GROUND SUPPORT, DATA ANALYSIS

and

ASSOCIATED RESEARCH AND DEVELOPMENT

for the

Rocket Grenade Experiment

16 August 1961 - 31 May 1965

FINAL REPORT

June 1965

Prepared for

Goddard Space Flight Center
National Aeronautics and Space Administration

in partial fulfillment

of

Contract NAS 5-2949

Prepared by

J. FRANK CASEY

Under the Supervision of

L. L. ABERNETHY, DIRECTOR

Edited by

JAMES B. BACON

SCHELLENGER RESEARCH LABORATORIES

TEXAS WESTERN COLLEGE EL PASO, TEXAS

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S C H E L L E N G E R   R E S E A R C H   L A B O R A T O R I E S
TEXAS WESTERN COLLEGE   EL PASO, TEXAS

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I. INTRODUCTION

This report summarizes the sound ranging support of the rocket grenade experiment with the associated research, development, and data analysis as performed by the Schellenger Research Laboratories under National Aeronautics and Space Administration contract NAS 5-2949 during the period August 15, 1962 through May 31, 1965. The work was performed under the direction of Professor Thomas G. Barnes and finished under the direction of Dr. L.L. Abernethy. Supervision was performed by Mr. James G. Pruitt, Electrical Engineer.

The scope of the work continued under this contract was an extension and expansion of the performance under contracts NAS 5-221 and NAS 5-556. The present contract may be divided into the following classes:

(1) Field support for sound ranging, including the research and development necessary to improve and facilitate the collection of data in the field. This support was managed by Mr. Pruitt.

(2) Data Reduction of sound ranging, including analysis of methods and procedures. This work was coordinated by Mr. J. Frank Casey, Physicist, with the Data Analysis Section of the Laboratories, which is under the direction of Professor Robert L. Schumaker.

(3) Research on sound propagation and absorption. This research was supervised by Mr. E. Alan Dean, Physicist.

The work to date has been detailed in ten progress reports and two papers. Titles and abstracts of these reports and papers are as follows:

(1) Sound Ranging for the Rocket Grenade Experiment, Quarterly Progress Report No. 1, James G. Pruitt, 15 August - 31 December, 1962.

A sound ranging station was constructed and installed at Fort Churchill, Manitoba, Canada. Four rocket firings were supported from this site and range personnel were trained to operate and maintain the sound ranging equipment. A joint effort by Schellenger and members of the High Altitude Research Laboratory of the University of Michigan was made to record the sound arrivals of eight-pound grenades exploded at very high altitudes at Eglin Air Force Base. The grenades were a part of Project Firefly sponsored by the U.S. Air Force. An 8-pound grenade was recorded from an altitude of 112 kilometers.

A paper entitled Absorption of Sound in Tubes Due to Viscothermal Boundary Effects by E. Alan Dean concerning work on the absorption tube was included as an appendix.

(2) Sound Ranging for the Rocket Grenade Experiment, Quarterly Progress Report No. 2, James G. Pruitt and E. Alan Dean, January - March, 1963.

Three rocket firings were supported at Fort Churchill during this period. As a result of the Firefly data, it was concluded that the "double" arrivals encountered in the grenade experiment were due to the presence of "N" waves. Further discussion was presented on the viscothermal boundary effects in tubes. Calibrations were made in nitrogen.

(3) Sound Ranging for the Rocket Grenade Experiment, Quarterly Progress Report No. 3, James G. Pruitt and E. Alan Dean, April - June, 1963.

Construction of equipment for future sound ranging stations was begun during this period. The speed of shock waves as a function of over-pressure was discussed and a graph included to illustrate this study.

The speed of sound in nitrogen was determined from data obtained from the absorption tube. A general method for determining the speed of sound in gases by the tube method was discussed.

(4) Sound Ranging for the Rocket Grenade Experiment, Quarterly Progress Report No. 4, James G. Pruitt, July - September, 1963.

The mechanical construction of the absorption tube was altered to a minor extent to correct some troublesome areas. The tube was spirally wrapped with copper tubing and insulated so that the temperature could be controlled and stabilized.

(5) Sound Ranging for the Rocket Grenade Experiment, Quarterly Progress Report No. 5, James G. Pruitt, October - December, 1963.

Final assembly and checkout of the sound ranging equipment for Ascension Island was completed. The equipment was installed in the SSD van at the Physical Science Laboratory in Las Cruces, New Mexico. Other equipment and cable were shipped directly to Ascension Island.

An integrating noise meter was developed for the hot-wire microphone in order to simplify field operations. The calibration of the device was mathematically deduced for use of the pistonphone.

(6) Sound Ranging for the Rocket Grenade Experiment, Quarterly Progress Report No. 6, James G. Pruitt and E. Alan Dean, January - March, 1964.

The sound ranging array at Ascension Island was installed and the equipment set up for operation. The tradewinds presented a problem in creating a noisy turbulence over the microphones located on a barren field. The installations for the microphones were modified to a multiport wind screen configuration. Two rocket firings were supported at this location. Three rocket firings were supported at Fort Churchill during this period.

(7) "Ray Tracing in a Layered Medium", E. Alan Dean, Paper included in Quarterly Progress Report No. 6, January - March, 1964.

This paper presents the theory on which the present data analysis will be extended to include the reduction of winds and temperature. The theory represents a different technique for computing the end results of the rocket grenade experiment.

(8) Sound Ranging for the Rocket Grenade Experiment, Quarterly Progress Report No. 7, James G. Pruitt, E. Alan Dean, and Dan Ramsdale, April - June, 1964.

A second sound ranging station was installed at Wallops Station on Assateague Island to locate an array more directly under the exploding grenades. One rocket firing was supported at Fort Churchill during this period and one firing was also supported at Wallops with both arrays. Continued work on the temperature control system of the absorption system was covered. Techniques of measuring the temperature of the gas in the tube was discussed. A method of measuring the effects of pressure on the speed of sound was presented. Results of absorption measurements were presented.

(9) "Grenade Explosions in the Upper Atmosphere", James G. Pruitt. This paper was delivered at the Conference on Atmospheric Acoustic Propagation, Fort Bliss, Texas, on April 22-23, 1964.

This paper is a result of studies of wave shapes and wave velocities in the rocket grenade experiment. A summation of material presented in previous Quarterly Reports plus new material is included.

(10) <u>Sound Ranging for the Rocket Grenade Experiment</u>, Quarterly Progress Report No. 8, James G. Pruitt and E. Alan Dean, July - September, 1964.

Three rocket firings were supported at Ascension Island during this period. Further modifications to reduce wind noise was tested without apparent success. The Point Barrow array was staked out and cable was laid to the microphone sites prior to the colder weather.

An analysis was made of the N shaped waves of the grenade arrivals to determine the harmonic content of the waves. The higher grenade arrivals shifted to lower frequencies. A modification to lower the hot-wire microphone response was used in the field with some apparent improvement in signal.

The first shot reported on the Assateague array was completed. Although using temporary recording equipment, nine grenades were reported and the array was termed operational. Several modifications were made in the data reduction process including the adoption of card input-output and the discarding of weighted results in the computation.

(11) Sound Ranging for the Rocket Grenade Experiment, Quarterly Progress Report No. 9, James G. Pruitt and J. Frank Casey, October - December, 1964.

The sound ranging equipment for Point Barrow was assembled, checked, and shipped. Extensive testing of various noise reduction devices on the hot-wire microphone was conducted. A side-by-side comparison was made of the Spider (Ascension "modification"), and various combinations of cylindrical "horsehair" covers and screen hemispheres. The spider was found to have an effective noise reduction range beyond the usable levels of the hot-wire microphone. A combination of cylindrical "horsehair" covers were selected for field use. The results are graphically portrayed. In the testing, it was found that the port spacing of the spider to a minimum diameter of six inches did not affect the cancellation of noise.

(12) Sound Ranging for the Rocket Grenade Experiment, Quarterly Progress Report No. 10, James G. Pruitt and J. Frank Casey, January - March, 1965.

The Point Barrow installation was completed and the station made operational. Three rocket firings were supported from this location during this period. Also, three rocket firings were supported at Fort Churchill during this period. A late design of the SRL capacitor microphone was employed at Churchill as an additional receiving device for the study of grenade arrivals. An analysis was made of the grenade arrivals as recorded on the capacitor microphone. This analysis indicated similar results to those obtained previously.

The British sound ranging array as installed at Eglin AFB, Florida, was described. Subsequently, a British microphone was brought to the lab and evaluated. The first thirteen rocket firings of 1964 were computed on the new program to conform to the format introduced in mid-year.

The final two months of this contract period has been divided between field work and completion of the data reduction. Field support was provided at Wallops Island and Point Barrow for a rocket grenade spring series in which no sound ranging data was retreived due to payload malfunctions. Final data reduction was completed on the January-February series.

The final report will summarize each field of work as outlined under the scope of the contract. Section II on field support outlines the area of most intensive effort. This includes not only actual field support but all research and development necessary to perform these field operations such as development of the noise level meter and research on noise reduction devices. During the period covered under this contract, 54 rocket grenade experiments were conducted. Four new stations were installed at Fort Churchill, Assateague Island, Ascension Island, and Point Barrow.

Section III summarizes the work completed in data analysis. The data reduction process has evolved into a semi-automated, card-oriented computation system. During this period, 60 final reports were issued on 47 rocket grenade experiments.

Section IV on research outlines the effort expended on the absorption tube and the related theoretical work. Experimental procedures and methods are carefully detailed. The results are presented in detail in this section.

Appendix II tabulates the data reduced during the contract period as detailed in Section III. This appendix represents the results of the work performed under this contract.

II. FIELD SUPPORT

At the beginning of this contract period, field support was limited to the sound ranging array located at Wallops Station Main Base. During this contract period field activities were broadened to include four additional sound ranging arrays located from Ascension Island in the South Atlantic to Point Barrow within the Arctic Circle. Equipment was developed for the measurement of noise level on the hot-wire microphone, field research was conducted on wind noise problems and noise reduction devices, and the harmonic analysis of grenade sound arrivals was determined in the field by use of a capacitor microphone.

WALLOPS MAIN BASE

The original sound ranging array at Wallops was located on the island near the launcher. Later, to alleviate the surf noise problem, the array was relocated on the main base of Wallops. At the beginning of this contract the 6-microphone main base array was being operated by Wallops personnel for all rocket grenade firings. Schellenger personnel conferred on technical problems with the Wallops operations.

The equipment consisted of six aluminum, hot-wire microphones tuned for 4.5 cps. These were connected by a 4-conductor shielded cable to individual control panels in the instrumentation building. A 14-channel magnetic tape recorder, an oscillograph recorder, and the necessary power supplies completed the essential equipment.*

*For a more detailed list of equipment and operations see: Operations Manual for Wallops Island Sound Ranging Station, James G. Pruitt, Schellenger Research Laboratories, Texas Western College, El Paso, Texas, September, 1962.

The output data from each of the microphones was recorded on a separate channel of the tape recorder as was the range timing. A quick-look paper record was processed on the oscillograph recorder.

The station operator had to determine if the sound ranging system was capable of receiving the grenade arrivals in readable form under the conditions then present and so advise the mission controller. This decision was arrived at by monitoring the control panels and anemometer, and from previous experience.

A total of 27 rocket grenade experiments were conducted at Wallops Island with the main base array operated by station personnel. Two of the firings experienced rocket and payload failure while the remainder were determined to be successful.

FORT CHURCHILL

The Fort Churchill array was installed at the beginning of this contract period on the Churchill Research Range in Manitoba, Canada, and operated by Pan American Airways for the U.S. Air Force (OAR).† The array was located at Twin Lakes, where sound ranging had previously been conducted for the IGY grenade program. Five of the original nine microphone sites were employed for these experiments.

The equipment was assembled at Schellenger Laboratories and shipped to Fort Churchill in working order. A 7-track magnetic tape recorder, an ink writing paper recorder, and a 5-microphone array (in place of 6) were the major differences from the Wallops installation.

The Twin Lakes site was located approximately seven miles

†Quarterly Progress Report No. 1

south of the launcher and slightly west of the flight path of the rocket. The instrumentation was located in a building with one of the DOVAP stations. Figure 1 shows the Fort Churchill station equipment.

Pan American Airways personnel at the Twin Lakes site maintained and operated the sound ranging station on all firings for impact location. Schellenger Laboratories provided supervision and consultation for the rocket grenade experiments. A total of 18 firings were conducted at Churchill with 15 of these being conducted under supervision of Schellenger personnel. There were two rocket failures and one payload failure. The remainder were determined to be successful.

Figure 2 shows a SRL capacitor microphone being set out near the Twin Lakes site for the recording of data to study the harmonic analysis of the grenade sound arrivals.

ASCENSION ISLAND

A third sound ranging array was established on Ascension Island in the Atlantic Ocean slightly south of the equator.† Assembly of equipment was completed at Schellenger Laboratories in El Paso and installed in the SSD van at the Physical Science Laboratory, Las Cruces, New Mexico. Microphones and other bulky items were shipped direct to Ascension.

The Ascension station was similar to the Churchill Station in the use of a 7-channel magnetic tape recorder. However, an oscillograph recorder was utilized for back-up as at Wallops. The instrumentation van is shown in Figure 3. The 5-microphone array

†Quarterly Progress Report No. 6

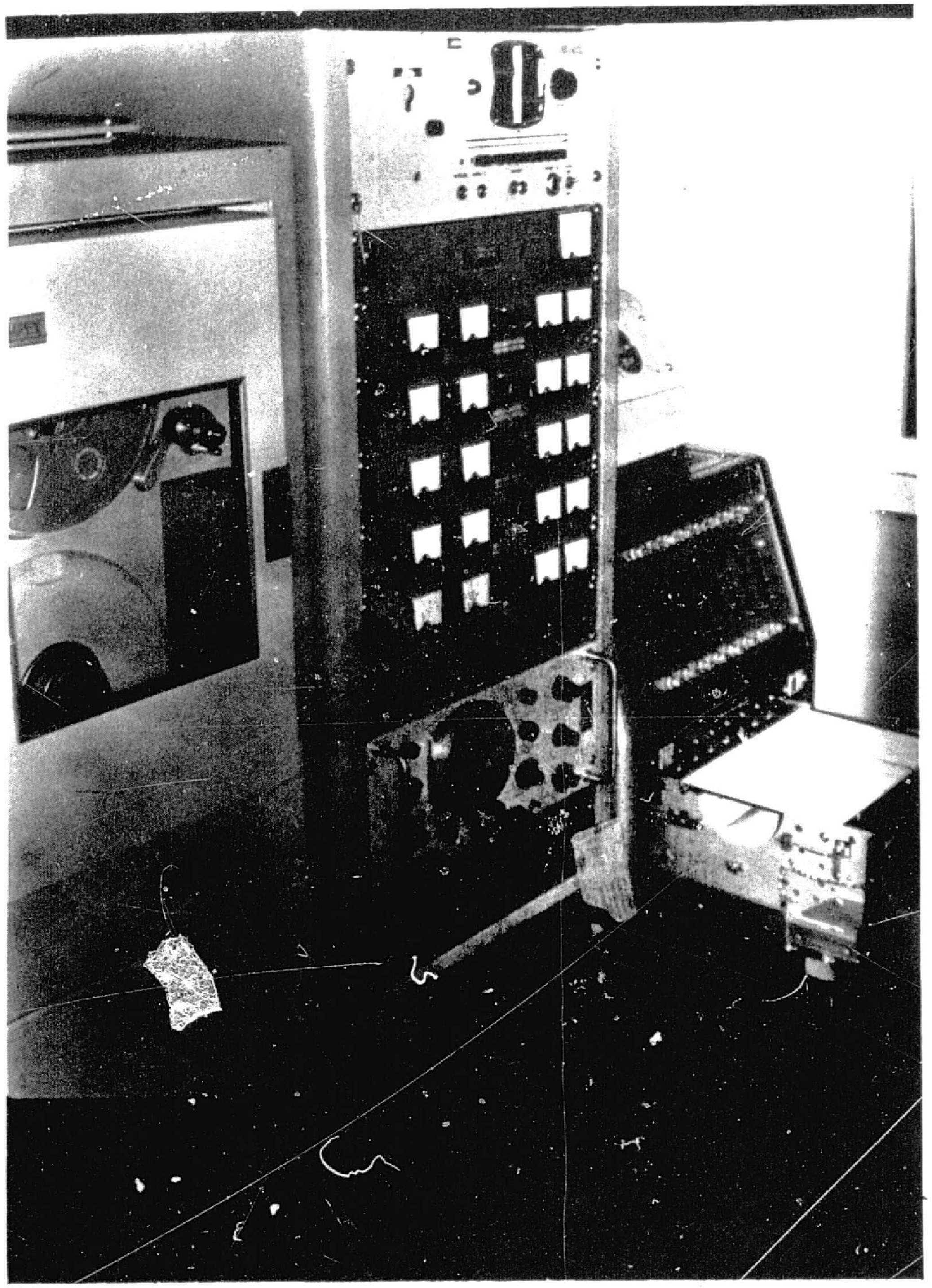

FIGURE NO. 1

SOUND RANGING INSTRUMENTATION AT TWIN LAKES

FIGURE NO. 2

SRL CAPACITOR MICROPHONE AT FORT CHURCHILL

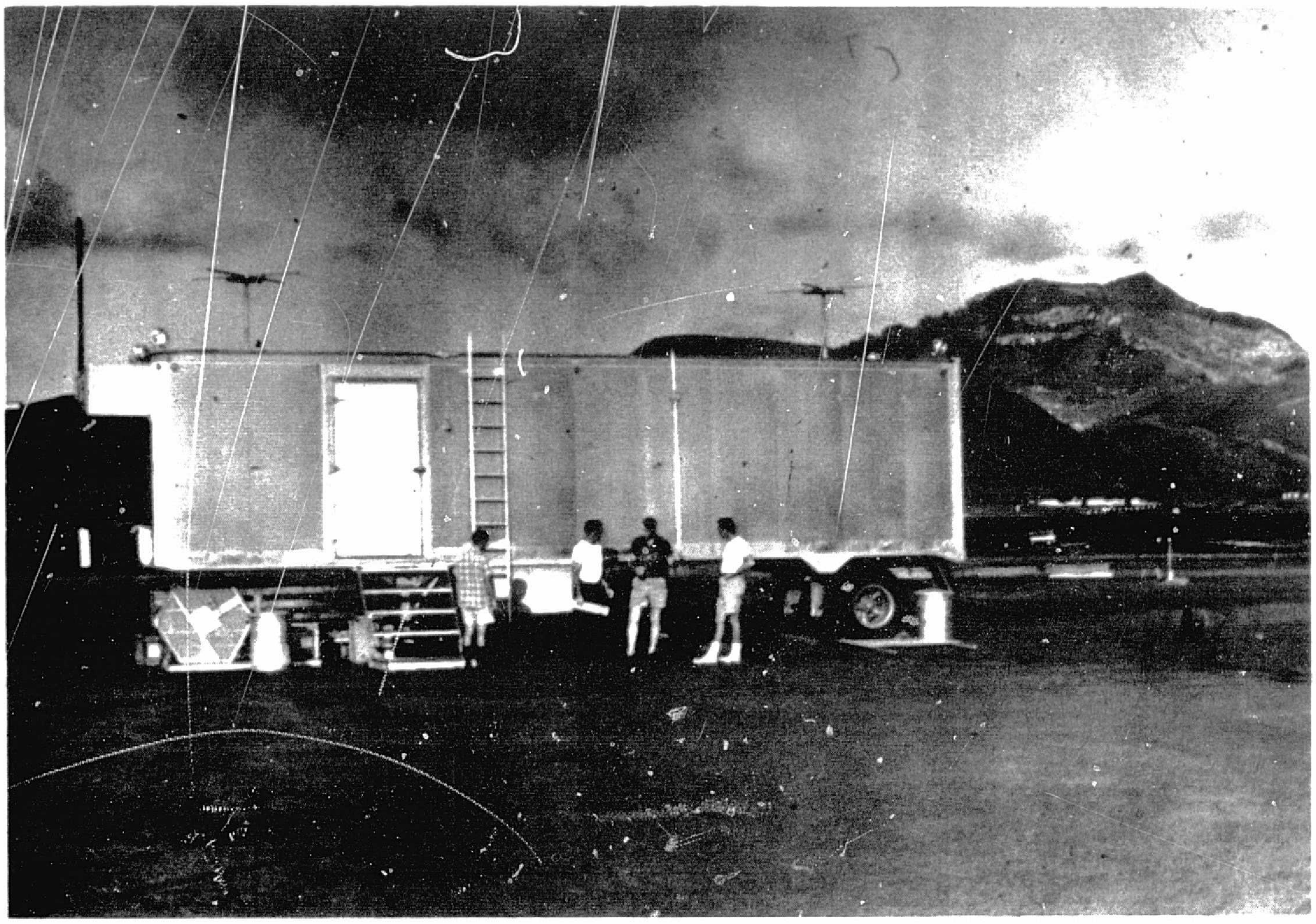

FIGURE NO. 3 ASCENSION ISLAND INSTRUMENTATION VAN

FIGURE NO. 4 SEARCHING FOR A MICROPHONE SITE AT ASCENSION ISLAND was located "behind" the launcher and was constricted into a smaller area than in previous installations due to local terrain.

The major problem encountered at Ascension were the trade winds that blew consistently from the southeast at 15 to 20 knots. As the array was located on a field devoid of vegatation, there was no boundary layer created as was done by the trees at Churchill and Wallops. Figure 4 pictures the checking of one of many sites studied for improved noise conditions. Figure 5 illustrates the microphone pit in the array.

A version of the "line microphone" was employed with some success in reducing wind noise. This technique utilizes a large number of ports venting the microphone to the atmosphere, thus reducing the noise signal by the addition of ramdom pressure perturbations at each port. The device consisted of a section of one-half inch conduit, ten feet in length, placed radially about the microphone pit as in Figure 6. A correction had to be made on the time of grenade arrivals as the precise time was of prime importance to the experiment.

A total of five rocket grenade experiments were conducted at Ascension with one firing failing due to payload malfunction. Of the four remaining shots, three were considered successful and one was unsuccessful due to sound ranging conditions. High wind noise level was encountered in all cases.

WALLOPS ASSATEAGUE

A second array was established at Wallops to improve the low elevation angles at which the grenade sound arrivals strike the main base array. The original array on Wallops Island proper had

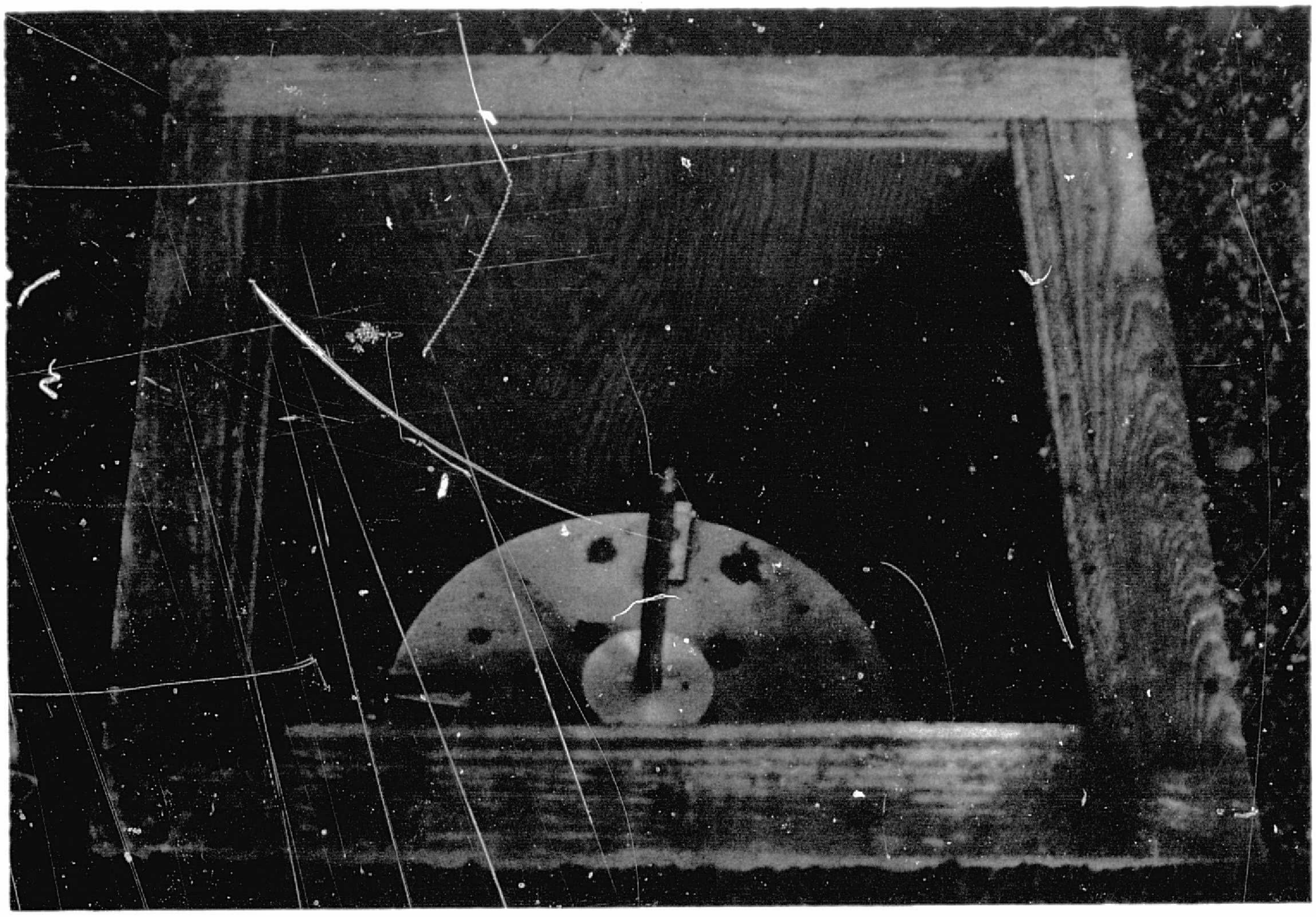

FIGURE NO. 5 MICROPHONE PIT

FIGURE NO. 6 ASCENSION "MODIFICATION"

experienced considerable surf noise and a lack of trees for a boundary layer. The Assateague site was chosen for the following reasons:†

a. The array could be located at a greater distance from the surf than at the Wallops Island site.

b. Assateague Island supported a substantial conifer forest.

c. The area is the closest land mass to the exploding grenades on an eastern flight path.

d. A building and electric power were available from the Coast Guard.

e. The area has limited access and is controlled by the U.S. Wildlife Service as a game refuge.

Additional equipment was assembled and shipped to Wallops for installation at Assateague. The instrumentation was located in a lighthouse as shown in Figure 7. The 5-microphone array was completed and operated by Wallops personnel under the supervision of Schellenger Laboratories.

Of the fourteen firings monitored by the Assateague array, all have been successful except one that failed due to payload malfunction. The Assateague array has proven to be as quiet as the main base site, and an improvement in elevation angles has been realized.

POINT BARROW

A fifth array was established inside the Arctic Circle at Point Barrow, Alaska. A preliminary trip was made during the late summer of 1964 to conduct noise level tests and locate the array.††

†Quarterly Progress Report No. 7

††Quarterly Progress Report No. 8

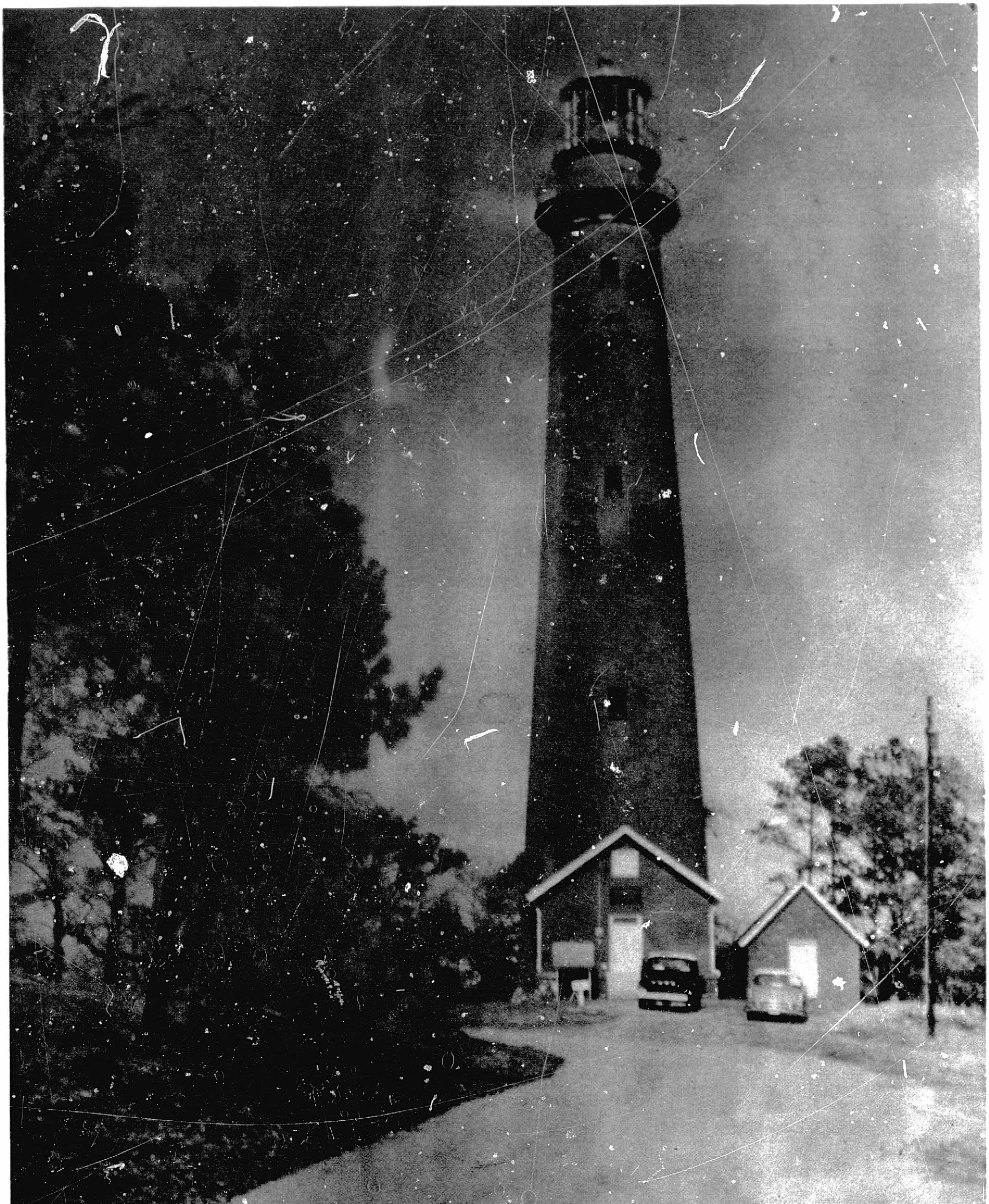

FIGURE NO. 7 ASSATEAGUE LIGHTHOUSE - INSTRUMENTATION BUILDING

A 5-microphone site was located after determining the sites acceptable insofar as noise conditions were concerned. Because of a profusion of small lakes, the array was formed in a "T" instead of the usual square.

As weather conditions were at their best in late summer, the microphone field cable was laid at this time and the microphone pits were dug for the retainer cans. The Arctic Research Laboratory staff and personnel were extremely helpful in providing not only valuable advice but physical effort in completing the field work. Laying of the cable is shown in Figure 8. Surveying of the array is illustrated in Figure 9.

The terrain at Barrow is barren, similar to Ascension. Wind noise was also similar to Ascension, except that during long periods of calm, good conditions were available.

It was noticed that considerable quieting was caused by natural snow drifts. It was difficult, however, to create "natural" drifts in the flat terrain around the array.

Horsehair windscreens were used at Barrow following considerable field testing which indicated that they were nine db better than the Ascension modification.† Two concentric cylindrical covers, one foot and two feet in diameter, enclosed the microphone to a height of two feet. A marginal zone of wind speed from 8 to 10 mph separated an acceptable noise level from that of "no go."

A total of four rocket grenade experiments were conducted at Point Barrow in which one suffered payload failure. The remaining three were successful.

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†Quarterly Progress Report No. 9

FIGURE NO. 8

LAYING MICROPHONE FIELD CABLE AT POINT BARROW

FIGURE NO. 9

SURVEYING POINT BARROW INSTALLATION

NOISE REDUCTION DEVICES†

A major interest in the grenade experiment has been wind noise on the microphones. The problem is more acute in clear areas, such as Ascension Island and Point Barrow than in wooded areas, such as Wallops and Fort Churchill.

Trees apparently act to create a thick boundary layer, and "stop" the wind at the microphone level. At moderate wind speeds, turbulence is presumably created at tree top level, a considerable distance from the microphone.

In clear areas, the boundary layer of wind flow is much thinner, and turbulence can exist very near the microphone. The greatest need exists for a wind screen to work in these clear areas.

Ascension Island was the first clear area encountered. The original installation at Ascension follows the lines of systems previously used at Wallops and Fort Churchill. The microphone was installed in a pit and covered with a canvas cover, flush with the ground. This was found to be inadequate.

Several devices were tested that did not work at all. One system that did show promise, however, has become known as the "spider" (also referred to as "The Ascension Island modification").†† This device is described later in this work. A second device, also included here, is the "IKE".

In this work, conducted at El Paso, various devices have been compared in a side-by-side arrangement.††† Each microphone was

† Quarterly Progress Report No. 9
†† Quarterly Progress Report No. 6
††† Quarterly Progress Report No. 9

carefully calibrated in the pistonphone with its individual noise meter. The microphones and windscreens were then set outdoors, and the output of the noise meters was recorded on a strip chart for a period long enough to sample a representative set of conditions (several days in some cases). The noise level was read from the chart at corresponding times for each device and was plotted as shown in the accompanying figures.

The spread in the plotted points graphically displays the difficulties encountered in the past in accurately evaluating noise reducing windscreens. The plots were fitted with curves that best represented the data; these curves were then used to evaluate the device.

A parameter noticeably absent from the data presented is wind speed. An anemometer was not available for these tests. However, from these observations in the field, it appears that the noise level rises approximately linearly with wind velocity until a wind velocity of about 8 mph is reached. At this speed, the noise level is about .3 dynes/cm^2. As the speed rises above the 8-mph range, the indicated noise rises very rapidly, and at about 12 mph the noise has doubled.

It appears that a critical Reynolds number is reached at about 8 mph and a change occurs in the state of the wind from laminar to turbulent flow. This seems to be more noticeable in clear areas than in wooded areas.

The original reference for comparing the various devices is the aluminum hot-wire microphone sitting on open ground. This is a noisier arrangement than the various below-grade installations used at the different field sites, so that the total quieting effect indicated by these tests is more than can be realized in the field. The standard microphone limited during high noise conditions, and the spider was later used as the reference.

