
FILE M
PROJECT MOGUL

<u>TITLE</u>	<u>TAB</u>
MEMO, CAPT TRAKOWSKI TO COL DUFFY, REVIEW OF PROJECTS MX 968 AND MOGUL, 10 DEC 1948	M 1
CORRESPONDENCE FROM/TO WOODS HOLE OCEANOGRAPHIC INSTITUTION REGARDING MOGUL	M 2
ASSORTED MOGUL PAPERS	M 3
CORRESPONDENCE REGARDING THE RELIEF OF MAJ ROBERT CRANE	M 4
MOGUL- ALASKA OPERATIONS	M 5
REVIEW OF AMC GEOPHYSICAL ACTIVITIES BY B/G D. N. YATES, AND STAFF, OF THE AIR WEATHER SERVICE, 10 FEB 1949	M 6
CONTRACT STATUS REPORT, GEOPHYSICAL RESEARCH DIRECTORATE, CAMBRIDGE FIELD STATION	M 7
CONTRACT STATUS REPORT, WATSON LAB, CAMBRIDGE FIELD STATION, GEOPHYSICAL DIRECTORATE	M 8
EMPTY	M 9
TRANSCRIPTION OF A.P. CRARY'S DIARY	M 10

TITLE

TAB

JOURNAL OF A.P. CRARY, APRIL 1946 - FEB
1948

M 11

LETTER, COL DUFFY TO COMMANDING
GENERAL ARMY AIR FORCES, REQUEST FOR
ENROUTE WEATHER ANALYSES, 8 MAY 1946

M 12

MEMO, WEATHER RESEARCH
ORGANIZATION, 24 JAN 47

M 13

MOGUL FILES- C/O PROF MOORE

M 14

OPERATION FITZWILLIAM

M 15

FINAL REPORT, ACOUSTIC DETECTION IN
THE TROPOPAUSE FOR SANDSTONE
NUCLEAR TEST, WRITTEN BY PEOPLES AND
CRARY

M 16

FINAL REPORT ON PROJECT BIRTHROOT

M 17

HEADQUARTERS FITZWILLIAM FORWARD
c/o Commander, Task Group 7.2
APO 187, c/o Postmaster
San Francisco, Calif.

17 May 1948

SONIC BALLOON TEST. KWAJALEIN

Inclosure G to FITZWILLIAM FORWARD Report

The Watson Laboratories of Air Materiel Command arranged for one (1) of its sonic balloon teams to participate in the FITZWILLIAM project as a mobile team to operate in the Central Pacific, at KWAJALEIN, GUAM and HICKAM FIELD, HAWAII, in that order, changing location for each of the three (3) explosions.

The purpose of this exploratory test was as follows: first, to determine if an atomic explosion's compressional waves are generated in the sound channel existing between 50,000 and 70,000 feet (such waves would conceivably travel unimpeded for long distances in this channel without touching the earth's surface); second, to determine whether a sound pick-up unit suspended from a floating balloon could detect compressional waves (possibly undetected by similar sound units at the earth's surface) by virtue of the decreased background noise in the high-level sound channel.

Balloons were made of high grade plastic, were of tear-drop shape, and were twenty-five (25) feet at their largest sea-level diameter. The sonic unit was a combination microphone-transmitter which was suspended from the balloon and picked up sound waves, transmitting them to a ground directional antenna connected to a radiosonde receiver (standard SCR 658 air weather radio receiver). The transmitted sound impulses were recorded on two (2) Esterline-Angus recorders.

A dribble constructed of a five (5) gallon tin incorporating a metered jet to allow a predetermined spillage rate of high grade kerosene-ethylene-glycol mixture was attached to the balloon. This was designed to counteract the helium gas seepage thru the surface pores of the plastic balloon. This metered loss of ballast and controlled the rising rate of the balloon at 500 to 600 feet a minute.

Ground sonic equipment consisted of World War II sound ranging devices utilized to pick up sound waves from an explosion traveling along the earth's surface.

A radio receiver was used to obtain explosion time notification code signals from the ENIWETOK radio station.

The balloon launching site had to have a down-wind clearance of about 1000 feet to lay out the 100 foot risers and cables to which were attached the microphone-transmitter and dribbler units. Also the site had to be sheltered from the wind to prevent damage to the balloon while it was being

B-17 CREW

1st Lieutenant Owen B. Dubell
1st Lieutenant Thomas F. Carroll
1st Lieutenant John Mertzen
Sergeant W. R. Rice

Pilot
Co-Pilot
Navigator
Engineer

Time notification signals were required and provided in order to afford sufficient time to make necessary launching preparations, and to position the balloons just a few minutes prior to the predetermined arrival of the explosion sound wave. Headquarters FITZWILLIAM FORWARD furnished ARPACAS 3-1 and 3-2 by officer courier. The team experienced no difficulty in obtaining the time signals.

Reports required of the team were a brief statement as to positive or negative results of the tests, and notification of team movement to its several locations. Reports of results were made to Headquarters FITZWILLIAM FORWARD and to AFMSW-1.

Results of the KWAJALEIN test were as follows: balloon-borne equipment results were positive and ground equipment results were questionable. An accurate final analysis and evaluation report will be submitted upon Dr. Crary's return to Watson Laboratories, including an accurate determination of results.

Due to time limitation and pending a thorough evaluation of results, the following recommendations, of necessity, should be considered tentative:

1. Before departing for field locations, a survey should be made to determine the best balloon launching sites, giving due consideration to shelter from high velocity and gusty winds, and sufficient clear space to lay-out shroud lines and control cables thus affording clear passage of the instruments which are suspended about one hundred (100) feet below the balloon.

2. That an SCR 658, radiosonde receiver be included in the team equipment list. For these tests, a receiver had to be borrowed from the air weather station at each location. This presented a problem because each station had only one (1) receiver and it was needed by the station personnel for upper air sounding operations. This necessitated selecting the best possible launching site adjacent to the weather station. Also, this precluded selection of a site without a weather station.

inflated. At KWAJALEIN a wind-break was constructed through the courtesy of the island commander, Captain Vest, USN. At a predetermined time, the balloon was inflated with a fixed amount of helium gas to raise it to an altitude of from 50,000 to 60,000 feet where it floated at a constant level. The balloon was cautiously launched and guided until it cleared all ground obstacles. Electrical power for the microphone-transmitter was provided through wet-cell batteries, especially constructed to prevent freezing. The balloon was tracked visually by use of theodolites. Prior to the actual test on KWAJALEIN on X-day (15 April 1948) two (2) practice runs were made to minimize chance of failure and to improve operating techniques.

The transportation requirement was for air lift to transport the team of six (6) scientists and twelve (12) thousand pounds of equipment from BELMAR, NEW JERSEY to KWAJALEIN, GUAM, HAWAII and then back to BELMAR, NEW JERSEY. The Air Materiel Command provided three (3) aircraft, a C-54, a B-29, and a B-17, and crews, under the direction of Captain Stanley C. Lewis, from the 4149th AFBU, MIDDLETOWN, PENNSYLVANIA. The C-54 was also utilized in carrying Tracerlab personnel and equipment to KWAJALEIN and GUAM. Maintenance assistance was afforded by the local base and tactical organizations.

The mobile team personnel was assembled and partially trained at Watson Laboratories. The team arrived at KWAJALEIN 31 March 1948; departed for NORTH FIELD, GUAM, on 16 April 1948; for HICKAM FIELD on 3 May 1948; and was scheduled to depart from HAWAII for its home station on Z plus one (1) day.

The balloon team and aircraft crew personnel were as follows:

BALLOON TEAM:

Dr. Albert P. Crary	"Q" clearance	Physicist
Mr. Charles S. Schneider	"Q" clearance	Meteorological Engineer
Mr. John W. Alden	"P" clearance	Radio Engineer
Mr. John A. Moulden	"P" clearance	Radio Repairman
Mr. Murry Hackman	"P" clearance	Meteorological Engineer
Mr. James Smith	"P" clearance	Meteorological Engineer

B-29 CREW

Captain Stanley C. Lewis	Pilot (Flight Commander)
1st Lieutenant Randall S. Kane	Co-Pilot
1st Lieutenant Wm. L. Adams	Navigator
M/Sergeant W. L. Halliday	Engineer
M/Sergeant R. A. Kabaste	Radio Operator
T/Sergeant R. A. Cox	Ass't Radio Operator
T/Sergeant L. D. Moon	Ass't Engineer

C-54 CREW

Captain John P. Clowry	Pilot
1st Lieutenant Richard Mesher	Co-Pilot
1st Lieutenant Chas. A. Lamana	Navigator
S/Sergeant James Brau	Engineer
S/Sergeant L. H. Campbell	Radio Operator
Sergeant George L. Fretwell	Ass't Engineer

Excluded from General Declassification Schedule

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SECURITY INFORMATION

~~SECRET~~
AUTH CS USAF

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EO 11652

8 Nov 1990

Report

of

Operation FITZWILLIAM

Vol. I

Introduction

Copy No. 17

DESIGN OF OPERATION
AND
SUMMARY OF RESULTS

UNITED STATES AIR FORCE

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SECURITY INFORMATION

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I. INTRODUCTION

A. Object.

The object of Operation FITZWILLIAM was to obtain from the atomic weapons tests at Eniwetok in the Spring of 1948 the maximum amount of scientific data and the maximum testing of all available equipment and methods bearing on the detection of an atomic explosion at long ranges.

B. Authority.

By memorandum dated 16 September 1947 from the Chief of Staff, U. S. Army, the Commanding General, Army Air Forces, was charged with the overall responsibility for detecting atomic explosions anywhere in the world, which included the collection, analysis and evaluation of the required scientific data and the appropriate dissemination of the resulting intelligence. The Commanding General, Army Air Forces, was directed, in carrying out this responsibility, to utilize to the maximum existing personnel and facilities, both within and without the War Department; to establish appropriate arrangements with other interested agencies for necessary assistance; and to effect and maintain liaison with all participating organizations.

In a memorandum dated 9 December 1947 to the Secretary of the Air Force, the Secretary of National Defense emphasized that "it is essential that methods be pursued with full vigor on the detection of atomic explosions, and tried out at the time of the next test in the Pacific".

C. Background.

On 14 March 1947 the Director of Central Intelligence addressed a letter to the Departments of the Army and Navy, the Atomic Energy Commission, and the Joint Research and Development Board, in which he stated that "there exists an urgent and high priority, in the interests of national intelligence, for the development and coordinated employment of equipment capable of locating and measuring foreign experiments of large scale nuclear explosions or other detectable activities in the nuclear field". As a result of this letter, a Committee on Long Range Detection of Atomic Explosions was formed, composed of representatives of the Army, Navy, Army Air Forces, Atomic Energy Commission, Research and Development Board, Armed Forces Special Weapons Project, and Central Intelligence Group, to survey the entire problem, and to make recommendations for its solution.

The Committee on Long Range Detection of Atomic Explosions concluded that:

a. The instruments and methods needed are available, actually or potentially, and possess adequate sensitivity.

b. The problem could be solved by:

- (1) Locating large explosions by a combination of sonic, sub-sonic and seismographic methods.
- (2) Obtaining samples of the explosion products by an aerial sampling technique as near the scene of the explosion as practical.
- (3) Determining the atomic nature of the products of the explosion by radioassays and radiochemical analyses.

c. The Army Air Forces should be assigned the overall titular responsibility for long range detection provided that, in the analysis and evaluation, the Armed Forces Special Weapons Project, Atomic Energy Commission, and other appropriate agencies were included.

On 30 June 1947 the Director of Central Intelligence, in a memorandum to the Secretary of War, the Secretary of the Navy, the Chairman of the Atomic Energy Commission, and the Chairman of the Research and Development Board, submitted the conclusions and recommendations of the Long Range Detection Committee, and recommended that:

"The conclusions of the Committee be accepted, and implemented forthwith by appropriate directive to the Army Air Forces for overall responsibility, supported by request to other interested agencies for necessary cooperation and assistance to carry out the program."

Concurrences in the recommendations of the Director of Central Intelligence were obtained from the Atomic Energy Commission (MLC) on 24 July 1947, the Secretary of War on 5 September 1947, and the Secretary of Navy on 15 September 1947; and the basic directive (see Section B, Authority) was issued on 16 September 1947. Concurrence of the Secretary of Defense is implied since Mr. Forrestal concurred on 15 September 1947 in his then capacity as Secretary of the Navy.

D. Codewords.

Atomic Weapons Test. The codeword CROSSROADS (Unclassified) referred to the atomic weapons tests conducted at Bikini Atoll in 1947. The codeword SANDSTONE (Unclassified) referred to the tests conducted at Eniwetok Atoll in the spring of 1948.

Long Range Detection of Atomic Explosions. The codeword WHITESMITH (Secret) was used during the period covered by this report to designate the overall problem of Long Range Detection of Atomic Explosions. The codeword FITZWILLIAM (Secret) refers to that portion of WHITESMITH (Secret) carried out in connection with SANDSTONE (Unclassified). Operation FITZWILLIAM (Secret) terminated on 30 June 1948.

FITZWILLIAM (Secret) Projects. To facilitate administration, transportation and supply for FITZWILLIAM (Secret) the restricted codewords were assigned as indicated below to designate the efforts of the respective participating agencies:

<u>Agency</u>	<u>Codeword</u>	<u>Scientific Field</u>
Air Materiel Command	BLACKHEART	Balloon acoustic
Air Weather Service	FIRSTRATE	Nuclear
Signal Corps, U. S. Army	BIRTHROOT	Acoustic net
Signal Corps, U. S. Army	CRIMPED	Nuclear Instruments
Signal Corps, U. S. Army	CHEESECLOTH	Light reflection from the moon
Naval Ordnance Laboratory	TENSOR	Acoustic and seismic
Naval Electronics Laboratory	VECTOR	Acoustic
Naval Research Laboratory	SCALAR	Nuclear

IV. DEVELOPMENT OF TEST PROGRAM

In accordance with the directive of 16 September 1947, to utilize to the maximum existing personnel and facilities, inquiry was made of all departments of the National Military Establishment, and of various other agencies of the government, as to the extent to which each agency was prepared to participate in FITZWILLIAM (Secret). Through a series of conferences held under the sponsorship of the Special Weapons Group, DCS/Materiel, Headquarters, USAF, it was determined that contributions could be made as follows:

<u>Scientific Field</u>		<u>Department</u>	<u>Agency</u>	<u>Type of Contribution</u>
<u>Nuclear</u>	1.	Air Force	Air Materiel Command	Furnish aircraft filter units, ground dust sampling units, ionization chambers and wrap-around Geiger counters.
	2.	Air Force	Air Weather Service	(a) Operate ground radioactivity measurement instruments; (b) Operate aircraft filter detection system.
	3.	Army	Signal Corps	Furnish ground dust sampling units and wrap-around counters.
	4.	Navy	Naval Research Lab.	(a) Furnish ground dust sampling units and radiological counters, and operate certain ground radiological stations. (b) Test balloonborne radiological counter methods.
<u>Acoustic</u>	5.	Air Force	Air Materiel Command	Test balloonborne acoustic detection instrument.
	6.	Army	Signal Corps	Test ground acoustic detection instruments in a six-station network covering northern hemisphere.

V. PREPARATIONS FOR THE TESTS

On 14 December 1947, Major General Albert F. Hegenberger, USAF, was assigned to the Special Weapons Group, DCS/M, Headquarters, USAF, to organize the long range detection program. Assisting him in the organization of the scientific effort were Colonel Benjamin G. Holzman, USAF, one of the principal scientific members of the original Long Range Detection Committee, and Dr. Ellis Johnson, formerly associated with the Carnegie Institute of Technology and the Naval Ordnance Laboratory. Shortly after 1 January 1948, Brigadier General Morris R. Nelson and Colonel Herbert W. Ehrigott were assigned to the Special Weapons Group to assist in the organizational, operational and general administrative aspects of the program. During this same period the technical staff was augmented by the addition of Mr. D. L. Northrup, Deputy Technical Director, Dr. William D. Urry, Chief Nuclear Research, and Mr. J. Allen Crocker, Chief Geophysics. This small group, together with a few airmen and clerical and administrative civilian employees, formed the nucleus of AFMSW-1, the subdivision of the Special Weapons Group which directed the long range detection program during SANDSTONE (Unclassified).

January and February of 1948 were spent in analyzing the mission and its background; obtaining personnel, working space and funds; establishing security standards and procedures; becoming familiar with the status of the preparation of the various participating agencies; settling upon locations of test stations; establishing close liaison with Joint Task Force Seven, the agency responsible for the conduct of the SANDSTONE (Unclassified) tests; and making detailed arrangements for the deployment of personnel and equipment.

By February 1, it became apparent that the majority of the radiological equipment would not be completed in time to permit adequate calibration and familiarization by operating personnel. The problem was intensified by the fact that equipment procured by the various participating agencies by contract or by manufacture within their own laboratories would, in many cases, have to be operated by personnel of other participating agencies to fit the overall plan. To provide a partial solution to the problem a contract was effected with Tracerlab, Inc., Boston, Massachusetts for the establishment at Fairfield-Suisun Air Force Base of a two weeks training course in operation of the various instruments. Officers and enlisted personnel of Air Weather Service detachments throughout the Pacific, Army and Air Force officer graduates of radiological defense schools at the Army Chemical Center, Edgewood, Maryland, and U. S. Navy Installation, Treasure Island, California, and officer and civilian scientific personnel furnished by the Office of Naval Research, U. S. Navy, attended the course. Although the time available was insufficient for completely satisfactory training, all equipment was placed in operation by graduates of the course in time for the first explosion on 15 April 1948. For details of this training course, see Tab C, Volume III.

Adequate testing of some of the equipment required its establishment and operation in the Marshall Islands area, at or close to Eniwetok Atoll. Since, for security reasons, complete authority over all activities in that area was vested in the Commander, Joint Task Force Seven (Lt. Gen. John G. Hull), it was necessary to request the Task Force to provide certain operational and logistic support. Joint Task Force Seven undertook to render all possible assistance which would not interfere with the accomplishment of its principal mission, which was to support the scientific tests of the atomic weapons by the Atomic Energy Commission. Specific assistance was requested of, and granted by, Joint Task Force Seven as follows:

- a. Permission to establish long range detection testing stations at Eniwetok, Kwajalein, Majuro, Rongerik, and a number of smaller atolls.
- b. Provision of logistic support to such stations.
- c. Construction of foundations and shelters for five seismicographic stations on Eniwetok Atoll.
- d. Notification to outlying stations of the anticipated times of the explosions.
- e. Meteorological information furnished through the Staff Weather Officer, Joint Task Force Seven by the 514th L. R. Reconnaissance Squadron, operating as Task Unit 7.4.4.

Preliminary arrangements with Headquarters, Joint Task Force Seven offered no difficulty since that headquarters was adjacent to AFMSW-1 in the Pentagon. Close liaison with Joint Task Force Seven was maintained through Colonel Nelson P. Jackson, FITZWILLIAM (Secret) Project Officer, Joint Task Force Seven. On 12 February 1948, Headquarters, Joint Task Force Seven moved to Schofield Barracks, T.H., in preparation for the further move to the Marshall Islands. On 24 February 1948, Colonel Ehrigott, accompanied by Major Stephen Pournaras of the Air Weather Service, proceeded to Hawaii to brief General Kepner and his staff on the status of preparation for Operation FITZWILLIAM (Secret). In a series of conferences the following unsettled points were resolved:

- a. Details of time notification procedure.
- b. Detailed arrangements for transportation of Naval Ordnance Laboratory personnel and equipment from the West Coast to Eniwetok, and for logistic support to Naval Ordnance Laboratory stations in the Joint Task Force Seven area.
- c. Additional radio sets and batteries for Naval Ordnance Laboratory stations.
- d. Arrangements between Staff Weather Officer, Joint Task Force Seven (Colonel Holzman), and Navy and Air Weather Service units for the supply of meteorological information needed for the proper conduct of the

VI. SUMMARY OF RESULTS

The prime purpose of operation FITZWILLIAM (Secret) was to explore all possible means by which an atomic explosion could be detected at long range. Toward this end, in the six weeks permitted for preparation, a rapid evaluation of possible methods, techniques and instrumentation was made, and those which were considered to be at all feasible were implemented to an extent consistent with available equipment, personnel, and the time schedule. The means of detecting and locating an atomic explosion which were investigated in Operation FITZWILLIAM (Secret) can be classified into two groups, namely (1) those which depend upon the tremendous energy released by such an explosion, and (2) those which depend upon the radioactive atomic debris released by such an explosion.

Into the first group falls acoustic and seismic instrumentation as a means of detection and location. The acoustic experimentation indicated that the maximum range of detection for test XRAY, YOKE and ZEBRA of Operation SANDSTONE (Unclassified) ranged between 1000 and 1700 miles, with signal periods greater than 10 seconds and a signal duration of several minutes. Before an accurate estimate of the reliability of acoustic measurements as a means of detecting large scale energy releases in the atmosphere can be made, much research must be done with respect to the phenomena of sound transmission in the upper atmosphere. Following this research, it might well be possible to give an accurate evaluation of the effectiveness of long range acoustic detection and location of atomic explosions.

The seismic data indicated that existing seismographs are incapable of detecting an air burst at long range. Signals were observed on seismographs within 500 miles of the atomic explosion. These signals had a velocity which corresponds with transmission through water. Seismic data should be quite useful for the long range detection and location of an atomic bomb provided that it is exploded under water or under ground. Unfortunately, as to date, there would be no way of making certain identification of the event as an explosion rather than as a small earthquake. It is possible that a research program involving detailed study of the characteristics of seismic waves from large scale explosions and earthquakes will lead to the development of instrumentation and techniques which will permit this distinction. Further, it is conceivable that research on seismic instrumentation might well lead to apparatus that will render it possible to record air bursts through seismic means at long range.

Detection dependent upon the release of radioactive debris following atomic explosions can be sub-divided into two classes, namely (a) those methods which involve the direct measurement of the BETA and GAMMA radiation in the neighborhood of an atomic cloud, and (b) those which involve the concentration of atomic debris from large volumes of air by methods such as filtration or rainfall scavenging. Procedures (b) are inherently more sensitive since they are capable of detecting about 1000 fold lower

concentrations of dispersed radioactive material. Moreover, it is only this procedure which results in samples of fission products which can be subjected to detailed radiochemical and physical studies, and it is only through these studies that unquestioned proof of an atomic explosion can result.

During Operation FITZWILLIAM (Secret) the direct measurement of the increase in the radioactive level (Procedure (a)) at any location due to the presence of an atomic cloud in the vicinity was investigated at numerous land and ship based installations strategically placed throughout the northern hemisphere. These installations ranged as far westward of Eniwetok as Japan and as far eastward as Bermuda. These measurements were carried out on the ground by automatic recording instrumentation which either involved the usage of gamma ray sensitive Geiger tubes plus the requisite auxiliary electronic equipment, or high pressure ionization chambers and their associated electronic equipment. These studies indicated that ground detectors of this type are unsuitable at long range. The maximum limit of detection was approximately 600 miles. Unlike the acoustic and seismic experimentation, the limits of detection were not due to the instrumentation per se, but to the small concentration of atomic debris which reaches ground level at distances greater than 600 miles from an explosion.

Long range detection of an atomic cloud was also carried out in the air by means of aerial counters and atmospheric conductivity apparatus. In general, these studies showed that aerial monitoring at altitudes ranging from 25,000 to 35,000 feet were capable of detecting atomic clouds which resulted from the SANDSTONE (Unclassified) Operation at distances ranging up to 2000 miles from the site of the explosion. It is to be concluded that the prime importance of properly engineered apparatus of this type is to delineate an atomic cloud, since during the aerial flights aerial filtration to collect fission product activity can be carried out with the utmost ease. Balloonborne counters were released from certain strategic locations following each of the three SANDSTONE (Unclassified) explosions and the pertinent data were telemetered back to the ground monitoring station. These studies showed that a balloonborne counter released 6000 miles from the site of the explosion and which passed through the atomic cloud trajectory is probably capable of detecting the presence of said cloud up to altitudes as high as 80,000 feet.

All of these monitoring means of detection, both ground and airborne, irrespective of their sensitivity have the obvious limitation that they only measure the increase in the radioactive background over that due to cosmic radiation and natural activity. They do not result in the unquestioned proof of the presence of fission products. This can only be done through the collection and concentration of fission products in the vicinity of an atomic cloud trajectory through aerial filtration at high altitudes, by air filtration at a ground monitoring station, and/or through the collection of rainwater.

Aerial filtration at high altitudes by means of filter boxes, which contained Chemical Warfare type V-5 filter paper, attached to I-29's was

Department of the Air Force
HEADQUARTERS UNITED STATES AIR FORCE
Washington, D.C.

20 March 1948

OPERATION PLAN - FITZWILLIAM

1. Authority.

a. By memorandum from the Chief of Staff, U. S. Army, to the Commanding General, U. S. Air Force, dated 16 September 1947, the U. S. Air Force was given the responsibility for detecting atomic explosions anywhere in the world, and was directed to utilize to the maximum existing personnel and facilities, both within and without the War Department.

b. In memorandum from the Secretary of National Defense to the Secretary of the U. S. Air Force, dated 9 December 1947, the importance of trying out all possible methods for the detection of atomic explosions at the time of the next tests in the Pacific was emphasized.

c. In accordance with the foregoing directive and expression of policy, the U. S. Air Force has organized in the Special Weapons Group, DCS/Materiel, U. S. Air Force, an office (AFMSW-1), to carry out the U.S. Air Force responsibility for long range detection of atomic explosions.

d. After reviewing all instruments and techniques which appear to be feasible for detecting physical phenomena ensuing from an atomic explosion, AFMSW-1 supervised and coordinated the design of a test program prepared in detail by various agencies concerned; supervised the development, procurement, and allocation of equipment; and coordinated the assignment of responsibility for field observations among the operating agencies.

2. General Plan.

a. The U. S. Air Force will investigate possible techniques and equipments for the detection of atomic explosions, by observing geophysical phenomena resulting from Project SANDSTONE, utilizing to the maximum existing facilities both within and without the armed services. This phase of the long range detection program is called FITZWILLIAM and is the subject of this plan. The purpose of FITZWILLIAM is to obtain the maximum of observational data consistent with the time schedule established for SANDSTONE.

b. The end objective of the U. S. Air Force program is to establish, as soon as possible, a system of surveillance which will permit detection of atomic explosions anywhere in the world. The overall program to accomplish this objective is called WHITESMITH. Only that part of WHITESMITH which will utilize data from Operation SANDSTONE, is covered in this plan.

Subject: Operations Plan - FITZWILLIAM

20 March 1948

c. FITZWILLIAM Forward will:

- (1) Arrange with Commanding Officer, Air Weather Detachment, at Eniwetok for assistance to the two scientists conducting ionospheric observations and arrange authority for these scientists to be furnished warning of the explosions.
- (2) Arrange with Commanding Officer, Air Weather Detachment, at Eniwetok to furnish two observers for operation of magnetometers. Obtain magnetometers from NOL detachment at Eniwetok and aircraft batteries from Air Weather Detachment (furnished by Air Materiel Command). Arrange for instruction of AWS observers in operation of magnetometers by NOL technician. Arrange authority for observers to be furnished warning of timing of explosions.
- (3) Notify CTU 7.4.4 at twelve hour intervals of position of radio active cloud for information of Air Materiel Command scientists conducting atmospheric conductivity observations from special B-29 based at Kwajalein.
- (4) Direct Commanding Officer of Air Weather Detachment at Kwajalein when to release "Rawin" 658 equipment at Kwajalein Air Weather station for use of scientists of the Air Materiel Command balloon sonic project during a five hour period at the proper time after the first explosion. Issue similar instructions to the Commanding Officers of Air Weather Detachments at Kwajalein, Guam and/or Hickam Field, as required, for subsequent explosions.
- (5) Vector weather reconnaissance and cloud chasing aircraft of TU 7.4.4 at Kwajalein to the radiological cloud as required, and direct as necessary the collection of aircraft filters and gaseous samples from aircraft based at Kwajalein.
- (6) Vector Destroyer-Mine-Sweepers Quick and Davison, under operational control of CTG 7.3, to positions to insure maximum probability of intercepting the radiological cloud with balloon-borne radiological counters. Inform NRI, FITZWILLIAM Stations on the two D'S's and at Ronjerik, Majuro and Pearl Harbor when to launch balloons.
- (7) Direct Commanding Officers of appropriate Air Weather Service reconnaissance units to move aircraft with radiological filters, from home bases to FITZWILLIAM stations in accordance with AWS Plan Doubleday, to be furnished FITZWILLIAM Advanced by Air Weather Service before April 4th, 1948.

20 March 1948

will actuate the Esterline-Angus recorders of each micro-barograph thus providing an accurate synchronization of data from all stations. A single station comprised of one 100-unit array will be installed at the NOL, White Oak. This array should have the lowest signal to noise level of any sonic station.

