a													
1f													
12a													
12f													

B.S.-98

FORM COMPLETED BY

Figure 4-3 FP Release Record



SYSTEMS DIVISION
OF THE GENERAL CORPORATION

PILOTS AND OPERATORS LOG

TRIAL NUMBER J42 MONTH DAY

DATE

ALL RELEASE LINES ON W-E BEARING
FIRST CHECK POINT IS INTERSECTION OF RELEASE LINE WITH ROAD
POINT A-POINT AT WHICH RELEASE LINE CROSSES RIVER LEON AND RELEASE BEGINS
POINT B-POINT AT WHICH RELEASE OF FP ENDS
SECOND CHECK POINT IS INTERSECTION OF RELEASE LINE WITH TUMARADÓ RIVER

FLIGHT PLAN

TAKE OFF	HOURS MINS	FLIGHT LEVEL	FT ABOVE MSL
TEMPERATURE AT FLIGHT LEVEL		WIND AT FLIGHT LEVEL	DEG MI/HR
TRUE AIRSPEED	MI/HR	INDICATED AIR SPEED	MI/HR
COURSE	DEGREES	TRUE HEADING	DEGREES
MAGNETIC HEADING	DEGREES	FIRST CHECK POINT	MI N OF STA 1 ON ROAD
TIME OVER FIRST CHECK POINT HOURS MINUTES			
FLIGHT TIME FROM CHECK POINT TO BEGIN RELEASE MINUTES SECONDS			
DURATION OF RELEASE MINUTES			
LENGTH OF RELEASE LINE TRUE AIR SPEED DURATION OF RELEASE MILES			

ACTUAL FLIGHT LOG

TAKE OFF	75th MERIDIAN TIME	FIRST CHECK POINT	POINT A REL- EASE	TIME IN MINUTES AFTER BEGINNING OF RELEASE				POINT B END REL- EASE	SECOND CHECK POINT
LAND									
TIME									
ELEVATION ABOVE MSL									
TEMPERATURE									
INDICATED AIR SPEED									
TRUE AIR SPEED									
MAGNETIC HEADING									
TRUE HEADING									
DISSEMINATOR	AIR PRESSURE								
REMARKS ON PERFORMANCE OF DISSEMINATOR									

FP DISSEMINATOR DATA

LOT NUMBER

	WEIGHT OF CARTON FULL	WEIGHT OF CARTON AND REMAINDER OF FP	WEIGHT OF FP RELEASED
TOP SCALE	LBS	LBS	
BOTTOM SCALE	LBS OZ	LBS OZ	
TOTAL	LBS OZ	LBS OZ	LBS OZ

B.S.-99

PILOT

OPERATOR

Figure 4-4 Pilots' and Operators' Log



SYSTEMS DIVISION
OF THE BENDIX CORPORATION

OPERATIONS LOG (ALL TIMES 75th MERIDIAN)

TRIAL NUMBER

J62 _____
MONTH DAY

FP RELEASE				
BEGINS	_____	HOURS	_____	MINS
ENDS	_____	HOURS	_____	MINS

FORM COMPLETED BY _____

FIRST INTERVAL BEGINS	_____	HOURS	_____	MINS
LAST INTERVAL ENDS	_____	HOURS	_____	MINS
NO. OF INTERVALS	_____	MEAN INTERVAL	_____	MINS

	TAPE STARTING TIMES				
	TAPE 1	TAPE 2	TAPE 3	TAPE 4	TAPE 5
STATION 1					
STATION 12					

	OPERATIONAL PROGRAM BY STATION NUMBER													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
ROTOROD GENERATOR														
NET SENSOR GENERATOR														
RODS CHANGED BY														

SAMPLING INTERVAL	GENERATOR VOLTAGES						GENERATOR FREQUENCIES						OPERATION OF TIMING SWITCHES MINS. SECS. AFTER HOUR				
	STATION 1			STATION 12			STATION 1			STATION 12			STATION 1		STATION 12		
	1	2	3	1	2	3	1	2	3	1	2	3	MINS	SECS	MINS	SECS	
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
9																	
10																	
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25																	
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27																	
28																	
29																	
30																	

B.S.-100

Figure 4-5 Operations Log

The importance of the other forms which document the meteorological conditions and supplement the instrument records, as well as giving an indication of the status of the electrical generating equipment and the wind sensors, is obvious.

During each trial 650 rotorods were exposed. It was important therefore to develop a labeling procedure that would identify the time and place of exposure of each rod. The first step in this procedure was the use of pressure-sensitive labels in two colors, red for all westerly samplers and blue for all easterly samplers. This simple color coding was of considerable aid in clarifying the procedures to the Colombians, but also led to an unexpected difficulty. The adhesive properties of the labels proved to be unequal and the red labels exhibited an unfortunate tendency to come off the rods. During the analysis of the data, when loose labels were reported, internal continuity checks were necessary and led to the reassignment of some samples. There is always some chance of error in this procedure but it is justified by the glaring errors that it eliminates.

The coding procedure that was adopted in inscribing the labels was as follows. The project and trial were numbered serially as J62nn where J signifies jungle, 62 identifies the year and nn the trial number. The first trial was coded J6201. The stations were numbered 1 through 12 from north to south along the major axis; 13 was west, 14 east of station 6. The letters a through h from bottom to top identified the eight levels. Each sampling point was specified by station number and level. Each sampling time was specified by the interval number, (1, 2, 3, etc.), and by the time of beginning of the trial which was logged on Form BS-96.

Every rotorod label was required to specify Trial Number, Sampling Point, and Sampling Time. It should be noted that the standard operating procedure for sequencing the samplers meant that specification of sampling time also specified the sense of rotation. As an example, using the above coding procedures, the inscription

J6202
5 a 1/2

on a label identifies the rotorod as having been exposed in the Jungle Canopy Program, in 1962 during trial 2, at the a-level of station 5, during intervals 1 (clockwise rotation) and 2 (counterclockwise rotation).

Prior to each trial a complete set of 650 labels was inscribed in the above manner and stored in the lids of the boxes containing the rotorods. The labels may be seen in Figure 4-6 where two members of the field crew are pictured, coating rotorods with silicone grease. After exposure, as the rotorod was removed from the sampler, the protective backing was peeled from the appropriate label and it was attached to the rotorod.

Routine duties during all trials included the preparation of logs on forms BS-96 and BS-100, the entry of frequent time checks on the strip charts, the changing of magnetic tapes, and regular observations of the temperature of the water bath which contained the reference junction of the tower temperature facility. These observations provided the bench mark needed to obtain absolute rather than relative temperatures. Occasional power failures were dealt with quickly by cutting in one of the spare generators. Essential repairs to equipment were carried out between trials. Figure 4-7 shows a technician making repairs to a bivariate power supply in the camp shop.

At the conclusion of every trial a check of successfully exposed rotorods was made back at the camp with the aid of form BS-97. Notice of missing samples was made in the field by affixing the unused labels inside the lid of the box. Millipore filters exposed by the sequential samplers on the two 200-ft towers were scanned at this time to estimate the level of fumigation achieved. Figure 4-8 is a view of the test director performing one of these assays. All rods, strip charts, magnetic tapes, and logs were then packaged and shipped out for analysis.



Figure 4-6 Coating Rotorods With Silicone Grease in Preparation for
a Trial.



Figure 4-7 Technician Performing Special Maintenance in the Shop

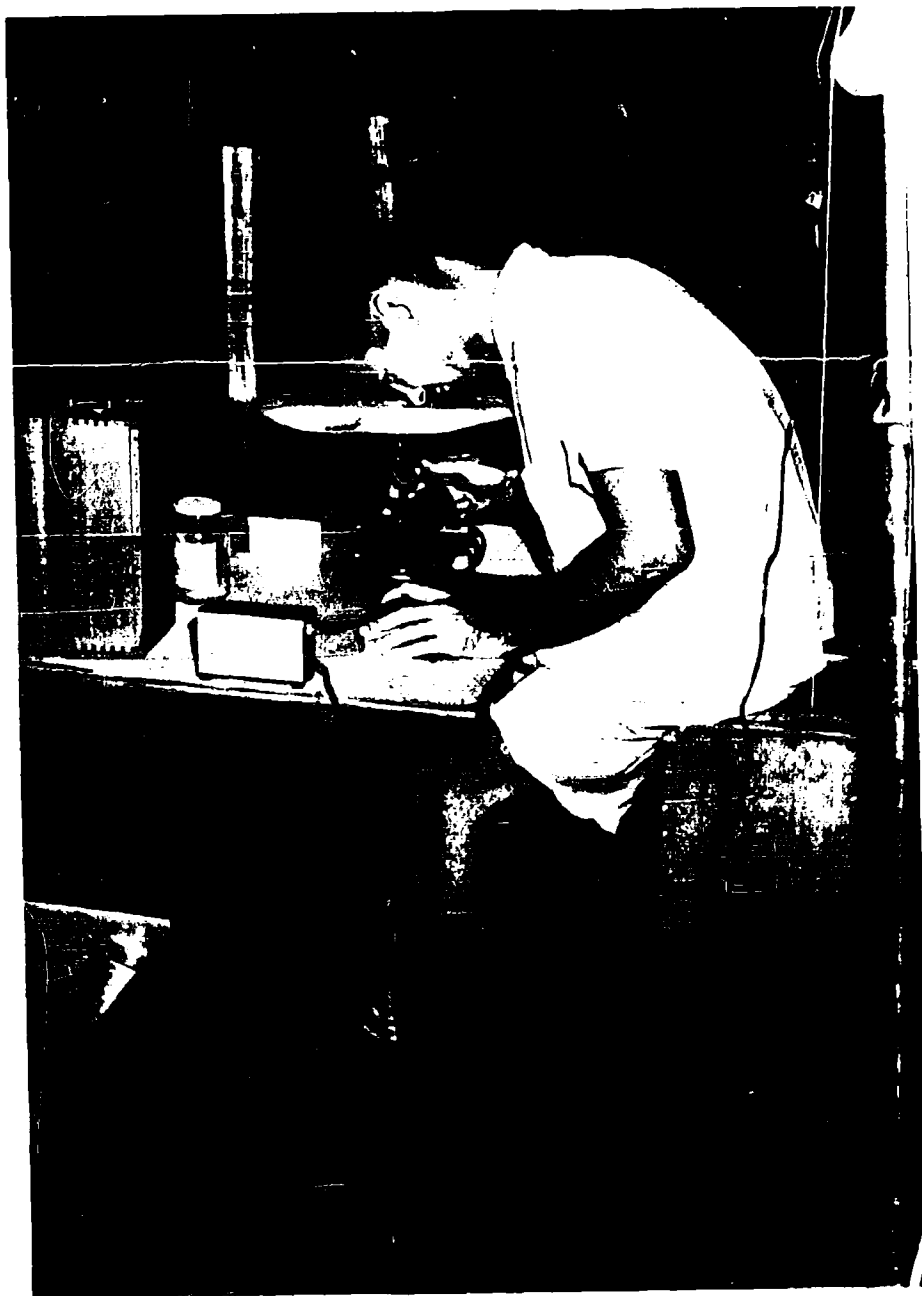


Figure 4-8 Facilities for Assaying Exposed Millipore Filters

SECTION 5

METEOROLOGICAL AND DIFFUSION INSTRUMENTATION

The field instrumentation was required to sense, measure, and record certain meteorological and diffusion variables during the testing period. The variables of interest were: the turbulent wind in and immediately above the jungle canopy, the prevailing wind at the top of the tall towers, the temperature lapse rate from the ground to approximately 200 feet up, the rainfall at a point above the jungle canopy, the relative humidity at the ground, and the concentration of fluorescent particles (FP) at various heights above the ground.

Figure 6-1 shows the relative locations of the 14 test stations. Twelve stations were spaced 100 meters apart along a North-South axis; the other two stations, 13 and 14 on section A-A in Figure 5-1 were located 200 meters east and west of the main sampling line.

Stations 1 and 12 were 200-ft guyed triangular steel towers^{*}, (sides 13 in. across), as shown in Figure 5-2, while station 6 was a 140-ft guyed steel tower. While semi-emergent trees surrounded this latter station, there was no foliage above the topmost rotorod position. Figure 5-3 shows the log raft-like footing used to support the towers, and Figure 5-4 shows how the guys supporting the tower were anchored to trees.

Meteorological sensors for the measurement of wind and temperature were mounted on the two 200-ft towers, and a rain gage was attached to the tower at station 1. Samplers for the collection of FP were also mounted on the towers at stations 1, 6, and 12. Large cotibo trees were chosen to support FP rotorod samplers at the other stations.

The meteorological sensors and FP samplers were installed at the heights shown in Table 5-1. Figure 5-5 shows the base of a 200-ft tower with the instrumentation of level a.

^{*}Manufactured by E-Z Way Towers, Inc., and erected by the Collier Tower Co., Tampa, Florida.

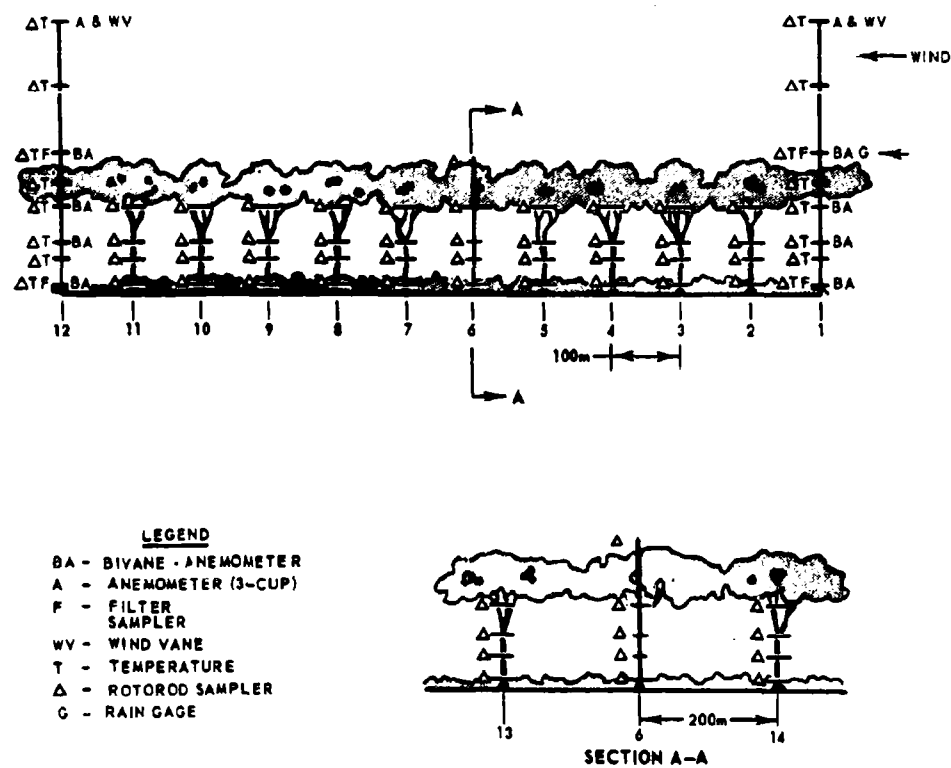


Figure 5-1 Test Array Used for Jungle Canopy Penetration Study



Figure 5-2 Two-hundred Foot Steel Tower With FP Samplers and Meteorological Sensors



Figure 5-3 Log Raft Support for a 200-foot Steel Tower



Figure 5-4 The Use of a Large Tree as the Anchor for the Guy Wires
on a 200-foot Steel Tower

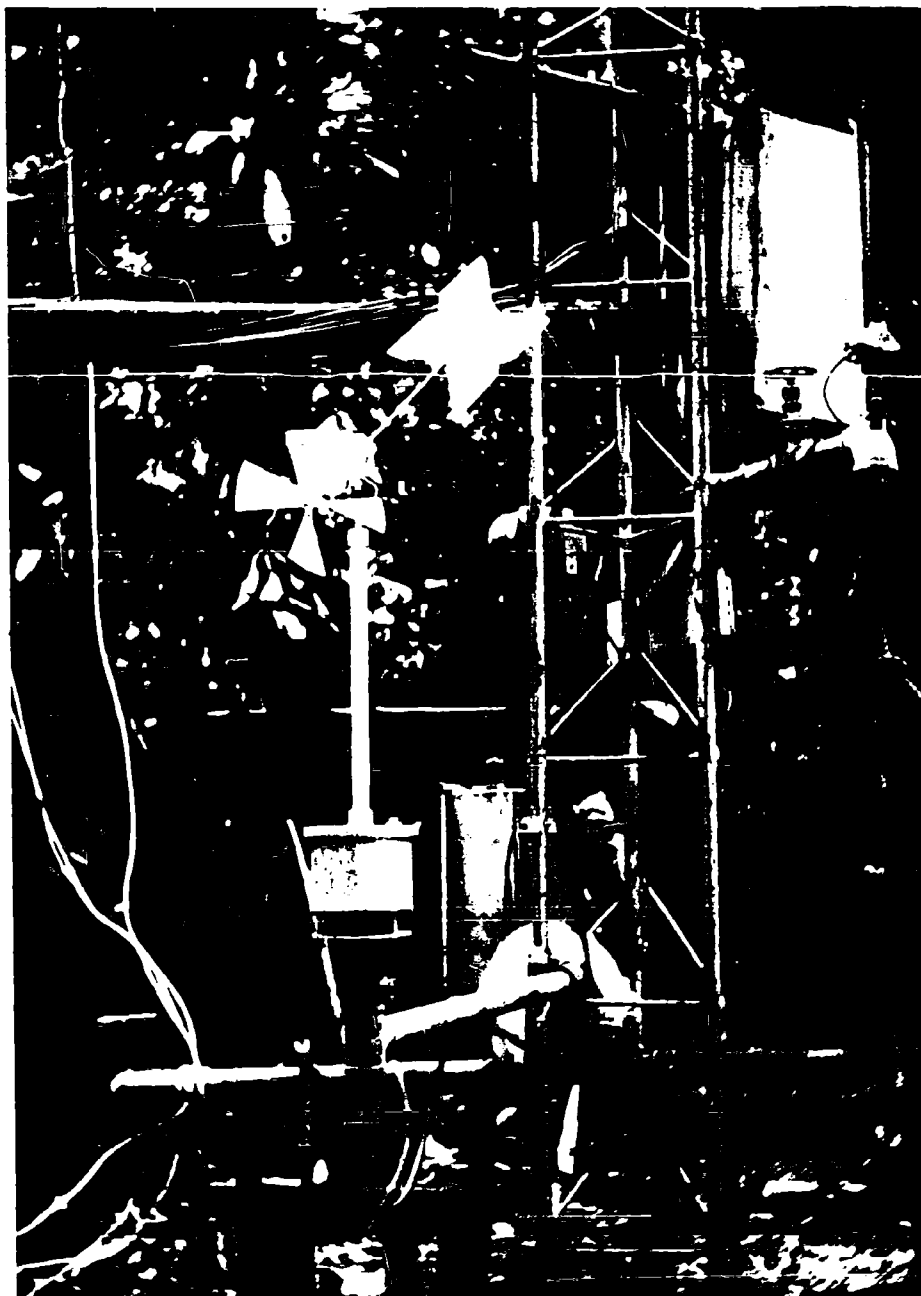


Figure 5-5 Instrumentation of Level a (6.5 feet) for One of the 200-foot Towers

TABLE 5-1

HEIGHTS OF SAMPLERS AND SENSORS AT TEST SITE

Level	Height Related to Stratification of Rain Forest	Height above Ground	
		Feet	Meters
a	2 meters above ground	6.5	2.0
b	2 meters above undergrowth	30.0	9.1
c	level intermediate between canopy and undergrowth	56.0	17.1
d	2 meters below canopy	74.0	22.6
e	mid-canopy	100.0	30.5
f	2 meters above canopy	146.0	44.5
g	12 meters above canopy	170.0	51.8
h	19 meters above canopy	192.0	58.5

The FP was collected by DC-type rotorod samplers at each level of the towers and trees shown in Figure 5-1. In addition FP was collected by millipore filter sequential samplers at levels a and f of stations 1 and 12.