SPIDER

The spider used in these tests was similar to the one used at Ascension, except that rubber tubing was substituted for rigid conduit. This allowed the microphone, and attached spider to be "gathered up" and calibrated in the pistonphone, as well as allowing the tip spacing to be varied. Basically, the spider consists of eight 12.5-foot arms. When attached to a microphone, it caused a slight lowering of the frequency response of the microphone and a reduction in sensitivity. The change in sensitivity was corrected by adjusting the system gain.

Results of the tests are shown in Figure 10. It is interesting to note that the noise reduction is essentially the same for the cases where the tips of the spider were in a 6-inch-diameter circle and where the tips were in a 25-foot-diameter circle. This apparently fails to support arguments presented concerning tip spacing.† It should also be pointed out, however, that these tests were limited to noise levels below 0.2 dynes/cm^2, as received on the spider, due to limiting on the reference microphone. It was observed but not documented, that at higher noise levels port spacing does play a role, and larger diameters give increased quieting.

IKE

The second device tested, referred to here as IKE, is

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† Quarterly Progress Report No. 6

SPIDER VS. STANDARD MICROPHONE

STANDARD MICROPHONE SITTING ABOVE GROUND.
SPIDER CONSISTS OF 8, 12½ FT. RUBBER ARMS.

NOTE VERTICAL SCALE.

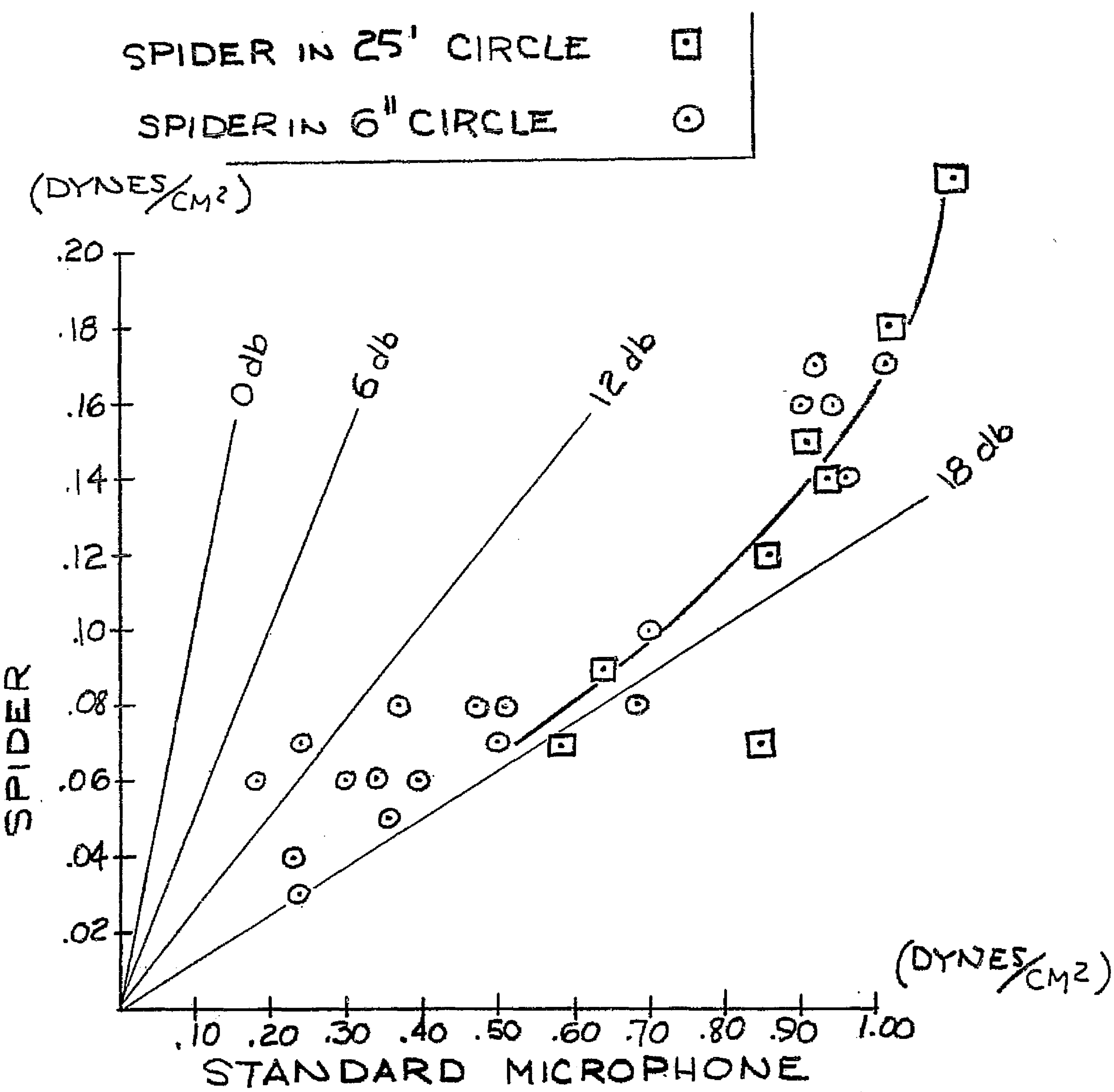


FIGURE NO. 10

essentially the same as the device tested at Ascension during the second series. At Ascension, three concentric right circular cylinders were used. The IKE is a more recent configuration and consists of three concentric hemispheres. These are frames, 3.5-feet, 2.75-feet, and 2-feet in diameter, covered with either copper screen wire or a loosely woven plastic cloth.

Results of the test are compared to the extended 25-foot-diameter spider in Figure 11. The data points show considerable spread. A curve is approximated to the points. It is interesting to note that the curve rises rather steeply near the origin and later bends toward the zero db line. This is to say that at low noise levels (under .3 dynes/cm^2) the IKE gives a higher improvement ratio than at high noise levels, as compared to the spider. This supports observations at Ascension that "this type of device was no better than the spider", where the noise level was consistently .6 dynes/cm^2 and higher. If the curvature of the line were extrapolated, the line might well cross the zero db line, making the spider the quieter of the two.

HORSEHAIR SCREENS

An extension of the idea of the IKE resulted in a similar device constructed of 2-inch thick "horsehair" matting. The material is porous; yet, because of its thickness, it offers more wind resistance than screen wire or cloth. Also, it has sufficient mechanical strength to be self-supporting, and microphone covers can be constructed without internal frames. These tests were run just prior to the Point Barrow operation, scheduled in early January, and construction time was a consideration.

IKE WINDSCREEN

THREE CONCENTRIC HEMISPHERIC COVERS, COVERED WITH COPPER SCREEN.

2 FT. DIAMETER
2 3/4 FT. DIAMETER
3 1/2 FT. DIAMETER

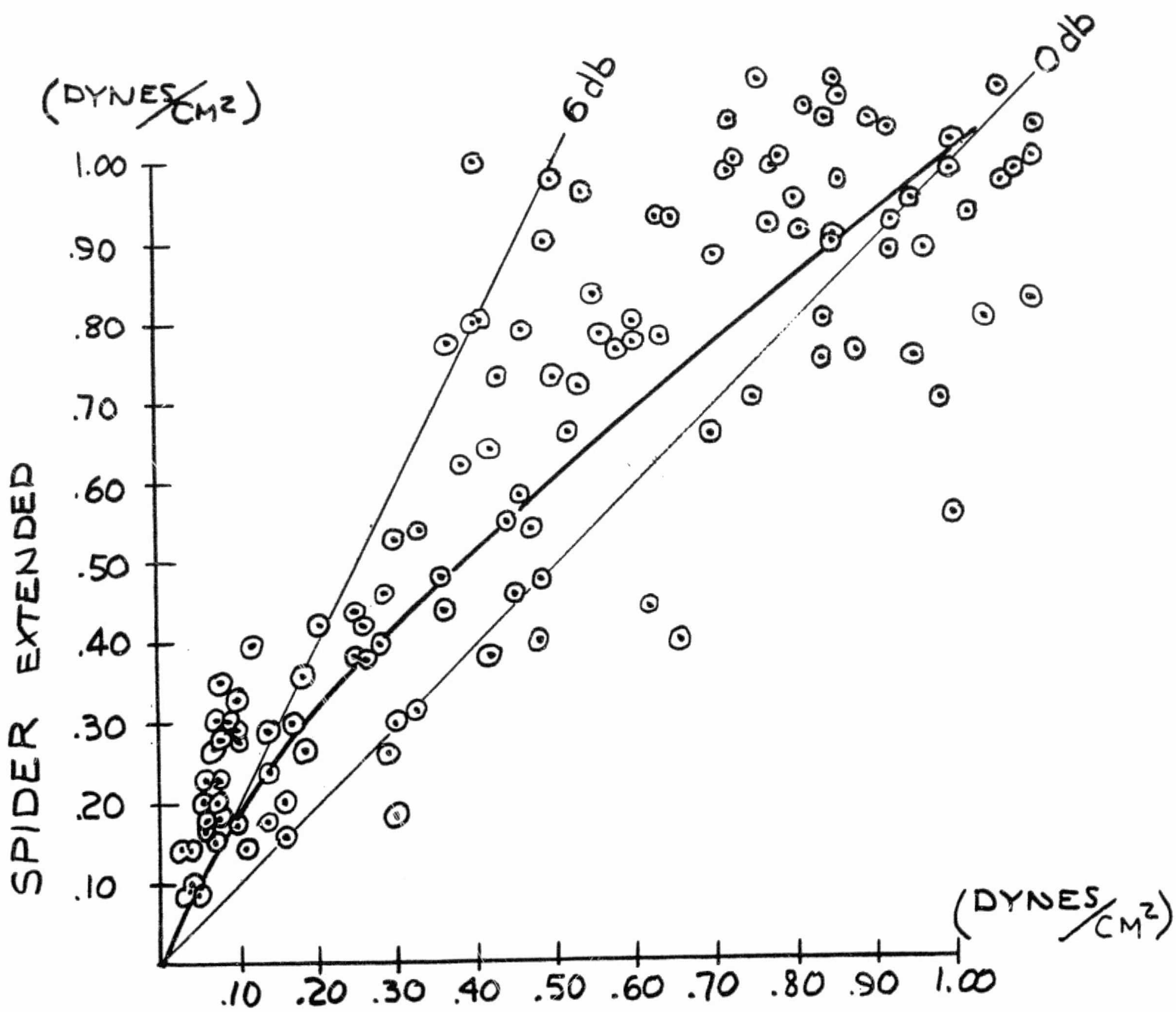


FIGURE NO. 11

All horsehair covers were right circular cylinders, 2 feet high, and all had covered tops. Combinations of three sizes were tested, and results appear in Figures 12, 13, and 14.

Figure 12 shows a single 1-foot-diameter cover. In Figure 13 a second cover, 2 feet in diameter, was placed concentrically over the microphone and the smaller cover. A considerable improvement is apparent. A third cover, 4 feet in diameter, was then placed over the inner two, and the results are shown in Figure 14. The benefit of the third cover is very slight; approximately the same results were obtained with the small cover and either of the other two, or with the outer two alone.

The two smallest covers were selected for use at Point Barrow, Alaska. They should also serve to shelter the microphones from ice and snow. The horsehair material seems unaffected by cold temperature.

CONCLUSIONS

The most interesting result of this series of tests was the information gained on the effect of port spacing on the spider microphone. The idea behind the spider was that, if the noise pressure at each tip was random, there would be some cancellation from the addition of these pressures. The grenade arrivals would be correlated at each tip, and this would have a cumulative effect on addition. These effects are apparently realized, as the spider shows a marked improvement over the standard microphone. It was surprising to find that the randomness was maintained when the tips of the spider arms were arranged in a circle whose diameter was reduced to 6 inches (in low wind).

HORSEHAIR WINDSCREEN

ONE COVER 1 FT. DIAMETER, 2 FT. HIGH
2 IN THICK MATERIAL.

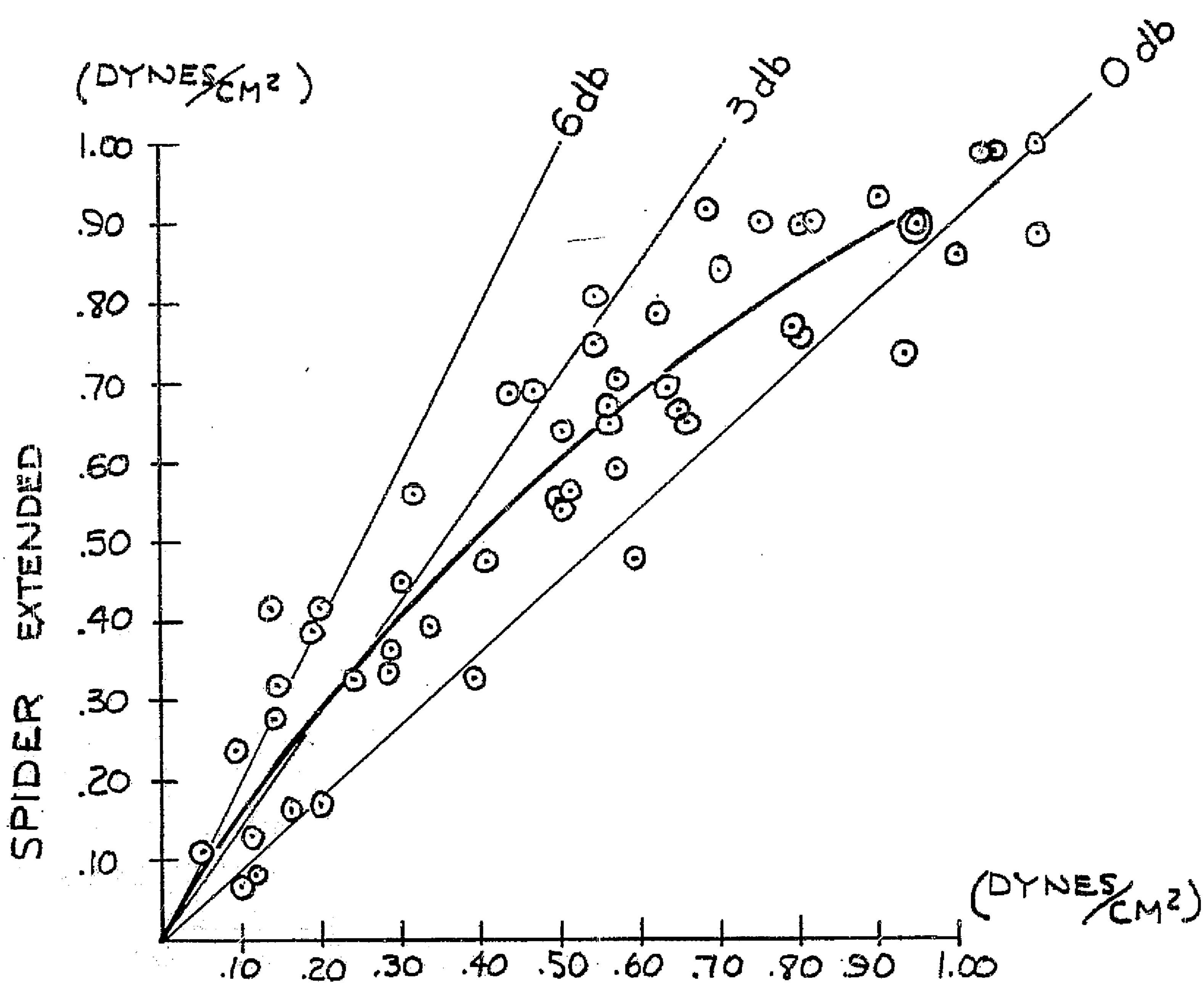


FIGURE NO. 12

HORSEHAIR WINDSCREENS

TWO CONCENTRIC COVERS, 2 FT. HIGH
1 FT. DIAMETER
2 FT. DIAMETER

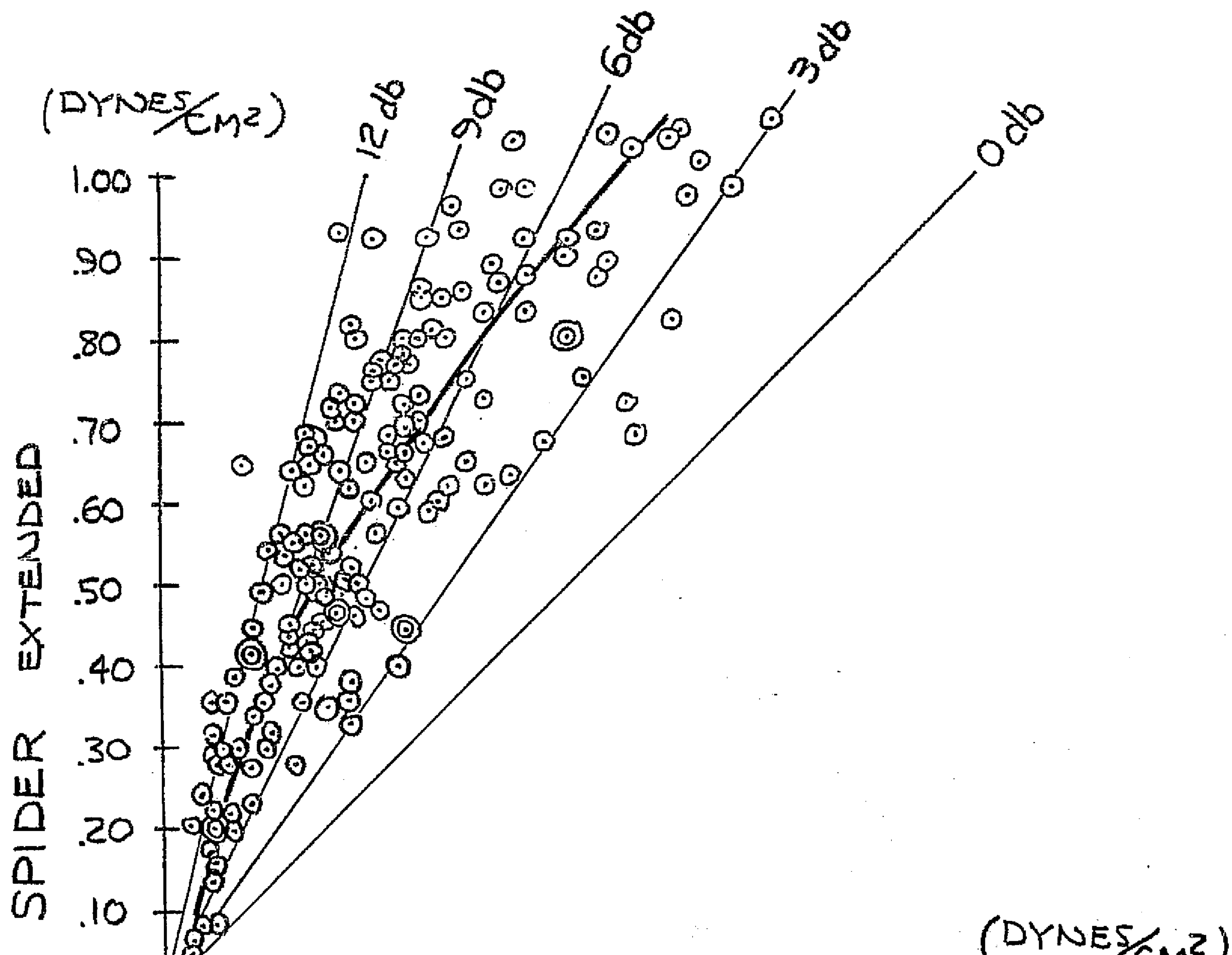


FIGURE NO. 13

HORSEHAIR WINDSCREENS

THREE CONCENTRIC COVERS, 2 FT HIGH.
1 FT. DIAMETER
2 FT DIAMETER
4 FT. DIAMETER

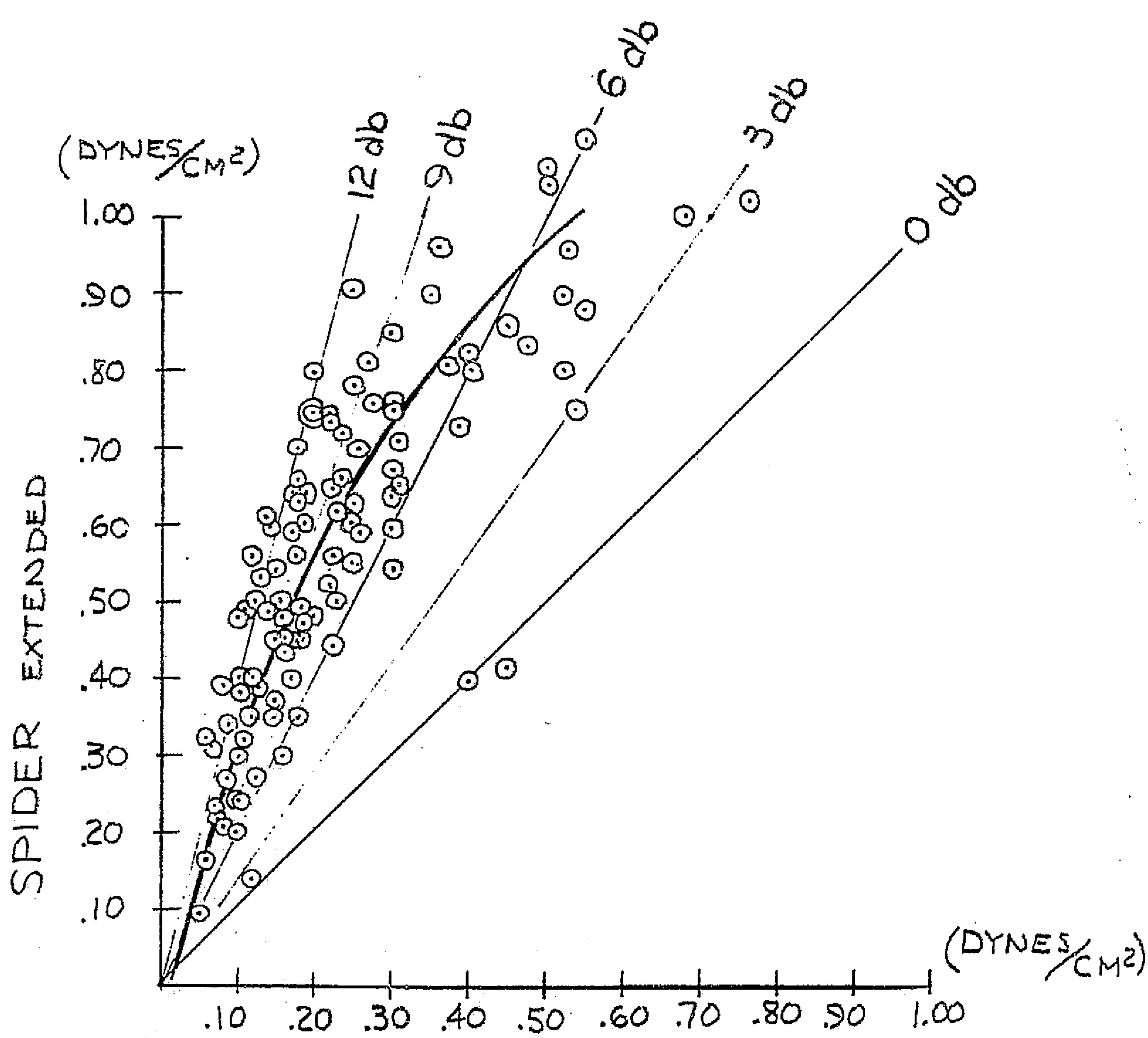


FIGURE NO. 14

One explanation for this effect may be that in conditions of low wind (under about 8 mph), there is little or no natural turbulence. The turbulence, or noise, shown by the standard microphone is created by the introduction of the neck of the microphone into the air stream. This turbulence appears not to extend very far from the neck of the microphone. The cancelling effects of the spider apply as well to this type of turbulence as to natural turbulence, which would presumably be on a larger dimensional scale. If the noise received at the tip of each spider arm was caused by the tip, then the spacing of the tips would make no difference.

This conclusion is also supported by the good results obtained with the use of covers. The IKE and horsehair covers serve to "stop" the wind before it reaches the microphone neck, and thus reduce turbulence at the neck. Presumably, noise is created at the surface of the cover, where the wind is stopped. But in the cases tested where good results were obtained, this surface was a foot or more from the neck. This distance from the port allows the level to be reached by divergence; also a reduction is achieved by having the noise created over a surface rather than at a point at the port.

During conditions of high noise and wind, the mode of things changes. At wind speeds of approximately 10 mph and above, a difference is noticed in the effect of the spacing of the spider tips. The 25-foot-diameter spacing produces more quieting than smaller diameters. This would seem to indicate the presence of large scale turbulence, probably due to natural causes. The microphone cover devices begin to lose their effectiveness as the scale size of these turbulent eddies becomes on the order of the same size as the cover.

When this happens, the entire cover is alternately immersed in a cell of a differential pressure.

Even though the spider has the ability to reduce the noise level in very bad conditions, it has little value in its present state for the Grenade Experiment. Its range of effectiveness is in conditions so severe that it cannot reduce the noise to a usable level. A background level of about 0.1 dynes/cm^2 is necessary to record all 12 grenades in the Grenade Experiment. The horsehair covers are most efficient in this range, and are capable of making bad and marginal situations usable. These facts were considered in the selection of the horsehair covers for the Point Barrow installation.

Microphones fitted with horsehair covers should allow firings with good results (12 grenade returns) in winds to about 8 mph. Unfortunately, the conditions at Ascension are usually worse than this, and more work is necessary before this problem can be overcome.

At high wind speeds, it is probable that a large portion of the noise received by the spider is caused by the presence of the tip in the air stream. This noise may be reduced by horsehair covers already developed. A combination of the two ideas tested here may prove superior to either idea alone.

N WAVE TRANSFORM

It was well established that the wave shape, arriving at the microphone, was an "N" shaped wave.† This shape is displayed by the capacitor microphone, whereas it is lost by the tuned response

†Quarterly Progress Report No.'s 2, 7 and 8

of the hot-wire. The formation of the "N" is discussed in other work.

After this determination of the wave shape of the grenade arrivals as N waves, an analysis was made of the N shape to determine the harmonic content of the waves.

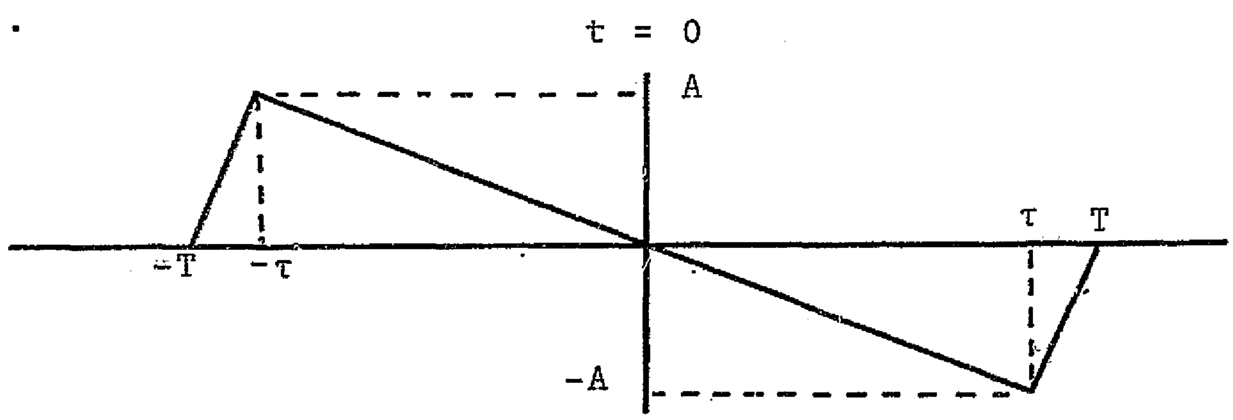
The more common method of analyzing waves is to expand them via the Fourier series. However, this method is valid only for cases of repetitive wave shapes, and cannot be applied in cases such as this where the arrival must be treated as a unique pulse.

Another method that can be applied is known as the Fourier transform. The Fourier transform does for the pulse what the Fourier series does for the repetitive function.

The Fourier transform has the general form

$$F(j\omega) = \int_{-\infty}^{+\infty} f(t)\, e^{-j\omega t} dt$$

For the case of the N wave, the f(t) function may be broken into three parts, and for convenience, the zero crossing is placed at $t = 0$.



Thus the integral takes the form

$$F(j\omega) = \int_{-T}^{-\tau} \frac{A(T+t)}{(T-\tau)} e^{-j\omega t} dt - \int_{-\tau}^{\tau} \frac{At}{\tau} e^{-j\omega t} dt$$

$$- \int_{\tau}^{T} \frac{A(T-t)}{(T-\tau)} e^{-j\omega t} dt$$

After integrating and substituting limits,

$$F(j\omega) = \frac{2jA}{(-j\omega)^2(T-\tau)} (\sin \omega T - \frac{T}{\tau} \sin \omega \;)$$

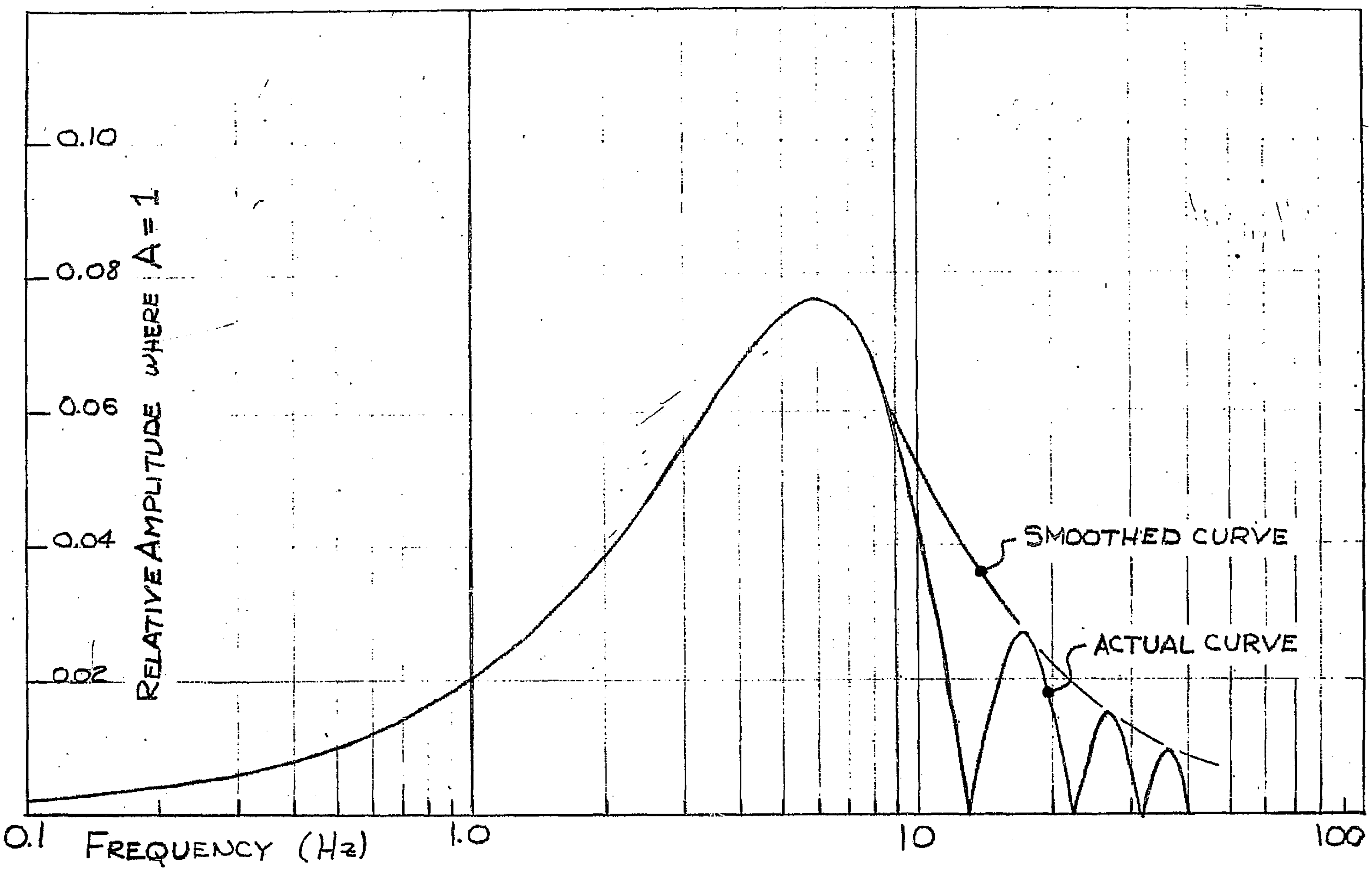
This is further reduced to

$$F(j\omega) = \left(\frac{2A}{\omega}\right) \left(\frac{T}{T-\tau}\right) \left(\frac{\sin \omega T}{\omega T} - \frac{\sin \omega\tau}{\omega\tau}\right)$$

This equation was programmed on a digital computer. Values for the variables A, T, and τ were taken from the waves recorded on shoot 10.87. These waves are shown in the paper in Appendix I, Grenade Explosions in the Upper Atmosphere. The value of A was taken as unity for the first grenade, and assigned relative values for succeeding grenades.

When actual values of $F(j\omega)$ are plotted, an envelope results, giving the amplitude of harmonics at various frequencies. At the higher frequencies, a series of "nulls" result from harmonic cancellation. The points at which these nulls occur change greatly with small changes in T or τ. The best interpretation of these plots is obtained by smoothing the upper portion of the plot through the peaks. This is illustrated in Figure 15.

Figure 16 shows the smoothed plots for the odd numbered grenades recorded on shoot 10.87. The shift to lower frequencies as the grenades go higher is noted. A most interesting phenomenon is the increase in peak amplitude of the higher grenades. The total



FREQUENCY SPECTRUM OF 1ST GRENADE, 10.87

FIGURE NO. 15

FREQUENCY SPECTRUM
ODD GRENADES, 10.87

VERTICAL SCALE IS RELATVE PRESSURE
WHERE A=1 FOR FIRST GRENADE.