- (2) NEL arrays. The NEL will operate three (3) sonic arrays composed of RRL microphone stations described above. The location of these stations is given on Annex D-3. Time notification for these stations and in fact for all remote sonic stations, will be achieved by special arrangement between JTF-7 and AFMSW-1.
- (3) AMC Acoustic balloons. The Evans Signal Laboratory of the U. S. Signal Corps has established a network of six (6) stations located as indicated on Annex D-3. A 24-hour continuous surveillance schedule is currently operating on all six (6) of these stations. No time signals or other notifications of the events will be required. Personnel of the Signal Corps will strive to effect identification of acoustic anomalies received on their networks and notify AFMSW-1 of all such anomalous behaviour according to a schedule agreed to separately between U. S. Signal Laboratory and AFMSW-1.
- (4) AMC acoustic balloons. The Watson Laboratory of AMC will launch balloon borne radiological equipment described above at the sites indicated on Annex D-3. Since there will be only one party from Watson Laboratory in the Pacific, the three (3) stations will be sequentially manned depending on favorable results from the preceding event. Ground level sonic measurements will be made by Watson Laboratory personnel at each of the stations indicated. Equipment for the ground level measurements consists of converted World War II gun ranging equipment. The conversion is essentially one of increasing the time-constant of the instrument to approximately 30 seconds.

d. Exploratory projects. Three (3) additional investigations of a preliminary type will be conducted as outlined below:

- (1) AES/MCL magnetic. AES will operate two (2) NOL high sensitivity magnetometers at the location indicated on Annex D-4. The NOL will operate one (1) high sensitivity magnetometer at a position shown on Annex D-4. With these three (3) magnetometer stations it is hoped to determine the feasibility of a future study of electromagnetic effects of atomic explosions due to dynamo action in the ionosphere resulting from the sonic or hydrodynamic waves.

Operation FITZWILLIAM - Annex "C"

20 March 1948

<u>STATION NAME & INDEX NO.</u>	<u>LATITUDE & LONGITUDE</u>	<u>OPERATING AGENCY</u>
Albrook Field, C. Z. (5-923)	08 59 N 79 34 W	Air Weather Service

INSTRUMENTS

<u>No.</u>	<u>Name</u>	<u>Transportation & Identification</u>
1	AMC Ground Filter Unit	All equipment flown from Wright Field to Albrook Field by ATC. (ID No. CR-UCR-1H-2408-AF2)
1	AMC Wrap-Around Counter	(ID No. CR-UCR-1H-2546-AF3)
1	AMC Precipitation Equipment	

MAINTENANCE - Tracerlab maintenance man stationed at Boston, Mass. (5-509) and Fairfield-Suisun (5-493)

OPERATING PERSONNEL - Lt. J. Smith (8th W. Gp.)

<u>STATION NAME & INDEX NO.</u>	<u>LATITUDE & LONGITUDE</u>	<u>OPERATING AGENCY</u>
Alamagordo, New Mexico (9-004)	32 54 N 105 55 W	Air Materiel Command

INSTRUMENTS

<u>No.</u>	<u>Name</u>	<u>Transportation & Identification</u>
1	AMC Microbarograph	All equipment will be flown from Red Bank to Alamagordo by AMC plane
1	AMC Sonic Balloon	
1	AMC Modified Gun Ranging Sonic Equipment	

MAINTENANCE - Operating personnel will supply all maintenance needs.

OPERATING PERSONNEL - Dr. Peoples

Operation FITZGERALD - Annex "C"

20 March 1948

<u>STATION NAME & INDEX NO.</u>	<u>LATITUDE & LONGITUDE</u>	<u>OPERATING AGENCY</u>
Guam (4-392)	13 33 N 144 55 E	Air Weather Service Air Materiel Command Signal Corps Naval Electronics Lab

INSTRUMENTS

<u>No.</u>	<u>Name</u>	<u>Transportation & Identification</u>
1	AMC ground filter unit	Wright to Guam by ATC
3	AMC wrap-around counters	(2) Wright to Guam by ATC (1) Wright to Tracerlab by ATC. Tracerlab to Fairfield-Suisun by ATC. Fairfield-Suisun to Guam by ATC. (ID No. WP-USR-1H-2554-AF3) and (2553)
1	RNL automatic radiological counter	Washington to Wright by ATC. Wright to Guam by ATC. (ID No. WP-US-1A-3163-AF3)
1	AMC microbarograph	
1	RNL microbarograph	New York City to Guam by WTS
1	AMC sonic balloon	
1	optical perturbation equipment	
1	AMC radioactive precipitation equipment	
1	AMC ionization chamber	Wright to Guam by ATC.

REFERENCE - Nearest Tracerlab maintenance man located at same station (4-392).

OPERATING PERSONNEL

LT. C. V. Wilson (30th W.S.)	Charles S. Schneider (NYU)
George E. Howser (30th W.S.) Tracerlab	Murray Hackman "
1st Com W.S. Greene CTR Proj. Off	James R. Smith "
Dr. Gilbert H. Carl (In charge Vector 13)	Martin Koenig "
F. E. Hale	Charles Moore, Jr. "
J. A. Strong	
G. W. Jones	
Mr. James A. Peoples (Watson)	Daniel F. Comstock (Tracerlab)
Albert Crary (")	Elton H. Turk "
John W. Alden (")	Don C. Atkins "
John A. Moulden (")	Emil L. Bernier "
Joseph B. Olsen (")	George S. Houser "
Peter H. Tschoff (")	Daniel M. Elkstein "
	William (RMI) Karp "
Mr. Donald J. Southard (Signal)	

VII. LIST OF SENIOR PERSONNEL

AFMSW-1

Maj. Gen. Albert F. Hegenberger, USAF
Brig. Gen. Morris R. Nelson, USAF
Col. Herbert W. Ehrigott, USAF
Col. Benjamin G. Holzman, USAF
Col. Nelson P. Jackson, USAF
Dr. Ellis Johnson
Mr. Doyle L. Northrup
Dr. Wm. D. Urry
Dr. Donald H. Rock
Mr. J. Allen Crocker

Geophysics Research Directorate of Watson Laboratory - Air Materiel Command

Dr. P. W. Wyckoff
Dr. James A. Peoples
Mr. Albert P. Crary

Air Reduction Research Laboratory (under contract to AMC)

Dr. Fred C. Balcor (Technical Director)
Dr. Hoke S. Miller (Group Leader)
Dr. Frank McKenna
Dr. Clayton S. Wynn

Columbia University (under contract to AMC)

Mr. Joseph M. Johnson

Tracerlab, Inc. (under contract to AMC)

Dr. F. C. Henriques, Jr.
Mr. D. W. Atchley, Jr.
Dr. L. R. Zumwalt
Dr. W. C. Percock

New York University (under contract to AMC)

Mr. Charles B. Moore
Mr. Charles S. Schneider

Air Weather Service

Maj. S. W. Pounaras

Operation FITZWILLIAM - Annex "C"

20 March 1948

STATION NAME & INDEX NO. (Cont'd)
Hawaii (Hickam) (4-998 & 4-999)

OPERATING PERSONNEL (Cont'd)

Mr. James A. Peoples	Watson	Conditional
Mr. Albert Crary	"	
Mr. John W. Alden	"	
Mr. John A. Moulden	"	
Mr. Joseph B. Olsen	"	
Mr. Peter H. Wyckoff	"	Conditional
Mr. Chas. S. Schneider	NYU	
Mr. Murray Maclean	"	
Mr. James R. Smith	"	
Mr. Martin Koenig	"	
Mr. Chas. Moore Jr.	"	
Mr. Leslie E. Burris, Jr.	Tracerlab	
Mr. John W. Cryder	"	
Miss Joy G. Whitney	"	
Mrs. Mary Jane Barker	"	
Mr. John W. Jones	"	
Mr. Dana W. Atchley, Jr.	"	
Mr. William H. Faulmer, Jr.	"	
Miss Theresa Jane Colson	"	
Mr. Frederick C. Henriques, Jr.	"	
Mr. Wendell C. Peacock	"	
Mr. Donald C. Thompson	"	

<u>STATION NAME & INDEX NO.</u>	<u>LATITUDE & LONGITUDE</u>	<u>OPERATING AGENCY</u>
Helena, Montana (5-772)	46 35 N 121 01 W	Office of Naval Research

INSTRUMENTS

<u>No.</u>	<u>Name</u>	<u>Transportation & Identification</u>
1	Radio frequency laboratory automatic counter	Washington to Helena by NATS

MAINTENANCE - Nearest Tracerlab maintenance man stationed at Fairfield-Suisun (5-493).

OPERATING PERSONNEL - N. J. Holter (Holter Research Foundation) (CNR)

C/o Prof Maese

FINAL REPORT

ACOUSTIC DETECTION IN THE TROPOPAUSE

by

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and

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Base Directorate for Geophysical Research
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Cambridge 39, Massachusetts

TABLE OF CONTENTS

<u>Contents</u>	<u>Page</u>
I. Abstract	7
II. Introduction	7
III. Telemetering System	
1. Introduction	9
2. Airborne System	11
3. Receiving System	12
4. Calibration	13
IV. Balloons	
1. Introduction	14
2. Balloon Construction and General Characteristics	15
3. Altitude Control	15
4. Other flight Equipment	16
5. Launching	16
V. Ground Receiving Equipment	17
VI. Results	
1. Test X at Kwajalein Island	18
2. Test X at Alamogordo, New Mexico	24
3. Test Y at Guam Island	26
4. Test Y at Alamogordo, New Mexico	27
5. Test Z at Oahu Island	30
6. Test Z at Alamogordo, New Mexico	30
7. Test Z at Montgomery, Alabama	33
VII. General Discussion	33

LIST OF ILLUSTRATIONS

Figure

- 1 Operational Schematic of Balloon-Borne Microphone System
- 2 Schematic Diagram of Airborne Microphone-Transmitter
- 3 Airborne Microphone-Transmitter Ready for Flight
- 4 View Showing Internal Construction of Microphone-Transmitter
- 5 Radio Set SCR-658 (Reproduced by permission of U. S. Army Signal Corps)
- 6 Block Diagram of Ground Receiving and Recording Equipment
- 7 Block Diagram - Pistonphone Calibration
- 8 Calibration Curves for All Equipment
- 9 Balloon just after Release
- 10 Appearance of Balloons at Ceiling Altitude (This is not a normal launching inflation.)
- 11 Simplest Balloon Flight Train
- 12 Normal Balloon Flight Train
- 13 Balloon-bring-down Device
- 14 Method of Launching Balloons
- 15 Test X, Kwajalein Island; Microphone Array and Sample GR-8 Record
- 16 Test X, Kwajalein Island; Low Frequency T-21 Record
- 17 Test X, Kwajalein Island; Recording Altimeter Record
- 18 Test X, Kwajalein Island; Balloon-Borne Microphone Record
- 19 Map of Alamogordo Operational Area
- 20 Test Y, Guam M. I.; Low Frequency T-21 Record
- 21 Test Y, Guam M. I.; Recording Altimeter Record
- 22 Test Y, Guam M. I.; Balloon-Borne Microphone Record

LIST OF ILLUSTRATIONS (cont'd)

Figure

- | | |
|---------|--|
| 23 | Test Z, Oahu, H. I.; Low Frequency T-21 Record |
| 24 | Test Z, Oahu, H. I.; Recording Altimeter Record |
| 25-1,-2 | Test Z, H. I.; Balloon-Borne Microphone Record |
| 26 | Test Z, Alamogordo, N. M.; Balloon-Borne Microphone Record |

LIST OF TABLES

<u>Tables</u>	<u>Page</u>
I. Summary of Operations	10
II. Test X with GR-8 Equipment (Kwajalein)	21
III. Test X with T-21 Microphone (Kwajalein)	22
IV. Test X with Recording Altimeter (Kwajalein)	23
V. Test X with Balloon-Borne Microphone (Kwajalein).	23
VI. Test X with Balloon-Borne Microphone (Alamogordo)	25
VII. Test Y with Balloon-Borne Microphone (Alamogordo)	29
VIII. Test Z with Balloon-Borne Microphone (Alamogordo)	32

I. ABSTRACT

This report deals with acoustic detection tests on Project "Fitzwilliam" conducted by the Geophysical Research Division of Watson Laboratories in April and May of 1948. The efforts of this group, using balloon-borne microphones and a radio telemetering system, were directed toward detection of acoustic disturbances near the tropopause in the atmosphere. Two field parties monitored each of the three explosions. One party remained at Alamogordo, New Mexico for all tests, and the other was stationed at Kwajalein for Test X, Guam for Test Y, and Oahu, H. I. for Test Z.

Positive results were obtained at Kwajalein, and there is a possible return on the Guam record. The remaining records generally indicate disturbances, but it is not possible to positively identify any of them as due to the explosion. A comparison of these results with the results on ground equipment made by other agencies may lead to more definite conclusions. The evidence of these tests indicates that the disturbances produced by the explosions are not unusual enough at ranges over 1,000 miles to permit identification without an array of three or more microphones.

II. INTRODUCTION

In connection with the long range acoustic detection program of Project "Fitzwilliam", the results of experiments conducted by the Geophysical Research Division of Watson Laboratories are hereby submitted.

At the time the acoustic program was planned, a system for detection on constant level balloons was being developed at Watson Laboratories under project "Mogul" (now "Rockfish") and was due to be in a usable

form in time for the Fitzwilliam tests. This equipment was designed to float in the tropopause, where sound velocities are a minimum, in order to take advantage of the sound propagation characteristics of the atmospheric sound channel. Since this laboratory was uniquely prepared to investigate sound detection at high altitudes, the principal efforts of the limited personnel available for the Fitzwilliam tests were directed toward this end.

The possible advantages of the balloon-borne equipment for these tests were:

- a. That pressure waves generated by the blast which transmitted in the sound channel without returning to the earth could only be detected by the balloon-borne equipment;
- b. That a sound which would not be distinguishable at a ground test station might be detected from floating balloons because of the better signal-to-noise ratio at the balloon level. The ground equipment which was used at the shorter ranges was required for the purpose of obtaining direct comparisons. Other agencies monitored the blasts on the ground with a number of elaborate arrays.

Because of a lack of time, personnel, and certainty that the equipment would work satisfactorily, it was decided to operate at no more than two locations for each test. One group remained in the United States to investigate long range detection, and the other group operated in the Pacific area at a different range for each test. A summary of these operations is given in Table I.

III. TELEMETERING SYSTEM

1. Introduction

The telemetering system described in this section was developed under the direction of Mr. Joseph M. Johnston of Columbia University, on Contract W28-099-ac-82. It is considered to be a good example of the advantages of keeping balloon-borne gear as simple as possible.

The balloon-borne microphone is so designed that the motion of a thin aluminum diaphragm varies a capacity in an oscillator circuit. Frequency modulated transmission is achieved with only one vacuum tube. A frequency of 400 megacycles was chosen largely because suitable receiving equipment had previously been developed using this frequency.

The ground system uses the SCR-658 radiosonde receiver which has a high gain directional antenna and means for determining the direction of the arriving signals. Two or more of these receivers placed 25 to 100 miles apart may be used to obtain a fairly accurate plot of a balloon's course. Connections are made to the receiver for special oscillograph recorders, tuning, meters, etc. The operation of the system is indicated in Figure 1.

TABLE I
Summary of Operations

Test	Location	Distance (Naut.Miles)	Type of Equipment	Time Operated*	Velocity Range Covered (deg/hr**)
X	Kwajalein Island	355-360 370	Airborne	20-53	17.8 - 6.7
			L.F.T.-21	34-56	10.8 - 6.6
			GR-8 Tri.	29-52	12.8 - 7.1
			Altimeter	28-56	13.2 - 6.6
X	Alamogordo, New Mexico	5160	Airborne	379-699	13.6 - 7.4
Y	Guam Island	1030	Airborne (rising)	29-94	35.5 - 11.0#
			Airborne (floating)	94-124	11.0 - 8.2
			L.F.T.-21	89-121	11.6 - 8.5
			GR-8 Tri.	94-116	11.0 - 8.9
			Altimeter	107-122	9.6 - 8.5
Y	Alamogordo, New Mexico	5160	Airborne	387-552	13.3 - 9.3
Z	Oahu Island	2350	Airborne (rising)	160-219	14.7 - 10.7#
			Airborne (floating)	219-264	10.7 - 8.9
			L.F.T.-21	205-268	11.4 - 8.9
			Altimeter	207-264	11.3 - 8.9
Z	Alamogordo, New Mexico	5160	Airborne	343-536	15.0 - 9.6
Z	Montgomery, Alabama	6000	Airborne	360-686	6.7 - 8.8##

* Time in minutes after occurrence of explosion.

** Conversion factors: $10^\circ/\text{hr} = 10 \text{ naut. mile/min.} = 309 \text{ m/sec} = 1014 \text{ ft/sec.}$

Recordings made with rising balloons and with higher attenuations.

Because of equipment trouble, this data is not considered significant.

2. Airborne System

Figure 2, a combination schematic and pictorial diagram, shows the essentials of the airborne system.

The acoustic frequency response of the entire system is largely determined by the acoustic construction of the microphone. The spun aluminum cup has a volume of approximately 800 cm³. The small bleed hole in the cup (number 69 drill) determines the low frequency cutoffs of the system. (This hole was experimentally established to be about the smallest which could be used without damaging the microphone on ascent.) The high frequency cutoff is determined by the hole in the acoustic plug in the bakelite head of the microphone and by the volume inclosed between the diaphragm and the head.

A type 955 tube is connected to two parallel lines in a modified tuned-plate tuned-grid oscillator. These lines terminate in two small plates which are spaced .005 to .008 inches from the microphone diaphragm so as to give a nominal capacitance of 15 mmfd. measured across the two lines. Since the motion of the diaphragm varies the capacity across the ends of the line, frequency modulation is produced.

The antenna, approximately one-half wave length, is attached directly to the plate lead of the vacuum tube.

Provision for altitude indication from the same transmitter is achieved in the following manner: A standard baroswitch, type ML310A, upon making the various contacts actuates a small relay which is connected as a buzzer having a frequency of about 500 cycles per second. The buzzer, connected as shown in the diagram, modulates the transmitter at this frequency. This frequency is too high to be

recorded on the oscillograph, but it can be heard on a loudspeaker. Because it was found that the buzzer system did interfere with the microphone signal, the system is normally used only up to about 35,000 feet. An accurate rate of ascent can thereby be determined. Because level-off time is clearly indicated by a great reduction of noise from the microphone, the rate of rise curve can be extrapolated to give the constant level altitude.

The battery supply used on these flights consists of special Burgess silver-chloride dunk batteries (A unit, type BA-256 and B unit, type BA-257). The A unit delivers 6 volts and the B unit delivers 110 volts. Two sets of these batteries, which are used in parallel on each flight, are sufficient to keep the transmitter in operation for six to eight hours. These batteries are extremely lightweight for the power delivered, and because they generate some heat upon being activated with water, their operation at low temperatures is maintained. They must be inclosed in a box which gives sufficient insulation to keep them from freezing, but not so much as to cause boiling.

Further details on the construction and assembly of this equipment can be determined by examining Figures 3 and 4.

3. Receiving Equipment

The primary unit in the receiving equipment is the SCR-658 radio-sonde receiver shown in Figure 5. This receiver has a high gain, highly directional antenna together with an excellent FM receiver and means for accurately training the antenna on the received signal. Only a general description of this equipment is given below. Detailed descriptions are to be found in Technical Manual No. 11-11588.

A connection by-passing the normal radiosonde audio circuits is made directly to the discriminator of this receiver. This output is connected directly to a Brush direct-inking oscillograph amplifier and recorder. A vacuum tube voltmeter is connected to the same output for tuning purposes, and a loudspeaker is used for indicating the baro-switch signals and for general monitoring purposes. The block diagram, Figure 6, shows the essentials of this equipment.

A careful operator can train the receiver antenna to an incoming signal to within about ± 0.1 of a degree. The instrument itself is very accurate. Reflections from nearby buildings, towers, and terrain features, however, may cause the apparent direction of transmission to shift several degrees from the true direction to the transmitter. The overall azimuth accuracy achieved in these experiments is believed to be good to approximately ± 3 degrees. Elevation readings below 15 degrees are unreliable because of ground reflections.

4. Calibration

Considerable effort was made to maintain calibration information as accurate as possible for these flights. Each transmitter was calibrated through the entire receiving and recording equipment. This calibration was accomplished by putting the transmitter in a closed vessel and varying the pressure at known amplitudes over the frequency range of the microphone. Figure 7 shows the method by which this calibration was done.

The magnitude of the generated signal is computed as follows:

Let V = volume of chamber, large in comparison to the volume of the microphone cup.

$\Delta V = \frac{1}{2}$ the volume displaced by the hypodermic syringe piston in extremes of travel.

p = ambient pressure in dynes/cm².

Δp = signal amplitude in dynes.

γ = 1.4 for adiabatic conditions.

$$\Delta p = \frac{\Delta V}{V} \gamma p$$

ΔV and V can be measured in any unit provided the same units are used in both cases.

For convenience, the field calibrations were conducted at ground level pressure (approximately 1,000 millibars). A very careful comparison of the response of a standard microphone at an ambient pressure of 1,000 mb. and at 146 mb. (approximate pressure at 45,000 feet) was made in the laboratory. This relationship is indicated in curves A and B of Figure 8, where it can be seen that at low pressures the low frequency response is extended and the peak sensitivity is somewhat greater. This relationship and the field calibration was used in determining the amplitude of observed disturbances.

Because of various factors including a variation of the calibration constant with radio signal strength, precision in amplitude measurements is not claimed. It is believed that stated amplitudes are within ± 6 db.

IV. BALLOONS

1. Introduction

The only known way of keeping a microphone at high altitude and at rest with respect to the atmosphere is by means of a constant level balloon. The techniques and operations of flying constant level balloons have been carried out by New York University on Contract W28-099-ac-241.

2. Balloon Construction and General Characteristics

The balloons used in this work were built and developed by General Mills, Inc. The essential features of these balloons are:

<u>Material:</u>	Extruded polyethylene .001 inch thick.
<u>Volume:</u>	Approximately 43,000 cubic feet. 4200 ft ³
<u>Shape:</u>	"Tear Drop" - spherical section about 20 feet in diameter.
<u>Construction:</u>	Twenty gores are heat sealed together and a special acetate tape is applied over the seams. The balloon converges to a 12 inch load ring at the bottom. The acetate tapes aid in distributing the load from the ring to the upper parts of the balloon fabric. Also attached to the ring are the load harness and an appendix.
<u>Pay Load Capacity:</u>	Seventy pounds to about 37,000 feet or 4 pounds to 67,000 feet when helium is used as the lifting gas. Typical loads were about 20 pounds which reached altitudes of about 55,000 feet.

The balloons are partially inflated at the ground. As they rise the gas expands. Then a balloon reaches its floating altitude, the excess gas passes out through the open appendix until the lift is just sufficient to balance the load. Figure 9 shows a balloon just after a normal release, and Figure 10 shows how a balloon appears at floating altitude.

3. Altitude Control

Although equilibrium conditions are almost unstable, experience has shown that for a period of two to four hours balloons with no altitude control at all will maintain satisfactory flight characteristics. This period can be extended until sunset by carrying a liquid ballast which is released at a constant rate, the rate being set to somewhat over compensate for the expected rate of loss of gas from the balloon.

Under these circumstances, the balloon will rise very gradually until all of the ballast is expended. A more positive altitude control uses an aneroid bellows to operate a ballast valve whenever the balloon descends below the ceiling altitude. In most of the flights for these experiments, the fixed rate ballast flow was used.

4. Other Flight Equipment

Figures 11 and 12 show typical balloon flight trains. The flag, about 6 ft. x 8 ft. is used to damp out pendulum-like oscillations. The inverted parachutes produce a drag which prevents the balloon from rising too rapidly if the free lift of the balloon is greater than expected.

On flights where there is a danger that the balloon may descend into air lanes, a bring-down device is used to reduce the descent time. This device is actuated by a baroswitch whenever the balloon descends below about 20,000 feet. The switch fires an electric squib (small detonator) which cuts a line and drops the balloon load 5 to 10 feet, pulling a rip cord in the side of the balloon. A part of the gas is thereby released so that the balloon descends more rapidly to the ground. This device is shown in Figure 13.

5. Launching

In dead calm conditions, the launching of a balloon is easy, but special techniques are required if a wind is present. By using the launching procedure described, balloons can be launched in winds up to 20 miles per hour.

A launching area is chosen where a building, truck, or canvas shield can be used as a wind break. Two lead-shot bags are placed on the

uninflated balloon at a point about 15 feet from the upper end and so that an inflation tube leading to the upper portion of the balloon passes between them. The remainder of the balloon and the flight train is laid out on the ground in a downwind direction. Gas is then run through the inflation tube into the upper portion of the balloon to form a bubble, which is protected by the windshield. When everything is ready, two men simultaneously remove the shot bags and the balloon rises freely in the air and passes over the train of equipment (see Figure 14). The person holding the bottom piece of equipment must get directly beneath the balloon before releasing it.

In some cases, the balloon shot bags are placed on a platform scale and the lift of the balloon is determined by weighing; but experience has shown that the proper amount of gas can be determined just as satisfactorily from the pressure and temperature of the gas in the helium cylinders.

V. GROUND RECEIVING EQUIPMENT

Three types of ground recording equipment were used in the Pacific Area:

1. A standard T-21 microphone, modified to have frequency characteristics similar to those of the airborne microphone, and a two channel-Brush recorder;
2. A standard GR-8 Signal-Corps recorder (see TM 11-2568) with T-21 microphones used in arrays so that the azimuth and elevation angles of arriving signals could be determined;
3. A recording altimeter.

The recording altimeter, which was borrowed from the United

Geophysical Company of Pasadena, California, is essentially a refined aneroid barometer operating as a null type pressure indicator. A state of balance between the pressure bellows and an opposing spring is indicated by a sensitive capacity bridge circuit. Bridge balance is maintained by means of a servo-motor which is mechanically coupled to the bellows spring and to a spiral in the recorder. The angular position of the recorder spiral is periodically indicated by means of a ribbon and striker mechanism. After a turn of the spiral has been completed, the trace reappears on the opposite side of the paper, so that the instrument is a sensitive indicator with a wide range. The sensitivity of the instrument is about 52 dynes/cm² per cm of paper (30 dynes/cm² per scale division of the recording paper). The speed of the servo-motor limits the response of the system to rapid pressure changes of about 4.2 dynes/cm² per second.

All recording equipment was calibrated from known pressure changes so that all signals and noise levels could be indicated in absolute units. The frequency characteristics of the different systems are shown in Figure 8.

VI. RESULTS

1. Test X at Kwajalein Island

Ground equipment was put into operation about 28 minutes after the X zero time and continued to about 55 minutes after. The low frequency T-21 recording on the Brush equipment did not function properly at first and, as a result, the first 6 minutes of recording were only partly usable. The GR-8 triangulation array consisted of three microphones in an approximate equilateral triangle about 220 meters on a

side. Because this equipment ran at fairly high speeds, several rolls were used and some recording time was lost changing rolls.

Compressional waves were recorded at Kwajalein for a period of more than 3 minutes, from about X plus 38 to X plus 41 minutes, and were picked up on all four types of recording equipment. At the time these signals were received at Kwajalein, the balloon equipment was approximately 14 miles northwest of Kwajalein. Signals were received there about 1 minute earlier.

Table II gives the results of the test obtained from the GR-8 triangulation equipment. The diagram of the field setup together with the signal arriving at X plus 38.9 minutes is shown in Figure 15.

It is noted that the azimuths obtained ranged from approximately 0 to 1 degree 30 minutes greater than 298 degrees 55 minutes, the true azimuth as calculated from positions. The average deviation indicates an average wind component of 9.5 miles per hour from the azimuth 209 degrees, at right angles to the path travelled by the wave. It is also noted that the angles of descent were quite uniform, and apparent velocities ranged from 351 to 362 meters/second as compared to 347 meters/second at the surface.

The recording obtained with the modified T-21 microphone (4 c.p.s.) operating into a Brush recorder very closely duplicated the records obtained with the GR-8 triangulation array. Table III indicates the signals received. The recording is reproduced in Figure 16.

Recordings from the altimeter are shown in Figure 17. Here the evaluation of any signals is difficult because of general pressure fluctuations in the lower frequencies. Some indications of high-

frequency signals, as recorded on the other instruments, are apparent within the 39 to 40 minute interval, but because of the limitations on speed of response imposed by the servo-system, these indications are very small. Other possible signals are given in Table IV.

The airborne equipment, at about 50,000 feet altitude and 14 nautical miles toward the test area from the ground equipment, showed about the same pattern of signals as the ground equipment. A reproduction of the recording is shown in Figure 18 and listed in Table V are the main signals received. Because a high signal strength was anticipated at this site, the attenuation was set too high for the signal which was received.