Differential thermocouples were used to measure the temperature at levels a through h of stations 1 and 12. The sensors were aspirated iron-constantan thermocouples, mounted in double cylindrical radiation shields. The temperatures at each tower were recorded in sequence on a Leeds and Northrup 10-point strip-chart recorder.

The azimuth angle, elevation angle, and speed of the air movement were measured with Gelman-Gill anemometer bivanes mounted at levels a, c, d, and f of stations 1 and 12. Each bivane produced two analog voltages proportional to the azimuth and elevation angles and a third, pulsating voltage whose frequency was proportional to the wind speed. These outputs were recorded on 12 channels of a 14-channel Pemco tape recorder.

Beckman and Whitley wind systems measured wind speed and azimuth at the top of the 200-ft towers. The analog signals from the wind system were recorded on dual-channel Esterline-Angus* strip chart recorders. Simultaneously, during FP tests, the wind direction signal was recorded on the 13th channel of the tape recorder, and an accurate independent 60-cycle signal was recorded on the 14th channel. The three recorders are shown in Figure 5-6.

A tipping bucket rain gage installed at level f (146 ft) of station 1 produced an electrical pulse for each .01 inch of rain. These pulses were recorded on the E. A. chart by an event-recording pen.

5.1 FLUORESCENT PARTICLE SAMPLERS

As mentioned earlier, FP was collected by filtration on millipore filters and by impingement or rotorod samplers. Details of both techniques as they were used are given below.

5.1.1 Millipore Filters

The millipore filters were exposed at 5.5 and 146 ft at stations 1 and 12 by means of a sequential sampler. A small vacuum pump provided the suction and a mechanical sequencer was used to obtain the filter exposure shown in Figure 5-7. With an ultraviolet light source and a microscope, the millipore filters were scanned at the test site for a quick qualitative evaluation of the success of each trial. This operation was depicted earlier in Figure 4-8.

5.1.2 Rotorod Samplers

Rotorod samplers Model 60A, as developed by the Aerosol Laboratory, (Stanford University) were used for the detailed collection of FP concentration data. These rotorod samplers were operated at all levels shown in Figure 5-1. Eight rotorods were mounted in a vertical line at stations 1 and 12, and four in a vertical line at each of the sampling stations 2 through 11, 13, and 14. In addition a sampler was mounted at the 140 ft level at station 6. Two strings of rotorods were used at each station so that one could be serviced while the other was in operation.

* Hereafter referred to as E. A.



Figure 5-6 Tape Recorder (Left), L and N Recorder (Center) and E and A Recorder (Right),
Shown in Instrument Shelter at North Tower

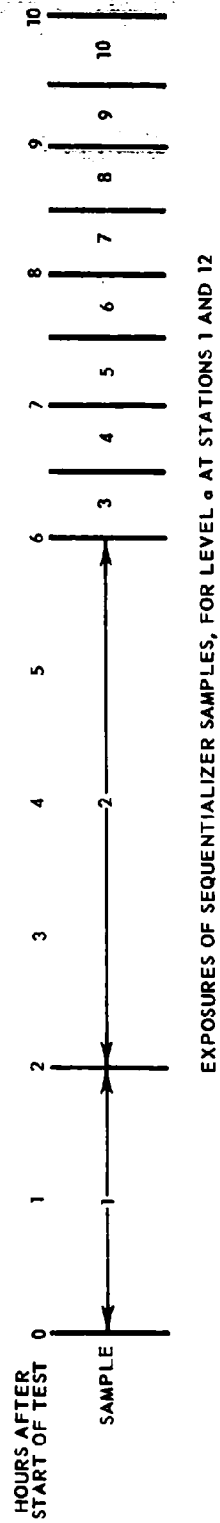
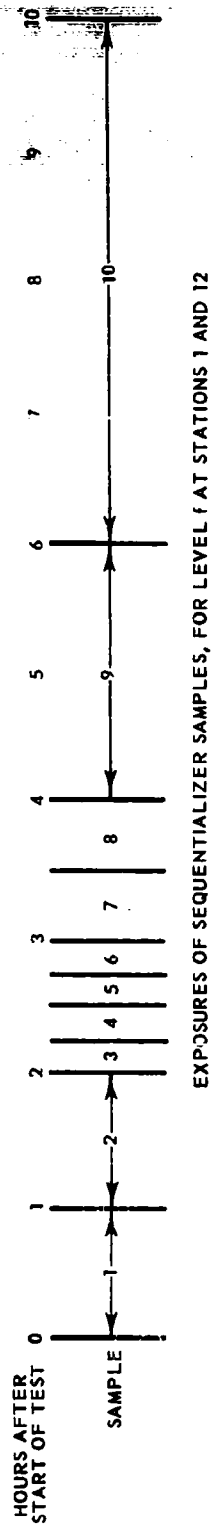


Figure 5-7 Sequentializer Schedule

As illustrated in Figure 5-8, a 4-to-6 in. pole was used as a cross arm to support the rotorods and elevator apparatus at each station. Bamboo poles were tried at first but were found to split and fail under the load. A native solid wood was finally selected. The cotibo tree is ideally suited as a rotorod support as it is a tall, straight tree of about 4 ft in diameter with no branches for the lower ninety to one hundred feet, and it has good holding power for spikes. Steps, as shown in Figure 5-9 were nailed to the tree, enabling a workman to install the rotorod system.

The rotorod elevator apparatus formed a continuous loop, half of which was a rope passing through pulleys on the cross arm, and the other half of which was ladder-like, with plastic-covered wire clothesline as the outside support and wooden strips as the rungs. Each wooden strip supported one rotorod sampler. The plastic-covered clothesline served both as a support and as a conductor of electrical power for the sampler motors.

Each rotorod sampler consisted of a standard commercial motor and rotorod mounted as shown in Figure 5-10. The protective cover was used to minimize contamination of the rotorod samplers by droppings from the vegetation. A snap hook, used to fasten the protective cover to an eyebolt in the wooden strip, allowed the sampler to hang freely and also provided for simple replacement.

The continuous-loop character of the rotorod elevator allowed each rotorod sampler to be pulled to the lowest point on the loop for changing rotorods. Exposed rotorods were removed in sequence and placed in storage boxes. After the top rotorod was removed, the loop travel was reversed, and fresh rotorods were installed as each sampler reached the bottom of the loop. With the loop construction, no tangling of elevator lines occurred. Due to the inverted position of the rotorod motors, it was necessary to tape the rotorods to the motor shaft at the upper levels to prevent rotorod loss during operations with stronger winds.

Half of the rotorod array was provided with power by the North tower site and the remainder from the South tower site. Eighteen-volt

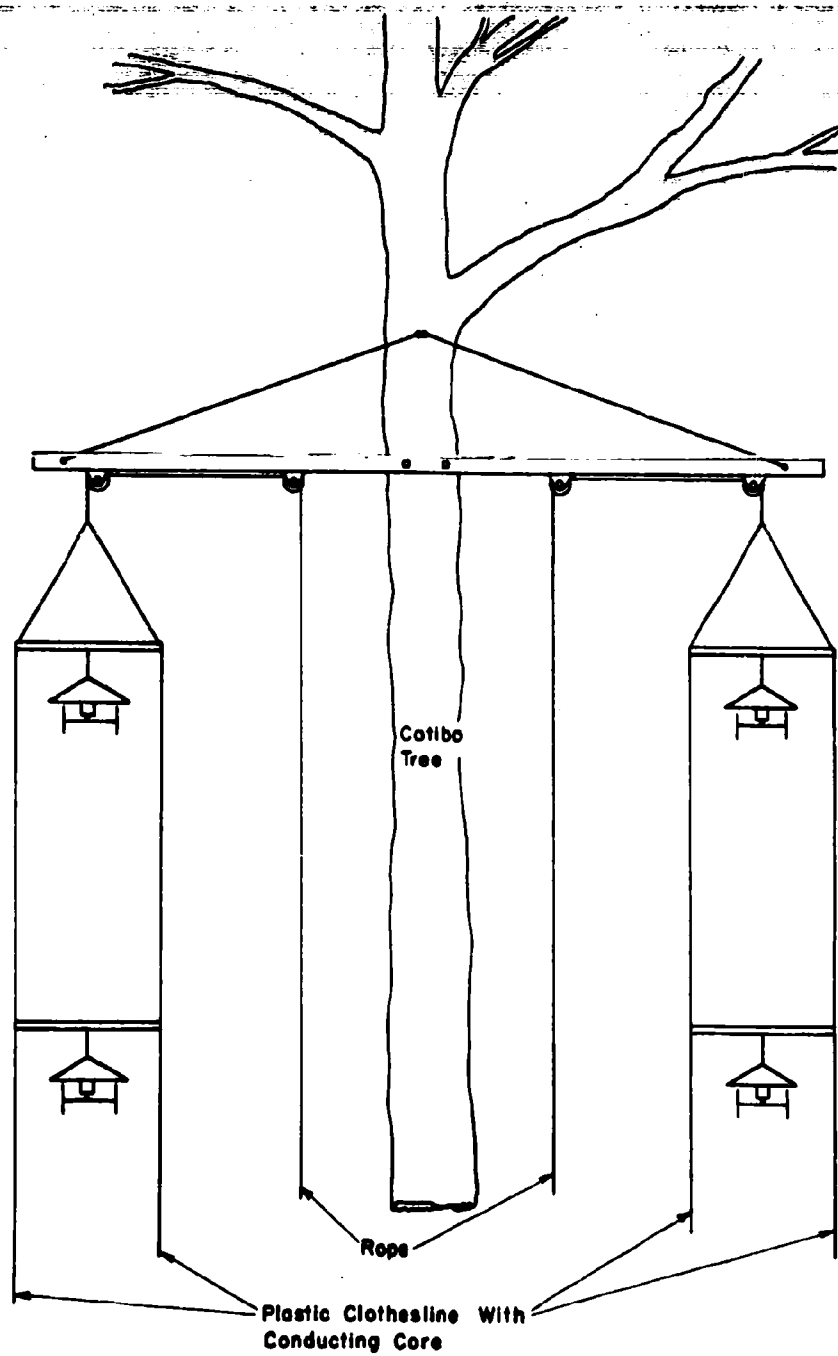


Figure 5 -8 Method of Supporting Rotorod Elevators on Cotibo Trees



Figure 5-9 Cotibo Tree, With Access Ladder, Used to Support Rotorod Elevator

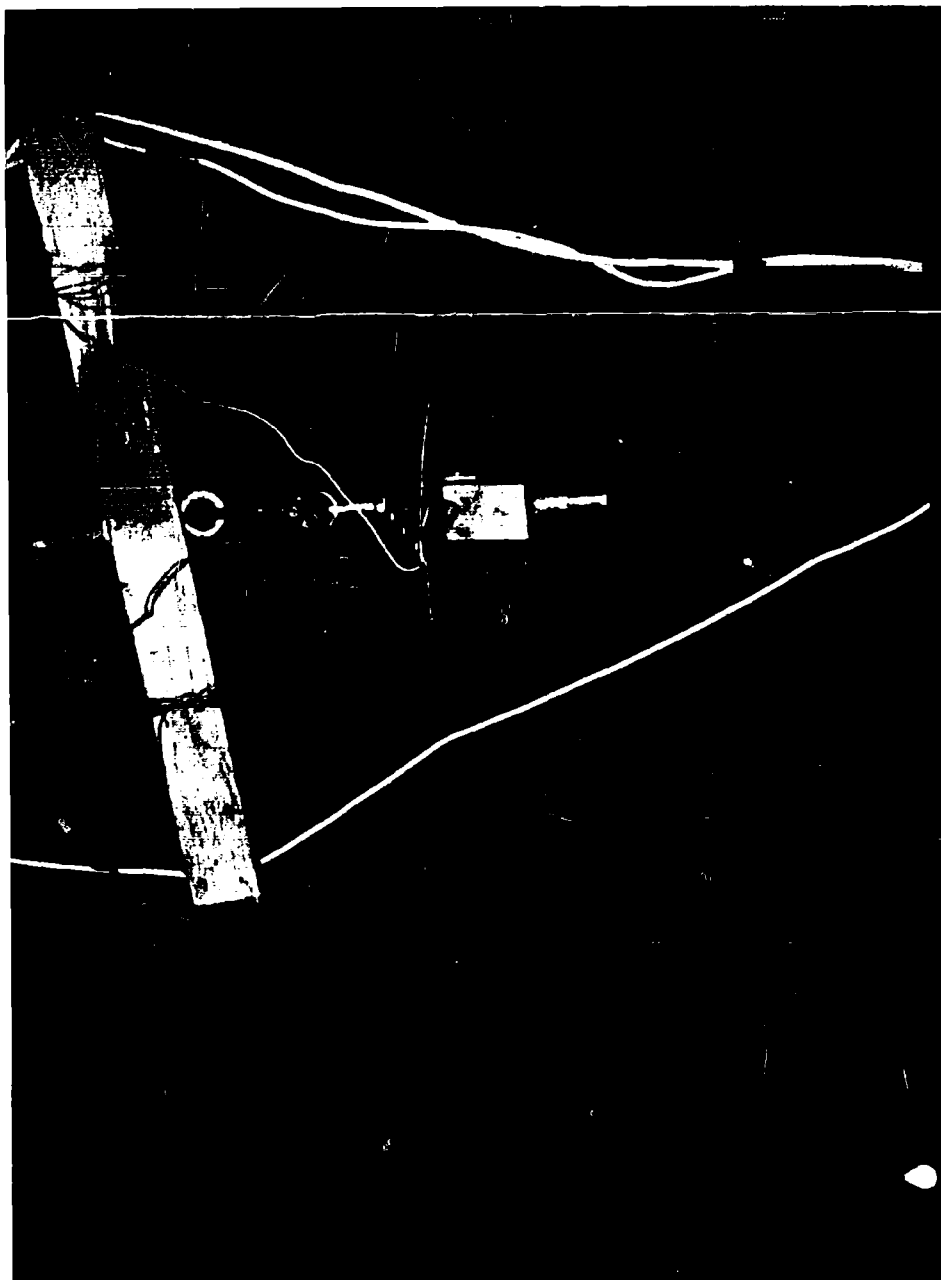


Figure 5-10 One of the Rotorod Samplers, With Protective Cover and Elevator System

D C power, obtained from an adjustable D C power supply, was distributed through a sequencer to the rotorod systems at each location. The rotorod sequencers, as illustrated in Figure 5-11, were synchronous motor-driven timers of 2-hour cycle. The control of polarity, and therefore direction of rotation of the rotorod motors, through the use of a 3-line distribution system is also shown in this figure. During installation, each rotorod system was checked for proper direction and speed of rotation. Number 14 solid copper wire was installed on trees to distribute rotorod power to the test stations and a resistance box was installed in the line at each test station to drop the voltage to the desired 12-14 volts. Polarity-coded plugs were used to connect each rotorod string to the power line so that the loop could be disconnected while the rotorods were changed and re-connected without changing rotation direction. On the 200-ft steel towers, the excessive voltage drop in the plastic-covered clothesline wire necessitated the connection of a parallel wire of number-18 copper from the power distribution line to the middle of each string.

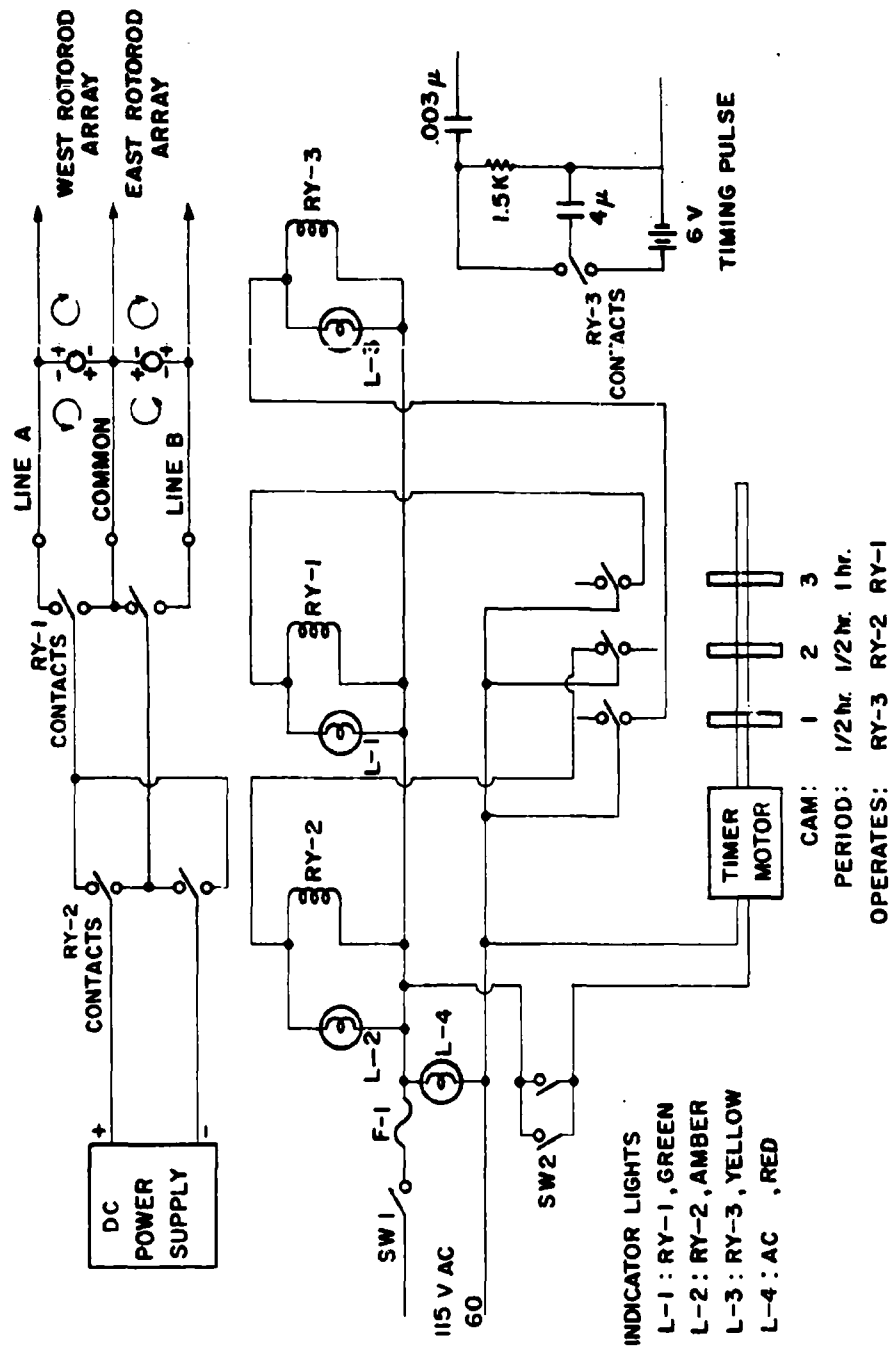
In order to measure the rotational speed of the rotorod motors under simulated test conditions, rotorods were mounted on all motors and power applied to the line being tested. With an extension cord and a polarity reversing switch in series with the power line, the speed of each motor was measured in both clockwise and counterclockwise rotation. An electronic Strobotac, which produced a flash of white light brilliant enough to provide the stroboscopic effect even in the daytime, was used to measure the speed of rotation.

5.2 METEOROLOGICAL SENSORS AND RECORDERS

Sensors were provided to measure temperature, winds and rainfall. Details of the temperature and wind sensors are given below. Rainfall was measured by the familiar tipping bucket sensor which requires no elaboration. An electric pulse for each 0.01 in. of rain actuated an event-pen on the E. A. recorder.