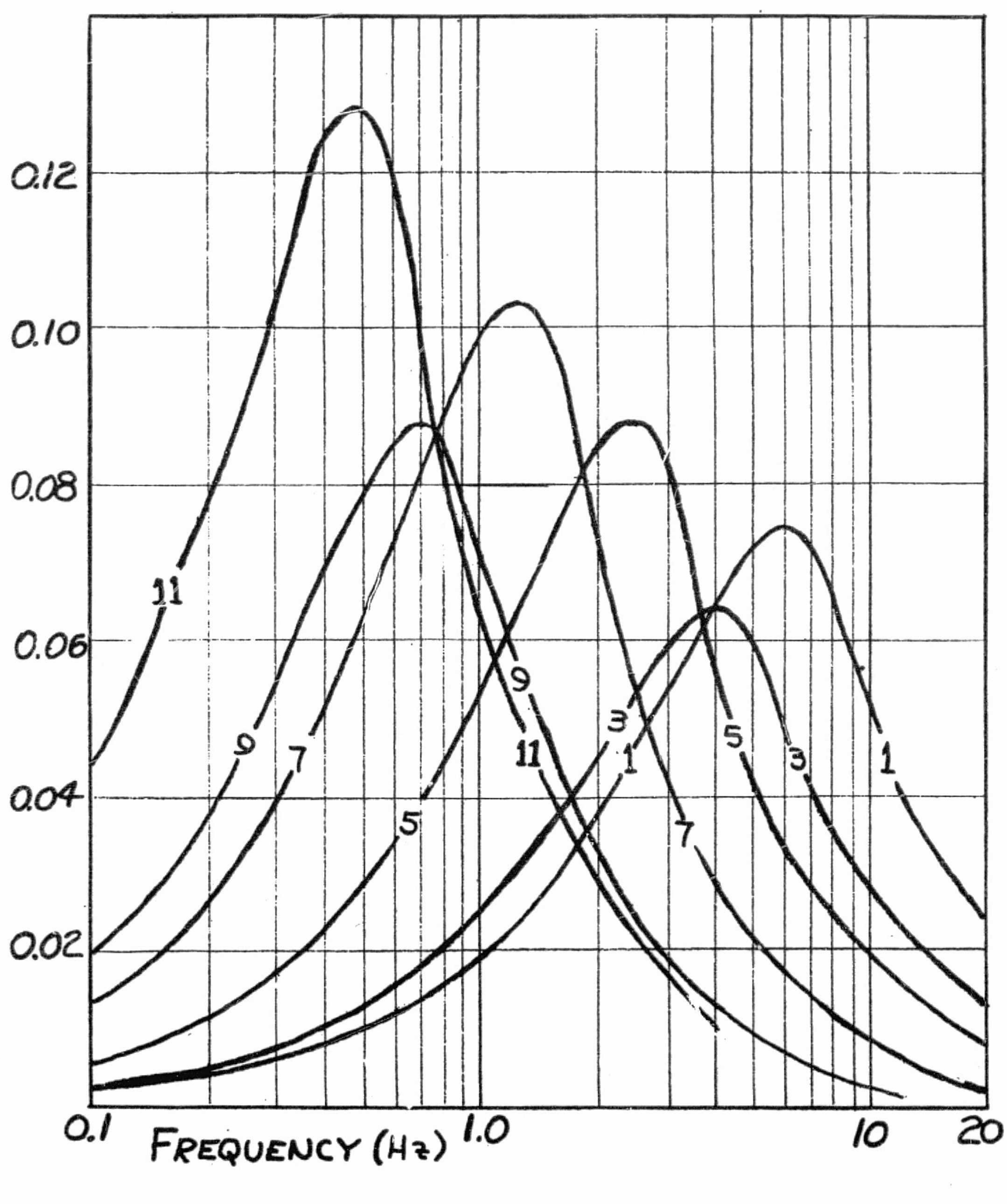


FIGURE NO. 16

energy received is a function of the area under the curve, and does not increase, however.

From what is known as matched filters, it can be shown that the maximum signal-to-noise is achieved when the transducer response curve matches the response curve of the signal to be received. The response of the SRL hot-wire microphone has a peak about 4.5 Hz. This would seem to match the third grenade, but would be too high for the upper grenades.

A longer neck was designed for the hot-wire microphone which placed its peak at about 1.6 Hz. This microphone was tried in the Wallops main base array for shoots 10.78, 10.84, and 10.85. Results of this test are shown in Figure 17. The amplitude of the received arrival, at the output of the microphone, was measured. Each set of readings was normalized so that the relative value of the first grenade was 1. Readings for the 1.6 Hz microphone, and several representative 4.5 Hz microphones, were taken from two firings.

In most cases, the second grenade appeared "loudest" to the old type microphone, and each succeeding grenade became weaker. In both cases, the largest indication from the 1.6 Hz microphone was grenade 7. This result agrees very well with the theoretical prediction of the "N" wave transform as shown in Figure 16. Signal to noise ratio was not indicated in these studies.

MICROPHONE STUDY

The aluminum can, hot-wire microphone has been used for some time in the grenade experiment. As reported several times, it has a tuned response with a center frequency of about 4.5 Hz. The

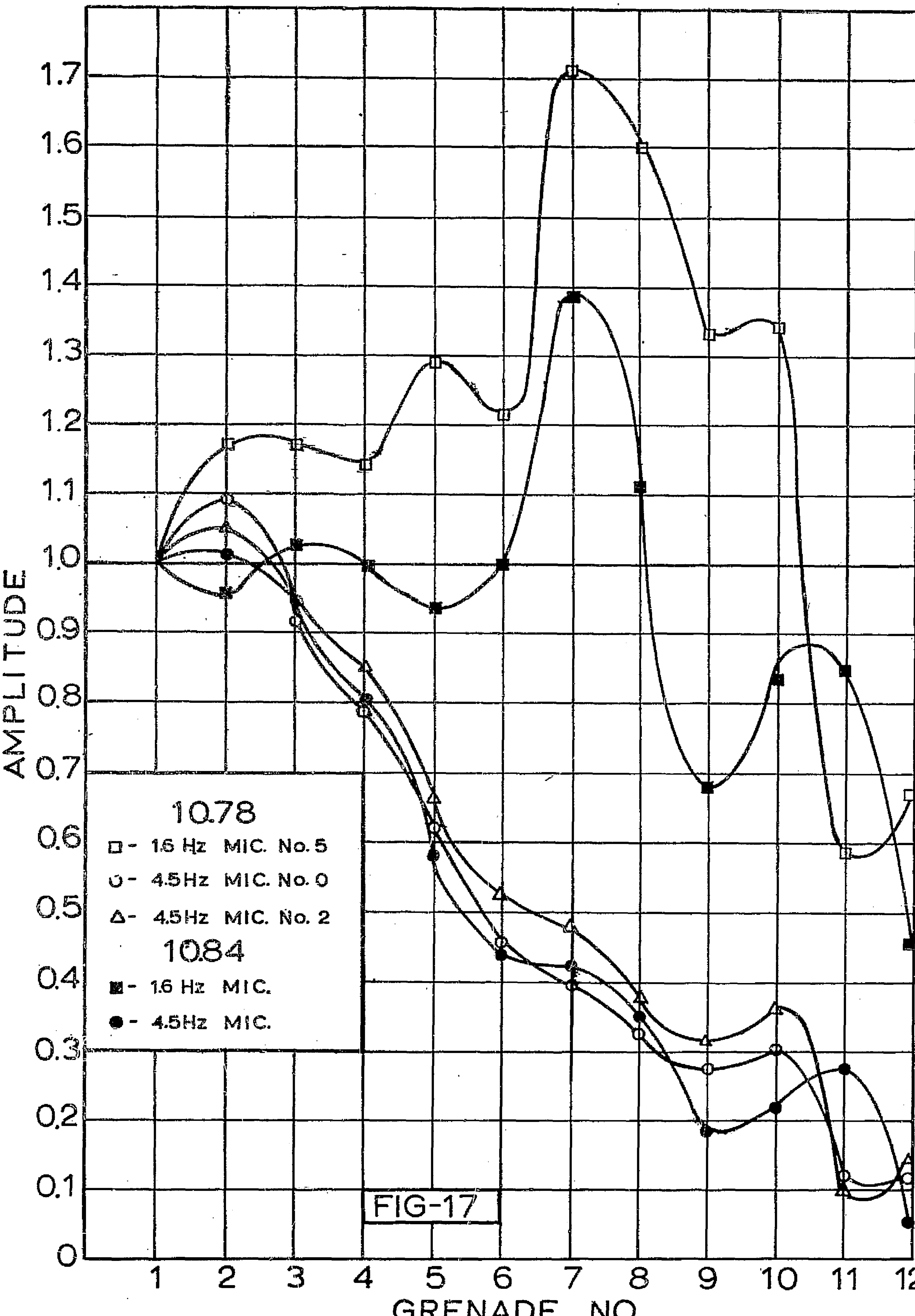

1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
AMPLITUDE
10.78
□ - 1.6 Hz MIC. No. 5
○ - 4.5Hz MIC. No. 0
△ - 4.5Hz MIC. No. 2
10.84
■ - 1.6 Hz MIC.
● - 4.5Hz MIC.
FIG-17
1 2 3 4 5 6 7 8 9 10 11 12
GRENADE NO.

FIGURE NO. 17

design was established by experimenting with various types of microphones in the field. Extension of this work is included here.

CAPACITOR MICROPHONE

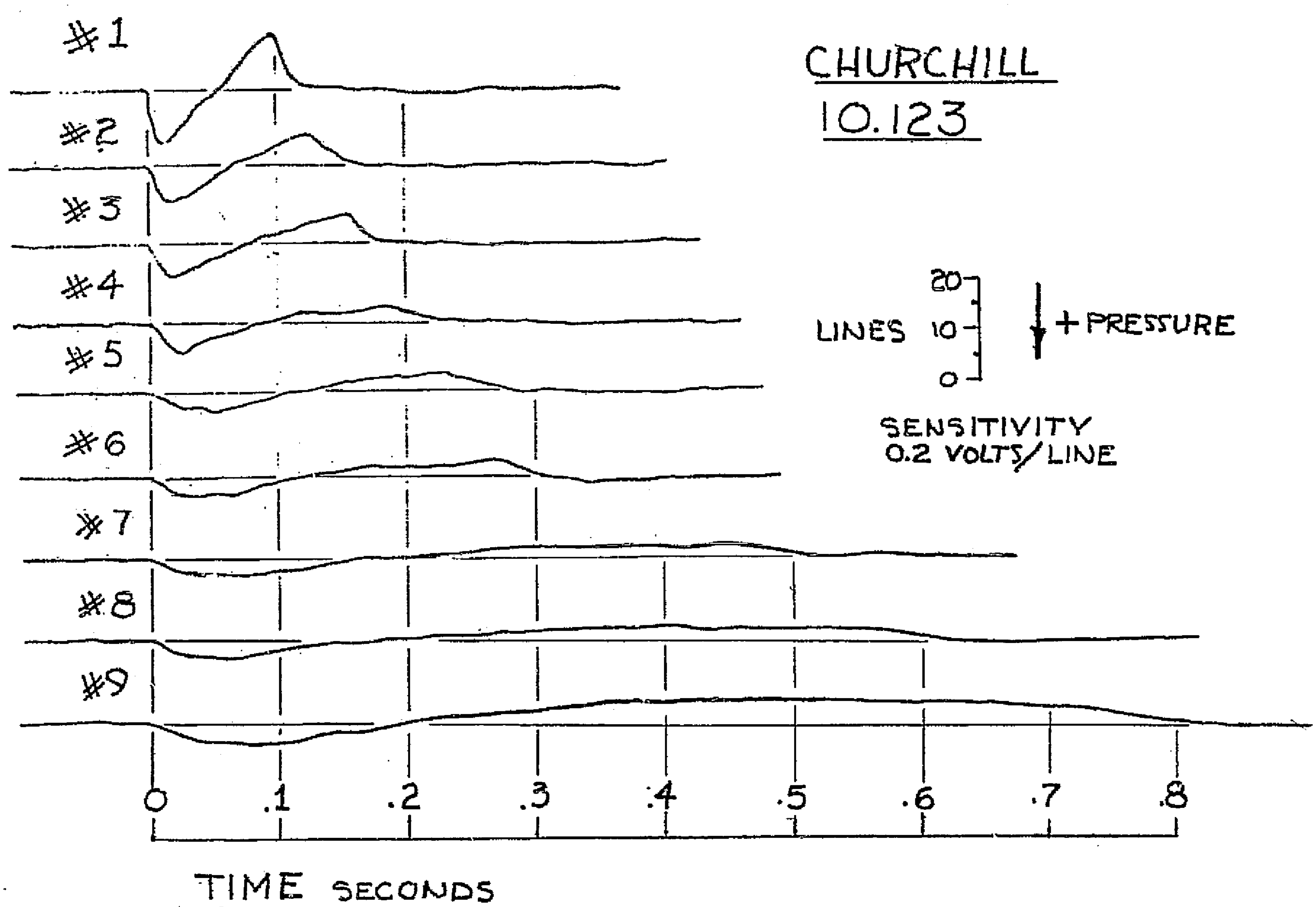
A late design of the SRL capacitor microphone was employed at Churchill during the Jan-Feb, 1965 series. The recordings of grenade arrivals were similar to results of the previous capacitor recordings,† except that a more accurate calibration of the microphone and associate equipment was accomplished.

The output of the microphone for the first nine grenades for shot 10.123 is shown in Figure 18. Measurements for the value of A were made from this and other arrivals on other shots in the series, and are shown in Figure 19. A late Cajun ignition occurred on 10.122, causing the grenades to arrive 12 seconds early. The grenade explosions were probably low, causing the pressures to be high.

The value of pressure shown is peak pressure and would seem to be high when compared to noise measurements (i.e. the upper several grenades are generally lost in noise levels above 0.1 - 0.2 dynes/cm^2). The value assigned to noise measurements is an RMS value, averaged for a period of seven seconds.

In general, the signal-to-noise ratio of the capacitor was lower than the hot-wire microphones. The highest readable grenade from the capacitor data was the ninth on 10.123, whereas all twelve grenades on all three shots were well indicated on the hot-wire microphones.

†Quarterly Progress Report No. 7



RECORDED VIA

SRL CAPACITOR MICROPHONE

S.N. # 22-3

SENSITIVITY - 0.32 VOLTS/DYNE

3db DOWN @ .33 Hz.

FIGURE NO. 18

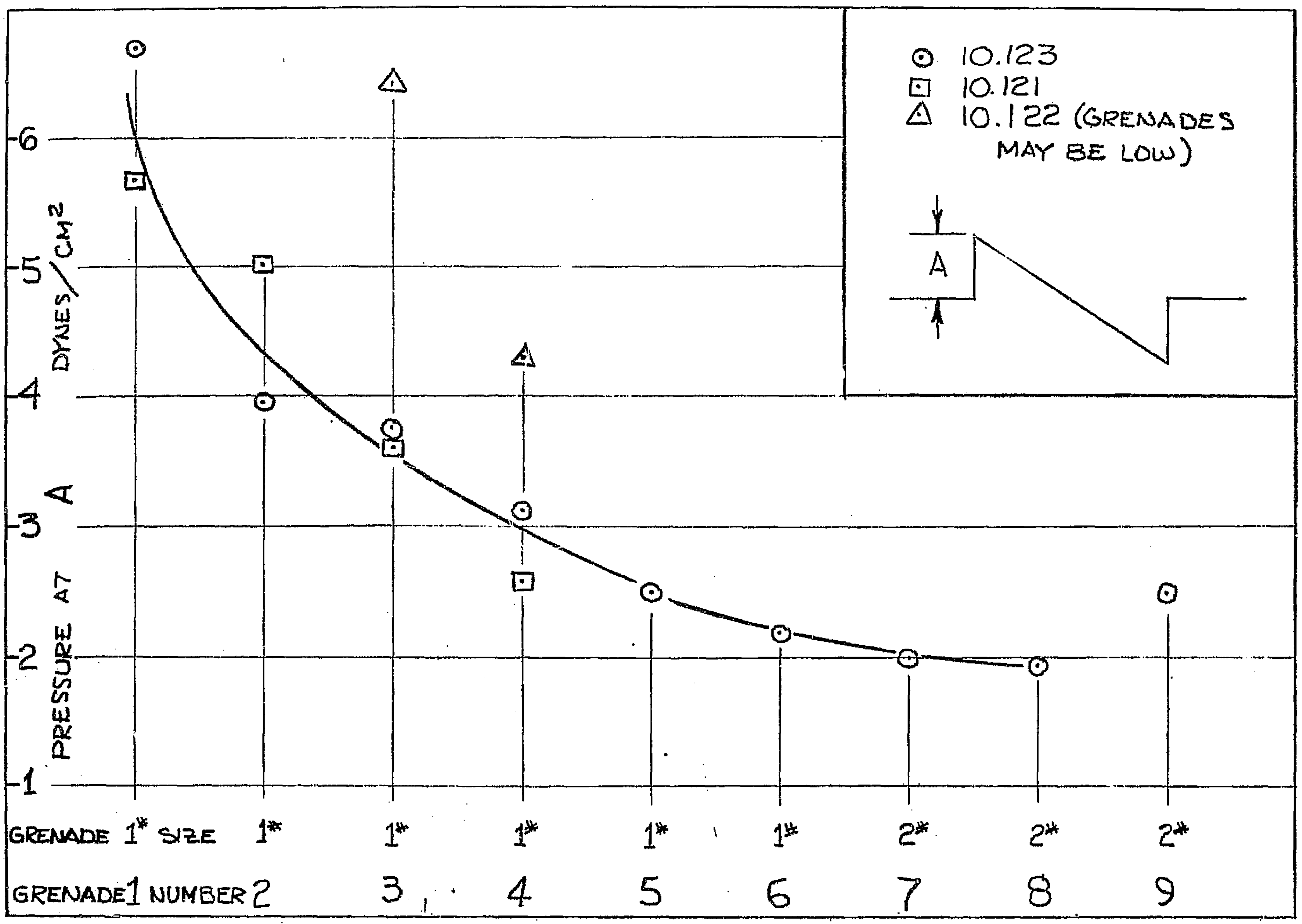

10.123
10.121
10.122 (GRENADES MAY BE LOW)
A
PRESSURE AT A DYNES/CM²
6
5
4
3
2
1
GRENADE 1* SIZE 1* 1* 1* 1* 1* 2* 2* 2*
GRENADE 1 NUMBER 2 3 4 5 6 7 8 9

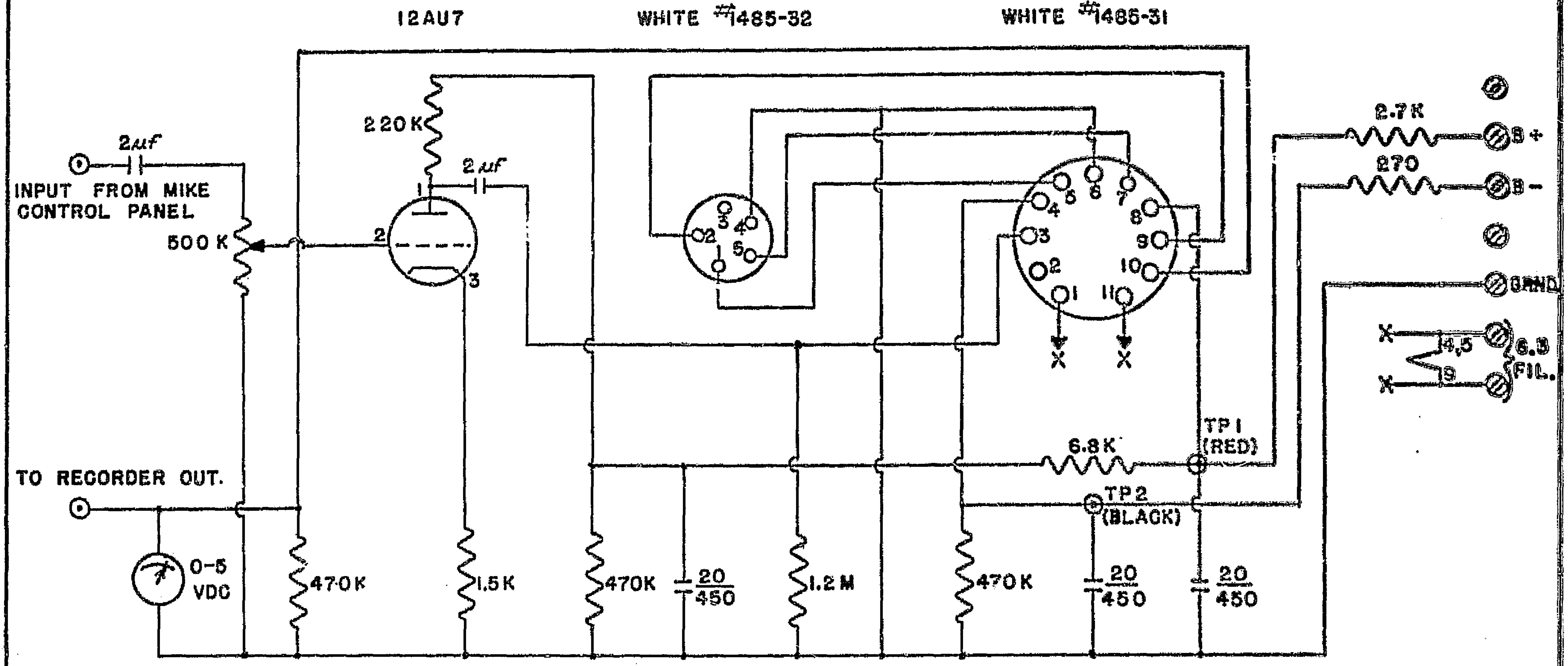
FIGURE NO. 19

This capacitor microphone was very reliable and was the best instrument of this type thus far tested.

NOISE METER

The principal addition to the sound ranging station equipment was the Noise Meter. The calibration of this device has been described in Quarterly Progress Report No. 5. The schematic is shown in Figure 20.

REVISIONS			
SYM.	DESCRIPTION	DATE	APPROVAL



CALIBRATION

INPUT–21.5 $V_{p\text{-}p}$ SINE WAVE, 7.6 V_{RMS}

OUTPUT–1.0 DYNE/CM^2, 5.0 VDC

NOTES

1. VOLTAGE AT TP1, +250VDC
2. VOLTAGE AT TP2, —100VDC
3. ALL RESISTORS IN OHMS
4. ALL CAPACITORS IN μfd.

UNLESS OTHERWISE SPECIFIED

DECIMAL .XX ± .02 .XXX ± .010
FRACTIONAL ± 1/64 ANGULAR ± ½°
CONCENTRICITY MACHINED DIAMETERS .004 TIR
SURFACE ROUGHNESS IN RMS MICROINCHES
ALL DIMENSIONS IN INCHES
REMOVE ALL BURRS AND SHARP EDGES
ALL DIMENSIONS TO BE MET BEFORE PLATING
DO NOT SCALE THIS DRAWING

DRILLED HOLE TOLERANCES			
.013 TO .136	+ .002 − .001	.234 TO .750	+ .005 − .001
.136 TO .234	+ .003 − .001	.750 TO 2.000	+ .010 − .002

		DATE
DRAWN	W. B. R.	7-22-64
REV.	J L Mc	6-1-65
ENGR.	JGP	7-29-64
APPD.	JFC	6-7-65
APPD.		
RELEASED		

TITLE

NOISE METER PANEL

SCALE WT.

SCHELLENGER RESEARCH LABORATORY
TEXAS WESTERN COLLEGE
EL PASO, TEXAS

DWG. NO.

FIGURE NO. 20

III. DATA ANALYSIS

Analyzing the sound arrivals of the rocket grenade experiment and converting this information into further useful data has been the responsibility of Schellenger Research Laboratories since 1961. During the succeeding four years and three months, 19 experiments were processed under a previous contract and 47 experiments, including 60 separate reports, were analyzed under the present contract. In this period, the methods and procedures utilized have evolved into a rapid and semi-automated reduction of the data.

The original computer program, consisting of a punched tape input, was for an array of six microphones as used at Wallops Island. Upon the installation of the 5-microphone array at Fort Churchill in 1962, a separate program was prepared using the concepts of the original program. As additional arrays were installed, all of the 5-microphone variety, the Fort Churchill program was adapted to the new location.

Many minor problems were encountered such as reading the data with an IRIG recording head and attempting to reproduce the information through an Ampex head. This difficulty was solved by using only the even or odd numbered channels on time-valued data. However, other problems remained as persistent as the typographical error.

In order to make the reduction and presentation process more efficient, several modifications for the program were introduced in mid-1964.† The original program required manual recording of

†Quarterly Progress Report No. 8

the break times which were then placed on a Flexowriter tape in an involved format. Coherence tests required a typed input. In copying information on data sheets and transferring again to the punched tape, checkers had to check each other to avoid a rash of errors.

An IBM card input-output system was adopted with the use of a Benson-Lehner Oscar Model F reader, shown in Figure 21. This piece of equipment was connected directly to an IBM 026 key-punch. The Oscar contains a motorized paper drive, a manually operated cross-hair, and an analog to digital converter. The real time corresponding to the microphone break time is transferred to the IBM card for direct input into the computer.

The input format was changed radically, allowing a more readable output format for the final report. In addition, the procedure for inserting array coordinates was simplified. This made possible a more rapid reduction of data from a new installation. These revisions made no significant change in the final data.

A minor change in the method of computation was made that did change the results, however. In averaging the results of the four readers, the original program fitted each reader's data by a least squares procedure, then obtained the weighted mean of the results. The new program first calculated the mean of the readers, then provided a least squares fit to these means. Standard deviations were larger but were considered to be much more realistic.

Upon receipt of the magnetic tape from the field, a playback was made of the data on a paper record using an oscillograph and chemical processor. Each of four readers made an independent reading of the breaks on the Oscar. The order of breaks, use of an

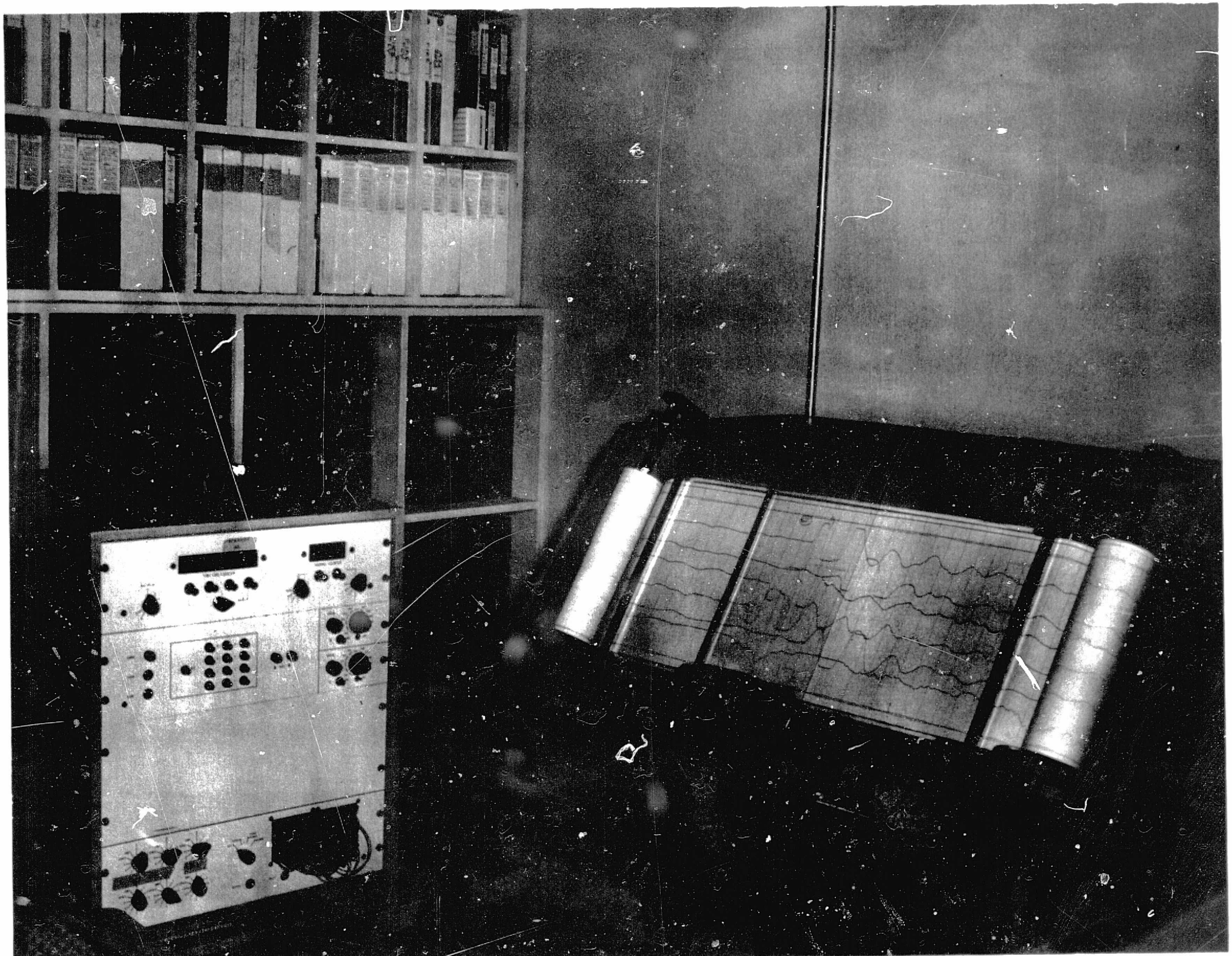


FIGURE 21   BENSON-LEHNER OSCAR

overlay from previous grenades, and an overlay of all traces on the same grenade helped in hard-to-read cases. One or two microphone breaks were left out if not readable in extreme cases. A coherence check was run on the computer of each grenade by each reader and had to pass with a predetermined minimum error. The output of the coherence check was then time averaged by grenade. The final output by card from the final computer program was transferred to a duplimat stencil. Figures 22 through 29 are flow charts of the four separate programs used in computation on the Bendix G-15. Figures 30 through 35 are a further breakdown of the final program.

To provide the final data as quickly as possible, the slant range from the array to the grenade, used to determine the effects of a spherical wave front, were estimated by past performances. A revision of the final report was issued upon receipt of the actual grenade positions. Occasionally, revisions were necessary to correct card punch and computer errors, to add a grenade previously left out due to added time needed for analyzing, or to correct a reader error usually of time or grenade number.

None of the five arrays operated during the contract period were identical and each had its own characteristics. Figures 36 through 40 illustrate their relative positioning of microphones and instrumentation location together with the actual array coordinates utilized in the computer program.