8

TABLE II
Test X at Kwajalein

GR-8 Equipment

X Plus Time in Min.	Velocity Deg/hr*	Time Diff. in Sec. 1-3 Mikes	Time Diff. in Sec. 1-4 Mikes	Azimuth (North = 0)	Elevation Angle	Freq. Cy/sec	Signal Strength Dynes/cm ²
37.8	9.8	.509	#4 Noisy			8	1.7
37.8		.515	"			8	1.4
37.9		.516	"			10	1.8
38.0		.498	"			4	2.3
38.3		.521	"			10	1.1
38.9		.497	"			11	0.6
38.9		.509	.016	299°20'	12°0'	11	4.7
39.5		.511	.006	300°30'	11°10'	12	1.7
39.5		.506	.009	300°00'	14°05'	13	1.8
39.5		.495	.009	300°10'	14°05'	8	2.9
39.6		.510	.010	300°00'	12°0'	11	2.1
39.6		.507	.013	299°40'	13°30'	10	2.5
39.6		.500	.011	299°50'	16°20'	6	3.1
39.7		.510	.013	299°40'	11°10'	10	2.7
39.7		.508	.023	298°40'	13°30'	8	3.5
39.7		.513	.012	299°40'	10°35'	8	2.7
39.8		.515	.011	299°50'	8°25'	9	1.7
(X plus 39.9 to X plus 40.8 lost changing paper rolls)							
40.8		.530	#4 Noisy			14	1.1
40.9		.507	"			9	2.0
40.9		.518	"			14	2.1
41.1		.520	"			13	2.0
41.1		.511	"			14	2.0
41.2	9.0	.528	"			4	2.3

Average noise level (Peak Frequency) 0.6 dynes/cm².

* Conversion factors: 10°/hr = 10 n.m./min. = 309 m/sec = 1014 ft/sec.

TABLE III

Test X at Kwajalein

Low Frequency T-21 Microphone

Travel Time Minutes	Velocity Deg/hr	Predominant Freq., cy/sec.	Amplitudes † Dynes/cm ²
37.7 - 38.2	9.8 - 9.7	4	2.7
38.9	9.6	4	7.4
39.5 - 39.8	9.4 - 9.3	4	4.0
40.6	9.1	$\frac{1}{4}$	7.6*
40.7 - 40.8	Equipment inoperative.		
40.8 - 41.2	9.1 - 9.0	4	2.4

† Noise level was approximately 0.8 dynes/cm².

* This disturbance is thought to be instrumental noise or of very local origin. No corresponding disturbance can be found on the record from the balloon equipment. It may however correspond to the 24 second period recorded on the recording altimeter.

TABLE IV

Test X at Kwajalein

Recording Altimeter

Travel Time Minutes	Velocity Deg/hr	Predominant Freq., cy/sec	Signal Strength Dynes/cm ²
37.6	9.8	1/12	25
38.6	9.6	1/12	22
40.5	9.1	1/25	30

TABLE V

Test X at Kwajalein

Balloon-Borne Microphone

Travel Time Minutes	Velocity Deg/hr	Predominant Freq., cy/sec	Signal Strength Dynes/cm ²
36.3 - 37.8	9.8 - 9.5	1.5 - 2.0	1.0 - 2.2*
38.0	9.4	1.2	8.1
38.2 - 38.7	9.3 - 9.2	2.0	1.9 - 3.8

* Noise level was less than 0.5 dynes/cm².

2. Test X at Alamogordo

There were three ground receiving and recording stations in the Alamogordo area: 1. The main station at Holloman Air Force Base; 2. Walker Air Force Base near Roswell, New Mexico; and 3. A station about five miles south of Carlsbad, New Mexico. Because the winds at 50,000 feet were generally westerly, most of the balloons launched at Alamogordo or near Hot Springs, New Mexico passed between the Walker Air Force Base and the Carlsbad receiving stations. Figure 19 shows the locations of the receiving stations and several of the balloon flight trajectories. Balloons which were launched upwind in the Rio Grande Valley remained within receiving range of the telemetering system for at least one hour longer than those launched at Holloman Air Force Base.

At the time these tests were made, there was speculation that transmission velocities might be higher than 12 degrees per hour, but there was also good reason to expect velocities as low as 9 degrees per hour. In order to cover this interval adequately and to obtain some undisturbed noise level data, it was necessary to monitor continuously for at least four hours. Also, because there were three receiving stations, it was planned to obtain simultaneous data from two balloons during as much time as possible. This program would make it possible to determine roughly an approximate west-east propagation-velocity component and would make identification of the source much more certain.

The plan was to launch two balloons in the Rio Grande Valley, with an interval of about $1\frac{1}{2}$ hours between launchings. As soon as Walker Air Force Base and/or Carlsbad were getting a good record from the first balloon, Holloman was to shift to the second flight.

TABLE VI

Test X at Alamogordo

Balloon-Borne Microphone

Travel Time Minutes	Velocity Deg/hr	Amplitude Dynes/cm ²	Predominant Freq., cy/sec	Duration Minutes	Notes *
379	13.6	First at level recording.			
385	13.4	11	0.2	1	) a.
388	13.3	11	0.2	0.5	
424	12.2	15	.15	3	) b.
		7.5	.5	3	
442	11.7	1.1	0.1 to 1.0	1.5	) c.
452	11.4	2.2	1	2	
497	10.4	3.4	.5 to 2	6	d.
611	8.4	3.4	.5 to 1	1	) e.
616	8.3	3.4	.5 to 1	1	
699	7.4	End of recording.			

* Notes:

a. Good correlation between ground stations recording the same flight, but it could be the balloon settling off. Also velocity is too high to be due to expected source.

b. This disturbance looks similar to results obtained in Test Z, but shows up only on the Alamogordo record. In considering effects observed on tuning meter, it is difficult to disregard this part of the record as due only to instrumental troubles.

c. Velocity high, if previous disturbances were due to natural disturbance, these could be also.

d. There was simultaneous recording on two flights at this time and this shows only on the first flight. The disturbance must be of local origin.

e. Very low velocity.

The weather was perfect and the balloons were launched according to plan. Records from at least one balloon cover the required period of time, but simultaneous records on two balloons cover only the velocity range between 10.6 and 9.4 degrees per hour. The only indication recorded in this range shows only the record for one of the balloons. The noise level is generally very low (from 0.8 to less than 0.25 dynes/cm²). All of the indications of reception of compressional waves are summarized in Table VI.

The three sets of extensive records taken on this test and the results outlined in Table VI were obtained only after very careful and detailed comparisons of all of the records. It is believed, however, that reproduction of the records in this report is not justified. The records are available at the laboratory to qualified persons.

3. Test Y at Guam Island

Test Y was recorded from Guam Island in the Marianas Islands, approximately 17.2° west of the test area. The rate of rise of the balloon was lower than was desired because it was launched during intermittent showers. Launching time was 29 minutes after Y zero time and recording at floating altitude lasted for about 30 minutes, from 94 to 124 minutes after Y zero time.

The low frequency ground equipment was operated from about 90 to 120 minutes after the Y zero time and consisted, as before, of the low frequency T-21 with a Brush recorder, a triangulation setup with the GR-8, and the recording altimeter. The triangulation consisted of four microphones in an L formation, spread about 172 meters on each

side. The recording altimeter lost about 15 minutes, the first half of the operation, through failure of the recorder to print legibly.

Because average velocities for the signals received at Kwajalein were from 9 to 10 great-circle degrees per hour, recordings at Guam for Test Y were made especially to cover this period. The recordings from Guam are shown in Figures 20, 21 and 22. No triangulation signals were obtained on the GR-8. It is believed that the frequency response of this equipment was too high to be effective for the longer distances. Consequently, although some signal-like impulses were received on other equipment, they cannot be positively identified. Correlation between airborne and ground equipment is not conclusive. Positive identification of reception of the compressional wave from the source was obtained on the low-frequency ground array operated by the Navy Electronics Laboratory on Guam for this test. It is probable that the disturbances indicated on the balloon-borne record for a velocity of 9.2 degrees/hour are of the same origin, but since at that time the radio signal-to-noise ratio was poor, this part of the record is not considered reliable. The recording altimeter for this test shows nothing above general noise level at the lower frequencies.

4. Test Y at Alamogordo, New Mexico

Because of the security situation, it was impractical to compare the results of the two field parties between tests, and, therefore, modifications in procedure for subsequent tests were based only upon the information gained by each party. It was first strongly suspected that the high-amplitude high-velocity signals received at Alamogordo on Test X were due to the explosion; and the plans for Test Y were modified to

verify this indication and to obtain continuous records on at least two balloons throughout the interval.

Two balloons were to be launched in the Rio Grande Valley. The launchings were spaced approximately $1\frac{1}{2}$ hours apart. A balloon having a reduced sensitivity microphone was to be launched at Holloman Air Force Base at the same time as the first launching in the Rio Grande Valley. Initially, Holloman Air Force Base was to monitor the first Rio Grande Valley balloon, and Walker Air Force Base and Carlsbad were to monitor the balloon launched at Holloman.

As a result of high surface winds, two attempts at launching in the Rio Grande Valley failed, and it was not considered wise to expend anymore of the limited supply of balloon equipment in further attempts. The first flight was launched at Holloman as planned, and a second flight was launched approximately $1\frac{1}{2}$ hours later. The Walker Air Force Base station lost the signal of the first balloon just before it leveled off. It was discovered later that the signal was lost because a truck trailer which had been used for a balloon wind screen was in the path of the radio transmission. Carlsbad and Walker Air Force Base obtained a poor quality recording on this flight for one hour. The Holloman Air Force Base record on the second flight is very good and shows generally a very low noise level. There were no simultaneous recording of two different flights in this operation. The results of this flight are given in Table VII.

TABLE VII

Test Y at Alamogordo

Balloon-Borne Microphone

Travel Time Minutes	Velocity Deg/hr	Amplitude Dynes/cm ²	Predominant Freq., cy/sec	Duration Minutes	Notes *
387	13.3	First at level recording.			
411	12.5	60	.2 to .6	5	(a.
424	12.2	18	.5 to 1	2	
458	11.3	1	.5 to 1	1	b.
533	9.7	1	1	0.5	(c.
538	9.6	1	1	0.5	
552	9.4	End of all recording.			

* Notes:

a. Records at this time were of poor quality. Amplitudes believed exaggerated due to probable slope detection. During the period between 408 and 448 minutes, the noise level appears to be very high.

b. This could be due to final leveling off disturbance on second balloon. The noise level between this time and 514 is generally less than 0.5 dynes/cm² on an excellent record.

c. This appears at the last part of a poor record.

5. Test Z at Oahu Island

Test Z was recorded from the Oahu Islands in the Hawaiian group, about 39.2° east of the test area. Recording at the floating altitudes lasted from 219 to 264 minutes after the Z zero time. Ground equipment for this test consisted of two low frequency T-21 microphones with a Brush recorder, and the recording altimeter. No triangulation equipment was used because ground reception within the frequency range of the equipment was improbable.

The recordings obtained at Oahu Island are shown in Figures 23, 24, and 25. No signals were obtained above the general noise level during the floating periods of the balloon. A period of increased noise level lasting for about three minutes was received during ascent of the balloon, corresponding to an average velocity of 11.7 degrees/hour. Signal strengths averaged about 60 dynes/cm². If this increase in noise level was due to the explosion, then the disturbance clearly recorded at Alamogordo with the same average velocity must also have been due to the explosion. At that time, ground recorders were not in operation.

6. Test Z at Alamogordo, New Mexico

Between Tests Y and Z, two experimental flights were made with considerably reduced payload which leveled off at approximately 65,000 feet. The upper winds at this level were very low and the balloons remained within range until long after the radio transmitter batteries had given out. The plan for Test Z was to launch three balloons from Holloman Air Force Base: One standard altitude (45,000 foot) balloon and a 65,000 foot balloon to be launched simultaneously, and a standard balloon to

be launched about two hours after the first two. It was expected that the first standard balloon would float over the Walker-Carlsbad area, and that the high altitude balloon would remain within the Holloman area. The third balloon would cover the latter part of the test.

The high altitude balloon took off normally, but burst just after leveling off. The first standard balloon ripped in the winds at launching, but another which was launched immediately, performed satisfactorily. A time switch was used on the second standard flight to turn the transmitter on after it had reached altitude; this was done to prevent the second transmitter from interfering with the flight which was in progress. It appears that the batteries on the last flight froze before they were turned on so that only a few minutes of records were obtained and the value of this record is questionable.

The record obtained with the successful high-altitude balloon is exceptionally good. A very marked disturbance is indicated between 435 and 445 minutes, an average velocity of 11.7 degrees/hour which seems rather high. All of the details on records made at the Holloman Air Force Base and Walker Air Force Base receiving stations correlate. The record showing this disturbance is reproduced in Figure 26, and Table VIII summarizes the results for the entire test.

TABLE VIII

Test Z at Alamogordo

Balloon-Borne Microphone

Travel Time Minutes	Velocity Deg/hr	Amplitude Dynes/cm ²	Predominant Freq., cy/sec	Duration Minutes	Notes *
343	15.0	Record starts.	No detectable noise.		
440	11.7	9	.3 to .5	10	a.
482	10.7	End of reliable record.			
536	9.6	8	.3 to .5	12	b.
560	9.2	End of all records.			

* Notes:

a. There is no doubt that this is due to change of pressure. Every detail of wave form is duplicated on the Walker Air Force Base record. Although made with a bad recorder, the Carlsbad record shows similar disturbances. This is the only disturbance recorded on this flight in which noise level was below 2 dynes/cm² at all times.

b. This was recorded on the flight in which the batteries froze and finally partly thawed out. The signal was very weak and the validity of this disturbance is very doubtful.

7. Test Z at Montgomery, Alabama

Because there appeared to be a possible confirmation of a high velocity disturbance in Tests X and Y at Alamogordo, it was felt that additional indications obtained at another station within the United States would be of great value. A third party operated a station at Maxwell Air Force Base, Montgomery, Alabama.

The only recording station was the Rawin station at Maxwell Air Force Base. Three balloons were to be launched at Selma, Alabama (40 miles west of Maxwell Air Force Base) at $1\frac{1}{2}$ hour intervals.

The first balloon flew successfully, passing within five miles of the recording station; the second balloon burst on ascent; and the third balloon which was launched about one-half hour early because the second had failed, flew normally. Because of receiver troubles, the records obtained from these two flights are very unsatisfactory.

In this test, there is no evidence of the disturbance recorded in the Alamogordo flight, but it is probable that such a disturbance would not have been recorded if it did occur. It is believed that the Maxwell Field records should not be considered as evidence either way.

VII. GENERAL DISCUSSION

All indications of reception of compressional waves during the monitoring intervals have been given in the tables above. It is believed that many of the listed phenomena are not due to the explosions, and for the most part conclusions must be largely speculative.

There is no doubt that the effects observed in the air and on the ground at Kwajalein on Test X were due to the explosion. The amplitude of the wave received on the balloon was not significantly greater than

the amplitude received on the ground equipment, but there was a slight advantage in signal-to-noise ratio in favor of the airborne equipment. Under conditions of high surface winds, the advantage would probably be greater.

If the observed amplitude of 8 dynes/cm² in the Kwajalein reception is assumed as representative, then an amplitude of 0.6 dynes/cm² would be expected at Alamogordo if it is assumed that the intensity of the disturbance varied inversely with the square of the distance, or an amplitude of approximately 2 dynes/cm² would be expected if it is assumed that most of the energy was trapped in the atmospheric sound channel so that the intensity varied inversely with the first power of the distance. A factor of at least two should be allowed for uncertainties in calibration, etc., giving a reasonable range of 0.3 to 4 dynes/cm² of amplitude to be expected at Alamogordo.

The propagation velocity observed at Kwajalein on Test X was approximately 9.4 degrees/hour, and, about 9.2 degrees/hour at Guam on Test Y. Since the direction of propagation to these two places differed by more than 90°, the effects of winds seem to have been within 0.1 to .3 degrees/hour. One would, therefore, expect this observed and identified disturbance to be propagated toward Alamogordo at a velocity between 9 and 10 degrees/hour.

Experience has shown that when the radio telemetering signal is above background, compressional wave disturbances with amplitudes above 1 dyne/cm² are clearly indicated. The atmospheric noise level appears to vary from approximately 0.3 dynes/cm² to above 1 dyne/cm². It is, therefore, concluded that there is about a 50% probability that the

disturbances could be observed on the records, but that positive identification cannot be made without reception on two or more balloons flying in the same general area, because natural disturbances of comparable frequency and magnitude do seem to occur.

Within the recorded velocity range of 9 to 10 degrees/hour at Alamogordo, there is a possibility that one or both of the recorded disturbances at 9.7 and 9.6 degrees/hour on Test Y and the recorded disturbance at 9.6 degrees/hour in Test Z were due to the explosion. The observed amplitudes are reasonable.

The disturbance recorded in Test Z with velocity 11.7 degrees/hour is the most outstanding recorded. Strong disturbances were also recorded at times corresponding to high velocities for Tests X (13.3 to 13.4 degrees/hour) and Test Y (12.5 and 12.2 degrees/hour). Even though such high velocities can be rationalized as due to propagation mostly at very high altitudes where velocities are high, there seems to be little reason to expect such a wide variation in velocities.

The flights made in connection with this experiment were the first successful telemetering flights. Since that time, the signal-to-noise ratio of radio signal has been improved by 10 to 16 db., and much operational experience has been gained which has greatly improved the reliability of the data obtained on such flights.