5.2.1 Lapse Rate Measurements

Ventilated iron-constantan thermocouples were used to sense temperature. Iron-constantan was used instead of copper-constantan because the sensitivity of iron constantan varies from 52.0 microvolts/ $^{\circ}\text{C}$ at 20 C to 53.0 microvolts/ $^{\circ}\text{C}$ at 40 C, that is, only about 2 percent change over the anticipated range in air temperature expected. Copper constantan has about 4 percent change in sensitivity over the same temperature range. Moreover iron-constantan junctions also have about 25 percent greater thermoelectric emf/ $^{\circ}\text{C}$ than copper-constantan, so that with a standard 0-1 millivolt recorder, zero center, a more open scale of lapse rate was obtained,



covering the approximate range $\pm 10^{\circ}\text{C}$ from a buried reference temperature. In practice this range was excellent.

If iron or constantan leads were run directly to the brass recorder terminals, the magnitude of small thermoelectric voltages caused by differences in temperatures across the terminal panel would be increased several times over that which would occur if copper leads were run to this same panel. To permit the use of copper leads to the panel and yet not have the effect of copper-iron thermojunctions, these latter junctions were buried 6 ft in the ground at a constant temperature.

Prior to shipment to the test site both recorders were tested for errors that might arise due to temperature variations across the terminal block in the recorder. By sealing the cable entrances to the recorder in the area adjacent to the terminal block, errors in indicated temperatures from different sensors were reduced to the order of $\pm 0.02^{\circ}\text{C}$.

Lapse rate measurements were made using a differential thermocouple system at each of the 200-ft towers. An iron-constantan thermojunction was mounted at each of the eight instrument heights. These thermojunctions were made by twisting and soldering the ends of Leeds and Northrup No. -16 gage iron-constantan premium grade duplex wire. As shown in Figure 5-12, these wires were led down the tower to a point in the ground where the constantan leads were joined in a common thermojunction with a copper lead, and the iron leads were individually joined with copper leads. The copper wire from the common copper-constantan junction was connected to all of the negative terminals of the lapse-rate recorder. The copper wires from the copper-iron junctions ran separately to the positive terminals of the recorder. By having continuous iron and constantan leads from the temperature-sensing thermojunctions to the underground junctions, there were only three dissimilar metal thermojunctions in any one complete measuring loop. The iron-copper and constantan-copper couples were soldered, wrapped with plastic electrical tape, dipped in Glyptol, and put at the bottom of a galvanized pipe, driven 6 ft 2 in. into the ground. At this depth the temperature was constant over any one test and was constant to within $\pm 0.4^{\circ}\text{C}$ over all tests. With this system, no extraneous thermal potentials were introduced, and the potentiometer of the recorder measured the potential due to the difference in

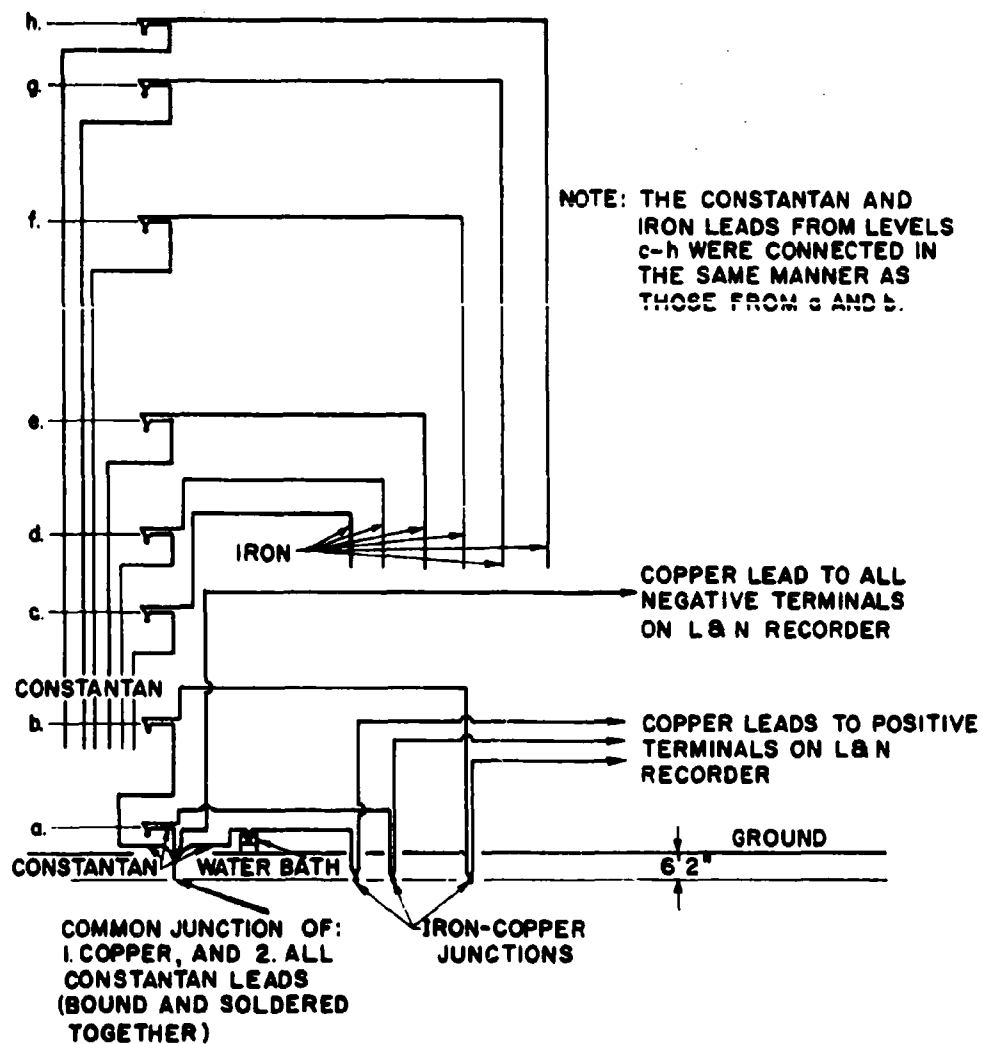


Figure 5-12 Thermocouple System for the Measurement of Lapse Rate

temperature between the thermojunction on the tower and the reference junction in the ground.

The temperature at each point on the tower was measured only as an increment of temperature above or below the temperature 6 ft 2 in. in the ground. To measure the actual temperatures, a ninth iron-constantan couple was placed in a "constant temperature bath," whose temperature was measured with an ordinary meteorological mercury thermometer. The "constant-temperature bath" was obtained originally to be used as the environment for the reference iron-constantan thermojunction. The bath consisted of electrical heaters, a stirring motor, and a very sensitive mercury thermoregulator (see Figure 5-13) in a 5-gallon pyrex jar of water. When the bath was operating correctly its temperature was maintained a few degrees above the ambient air temperature. However, the circuits sometimes failed to turn off the heaters after they had returned the bath to the desired temperature and continued to add heat in an uncontrolled manner. Thus they were unacceptable as reference baths, and the reference junctions were put into the ground.

The iron-constantan thermojunctions located on the tower were insulated with plastic electrical tape and mounted in conventional Leeds and Northrup thermocouple tubes, with resulting time constant* of 2.5 to 3.5 minutes. The tubes were installed in two concentric chrome-plated radiation shields as shown in Figure 5-14.

The outer radiation shield, a piece of 1-1/2 inch chromeplated copper pipe, was an integral part of the thermocouple aspiration system. As shown in Figure 5-15, the air passed by the thermocouple tube, through a control valve, and into a common riser pipe extending the full height of the tower. Three-inch plastic pipe was used from the turbine exhaustor to the five lowest thermocouple aspirators (up to 100 ft) while two-inch pipe was adequate for the remaining three aspirators. The lightness and convenience of cemented joints in plastic pipe facilitated easy and rapid installation, while its flexibility allowed for discrepancies in the alignment of the thermocouple units.

An electric motor-driven air turbine was used to ventilate the aspiration system. To minimize the influence of the turbine exhaust on the micrometeorology of the area, the south tower turbine was located 20 ft south of the tower, and the north tower turbine 60 ft northwest of the

* Defined as the time for the sensor to respond to 63 percent of a step change.



Figure 5-13 Constant-Temperature Bath Showing Heaters and Stirring
Motor in Pyrex Water Jar



Figure 5-14 Thermocouple Radiation Shield and Aspiration System

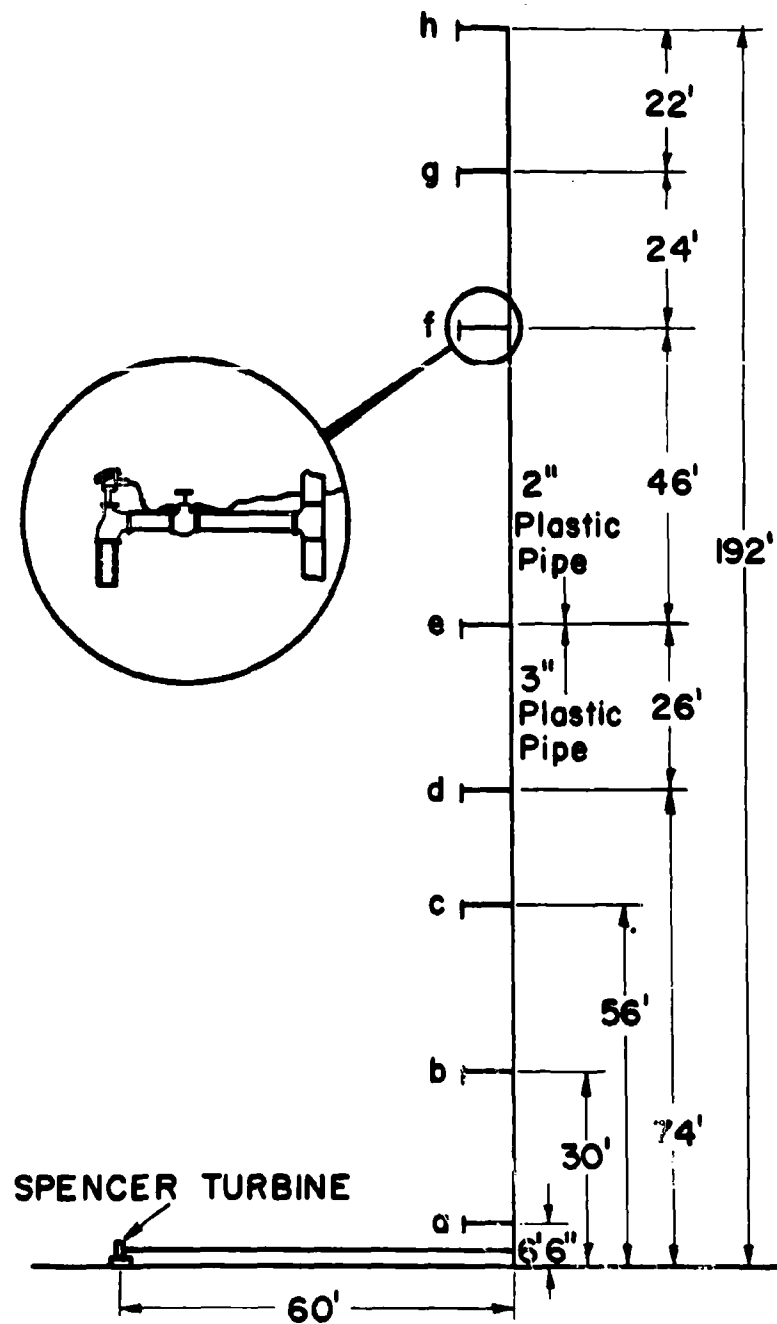


Figure 5-15 Thermocouple Aspiration System

tower. Visual observation detected no leaf motion that could be attributed to the upward turbine exhaust. The valves were adjusted, using a plastic pipe elbow and a Dwyer Manufacturing Co. wind meter, to allow an air flow of approximately 15 ft per sec through each aspirator.

The lapse rate measurements were recorded on a Leeds and Northrup Model G ten-point strip-chart recorder. Points one through eight were connected to the eight thermocouples on the tower while the ninth point was connected to the thermocouple in the water bath. The positive and negative terminals of the tenth point were connected by copper wire, and this connection enabled the point to record zero potential and to serve as a printed zero for each set of data. With a range from -0.5 mv to +0.5 mv and a thermocouple response of .052 mv per $^{\circ}\text{C}$, temperatures could be recorded from approximately 10°C below to 10°C above the temperature 6 ft 2 in. below the ground level.

5.2.2 Beckman and Whitley Wind-Measuring System

Figure 5-16 shows a block diagram of the entire wind measuring and recording equipment used in this investigation. A Beckman and Whitley (hereafter referred to as B. and W.) windspeed transmitter, Model 405, and a B. and W. wind-direction transmitter, Model 421, were mounted on the top of each tower at test stations 1 and 12. The wind-direction transmitter was mounted so that the mid-value of voltage occurred for a north wind, and zero and full-scale voltage indicated a south wind. This orientation prevented many discontinuities in the record, as the wind was predominantly from the north. Three- and four-conductor cables connected these transmitters to the Wind Translator, Model 410, in the instrument shelter.

The outputs from the Wind Translator were analog voltages proportional to the wind speed and wind direction. The windspeed voltage was measured and recorded by one channel of an E. A. dual-channel strip-chart recorder, Model 602. The wind-direction signal was recorded on the second channel of the E. A. recorder but had an additional resistor in series to develop a voltage for simultaneous recording on the tape recorder. This resistor, located in the wind monitor unit, was a 5,000-ohm potentiometer.

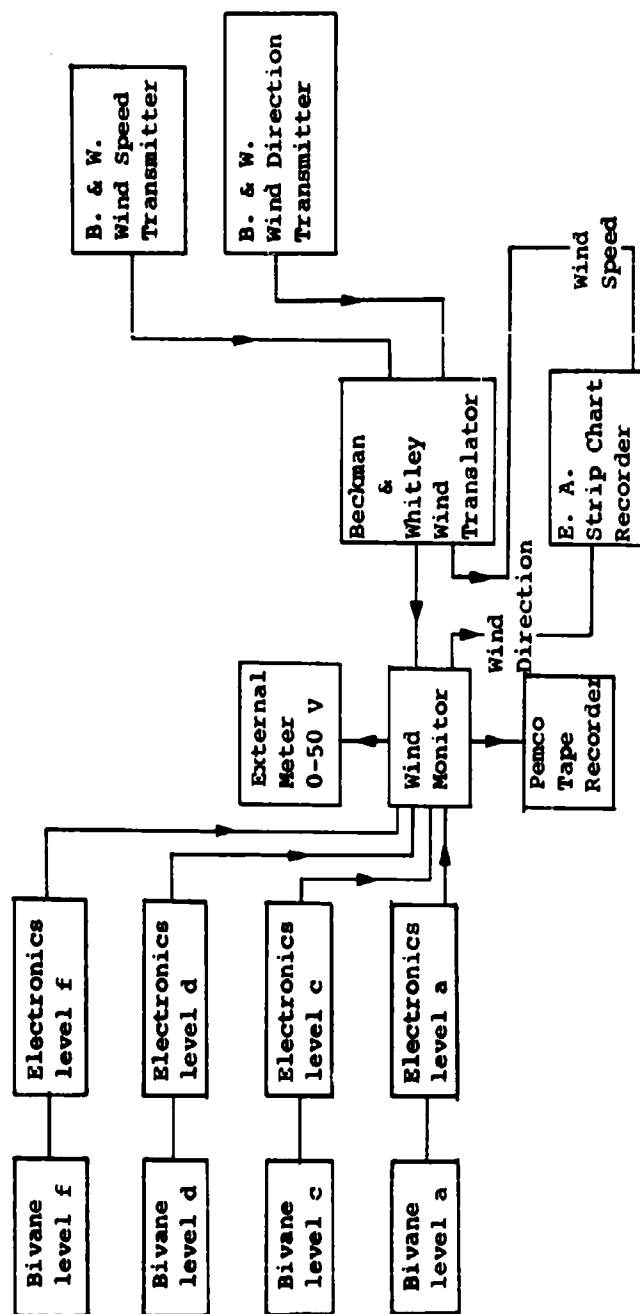


Figure 5-16 Block Diagram of Wind Measuring and Recording Equipment

The B. and W. wind-measuring system had battery power as well as a 110 VAC power supply. Therefore it was possible to operate this system continually, since the E.A. recorder is driven by a spring-wound motor.

Standard calibration procedures were used for the wind-direction system using the zero and full-scale adjustments on the B. and W. translator. However, adjustment of the full-scale of the wind speed required an input of pulses to the B. and W. translator. With a frequency of 868 cycles per sec, simulating a wind speed of 30 mph, the wind-speed full-scale potentiometer was set so that the E.A. pen tracked along the full-scale line. A Knight Audio Generator, 83YX 137, was used to generate the audio frequency pulses and a Beckman EPUT Meter, Model 5210, was used to monitor the frequency whenever the B. and W. wind-speed calibration was adjusted.

5.2.3 Gelman-Gill Anemometer Bivane

Recent developments in diffusion have placed increasing emphasis on the orthogonal components of the wind and their associated standard deviations. In the present study these parameters were extracted by analog computer from tape recordings of the output of the Gelman-Gill anemometer bivane.

Gelman-Gill bivanes modified by the addition of the propeller anemometer in place of the customary counterweight (hereafter referred to simply as bivanes), were used to measure the wind speeds, azimuth angles, and elevation angles (see Figure 5-17). The wind-speed output was a series of pulses with the pulse rate proportional to the wind speed, while the azimuth and elevation angle signals were positive analog voltages. As with the B. and W. wind direction transmitter, the bivane was oriented so that the voltage jump between zero and full scale occurred for a south wind. Table 5-2 gives the azimuth angles and their corresponding analog voltages. A stop on the bivane limited its elevation travel from 50° up to 50° down from the horizontal. The elevation angles and the corresponding voltages are shown in Table 5-3.

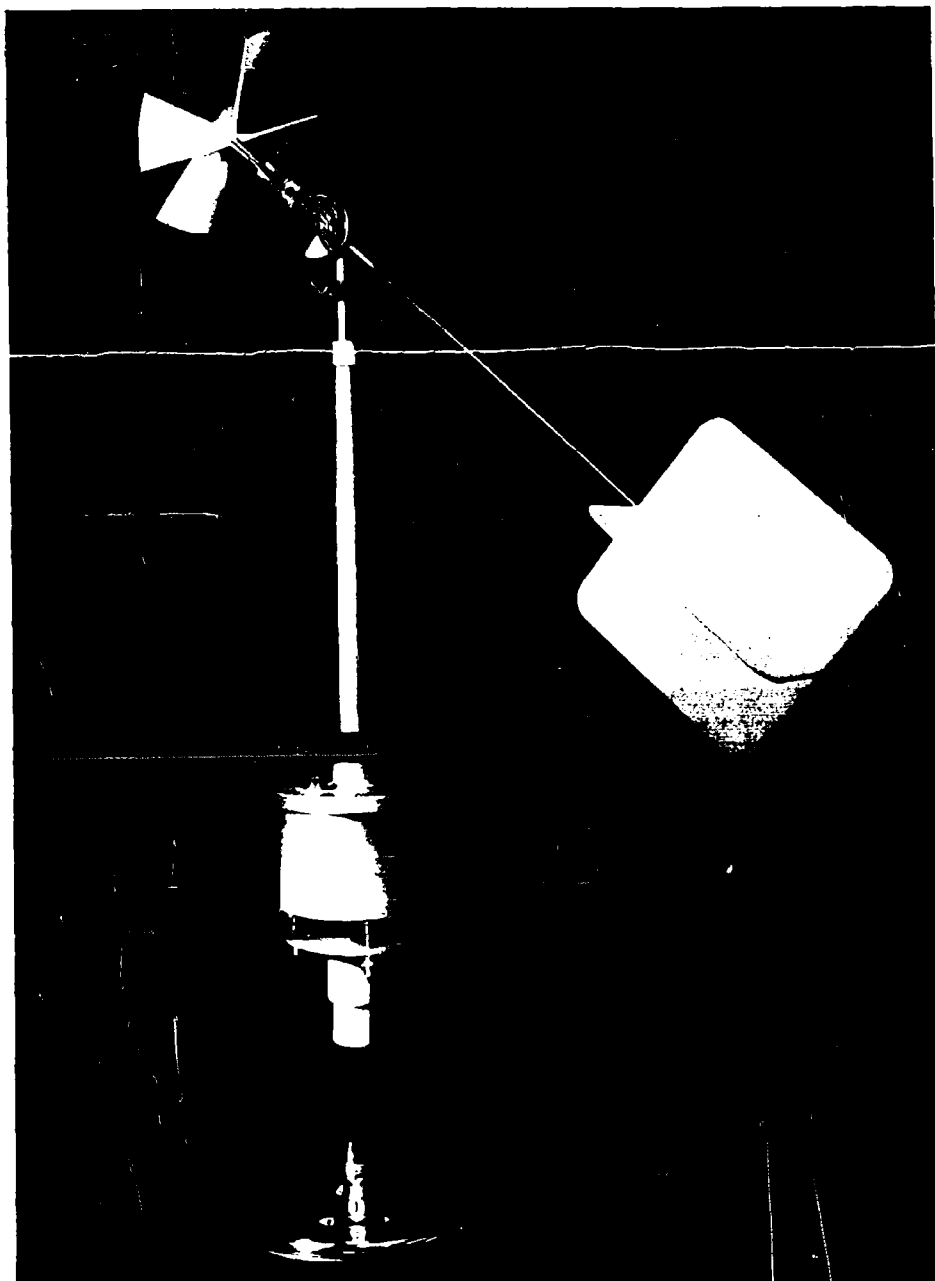


Figure 5-17 Gelman-Gill Anemometer Bivane

TABLE 5-2

RELATION BETWEEN AZIMUTH ANGLE, AS MEASURED FROM
MAGNETIC NORTH, AND THE BIVANE ANALOG VOLTAGE

<u>Azimuth Angle</u>	<u>Analog Voltage</u>
180° +	0
270°	12
360°	24
90°	36
180° -	48

Note: There was a dead spot of 3 degrees at the end of the potentiometer windings; i. e., at 180°.