A summary of 60 reports issued on the 47 rocket grenade experiments is shown in Table 1. The 13 additional reports represent the data from the Wallops Assateague array reflecting information from a different vantage point. Also shown are seven

COGE FLOW
(0900-1090)

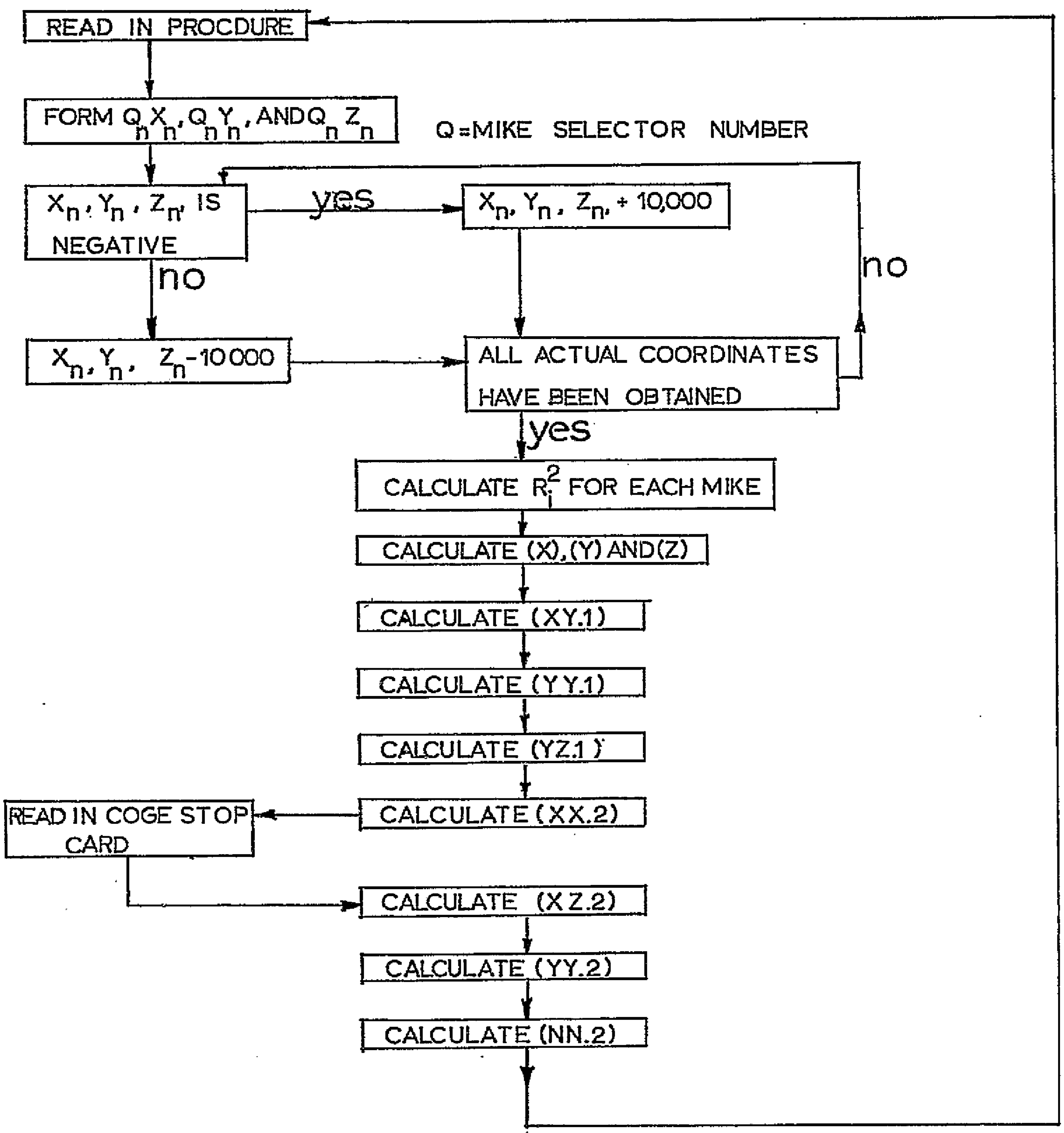


FIGURE NO. 22

COHERENCE FLOW-1

(0900-0975)

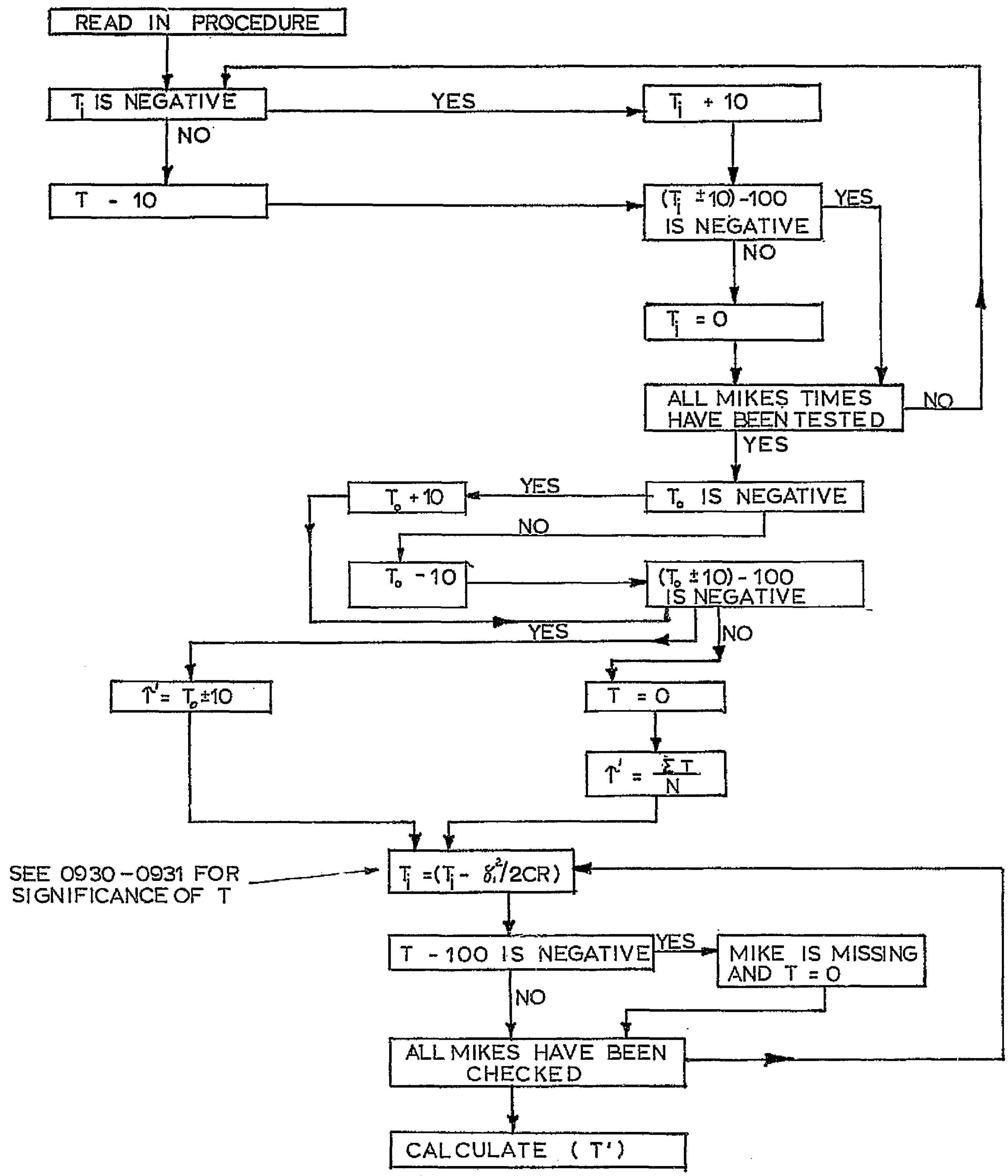


FIGURE NO. 23

COHERENCE FLOW - 2
(0975-1097)

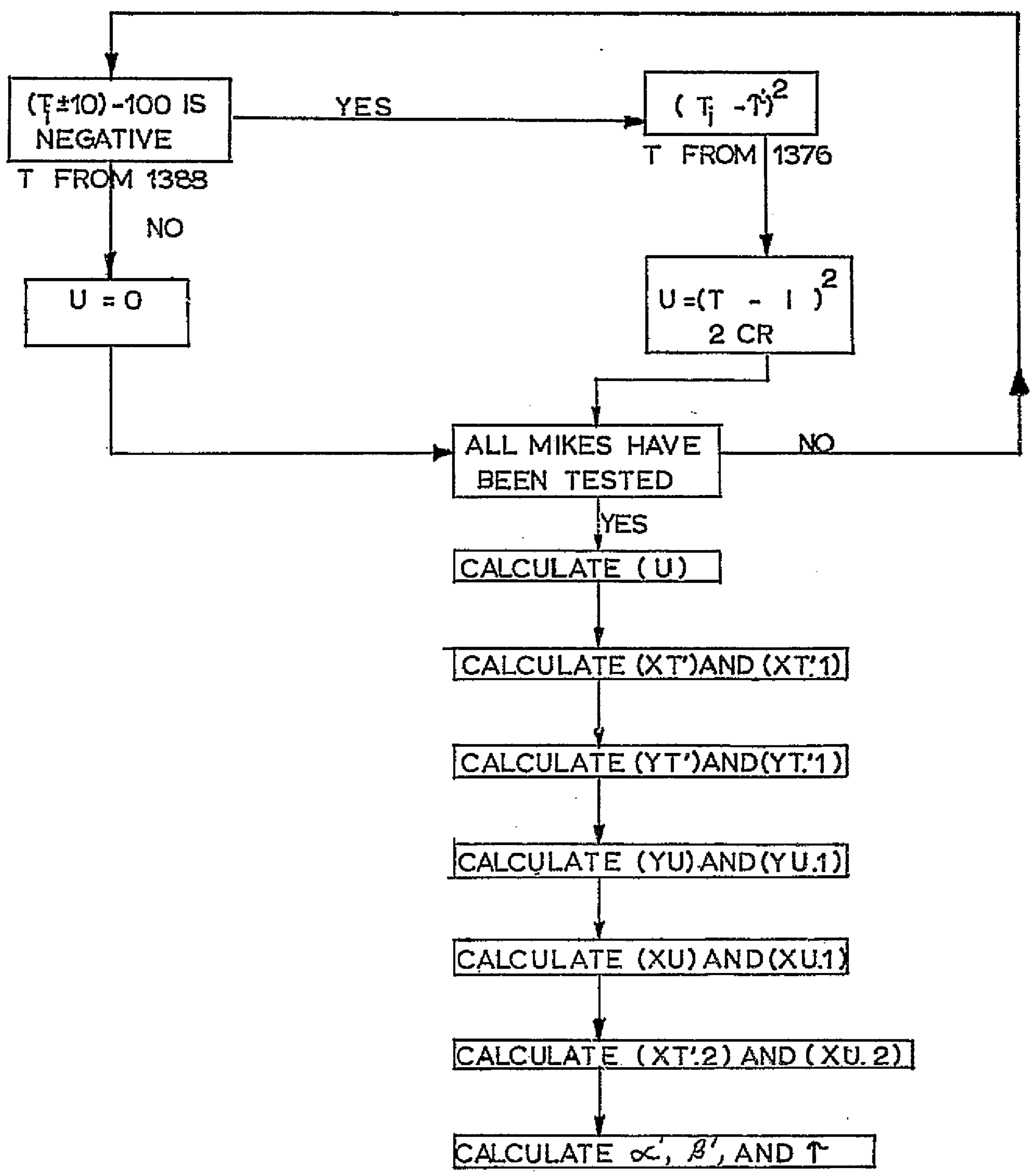


FIGURE NO. 24

COHERENCE FLOW - 3

(1098 - 1156)

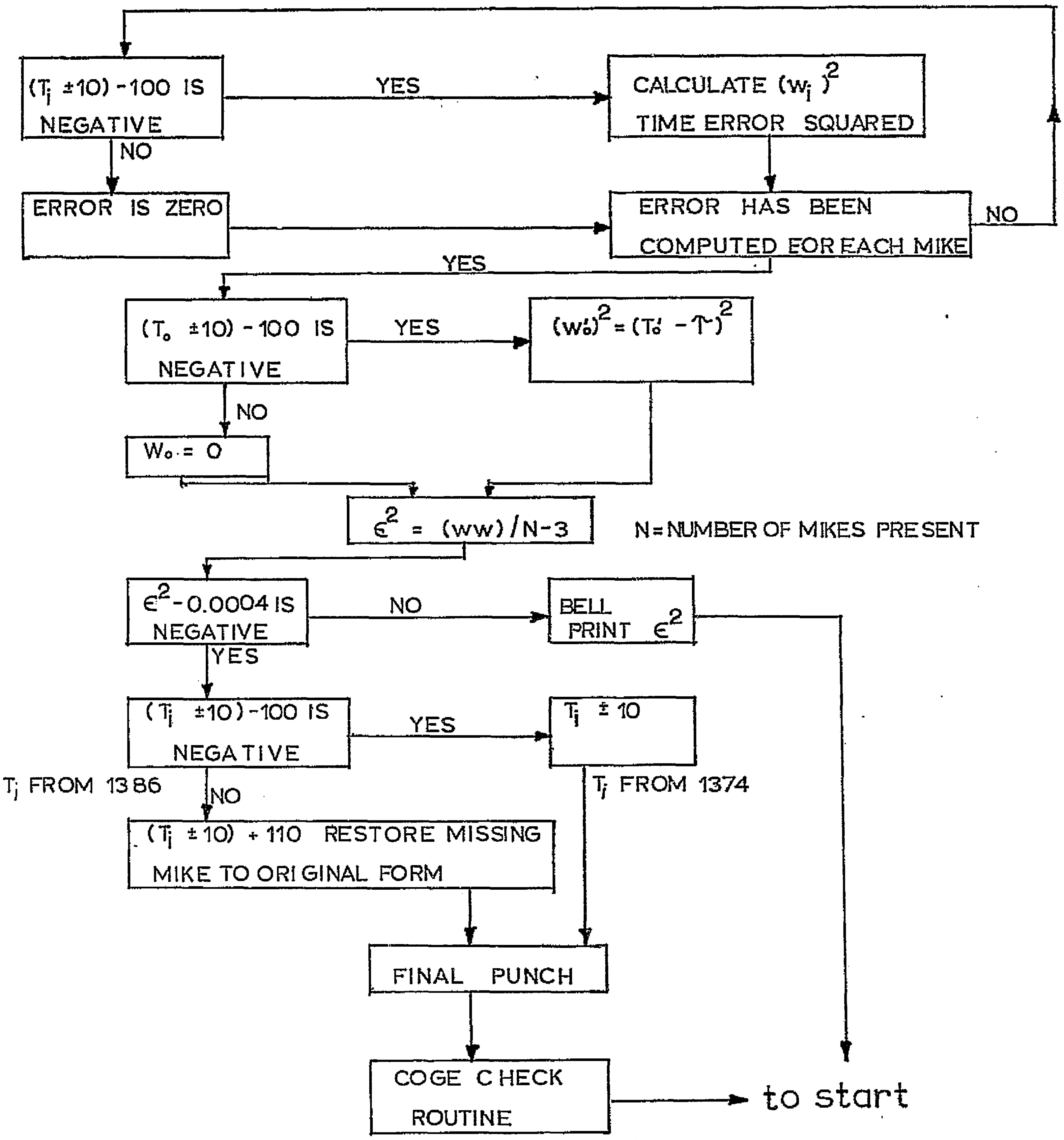


FIGURE NO. 25

TIME AVERAGING FLOW-1
(0900-0963)

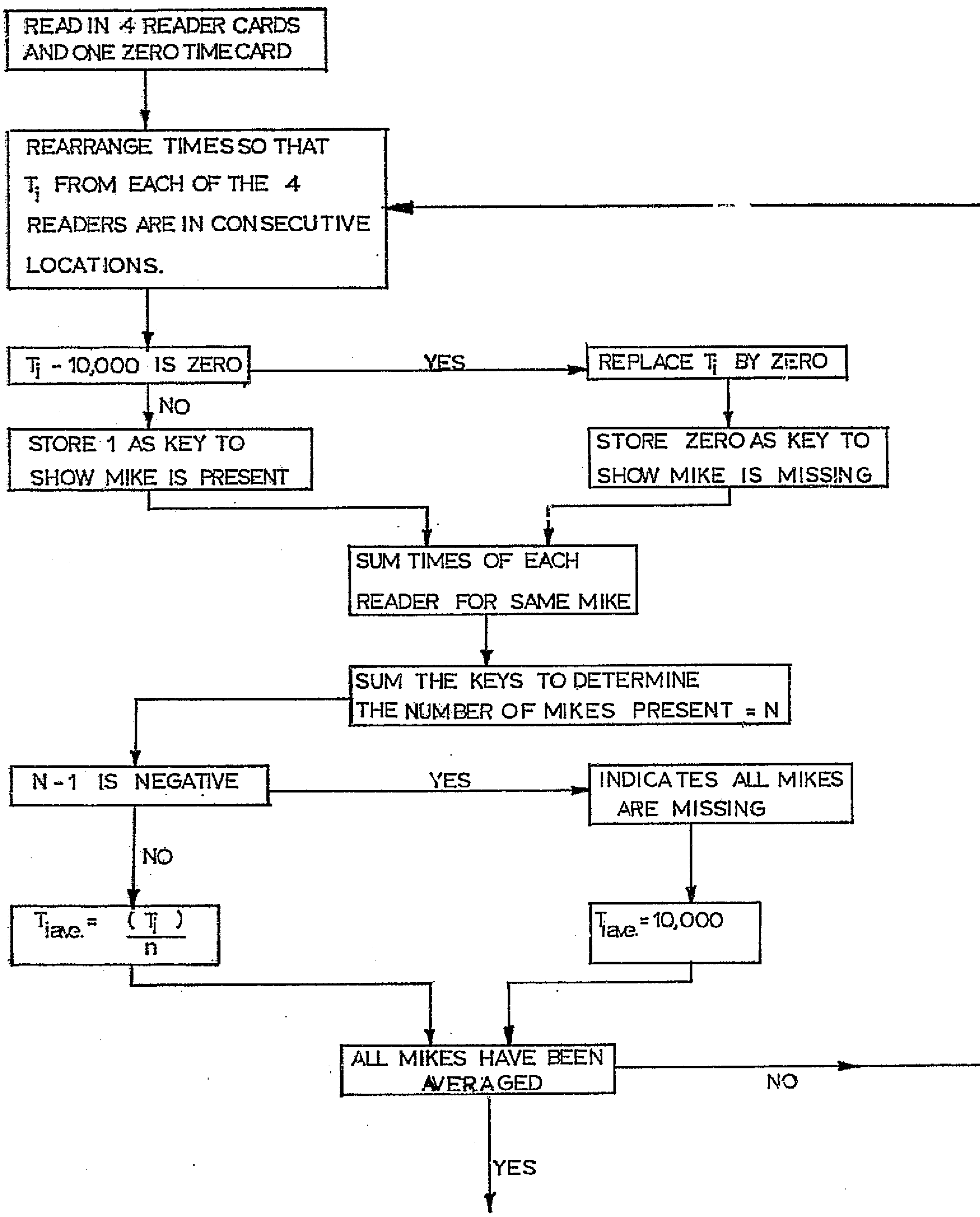


FIGURE NO. 26

TIME AVERAGING FLOW - 2

(0955-0999 , 1102-1104)

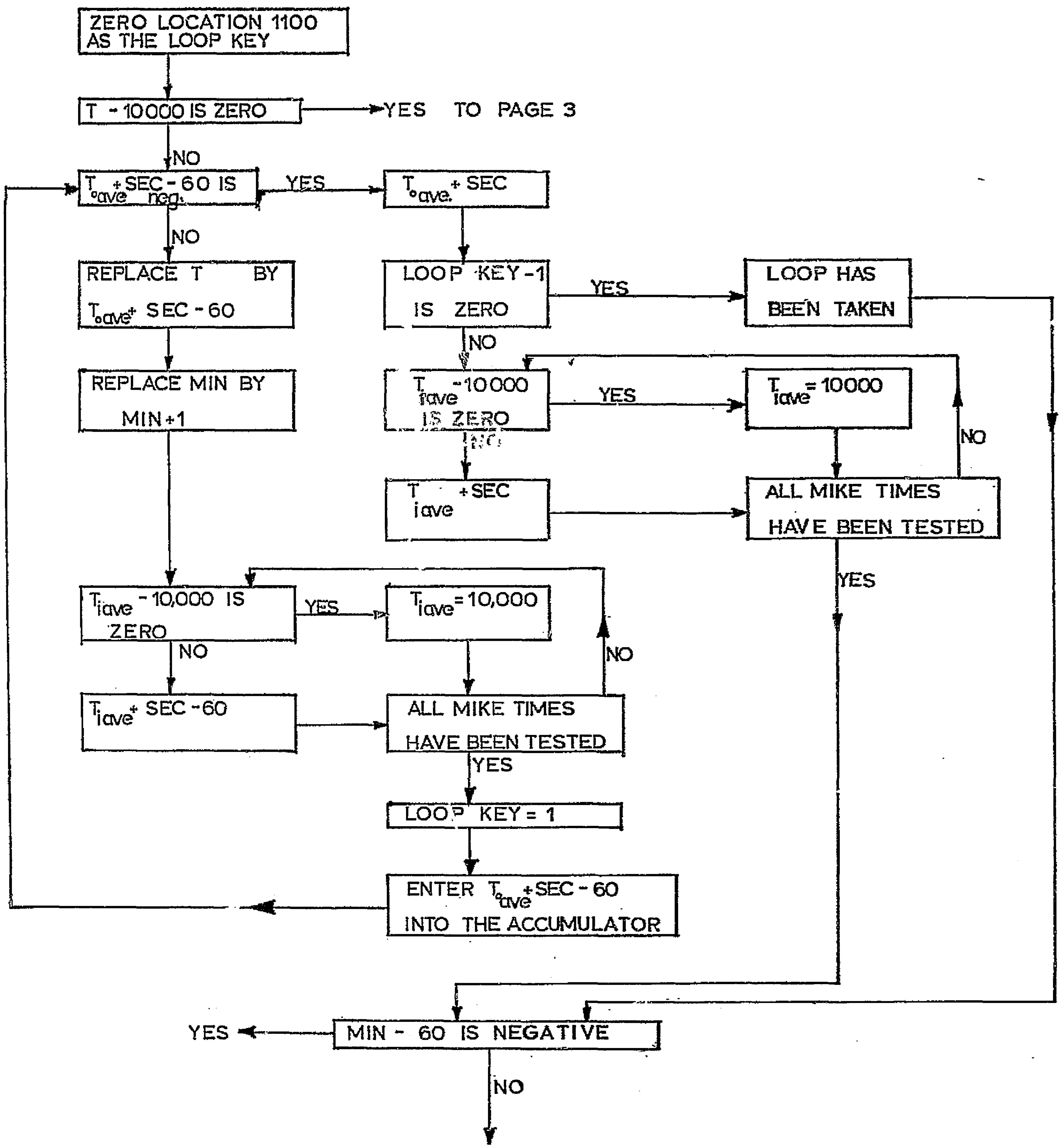


FIGURE NO. 27

TIME AVERAGING FLOW - 3
(1104 - 1153)

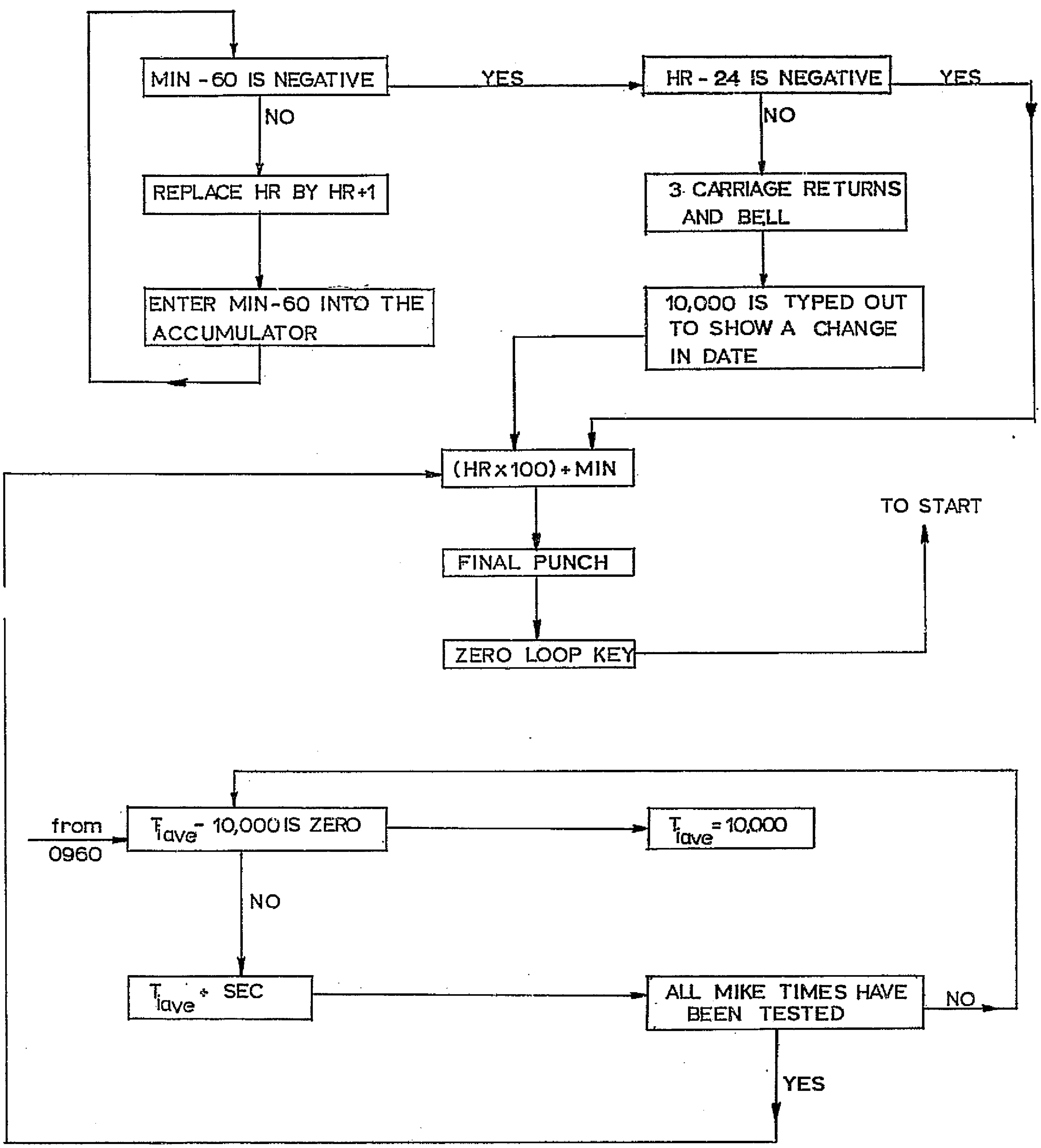


FIGURE NO. 28

SUMMARY FINAL FLOW

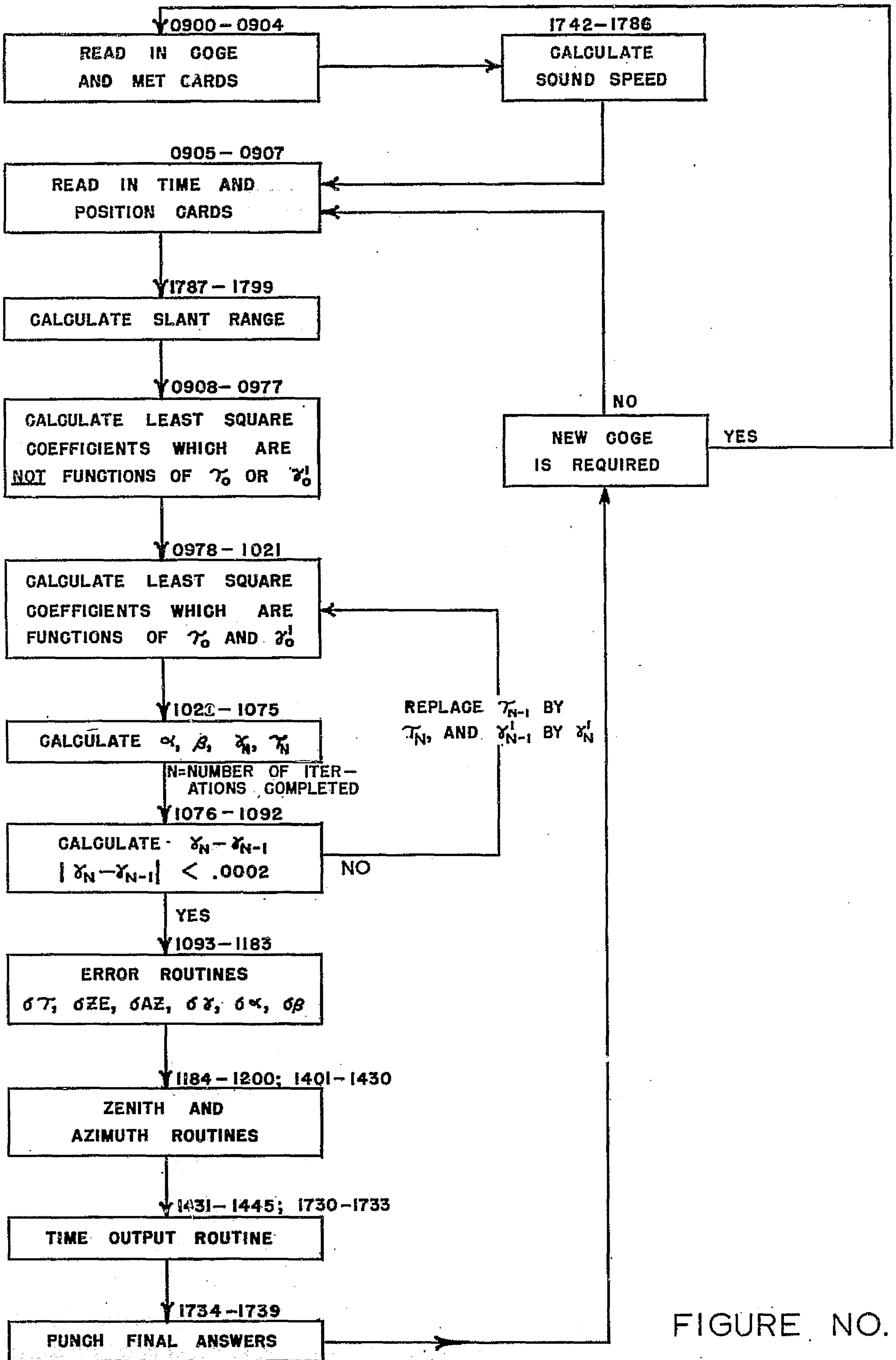
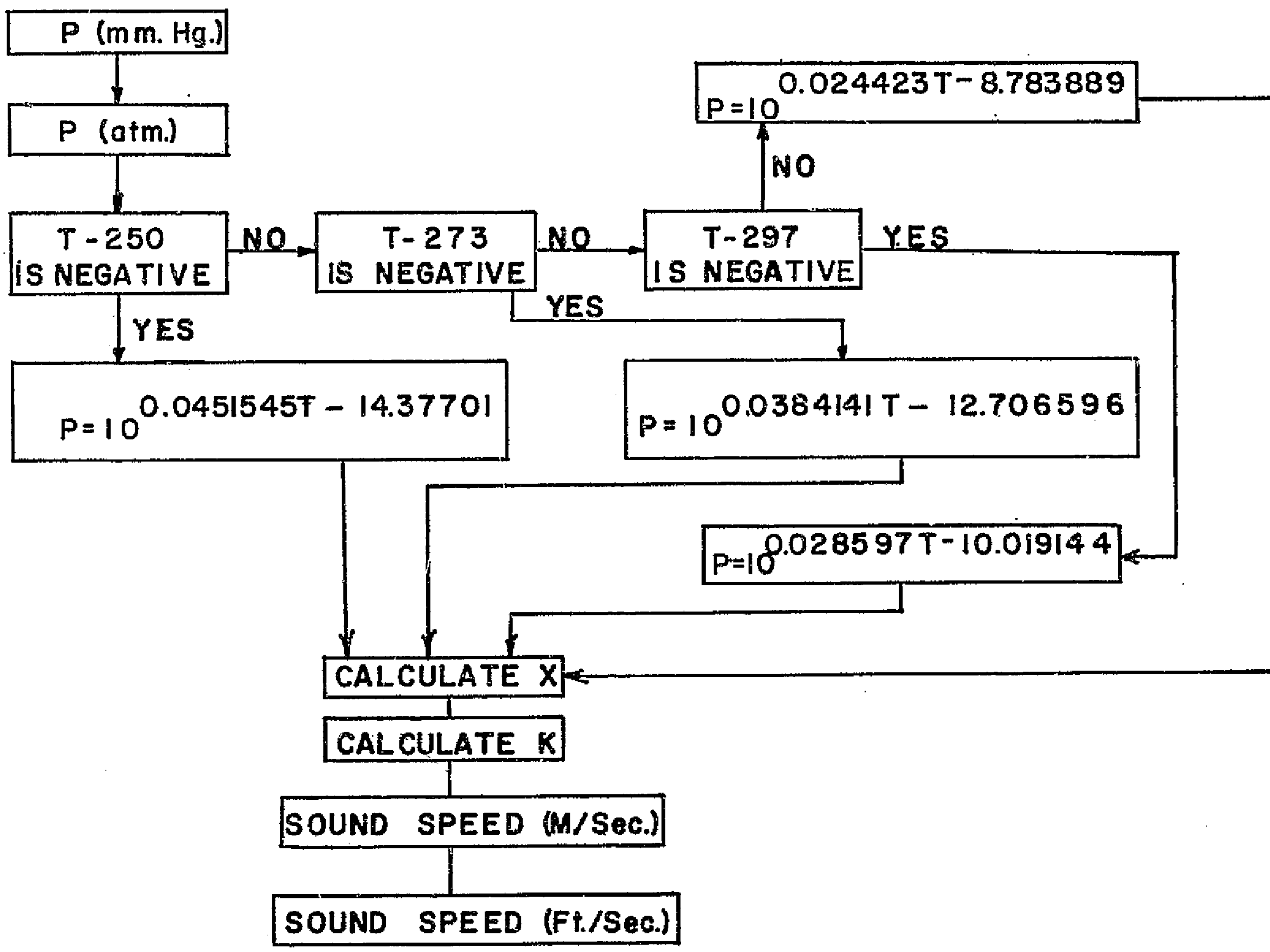


FIGURE NO. 29

SOUND SPEED FLOW
(1742-1786)

DATA INPUT:

VIA MET CARD:
- AMBIENT PRESSURE (mm.Hg.)
- TEMPERATURE (°K)
- RELATIVE HUMIDITY
- *WIND DIRECTION
- *WIND VELOCITY (mph)



* ALTHOUGH THE WIND DIRECTION AND WIND SPEED ARE NOT USED IN CALCULATING THE SOUND SPEED, THEY ARE INCLUDED ON THE CARD FOR INFORMATIONAL PURPOSES.

FIGURE NO. 30

FLOW SHEET FOR CALCULATION OF LEAST SQUARES COEFFICIENTS WHICH ARE NOT FUNCTIONS OF τ_o OR γ_o'. (0908-0977)

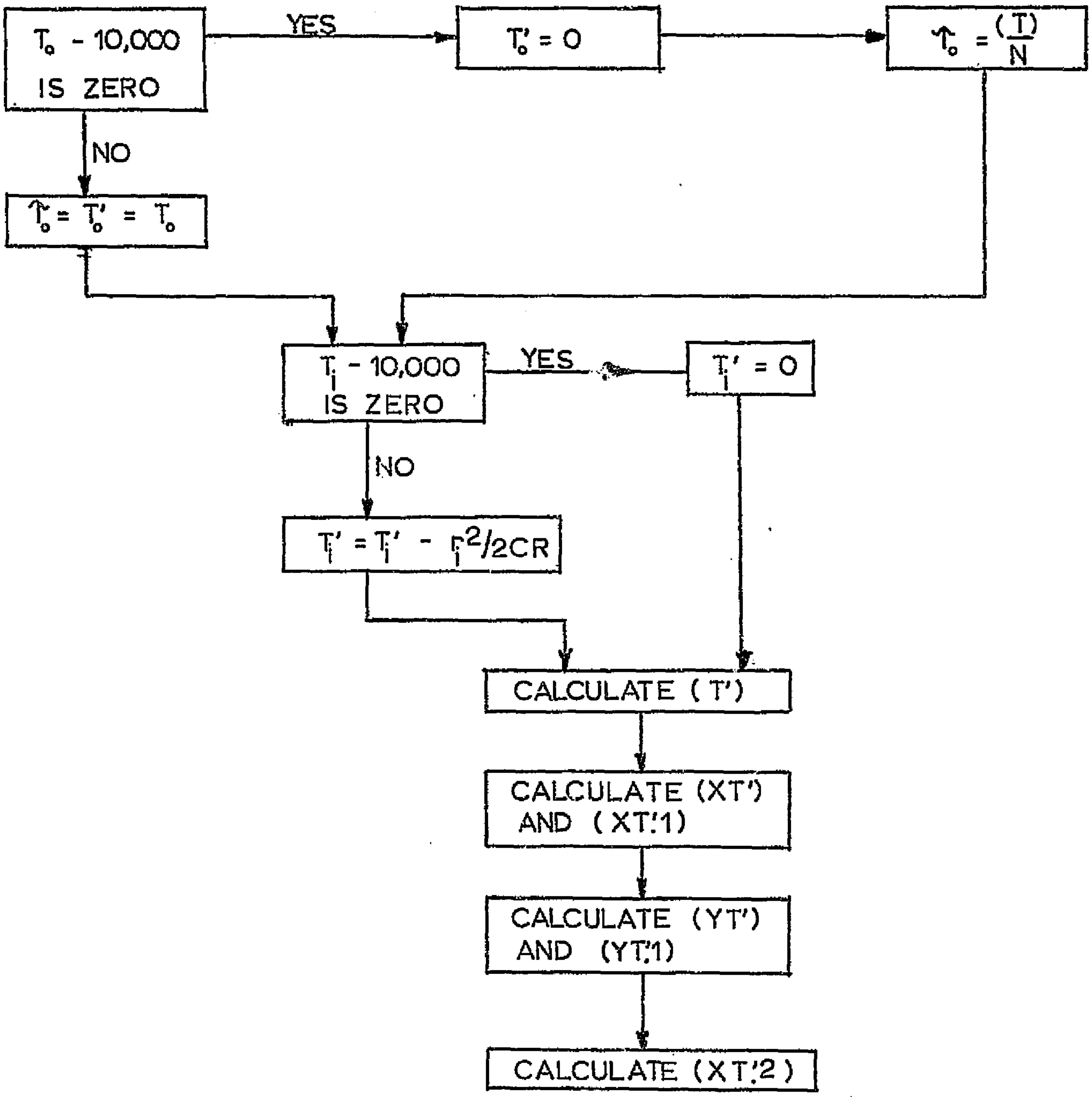
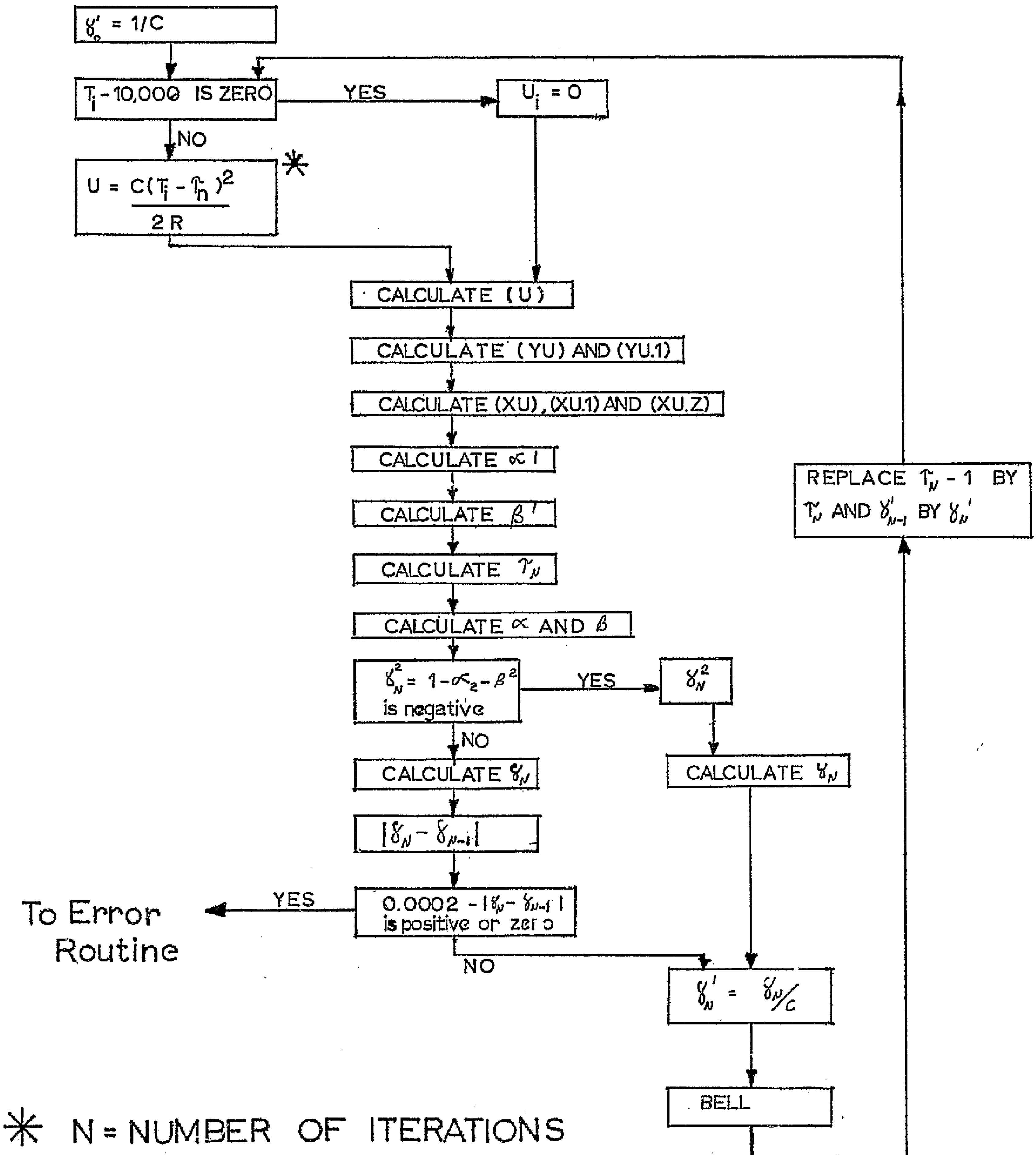


FIGURE NO. 31

FLOW SHEET FOR CALCULATING THOSE LEAST SQUARE COEFFICIENTS WHICH ARE FUNCTIONS OF τ_o AND γ_o' (0978–1092)



* N = NUMBER OF ITERATIONS COMPLETED

FIGURE NO. 32

ERROR ROUTINE (1093-1183)

THE PURPOSE OF THIS ROUTINE IS TO CALCULATE THE DEVIATION IN THE DIRECTION COSINES, DEVIATION IN ZENITH AND AZIMUTH ANGLES, AND THE TIME DEVIATION IN DETERMINING THE TIME THE FRONT CROSSES THE ZERO MIKE.