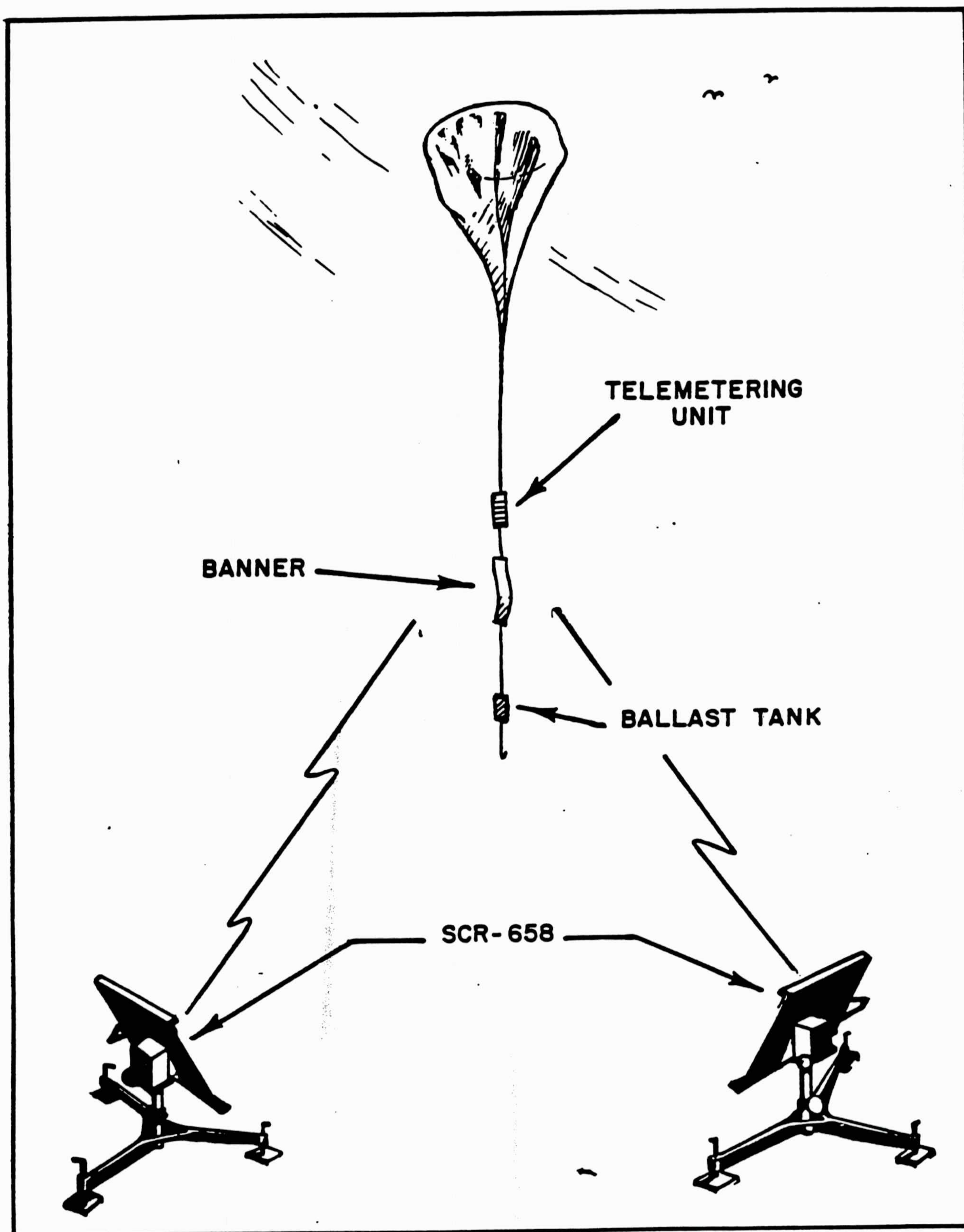


Figure 1 Operational Schematic of Balloon-Borne Microphone System

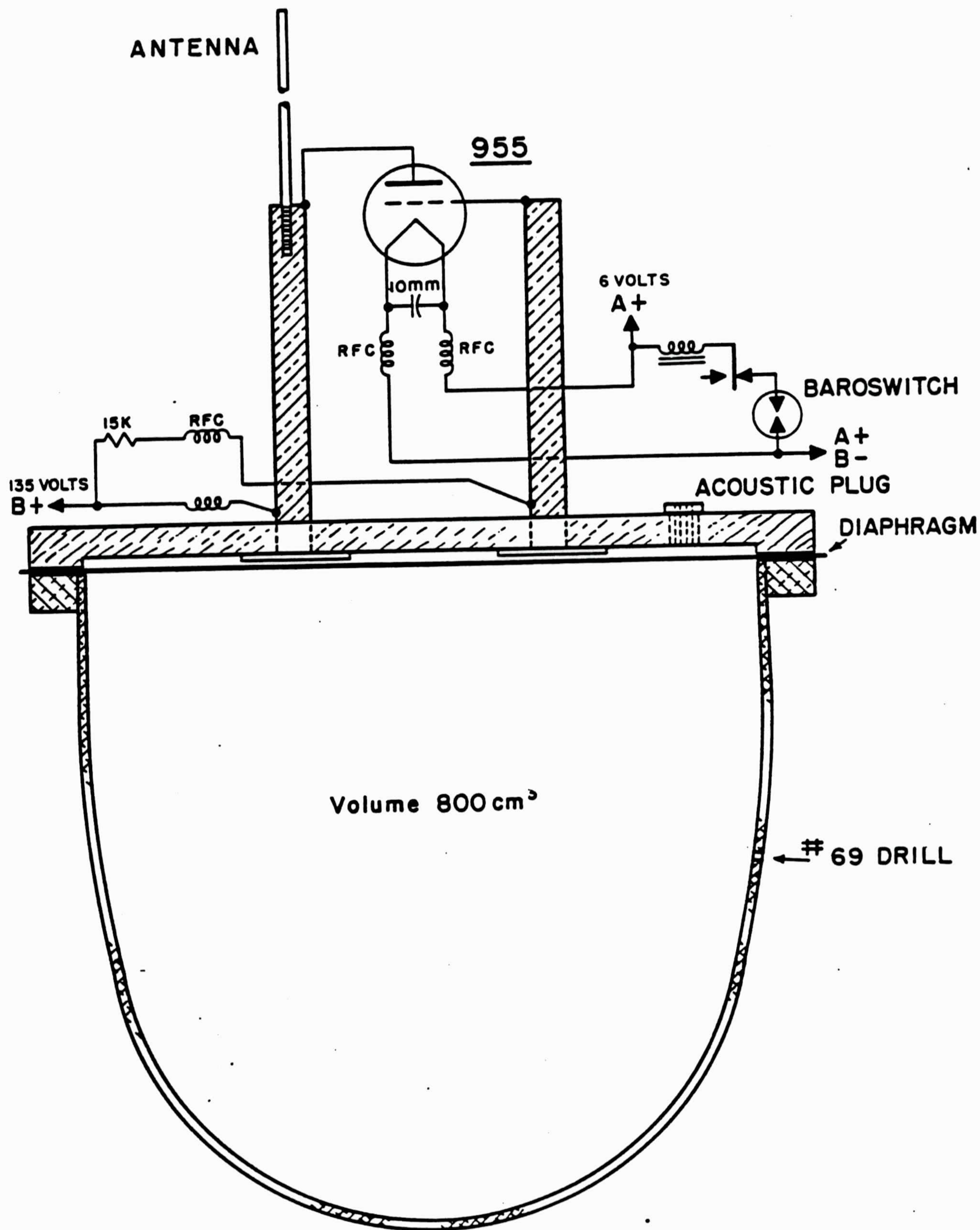


Figure 2 Schematic Diagram of Airborne Microphone-Transmitter

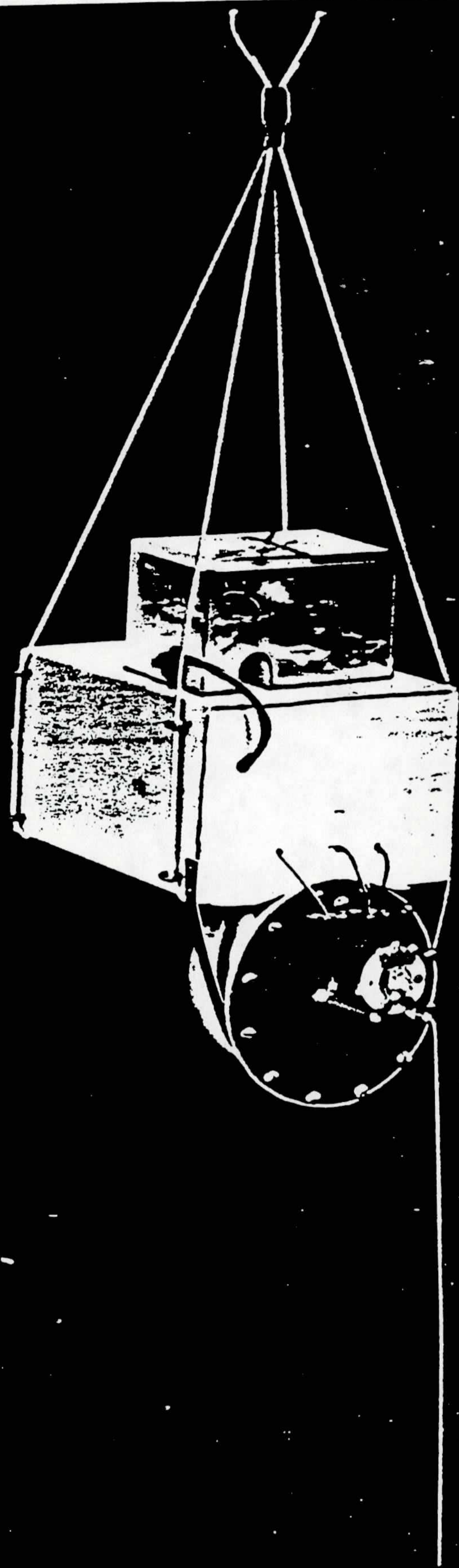


Figure 3 Airborne Microphone-Transmitter Ready for Flight

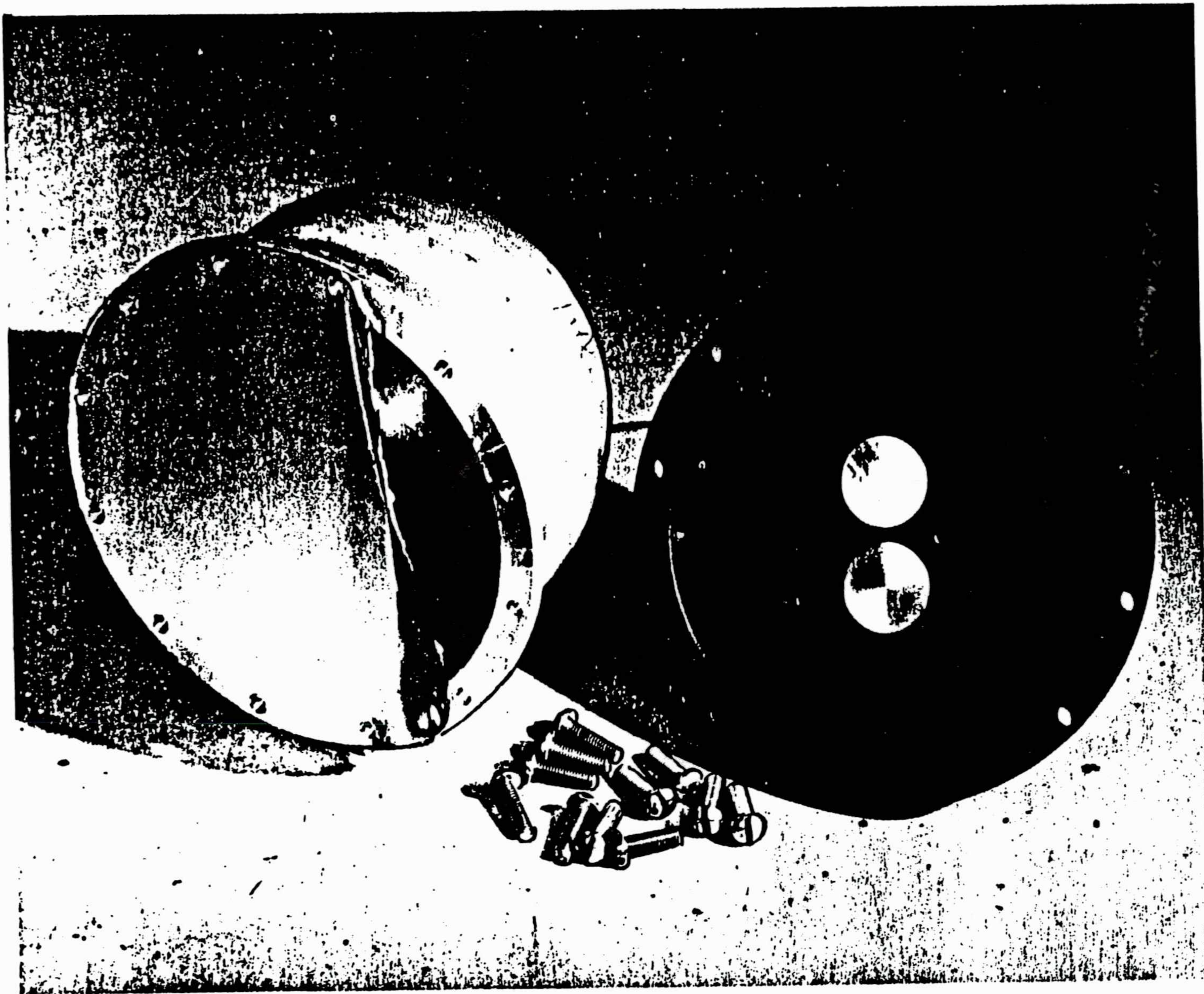


Figure 4 View Showing Internal Construction of Microphone-Transmitter

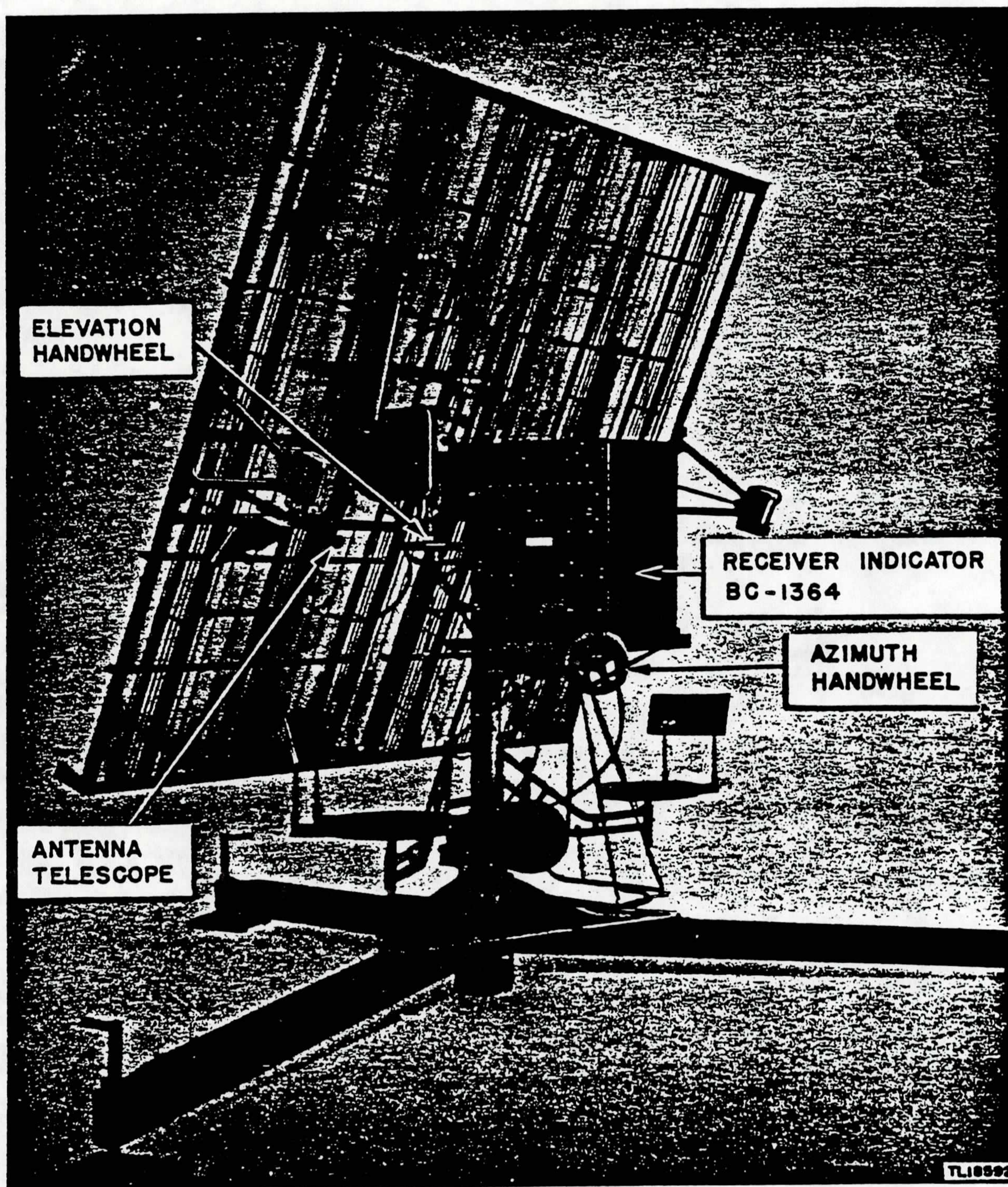


Figure 5 Radio Set SCR-658 (Reproduced by permission of U. S. Army Signal Corps)

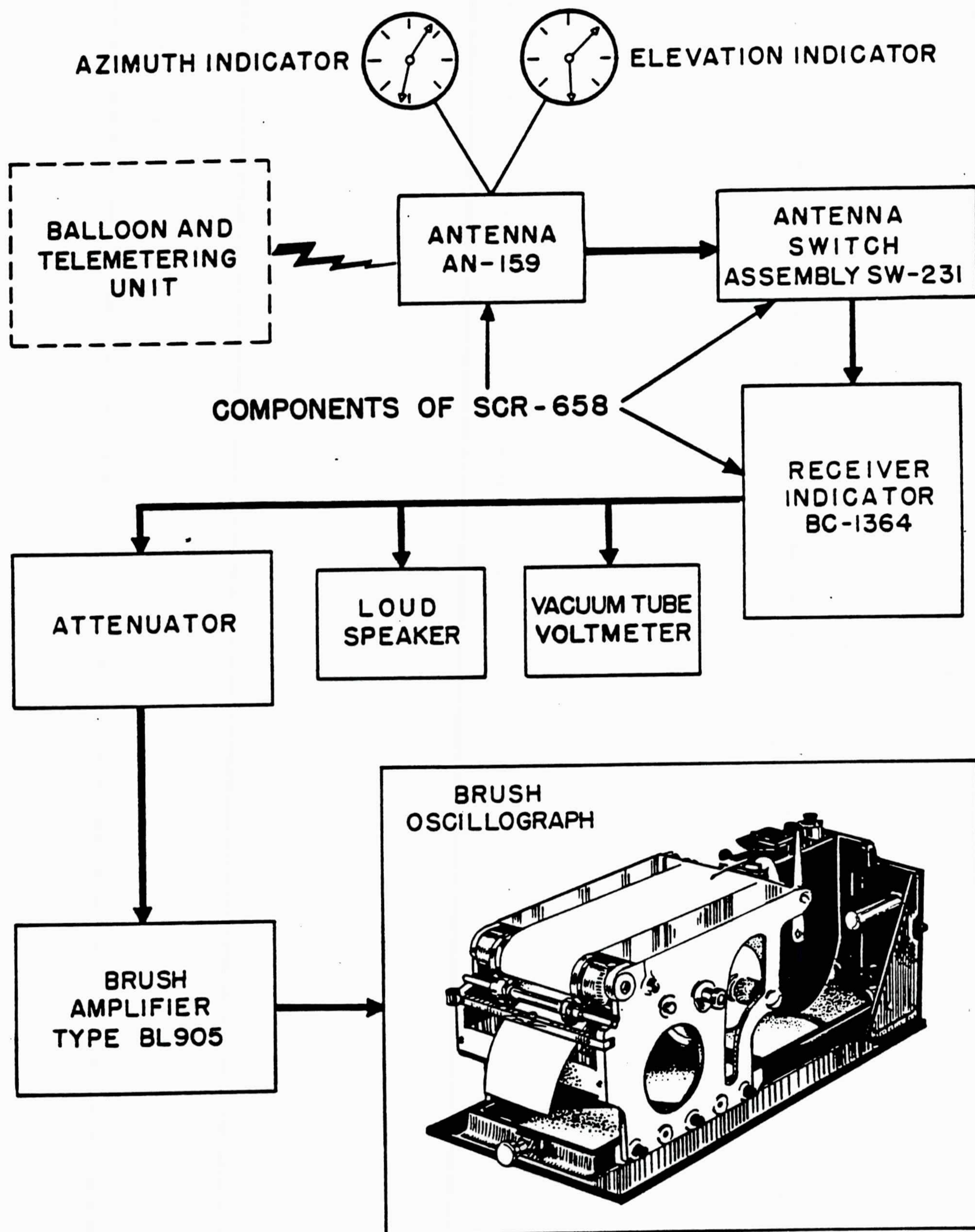


Figure 6 Block Diagram of Ground Receiving and Recording Equipment

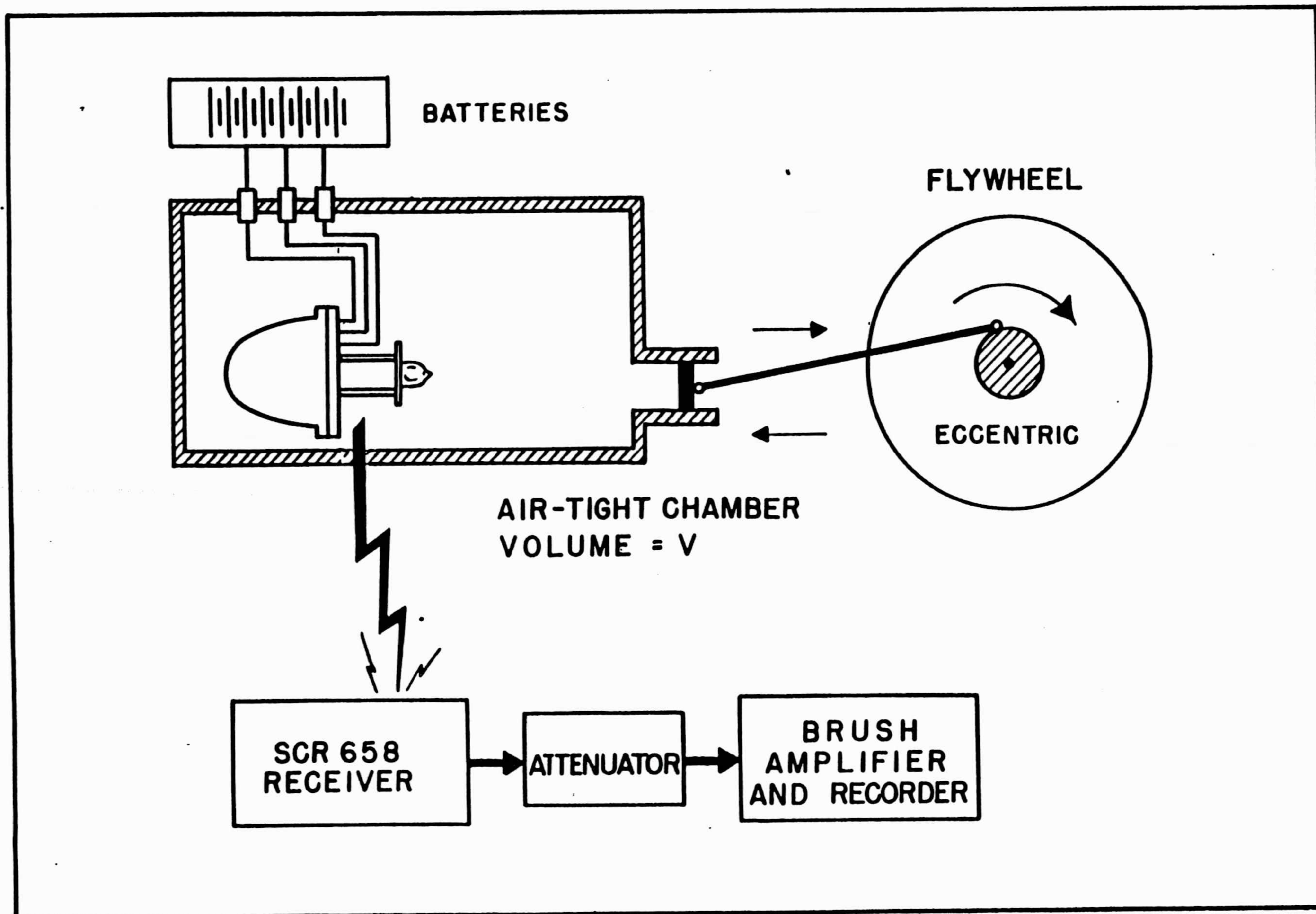


Figure 7 Block Diagram—Pistonphone Calibration

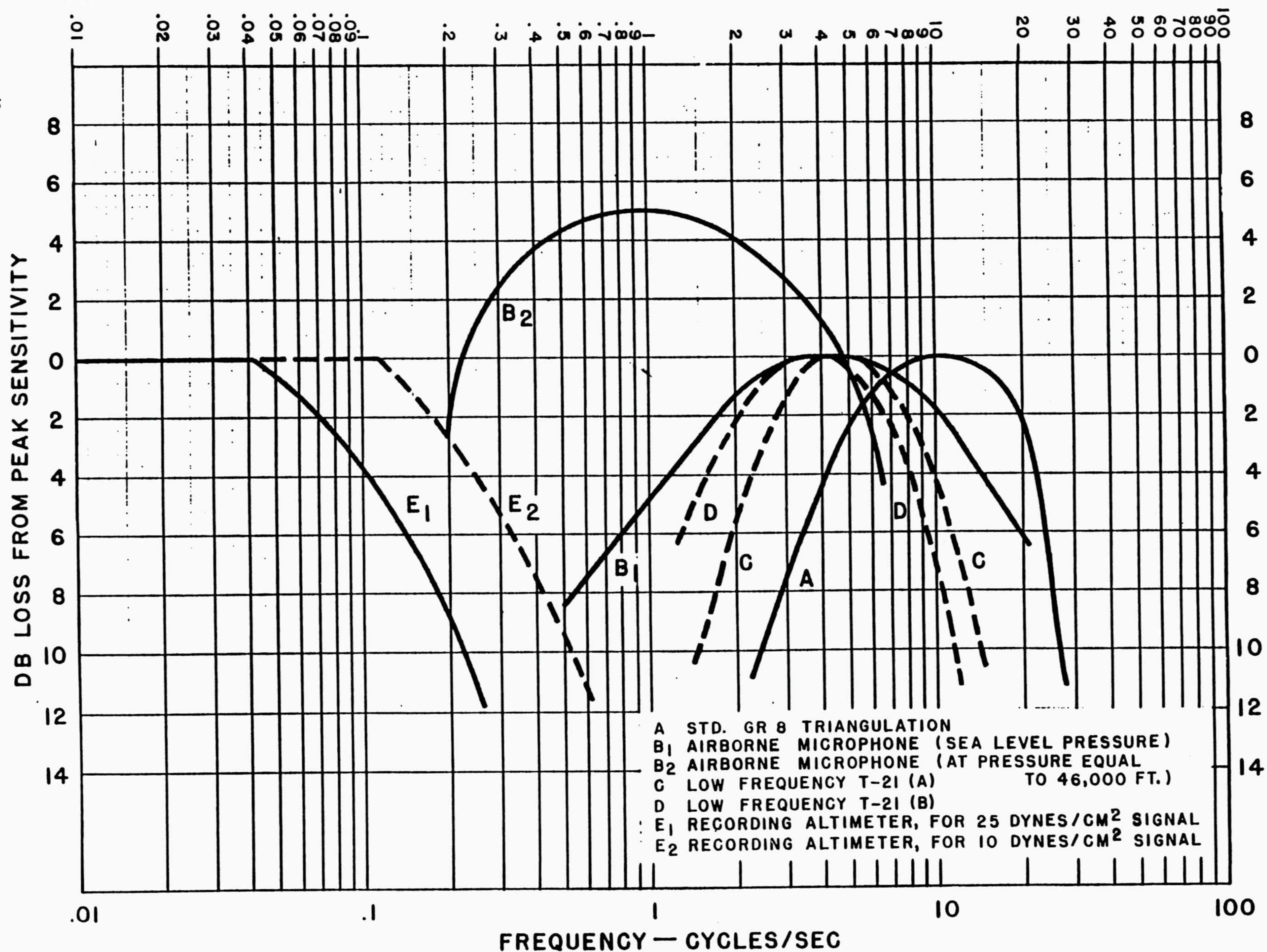


Figure 8 Calibration Curves for All Equipment



Figure 9 Balloon just after Release

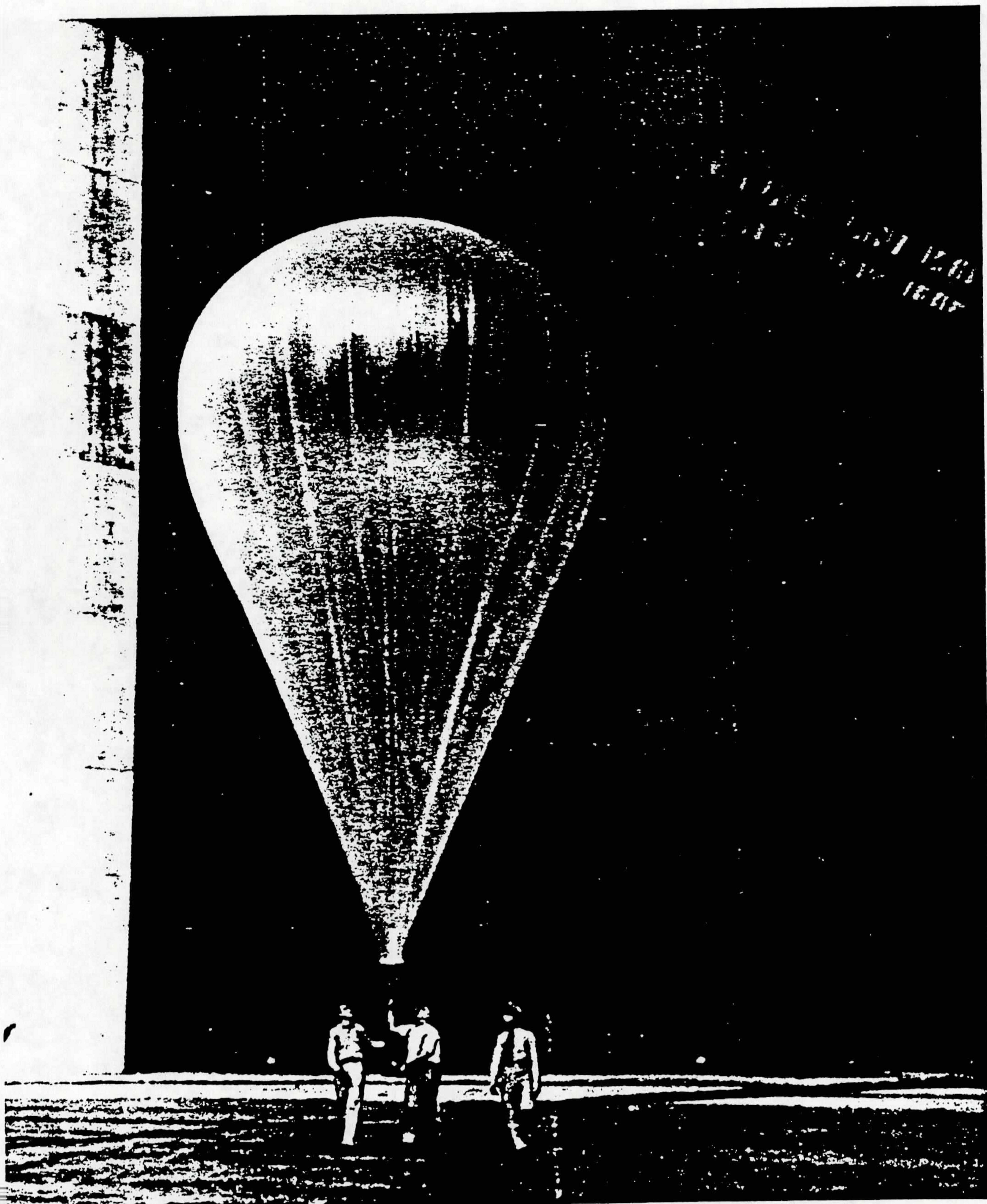


Figure 10 Appearance of Balloons at Ceiling Altitude (This is not a normal launching inflation)

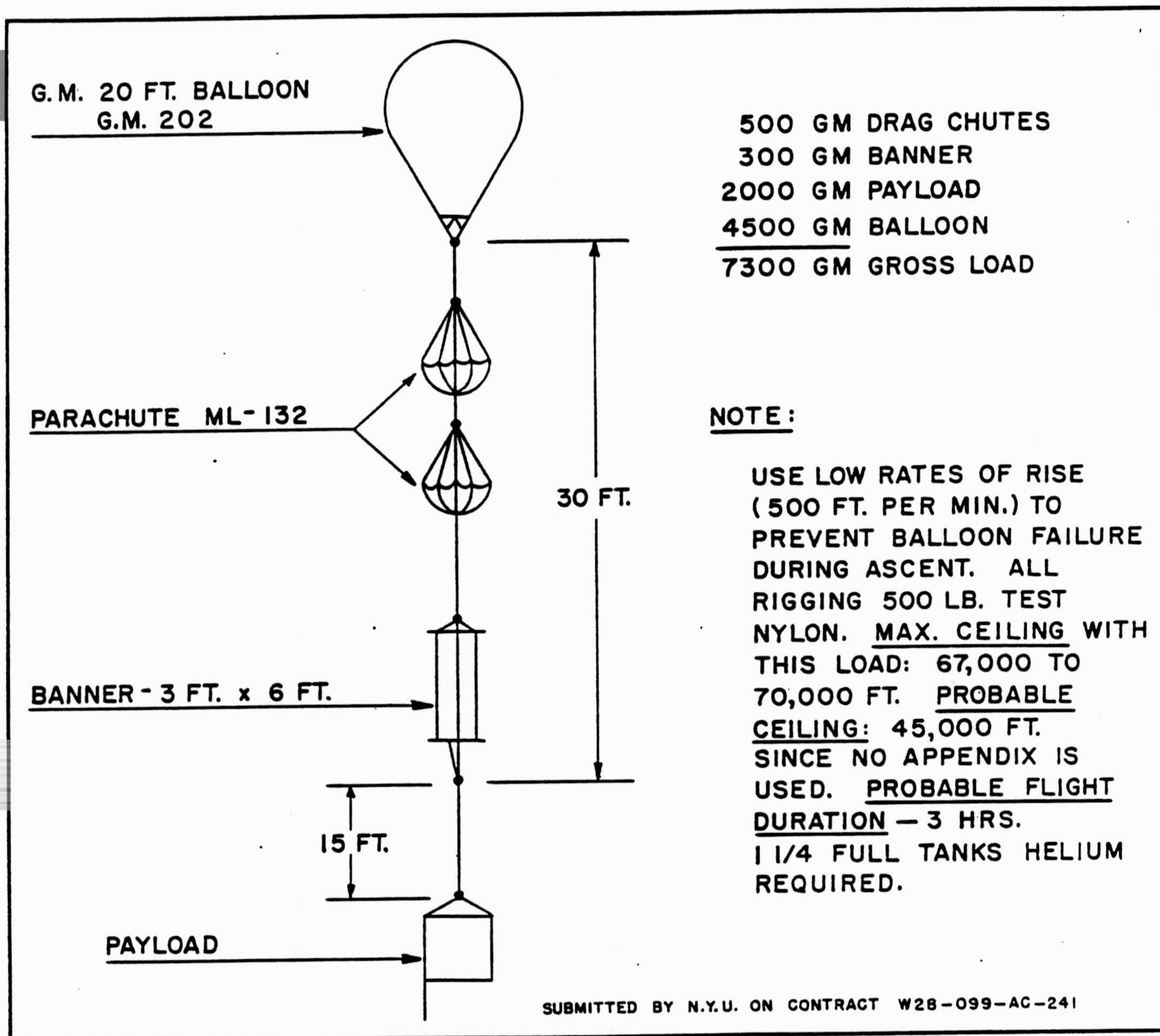
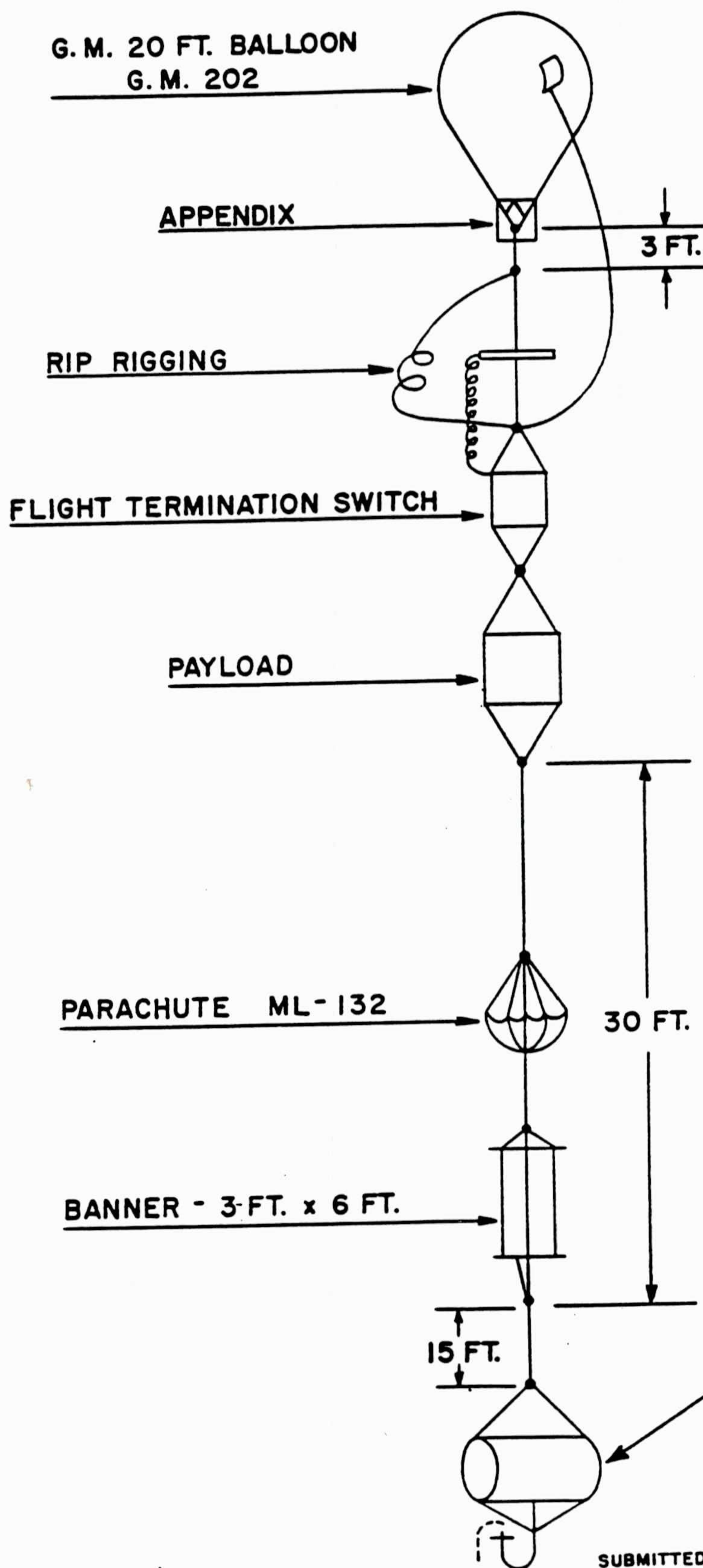


Figure 11 Simplest Balloon Flight Train



1500 GM FT. SWITCH
 500 GM RIGGING
 2500 GM PAYLOAD
 500 GM DRAG & BANNER
 500 GM RESERVOIR
 1500 GM BALLAST

 7000 GM NET
 4500 GM BALLOON

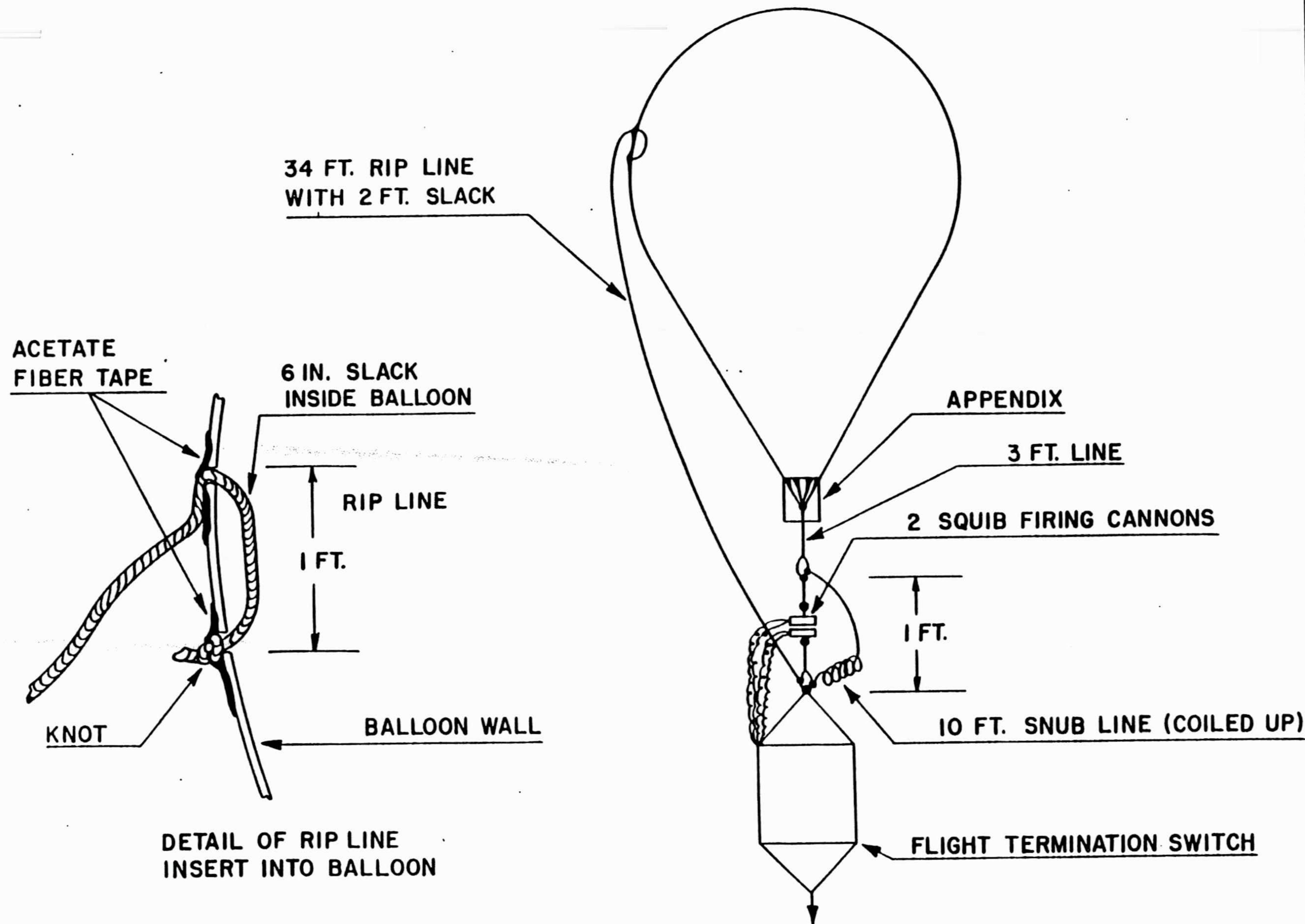
 11500 GM GROSS

NOTE:

CEILING - 59,000 FT. TO
 63,000 FT. ALL RIGGING
 500 LB. TEST NYLON.
 2 FULL TANKS HELIUM
 REQUIRED. PROBABLE
 FLIGHT DURATION - 10 HRS.