TABLE 5-3

RELATION BETWEEN ELEVATION ANGLE
AND ITS ANALOG VOLTAGE
FROM THE BIVANE.

<u>Elevation Angle</u>	<u>Analog Voltage</u>
50° up	1.84
Horizontal	7.80
50° down	13.70

5.2.3.1 Construction Details

The wind-direction system consisted of a vane mounted with two degrees of freedom so that it might rotate about both the vertical and horizontal axes.

The fins of the bivane were made of expanded polystyrene beads selected because of their extreme lightness, rigidity, very low water absorptivity, and good durability in sunlight. By using vanes of extreme lightness the dynamic performance of the direction sensor is almost ideal. No limit has been established for the wind speeds that may damage the plastic tail fins. They have suffered no injury when exposed to winds in excess of 50 mph in actual use.

The wind-speed sensor of the anemometer bivane is shown mounted on the instrument in Figure 5-17, in parts in Figure 5-18, and in assembly in Figure 5-19. The sensor is a 4-bladed 9-in. diameter helicoid propeller (Figure 5-20) molded from polystyrene beads--the same material as used in the tail fins. The polystyrene-bead construction has produced propellers weighing as little as 6 grams. Those used in this study weighed between 11 and 13 grams. The propeller was designed to have a pitch of 360° in 12.0 inches; i. e., with no friction losses it would produce 1.00 revolution for each 1.00 ft of air passage.

There were five slots in the light chopper, and therefore five light pulses were allowed to fall on the photo cell for each revolution of the propeller, producing five current pulses per propeller revolution.

5.2.3.2 Electronic Circuits

Figure 5-21 is a schematic diagram of the electronic circuit used with the bivane. Two circuits of two parts each were built into each chassis. They were: (1) the anemometer-section power supply and pulse amplifiers, and (2) the bivane-section power supply and calibration circuits.

The current pulses developed by the photo cell were amplified by the two-stage transistor amplifier and rectified by diode D_5 so that voltage pulses of about 10-volt amplitude were available for the recorder. The potentiometer R_{16} was used to adjust the size of the output anemometer pulses. In the field operation this control was usually set for the maximum signal.

The bivane-section power supply consisted of a conventional vacuum-tube full-wave rectifier with a choke input filter and gas tube (OD3 or VR-150) voltage regulation. Resistor R_1 and potentiometer R_3

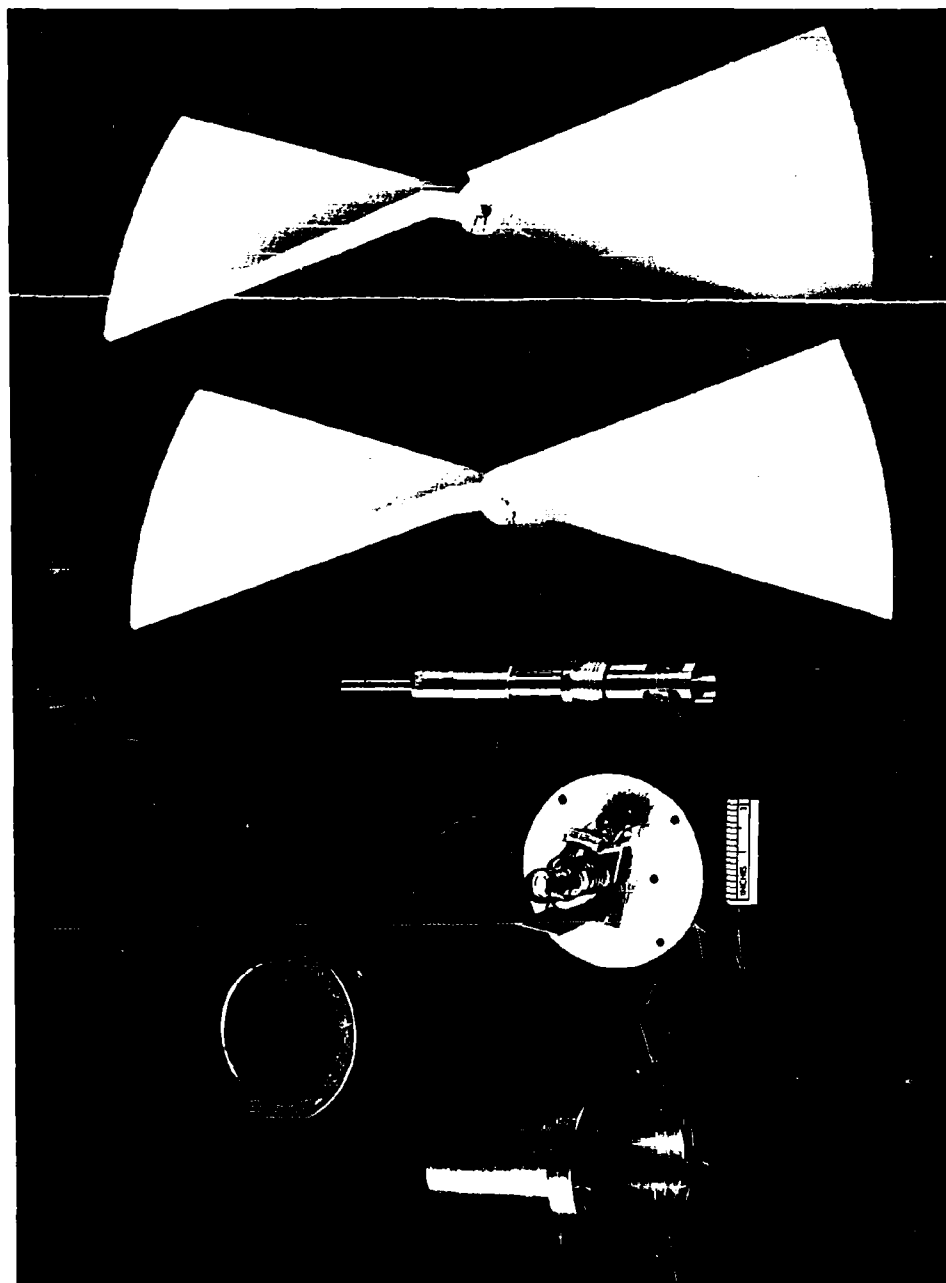


Figure 5-18 Parts of the Anemometer Section of the Gelman-Gill
Anemometer Bivane

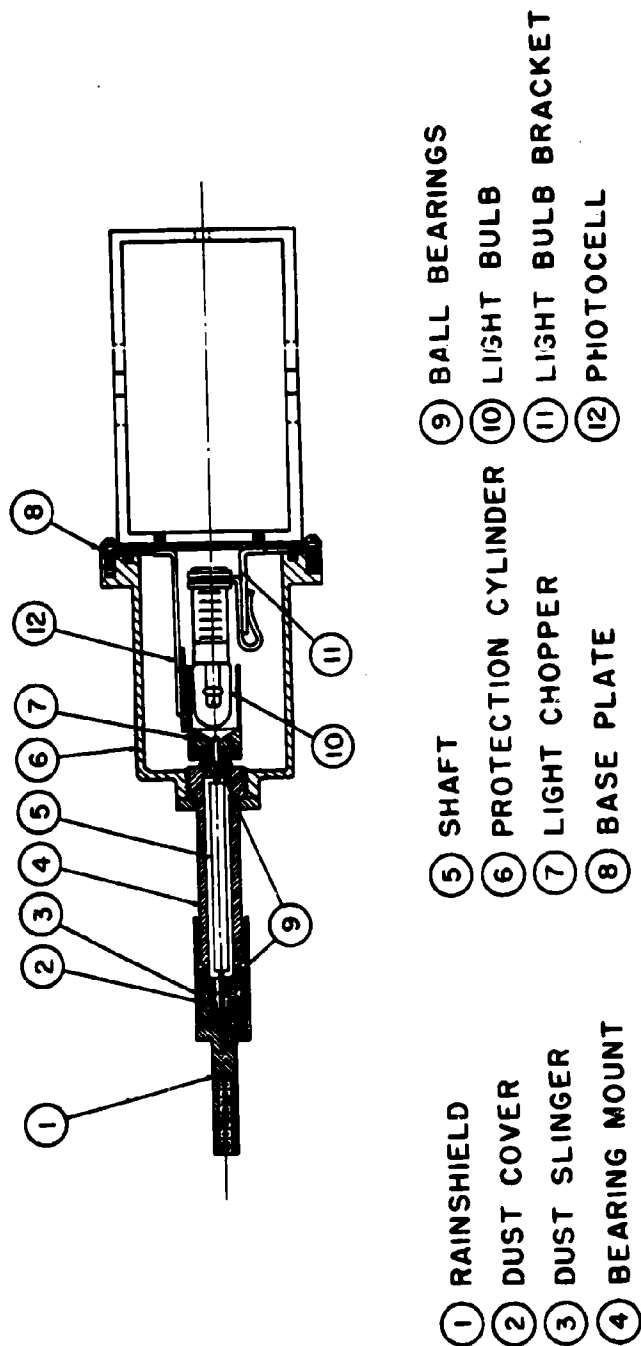


Figure 5-19 Assembly Drawing of Anemometer Portion of the Gelman-Gill Anemometer Bivane

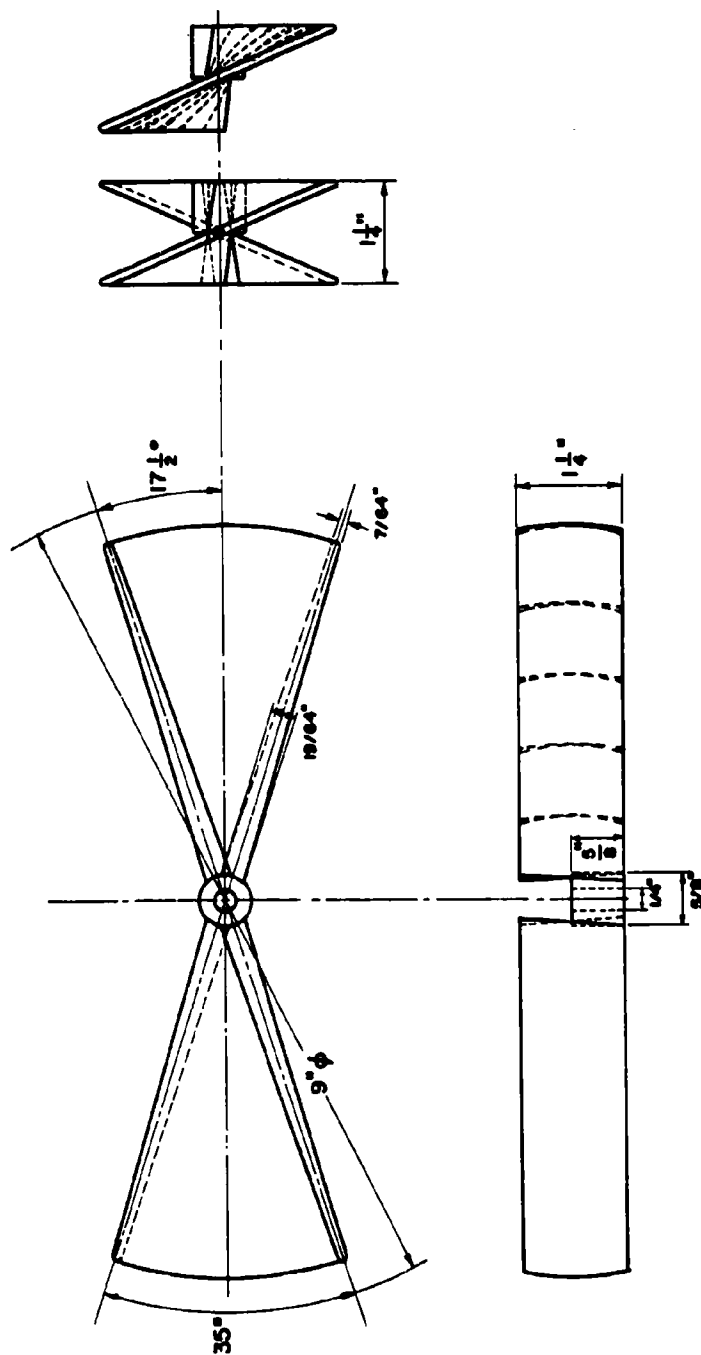


Figure 5-20 Details of Anemometer Propeller

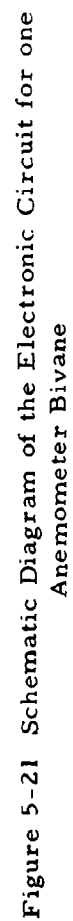


Figure 5-21 Schematic Diagram of the Electronic Circuit for one Anemometer Bivane

were used to adjust the voltage across the bivane azimuth potentiometer to +48 VDC; resistor R_2 and potentiometer R_4 were used for the same purpose for the bivane elevation potentiometer.

With switches S_2 and S_4 in the position shown in Figure 5-21 (Read Position), the analog voltages for the bivane azimuth and elevation angles were transmitted to the monitor box and tape recorder. When S_2 and S_4 were in the calibration position four resistors in series were substituted for the bivane potentiometers. These resistors were chosen so that their series sum was equal to 5,000 ohms and each resistor had the same value as the resistance of a significant angular displacement of the azimuth or elevation potentiometer. Table 5-4 shows the angles equivalent to the various voltages based on the relation that 5000 ohms is equivalent to 360° .

TABLE 5-4

CALIBRATION RESISTORS AND THEIR EQUIVALENT
AZIMUTH OR ELEVATION ANGLES

Resistors between ground and moving contact of switch	Resistance	Angular Increment	Elevation or Azimuth Angle
R_{12}	191 ohms	13.8°	45° Down
$R_{12} + R_{11}$	810	58.3°	Horizontal
$R_{12} + R_{11} + R_{10}$	1429	102.9°	45° Up
$R_{12} + R_{11} + R_{10} + R_9$	4999	360.0°	--
No Resistors	0	0.0°	180° Azimuth
R_8	698	50.2°	230° Azimuth
$R_8 + R_7$	1396	100.4°	280° Azimuth
$R_8 + R_7 + R_6$	2796	201.1°	380° or 20° Azimuth
$R_8 + R_7 + R_6 + R_5$	5006	360.0°	180° Azimuth

The peculiar azimuth calibration angles were due to a desire to have the jump in resistance occur for a south wind.

5.2.3.3 Static and Dynamic Response of the Instrument

The bivane was tested for friction error over a range of speeds by mounting it in a wind tunnel, deflecting it 20° from the wind direction, releasing it, and noting the new rest position. The results are shown in Table 5-5.

TABLE 5-5

BIVANE ERROR ANALYSIS

Tunnel Air Speed	Friction Error of Vane
2.0 mph	$\pm 2.8^\circ$
1.5	± 4.4
1.0	± 7.6
0.5	± 10.0

The following brief descriptions with tables and figures describe the response of the bivane.

The ratio $\frac{\text{indicated amplitude of wind fluctuation}}{\text{true amplitude of wind fluctuation}}$

is called the amplitude ratio. For accurate recording, this ratio should be 1.00. In Figure 5-22, the amplitude ratio is plotted versus gust wave length for sinusoidal azimuth angle, elevation angle, and speed fluctuations. In Table 5-6 some of the constants of the bivane are given.

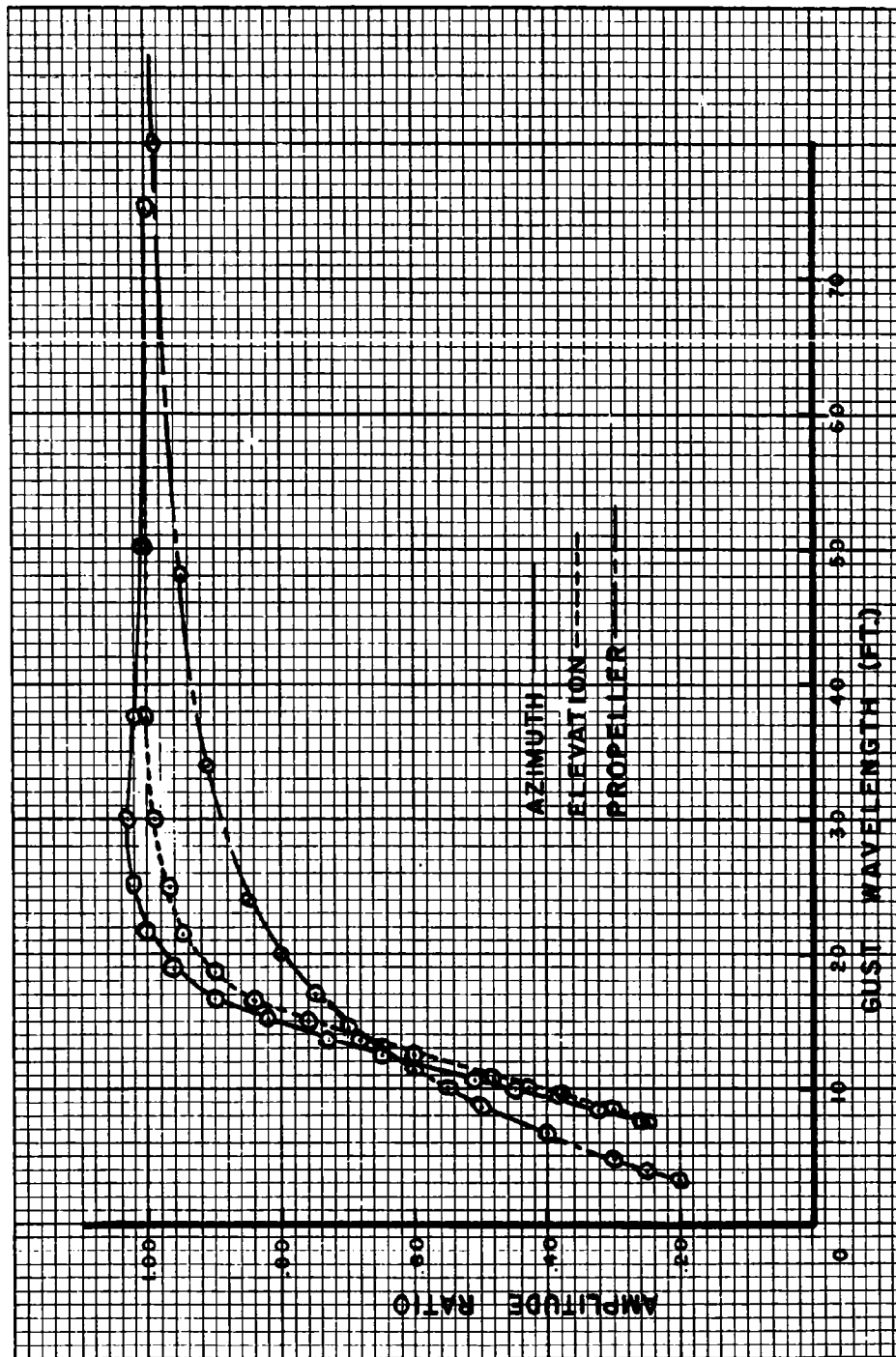


Figure 5-22 The Amplitude Ratio for Elevation Angle, Azimuth Angle, and Propeller as a Function of Gust Wave Length for the Anemometer Bivane

TABLE 5-6
CONSTANTS FOR BIVANE

a. Constants of wind direction portion of bivane.		
Parameter	Azimuth	Elevation
Average first overshoot	9%	7%
Average damped wave length	18.0 ft	19.8 ft
Average damping ratio	.60	.65
Average distance constant	14.4 ft	15.2 ft
Max overshoot for sinusoidal wind direction fluctuation	3%	0%
b. Constants for anemometer portion of bivane		
Starting speed	0.3 ft/sec	
Threshold for linearity of pulse output to wind speed	3. to 4 ft/sec	
Output per foot of air passage	4.80 $\pm$.05 pulses	
Distance constant	2.4 ft	
Error with an off-axis wind	11.6% for 20° off-axis	

The bivane responds fully, but without overshoot, to all elevation angle fluctuations of wave length 40 ft or longer, and the azimuth angles are similarly recorded but with a maximum of three percent overshoot. Practically, it is unlikely that this three percent will even be indicated since such an overshoot occurs only if two or three gusts of approximately 30 ft in wave length occur in sequence, one after another.