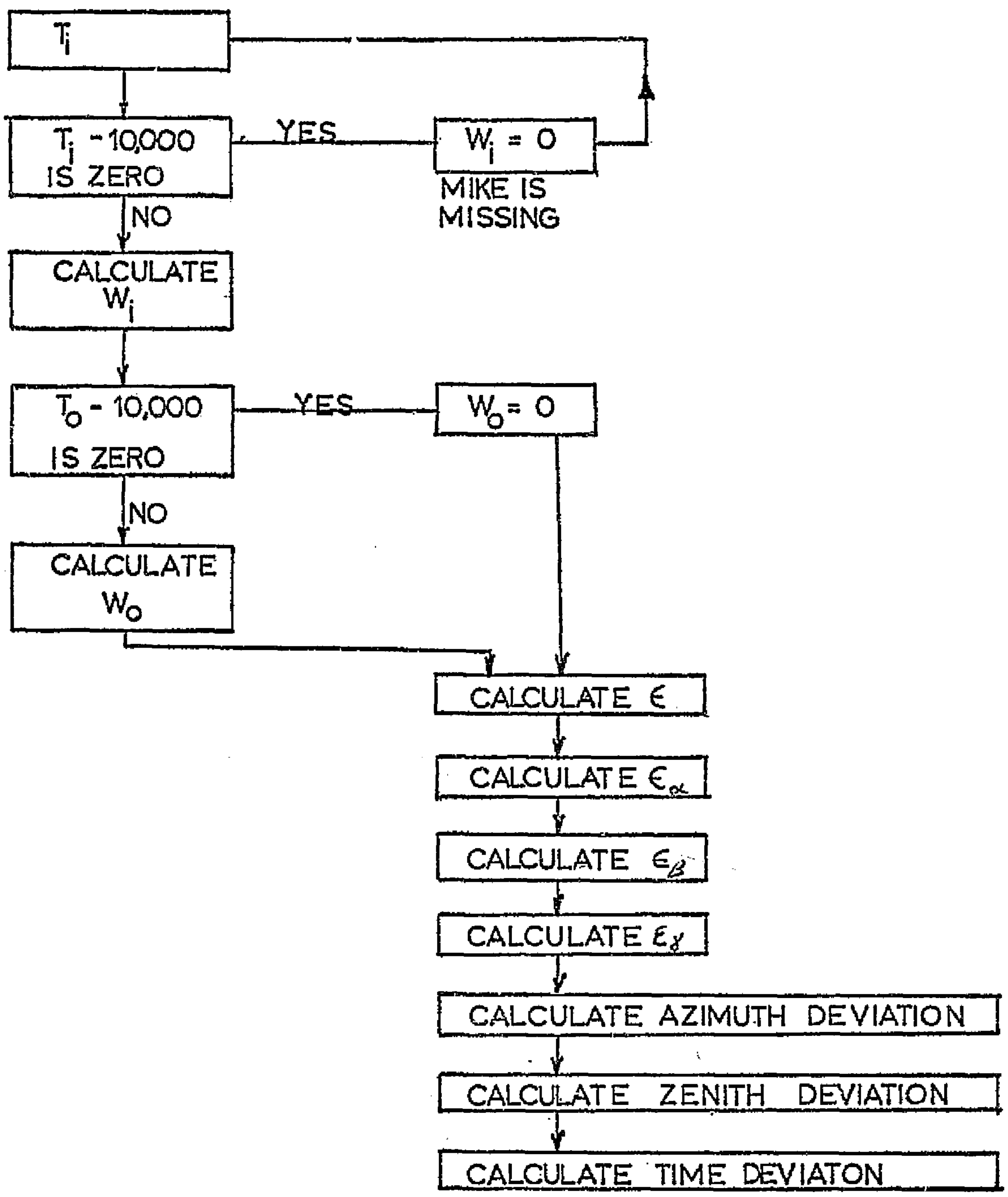


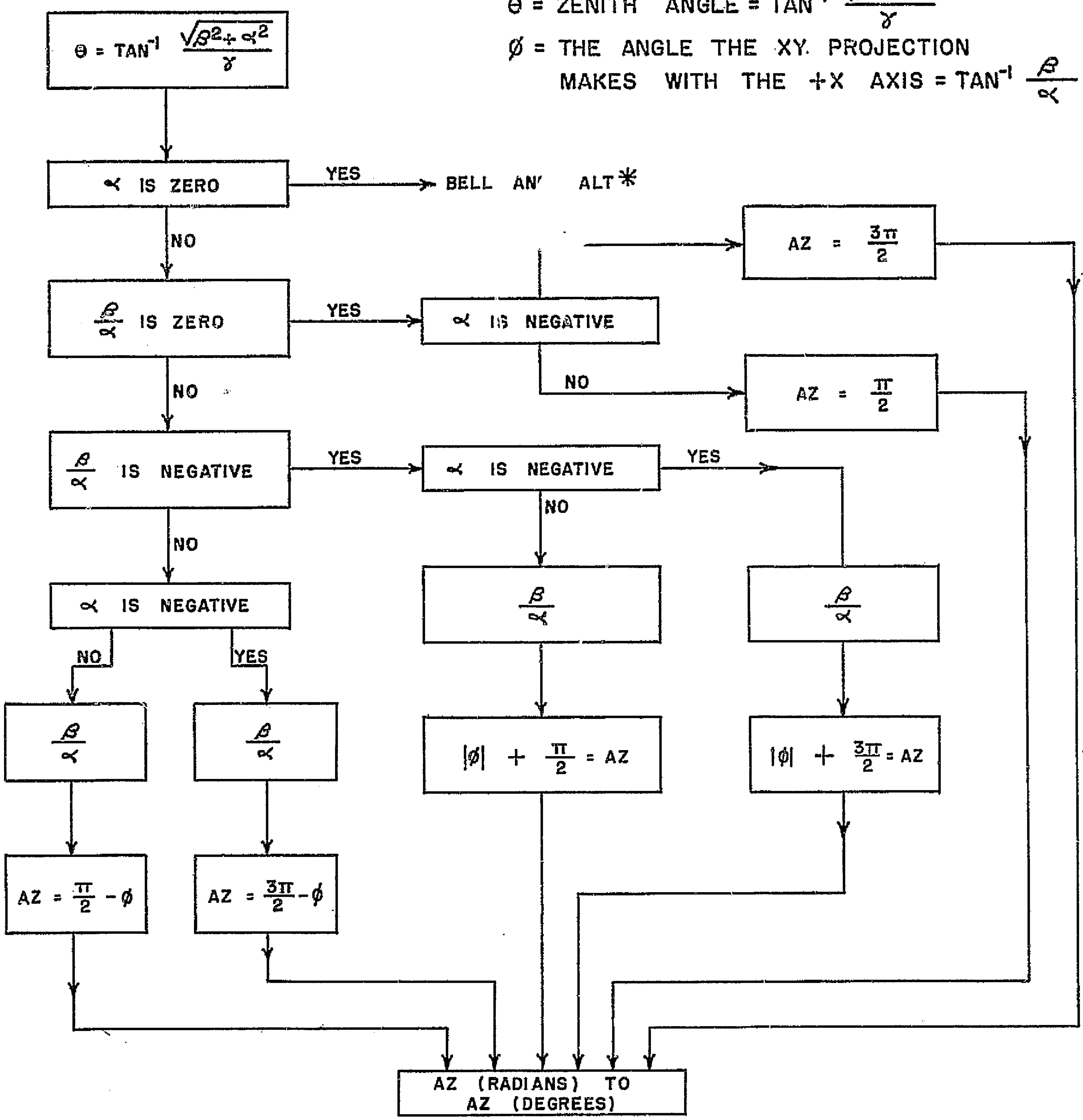
FIGURE NO. 33

ZENITH AND AZIMUTH FLOW
(1184–1200; 1401–1430)

+Y AXIS IS TRUE NORTH

θ = ZENITH ANGLE = $\tan^{-1} \frac{\sqrt{\beta^2+\alpha^2}}{\gamma}$

ϕ = THE ANGLE THE XY PROJECTION MAKES WITH THE +X AXIS = $\tan^{-1} \frac{\beta}{\alpha}$



*INDICATES AZIMUTH IS EITHER 0° OR 180°. BEGIN COMPUTATION AT 1431. IF B>0, AZ IS ZERO DEGREES; IF B<0, AZ IS 180°.

FIGURE NO. 34

TIME OUTPUT FLOW

(1431-1445, 1730-1733)

THE PURPOSE OF THIS ROUTINE IS TO DETECT A TIME IN SECONDS GREATER THAN 60, A TIME IN MIN. GREATER THAN 60, AND A DATE CHANGE.

Υ = TIME (SECONDS) PAST THE ZERO MIKE.

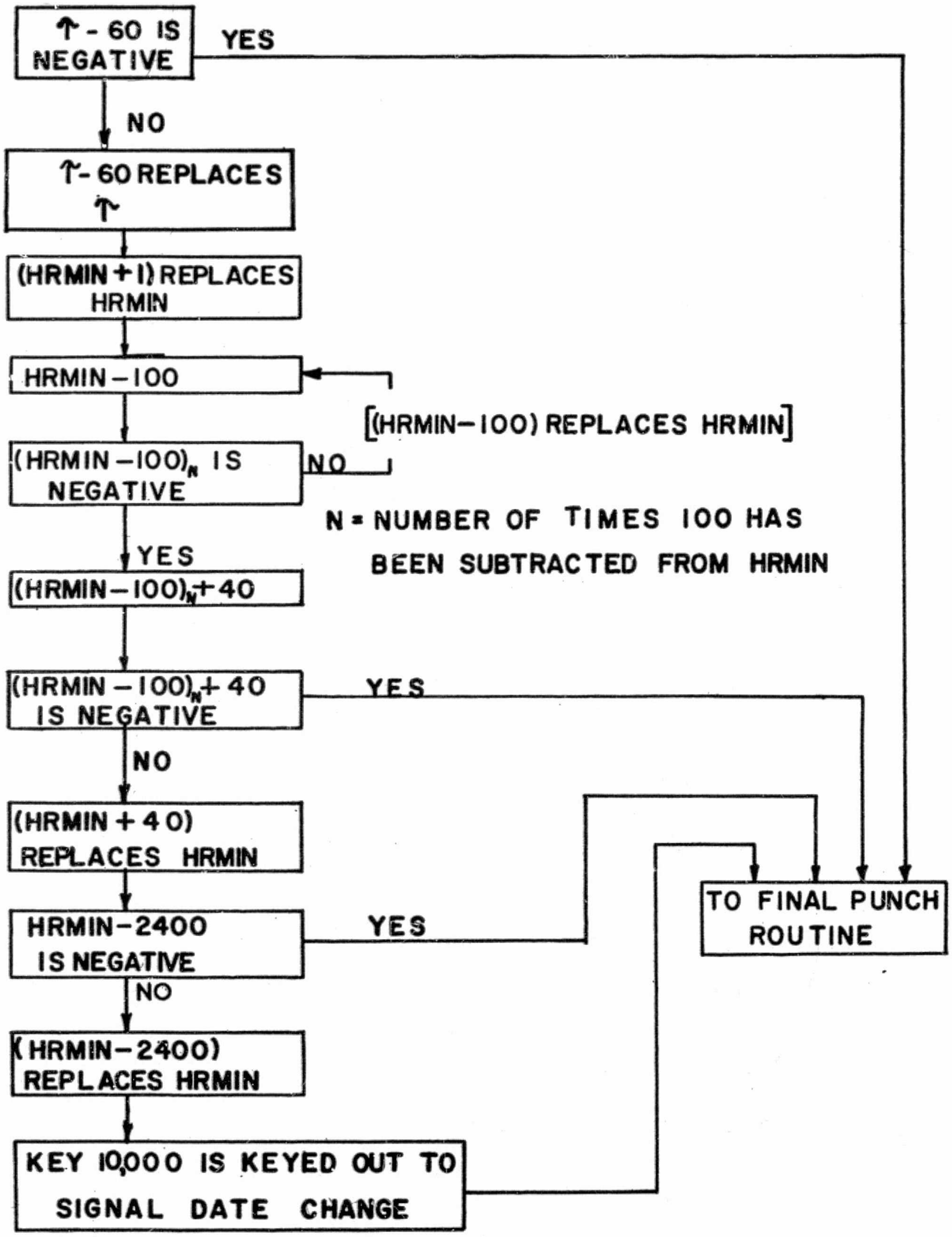
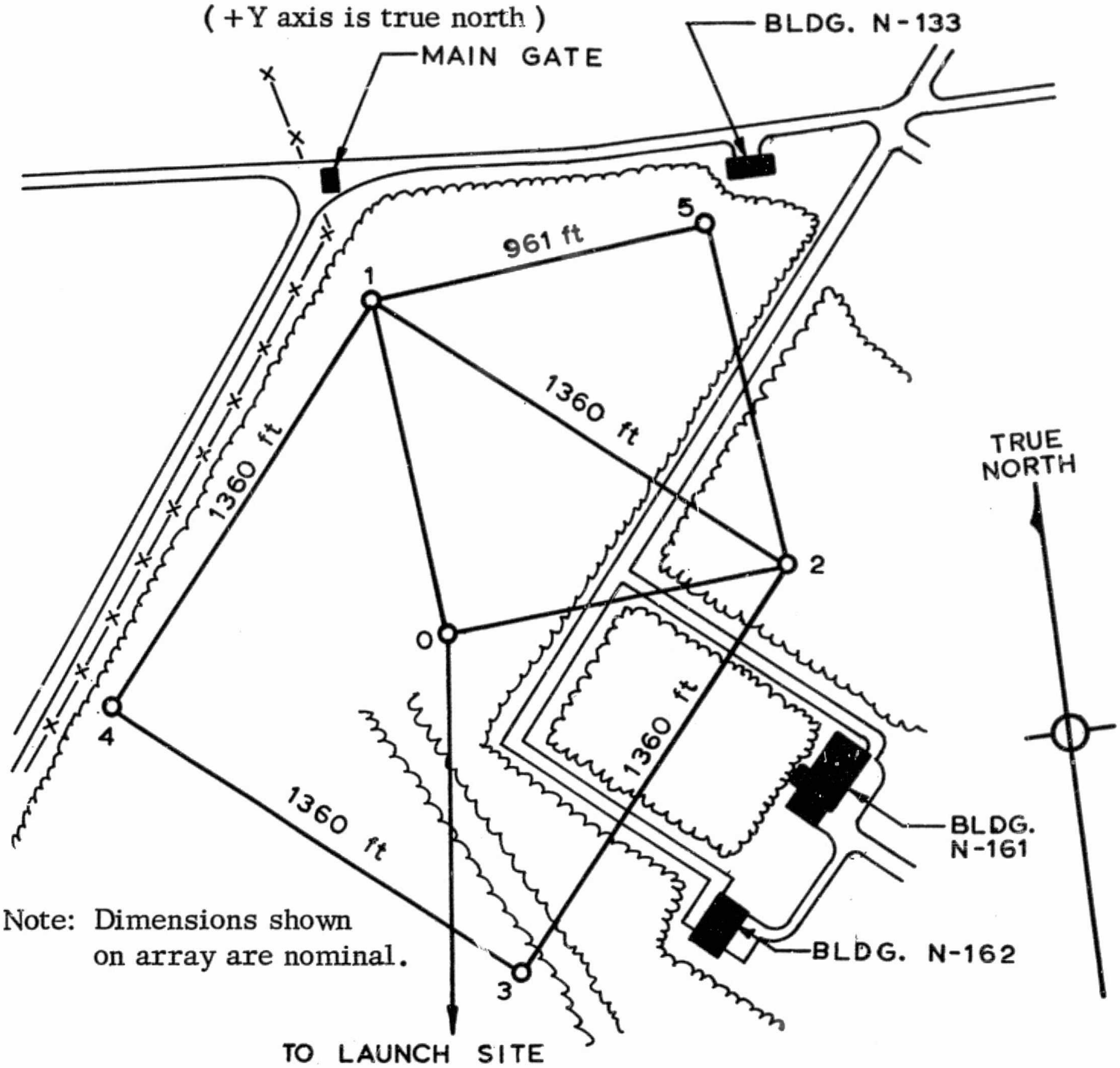


FIGURE NO. 35

ARRAY COORDINATES

	X	Y	Z
Mike 0	0.00	0.00	0.00
Mike 1	-213.10	+938.12	-1.11
Mike 2	+937.01	+213.21	+2.72
Mike 3	+213.41	-937.41	+3.85
Mike 4	-938.65	-213.16	+0.45
Mike 5	+724.36	+1151.22	+0.77

(+Y axis is true north)



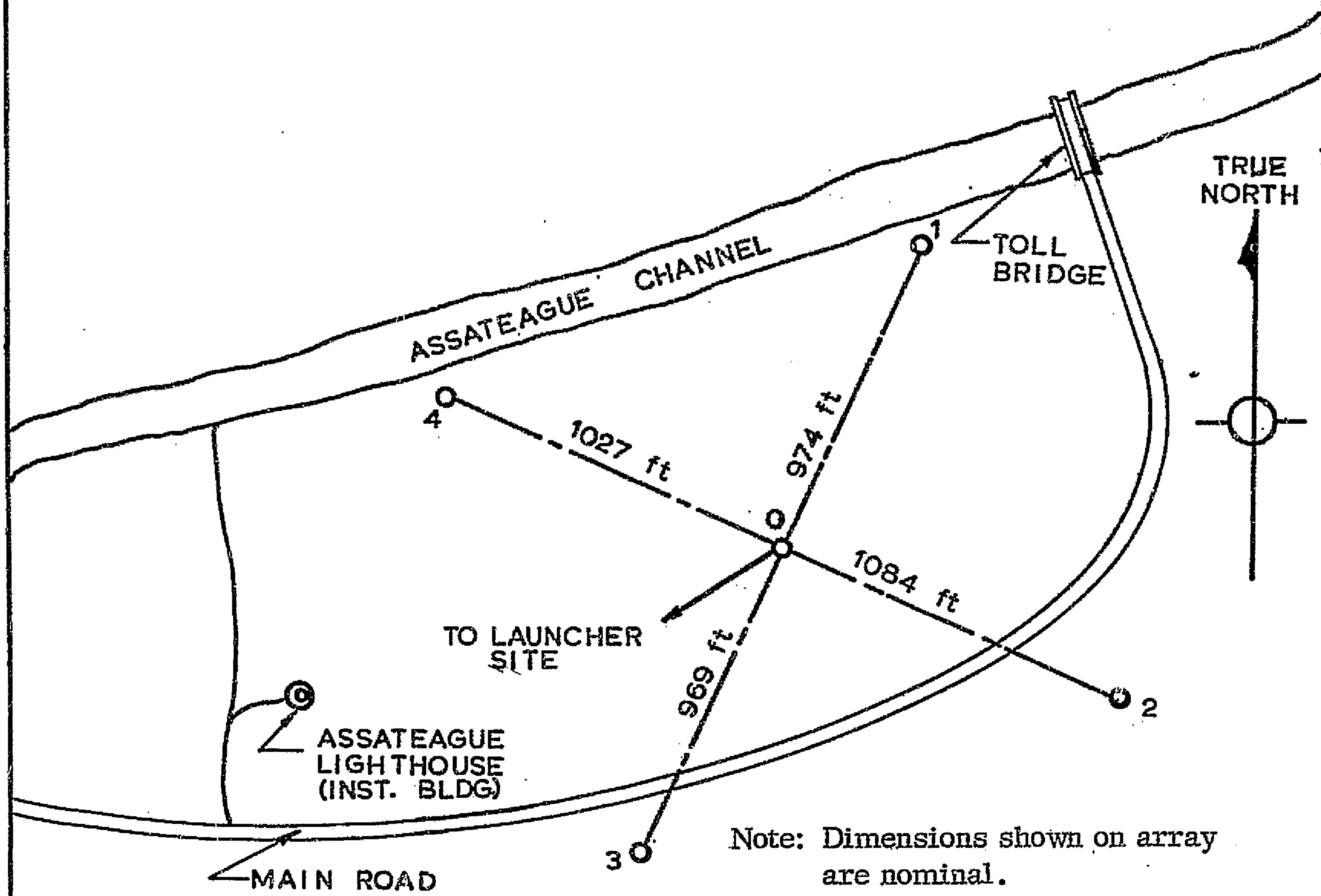
Note: Dimensions shown on array are nominal.

	LATITUDE	LONGITUDE	ELEVATION (MSL)
Mike 0	N37°55'48.7869"	W75°28'42.0657"	32.48 ft.

WALLOPS MAIN BASE SOUND RANGING ARRAY

FIGURE NO. 36

	LATITUDE	LONGITUDE	ELEVATION (MSL)
Mike 0	N37°54'43.2141"	W75°21'10.8579"	23.67 ft.



Note: Dimensions shown on array are nominal.

ARRAY COORDINATES

	X	Y	Z
Mike 0	0.00	0.00	0.00
Mike 1	+413.55	+881.47	-20.64
Mike 2	+919.35	-573.89	-19.85
Mike 3	-415.89	-874.70	-19.85
Mike 4	-894.82	+503.32	-21.99

(+Y axis is true north)

WALLOPS ASSATEAGUE SOUND RANGING ARRAY

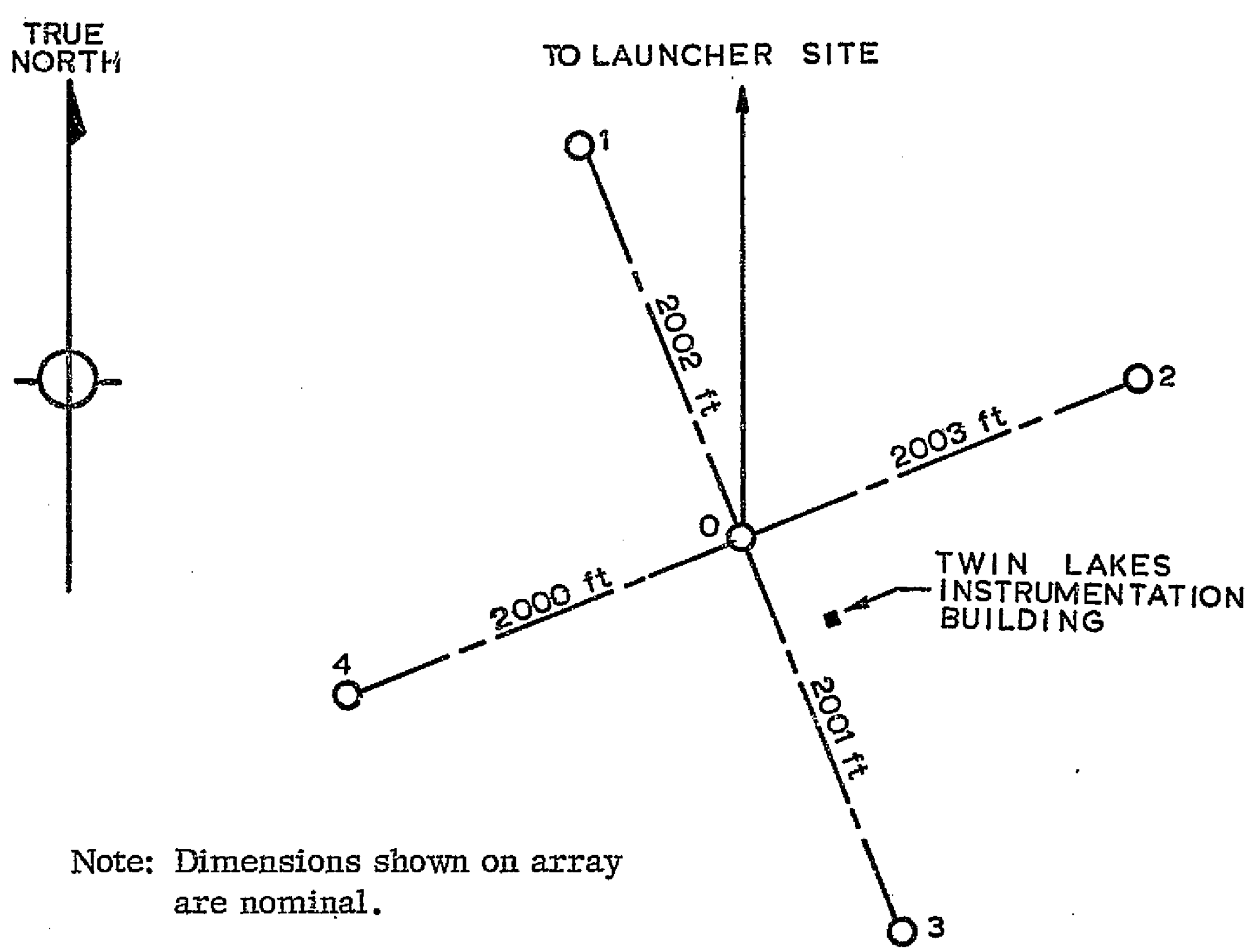
FIGURE NO. 37

ARRAY COORDINATES

	X	Y	Z
Mike 0	0.00	0.00	0.00
Mike 1	-739.84	+1859.96	-1.44
Mike 2	+1860.50	+742.63	-6.10
Mike 3	+741.34	-1858.86	-12.01
Mike 4	-1858.42	-740.25	-13.16

(+Y axis is true north)

	LATITUDE	LONGITUDE	ELEVATION (MSL)
Mike 0	N 58°37'07.186"	W 93°48'46.280"	121.27 ft.



Note: Dimensions shown on array are nominal.

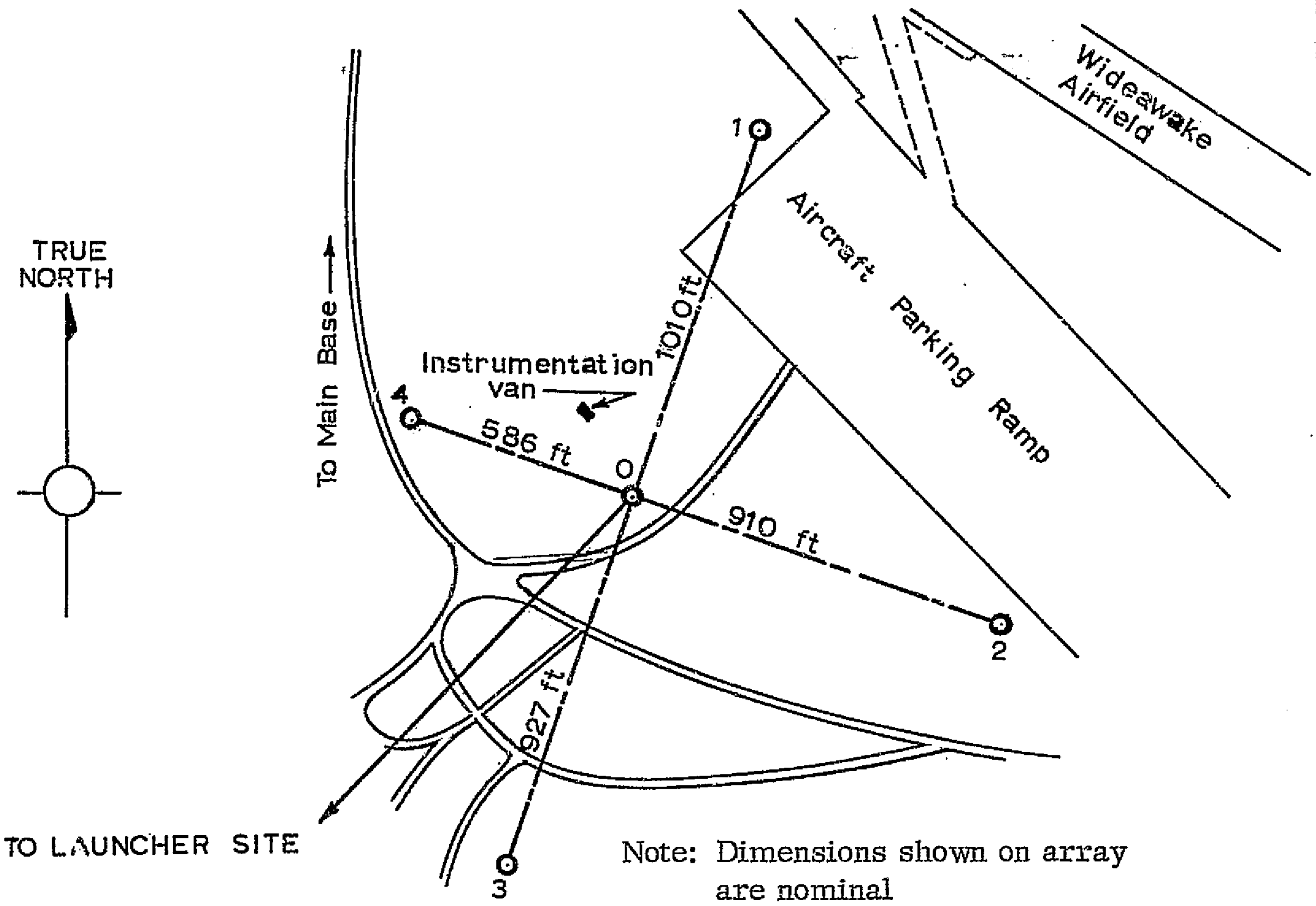
FORT CHURCHILL SOUND RANGING ARRAY

FIGURE NO. 38

ARRAY COORDINATES

	X	Y	Z
Mike 0	0.00	0.00	0.00
Mike 1	+344.97	+948.70	+8.95
Mike 2	+855.36	-310.93	+3.48
Mike 3	-347.03	-859.03	-15.39
Mike 4	-548.92	+203.19	-21.10

(+Y axis is true north)



Note: Dimensions shown on array are nominal

	LATITUDE	LONGITUDE	ELEVATION (MSL)
Mike 0	S 7°58'8.780"	W 14°24'22.072"	248.69 ft.