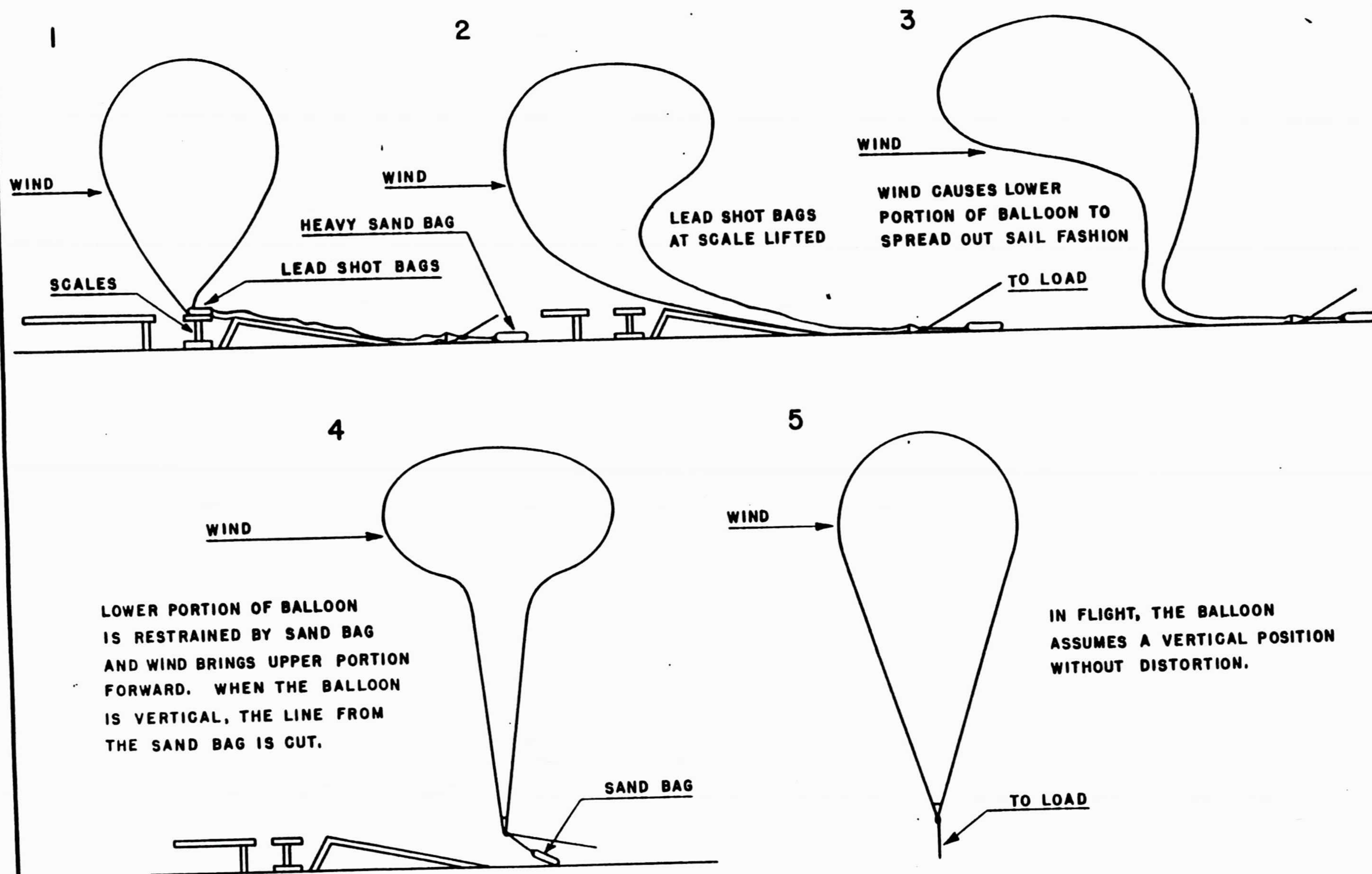
SUBMITTED BY N.Y.U. ON CONTRACT W28-099-AC-241

Figure 12 Normal Balloon Flight Train



SUBMITTED BY N.Y.U. ON CONTRACT W28-099-AC-241

Figure 13 Balloon-bring-down Device



SUBMITTED BY N.Y.U. ON CONTRACT W28-099-AC-241

Figure 14 Method of Launching Balloons

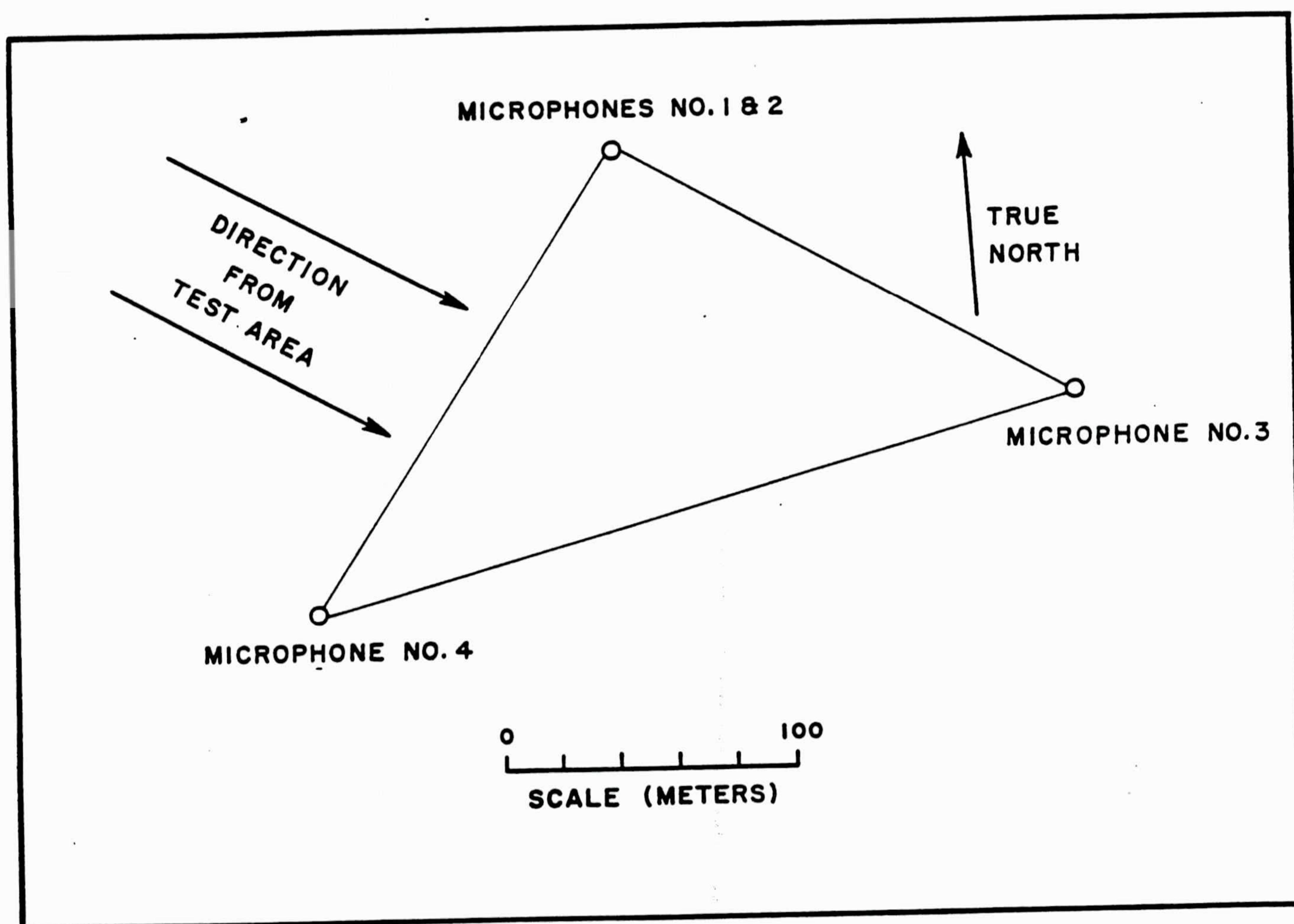
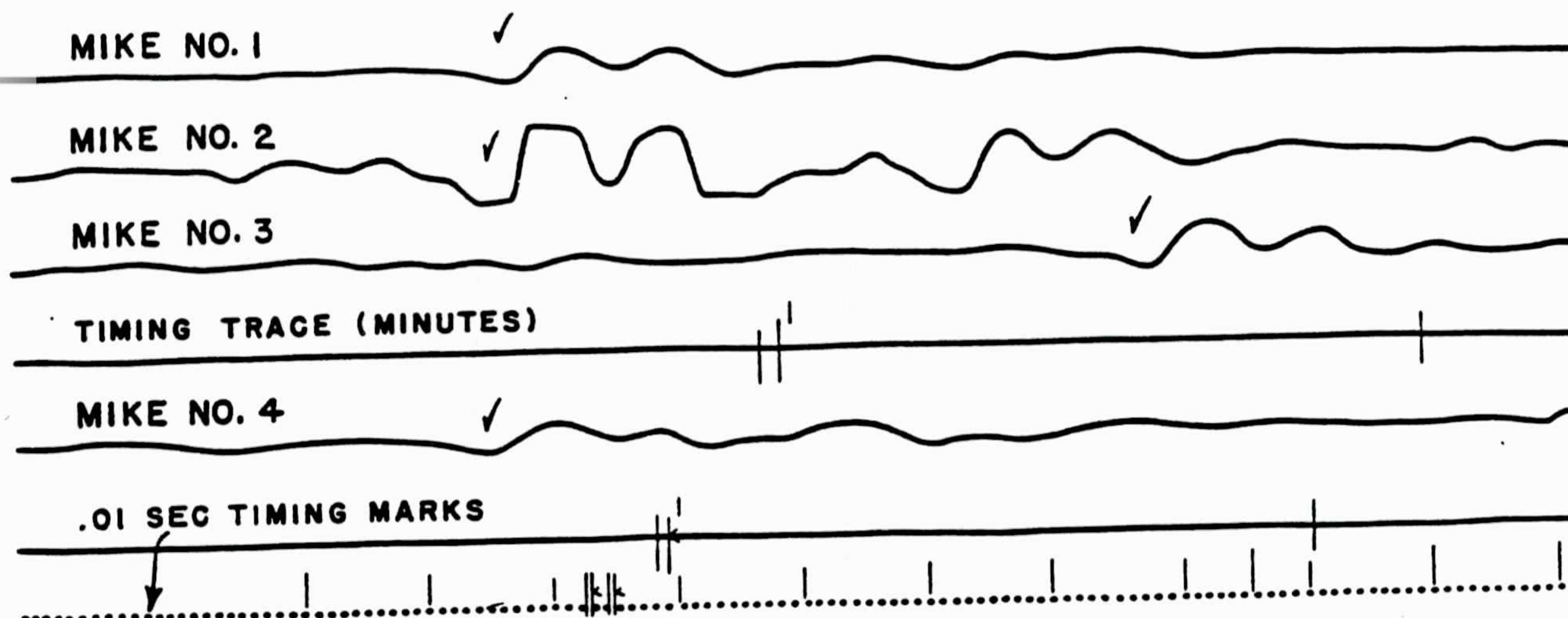
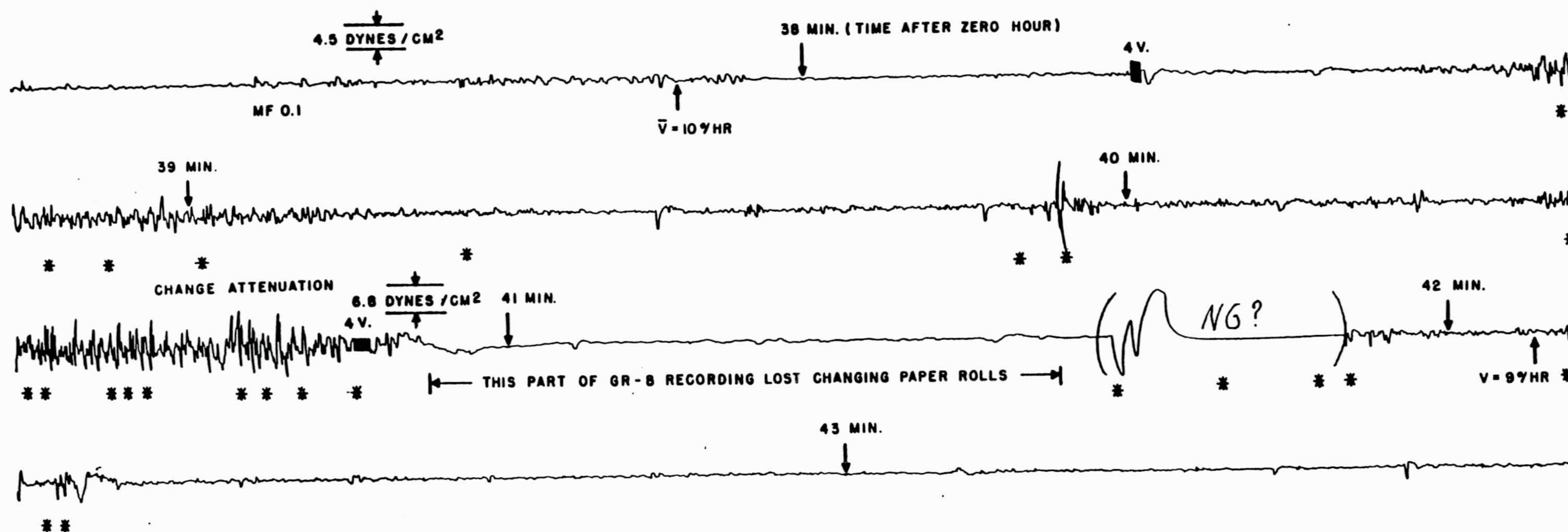