Figure 5-23 portrays the calibration of eight propellers conducted in the field test facility; Figure 5-24 is the calibration of two typical propellers conducted in the University of Michigan wind tunnel.

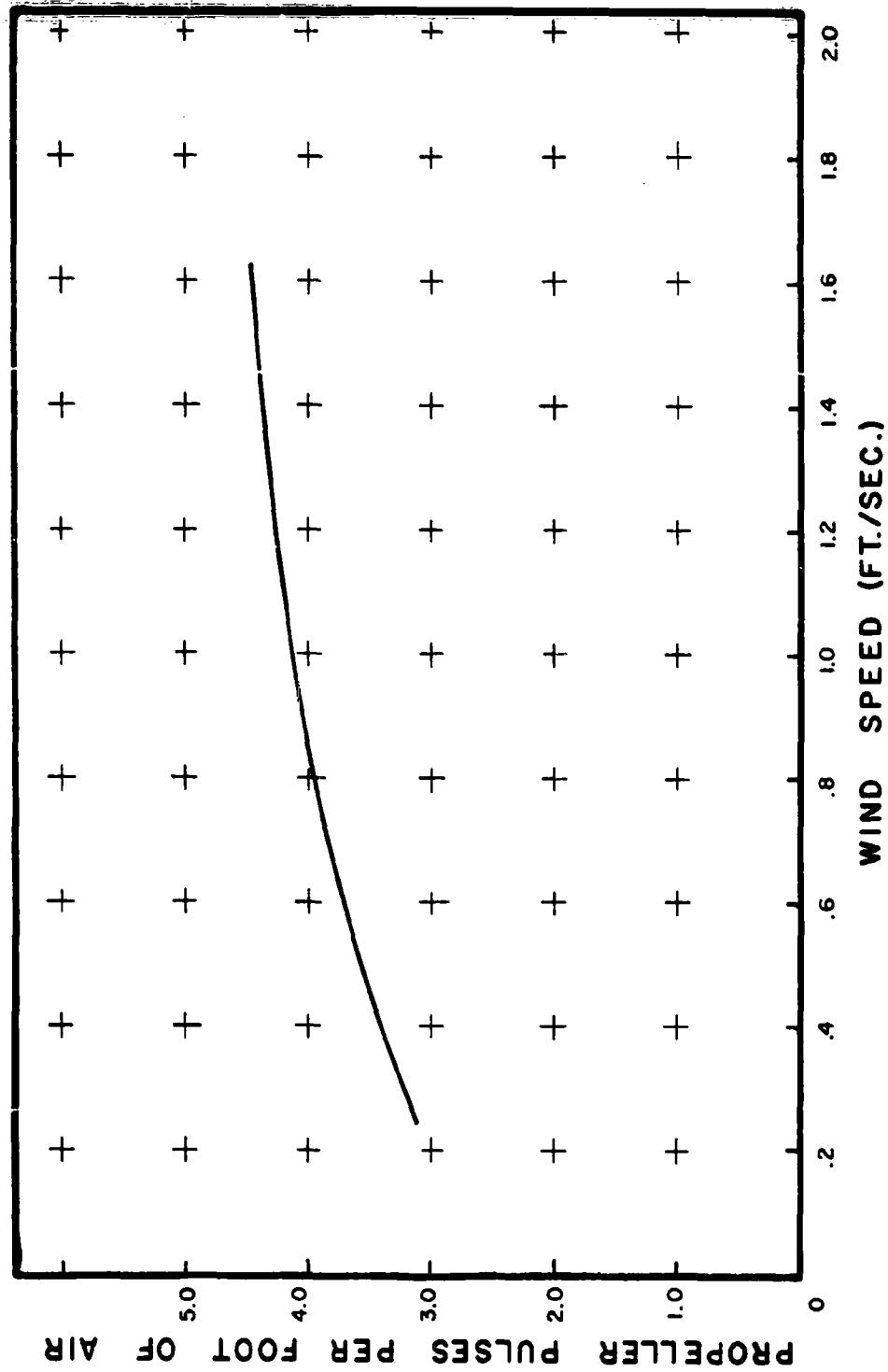


Figure 5-23 Response Curve of the Anemometer Portion of the Bivane Anemometer as a Function of Wind Speed
Less Than 1.5 ft/sec

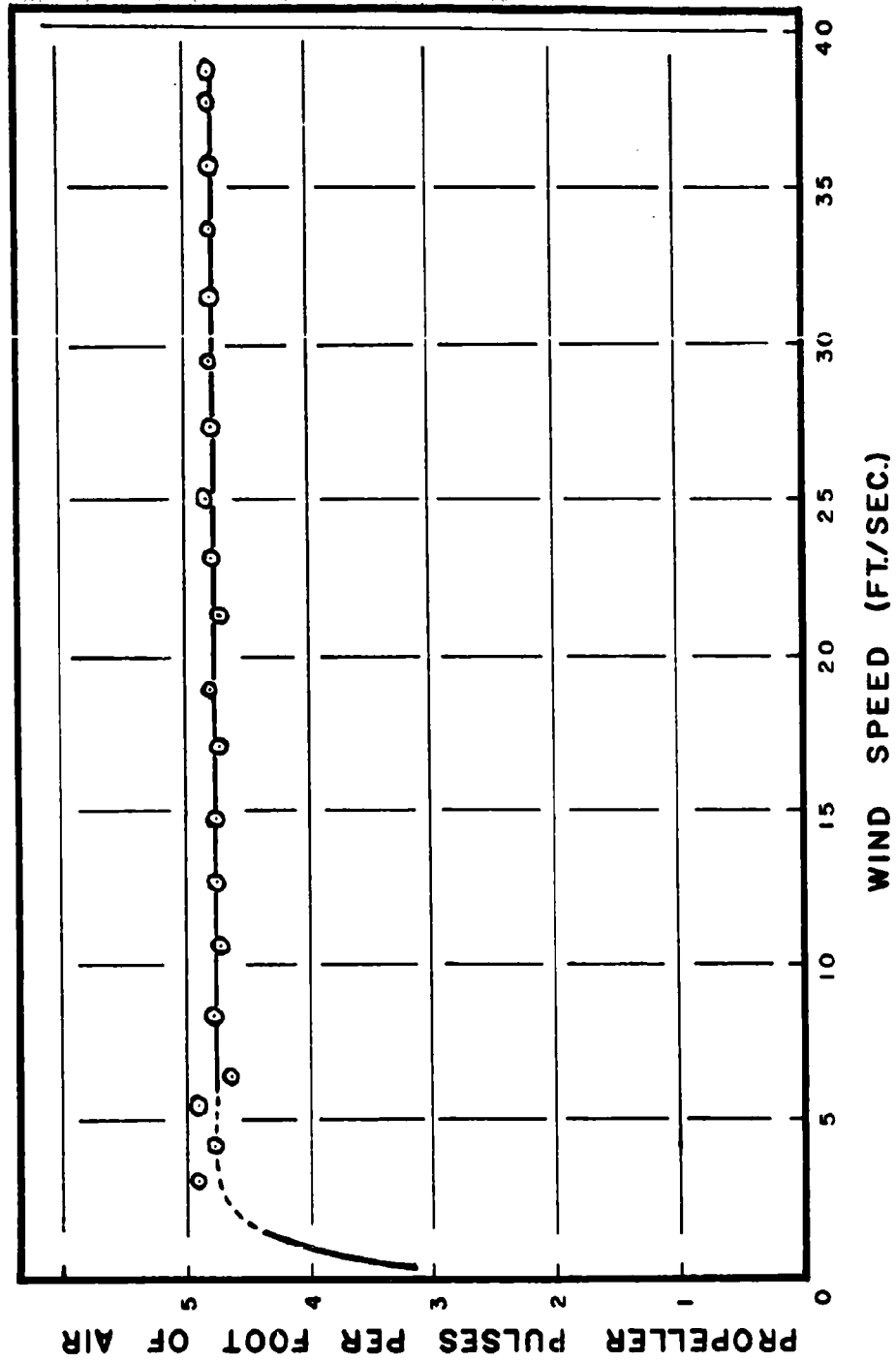


Figure 5-24 Response Curve of the Anemometer Portion of the Bivane Anemometer as a Function of the Wind Speeds up to 36 ft/sec

The following points are noteworthy from the graphs:

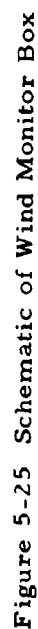
1. The friction effect is small above 3 ft/sec
2. The calibration is very linear above 3 ft/sec; the wind speed sensor transmitting $4.80 \pm .05$ impulses per ft of air passage for all wind speeds above 3 ft/sec.
3. Between 3.0 and 0.5 ft/sec the calibration factor drops from 4.8 to 3.5 impulses per ft of air.

Study of the curves of Figure 5-22 shows that: (1) for gust wave lengths longer than 13 ft wind direction fluctuations are recorded somewhat more accurately than wind speed fluctuations; (2) for gust wave lengths of 20 to 30 ft, wind directions are recorded within the range 92 to 103 percent of true amplitude, and wind speeds 80 to 90 percent of true amplitude; (3) for gust wave lengths of 40 ft or longer, wind direction fluctuations are transmitted within the range 100 to 102 percent of true amplitude; (4) for gust wave lengths shorter than 13 ft neither wind direction nor wind speed fluctuations are adequately recorded; (5) the wind direction and wind speed sensors are well matched, not differing in their fidelity of response by more than 15 percent of true amplitude for gust wave lengths from infinity down to 10 feet, and for gust wave lengths shorter than 10 feet neither sensor is adequate.

5.2.4 Wind Monitor

A monitor box was constructed to allow the output signals from the bivanes to be monitored during operation. A schematic of this circuit is shown in Figure 5-25; in addition to serving as a monitor, the chassis was the junction box between the bivanes and B. and W. wind system and the tape recorder.

The wind-direction signal from the B. and W. translator went to one terminal of the monitor selector switch and also to the E. A. strip-chart recorder. The 5 K, 2 w potentiometer in the wind-direction circuit was used as a load to produce voltage signals for the tape recorder. A similar system was available for the B. and W. wind-speed signal, but it



was not used during the diffusion testing since this channel on the tape recorder was used to record a 60-cycle reference signal for playback speed control.

The monitor selector switch allowed the operator to monitor any of the signals going to the tape recorder. Either the internal voltmeter or an external voltmeter could be used to measure the signal. In operation, either a VTVM or a VOM external meter was used the majority of the time, since they had higher internal resistance and thus loaded the circuit less than the built-in meter. When the bivanes were operating correctly, a DC voltage from 0 to +48 volts for azimuth, a DC voltage from +1.84 to +13.7 volts for elevation, and a pulsating DC from +2 to +15 volts for wind speed were observed. If deviations from the preceding values existed, they were noted in the log during the half-hourly monitoring of wind data, and corrective action was attempted.

5.2.5 Pemco Tape Recorder

Pemco Series PMR-500 tape recorders were used at stations 1 and 12 to record the wind data from both the B. and W. wind system and from the Gelman-Gill anemometer bivanes. The Pemco tape recorder system records on 5-in. diameter reels of 1-in. wide magnetic tape using 14 tracks. As the wind-data analog voltages were often slowly varying DC signals, it was necessary to use a frequency-modulation recording system. To conserve magnetic tape, a recording speed of 15/16 in. per sec was standard for all tests.

The FM record amplifiers of the tape recorder were calibrated according to the manufacturer's instructions. With an input of zero volt, the center frequency was adjusted to be 844 cycles per sec. To maintain an error less than 2 percent it was necessary to limit the maximum frequency modulation to 40 percent. With the maximum voltage for each channel applied to the tape recorder, the FM record amplifier was set to produce 40 percent modulation or 1181 cycles per sec. As the zero and 40 percent modulation adjustments were partially interdependent, both adjustments were repeated until they were simultaneously correct. A Beckman EPUT meter was used to measure the frequency during calibration.

Calibration of the tape record was provided by recording a voltage proportional to certain fixed azimuth and elevation angles. Table 5-7 gives the tape track assignments and the voltages used for calibration. These

TABLE 5-7

**TAPE RECORDER CHANNEL ASSIGNMENTS AND CALIBRATION
VOLTAGES FOR 40% MODULATION OF FM RECORD AMPLIFIERS**

Input Signals	Calibration Voltage	Track Assignments	
		Station 1 North Tower	Station 12 South Tower
Bivane A, WS	+ 8.0	1	14
Bivane A, AZ	+48.0	2	13
Bivane A, EL	+14.4	3	12
Bivane C, WS	+ 8.0	4	11
Bivane C, AZ	+48.0	5	10
Bivane C, EL	+14.4	6	9
Bivane D, WS	+ 8.0	7	8
Bivane D, AZ	+48.0	8	7
Bivane D, EL	+14.4	9	6
Bivane F, WS	+ 8.0	10	5
Bivane F, AZ	+48.0	11	4
Bivane F, EL	+14.4	12	3
60-Cycle Timing Signal	+ 8.0	13	2
B. and W., AZ	+ 1.7	14	1

voltages were developed by the calibration-signal voltage divider in the bivane electronic circuits. The B. and W. wind-direction zero and full scale calibration signals came from the B. and W. translator as the zero or full scale buttons were depressed. When the B. and W. wind speed was being tape-recorded, the cable from the wind-speed transmitter on the tower was disconnected and calibration pulses put in with the Knight audio generator. No calibration was required for the bivane wind-speed channels or the 60-cycle channel as the frequency, and not the amplitude, was the parameter of interest.

5.3 LOW SPEED CALIBRATION FACILITY FOR THE PROPELLER AND SHAFT ASSEMBLIES OF THE ANEMOMETER BIVANES

The faithfulness of the wind speed indication of an anemometer bivane to the actual wind speed depends on the efficiency of the propeller, the friction losses to turbulence, and especially the friction losses in the propeller shaft bearings.

The first two losses should remain constant with time, but the latter could vary gradually or abruptly during exposure to the jungle environment, and therefore a means of calibration at the test site was essential. Such calibration required that a controlled relative motion be developed between a volume of air and the propeller.

To provide this at the field site, a system was developed by which the propeller was moved through stationary air. The objections to the conventional wind tunnel approach were overcome because for this test facility the tunnel needed to be only relatively air tight, its cross-sectional area could vary and the wall could be very rough. It is also very easy to measure the speed in such a test facility.

5.3.1 Construction of the Test Facility

Figure 5-26 is a photograph of the completed test facility, and Figure 5-27 is a drawing of its cross section.

Movement of the anemometer assembly through the tunnel was accomplished by mounting it on a cart suspended on taut cables. Figure 5-28 shows the test facility with entrance door removed, the cables, the cart, and the bivane



Figure 5-26 Test and Calibration Facility for Anemometer and
Propeller Shaft Assembly