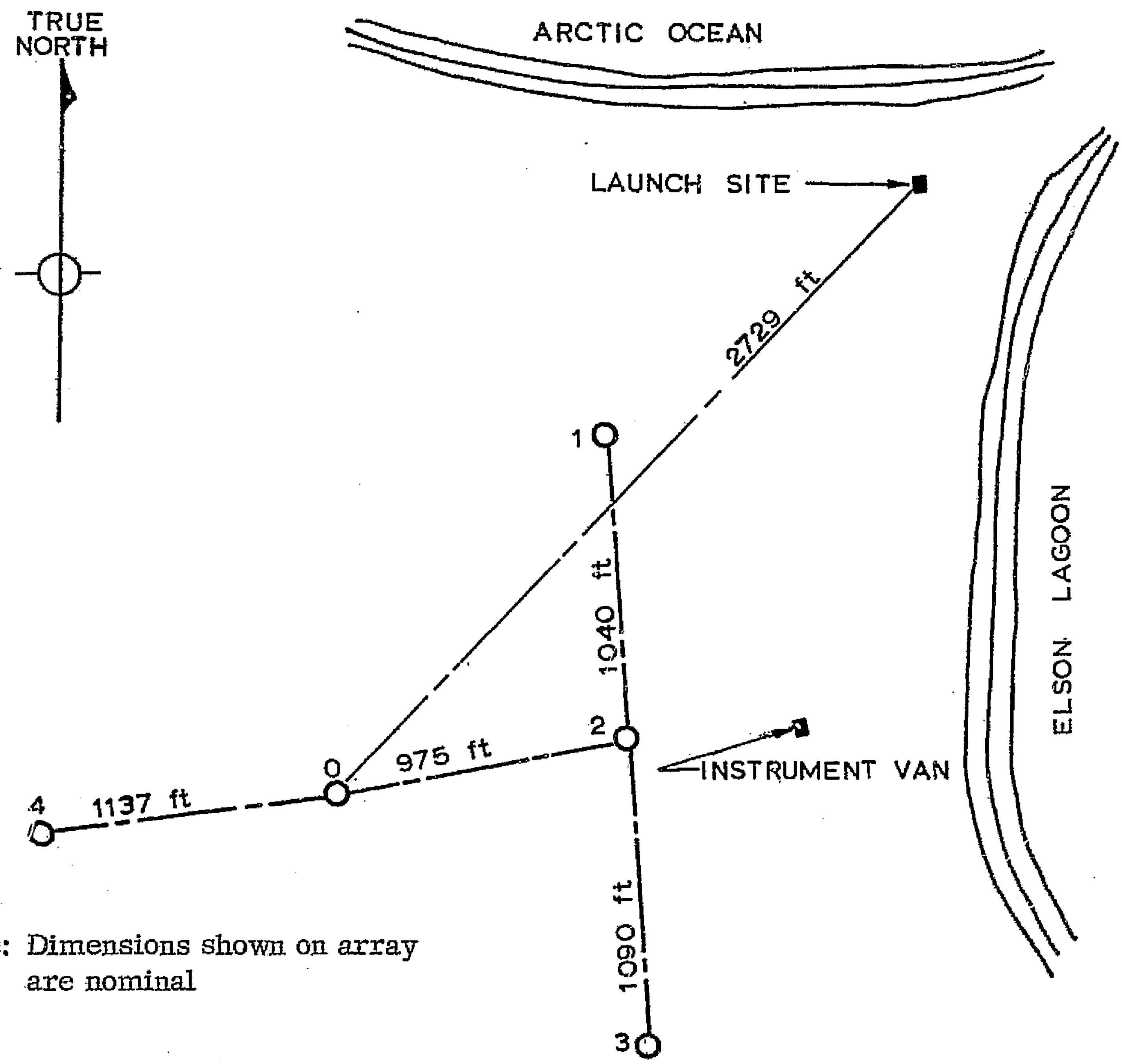
ASCENSION SOUND RANGING ARRAY

FIGURE NO. 39

ARRAY COORDINATES

	X	Y'	Z
Mike 0	0.00	0.00	0.00
Mike 1	+922.93	+1201.14	+2.88
Mike 2	+961.27	+161.88	-1.91
Mike 3	+1014.60	-926.45	+0.45
Mike 4	-1130.51	-127.08	+0.72

(+Y axis is true north)



Note: Dimensions shown on array are nominal

	LATITUDE	LONGITUDE	ELEVATION (MSL)
Mike 0	N 71°20'41.5"	W156°35'58"	3.00 ft.

POINT BARROW SOUND RANGING ARRAY

FIGURE NO. 40

TABLE 1

SUMMARY OF ROCKET GRENADE DATA

SHOOT NUMBER	STATION	DATE (GMT)	NO. OF GRENADES EXPLODED	NO. OF GRENADES DETECTED	RANGE IN ALTITUDE OF DETECTED GRENADES (KM)	REMARKS
10.65	C1	16 Nov 62	--	--	---	Cajun Failed
10.68	C1	1 Dec 62	---	---	---	Payload Malfunction
10.45	W2	1 Dec 62	12	12	37.5 - 92.9	
10.67	C1	4 Dec 62	12	12	38.9 - 88.2	
10.46	W2	4 Dec 62	--	--	---	Broke-up
10.66	C1	6 Dec 62	12	12	38.9 - 90.5	
10.47	W2	6 Dec 62	12	11	40.1 - 88.5	12M-Noise
10.58	C1	20 Feb 63	12	9	39.4 - 79.6	10,11,12M-Noise
10.48	W2	20 Feb 63	12	12	40.0 - 89.3	
10.59	C1	28 Feb 63	12	11	39.3 - 89.7	12M-?
10.53	W2	28 Feb 63	11	11	34.7 - 82.1	7 DNE
10.60	C1	9 Mar 63	12	12	39.1 - 93.2	
10.54	W2	9 Mar 63	12	12	38.3 - 90.7	
10.55	W2	7 Dec 63	11	11	31.8 - 80.3	Inflatable Sphere in 12
10.61	W2	24 Jan 64	11	9	37.7 - 81.9	12DNE; 10, 11M-Noise
10.86	C1	23 Jan 64	--	--	---	Cajun Failed
10.89	C1	29 Jan 64	12	12	35.8 - 90.1	
10.81	A1	29 Jan 64	11	4	36.5 - 52.3	5 DNE; 6,7,8, 9,10,11,12M-Noise
10.71	W2	29 Jan 64	12	12	34.6 - 88.9	
10.87	C1	5 Feb 64	11	11	38.6 - 89.6	12 DNE
10.62	W2	4 Feb 64	12	9	33.8 - 77.8	10,11,12M-Horiz Range
10.63	W2	5 Feb 64	12	9	37.1 - 80.9	10,11,12M-?
10.88	C1	13 Feb 64	10	10	38.0 - 90.4	10,11 DNE
10.82	A1	13 Feb 64	12	10	36.1 - 68.4	11,12M-Noise
10.136	W2	13 Feb 64	12	12	37.9 - 93.2	
10.137	W2	7 Mar 64	12	12	35.4 - 89.1	
10.73	C1	18 Apr 64	12	12	38.4 - 91.4	
10.83	W2	18 Apr 64	12	12	39.5 - 96.1	

TABLE 1

SUMMARY OF ROCKET GRENADE DATA

(continued)

SHOOT NUMBER	STATION	DATE (GMT)	NO. OF GRENADES		RANGE IN ALTITUDE OF DETECTED GRENADES (KM)	REMARKS
			EXPLODED	DETECTED		
10.83	W3	18 Apr 64	12	9	39.5 - 84.8	10,11,12M-Paper Record
10.114	A1	5 Aug 64	--	--	---	Payload Malfunction
10.78	W2	7 Aug 64	12	12	36.8 - 92.0	
10.78	W3	7 Aug 64	12	12	36.8 - 92.0	
10.104	C1	8 Aug 64	11	11	45.0 - 90.7	1 DNE
10.84	W2	12 Aug 64	12	12	36.7 - 90.2	
10.84	W3	12 Aug 64	12	11	36.7 - 90.2	11M-?
10.105	C1	12 Aug 64	12	12	35.8 - 89.7	
10.85	W2	16 Aug 64	12	12	37.1 - 92.6	
10.85	W3	16 Aug 64	12	12	37.1 - 92.6	
10.115	A1	16 Aug 64	12	11	32.4 - 73.8	12M-Noise;MIC "0" Not Used
10.116	A1	17 Aug 64	12	12	38.9 - 80.6	MIC "0" Not Used
10.113	W2	18 Aug 64	11	11	41.8 - 96.0	9 DNE
10.113	W3	18 Aug 64	11	11	41.8 - 96.0	9 DNE
10.106	C1	18 Aug 64	12	12	34.8 - 89.0	
10.107	W2	5 Nov 64	12	10	41.3 - 90.0	11,12M-?
10.107	W3	5 Nov 64	12	10	41.3 - 90.0	11,12M-Noise
10.133	W2	6 Nov 64	12	12	40.0 - 93.8	
10.133	W3	6 Nov 64	12	12	40.0 - 93.8	
10.134	W2	6 Nov 64	12	12	39.4 - 94.7	
10.134	W3	6 Nov 64	12	10	39.4 - 87.5	11,12M-Noise
10.135	W2	6 Nov 64	12	10	45.6 - 91.6	11,12M-Altitude
10.135	W3	6 Nov 64	12	10	45.6 - 95.2	10,12M-Noise
10.117	W2	19 Nov 64	11	10	43.2 - 92.6	12DNE; 11M-Altitude
10,117	W3	19 Nov 64	11	10	43.2 - 92.6	12 DNE; 11M Noise,Altitude
10.124	B1	27 Jan 65	12	11	38.6 - 89.0	12M-Noise
10.121	C1	27 Jan 65	12	12	*	

TABLE 1

SUMMARY OF ROCKET GRENADE DATA

(continued)

SHOOT NUMBER	STATION	DATE (GMT)	NO. OF GRENADES EXPLODED	DETECTED	RANGE IN ALTITUDE OF DETECTED GRENADES (KM)	REMARKS
10.118	W2	27 Jan 65	9	9	37.3 - 80.2	4,11,12 DNE
10.118	W3	27 Jan 65	9	9	37.3 - 80.2	4,11,12 DNE
10.125	B1	4 Feb 65	12	12	38.4 - 93.5	
10.122	C1	4 Feb 65	12	11	*	12M-?
10.119	W2	4 Feb 65	10	10	36.1 - 88.4	9,11 DNE
10.119	W3	4 Feb 65	10	10	36.1 - 88.4	9,11, DNE
10.126	B1	8 Feb 65	12	12	39.2 - 96.7	
10.123	C1	8 Feb 65	12	12	*	
10.120	W2	8 Feb 65	10	10	36.0 - 83.8	10,12 DNE
10.120	W3	8 Feb 65	10	10	36.0 - 83.8	10,12 DNE
10.150	B1	28 Apr 65	--	--	---	Payload Malfunction
10.127	W2	3 May 65	--	--	---	Payload Malfunction
10.127	W3	3 May 65	--	--	---	Payload Malfunction

DNE - DID NOT EXPLODE

M - MISSING, EXPLODED GRENADE NOT DETECTED

*ESTIMATED

experiments which failed due to payload or rocket malfunctions.

The table shows that all stations had detected grenades above 90 kilometers except Ascension. The highest grenade had been received from the newest station at Point Barrow at 96.7 kilometers. It must be pointed out that even though a grenade is reported, it may not be useful for further solution.

Table 2 reflects the reported grenades by station. Fort Churchill indicates the highest percentage of returns at 97.16%. This could be expected because of its ideal size and location "in front of" the launcher. Point Barrow records have indicated noise problems yet preliminary results indicate good returns for three experiments. Ascension's percentage was dropped by the first shoot and later experiments were only fair in results.

The main base array at Wallops has a good percentage considering the size of the array and its positioning with respect to the launcher. The Assateague array has not proved as successful as the main base array as yet. However, three grenades were believed lost on the first attempt because of the small paper record and two were lost during a three-shot day because of wind. The Assateague array did pick-up a higher grenade missed by the main base array on experiment 10.135 yet lost a lower grenade due to noise.

The overall percentage of 94.52% detection improves to 96.00% if Ascension is deleted as an active array. During the tests, no grenades were lost becuase of inoperative or defective sound ranging equipment.

Work on completing the data analysis to include the reduction of wind and temperature was initiated. This analysis was based on theory presented in a paper entitled "Rav Tracing in a Layered Medium" by E. Alan Dean. The paper, showing a different technique for computing wind and temperature in the rocket grenade experiment, is included in Appendix I.

A copy of each report including the final revision is contained in Appendix II.

TABLE 2

SUMMARY OF DETECTED GRENADES

STATION LOCATION	NO. OF GRENADES EXPLODED	DETECTED	PERCENTAGE DETECTED
Wallops Main Base (W2)	288	274	95.14
Wallops Main Base (W2) }*	147 }	142 }	96.60 }
Wallops Assateague (W3) }	147 }	136 }	92.52 }
Fort Churchill (C1)	176	171	97.16
Ascension (A1)	47	37	78.72
Point Barrow (B1)	36	35	97.22
TOTALS	547	517	94.52

*Brackets indicate a comparison of the same experiments as recorded at the two different arrays. The figures are not carried forward to the total.

IV. RESEARCH - ABSORPTION AND VELOCITY OF SOUND MEASUREMENTS*

INTRODUCTION

Previous to this contract period, a tube with associated electronics and vacuum equipment had been constructed. This tube was designed to measure the absorption of sound in gases. The viscothermal wall losses had been measured for both nitrogen and argon. These losses agreed with the classical calculations of Helmholtz and Kirchoff, an agreement which is in contrast to results obtained in tubes by other investigators.

The goal of our work was threefold:

(1) the provision of temperature control and measurement for the apparatus.

(2) the measurement of absorption, with particular attention to oxygen and the effect of impurities; and

(3) the use of this data and other recent data to extend previous tables on the absorption of sound in the atmosphere.

The first phase has been completed to our satisfaction. However, experimental problems have resulted in the lack of sufficient experimental control for the attainment of phase two, thus making consideration of phase three impractical.

Following the introduction, this progress report is divided into four sections, three of which detail our work. The first is

*This section taken from technical report, contract DA-29-040-ORD-2410, (1964). The work reported was jointly supported by the above contract and NAS 5-2949.

a description of preliminary measurements and summarizes previous results which are felt to be helpful in the understanding of our work. The next section details the modification carried out to obtain temperature control and the results of our studies in the measurement of the temperature. Certain problems which have developed in the viscothermal wall loss measurements are outlined in a separate section, followed by a section on velocity of sound measurements which have been conducted. The remainder of this introduction will outline the theory and apparatus used in the experiment.

A. Theory

The classical theory of absorption of sound due to viscothermal boundary losses along the walls of a circular cylindrical tube is given by:[1]*

$$\alpha = \frac{1}{rc}\left(\frac{\omega}{c}\right)^{\frac{1}{2}}\left[\left(\frac{\eta}{\rho}\right)^{\frac{1}{2}} + \left(\gamma^{\frac{1}{2}} - \gamma^{-\frac{1}{2}}\right)\left(\frac{k}{c_v\rho}\right)^{\frac{1}{2}}\right] \qquad (1)$$

where r = radius of tube,

c = speed of sound,

$\omega = 2\pi f$, the angular frequency,

η = coefficient of viscosity of the gas,

ρ = density of the gas

γ = ratio of specific heats for the gas,

k = coefficient of thermal conductivity of the gas, and

c_v = specific heat at constant volume for the gas.

*Numbers in brackets refer to references at the end of this paper.

The use of the Prandtl number, $[Pr] = \eta c_p/k$ where c_p is the specific heat at constant pressure, and the use of the ideal gas expression $\rho = \gamma P/c^2$, where P is the ambient pressure, reduces equation (1) to

$$\alpha = \frac{1}{r}\left(\frac{\pi\eta}{\gamma}\right)^{\frac{1}{2}}\left[1 + \frac{\gamma - 1}{[Pr]^{\frac{1}{2}}}\right]\left(\frac{f}{P}\right)^{\frac{1}{2}}. \qquad (2)$$

This simple dependence on the square root of the frequency-to-pressure ratio allows separation between tube losses and gas absorption, since gas absorption varies with the square of this ratio.

Following Parker[2], the absorption may be measured by determining the bandwidth of the resonant modes for the tube. If $\delta = f_2 - f_1$, where f_1 and f_2 are the lower and upper 3 db frequencies (frequencies for which the power is one-half that of the resonant frequency, f_0), then

$$\delta = \frac{\alpha c}{\pi}. \qquad (3)$$

This relation becomes, in the case of wall absorption,

$$\delta = \frac{c}{r}\left(\frac{\eta}{\pi\gamma}\right)^{\frac{1}{2}}\left[1 + \frac{\gamma - 1}{[Pr]^{\frac{1}{2}}}\right]\left(\frac{f_0}{P}\right)^{\frac{1}{2}} \qquad (4)$$

or, in terms of the mode number n,

$$\delta = \left(\frac{c^3\eta}{V\gamma P}\right)^{\frac{1}{2}}\left[1 + \frac{\gamma - 1}{[Pr]^{\frac{1}{2}}}\right]\sqrt{n} \qquad (5)$$

where V is the volume of the tube, $V = 2\pi r^2 L$, where L = length.

The speed of sound, c' in a tube differs from that in free space c, due to the viscothermal boundary layer. Thus

$$c = c' \left(1 + \frac{\alpha c}{\omega}\right), \quad [3] \qquad (6)$$

where α is the absorption coefficient due to the viscothermal boundary losses. The use of Equation (3) reduces this expression to

$$c = c' \left(1 + \frac{\delta}{2f_0}\right). \qquad (7)$$

Consequently, the measurement of δ can be used to determine the absorption by Equation (3) and may also be used to accurately determine the speed of sound by Equation (7). In this latter case, the sound speed in the tube is determined by the relation fixing the resonant frequencies in the tube.

$$f_0 = \frac{nc'}{2L} \qquad (8)$$

where f is the nth mode resonance frequency.

B. Apparatus

The following description of the tube with its associated electronics and vacuum system pertains to the apparatus as of the beginning of this contract period. Modifications carried out in the performance of this contract are detailed in Section III.

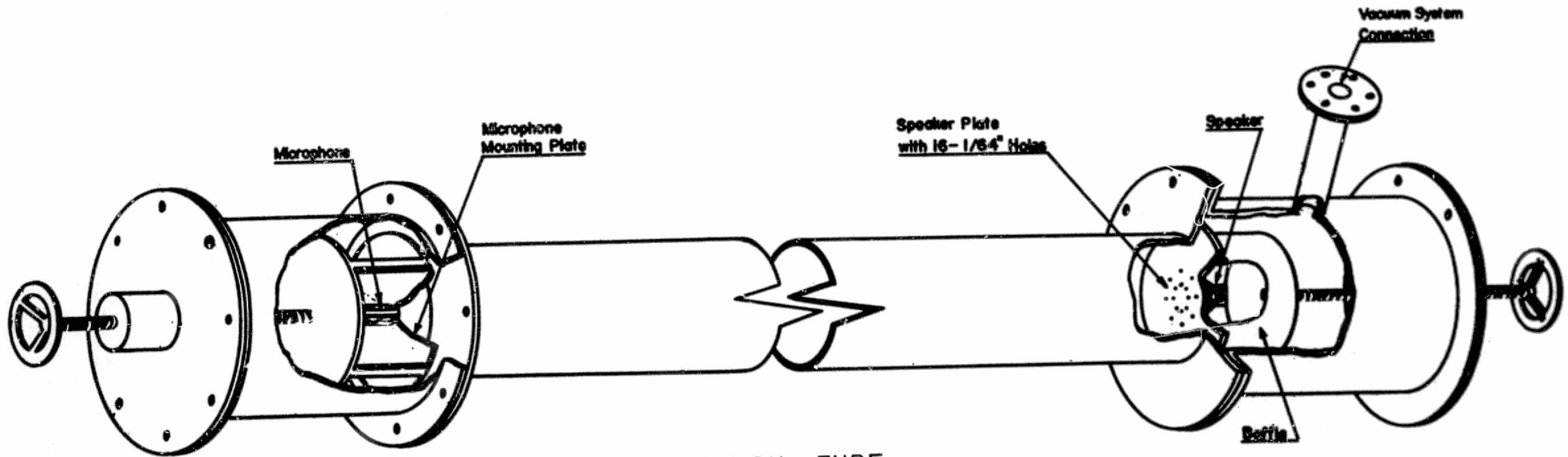
The tube and vacuum system have been described in detail by P. Harris and G.I. Good[4]. It had a radius of 2 in. and was about 10 ft. long, yielding a fundamental mode of about 50 cycles/sec. At either end were flat plates. A Bruell and Kjaer 4133 capacitor microphone was mounted flush with one plate, and the other had sixteen 1/64-in. holes in it to allow excitation of the tube by means of a University 1D-40 driver mounted back of the plate. (See Figure 41.)

Both plates could be moved back from their seats to allow evacuation of the tube. This was accomplished by means of long screws which passed through either end of the system. A vacuum-tight seal was assured by "O" rings. The gas system associated with the tube consisted of a Welch 1402B forepump, a Welch 1384E diffusion pump, a Todd 3-scale McLeod gage, and the necessary tubing to evacuate the system and to introduce gases from cylinders. (See Figure 42.)

The excitation of the tube was generated by a Hewlett-Packard 202C oscillator which had been provided with a 25:1 reduction gear for fine frequency control. The oscillator output was amplified by a MacIntosh MI-75 power amplifier, which supplied power to the driver. The output of the microphone was amplified by the B & K 2603 amplifier. The frequency was determined by measuring the period with a Berkley 7360 counter, while the output was measured by a Nonlinear Systems V35A digital voltmeter. (See Figure 43.)

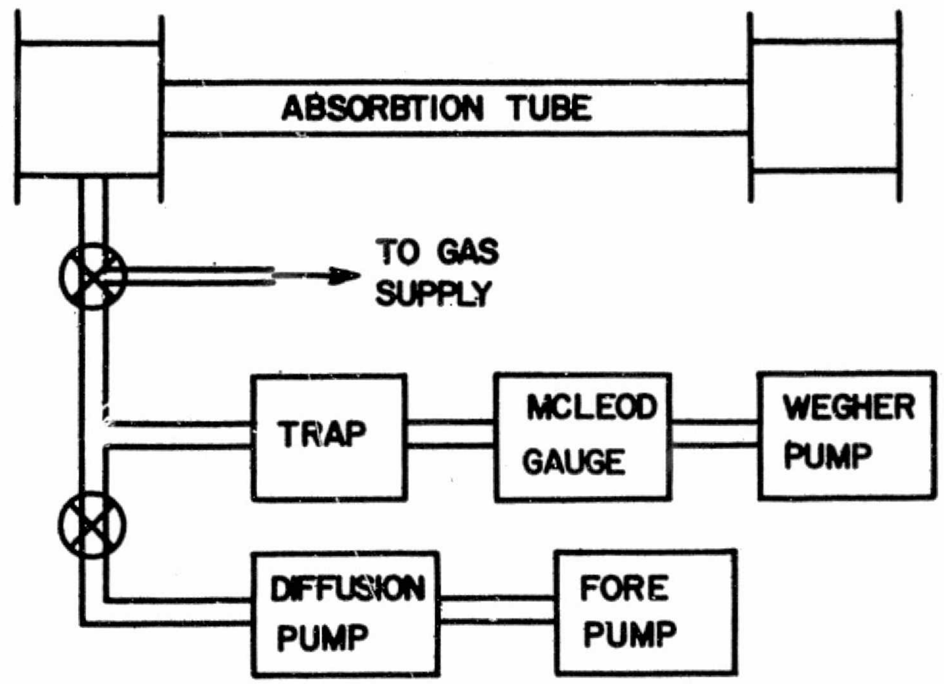
PREVIOUS RESULTS

During the nine months previous to June 1963, several determinations of the resonance bandwidth for argon and nitrogen were determined. In addition a determination of the sound speed in nitrogen was made. Experimental determinations of the bandwidth vs. the square root of the mode number consisted of the measurement of bandwidth for modes 2 through 16 to 20, or over a frequency range from 100 cycles/sec to 1000 cycles/sec.



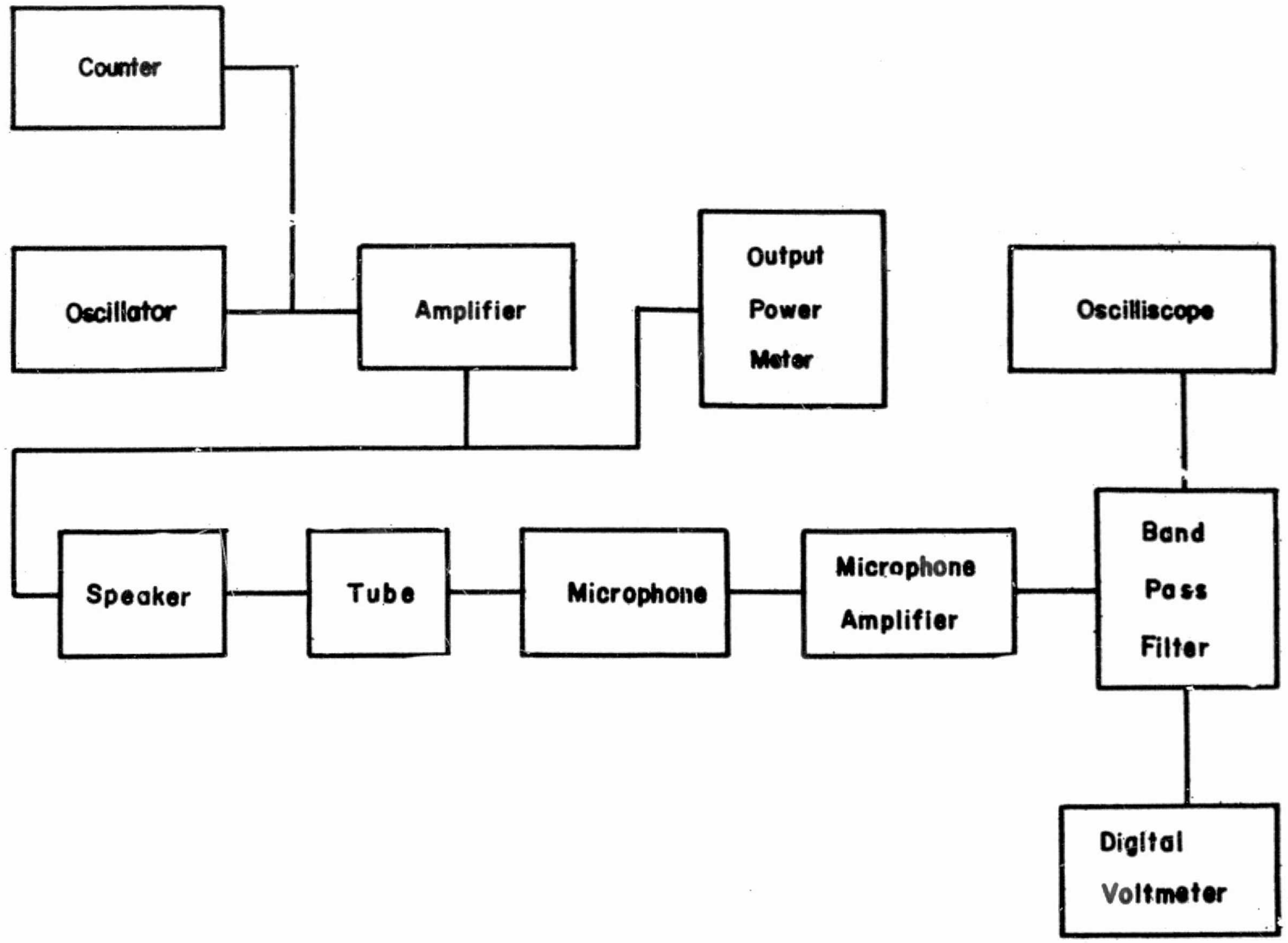
ABSORPTION TUBE

FIGURE NO. 41



BLOCK DIAGRAM OF VACUUM SYSTEM

FIGURE NO. 42



BLOCK DIAGRAM OF ELECTRONIC SYSTEM

FIGURE NO. 43

Band Width

The results of argon[5], a monatomic gas which has no rotational or vibrational energy, were in agreement with the classical theory of Helmholtz and Kirchhoff to this extent: the ratio of $\delta/\sqrt{n}$ was given by the coefficient in Equation (5). However, the value of δ when extrapolated to zero frequency was not zero. Thus the band width was found to be

$$\delta = A\sqrt{n} + B \qquad (9)$$

The value of A was measured over a temperature range from 20° to 24°C and over a pressure range from 88 mm Hg to 763 mm Hg. The mean value of A when normalized to 22° C and 760 mm Hg. was 0.547 ± 0.012, whereas the theoretical value obtained from Equation (5) after substitution of values obtained from Hilsenrath, etal.[6] is 0.543. Consequently, the experimental agreement was well within the deviation. The value of B was on the order of 0.1 cycles/sec.

The results for nitrogen[7], a diatomic gas which has rotational energy but very little vibrational energy at room temperature, were also in agreement with the theoretical slope of the δ vs. $\sqrt{n}$ curve. The fact that N_2 boundary effects were as predicted by the Helmholtz-Kirchhoff theory indicates that molecular rotation does not affect the boundary losses. The value of the slope was measured over a temperature range from 21° C to 25° C and over a pressure range from 77 mm Hg to 838 mm Hg. The mean value of A in Equation (9) when normalized to 24° C and 760 mm Hg was 0.485 ± 0.004, whereas the theoretical value is 0.492. The value of B was again on the order of 0.1 cycles/sec.

The agreement between the measured value of $\delta/\sqrt{n}$ and the theoretical value is deserving of comment since a majority of other investigators[8,9,10,11,12,13] have reported experimental values which exceeded the theoretical value by 10% to 50%. However, there have been others[14,15,16] who have been able to reproduce the Helmholtz-Kirchhoff results, notably the work of Shields. The non-zero intercept, representing a constant absorption of about 10^{-3} neper/m was unexplained.

B. Velocity

The sound speed in nitrogen was calculated.[17] The goal of the experiment was to measure the ratio of specific heats for nitrogen at room temperature and one atmosphere of pressure. The calculations of the sound speed were based on Equations (7) and (8).

The length of the resonance tube was measured by means of a steel surveying tape which had been certified by the National Bureau of Standards. The mean and standard deviation of ten measurements made at 25° C was 3.04535 ± 0.00007 m. The end plates did not fit exactly flush to the tube due to improper "O" ring seating. This separation was found to be 1.22 ± 0.51 mm, making the total distance between the plates 3.0466 ± 0.0006 m.

There was no provision for temperature control; however, the massive apparatus kept the temperature constant to within

0.5° C. The temperature was measured with mercury in glass thermometer which was later calibrated against another mercury in glass thermometer certified to within 0.02° C by the manufacturer. The measurement thermometer was found to have a correction of-0.04° at 25° C.

The N_2 was certified to be better than 99.9% pure, with O_2 as the largest impurity, and with less than 0.03% H_2O.

The data, when normalized to 298° K, were characterized by a mean and standard deviation of 351.81 ± 0.02 m/sec. The precision of the length and temperature measurements resulted in an overall precision of ± 0.08 m/sec.

The figure of 351.81 m/sec at 760 mm Hg and 298° C must be reduced to 760 mm Hg and 273.15° K to be compared with other results. The details of this reduction will be presented in Section V; the results of the reduction for this datum were 336.78 m/sec.

Previously obtained values for N_2 at STP include the following:

Coldwell & Gibson (1941)[18]	337.1 m/sec
Harlow (1961)[19]	336.79 m/sec
Lestz (1963)[20]	336.96 m/sec

The A.I.P. Handbook[21] gives the sound speed in nitrogen to be 337 m/sec. Hilsenrath, et,al.[6] report the average of five different observers (1906-1941) to be 337.65 m/sec. The last of these values in that of Coldwell & Gibson cited above, which indicates that the spread in the early data is quite large. There is no precision stated for this measurement;

however, comparing the data for different pressures with the authors' statement that the velocity did not vary with pressure indicates that the accuracy of the measurements is of the order of ± 0.5 m/sec. All things considered, the Handbook value of 337 m/sec seems to be an accurate indication of the precision of the value as measured previous to 1960.

Regardless of the above mentioned values, Hilsenrath, et. al.[6] used the theoretical value of the speed of sound in nitrogen, 336.96 m/sec, in their tables of thermal properties. Although they do not give a precision for the theoretical value, one may assume that it is of the same order as that calculated for air by Hardy, et. al.[22], ± 0.05 m/sec. The precision reported by Harlow is ± 0.01 m/sec, while Lestz does not report any precision.

It may be seen from this data that this method of measurement of sound speed yields comparable accuracy with other methods. It is possible that the method may be used to help clarify a rather vague situation with regard to knowledge of the speed of sound in nitrogen; this vagueness is in contrast to the close agreement between various experimental and theoretical values for air, a gas containing 80% nitrogen (See Hardy, et. al.[22]).

TEMPERATURE CONTROL AND MEASUREMENT

The method of temperature control chosen for the tube consisted of the following items:

(1) A heating unit with variable output

(2) A refrigeration unit

(3) A reservoir in which these units may be immersed in a fluid

(4) A pump to circulate the fluid about the tube

(5) Coils encircling the tube to achieve heat transfer between the fluid and the tube

(6) Insulation for the reservoir and tube.

Since the coils required the tube to be modified in a machine shop, it was felt best to also modify the method of obtaining pressure equalization across the driver and microphone plates. The previous method, as described in the introduction, suffered two failings: the screws which moved the end plates tended to leak, and the uncertainties in "O" ring compression were a significant factor in the sound speed precision.

The modification of the tube for pressure equalization was accomplished by removing the large screws, closing the vacuum seals where these screws emerged from the system, flush mounting the transducer end-plates, and providing a new path for pressure equalization. This new path shown in Figure 44 allows gas flow around the transducer plate while the vacuum valve is open, but isolates the separate sides of the plate when the valve is closed. To keep the tube acoustically smooth, a plunger was attached to the valve plate which provides a smooth inside surface for the tube when the valve is closed. The valve is opened during flushing and gas filling and closed during resonance measurements.

A. <u>Temperature Control</u>

The heating-control unit is a Sargent Model SW Thermonitor. The control elements consist of a thermistor which forms

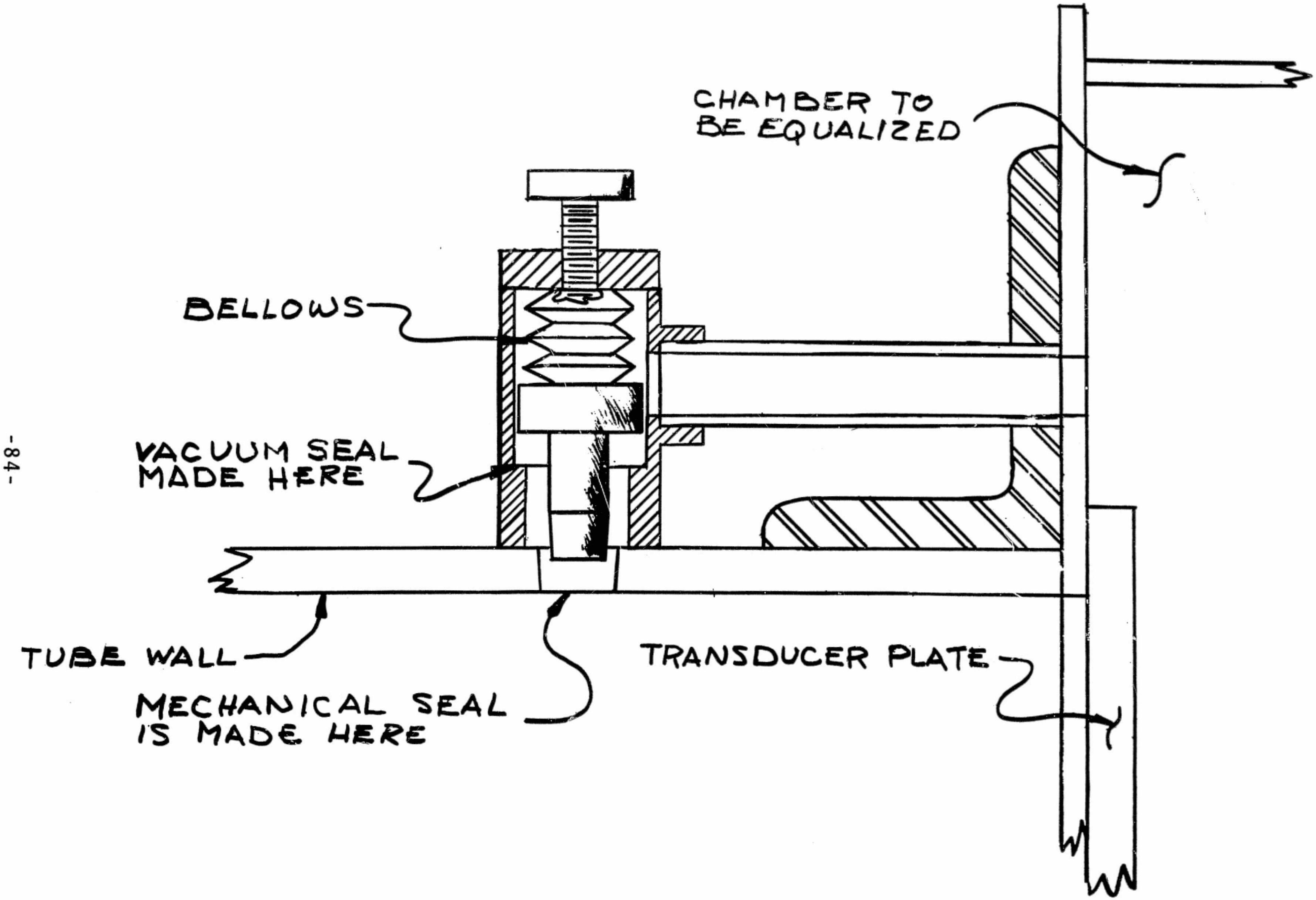


FIGURE NO. 44

DETAIL OF PRESSURE EQUALIZATION MODIFICATION one arm of a Wheatstone bridge. Another arm is a pair of ten-turn resistors. When the bridge is unbalanced, the signal is amplified and applied to a saturable core reactor which varies the voltage across a 250-watt heating unit. Also provided is a 300-watt unit controlled by a variable transformer and a 400-watt unit which may be used for higher heating requirements. This unit is also provided with a circulating stirrer. Manufacturer's specifications state that regulation to 0.01°C may be obtained.