Figure 15 Test X, Kwajalein Island; Microphone Array and Sample GR-8 Record



ASTERISKS (*) INDICATE TIMES OF POSITIVE SIGNALS ON GR-8 TRIANGULATION SYSTEM

Figure 16 Test X, Kwajalein Island; Low Frequency T-21 Record

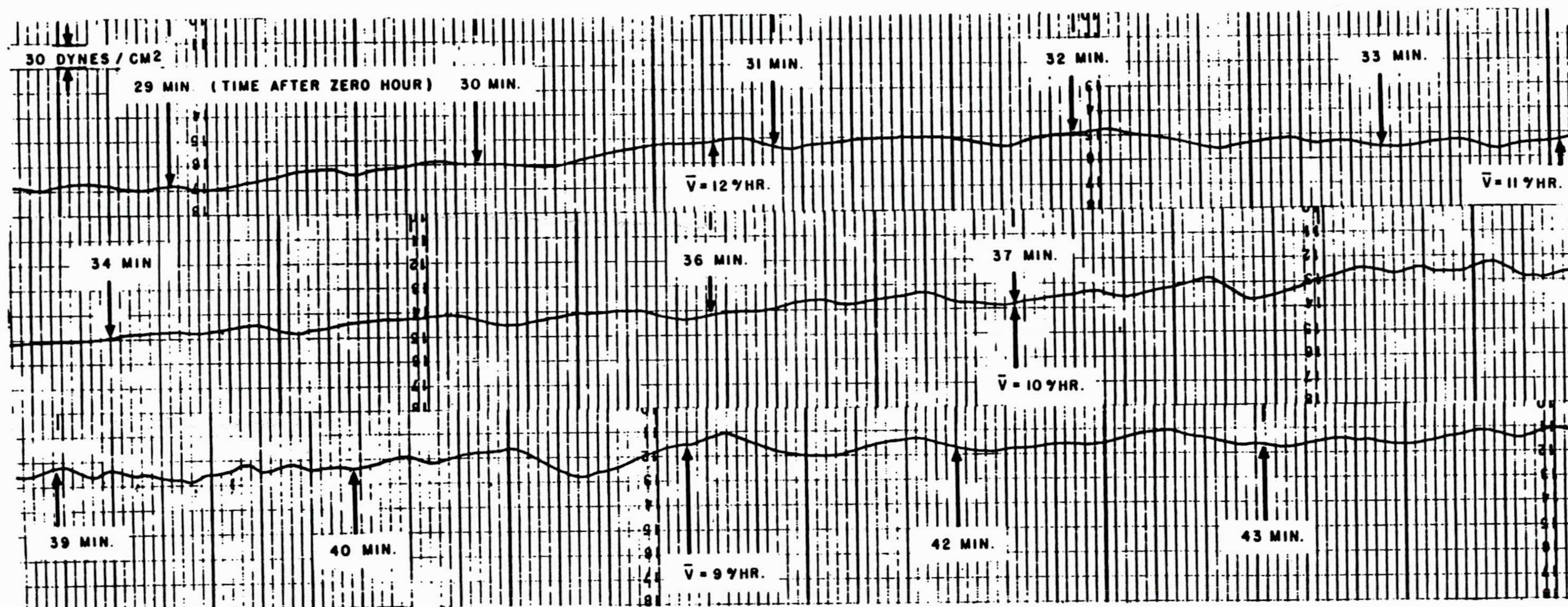


Figure 17 Text X, Kwajalein Island; Recording Altimeter Record

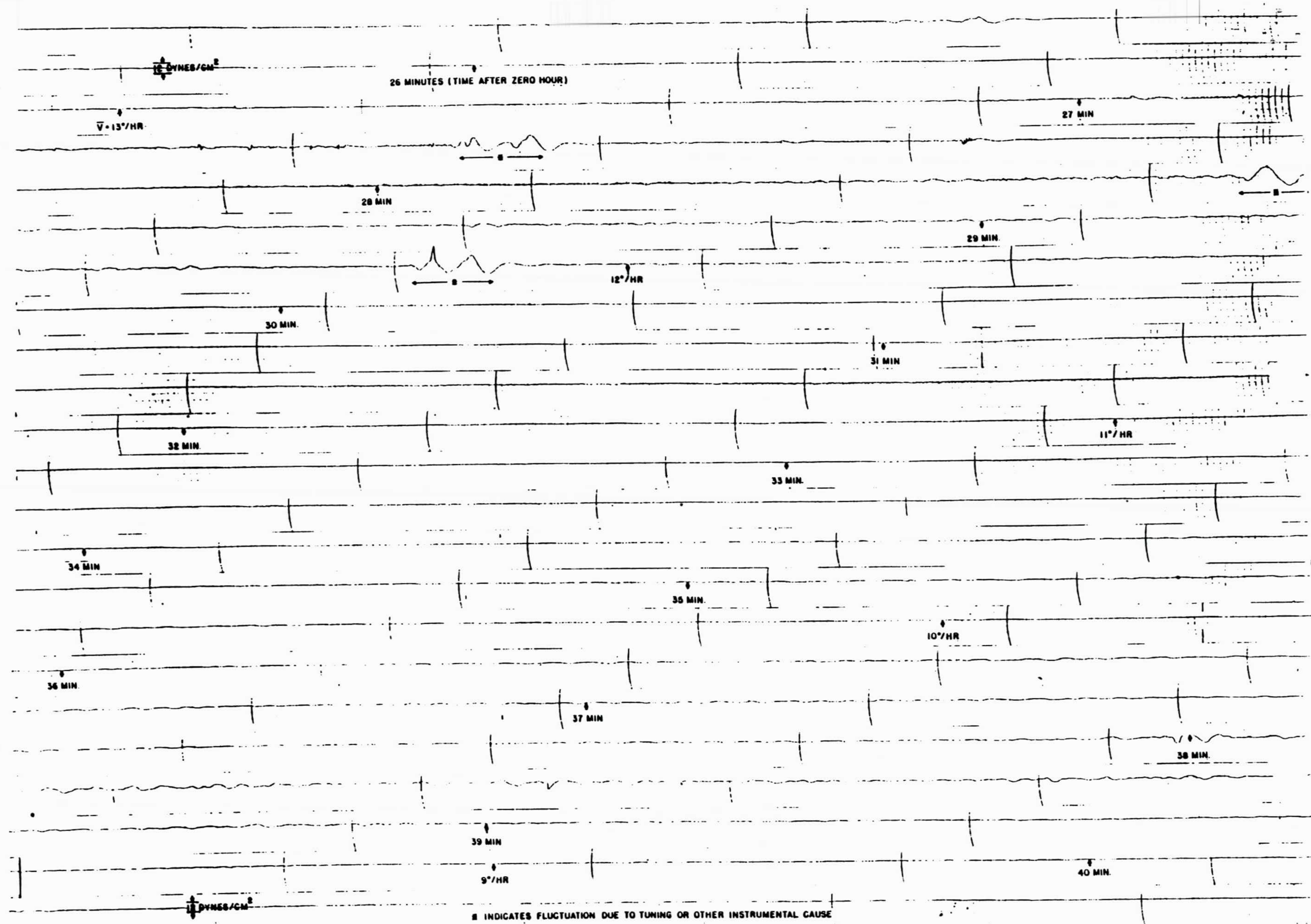


Figure 18 Test X, Kwajalein Island; Balloon-Borne Microphone Record

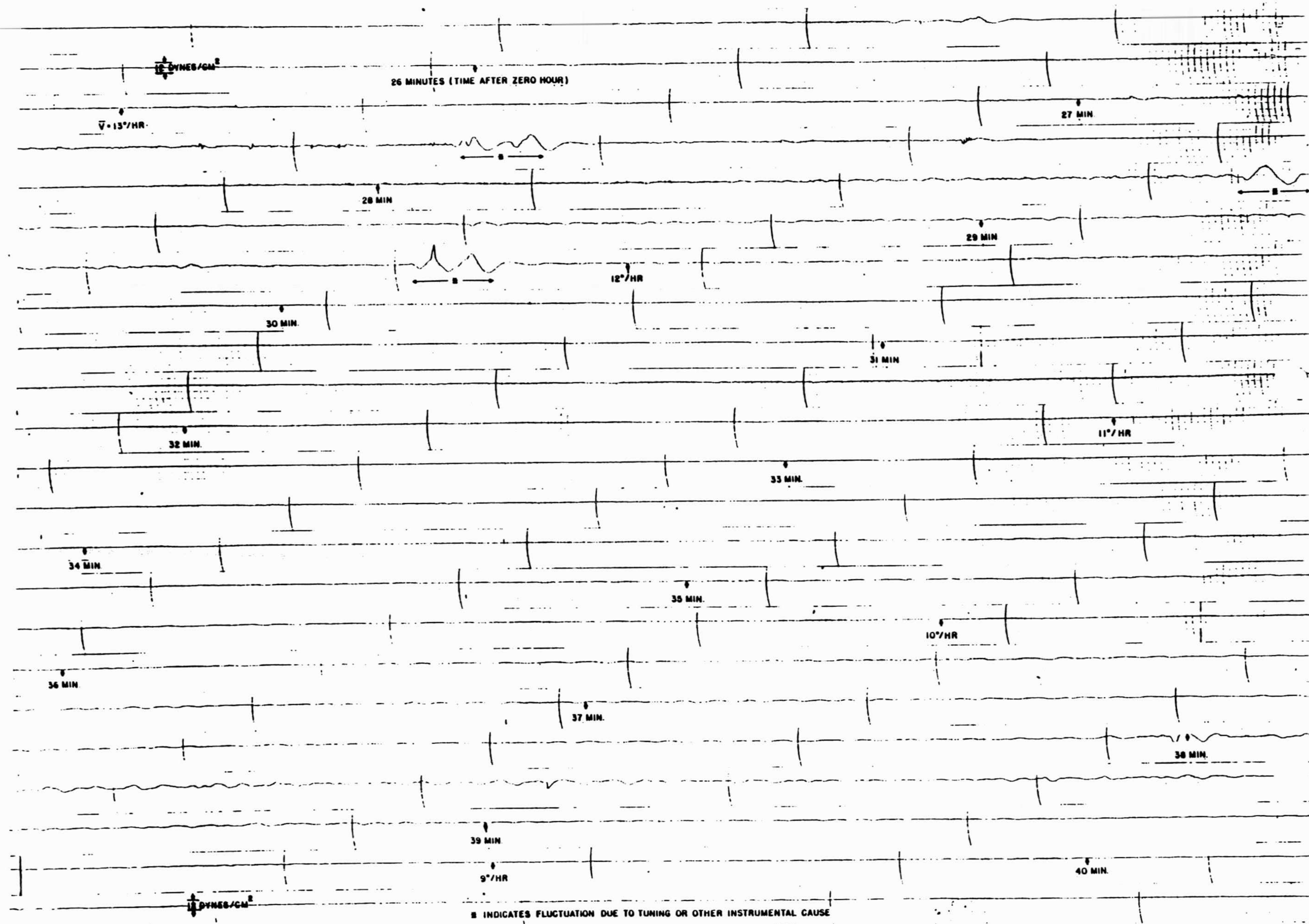


Figure 18 Test X, Kwajalein Island; Balloon-Borne Microphone Record

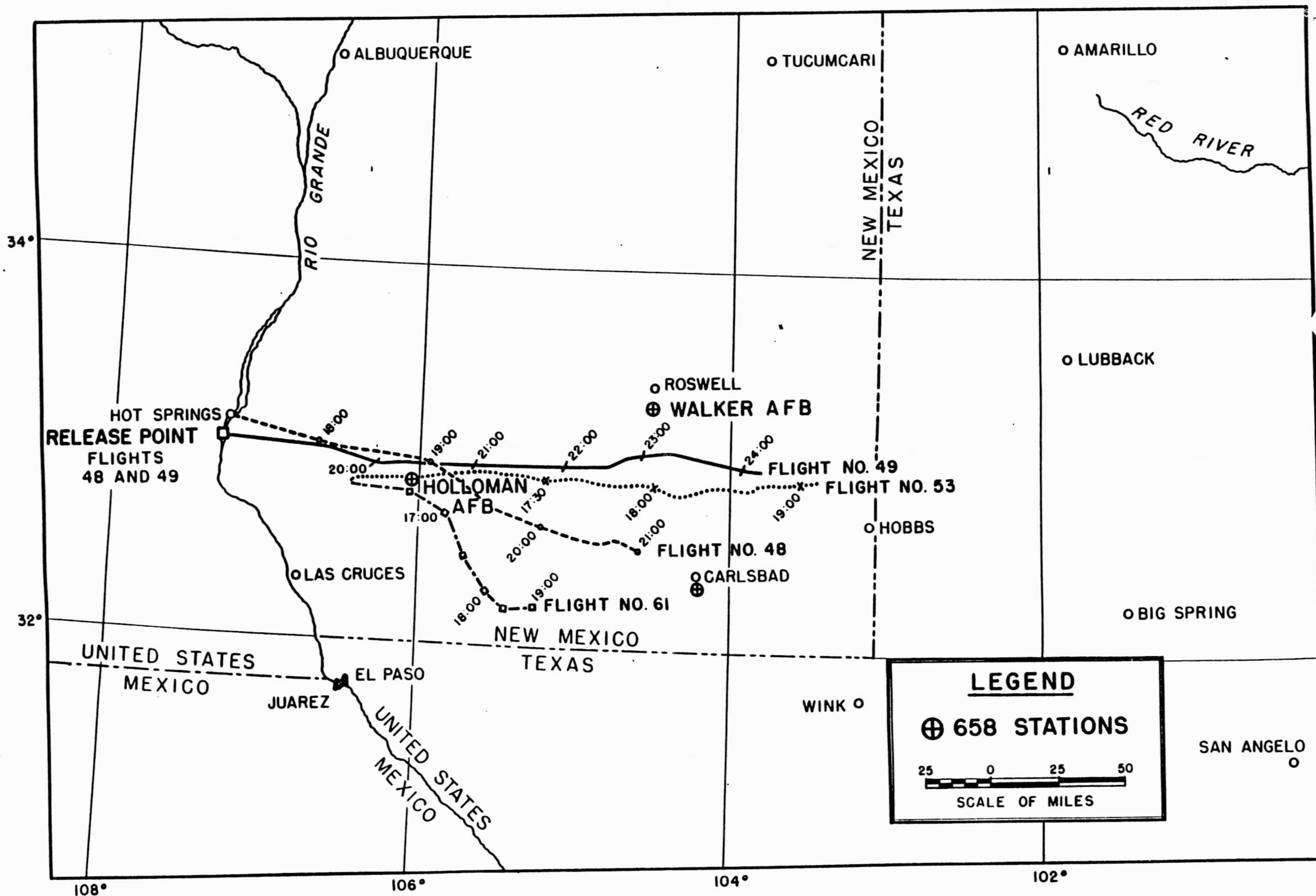
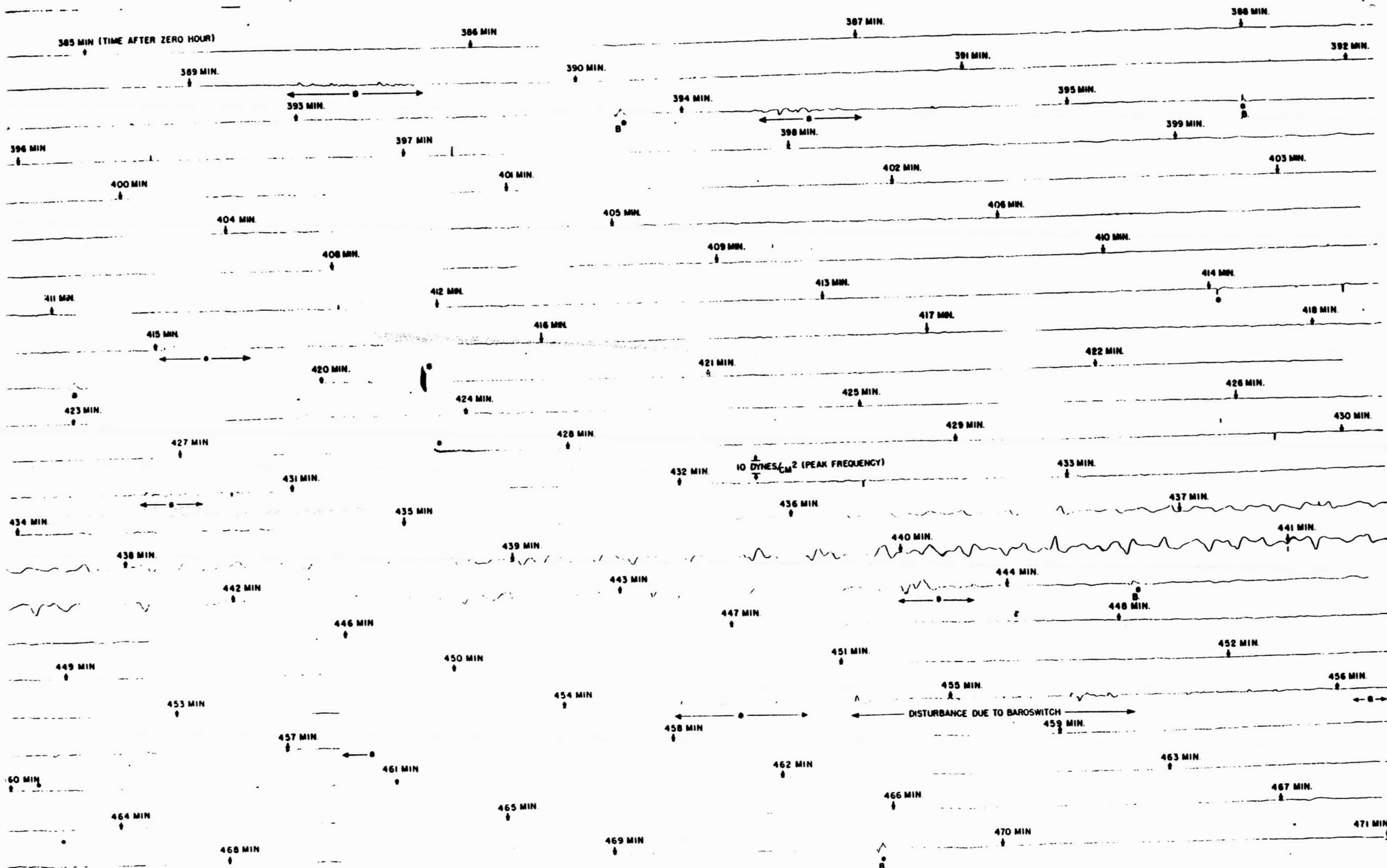


Figure 19 Map of Alamogordo Operational Area



* INDICATES FLUCTUATION DUE TO TUNING OR OTHER INSTRUMENTAL CAUSE

Figure 26 Test Z, Alamogordo, N. M.; Balloon-Borne Microphone Record

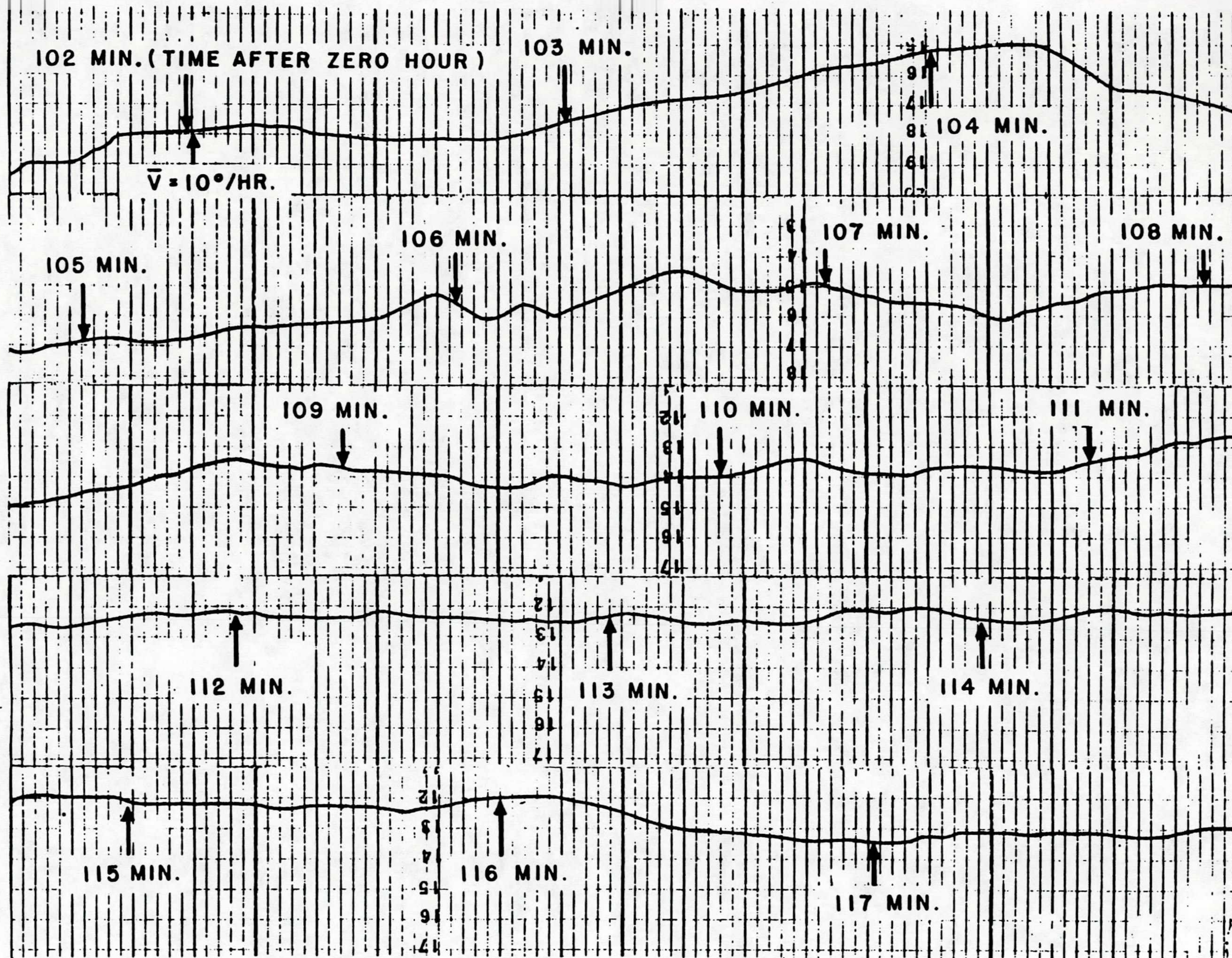
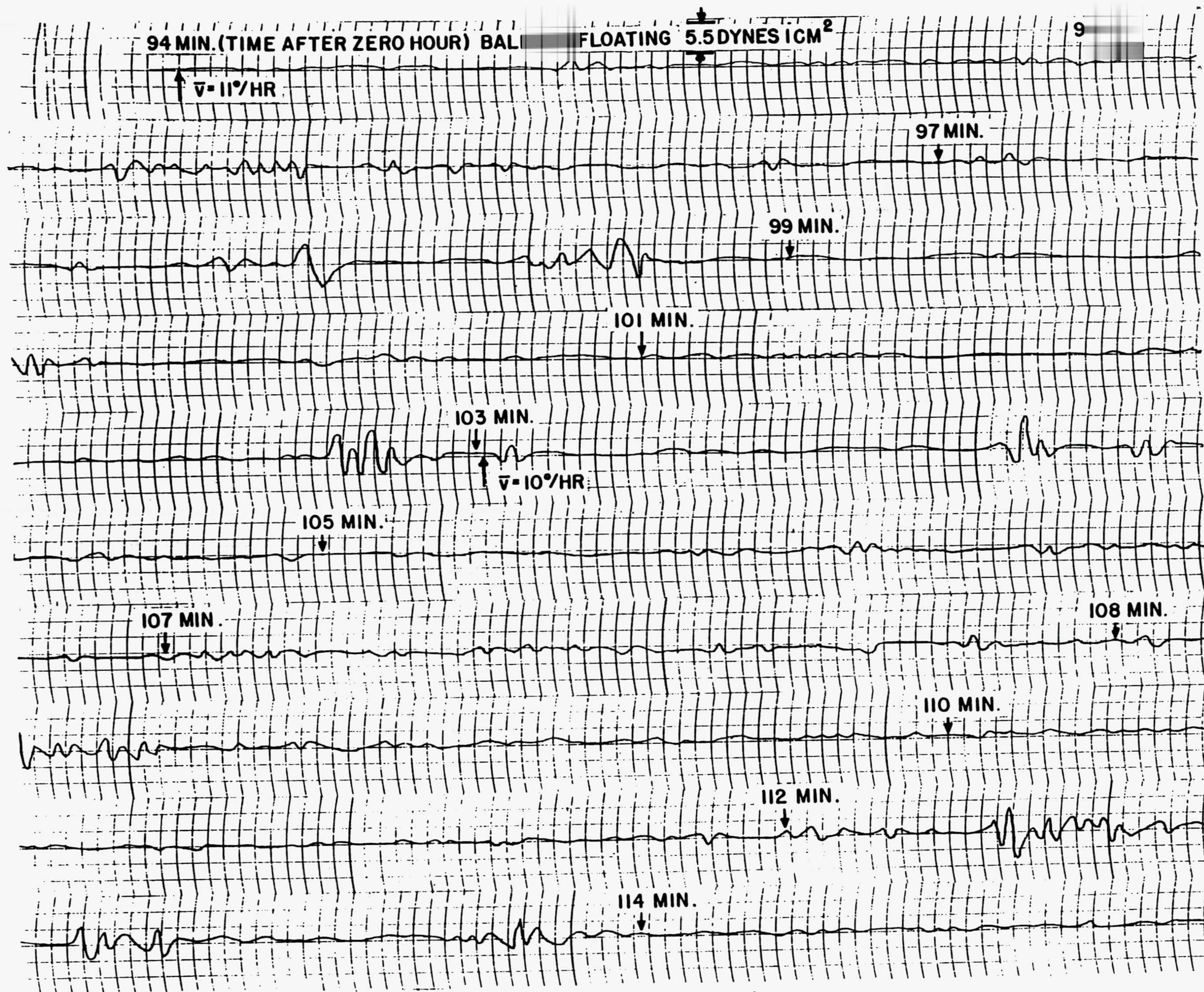
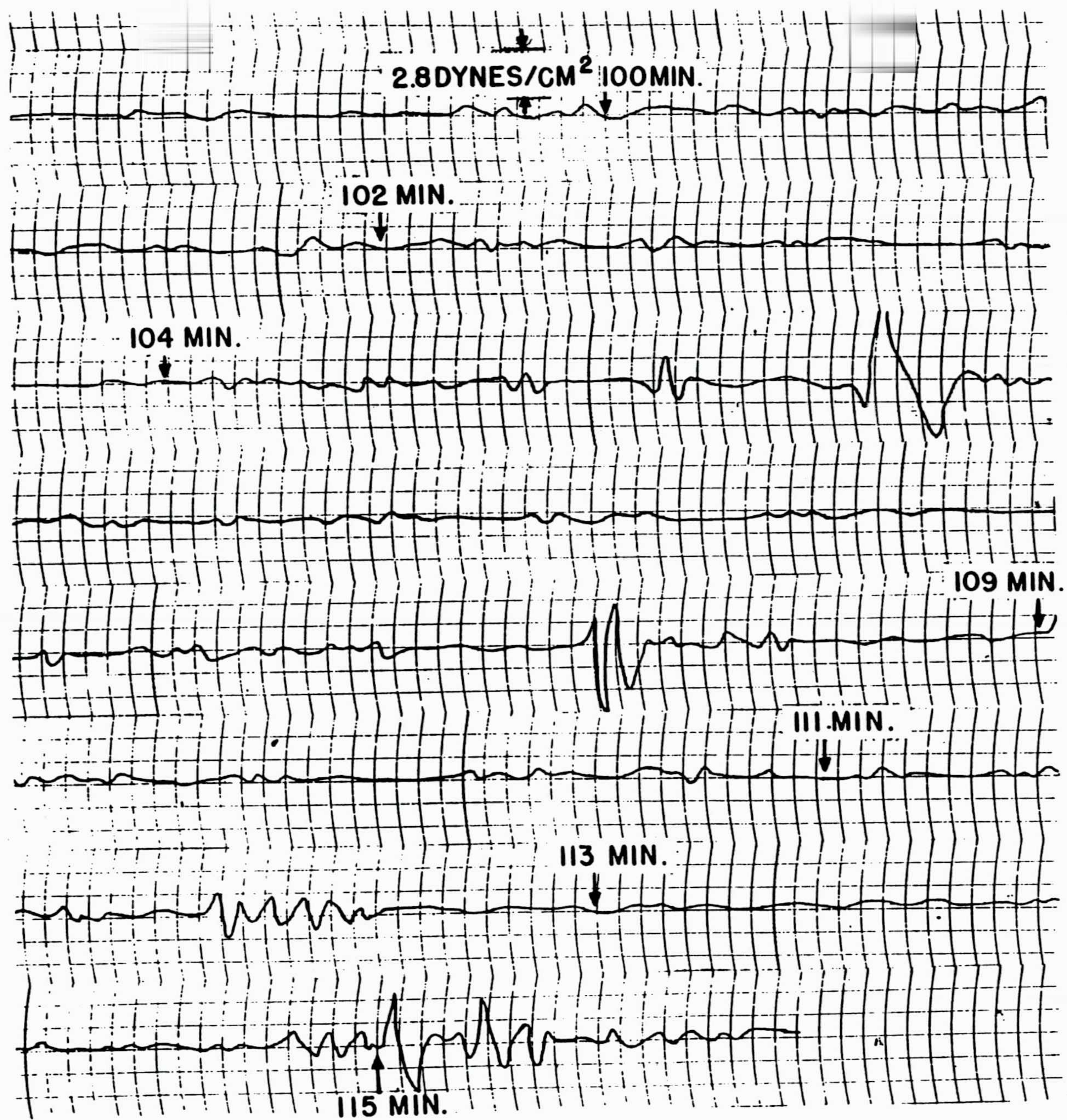


Figure 21 Test Y, Guam M. I.; Recording Altimeter Record



(THIS RECORD IS A COPY OF THE ORIGINAL WITH A REDUCED TIME SCALE.)