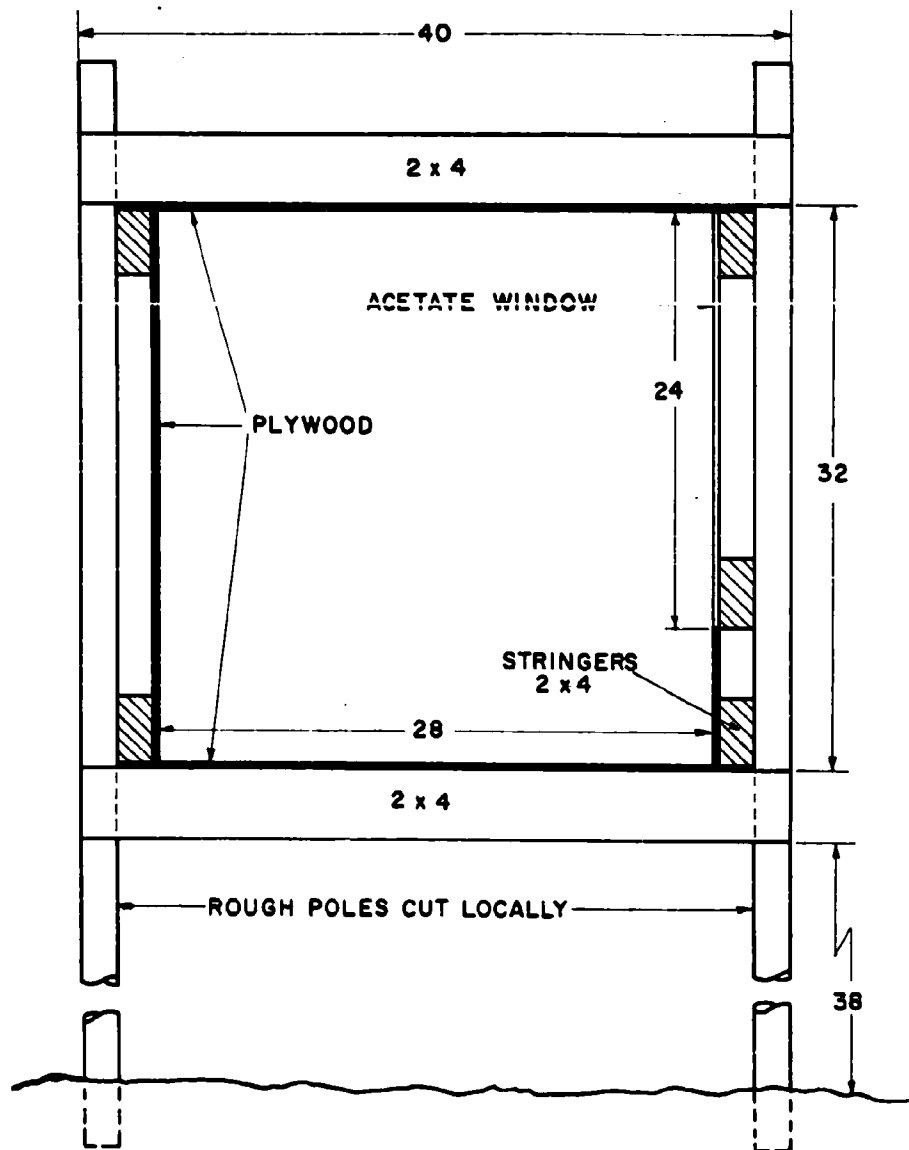


Figure 5-27 Cross-Section of Test Facility

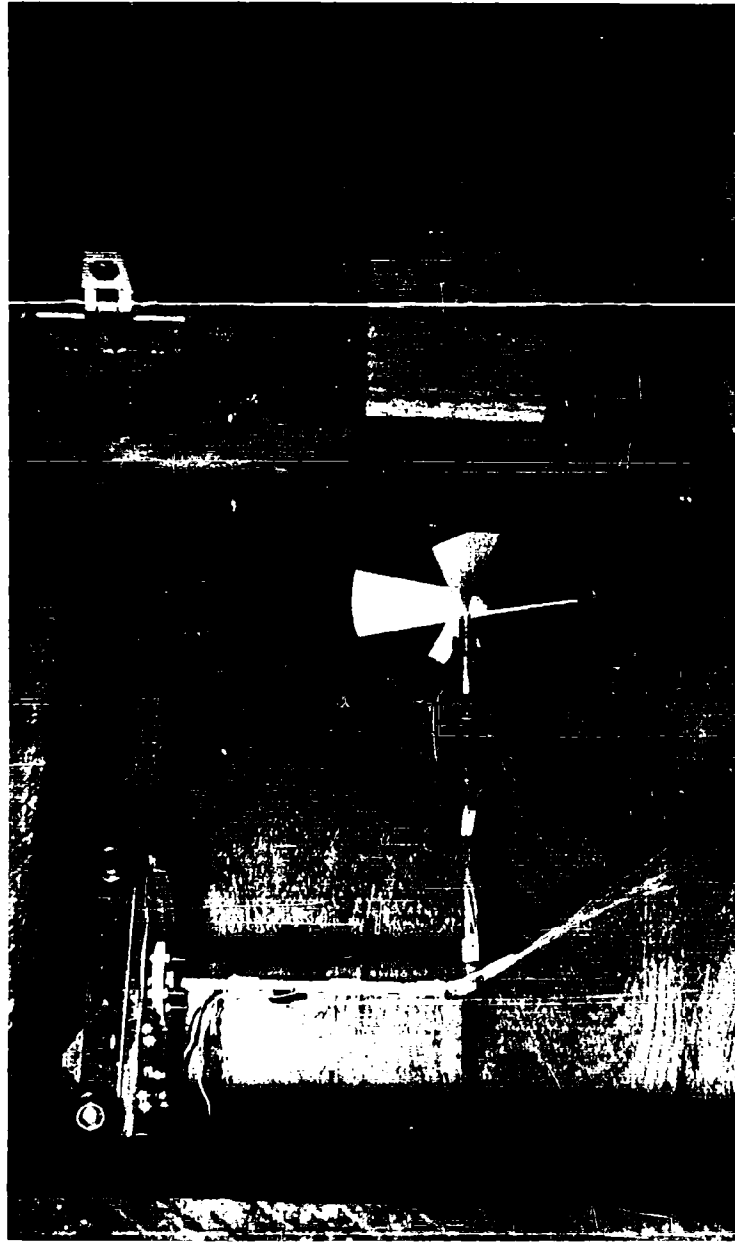


Figure 5-28 Test Cart of Calibration Facility With Propeller and
Shaft Mounted Assembly

anemometer assembly with the propeller shaft and propeller mounted. Figures 5-29 and 5-30 illustrate the mounting brackets for the cables at each end of the test facility tunnel. These brackets, bolted to cotino trees, provided support for four steel cables and the drive motor. The two outermost fixed cables were the support cables for the test cart. The third fixed cable was a brake cable used to stop the cart at the end of a calibration run. The fourth cable was a continuous loop driven by a variable speed drive, as illustrated in Figure 5-31. The drive pulley had a circumference of one foot; thus each revolution of the variable speed transmission produced one foot of linear movement of the drive cable.

A pin on the drive pulley operated a micro-switch connected in series with a 6-volt battery, a resistor, and one channel of an E. A. recorder and gave one electrical pulse per revolution of the pulley, i. e., one pulse per foot of cable travel.

The test cart, shown in Figure 5-32, was supported on the two support cables by four aircraft control pulleys used as wheels. The clamp mechanism locked the cart to either the drive cable or the stop cable, depending on whether the drive solenoid or the stop solenoid was activated. Clamp shoes of a composition material were used to prevent slippage between the cart and the cable being used. An electrical cable of five wires, which connected the cart to an anemometer-bivane electronics chassis and to the solenoid control switch, was pulled along by the test cart during operations.

An E. A. dual-channel strip-chart recorder was used to record both the drive cable pulses and the anemometer pulses.

5.3.2 Operation of the Test Facility

The anemometer assembly being tested was mounted on the test cart. With the cart clamped to the stop cable, the drive motor was started, and the variable speed transmission was set at the desired speed. After the E. A. recorder was started, the solenoid control was thrown to "drive", which released the cart from the brake cable and locked it to the drive cable. Upon reaching the far end of the test facility, the cart was released from the drive cable and locked again to the stop cable. The facility worked well and performed the service for which it was intended.

Although the facility would transport the wind speed sensor at speeds up to 4 ft/sec, field personnel used it only up to 1.6 ft/sec. This limitation

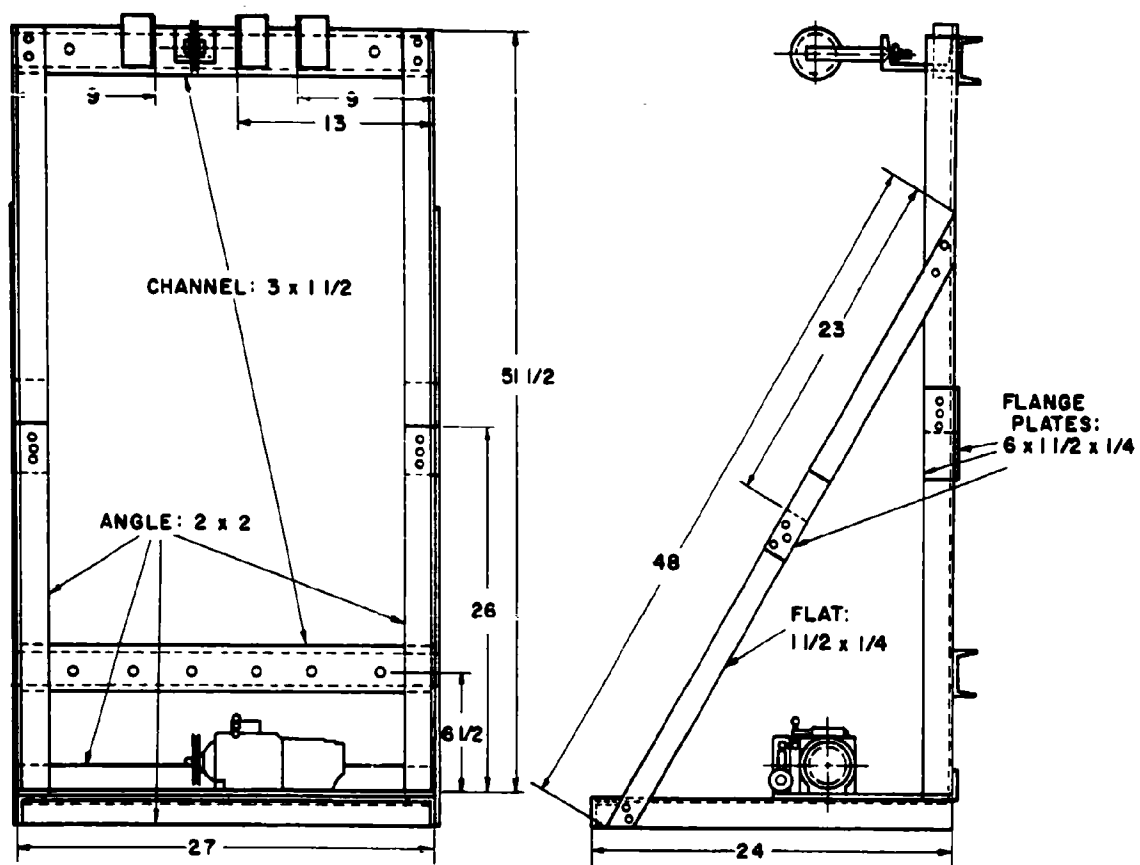


Figure 5-29 Support Bracket for Cable at Motor Drive End of Test Facility



Figure 5-30 Cable Connectors for Stationary Cables and Pulley for
Drive Cable of Test Facility



Figure 5-31 Graham Variable Speed Transmission and Drive Pulley
for Jungle Test Facility

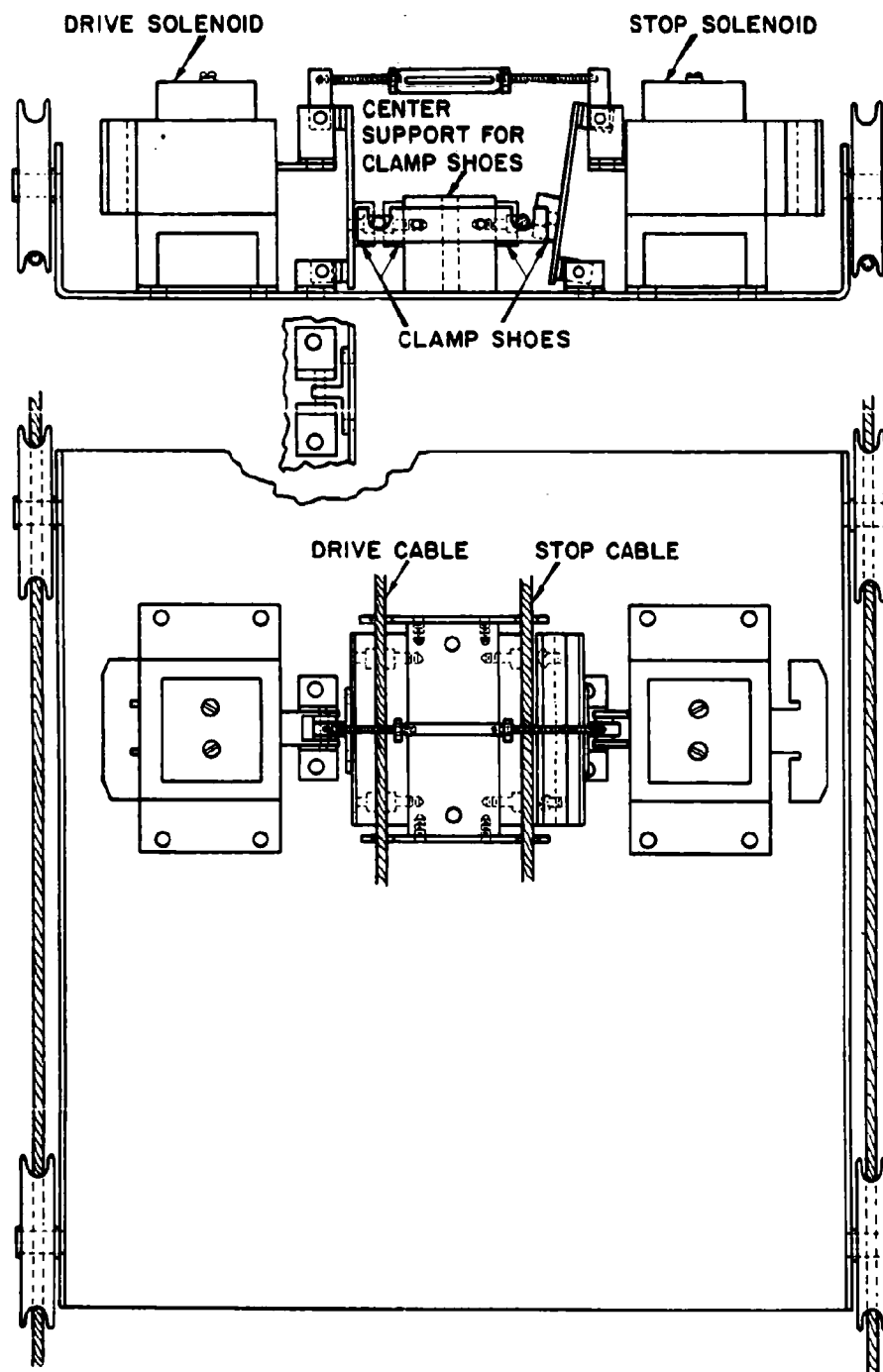


Figure 5-32 Test Cart For Moving Propellers Through The Test Facility

was imposed by the fact that the E. A. recorder was unable to record pulse rates greater than 8 pulses per sec. ($8/5 = 1.6$ ft/sec).

5.4 RELIABILITY OF THE MEASURING EQUIPMENT AND THE RECORDED DATA

The data collected in this investigation contained irregularities in some instances and were missing in other instances. Each type of equipment and data has been considered here and most factors which may have caused omissions or errors have been discussed. Where possible, corrective measures have been suggested for any future use of the equipment.

In spite of the shortcomings of some aspect of the instrumentation, procedures or fixes accomplished in the field, or intensive analysis of recorded data, produced sufficient meteorological data and tracer samples to permit the derivation of a description of the diffusion properties of the tropical rain forest.

The largest area of missing or questionable data was in the wind recording and measuring systems. A major reason for this was insufficient time for instrument design, fabrication, and testing prior to shipment to the test site. Only one completely assembled bivane unit was shipped, the other units were fitted, assembled, and tested at the field site.

5.4.1 Fluorescent Particle Data

This study assumed that the distribution of FP could be accounted for by influences of the air and the jungle. It is therefore important to consider how well zinc cadmium sulfide approximates the properties of an ideal tracer. The required properties include:

1. A specific property for identification
2. Ease of detection
3. Dispersibility
4. Availability
5. Uniformity

6. Stability both during storage and after release

7. Safety.

Identification of ZnCdS is positive. Each particle consists of a mixture of zinc and cadmium sulfides which has been specially treated to fluoresce yellow under ultraviolet light. Detection is easy. A single particle can be detected and since as many as 1.4×10^{10} particles are contained in one gram, the aerosol cloud can be detected over distances of hundreds of miles.

Dispersibility of FP is very good. Approximately 35 percent of the mass disseminated during airborne release is in the form of individual particles. Any large aggregates quickly settle out and are not a factor in the diffusion experiments. The individual particles have slightly rounded and irregular surfaces, but their dimensions are more nearly cubic than platelet - or needle-like. Therefore, in calculating their rate of fall it is justifiable to consider them as spherical and to employ their apparent diameter as measured under a microscope. From the densities of crystalline zinc sulfide (4.1 g/cm^3) and cadmium sulfide (4.8 g/cm^3), the density of FP is estimated to be 4.0 g/cm^3 . This allows for some lack of compaction in the particles. Assuming a mass mean diameter of 2.5 microns, the calculated Stokes' settling rate is 2.74 m/hr, or approximately 9 ft/hr. Under normal conditions of atmospheric travel, the FP is carried by the air currents, and losses due to gravitational settling are negligible.

FP is readily available and is manufactured to a high degree of uniformity. Tables 5-8 and 5-9 show good uniformity of size distribution and particle counts in the three batches which were blended into the lot used in Colombia.

The stability of ZnCdS has been investigated by Stanford Aerosol Laboratory¹ who report the following conclusions: (1) The rate of chemical reaction is surprisingly small in view of the finely divided nature of the material. It will continue to fluoresce after a two-hour exposure to the air

¹ Leighton, P. A., 1955, "The Stanford Fluorescent-Particle Tracer Technique", pp 153, Stanford University, Aerosol Laboratory.

TABLE 5-8

PARTICLE SIZE DISTRIBUTION OF ZINC CADMIUM SULFIDE
IN LOT USED IN COLOMBIA, 1962*

Particle Size Range (μ)	Percent of Particles in Each Size Range			
	Batch 49	Batch 50	Batch 51	Blend of Lot 15
0.00 - 0.47	1.07	0.29	0.48	0.29
0.47 - 0.66	1.46	1.47	0.97	0.88
0.66 - 0.93	3.11	3.13	2.71	1.66
0.93 - 1.32	5.83	5.67	4.93	3.03
1.32 - 1.87	19.05	11.73	14.89	16.24
1.87 - 2.64	35.38	36.36	32.11	31.90
2.64 - 3.73	27.31	33.63	34.72	35.03
3.73 - 5.27	5.25	6.55	7.64	9.20
5.27 - 7.45	1.55	1.17	1.55	1.76
* Based on a minimum of 1000 particles per sample.				

TABLE 5-9

NUMBER OF PARTICLES $\times 10^{10}$ PER GRAM OF ZINC CADMIUM
SULFIDE IN LOT USED IN COLOMBIA, 1962

Aliquot	Batch 49	Batch 50	Batch 51	Lot 15
1	1.40	1.20	1.27	1.44
2	1.31	1.11	1.12	1.27
Mean	1.35	1.16	1.19	1.35

at 450 C, and when immersed in concentrated hydrochloric acid the material is not completely destroyed until some eight hours have elapsed. (2) Under ordinary conditions of outdoor and laboratory exposure, less than 2 percent of the FPs are likely to lose their fluorescent properties. (3) Under many hours of exposure to bright sunshine at high temperature and humidity, the less resistant batches of material may lose up to 10 percent of the actively fluorescing particles originally present; (4) It is extremely unlikely that the fluorescent properties of the particles will be impaired by the presence of any atmospheric contaminants which do not also produce marked difficulty in breathing.

Finally, ZnCdS is effectively nontoxic under the conditions of use, and it poses neither fire nor explosion hazard during storage or dissemination.

5.4.1.1 Millipore Filter Samplers

The recorded data from these samplers were FP retained on the surfaces of the millipore filters through which the air had been drawn. The number of particles deposited depended on three main factors: (1) the concentration of particles in the atmosphere, (2) the flow rate through the filter, and (3) the length of time air was drawn through each filter. Variations in the latter two would affect the apparent concentrations.

The only difficulty encountered was in the synchronous motor-controlled timing switch which regulated a sequential program of exposure of the filter and the time duration of each exposure. Failure of this switch caused some filters to be exposed for longer than the programmed time and other filters to be unexposed at the end of the sampling period. Even so, a sufficient number of correctly exposed filters were obtained to provide a basis for a quick appraisal in the field of the success of the individual diffusion trials.

5.4.1.2 Rotorod Samplers

The data collected by the rotorod samplers consisted of FP embedded in silicone grease on the edges of each rotorod. Three factors could affect these data.

If the coating of the rotorods were poorly done, the assumption of a uniform collection efficiency would be in doubt. During this investigation, the rotorods were greased according to standard procedure. There was no way the rotorod greasing could be evaluated during the field studies, so no statement as to its effectiveness is possible at this time.

Secondly, each rotorod was specified to spin at 2400 ± 50 rmp; so a calculation could be made of the volume of air sampled. The speed of each rotorod was recorded prior to the start of trial #1, but neither time nor manpower permitted periodic rechecking or speed adjustment of the rotorods until all runs had been made. At that time the speed of each rotorod was again recorded. During trials a visual check was made to ensure that each sampler was rotating.

The third factor affecting rotorod reliability was the time period during which the rotorods rotated in each direction. These periods were controlled by the rotorod sequentializers and were accurate to within 1 to 2 min. for each half hour. The sequentializer at station 12 failed part way through the diffusion testing, but the operation was continued manually. It is suggested that manual switches be installed in parallel with all realys on the rotorod sequentializer.