The refrigeration unit and reservoir were obtained in the form of a surplus soft drink unit. This unit is insulated and is provided with a circulation stirrer mounted inside the cooling coils. The thermostat on the electric refrigeration unit was modified so that a minimum temperature of -4° C may be obtained.

The circulating pump is a Planet gear-type pump. The pumping speed has been set at 2.5 gal/min. The plastic pump is connected to the reservoir and tube coils by means of flexible rubber tubing.

The heat transfer coils are 3/8 in. soft annealed copper tubing which has been soldered to the absorption tube. The input fluid is divided into four parallel paths, two starting from either end of the absorption tube. This path, coupled with alternating clockwise and counter-clockwise coils provides a more constant temperature over the surface of the absorption tube.

The system described above was assembled and a series of checkout runs were made. These seemed to be successful and the insulation was then completed. To keep heat transfer to a minimum, the vacuum system was completely modified so that the only connection with the absorption tube was through a 2 in. inside diameter rubber vacuum hose. At this time, the pressure measuring system was also modified so that the vacuum system could be completely isolated from the absorption tube. Previously the pressure measuring system was connected to the vacuum system, rather than the tube--the modification provided direct pressure measurement within the tube. The necessary vacuum hose was connected to the tube through a vacuum valve.

A large plywood box was constructed to completely surround the tube and all metal appendages. Only rubber tubes and signal wires enter the walls of the box. The box containing the tube was then potted with a chemically-expanded polyurethane foam, Arothane. This foam has excellent characteristics, including a thermal conductivity of 0.13 BTU/hr/sq.ft/°F/in (about 5×10^{-5} cgs units, essentially that of air).

Later results have verified the preliminary test results that the temperature can be controlled between 0° C and 50° C to a long term (several hours) accuracy of ± 0.10° C.

B. Temperature Measurement

The accurate measurement of temperature was approached through an extended series of measurements using three thermometers and four different locations. The thermometers used were:

(1) A Leeds & Northrup 8163 platinum resistance thermometer calibrated at the ice, steam, and sulphur points by L & N.

(2) A Taylor 21001 mecury in glass thermometer calibrated at 0°, 10°, 20°, and 40° C by Taylor.

(3) A differential thermometer with 6° C scale divided into 0.01° C divisions.

An L & N type E galvanometer and an L & N type G-1 Mueller bridge were used to measure the resistance of the platinum thermometer. This thermometer was used as a standard and others were calibrated against it.

The locations used to measure the temperature were the following:

(1) At the exit of the reservoir.

(2) At the entrance of the reservoir.

(3) Inside the absorption tube.

(4) Thermometer wells which made contact with the outside of the absorption tube and emerged from the insulation.

The thermometer wells were designed to provide thermal contact with the tube and to allow the reading of the thermometer scale at the same time.

The results of measurements and calibrations indicated that the temperature of the thermometer wells and that of the exit fluid were not in agreement with that of the inside of the abosrption tube. However, it was found that after equilibrium was reached, the temperature of the exit fluid was consistently 0.06° C warmer than the actual temperature inside the tube. This empirical relationship was of great value in the velocity of sound work discussed in VELOCITY OF SOUND MEASUREMENTS.

Since it was believed that it was impractical to put any accurate thermometer inside the tube during the resonance measurement, our present practice is to measure the temperature of the gas in the absorption tube by measuring the temperature of the heat transfer (exit) fluid as it enters the reservoir. This is done by surrounding the thermometer with a container which is fed by the fluid as it enters the soft drink unit from the cooling coils of the tube. The fluid, of course, constantly overflows into the reservoir proper at the rate of 2.5 gallons per minute.

The temperature control system, including modifications of the tube and vacuum system, were completed in December 1963. The measurement of temperature continued to be a problem which was not completely solved until April 1964.

NON-CLASSICAL ABSORPTION RESULTS

During January and February, bandwidth measurements were made at 0° C, 10° C, 20° C, 30° C, 40° C, and 50° C. At each temperature, data was taken at each of three pressures, 1.0 atmosphere, 0.7 atmosphere, and 0.4 atmosphere, respectively. These data were used to calculate the speed of sound in nitrogen, but no comparison was made between the experimental and theoretical bandwidth at this time. Certain problems in the measurement of the sound speed led to research on the more accurate measurement of temperature in the tube. This research delayed the comparison of experiment and theory until March 1964.

When the comparison was made, it was found that the measured slope of $\delta/\sqrt{n}$ no longer agreed with the theory. The earlier data (which did agree with the theory) was then re-evaluated in an attempt to find a calculation error. No errors were found; the data obtained before the temperature control modifications were accomplished agreed with theory.

The absorption tube was dismembered many times; each time one thing was cleaned, checked, or modified. No apparatus change brought experiment together with theory. The vacuum system and all possible leaks were worked over to no avail. The electronic counter and digital voltmeter were calibrated with no change in the results.

A recent re-examination of existing data revealed that even though the experimental δ vs $\sqrt{n}$ curve does not match the like theoretical curve, the absorption tube is nevertheless responding in a theoretical fashion. An explanation of this seemingly contradictory statement is provided by the following three δ vs $\sqrt{n}$ graphs. The first is a plot constructed from bandwidth data taken on May 29, 1964, at 34.0° C under a pressure of 753.55 mm Hg. A straight-line least squares curve was fitted to the data points. The second graph is a similar plot of bandwidth data taken on June 27, 1964, at a temperature of 36.5° C under a pressure of 662.6 mm Hg. Notice that on both plots, the experimental points (and the least squares curve) lie well above the theoretical curve.

The third graph is a superposition of the first two graphs formed by rotating the 34.0° C plot counter-clockwise into the

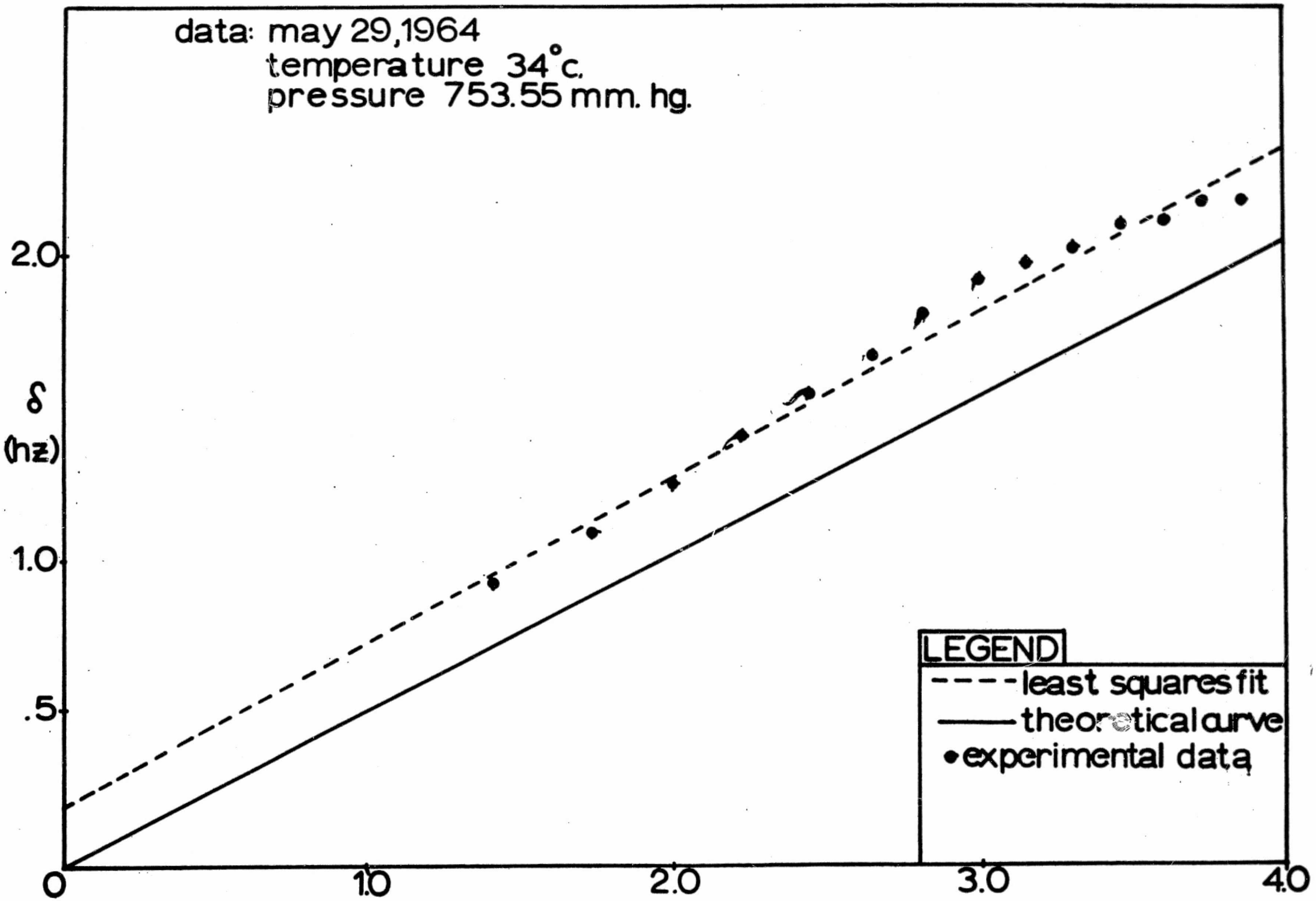

data: may 29,1964
temperature 34°c.
pressure 753.55 mm. hg.
δ
(hz)
2.0
1.0
.5
0
1.0
2.0
3.0
4.0
LEGEND
least squares fit
theoretical curve
experimental data

FIGURE NO. 45

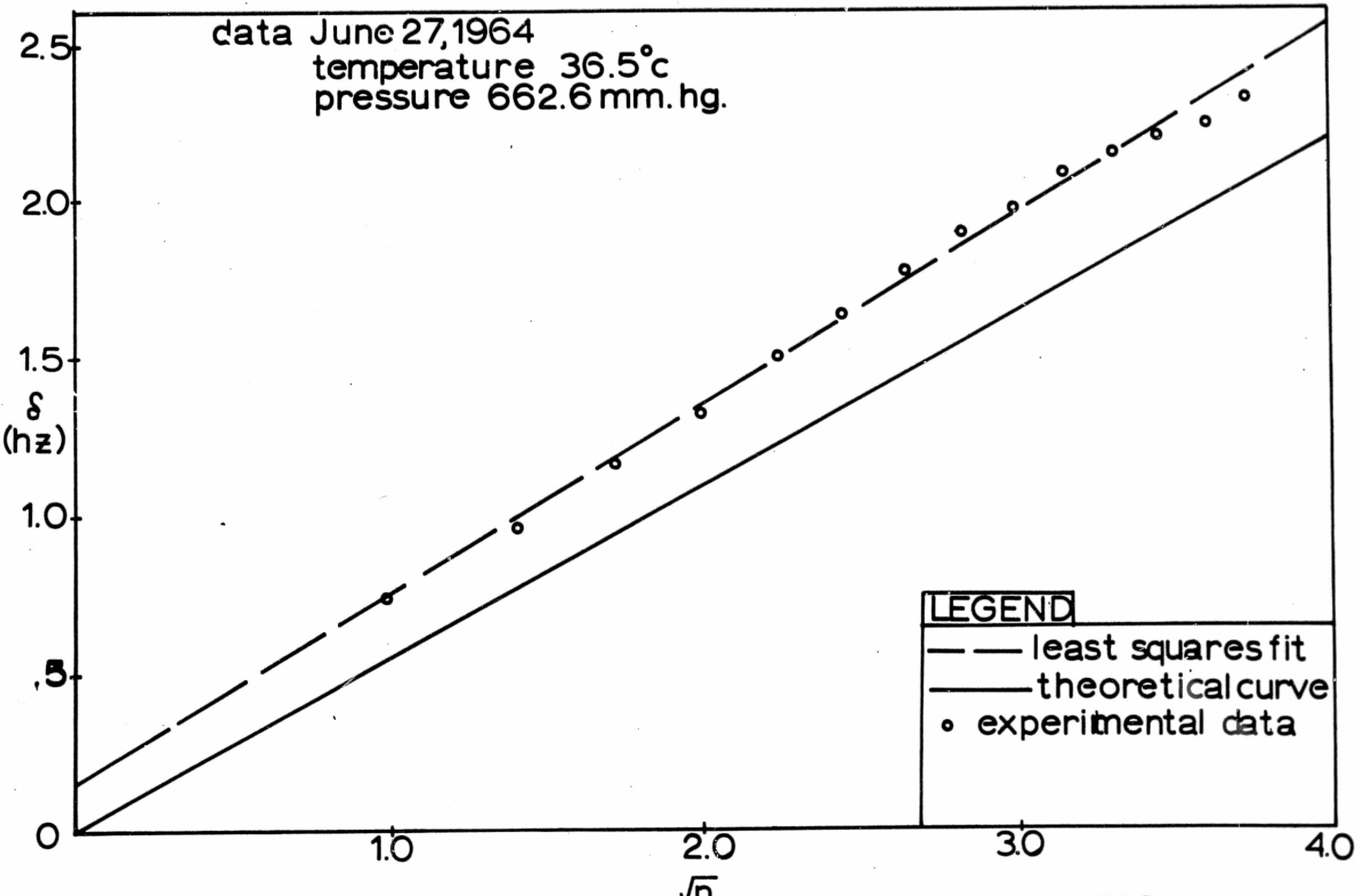

data June 27, 1964
temperature 36.5°c
pressure 662.6 mm. hg.
δ (hz)
0
.5
1.0
1.5
2.0
2.5
1.0
2.0
3.0
4.0
√n
LEGEND
least squares fit
theoretical curve
experimental data

FIGURE NO. 46

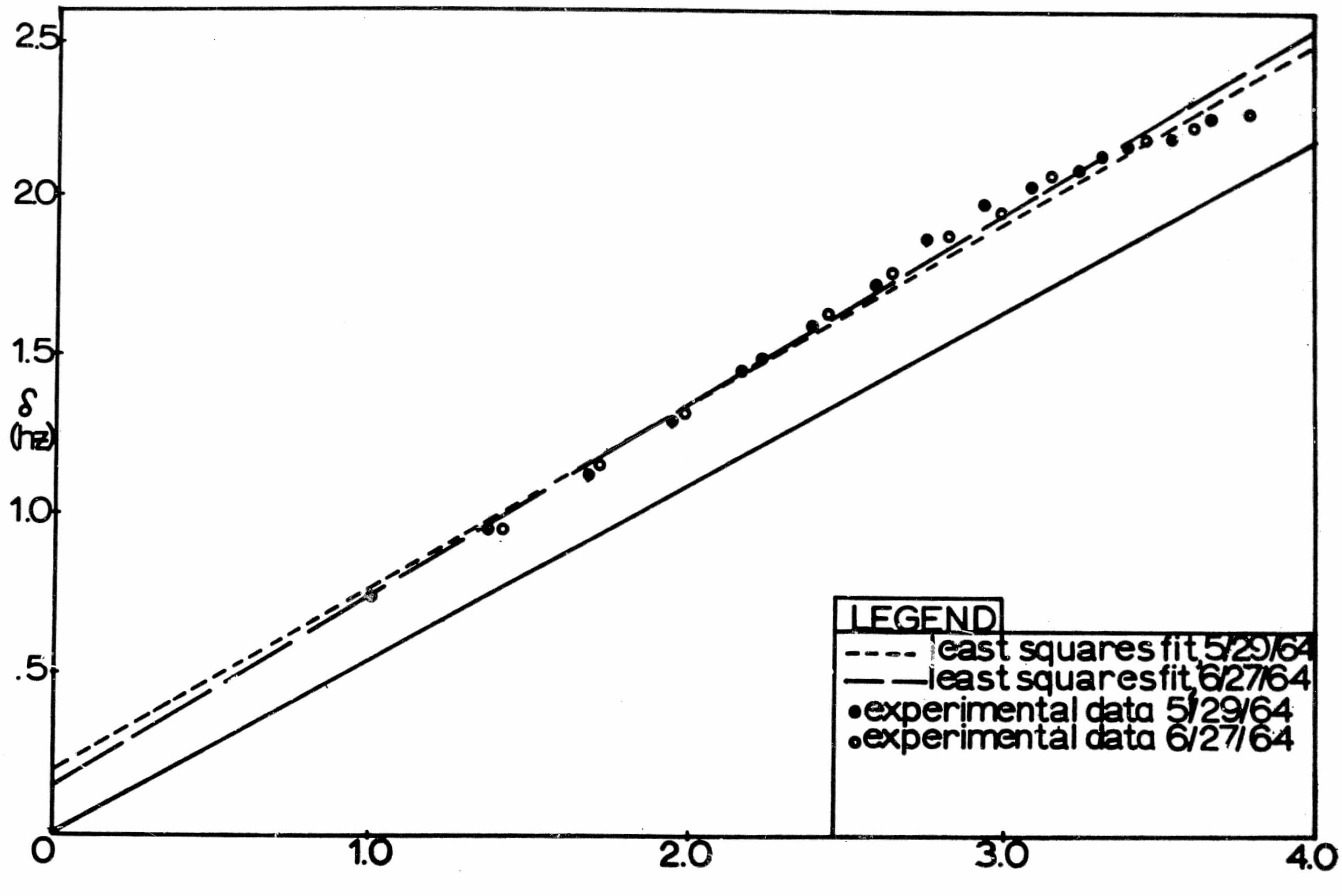

2.5
2.0
1.5
δ
(hz)
1.0
.5
0
1.0
2.0
3.0
4.0
√n
LEGEND
least squares fit 5/29/64
least squares fit 6/27/64
experimental data 5/29/64
experimental data 6/27/64

FIGURE NO. 47

36.5° C plot until the theoretical curves become coincident. Two important factors emerge from this rotation: (1) The two least squares curves are nearly coincident, differing in slope by only 3%. (2) Perhaps more important is that the variation in the data points is regular from one curve to another.

From many such analyses, it was concluded that the absorption tube was responding correctly to the classical theory. The experimental bandwidth data then appears to be the superposition of the theoretical variation onto a frequency-independent base, the source of which as yet remains unexplained.

VELOCITY OF SOUND MEASUREMENT

According to the ideal gas law, the speed of sound in an ideal gas is independent of the pressure. Since no gas is ideal, each exhibits (in proportion to its non-ideality) a slight pressure dependence of sound speed. Theory[23] predicts that at a fixed temperature, the square of the sound speed in a gas is a linear function of the pressure. The absorption tube was used to determine the velocity of sound in nitrogen gas at 0° Centigrade under pressures varying from 0.320 atmospheres to 0.993 atmospheres, respectively. From the resulting data, a plot of sound speed vs pressure was constructed, from which the experimental slope (pressure-dependence coefficient) was determined. As an important corollary to this pressure-dependence coefficient, the non-dispersive sound speed in nitrogen gas at STP was also determined. Both the pressure-dependence coefficient and the sound speed in nitrogen gas were compared with the theoretical values. This section is subdivided into three parts:

(A) Theory; (B) Experimental Procedure; and (C) Methods of Analysis; Results.

A. Theory

For an ideal gas, the sound speed is given by

$$c_0 = \sqrt{\frac{\gamma RT}{M}} \tag{10}$$

where R = molar gas constant

T = absolute temperature

M = molecular mass of the gas.

The subscript on the sound speed is used to distinguish it as the ideal gas sound speed, which is of course pressure independent. If, instead of the ideal gas equation, we now use the Kammerlingh-Onnes equation of state[23],

$$\frac{PV}{RT} = 1 + \frac{B}{V} \tag{11}$$

where B = first virial coefficient.

Herzfeld and Litovitz have shown that the sound speed can be described by

$$c^2 = c_0{}^2 \left\{ 1 + 2P \left[B' + \frac{R}{c_v} \frac{\partial (TB')}{\partial T} + \frac{1}{2} \frac{R^2 T}{c_p c_v} \frac{\partial^2 (TB')}{\partial T^2} \right] \right\} \tag{12}$$

where $B' = B/RT$.

Equation (12) may be simplified somewhat by using Carnot's relationship, $c_p - c_v = R$ and denoting $B_1{}' = \frac{\partial (TB')}{\partial T}$,

$$B_2{}' = T\partial^2 \frac{(TB')}{\partial T^2}$$

Using this notation Equation (13) reduces to

$$c^2 = c_0^2 \left\{1 + P \left[2B' + 2(\gamma - 1)B_1' + \frac{(\gamma - 1)^2}{\gamma} B_2'\right]\right\} \quad (13)$$

At any given temperature, the quantity in brackets is a constant and may be calculated theoretically using a Lennard-Jones potential to determine B', B_1', and B_2'[24]. Rewritten with the bracketed quantity labeled a constant, Equation (14) shows the theoretical linear dependence of the square of the sound speed on the pressure, all other factors constant.

$$c^2 = c_0^2 \, [1 + P \text{ (constant)}]. \quad (14)$$

B. Experimental Procedure

Early in March, 1964, work was begun on determining the sound speed pressure-dependence coefficient. The velocity of sound was determined using Equations (7) and (8), i.e., measuring the bandwidth, the resonant frequency, and temperature. The empirical relationship between the temperature of the fluid leaving the tube and the actual tube temperature was determined at this time. Since accurate knowledge of the temperature is vital in a precision measurement of sound speed, this preliminary temperature work was a crucial point in the success of this experiment.

Although the general technique used to measure velocity remained the same, great care was taken in reading the experimental parameters. In addition several mechanical precautions were taken to insure against faulty readings. The tube was flushed repeatedly before each run to obtain maximum purity of the nitrogen in the tube. After immediately entering the gas into the tube or after apressure change, time was taken to allow the gas to come into equilibrium before readings were taken. In general, all runs were made to 0° C ± 0.1° C; each three-run series was begun near one atmosphere with subsequent runs made near 0.7 atmosphere and 0.4 atmosphere, respectively. Eighteen points of frequency resonance (called modes) were obtained for each run.

C. Methods of Analysis; Results

For each resonance frequency, the velocity of sound was calculated using Equations (7) and (8). Since these computations were tedious and prone to human error, a computer program was written to perform the task. In addition to calculating sound speed for each mode, provision was made for normalization of the sound speeds to a standard mean temperature. For example, if during a run, the temperature varied from 0.08° C at the beginning to 0.04° C at the end, the mean temperature would be 0.06° C. Each modal sound speed would then be multiplied by the square root of the ratio of the normalizing temperature to the modal temperature. If the temperature at a mode were 0.07° C, then (using the previous example) the sound speed as calculated from (7) and (8) would be multiplied by the square root of 273.22/273.23.

After the eighteen modal speeds were determined and thus normalized, the mean and standard deviation were computed. If any modal sound speed deviated from the mean by more than four standard deviations, it was rejected with a new mean and standard deviation computed. Any run whose standard deviation in sound speed was greater than ± 0.05 m/sec was discarded.

The final correction to the mean sound speed for a run was the reduction to 0° C. This was accomplished by multiplying the mean sound speed by the square root of the ratio of 273.16 to the normalizing temperature for that run. Again using the previous example, the mean sound speed would be multiplied by the square root of 273.16/273.22. This type of normalization assumes that within a range of ± 0.10° of the ice point, the sound speed pressure-dependence coefficient does not change. If, however, (as in reference [17]) it were desired to convert sound speed at 298° K, 760 mm Hg, to 273.16° K, 760 mm Hg, a different method would be used, since the pressure-dependence coefficient is a function of the temperature.

In analyzing the results, perspective is gained on the magnitude of the quantity to be measured by realizing that the pressure would have to be varied over a 20 atmosphere range to produce a 5 m/sec change in the velocity of sound. Since our apparatus is limited to operation at pressures of one atmosphere or less, the pressure-variation in the sound speed is small indeed; however, it is measurable.

Since the pressure dependence of sound speed is second order in the sound speed, strictly speaking the pressure dependence is not constant but is a parabola folded on the pressure axis. However, in the range from "zero" pressure to one atmosphere, the variation in sound speed is so slight that the sound speed may, in this region, be regarded as a linear function of pressure, i.e., a small enough section of the parabola is under consideration so that it may be considered a straight line. In this case, a constant pressure-dependence coefficient may be determined as m in the equation

$$c = mP + b. \tag{15}$$

From the reduced data, a plot of sound speed vs pressure was constructed (See Figure 48); note the expanded y-scale. A first order least squares fit was determined as Equation (16),

$$c = 0.11\ P + 336.90 \tag{16}$$

with a standard deviation in the sound speed of ± 0.03 m/sec and a standard deviation in the slope of ± 0.01 m/sec/atm. Thus at 0° C the sound speed pressure-dependence coefficient in nitrogen gas is 0.11 ± 0.01 m/sec/atm valid in the pressure range from "zero" to one atmosphere. The sound speed in nitrogen gas at 0° C under a pressure of one atmosphere may be obtained by substituting this value for P in Equation (16). This yields 337.01 ± 0.03 m/sec.

A final correction factor to the sound speed results from a consideration of relaxation phenomena. The vibrational relaxation frequency in nitrogen gas is in the order from 1 to 5 cycles/sec[25]. Since the first mode in the tube occurred near 50 cycles/sec, the vibrational degrees of

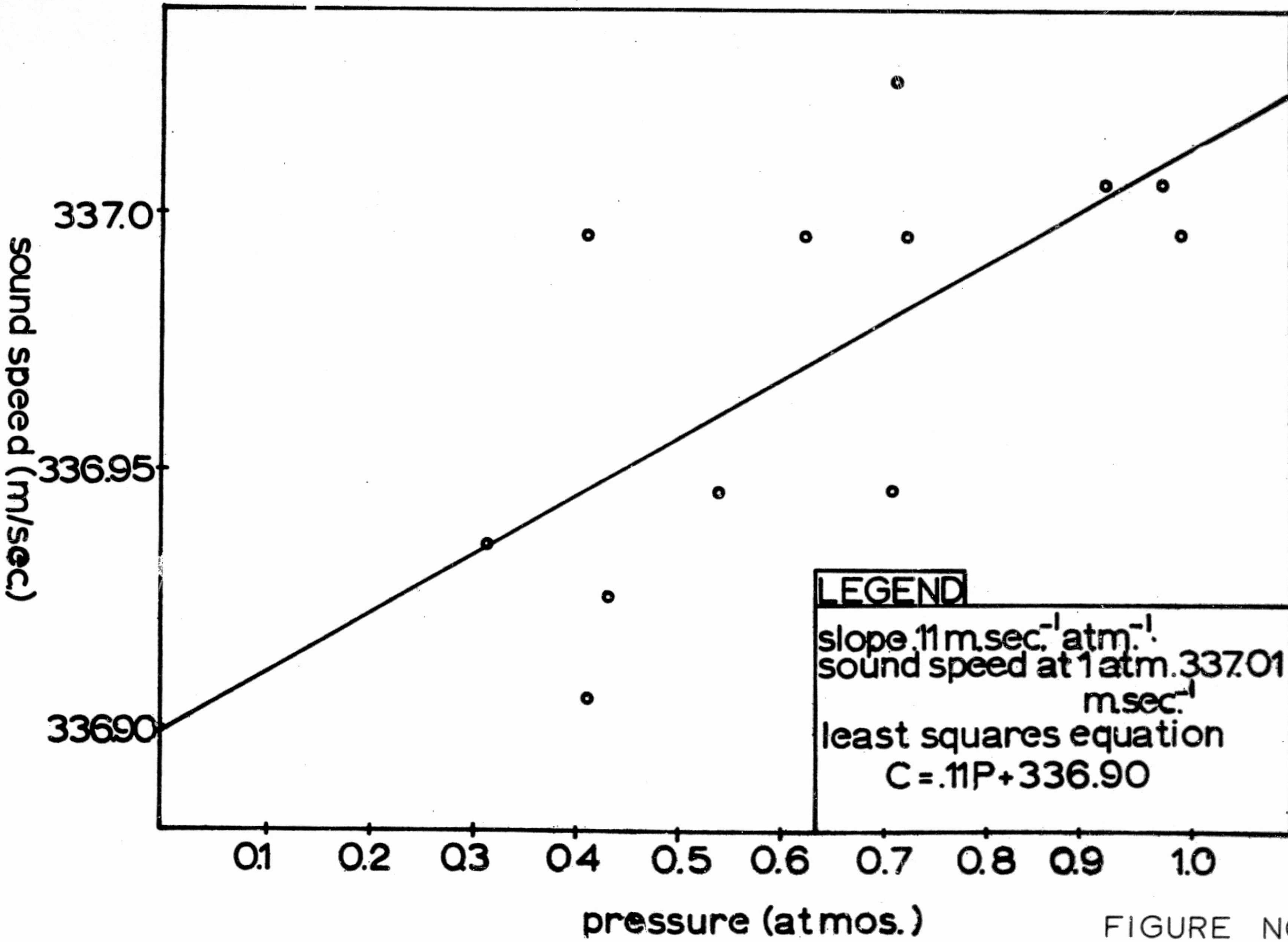

sound speed (m/sec.)
337.0
336.95
336.90
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
pressure (atmos.)
LEGEND
slope .11 m.sec.$^{-1}$ atm.$^{-1}$.
sound speed at 1 atm. 337.01 m.sec.$^{-1}$
least squares equation
C = .11P + 336.90

FIGURE NO. 48

freedom were not participating. Sound speed is reported, however, as non-dispersive, which means the vibrational modes are in equilibrium. Following E. A. Dean[17], this correction reduces sound speed in nitrogen gas at STP by 0.03 m/sec to the non-dispersive value of 336.98 ± 0.03 m/sec.

Both the experimental values for the pressure-dependence coefficient and the non-dispersive sound speed at STP agreed well with the theoretical values. A previous theoretical calculation of the sound speed pressure-dependence coefficient by E. A. Dean yielded a value of 0.11 m/sec/atm with no precision listed.[17] The non-dispersive sound speed in nitrogen gas at 0° C and one atmosphere pressure compares well with the 336.96 m/sec reported by Lestz[20] and the theoretical value of 336.96 m/sec listed by Hilsenrath, et. al.[6]

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APPENDIX I

RAY TRACING IN A LAYERED MEDIUM

by

E. A. Dean

Paper included in

SOUND RANGING FOR THE ROCKET GRENADE EXPERIMENT

QUARTERLY PROGRESS REPORT NO. 6

January - March 1964

Schellenger Research Laboratories
Texas Western College
El Paso, Texas

RAY TRACING IN A LAYERED MEDIUM

THEORY

As a sound ray moves from a medium where the sound speed is c_1 to a medium where the sound speed is c_2, the refraction is determined by the following two laws:

(1) $c_1 \sin \theta_2 = c_2 \sin \theta_1$, where θ is the angle the ray makes with the normal to the boundary and,

(2) the ray in both media lies in a plane normal to the boundary.

Suppose that the boundary is normal to the z - axis and the direction of the ray is specified by the unit vector $\underset{\sim}{n} = \underset{\sim}{i}\alpha + \underset{\sim}{j}\beta + \underset{\sim}{k}\gamma$, where α, β, and γ are the directional cosines of the ray. With this symbolism, the laws of refraction become

$$c_1\sqrt{1 - \gamma_2^2} = c_2\sqrt{1 - \gamma_2^2} \tag{1}$$

and

$$\frac{\beta_1}{\alpha_1} = \frac{\beta_2}{\alpha_2} \tag{2}$$

For moving media, the coincidence between the movement of the wave front and the propagation of energy disappears. The former, called the phase velocity c_p, is determined by

$$c_p = c + \underset{\sim}{n}\cdot\underset{\sim}{w} \tag{3}$$

where $\underset{\sim}{w}$ is the velocity of the medium, while the latter, called the group velocity $\underset{\sim}{c}_g$, is

$$\mathbf{c}_g = \mathbf{n}c + \mathbf{w} \tag{4}$$

It is the phase velocity which determines the refraction of a ray, demanding that Equation (1) become

$$(c_1 + \mathbf{n}_1 \cdot \mathbf{w}_1)\sqrt{1 - \gamma_2^2} = (c_2 + \mathbf{n}_2 \cdot \mathbf{w}_2)\sqrt{1 - \gamma_1^2} \; . \tag{1a}$$

If the x - component of $\mathbf{w}$ is u, the y - component is v, and it is assumed that $w_z = 0$, then Snell's Law (Equation 1a) becomes

$$(c_1 + \alpha_1 u_1 + \beta_1 v_1)\sqrt{1 - \gamma_2^2} = (c_2 + \alpha_2 u_2 + \beta_2 v_2)\sqrt{1 - \gamma_1^2} . \tag{1b}$$

Two quantities remain constant as the ray moves from one medium to another. One is obtained directly from Equation (2) by letting

$$\varepsilon = \frac{\beta_1}{\alpha_1} = \frac{\beta_2}{\alpha_2} \; . \tag{5}$$

The other "constant of motion" comes from Equation (1b)

$$\mu = \frac{c_1}{\alpha_1} + u_1 + \varepsilon v_1 = \frac{c_2}{\alpha_2} + u_2 + \varepsilon v_2 , \tag{6}$$

since

$$\sqrt{1 - \gamma^2} = \sqrt{\alpha^2 + \beta^2} = \sqrt{1 + \varepsilon^2} \; .$$

Mathematical induction leads to the fact that ε and μ are constants for a particular ray in any layer of a layered medium.