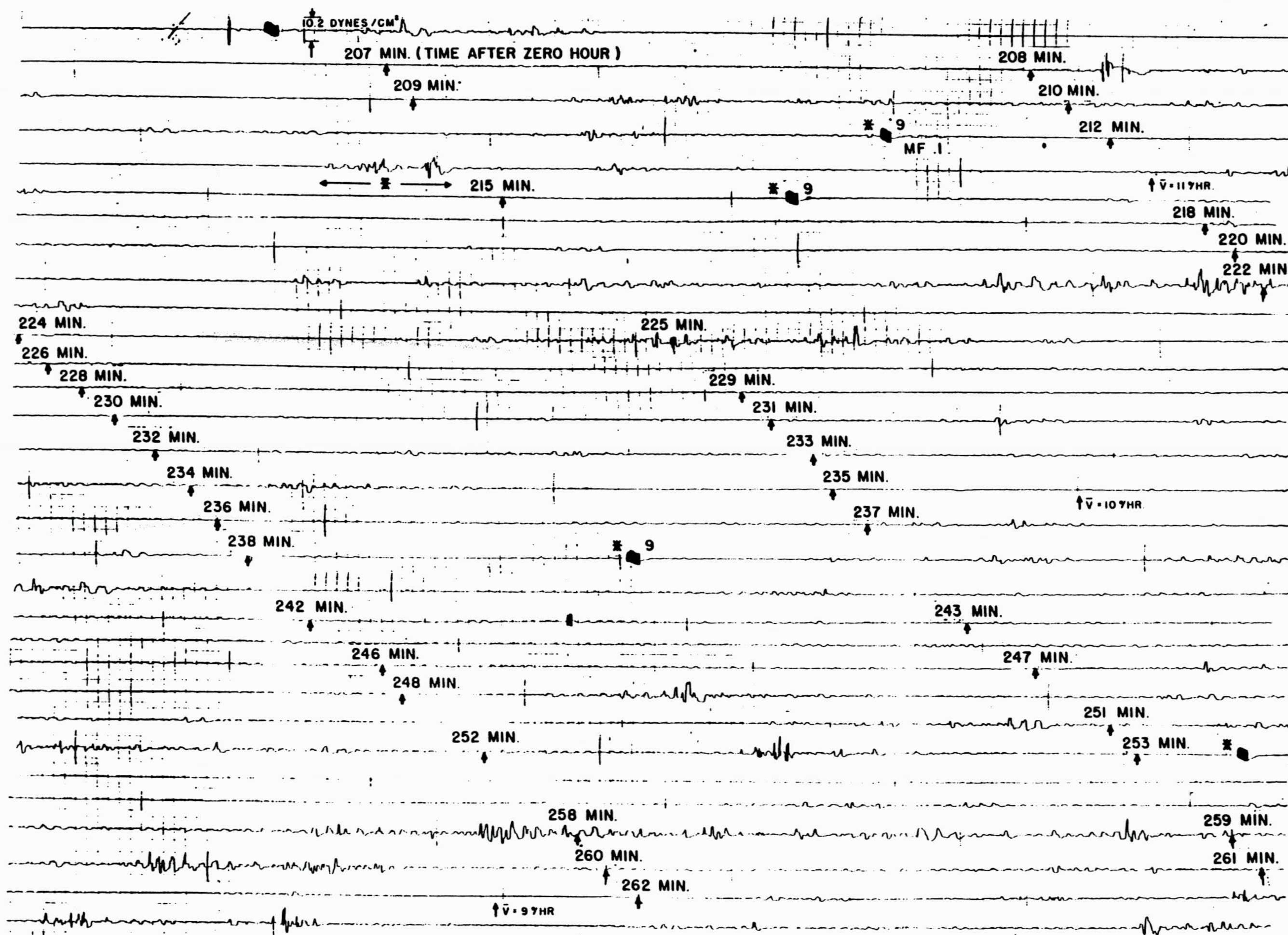


Figure 23 Test Z, Oahu, H. I.; Low Frequency T-21 Record

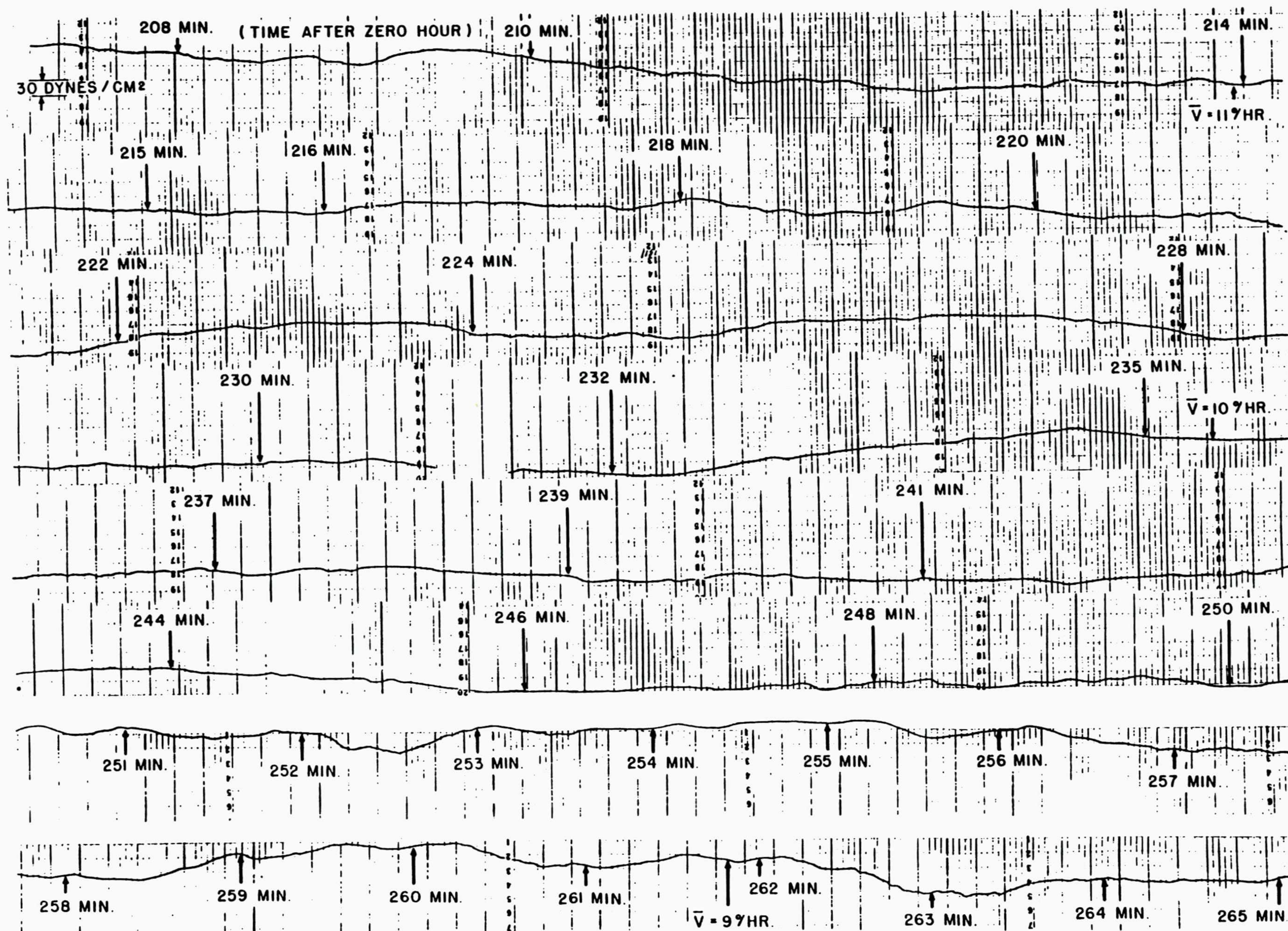


Figure 24 Test Z, Oahu, H. I.; Recording Altimeter Record

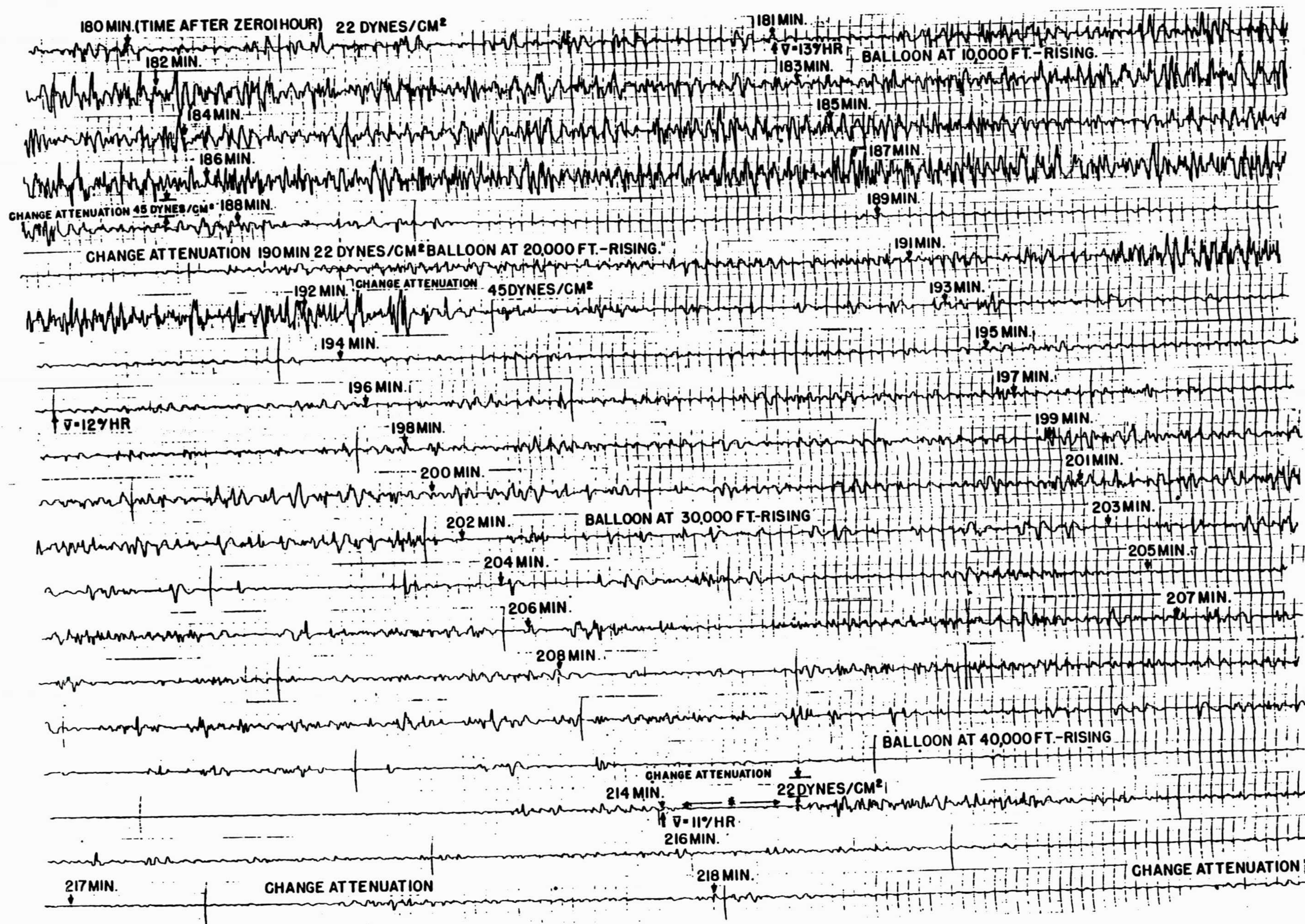
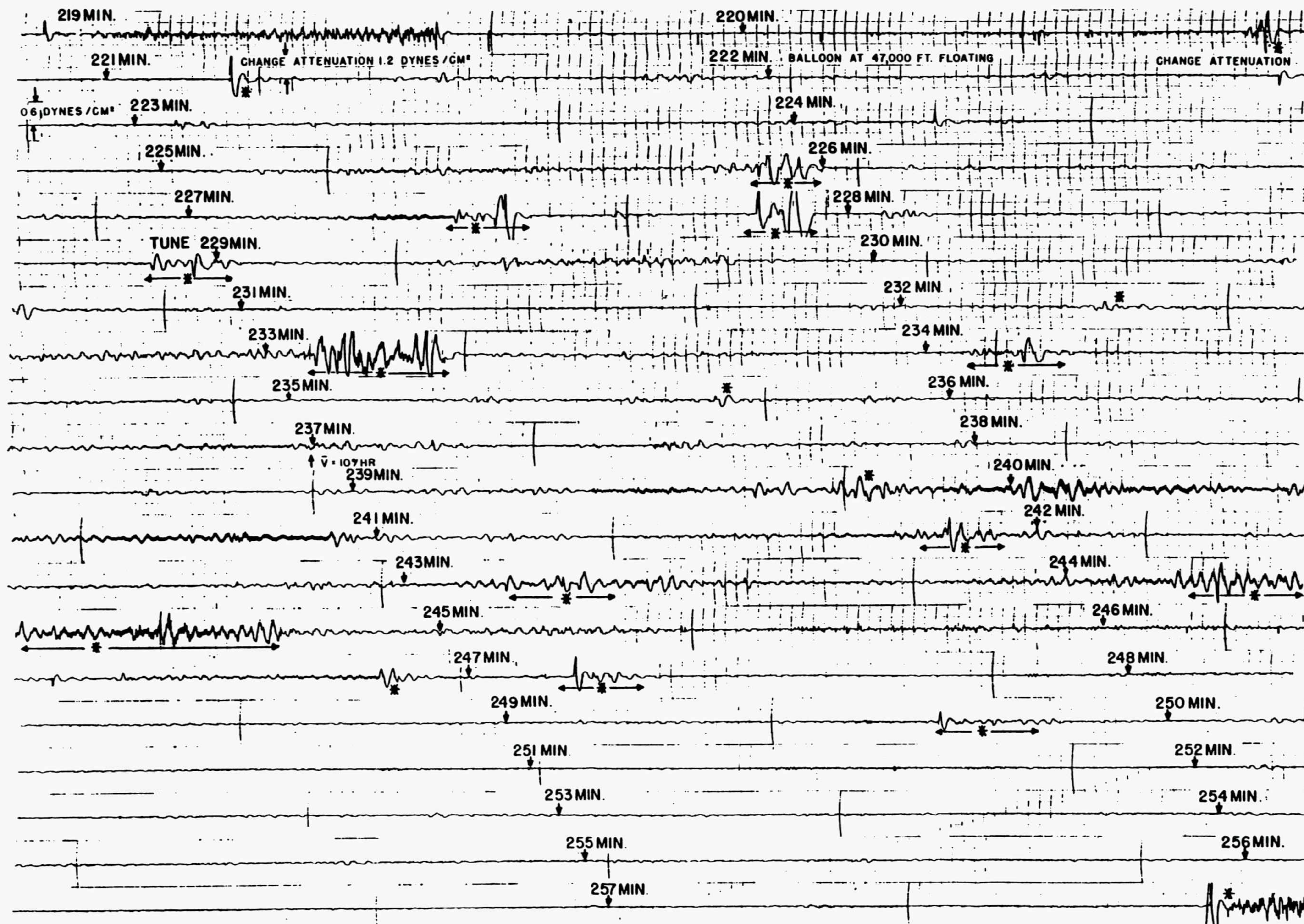
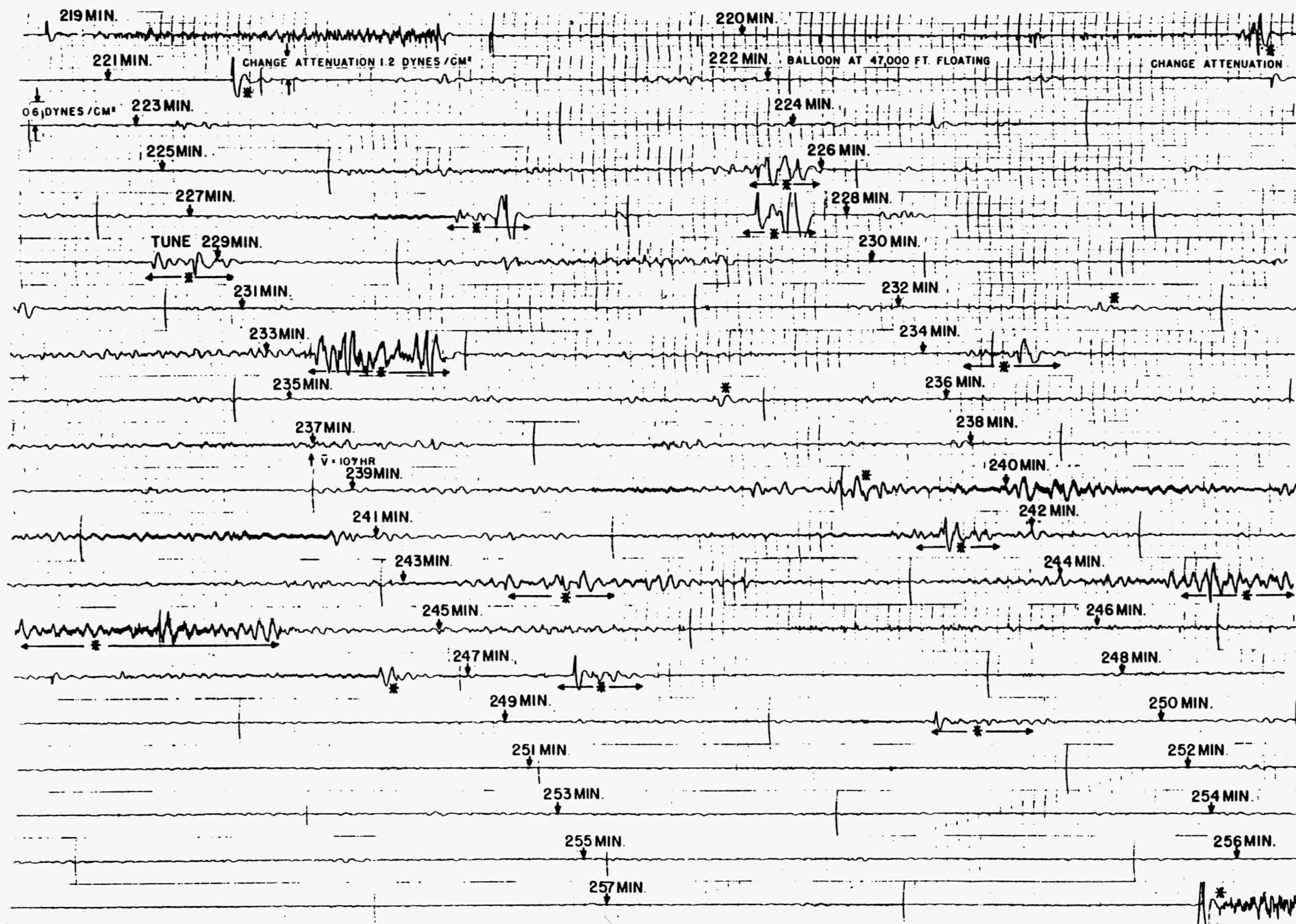


Figure 25-1 Test Z, H. I.; Balloon-Borne Microphone Record



* INDICATES FLUCTUATION DUE TO TUNING OR OTHER INSTRUMENTAL CAUSE.

Figure 25-2 Test Z, H. I.; Balloon-Borne Microphone Record



* INDICATES FLUCTUATION DUE TO TUNING OR OTHER INSTRUMENTAL CAUSE.

Figure 25-2 To — Balloon-Borne Microphone Record

Charles B. Moore
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505 835 0975

June 11, 1994

Col. Jeffrey C. Butler
Lt. James McAndrew
SAF/AA
1720 Air Force Pentagon
Washington, DC 20330-1720

Gentlemen:

Enclosed for you are copies of the first papers published in the open scientific literature by Albert Crary on the Watson Laboratories investigation of the propagation of explosion-generated pressure waves. Also included are copies of pertinent pages from the 1983 Smithsonian Press book, *Krakatau 1883*, by Tom Simkin and Richard S. Fiske.

After your visit, I examined the Signal Corps Drawing # SC-14407 (PILOT BALLOON TARGET ML-307C/ AP ASSEMBLY) more carefully and discovered several interesting and significant features in the notes on the right side:

The drawing was first made on June 9, 1944 to describe a ML-307 /AP target. It was modified on Nov. 21, 1944 with Revision B and the figure was redrawn. After the revision, the target designator was changed to ML-307-B/AP.

Revision C was made, without change of designator, on March 12, 1945 when components #17 and #21 (whatever they were) were deleted. At this time, item #23 (a bracket at the vertex of the three corners) and the "Enlarged View J" (in the upper left) were added. The incorporation of this bracket in the target design on March 12, 1945, so close to the end of the war, suggests that few targets with this feature could have been procured and then distributed for use before the end of hostilities. This note is of particular interest because the targets we flew from Alamogordo had such a center bracket.

The ML-307-B/AP nomenclature apparently was continued until January 8, 1951 when Revision D was made. At this time, the "CENTER SUSPENSION [was] REMOVED" from the design, two or three indecipherable features were deleted, a material specification was added (but not given on this drawing), and the target was renamed the ML-307C/AP.

In 1953 (February 18 and 4[?] March), revisions E₁ and E₂ were made to specify the glue, the tolerances on the dimensions and the elimination of glue in foil-to-foil joints. The targets that we have, apparently procured under the March 1953 revision, were manufactured in December, 1953, so there was a fairly long time lag in the 1950's between design changes and the manufacture of new targets.

It should be noted that this drawing is not an accurate depiction of the ML-307 C/AP targets manufactured in 1953. In the sketch on panel B (View V[?] just below the center of the figure), item 22 (Scotch Acetate tape) is shown as holding the turning vane to panel B. There is no tape in the 1953 model C targets either on the vanes or associated with Faces B, C or D. Similarly, "Enlarged View J" is not applicable to these targets and the metallic surfaces are not the specified aluminum foil.

In view of the subsequent revisions, it is unlikely that Drawing SC-D-14407 is an accurate description of the ML-307- B/AP version of the targets. The important information conveyed by this drawing, however, is that the ML-307- B targets with the bracket were manufactured after March 1945 which suggests that

these targets could not have been distributed widely during the war. However, since the targets we used in 1947 had such brackets, from the preceding, it seems probable that they were the ML-307-B/ AP version.

In September, 1993, Edwin J. Istvan (who was a lieutenant on Col. Duffy's staff in 1944 responsible for aiding the development of radar targets to be used in wind measurements with a SCR-584 radar) told me that, when production models of the improved design corner reflectors (apparently the ML-307-B) were first flown in late 1944 or early 1945, they failed and had to be reinforced. He also told me that, after this problem arose, he had devised the vertex bracket to strengthen the targets. His memory is consistent with the revisions made to the B model on March 12, 1945. The identifier for the Scotch acetate tape on the drawing is #22, near the end of the list. The bracket is identified as #23, the vane is #24 and the last item (the swivel) is #25. The location of items #24 and #25 in the list suggests that they were added on or after March 12, 1945.

Istvan's current address is 1216 Swan Harbour Circle, Fort Washington, MD 20744. His telephone number is 301 292 2342. He probably could add more information if his memories were refreshed by looking at a ML-307 target and at the assembly drawing. From the notations on this drawing, it appears that the Signal Corps personnel produced other, more detailed drawings such as the Exploded View #SC-D- 17239, # SC-D-14408, #SC-D-14409 and Drawing List # SC-DL- 20560, all of which might be informative.

On June 10, I sent you (via UPS) the ML-307(C) target that we examined here. After shipping it to you, I found the eyelet/hook used to attach the horizontal cord that keeps the target erect. The eyelet is enclosed in the attached polyethylene bag.

I would appreciate your finding a suitable home for the target when your need for it has ended. Perhaps one of the museums at Fort Monmouth, the Smithsonian or at Fort Sill might wish to add it to their collections. If none of them do, I'd appreciate its return here for storage at Langmuir Laboratory.

Carl Day, at WDTN -TV in Dayton, recently produced a television program on the "Roswell incident" that was entitled "Alien Encounters: The WPAFB Connection". During a telephone conversation with me in preparation for the program, Day told me that he had been in school during the 1950's with one or more of Col. Duffy's children. Since Col. Duffy remembered their interest in his identification of the UFO, perhaps they might have a more vivid memory of the late night visit to Col. Duffy in his quarters at Patterson. Probably the best contact with them might be through Emily Duffy at 4 Collins Court, Barrington, RI 02806 (Telephone in 1993: 401 245 2839).

I wish you success in reconstructing the events that led to the "incident". If I can help, please let me know.

Sincerely,

Charles B. Moore

cc: Lt. McAndrew

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REVIEW BY CHIEF OF STAFF
BY W R F
AFOATC
DATE 12 Dec 49

FINAL REPORT ON PROJECT "BIRTHROOT"

BY

GEORGE D. LUKES

FRED B. DANIELS

JOHN M. BRITTAIN

27 MAY 1949

Official: C. F. Matthews
C. F. MATTHEWS
Lt. Colonel, Signal Corps
Executive Officer
Evans Signal Laboratory

Copy No. 30

**EVANS SIGNAL LABORATORY
BELMAR, NEW JERSEY**

DECLASSIFIED BY: Army - DAMO-SSN Ltr,
14 Feb 94

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FINAL REPORT ON PROJECT "BIRTHROOT"

TABLE OF CONTENTS

<u>TEXT</u>		<u>PAGE</u>
SECTION I	INTRODUCTION	1
SECTION II	OPERATION CROSSROADS	2
SECTION III	THEORETICAL AND EXPERIMENTAL BACKGROUND	6
SECTION IV	INSTRUMENTATION	9
SECTION V	SANDSTONE TEST RESULTS	12
SECTION VI	CONCLUSIONS	16
SECTION VII	RECOMMENDATIONS	18
		<u>AUTHOR</u>
APPENDIX A	SCHRÖDINGER'S TREATMENT OF DIS- PERSION AND ATTENUATION IN THE ATMOSPHERE	Fred B. Daniels
APPENDIX B	DESCRIPTION OF EQUIPMENT	John. M. Brittain
APPENDIX C	NOISE REDUCING ACOUSTICAL ARRAY	Fred B. Daniels
APPENDIX D	PROCEDURE FOR ANALYSIS OF DATA FROM INFRASONIC SYSTEM M-2	George D. Lukes
APPENDIX E	ANALYSIS OF THE SOUND PROPA- GATION FIELD OF AN ATMOSPHERE OF VARIABLE TEMPERATURE AND WIND	George D. Lukes

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FINAL REPORT ON PROJECT "BIRTHROOT"

SECTION I

INTRODUCTION

A world-wide net of six experimental stations was established by the Signal Corps to participate in Operation SANDSTONE. Analysis of recordings secured at the six stations of the net has disclosed that no pressure waves corresponding to a source at Eniwetok were recorded at any station in the net, on either Xray, Yoke or Zebra tests. These observational data are in conflict with previous data secured by the Signal Corps at two installations in the United States during the Able test of Operation CROSSROADS in July of 1946, even though present equipment is approximately ten times more sensitive than that used during the CROSSROADS test. The reason for the variance is not known at the present time, but it is considered probable that the explanation may be found in the following considerations:

a. The propagation properties of the atmosphere during the SANDSTONE tests may have obviated against the transmission of sound to long distances, either as a result of time of day, season, or atmospheric structure.

b. The intrinsic nature of the explosions accompanying Xray, Yoke and Zebra tests may have obviated against transmission of sound to long distances.

The instrumentation utilized by the Signal Corps for the purpose of the SANDSTONE tests is based on theoretical considerations and experimental data, the bulk of the latter being the Krakatoa Explosion (1883), the CROSSROADS tests (1946), the Arco tests (1946) and Helgoland (1947). In order to provide this factual background, Section II below gives a detailed account of the CROSSROADS tests; Section III presents the theoretical and experimental considerations influencing the development and design of Signal Corps instrumentation, followed by Section IV in which is presented the details of this instrumentation; Section V, the detailed SANDSTONE results; Section VI, the conclusions; and Section VII, recommendations.

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SECTION II

OPERATION CROSSROADS

1. GENERAL CONSIDERATIONS

Operation CROSSROADS afforded an opportunity for determining the feasibility of sound ranging on atomic bomb detonations. To this end, infrasonic microphones were operated at various locations during CROSSROADS tests Able and Baker. Equipment used was of two types: standard sound ranging microphones, responding to the range from 5 cps to 25 cps and specially developed infrasonic microphones used in pairs, which, together, covered the range from 1 cycle per half hour to 1 cycle per second. The locations selected were as follows:

a. Stations at which special infrasonic microphones were employed:

(1) Fort Monmouth, New Jersey

b. Stations at which both special infrasonic microphones and standard sound ranging microphones were employed:

(1) San Francisco, California

(2) Nome, Alaska

c. Stations at which only standard sound ranging microphones were employed:

(1) Hawaii, T. H.

(2) Manila, P. I.

(3) Grafenwohr, Germany

The specially developed infrasonic microphones were operated by personnel from SCEL, and regular sound ranging equipment was operated by various Field Artillery Observation Battalions.

2. INSTRUMENTATION

a. Special Infrasonic Equipment

The special infrasonic microphones which were designed and constructed by personnel of Sound Section, General Engineering Branch, ESL, respond to pressure variations as low as 1 cycle per 30 minutes. Two such microphones are used to cover the range from 0.5×10^{-3} cps to approximately 1 cps, the "low frequency" microphone responding to frequencies from 0.5×10^{-3} to 0.06 cps and the "high frequency" microphone to frequencies from 0.06 to 1 cps.

The device is essentially a condenser type pressure microphone, the capacitive element of which forms one arm of an a.c. bridge, which is powered by a 4000 cycle vacuum tube oscillator. The output of the bridge is amplified, rectified, and impressed upon a recording voltmeter. In operation, the bridge is first balanced and is then unbalanced by a definite amount and the amplifier gain adjusted so the pen of the recording voltmeter is at mid-scale. Variations in pressure will then cause variations in the degree of unbalance of the bridge, and a continuous record of the pressure changes will thus be obtained.

The shell and condenser head of a standard sound ranging Microphone T-21-B serves as a pressure-sensitive element. The response of this microphone is determined by acoustical filters consisting of volumes and drilled plugs. The low frequency cut-off is determined by the size of a leak connected to the chamber behind the diaphragm. The constants of the plugs and leaks of the T-21-B were changed so as to obtain the desired frequency characteristics.

Due to the fact that a 1°C temperature change corresponds to a pressure change of 3450 bars (dynes/cm²), the "low frequency" microphone (0.05×10^{-3} to 0.06 cps) must be well insulated thermally. Inclosing the condenser element in a box, the walls of which consisted of two thicknesses of $3/4$ " lumber and two inches of "Sytrafloat", proved sufficient. Connection to the bridge is accomplished through a $4\text{-}1/2$ foot length of coaxial cable.

An Esterline Angus 0-1 ma recording milliammeter is used as an indicating instrument. A paper speed of 12" per hour is used for the "low frequency" microphone, and 6-12" per minute for the "high frequency" microphone. A resistor in series with the Esterline Angus recorder compensates for non-linearity in the system and provides optimum damping of the meter movement. As the mechanical resistance between the recorder pen and the paper is not independent of amplitude, small amplitude signals are not recorded satisfactorily. This difficulty is overcome by "agitating" the meter movement at about 12 cps by a voltage of the proper magnitude to approximately double the width of the line drawn by the pen. The upper frequency cut-off of the "high frequency" microphone is determined by the constants of the meter movement and the series damping resistance. For small amplitude signals, response is down about 9 db at 1 cps; for large amplitude signals, it is down 3 db at 1 cps.

The sensitivity of the microphone is determined by the magnitude of the capacitance used to unbalance the bridge, the amplifier gain being adjusted for mid-scale meter deflection in every case. Two different unbalancing capacitors were provided in the model constructed. On the "High Sensitivity" setting, a sensitivity of $1/3$ mm per bar was obtained. The maximum usable sensi-

vity is determined by meteorological factors, and on very quiet days, a sensitivity of at least ten times that given above could be used. This could easily be obtained by decreasing the size of the unbalancing capacitor and increasing the amplifier gain.

b. Standard Sound Ranging Equipment

Standard Sound Ranging Sets GR-8 or GR-3-C were installed at those sites listed under paragraph 1c above, with standard microphones T-21-B (response 5 to 25 cps) disposed at the vertices of a two mile square. Duplicate installations were made at each site and equipment was operated alternately to cover the two hour period during which it was anticipated that the sound waves might arrive.

3. RESULTS OF TEST ABLE

a. Standard Sound Ranging Microphone (5 cps to 25 cps).

No sound other than that of local origin (background noise) was discernible on records obtained with this equipment.

b. "Low Frequency" Infrasonic Microphone (1 cycle per half hour to 1 cycle in 16 seconds).

No identifiable signals were recorded with this equipment.

c. "High Frequency" Infrasonic Microphone (1 cycle in 16 seconds to 1 cps.)

The only signals recorded were the following:

(1) Direct Arrival from Bikini at San Francisco (Point Reyes), California.

Two arrivals, spaced approximately one minute apart were recorded 351.7 minutes after the explosion. Signal amplitude was 30-40 dynes/cm² and periods were about one and two seconds. Signals were somewhat above background noise and identifiable because of their distinctive character (figure 1).

(2) Arrival from Bikini via Antipodes of San Francisco, California.

Two pairs of arrivals were recorded, the first pair arriving 1643.3 minutes after the explosion and the second approximately 15 minutes later. The first pair was spaced about 1½ minutes apart, with amplitudes of the order of 60 dynes/cm² and periods of the order of two seconds (figure 2a). The second pair was also spaced about 1½ minutes apart; amplitudes of the order

of 40 dynes/cm² and periods of the order of four seconds (figure 2b).

(3) Arrival from Bikini at Fort Monmouth, N. J.

A single arrival was recorded 516.6 seconds after the explosion, having an amplitude of about 30 dynes/cm² and period of about four seconds (figure 3).

4. RESULTS OF TEST BAKER

No identifiable signals were recorded from this underwater (surface) explosion.

SECTION III

THEORETICAL AND EXPERIMENTAL BACKGROUND

1. GENERAL CONSIDERATIONS

The design of instruments for detection of sound at long ranges must be based upon two considerations, (a) the frequency spectrum of the source, as determined by Fourier analysis and (b) the transmission characteristics of the atmosphere. The second factor has been considered in detail in Appendix A, in which the conclusion was drawn that, for sound refracted at the second atmospheric inversion (approximately 100-110 KM high), the atmosphere transmits sound best in the band below 1 cps. For sound refracted at the first inversion (50 KM) as well as for sound refracted at low-level inversions ("direct" waves) atmospheric transmission is good to frequencies considerably above 1 cps. As the sound detected at long ranges (1000 KM and upwards) may arrive at the detection point after several refractions at the first inversion, or may even travel as a "direct" wave, the equipment used would have to respond to frequencies considerably above 1 cps unless it can be shown that comparatively little energy in this region is emitted by the source.

2. FREQUENCY SPECTRUM OF EXPLOSIONS

The pressure pulse due to an explosion will have a frequency spectrum which is a function of the energy and possibly of the character of the explosion. Records made with microbarographs and other types of recording equipment of explosions covering a range of magnitudes from the muzzle blast of a rifle to the great explosion of Krakatoa indicate a gradual progression from an energy spectrum peaked at 200 cps to one peaked at one cycle per hour.

Much valuable information of a general nature has been obtained from a detailed harmonic analysis of wide range recordings of ballistic waves, small nitrostarch explosions, and muzzle blasts of guns from a 30 caliber machine gun to a 240 mm howitzer. From these and similar studies, it has been learned that the characteristic wave shape, in the neighborhood of the source, is a sudden pressure increase, followed by a more gradual return to ambient pressure, then a relatively shallow rarefaction, after which pressure again returns to ambient. At greater distances from the source, the initial rate of pressure increase as well as the amplitude of the positive phase decreases, and at sufficiently great distances (if there is no interference due to multiple paths) the pulse resembles one or one and a half cycles of a sine wave.

3. RELATION BETWEEN FREQUENCY SPECTRUM AND ENERGY

Published data on long range observations of explosions indicate a frequency peak in the neighborhood of 1 cps for explosions where the total energy expended was of the order of 10^{19} or 10^{20} ergs. Pekeris (Proceedings of the Royal Society of London, Series A, No. 947, vol. 171, pp. 434-449, July 1939) estimates the total energy of the Krakatoa wave, which had a period of about one hour, at 6.4×10^{23} ergs. If we take 20,000 tons of TNT as the approximate equivalent of an atom bomb (the figure suggested in the Smythe report), the energy expended would be of the order of 10^{21} ergs, and we would expect the peak frequency to fall somewhere between 1 cps and one cycle per hour.

4. CROSSROADS TESTS

A detailed account of the results of the CROSSROADS tests is given in Section II above.

5. ARCO TESTS

In October 1946, the Army-Navy Explosives Safety Board detonated a number of charges of explosives, the largest of which was 250 tons, at Arco, Idaho. During these tests, SCEL equipment having a frequency range of 1 cps to 1 cycle per minute was installed at Montpelier, Idaho (177 KM), Green River, Wyoming (334 KM) and Fort Warren, Wyoming (720 KM). Analysis of the results indicated that, for ranges of 330 KM and upwards, most of the energy was to be found in the range between 1 cps and 1 cycle in ten seconds.

Data obtained at the same time by Cox (Journal of the Acoustical Society of America, Vol. 19, pp. 832-846, September 1947) at a range of 89 KM indicated that, although a better signal-to-noise ratio was obtained with a microphone responding to 1-20 cps, most of the energy was below 1 cps.

A detailed analysis of the Arco results is presented in Appendix E, in which the general theory of the sound field is developed for the case of variable temperature and wind on a spherical earth.

6. SUMMARY

It has been demonstrated experimentally that, at ranges of 7600-32,400 KM, most of the energy from an atom bomb explosion was found to be in the band from 1 cps to 1 cycle/10 seconds. (If higher frequencies were present near the source, they were not transmitted by the atmosphere.) It has also been demonstrated that, at only a few hundred kilometers from the source, most of the energy of a 250 ton TNT explosion was found to be in the same frequency band. From these data it can be concluded that the region from 1 cps to 1 cycle/

10 seconds is the optimum band upon which to base equipment design.

The above analysis is postulated upon transmission along a single path from source to detector. If transmission takes place along several adjacent paths having different transmission characteristics, destructive interference will occur which will be more pronounced at the higher frequencies. The net result will be to shift the frequency of maximum energy toward the low frequency end of the spectrum.