5.4.2 Meteorological Sensors and Recorders

5.4.2.1 Lapse Rate System

Of all the equipment used during this investigation, the lapse rate system was the most reliable and produced the most dependable data. Two factors contributed markedly to this good operation:

1. Time-tested components were employed as much as possible, e.g. L. and N. multipoint recorder, heavy-duty thermocouple cable, single large capacity exhaustor, standard concentric chromium-plated radiation shields, and standard commercial constant-temperature baths.

2. Delivery of most of these components was made about one month prior to reshipment, permitting testing of the more critical components--the recorders and the constant temperature baths. Both recorders 'checked out', but both constant temperature baths developed troubles. Replacement parts were obtained, but in view of the possibility that further trouble might be encountered at the test site the thermocouple circuit was modified so as not to be dependent on the constant temperature bath. The circuit was changed so that the reference thermojunction for all thermocouples was located 6 ft below the ground surface (at a location where weekly temperature fluctuations were expected to be less than 1.0°C) and the 'constant temperature bath' controlled the temperature of only one thermojunction. The lack of a recorded base temperature was a drawback to the above technique, because the system calibration depended on the visual reading of a mercury thermometer. The thermometers used could be read to an accuracy of $\pm 0.5^{\circ}\text{F}$.

No trouble occurred with the thermocouple aspiration system.

The Leeds and Northrup recorders were satisfactory except for an expansion and contraction of the chart paper due apparently to humidity which caused a drifting of the zero point. This made an insignificant error in the lapse rate measurements.

Spurious recordings were introduced when extraneous signals were imposed on the thermocouple circuits. Pick-up from the communications radio transmitter caused a very erratic record. These short erroneous periods of data were by-passed when abstracting the records. The 'constant temperature' bath introduced spurious voltages due to the breakdown of the insulation in the stirring motor. This was overcome by potting the reference thermocouple in epoxy before putting it in the water bath. The Leeds and Northrup case and the common wire from the iron-copper thermojunction were grounded to stabilize the reference point. Examination of all the abstracted data indicates confidence to the nearest $\pm 0.1^{\circ}\text{C}$ in the sensitivity of the observations. Thus the above problem did not contribute a significant amount to the overall accuracy of the abstracted lapse rate data.

At a future installation it would be advisable to shield the thermocouple leads and to pot the underground thermocouples in epoxy instead of trusting tape and Glyptol, although no evidence existed of insulation breakdown at this point. The constant temperature baths were not reliable and should not be used in the future because of insulation breakdowns that produced an electrical shock hazard.

5.4.2.2 Wind Recording and Measuring Systems

The most difficulties and the poorest data occurred in this group of measurements.

Beckman and Whitley Wind Sensors

The B. and W. system at station 1 operated satisfactorily throughout the test period except for a short period of time when a transistor became loose in the wind speed transmitter. The B. and W. wind speed translator at station 12 ceased to operate just before the test period commenced and could not be repaired during this period due to a lack of time and replacement parts.

The E. A. recorders operated without fault for the entire test. The B. and W. electronic circuits are low-resistance circuits, so that recorder response was relatively slow, thus making adjustment of the calibration slow and less accurate than for a less damped recorder.

Gelman-Gill Anemometer Bivane

Several of the anemometer sections of the bivanes became inoperative or gave low level signals during the course of the tests. The primary causes of failure were:

1. Rapid deterioration of the voltage output from some of the photocells, causing weak pulses or no pulses to be recorded on the magnetic tape recorder.
2. Leakage currents developing between the photocell and the bivane proper (up to +18 volts), between the positive end of the chopper light and the bivane proper (up to +12 volts), and across terminals of the Cannon connectors.

The IRC type B2M photocell was selected because of its small size, adequate output, common use, and adaptability to a low resistance transistor circuit. It was expected to have a long stable life, but several units failed in the jungle environment after only a few hours of use.

The van portions of the bivanes appeared to operate satisfactorily when monitored during tests. However, inspection of the data after extraction from the magnetic tapes and computation by the analog computer indicates there were discrepancies. The +48 volts applied to the potentiometers in the bivane base varied by one to two volts during the course of a test. There was also a variation of up to 2 volts when the calibration resistors were switched in place of the bivane potentiometer.

The accumulation of rain or dew on the fins of the bivane tail caused it to droop and produce an erroneous elevation angle of 50° down. The fins were wiped to remove the moisture, but this was only a temporary solution if dew were forming or rain falling. In order to obtain some data, the bivanes were modified with locking screws to hold them in a horizontal position. No elevation data were available when the bivanes were locked horizontally, but azimuth angle and wind speed were still available.

An error can occur for wind speed measurements less than 0.5 mph, as the vane does not orient into the wind at this low speed. Occasionally, an anemometer propeller was observed to be running backward, during very low wind speeds. It is impossible to know when this type of error is present in the data.

Wind Monitor

In general, the wind monitor operated as desired although at times the switch contacts were poor at station 1. As there were direct connections between inputs and outputs on the chassis, the poor contacts could not affect the signal going to the tape recorder.

Pemco Tape Recorders

The most serious discrepancies in the data were due to a complete lack of signal coming from the tape recorder playback for several channels, and a lack of linearity in calibration signals.

At the test site in Colombia, the tape recorders were calibrated for center frequency and 40 percent modulation before and after diffusion testing. The tape transport mechanism of the tape recorder at station 1 failed during trial #13 but the frequency modulation units were still operating, so they could be checked. The frequency calibration of the recorder at station 12 was checked and readjusted between the diffusion-testing and the 72-hour meteorological data test. Tables 5-10 and 5-11 show the frequencies produced by the FM units when zero volt or full-scale voltages were applied to the FM inputs. Changes of the frequency response are apparent between the March and April values, but in all cases there is a frequency change when the input voltage changes. As each day's record contained calibration signals, the long-term drift of frequency response should not have caused serious errors in the output data and definitely cannot be the cause of missing data. If the frequency calibration changed during a test errors would be introduced. No data are available to determine short-term frequency variations, although the frequencies remained constant during calibration periods lasting up to a half hour.

During a test, the analog voltage going to the tape recorder was monitored every 30 min and the proper voltage was present or a note of the discrepancy was made on the technical log sheet. However, no data were recovered later from several of the tape recorder channels where a good analog voltage was present during recording. This is attributed to a failure in the tape recorder. However, its reliability could not be checked at the test site, because there was no playback equipment available at that location. By the time the lack of data was discovered during analysis, the bivanes and tape recorders were unavailable for investigation and nothing can be said concerning the cause of these missing data. It is highly recommended that concurrent playback and display equipment be available on any tape recorder used in the future so that each channel of the tape record can be monitored periodically during test operations.

In Colombia, the bivane calibration signals were supposedly a constant DC voltage recorded for 10 min by the tape recorder. During playback, the calibration signals drifted and caused considerable trouble to the data analyst. Also, the bivanes in the jungle were constrained to elevation angles between 50° up and 50° down from the horizontal. Yet during tape analysis, elevation angles outside of these values were observed, and therefore indicate erroneous data.

TABLE 5-10

FREQUENCY RESPONSE OF PEMCO FM UNITS TO ZERO AND FULL-SCALE VOLTAGE INPUTS, BEFORE AND AFTER DIFFUSION TESTING, STATION 1

Track	Station 1			
	7 March 1962 40% Modulation		15 April 1962 40% Modulation	
1	Center Freq	1182	Center Freq	2723
2	844	1186	893	1282
3	842	1180	893	1225
4	847	1181	844	2923
5	844	1182	913	1223
6	846	1185	907	996
7	843	1181	903	2491
8	844	1182	904	1259
9	847	1180	904	982
10	842	1180	904	1614
11	843	1181	908	1294
12	845	1182	902	1022
13	842	1180	508	1261
14	843	1179	906	1240

TABLE 5-11
 FREQUENCY RESPONSE OF PEMCO FM UNITS TO ZERO AND FULL-SCALE
 VOLTAGE INPUTS, BEFORE AND AFTER DIFFUSION TESTING, STATION 12

Station 12			
Track	8 and 10 March 1962 Center Freq 40% Modulation	15 April 1962 Center Freq 40% Modulation	
1	842 1189	898 2425	
2	850 1185	890 2548	
3	848 1178	900 981	
4	848 1180	897 1203	
5	846 1178	909 1440	
6	847 1190	897 1008	
7	847 1184	897 1228	
8	844 1185	904 1450	
9	848 1184	900 981	
10	847 1186	897 1258	
11	850 1181	912 2480	
12	848 1186	897 1262	
13	848 1184	898 1292	
14	844 1192	914 1387	

The above two discrepancies could be caused by the voltage not remaining constant in the vane section of the bivane electronics, or by the tape recorder speed varying due to voltage and frequency variations in the electrical generators used in the jungle. A power supply of the same construction as the one used with the anemometer bivane was used for many months at New Albany, Indiana, with no detectable voltage variations. The jungle heat and humidity may have caused component changes that affected voltage regulation. Pemco stated that a small frequency variation in the input electrical power can cause a much larger variation in the frequency recorded on the tape. An investigation with a bivane, its electronic circuit, and a tape recorder with playback and display equipment would be required to discover the cause of the above errors, and this equipment was not available after the troubles had become apparent.

5.4.3 Anemometer Test Facility

Despite its crude appearance, the anemometer test facility did fulfill its mission. The feet of air passage per revolution of the propeller was a parameter that could be determined accurately. This ratio came directly from counting the anemometer pulses and the drive-cable pulley pulses for the same length of record on an E. A. chart so that no approximations were necessary. The lack of response of the E. A. recorder to higher frequencies was a limitation because it placed a very low upper limit to the "air speed" for which a calibration could be obtained. This limitation could be easily overcome in future operations by putting a one-slot light chopper in place of the five-slot chopper used on the anemometer bivanes or by putting a decade frequency divider between the pulse generator and the E. A. recorder. Another method for obtaining data would be to use an electronic events counter in place of the E. A. recorder. The test facility was run at considerably higher speeds than could be followed by the E. A. recorder pen and operated well, so the recorder was the only limitation to higher speed calibration.

Original plans called for testing the calibration of anemometer systems between every two runs, but the making of diffusion tests every available day prevented the accomplishment of this schedule, and calibration was obtained only before and after the diffusion testing. The results for all bivane anemometers were similar and are averaged together to produce the curve shown in Figure 5-23.

5.4.4 Non-Linear Response of Anemometer Propeller to Very Low Wind Speeds

Figures 5-23 and 5-24 show that the anemometer propeller had a threshold velocity of about .22 ft/sec. From this threshold up to about 3.0 ft/sec the propeller pulses per foot of air passage depend on the air velocity. For velocities greater than 3.0 ft/sec the propeller response is constant at 4.8 pulses per foot of air. In the analog computer analysis of the bivane data, it was necessary to set in a conversion factor between propeller pulses and the feet of air passing the propeller. To achieve the best accuracy, the average value of 4.0 pulses per foot of wind was used for the lower three bivanes (levels a, c, and d), where the wind speeds were very low, and the value of 4.8 pulses per foot of wind was used for the bivane at level f, where the wind velocity was consistently much higher. While this procedure introduces as much as 20 percent error in the extreme cases, the error should be much less for most of the data. If, as an alternative procedure, 4.0 or 4.8 pulses per foot of wind had been used for all calculations, the maximum error could have been as large as 50 percent.

SECTION 6

MACHINE PROCESSING OF ANEMOMETER-BIVANE DATA

The field operations produced wind vane and anemometer-bivane data recorded on magnetic tape. These data were reduced using the facility at The University of Michigan Willow Run Analog Computer Laboratory (See Figure 6-1).

6.1 OBJECTIVES

The objectives of the bivane analysis were to obtain the mean and standard deviation of the three wind components in rectangular coordinates at each bivane location. For the B. and W. sensor only the mean and standard deviation of the azimuth were to be computed.

The relations between coordinate systems are shown in Figure 6-2. The bivane data were presented in spherical coordinates: azimuth, θ ; elevation, ϕ ; and total wind speed, U . The resolved vector yields the three components u , v , and w . Means and standard deviations were calculated using 5-minute (real time) moving averages. The choice of a five-minute averaging time is related to what was to be the scale of turbulence expected above and below the forest canopy. Effectively a five minute average is looking at eddy sizes of about 4000 feet above the canopy where the mean wind was shown to be about 13.5 ft/sec decreasing to eddy sizes of about 40 feet at the lowest levels below the canopy where mean speeds are about .13 ft/sec. (See Part II, Vol II of this report).

Commencing with Trial #5, the means and standard deviations were further averaged over 30 minutes in real time.

Note that since all of the computer work was done in compressed time, 1:64, the 5-min. mean corresponds to 4.68 sec and 30-minute mean to 28.1 sec in compressed time.

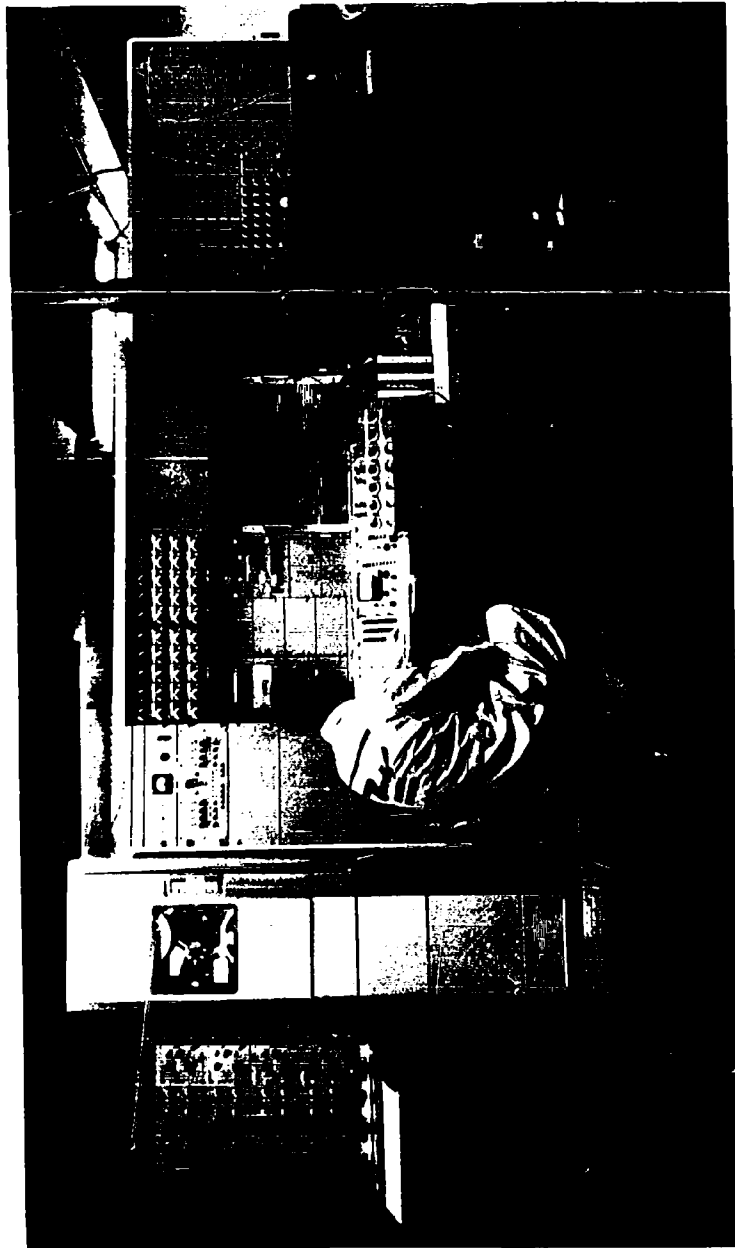


Figure 6-1 Analog Computer Facility Used for Wind Data Reduction

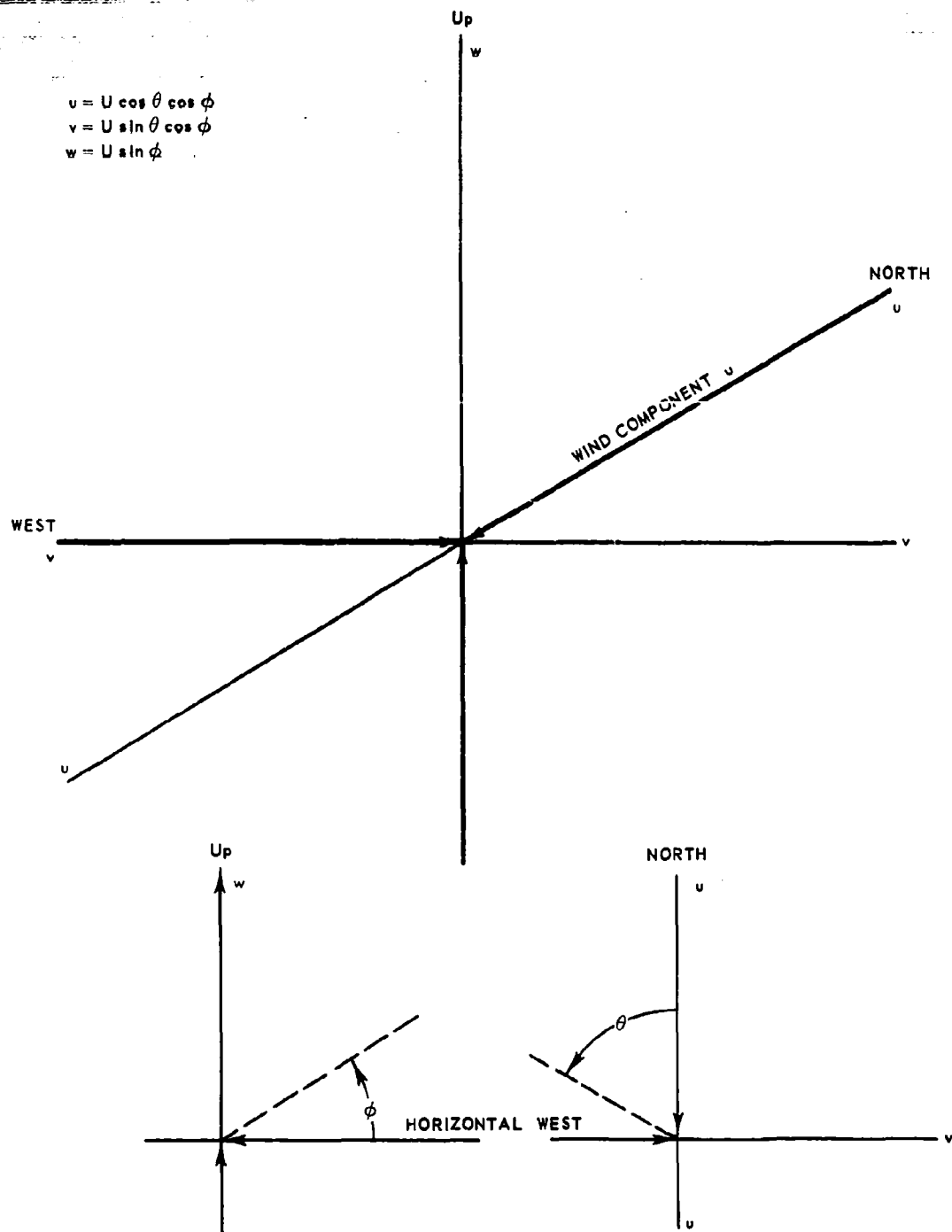


Figure 6-2 Coordinate System Used in Reduction of the Wind Vector

6.2 COMPUTER CIRCUITRY

The computational procedure was based upon the work by Brock and Provine¹ utilizing an electronic analog computer of the Analog Computer Laboratory at Willow Run.

The computational procedure may be conveniently divided into six parts: signal conditioning, vector resolution, mean value, standard deviation, final mean value, and the sample and hold circuits. These circuits cover all of the steps from accepting the tape reproduce unit output to producing the final averaged means and standard deviations.