If the source is not located at the earth's surface, destructive interference will occur between the direct ray, and the ray which is reflected from the earth's surface. For example, if the explosion is assumed to take place at an altitude of 1500 feet and if the particular ray which is picked up by the microphone leaves the source at an angle of 30° above the horizontal, there will be complete destructive interference at a frequency of 0.36 cps. The effective frequency spectrum of the source will therefore have two maxima, one below and one above 0.36 cps, and the signal corresponding to such a distribution will not be identical to a signal from a surface source. It is possible that, due to suppression of frequencies for which the noise background has its greatest amplitude, the signal from an elevated source might be more easily identifiable in the presence of a high noise level.

SECTION IV
INSTRUMENTATION

1. GENERAL

The equipment used for Operation SANDSTONE has been designated as Infra-Sonic System M-2 to distinguish it from the M-1 equipment used in connection with Operation CROSSROADS. The M-2 equipment differs from M-1 chiefly as follows:

- a. It is designed for multi-channel operation, using an array of microphones instead of a single microphone.
- b. It is more sensitive.
- c. It is installed in such a manner as to greatly reduce background noise.
- d. The frequency band covered has been modified in the light of CROSSROADS experience.
- e. Design emphasis has been placed on continuous operation.

A detailed technical description of Infra-Sonic System M-2 is included as Appendix B.

A microphone installation and the central station equipment are depicted in the accompanying photographs.

In the following sections a brief description of the equipment will be given, together with a discussion of some of the considerations which led to the design adopted.

2. EQUIPMENT

a. General Arrangement of a Field Station

Each field station consists of an array of four sound detection points, arranged approximately in a square with a side dimension of from six to twelve miles. Choice of this dimension was based upon a desired accuracy of ± 2 degrees in azimuth and an assumed probable error of $\pm 1/2$ sec. in determining the time of arrival of the sound signal at an individual detection point.

At each sound detection point, a microphone and its associated bridge are located, together with batteries for heater and plate power. This equipment is mounted in a box, the top of which is made flush with the earth's surface, in order to prevent formation of a velocity head which would cause variations in wind velocity to be

evidenced as pressure changes. Additional reduction in background noise has been obtained by installing equipment in woods with dense underbrush, wherever possible.

The signals from the microphones at the four sound detection points are transmitted over wire lines to a central station where, after additional amplification, they are recorded on paper record rolls by means of four Esterline Angus recording milliammeters. These recorders are coupled together mechanically, in order to match paper speeds, and timing marks are inserted along the margins in order to permit determination of the absolute times of arrival as well as time differences between arrivals at the individual microphones.

b. Microphone

The microphone is a Sound Ranging Microphone T-21-B (a condenser type microphone) which has been modified to extend its frequency response. Figure 1 gives the frequency ranges covered by the two types of microphones used. For tests Xray and Yoke, all stations of the net used the standard M-2 equipment only (responding to sound having periods from 1 to 15 seconds). For test Zebra, equipment at the Fort Lewis station was replaced by low frequency equipment (10 to 220 seconds). Both standard M-2 and low frequency equipment were used at the Fort Monmouth station during test Zebra.

Choice of frequency range for the standard equipment M-2 was based upon theoretical considerations (see Appendix A) as well as the experimental results of projects CROSSROADS and Arco.

3. SENSITIVITY

As usually operated, full scale deflection of the recorder (i.e., from the center of the paper to one edge) corresponds to a signal of 20 bars (dynes/cm²) when the central station gain is set at maximum. This corresponds to a sensitivity of 3.4 mm/bar. On a very quiet day, deflections corresponding to pressure variations of one or two bars are caused by atmospheric fluctuations. Because of these fluctuations it would be of no value to design the equipment for higher sensitivity. As it is now, there is a 15 db unused gain reserve in the bridge amplifier.

4. NOISE REDUCING ACOUSTICAL ARRAY

At the Fort Monmouth station, equipment already installed was augmented by a microphone connected to a noise reducing acoustical array, in order to make direct comparisons of signal strengths and noise levels as recorded by the two systems. This noise reduc-

ing array and the theory underlying its design are discussed in Appendix C. This array was designed to improve the signal-to-noise ratio in the frequency band covered by the standard equipment M-2, and was therefore used only in conjunction with M-2 equipment. Results obtained indicated considerable improvement over results obtained with an unprotected microphone. The chief value of the array would be for use where no wooded areas are available.

5. NOMOGRAMS

The azimuth of arrival and the velocity with which the wave front sweeps the array (the apparent velocity) are computed by use of a nomogram. Detailed instructions on preparation of nomograms and interpretation of results are included in Appendix D.

SECTION V

SANDSTONE TEST RESULTS

Signal Corps equipment was installed at the following locations:

Kyoto, Japan
Schofield Barracks, Territory of Hawaii
Fairbanks, Alaska
Fort Lewis, Washington
Fort Monmouth, New Jersey
Herzo Base, Germany

To insure the utmost in efficiency in the performance of the equipment and to provide competent personnel for spot analysis of the recordings on a 24-hour alert basis, professional physicists with long experience in sound instrumentation and propagation were assigned to overseas field stations for the duration of the test. The results for Xray, Yoke and Zebra are tabulated in Tables I, II and III respectively.

It will be noted that during Test Zebra low frequency microphones were installed at two stations, i.e., low frequency equipment replaced the high at the Fort Lewis station whereas both low frequency and high frequency equipments were installed adjacent to each other at the Fort Monmouth station.

The "remarks" columns of Tables I, II and III summarize conclusively the results of the three tests; that is to say, there is no evidence of sound arrival from Eniwetok at any of the six stations in the net, although the equipment used had a sensitivity ten times that used in the CROSSROADS test. It is not believed that this lack of evidence is a result of masking background noise since at a majority of stations the noise level and the allowable gain settings were such that any signal of the magnitude detected during the Able test of Operation CROSSROADS should have been in evidence during the current operations.

TABLE I - SUMMARY OF TEST RESULTS - XRAY

	MICROPHONE	GAIN SETTINGS*				NOISE LEVEL	REMARKS
		1	2	3	4		
KYOTO, JAPAN	HF	0	0	0	6	U	Station reports no arrival
SCHOFIELD BARRACKS T. H.	HF	6	6	6	12	High	No evidence of arrival
FAIRBANKS, ALASKA	HF	-	-	12	6	Medium	No evidence of arrival
FORT LEWIS, WASHINGTON	HF	0	0	0	0	Low	No evidence of arrival
FORT MONMOUTH, NEW JERSEY	HF	0	6	6	6	Low to Medium	No evidence of arrival
HERZO BASE, GERMANY	HF	0	0	0	0	Low	No evidence of arrival

* Zero gain represents maximum sensitivity. Figures given in table are decibels below maximum.

CODE: HF: High frequency, response 1 cycle per 15 seconds to 1 cycle per second (6 db. points)

LF: Low frequency, response 1 cycle per 220 seconds to 1 cycle per 10 seconds (6 db. points)

U: Unknown, original records not received at Central Evaluation Station

?: No record in station log

X: Log not received from station

TABLE II - SUMMARY OF TEST RESULTS - YOKE

	MICROPHONE	GAIN SETTINGS*				NOISE LEVEL	REMARKS
		1	2	3	4		
KYOTO, JAPAN	HF	6	6	6	6	U	Station re- ports no ar- rival
SCHOFIELD BARRACKS T. H.	HF	6	6	6	12	Medium to High	No evidence of arrival
FAIRBANKS, ALASKA	HF	0	6	12	6	Medium	No evidence of arrival
FORT LEWIS, WASHINGTON	HF	6	12	12	6	Low	No evidence of arrival
FORT MONMOUTH, NEW JERSEY	HF	12	6	12	12	Low to Medium	No evidence of arrival
HERZO BASE, GERMANY	HF	0	0	6	18	Low to Medium	No evidence of arrival

* Zero gain represents maximum sensitivity. Figures given in table are decibels below maximum.

CODE: HF: High frequency, response 1 cycle per 15 seconds to 1 cycle per second (6 db. points)

LF: Low frequency, response 1 cycle per 220 seconds to 1 cycle per 10 seconds (6 db. points)

U: Unknown, original records not received at Central Evaluation Station

?: No record in station log

X: Log not received from station

TABLE III - SUMMARY OF TEST RESULTS - ZEBRA

	MICROPHONE	GAIN SETTINGS*				NOISE LEVEL	REMARKS
		1	2	3	4		
KYOTO JAPAN	HF	6	12	6	12	Low	No evidence of arrival
SCHOFIELD BARRACKS T. H.	HF	6	0	0	6	Medium to High	No evidence of arrival; some local firing in this period
FAIRBANKS, ALASKA	HF	18 18	12 -	12 12	12 12	Low to Medium	No evidence of arrival
FORT LEWIS, WASHINGTON	LF	12	6	12	12	Medium to High	No evidence of arrival
FORT MONMOUTH, NEW JERSEY	HF	0	0	0	0	Low	No evidence of arrival on either HF or LF microphones; high background on LF, low background on HF
	LF	0	0	0	0	High	
HERZO BASE, GERMANY	HF	0	0	0	0	Low	No evidence of arrival

* Zero gain represents maximum sensitivity. Figures given in table are decibels below maximum.

CODE: HF: High frequency, response 1 cycle per 15 seconds to 1 cycle per second (6 db. points)

LF: Low frequency, response 1 cycle per 220 seconds to 1 cycle per 10 seconds (6 db. points)

U: Unknown, original records not received at Central Evaluation Station

?: No record in station log.

X: Log not received from station.

SECTION VI

CONCLUSIONS

The negative results secured by Signal Corps installations during Operation SANDSTONE are in conflict with positive results secured by the Signal Corps at two distant stations during Operation CROSSROADS. At the present time these conflicting data have not been resolved. However, major considerations for the discrepancy that have been advanced to date are the following:

a. It is not known how the intensity of the A-bombs used in either Xray, Yoke or Zebra tests compares with that of the Able test of Operation CROSSROADS, and what is considered to be particularly important, how the pressure-time curve of the later bombs compares with that of the earlier one. Any pronounced difference in this respect would result in a different frequency characteristic for the wave shape, and the peak of the frequency spectrum of the later bomb may have occurred at a frequency for which transmission characteristics of the atmosphere are poor. (This factor has been discussed in considerable detail in Section III).

b. It is not known whether propagation vagaries may not have been encountered in the current tests as a result of diurnal or seasonal variations in the characteristics of the upper atmosphere. It should be noted that the CROSSROADS test took place at 0900 local (Bikini) time in July, whereas the current tests took place at 0500 local (Eniwetok) time in April and May. From theoretical considerations discussed in Appendix A, a diurnal or seasonal change in the velocity gradient near the 120 KM level would have a pronounced effect upon sound waves refracted at that altitude.

c. The variation in source altitude discussed in Section III, par. 6 probably had no bearing on the results in this particular case, as the noise background was so low at some stations during the SANDSTONE tests that a signal having the same intensity as the CROSSROADS Able signal would have been easily distinguished from the background.

d. Experience in sound ranging on artillery has demonstrated that, under some conditions, propagation occurs along a single path, and the arrival is a sharply defined single transient, whereas on other occasions, transmission occurs along several adjacent paths, and interference occurs. The result of this interference is a change in the character of the signal received; instead of a single isolated pulse, an extended irregular pressure fluctuation is recorded which is difficult to distinguish from the noise background. The signals recorded during the CROSSROADS Able test were very sharply defined, and, although four arrivals were recorded at San Francisco for the signal traveling along the antipodes path,

these arrivals were so widely spaced in time that no interference occurred. Signals recorded by NEL personnel at shorter ranges during SANDSTONE tests were of the second type described above, indicating considerable destructive interference. It is therefore possible that failure to record the SANDSTONE tests at greater ranges may have been due to a combination of propagation conditions which favored transmission along multiple, closely adjacent paths.

e. The possibility should not be completely ruled out that signals recorded during the CROSSROADS tests were background noise peaks and not sound arrivals. As only one microphone covering each frequency band was used at a given location, the corroborative evidence which would have been furnished by an additional microphone was lacking. However, the travel velocities of the direct waves recorded at San Francisco and at Fort Monmouth, although somewhat high, were in good agreement. This factor, together with the excellent match of wave forms, led to the decision that the signals were bona fide sound arrivals.

SECTION VII.

RECOMMENDATIONS

A. It is strongly recommended that an extensive program with the viewpoint of determining the propagation characteristics of the atmosphere to great distances be initiated. This program of investigation should provide for both theoretical analysis and experimental studies, namely as follows:

1. Theoretical analysis of sound propagation through the atmosphere in the infrasonic range, based on best available meteorological and ionospheric data. The experimental results secured to date during the CROSSROADS and Arco tests should serve as a basis for consideration of the atmospheric parameters which may effect sound propagation to great distances.

2. Experimental studies under controlled conditions as to nature of source, time of day of explosion, season of tests, sufficiency of simultaneous upper air meteorological information, and fully coordinated plans in a net of stations extending east-west and north-south through the source position so that meteorological effects can be appraised. Detailed recommendations for such an experimental program are contained in a separate report prepared by the Signal Corps Engineering Laboratories.

B. It is further recommended that investigations of noise reduction techniques be prosecuted vigorously so that the best available instrumentation be developed for sonic surveillance. Under atmospheric conditions where destructive interference may occur, leaving for detection only the weaker lower frequency (i.e., 5 to 30 second period) components, success of detection will depend upon the best possible signal-to-noise ratio instrumentally attainable. A consideration that destructive interference due to atmospheric conditions may have been the cause of negative results during Operation SANDSTONE has been stated in the conclusions of Section VI above.

C. It is also recommended that development work on all phases of instrumentation be continued so that future tests with atom bombs or other sources can be carried out with equipment constructed in accordance with the best current practice.

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FIGURE 1

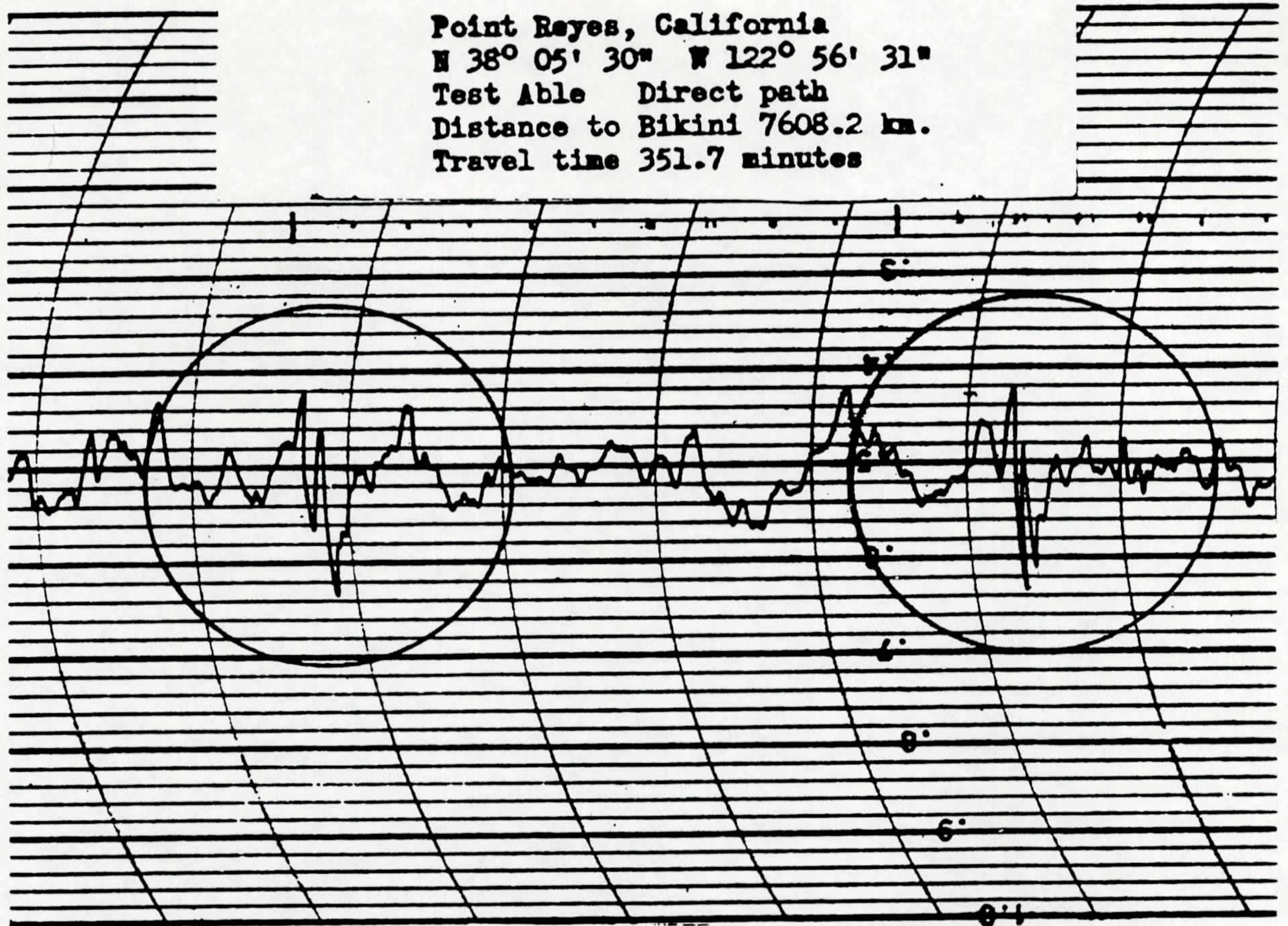
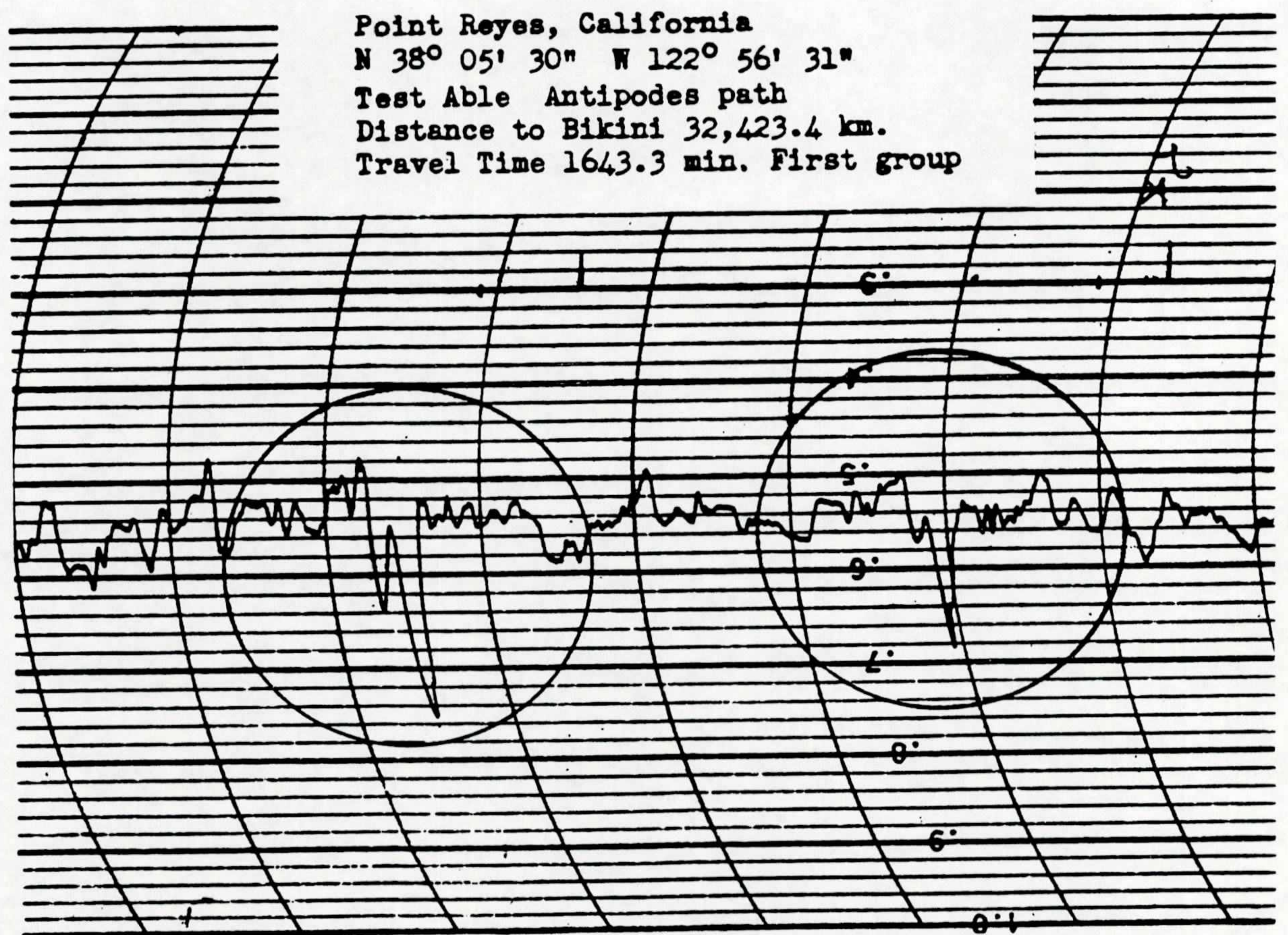


FIGURE 2(a)



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FIGURE 2(b)

Point Reyes, California
N 38° 05' 30" W 122° 56' 31"
Test Able Antipodes path
Distance to Bikini 32,423.4 km.
Travel time 1658.2 min. Second group

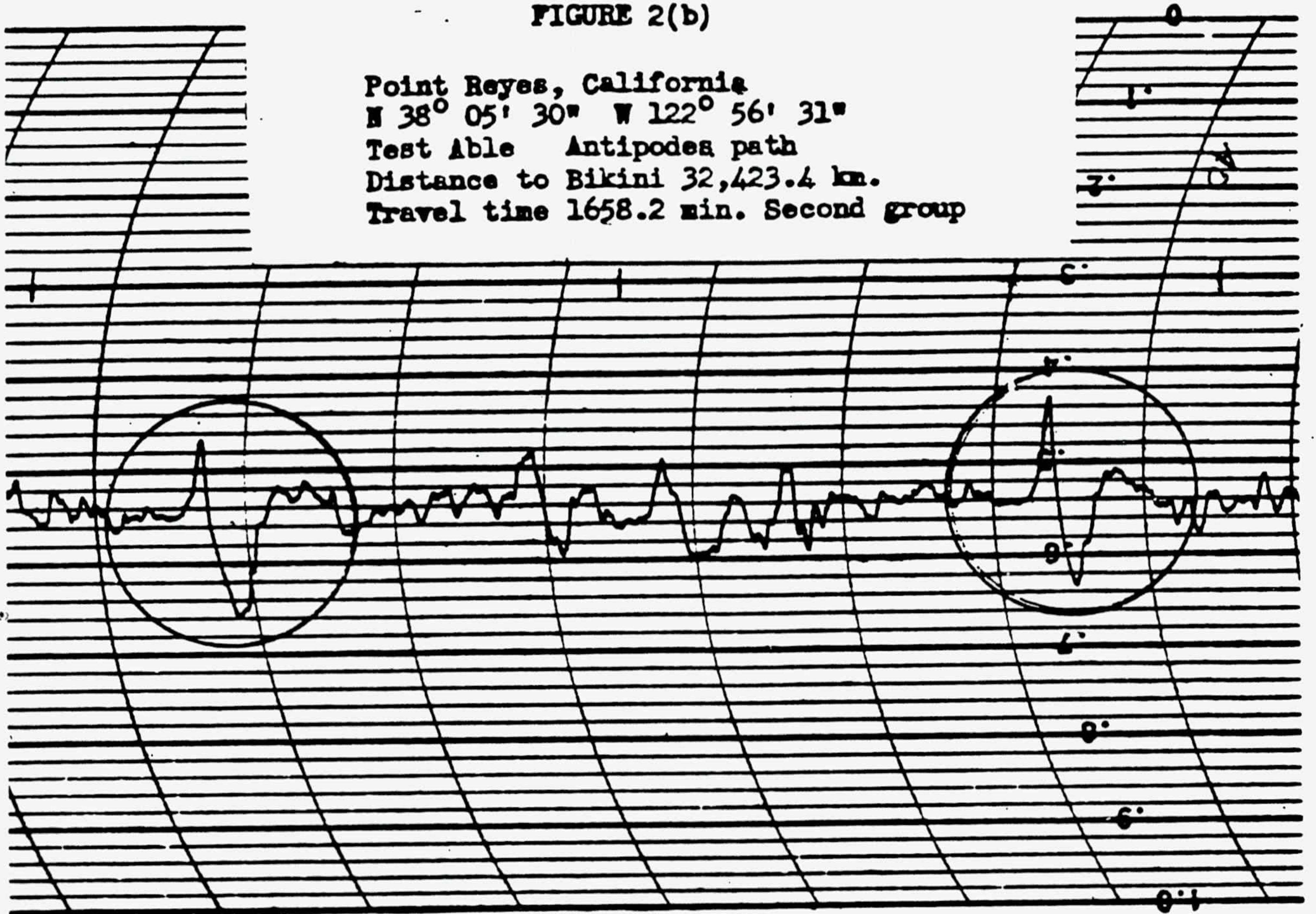
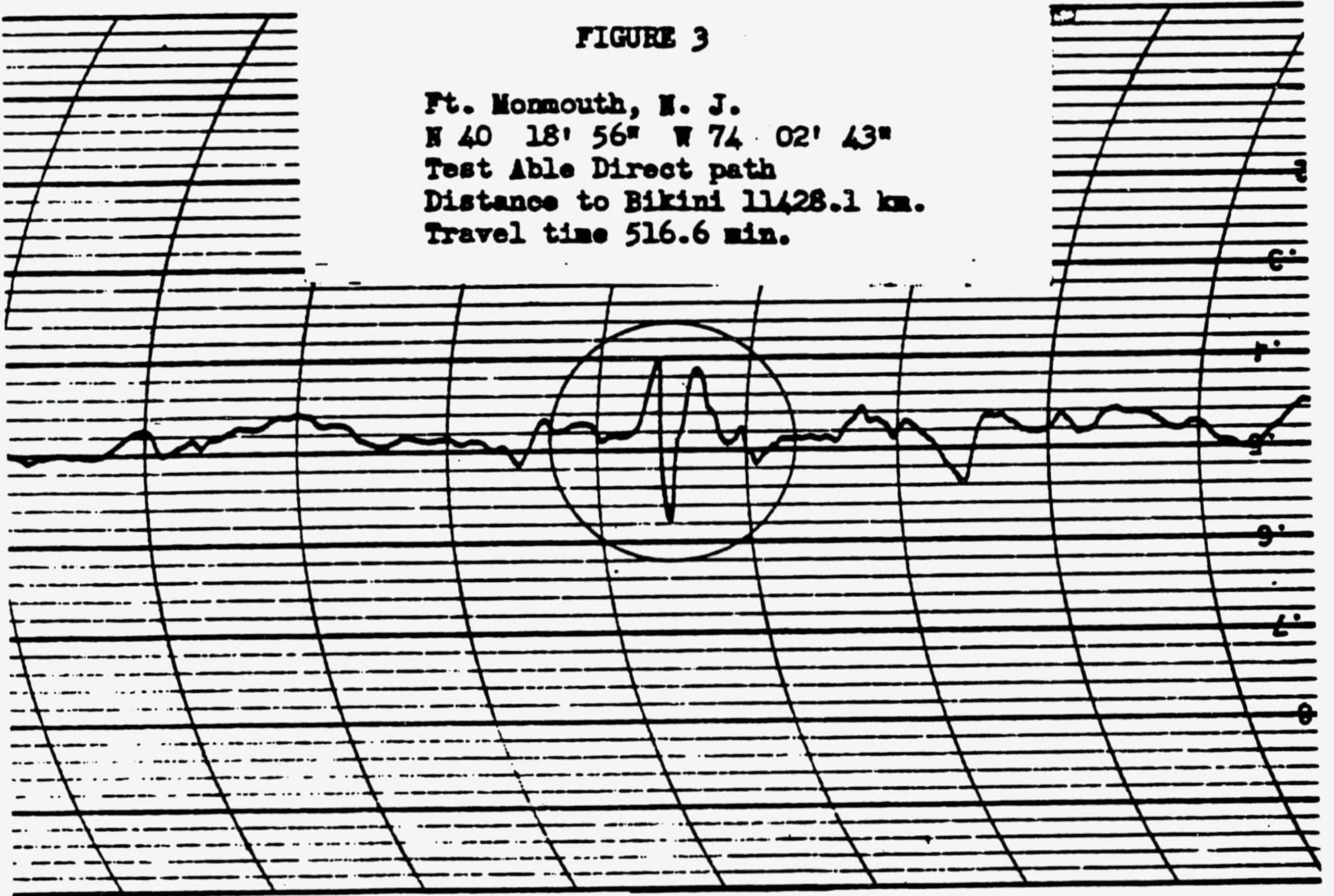


FIGURE 3

Ft. Monmouth, N. J.
N 40° 18' 56" W 74° 02' 43"
Test Able Direct path
Distance to Bikini 11,428.1 km.
Travel time 516.6 min.



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