6.2.1 Signal Conditioning

The Computer received from the magnetic tape playback essentially the instantaneous wind vector i. e. direction angles (azimuth and elevation angles), and the magnitude (speed). The azimuth and elevation signals received from the magnetic tape reproduce unit were analog voltages in the range $+e_1 \leq (\theta, \phi) \leq +e_2$, where $+e_1$ was typically about 1.0 volt and $+e_2$ was about 4.0 volts ranging up to about 6.5 volts. There was considerable noise in the signal, ranging up to 10 percent of the full-scale signal amplitude, $e_2 - e_1$. The signal conditioning circuits applied bias and amplified these signals to ± 90 volts for the azimuth and ± 50 volts for the elevation. This conversion is shown schematically in Figure 6-3. Also, the conditioning circuits filtered out most of the noise. The gain and bias settings for azimuth and elevation had to be reset for each bivariate for each run since the signal level and range varied from run to run.

Signal conditioning of the speed included demodulation of the pulse frequency signal. The pulse-to-DC converter accepted pulses of almost any wave form above some minimum amplitude and converted them to an analog voltage. A low pass filter was required to suppress the noise below the critical amplitude. The converter output was amplified, corrected for a nonlinear calibration, and filtered again to remove more noise.

¹Brock, F. V., and D. J. Provine, 1962. A Standard Deviation Computer. Journal of Applied Meteorology 1(1).

Angle	Bivane	Computer
+ 180	+ e ₄	+ 90 V
Azimuth	V _A	θ
- 180	+ e ₃	- 90 V
+ 50	+ e ₂	+ 50 V
Elevation	V _E	φ
- 50	+ e ₁	- 50 V
$\theta = GA (V_A - B_A)$ $\phi = GE (V_E - B_E)$ $B_A = \frac{e_3 - e_4}{2} + e_3$ $B_E = \frac{e_2 - e_1}{2} + e_1$ $B = \text{Bias Voltage}$ $G = \text{Gain}$ $GA = \frac{180}{e_4 - e_3}$ $GE = \frac{100}{e_2 - e_1}$		

Figure 6-3 Transformation from Magnetic Tape Playback Unit Output to Computer Variables.

The signal conditioning circuits are shown to the left of the dotted line in Figure 6-4. The points marked "AZ," "EL," and "SP" are the entry points for the signals from the tape playback unit. The outputs are the signals θ , ϕ , and U which represent the three-dimensional wind vector. The component complement was 6 amplifiers, one function generator, and one pulse demodulator.

6.2.2 Vector Resolution

The instantaneous wind vector is resolved into its three orthogonal components using the resolution circuit shown in the right half of Figure 6-4. This circuit resolves the wind vector (θ , ϕ , U) into its components (u , v , w). The circuit was built up of diode function generators and diode multipliers to operate at the necessary high frequencies. The voltage range of the components was $-100 \leq u, v, w \leq +100$ volts. The component complement was 16 amplifiers, 6 function generators, and 5 multipliers.

6.2.3 Mean Value

The mean value circuits comprised three independent circuits which computed running means of the vector components u , v , and w . It was discovered early in the computation that it was convenient to introduce a gain of 2 in these circuits. This raised the output voltage level which improved the accuracy without causing overload (voltage in excess of ± 100 volts). Switches were included to enable computation of the mean of the original vector (θ , ϕ , U). This was a convenience in troubleshooting and was necessary for computation of the mean of θ when the B. and W. was analyzed. Nine amplifiers were used.

6.2.4 Standard Deviation

Three independent standard deviation circuits were used to obtain the standard deviation of u , v , and w . These circuits used the approximation given in Brock and Provine, viz. to a good approximation, the standard deviation is equal to 1.25 times the mean absolute deviation. The factor 1.25 was incorporated in the circuits as well as a gain of 4 to improve accuracy and resolution. Both the mean and the standard deviation circuits, shown in Figure 6-5 used a 5-min. mean in real time (4.68 sec in compressed time). The component complement was 21 amplifiers.

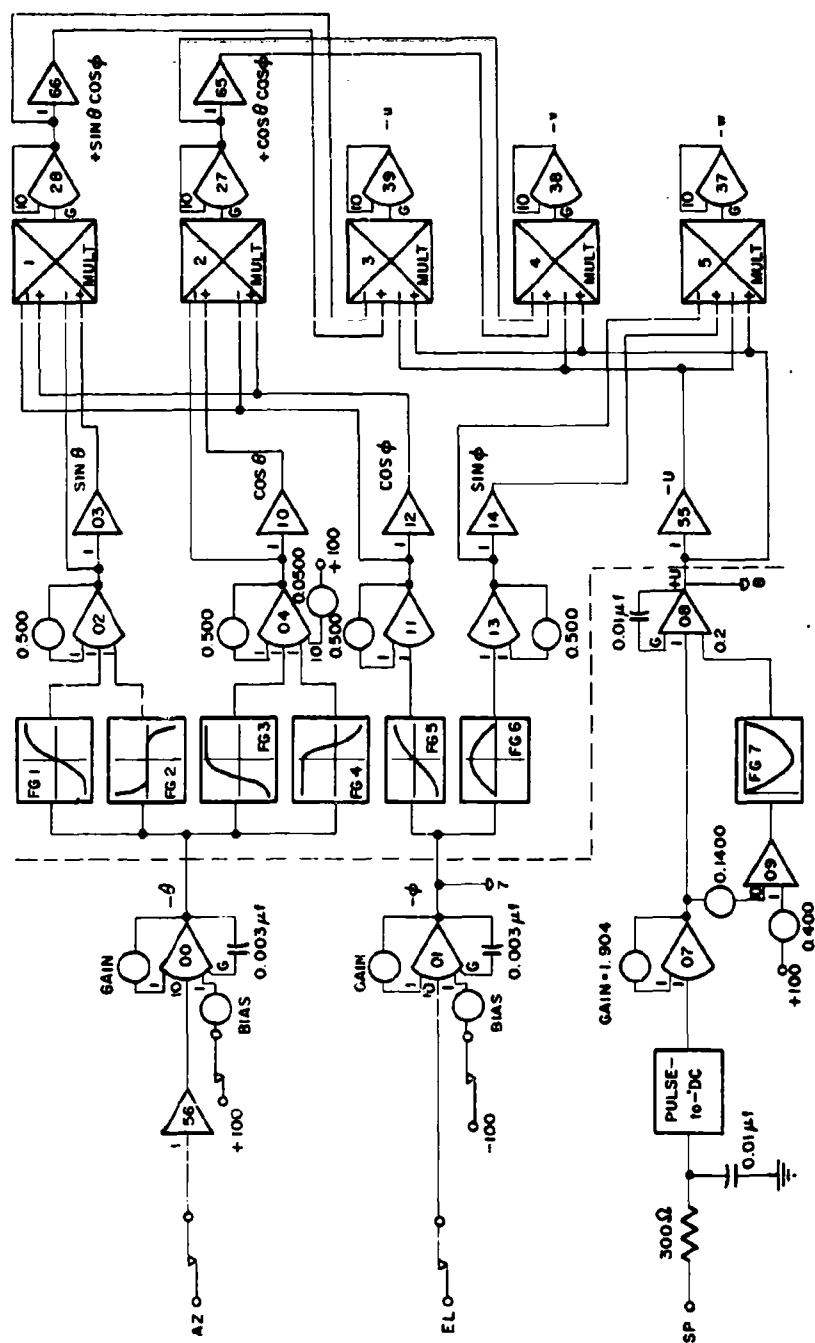


Figure 6-4 Computer Circuits: Signal Conditioning and Vector Resolution

6.2.5 Final Mean Value

The quantities $\bar{u}$, $\bar{v}$, $\bar{w}$, σ_u , σ_v , and σ_w were further averaged over 30 minutes in real time (28.1 sec in compressed time). The six parallel circuits which accomplished this are shown in the left of Figure 6-6. These circuits are similar to the previous mean value circuits and used a total of 18 amplifiers.

6.2.6 Sample and Hold

A sample and hold circuit was implemented to sample the output of the final mean value circuits ($\bar{u}$, $\bar{v}$, $\bar{w}$, σ_u , σ_v , σ_w) every 30 minutes (real time) and hold these values until they could be converted to digital signals and printed out. There is a time delay involved in computing means and standard deviations which amounted to a total of 17.34 sec (compressed time) for $\bar{u}$, $\bar{v}$, and $\bar{w}$, and 19.69 sec for σ_u , σ_v , and σ_w . The procedure was to initiate a timing sequence when the magnetic tape playback unit started. The timing sequence waited 30 sec (compressed time) for the means and standard deviations to settle down after the start of the tape and the calibration sequence plus an additional 17.34 sec before initiating a hold on $\bar{u}$, $\bar{v}$, and $\bar{w}$. The first hold on σ_u , σ_v , and σ_w was initiated 2.35 sec later, and these holds were repeated every 28.1 sec thereafter until the end of the tape. Each hold lasted 14 sec during which the values held were digitalized and printed out under manual control. Then the sample and hold units were returned to track for 14.1 sec when the next hold cycle was started. The sample and hold integrators are shown in the center of Figure 6-6. These units operate in two modes called track and hold. In track they simply follow the input and when the hold is initiated they retain the last value of their input until returned to track. The sample and hold control circuit is shown on the right of Figure 6-6. This circuit generates the timing sequence and the control signals. The equipment complements was 13 amplifiers, one digital volt meter, and one printer.

In all 83 amplifiers, 7 function generators, and 11 other instruments were simultaneously employed in this machine reduction of the anemometer-bivane data.

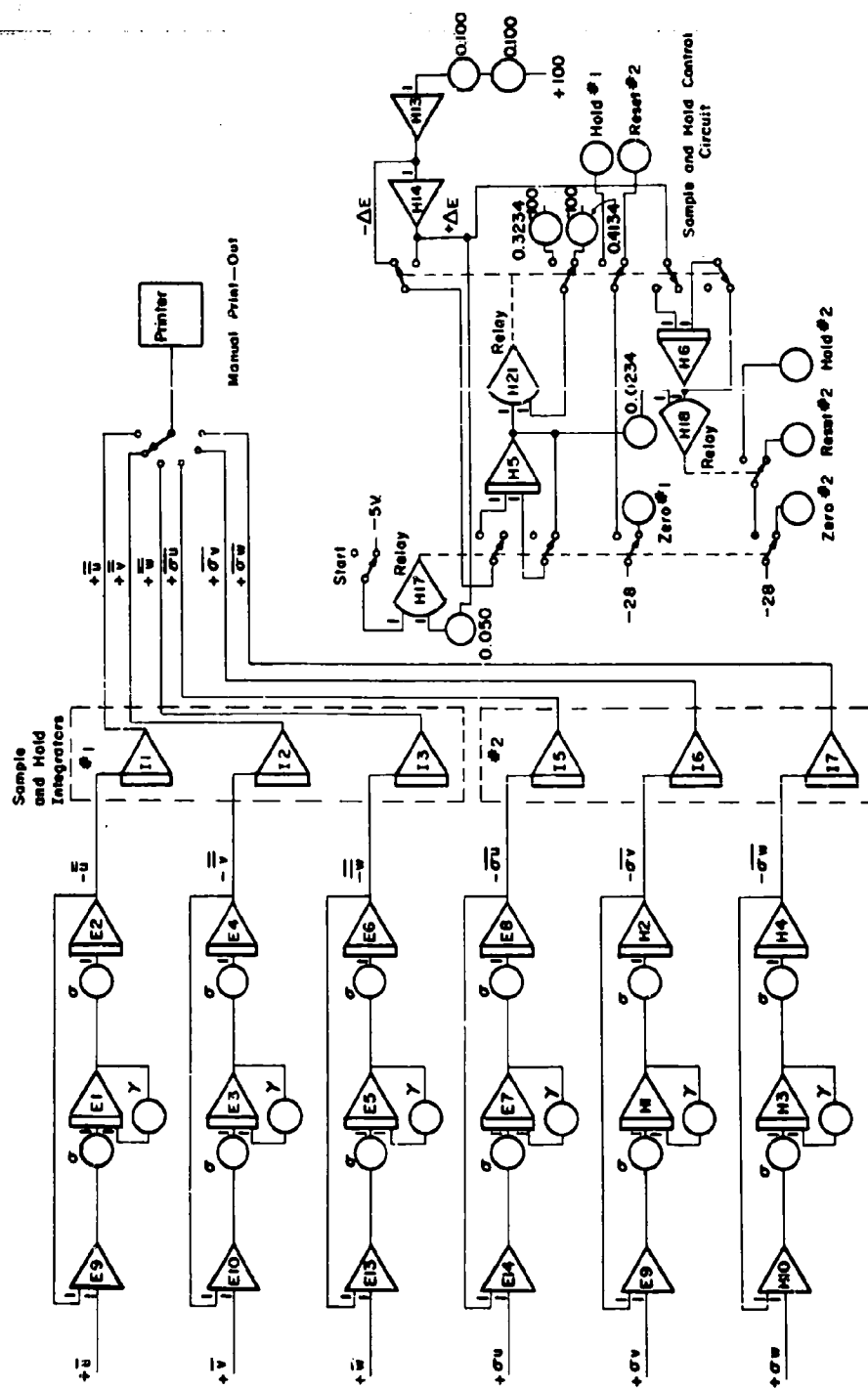


Figure 6-6 Computer Circuits: Final Averaging and Sample

6.2.7 Output Recording

Three recording media were used: analog recording on chart paper and on magnetic tape, and digital recording on paper tape. The digital recording has been described in the previous section. Its output, for bivariate analysis, was $2\bar{u}$, $2\bar{v}$, $2\bar{w}$, $4\sigma_u$, $4\sigma_v$, and $4\sigma_w$ in terms of computer variables. Each of these must subsequently be multiplied by a scale factor to convert from volts to feet per second. For B. and W. analysis, the output was $\bar{\theta}$ and σ_θ .

An 8-channel Sanborn recorder was used to give a continuous record of the computer output. The format is given in Table 6-1. These values were subsequently abstracted and multiplied by a scale factor. The digital recording, when used (Trial #5 and thereafter) largely eliminates the need for abstracting from the chart record.

TABLE 6-1

FORMAT USED IN RECORDING ON THE 8-CHANNEL SANBORN RECORDER

Instrument	Channel No.							
	1	2	3	4	5	6	7	8
Bivariate	$2\bar{u}$	$4\sigma_u$	$2\bar{v}$	$4\sigma_v$	$2\bar{w}$	$4\sigma_w$	$-\phi$	$+U$
B & W	$\bar{\theta}$	-	-	-	θ	σ_θ	-	-

Analog recording on magnetic tape was used for the 72-hr. run only. The parameters $2\bar{u}$, $2\bar{v}$, $2\bar{w}$, $4\sigma_u$, $4\sigma_v$, and $4\sigma_w$ were recorded.

6.3 RESULTS

The output voltage from the tapes recorded in the field was related by a constant but unknown factor to the input voltage. This was not a severe handicap as the calibration voltages at the beginning of each tape were read to establish needed bias and gain. A measure of the extreme variability of these voltage levels is afforded by the range of values for bias and gain. For the azimuth the ranges were:

$$35 \leq \text{GAIN} \leq 190$$

$$0.55 \leq \text{BIAS} \leq 3.90 \text{ volts}$$

and for the elevation angles the ranges were:

$$25 \leq \text{GAIN} \leq 237$$

$$0.68 \leq \text{BIAS} \leq 3.30 \text{ volts}$$

These values had to be ascertained for each bivane at the beginning of each run and the corresponding computer potentiometers set. No trend or pattern was ever detected that permitted a short-cut or speed-up of the procedure.

All data were processed except those for instruments which were stated to be inoperative in the log, or for which no signal appeared on the tape. Starting with Trial #7 some tracks of the tapes were observed to be blank or to contain no usable signal. In all cases where this was observed, no comment appeared in the log to indicate the presence of trouble. About 194 hours (15 percent) of the bivane data were in this category, plus 102 hours (31 percent) of the B. and W. data.

Table 6-2 indicates that a total of 894 bivane hours (67 percent) and 250 B. and W. hours (75.3 percent) were processed.

Not all of the data processed were complete. There were 268 bivane hours where either azimuth or elevation was missing.

TABLE 6-2
SURVEY OF DATA PROCESSED

<u>Bivane Level</u>					
Trial	A	C	D	F	B & W
01 N	X	X	X	X	X
01 S	X	X	X	X	X
02 N	X	X	X	X	X
02 S	NO	EL	EL	X	X
03 N	X	X	X	X	X
03 S	X	EL	IO	EL	X
04 N	IO	CAL	NO	X	X
04 S	X	X	X	X	X
05 N	X	X	X	X	X
05 S	NO	X	X	X	X
06 N	IO	IO	X	X	X
06 S	NO	X	X	EL	X
07 N	IO	IO	NO	AZ	X
07 S	NO	X	X	EL	X
08 N	IO	NO	NO	NO	X
08 S	IO	NO	X	X	X
09 N	IO	IO	NO	AZ	X
09 S	IO	NO	EL	EL	X
10 N	IO	IO	IO	NO	X
10 S	IO	NO	NO	X	X
11 N	IO	IO	NO	NO	NO
11 S	IO	NO	X	X	X
12 N	IO	NO	NO	NO	NO
12 S	X	NO	NO	X	X
13 N	IO	IO	NO	NO	NO
13 S	IO	NO	X	X	X
72-Hour Run by Reels (1-6)					
1	X	AZ	EL	AZ	NO
2	X	AZ	EL	AZ	NO
3	EL	AZ	NO	NO	NO
4	X	AZ	AZ	AZ	NO
5	AZ	AZ	AZ	AZ	NO
6	AZ	AZ	AZ	AZ	NO
Legend: X - data completely processed IO - data stated to be inoperative and not processed CAL - no calibration, data not processed NO - no usable signal on tape AZ - no usable azimuth signal, elevation and speed processed EL - no usable elevation signal, azimuth and speed processed					

By far the greatest source of error in the data reduction was in the process of evaluating the calibration signals. These were probably accurate to within 1 percent. This does not necessarily mean that the results are good to 1 percent. Observation of the data seems to indicate that the calibration values, did drift during a run. Thus it would seem that the results may have errors ranging typically from 1 to 10 percent and in isolated cases may be wholly erroneous. In most cases inspection of the Sanborn recorder charts of the results established which data should be ignored.

AD	THE BENDIX CORPORATION BENDIX SYSTEMS DIVISION ANN ARBOR, MICHIGAN LOGISTICS, INSTRUMENTATION, AND DATA PROCESSING, January 1963. 140 pp. incl. illus. (Jungle Canopy Penetration Final Report, Vol. III, Contract No. DA-42-007-530) Unclassified Report. The Jungle Canopy Penetration study had as its primary objective, the investigation of the ventilation processes of the rainforest. The results of this phase of the study are given in Volume I of this report. Subsidiary investigations of the vegetation and the meteorology of the site are reported in Volume II. This volume presents a detailed account of the many preliminary activities and support functions that were an essential part of the data acquisition and their eventual interpretation. Subjects dealt with include the selection of a study site, preparations for going into the field, logistics in the field, erecting the test facility and field procedures. Also included is a description of the instrumentation including an anemometer binnacle of original design, and an account of analog-computer processing of wind records.	UNCLASSIFIED	AD	THE BENDIX CORPORATION BENDIX SYSTEMS DIVISION ANN ARBOR, MICHIGAN LOGISTICS, INSTRUMENTATION, AND DATA PROCESSING, January 1963. 140 pp. incl. illus. (Jungle Canopy Penetration Final Report, Vol. III, Contract No. DA-42-007-530) Unclassified Report. The Jungle Canopy Penetration study had as its primary objective, the investigation of the ventilation processes of the rainforest. The results of this phase of the study are given in Volume I of this report. Subsidiary investigations of the vegetation and the meteorology of the site are reported in Volume II. This volume presents a detailed account of the many preliminary activities and support functions that were an essential part of the data acquisition and their eventual interpretation. Subjects dealt with include the selection of a study site, preparations for going into the field, logistics in the field, erecting the test facility and field procedures. Also included is a description of the instrumentation including an anemometer binnacle of original design, and an account of analog-computer processing of wind records.	UNCLASSIFIED	UNCLASSIFIED
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