These two constants, with the relation

$$\alpha^2 + \beta^2 + \gamma^2 = 1 \tag{7}$$

completely determine the direction of a ray in any layer if its direction in one layer is known. Once the ray directionn $\mathbf{n}$ is known, the propagation path through a layer can be obtained by means of the group velocity. Thus, if $\underset{\sim}{r}_1$, is the position of a ray as it enters a layer and $\underset{\sim}{r}_2$ is the position as it exits,

$$\underset{\sim}{r}_2 = \underset{\sim}{r}_1 + \underset{\sim}{c}_g t \ , \tag{8}$$

where t is the transit time. Thus we have the three component ray equations ,

$$x_2 = x_1 + (\alpha c + u)t, \tag{9}$$

$$y_2 = y_1 + (\beta c + v)t, \tag{10}$$

and

$$z_2 = z_1 + \gamma ct. \tag{11}$$

RAY TRACING THROUGH A LAYERED MEDIUM

Consider a medium made up of N layers normal to the z - axis, each layer being of height h_n. Extension of Equation (8) and (9) yields

$$x = \sum_{n-1}^{N} (\alpha_n c_n + u_n)t_n \tag{12}$$

and

$$y = \sum_{n-1}^{N} (\beta_n c_n + v_n)t_n \tag{13}$$

for the x and y position differences in traveling through the N layers. Knowledge of the height of the array coupled with Equation

(10) yields

$$t_n = \frac{h_n}{\gamma_n c_n} \tag{14}$$

which may be substituted into Equation (11) and (12) to obtain ray displacement in terms of α_n, β_n, γ_n, and h_n; and may be used to obtain the total travel time

$$t = \sum_{n-1}^{N} \frac{h_n}{\gamma_n c_n} . \tag{15}$$

The equations for the directional cosines are the following:

$$\alpha_n = \frac{c_n}{\mu - u_n - \varepsilon v_n} \tag{16}$$

$$\beta_n = \varepsilon \alpha_n , \tag{17}$$

$$\gamma_n = \sqrt{1 - \alpha_n^2 - \beta_n^2} , \tag{18}$$

where

$$\varepsilon = \frac{\beta_0}{\alpha_0} \tag{19}$$

and

$$\mu = \frac{c_0}{\alpha_0} + u_0 + \varepsilon v_0 , \tag{20}$$

the zero subscripts referring to a layer in which α, β, γ, c, u, and v are known.

CALCULATION OF SOUND AND WIND SPEEDS IN A LAYER WITH KNOWN RAY DISPLACEMENTS

The converse problem to ray tracing is that in which the displacements $\zeta = x_2 - x_1$, $\eta = y_2 - y_1$, $h = z_2 - z_1$, and travel time t are known, as are the constants μ and ε; but c, u, and v are to be calculated. Let α, β, and γ be the unknown directional cosines then the following system of equations describes the refraction and ray displacements within the layer:

$$\alpha^2 + \beta^2 + \gamma^2 = 1 \tag{21a}$$

$$\beta = \varepsilon\alpha \tag{21b}$$

$$c + \alpha u + \beta v - \alpha\mu = 0 \tag{21c}$$

$$\alpha c + u = \zeta/t \tag{21d}$$

$$\beta c + v = \eta/t \tag{21e}$$

$$\gamma c = h/t. \tag{21f}$$

These six equations represent (a) the orthoganility of the directional cosines; (b) the consistance of the azimuth angle; (c) Snell's Law; and finally the three component equations for the ray displacement. All but the second are quadratic in the unknowns α, β, γ, c, u, and v, but the system may be solved in the following manner: Multiplication of equations (d), (e) and (f) by α, β, and γ respectively and summing results in

$$(\alpha^2 + \beta^2 + \gamma^2)c + \alpha u + \beta v = \frac{1}{t}(\alpha\zeta + \beta\eta + \gamma h).$$

Use of equation (a) and the subtraction of equation (c) yields

$$t\alpha\mu = \alpha\zeta + \beta\eta + \gamma h.$$

Finally Equations (a) and (b) allow the above to be solved for α

$$\alpha = \pm h[(t\mu - \zeta - \varepsilon\eta)^2 + h^2(1 + \varepsilon^2)]^{-\frac{1}{2}}, \tag{22}$$

where the $\pm$ sign takes on the sign of α in the previous layer. The solution for the other variables in the layer is now straight forward, yielding

$$\beta = \varepsilon\alpha \tag{23}$$

$$\gamma = \sqrt{1 - \alpha^2 - \beta^2} \tag{24}$$

$$c = h/\gamma t \tag{25}$$

$$u = \zeta/t - \alpha c \tag{26}$$

$$v = \eta/t - \beta c \; . \tag{27}$$

NOTE ON THE ROCKET GRENADE EXPERIMENT

In the Rocket Grenade Experiment the values of α_0, β_0, and γ_0 from which ε and μ are to be calculated are derived from the sound ranging array as the directional cosines for the vector which points in the direction of the arrival of the sound front, not in the direction of propagation. This requires the wind vector to point in the direction from which the wind is blowing, not the direction of motion.

GRENADE EXPLOSIONS I˙ THE UPPER ATMOSPHERE

by

J. G. Pruitt

Paper delivered at

CONFERENCE

ON

ATMOSPHERIC

ACOUSTIC PROPAGATION

Fort Bliss, Texas
April 22-23, 1964

GRENADE EXPLOSIONS IN THE UPPER ATMOSPHERE*

J. G. Pruitt**

INTRODUCTION. The aftermath of an explosion is a spherically expanding wave. This wave is led by a region of high pressure, which is in turn followed by a region of low pressure. The wave soon stabilizes into an "N" shape, since its velocity is faster in the region of higher condensation and slower in the region of lower condensation.

Waves recorded from Rocket Grenade Experiments which are conducted by Goddard Space Flight Center of the National Aeronautics and Space Administration (NASA) have this "N" form. In the grenade experiment, a rocket is fired containing 12 grenades. The grenades are ejected and exploded as the rocket ascends. The first grenade explodes at about 40 km, and the last at about 90 km. The acoustic energy from these grenades travels down through the atmosphere and is recorded by an array of microphones. These data are used to determine the temperature and wind velocity in the region between the explosions.

The shape of the wave was observed when wide-band microphones were used to supplement the normal narrow-band microphones in recording wave-arrivals from the rocket grenade experiment. This observed wave form also explained double arrivals which had been obtained with the narrow-band microphones.

DATA. Typical grenade arrivals, as recorded on a low frequency capacitor microphone, are shown in Fig. 1. It can be noticed, particularly on the first few grenades, that the wave has the shape of an inverted "N."

* This work supported by NASA Contract NAS 5-2949.

** Schellenger Research Laboratories, Texas Western College.

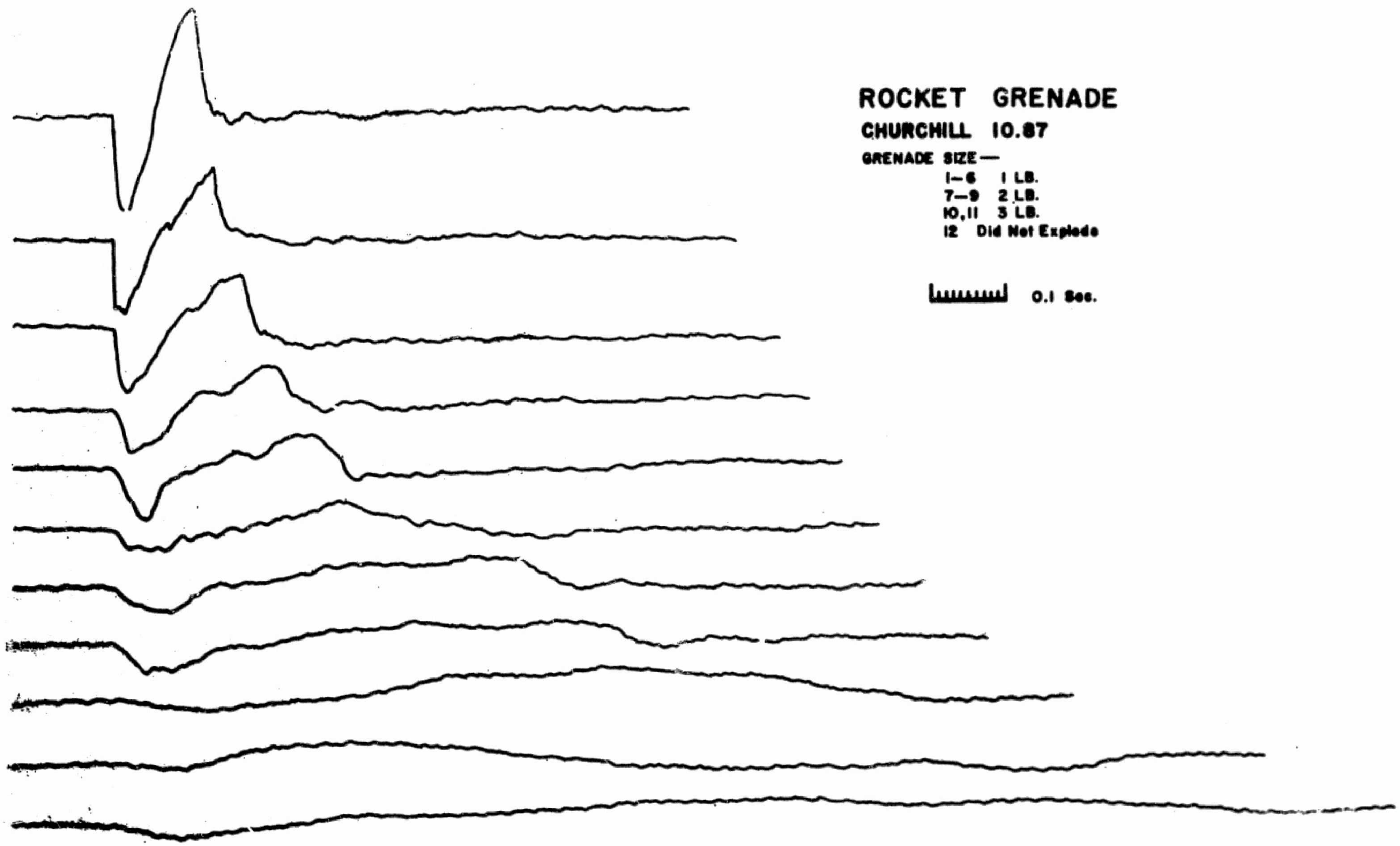
ROCKET GRENADE
CHURCHILL 10.87
GRENADE SIZE —
1—6 1 LB.
7—9 2 LB.
10,11 3 LB.
12 Did Not Explode
0.1 Sec.

FIGURE NO. 1

The wave shape is somewhat hidden for the middle and higher grenades by ambient background noise. The amplitude of the peaks received from the upper grenades is on the order of 0.5 dyne/cm^2.

A second set of data is shown in Fig. 2. These signals were recorded from Project Firefly during October,1962. The grenades were 8-lb charges, exploded at altitudes between 90 and 106 km. In this experiment three types of microphones were used:

(1) A Schellenger Research Laboratories (SRL) capacitor microphone, similar to the type used to record the previous data;

(2) An SRL hot-wire microphone, the microphone normally used for sound ranging in the rocket grenade experiment; and

(3) A microbarograph.

The capacitor unit and the microbarograph produce similar outputs, dur to their similar response characteristics. Both are low-frequency, flat response devices, and record the "N" shape of the incident wave.

The hot-wire unit is a tuned cavity and has a peaked response about two octaves wide with a center frequency at about 4.5 cycle/sec. Thus, the leading and trailing steps of the "N" act as an impulse to the cavity, causing it to ring. The damping is so adjusted that the ringing is quickly damped out. The comparative responses of the microphones are shown in Fig. 3.

The hot-wire output does not truly represent the arriving signals, but nevertheless has proved useful in the rocket grenade experiment where the principal interest is the arrival time, not the wave shape. The hot-wire microphone also yields a better signal-to-noise ratio on the higher grenades than other types thus far tested.

<u>THEORETICAL CONSIDERATIONS.</u> "N"-shaped waves have previously been recorded from ballistic sources. In this case, the leading edge of the wave is due to the nose of the object causing the wave and is called

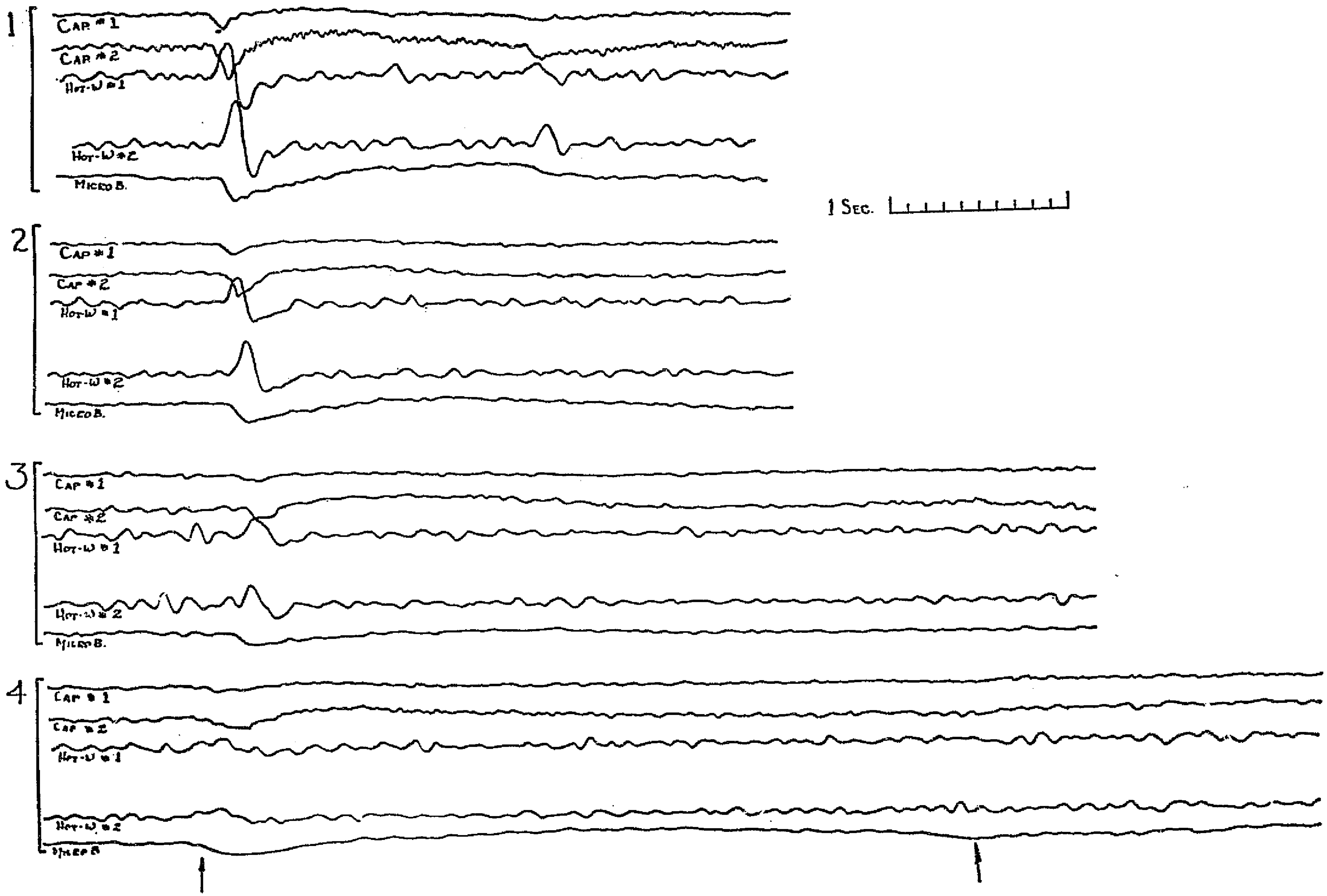

FIGURE NO. 2

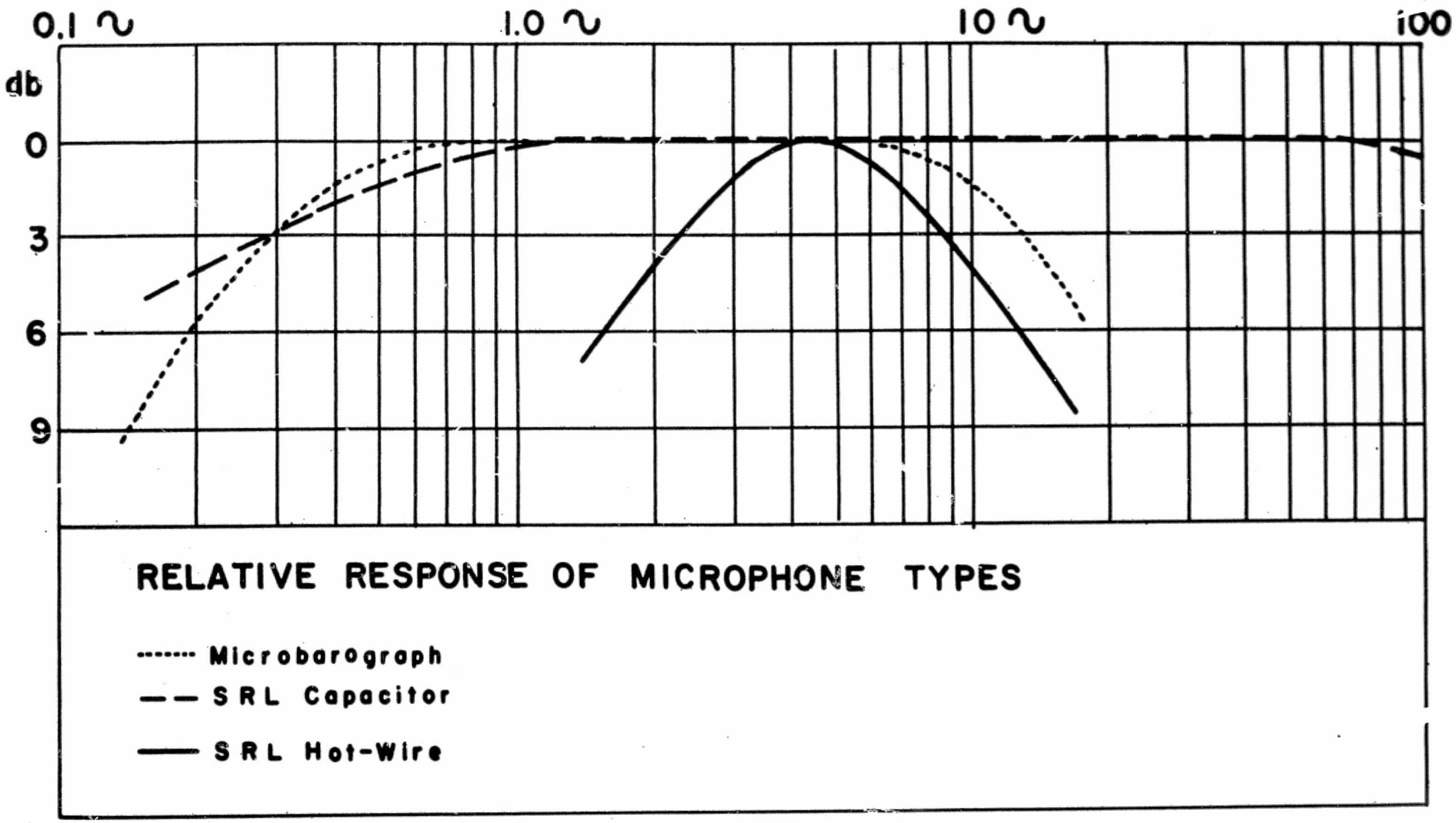
0.1 ∿
1.0 ∿
10 ∿
100
db
0
3
6
9
RELATIVE RESPONSE OF MICROPHONE TYPES
Microbarograph
SRL Capacitor
SRL Hot-Wire

FIGURE NO. 3

a "bow wave." The trailing edge is due to the tail of the object and is called a "tail wave." To our knowledge, "N"-shaped waves due to explosive sources have not been experimentally observed. However, DuMond, et al., ---- [1] have predicted such waves from theoretical considerations, as did Landau in 1942.

The characteristic "N" shape is due to finite amplitude effects on the propagation. Unlike the small amplitude case, the speed of a wave is dependent on the amplitude when these effects are considered. If π is the overpressure ratio, defined as P_1/P_o where P_1 is the crest pressure and P_o is the ambient pressure, DuMond et al have shown that the wave velocity u is given by

$$u^2 = P_o v_o \frac{\pi\zeta + 1}{\zeta - 1} , \qquad (1)$$

where v_o is the specific volume and $\zeta = \frac{2C_v}{R} + 1$, where C_v is the molar heat at constant volume and R is the gas constant. This expression reduces to the well-known

$$u^2 = \gamma P_o v_o ,$$

where γ is the ratio of specific heats, when $\pi = 1$.

Thus, regions of overpressure travel faster than the local sound speed, and regions of underpressure travel slower, causing any type of wave shape having both regions to eventually acquire an "N" shape. This is demonstrated in Fig. 4, where point 1 travels faster than the local sound speed, which is the speed of point 2. The opposite is true of point 3, leading at some later time to the wave shape shown in B. Eventually the wave will stabilize with the "N" shape of C. Since the

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[1] J. W. M. DuMond, E. R. Cohen, W. K. H. Panofsky, and E. Deeds. Jour. Acoust. Soc. Am. 18:97 (1946).

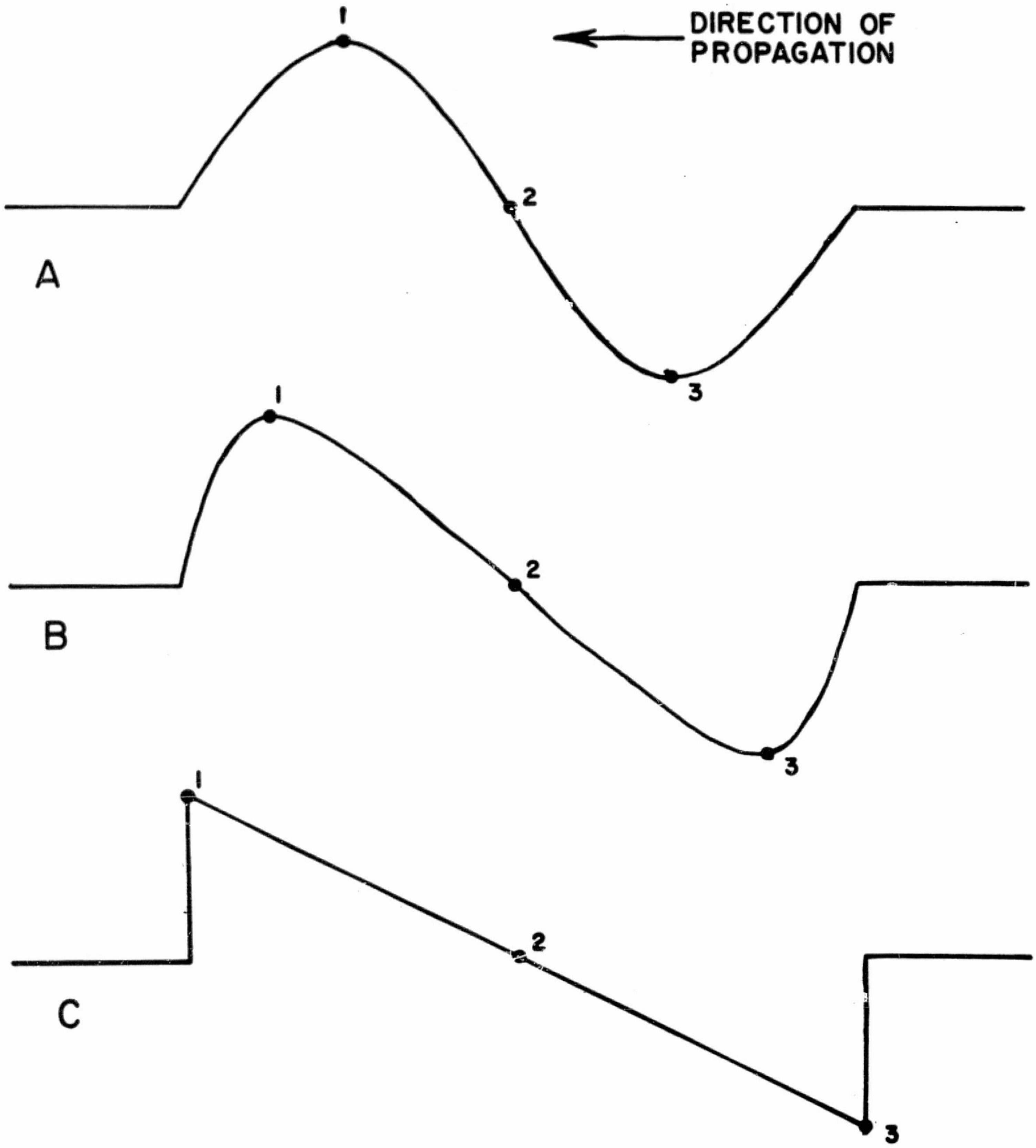

FIGURE NO. 4

pressure is a single-valued function, point 1 will stop its forward movement somewhat short of a finite discontinuity.

In the actual physical case, the compression of the medium caused by the shock wave is irreversible, and the final pressure of the medium, after passage of the "N" wave, is lower than the original pressure.[(2)] The medium returns to its original ambient value long after the passage of the wave; the approach is asymptotic. This possibly accounts for the lack in definition of the trailing edge of observed wave forms.

As the "N" wave propagates, the wavelength increases due to the excess speed of the leading edge over that of the trailing edge. During this propagation, the amplitude of the wave is diminished due to the combined effects of spherical divergence, absorption, and its own lengthening. Finally, the amplitude is so small that there is no sensible lengthening, since the leading and trailing edges are both moving at the speed of sound. Thus, the wavelength is a function of the original overpressure and the distance from the source. Brode[(3)] has introduced the scale factor $(E/P_o)^{1/3}$ as a quantitative measure of the strength of an explosion. Here E is the energy of the explosion and P_o is the ambient pressure. This quantity reflects both the magnitude of the explosion and the pressure in the region surrounding the explosion.

At the time of the writing of this paper, the actual altitudes of the grenade explosions were not known. These data are in the process of being reduced. The explosions were assumed to have taken place at the predetermined altitudes, and the corresponding pressures were taken from the CIRA 1961 standard atmosphere. The values of $(\frac{E}{P_o})^{1/3}$

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(2) L. P. Landau and E. M. Lifshitz. Fluid Mechanics. (Addison-Wesley, Reading, Mass., (1959) pp. 310+.

(3) H. L. Brode, Phys. Fluids 2:217 (1959).

were computed for the grenade shots designated as 10.87 and 10.88. These values, together with the wavelength of the recorded "N" wave, are presented in Fig. 5. Both of these quantities have dimensions of length, and their ratio is also tabulated in Fig. 5. This ratio appears to be constant for the two grenade experiments. The spread in these ratios can be possibly accounted for in the assumptions concerning the ambient pressure at which each explosion took place.

The lack of agreement between the Firefly data and rocket grenade data has not been fully explained. The most probable explanation lies in the differences in the explosive used. The NASA grenade experiment contained 26% TNT, 19.11% RDX, 20.89% AL, 30.5% C_5NO3 and traces of two other chemicals. The specific energy of the NASA grenades is approximately 1900 gram-calories/gram. Only the TNT and RDX components are efficient explosives in the Firefly grenades; these components constitute less than half the value of the weight of the grenade. Therefore, a specific energy of half the value of the NASA grenades was used for the Firefly grenades. The density of an explosive is also known to affect the shock wave from an explosion. A difficulty inherent in calculations of this type is knowledge of the net energy release of an explosion.

SHOCK VELOCITIES. A set of curves has been published by Brode[4] giving the pressure ratio π as a function of distance from a given type of explosion. Values of π were obtained from these curves and substituted into equation (1), which relates the speed of the shock wave to π.

---

[4] H. L. Brode, Research Memo. RM-1913-AEC, Rand Corporation (1957).

GRENADE NUMBER	GRENADE SIZE (lbs.)	ALTITUDE (km)	$(\varepsilon/p)^{1/3}$ (m)	"N" LENGTH (m)	$(\varepsilon/p_0)^{1/3}$ / "N" Lgth.
CHURCHILL 10.87					
1	1	40	22.8	41.7	0.546
2	1	44.5	28.0	49.4	.568
3	1	49	34.2	62.2	.550
4	1	53.5	40.9	75.4	.543
5	1	58	49.4	102.	.484
6	1	62.5	60.8	108	.563
7	2	67	91.3	196	.466
8	2	71.5	119	231	.516
CHURCHILL 10.88					
4	1	53.5	40.9	69.2	0.591
5	1	58	49.4	91.6	.539
6	1	62.5	60.8	103.	.588
8	2	71.5	119	199	.598
FIRE FLY					
1	8	90.7	457	625	0.736
4	8	106	1035	1455	.711

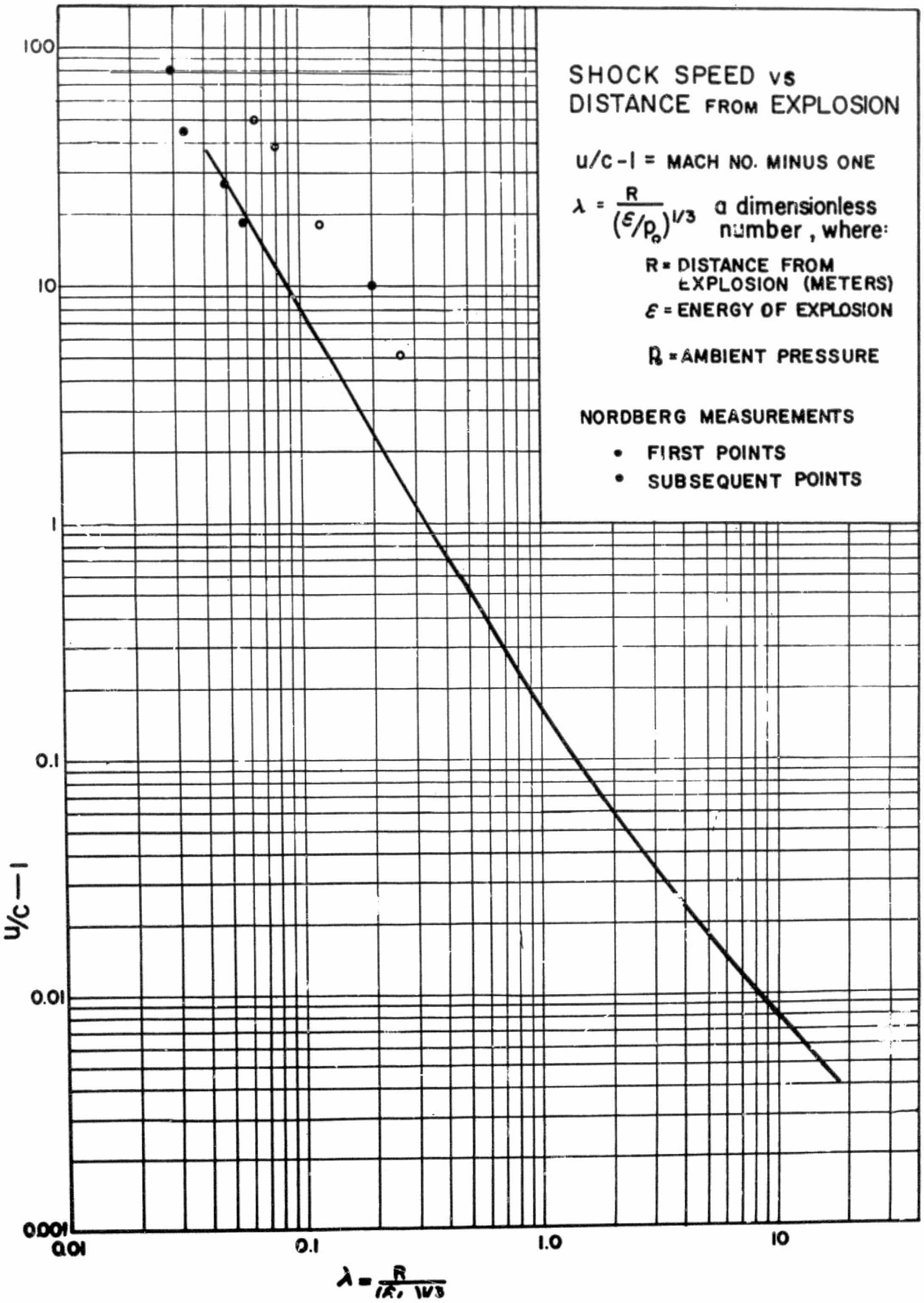
FIGURE NO. 5

Mach Numbers $\frac{u}{C}$, corresponding to these shock speeds, were calculated and the resulting quantity $\frac{u}{C} - 1$ was plotted as a function of λ in Fig. 6. Here λ is the dimensionless ratio $R/(\frac{E}{P_o})^{1/3}$ where R is the distance from the explosion. Similar results were obtained by Nordberg[5] from the NASA grenade experiment data by a different method. The wave velocity near the explosion ($\lambda \approx 0.5$) is of the order of Mach 30, corresponding to an overpressure ratio of 1200.

An illustration of the wave velocity in the case of the rocket grenade experiment is shown in Fig. 7. Here $\frac{u}{C} - 1$ is plotted vs. R for 2-lb grenades exploded at various altitudes. The effect of the reduced pressure at higher altitudes is readily apparent. A correction for these effects is made in data analysis for the rocket grenade experiment, as would be necessary for any calculation demanding accurate travel times.

CONCLUSION. The predictions of Landau and others concerning the "N" profile as the characteristic shock wave profile appear to be verified in the recorded signals from the grenade experiments. It appears that the ratio of $(\frac{E}{P_o})^{1/3}$ to the wavelength of the recorded "N" is essentially constant. This wavelength may prove useful in predicting the fundamental frequency of arrivals from explosions if E/P_o is known. Likewise, a measure of either E or P_o can be obtained if the wavelength and one of the parameters P_o or E are known.

(5) W. Nordberg, Tech. Note D-1294, Goddard Space Flight Center, (1962).



SHOCK SPEED vs DISTANCE FROM EXPLOSION
u/c - l = MACH NO. MINUS ONE
λ = R / (ε/p₀)^1/3 a dimensionless number, where:
R = DISTANCE FROM EXPLOSION (METERS)
ε = ENERGY OF EXPLOSION
p₀ = AMBIENT PRESSURE
NORDBERG MEASUREMENTS
FIRST POINTS
SUBSEQUENT POINTS
100
10
1
0.1
0.01
0.001
u/c — l
0.01
0.1
1.0
10

FIGURE NO. 6

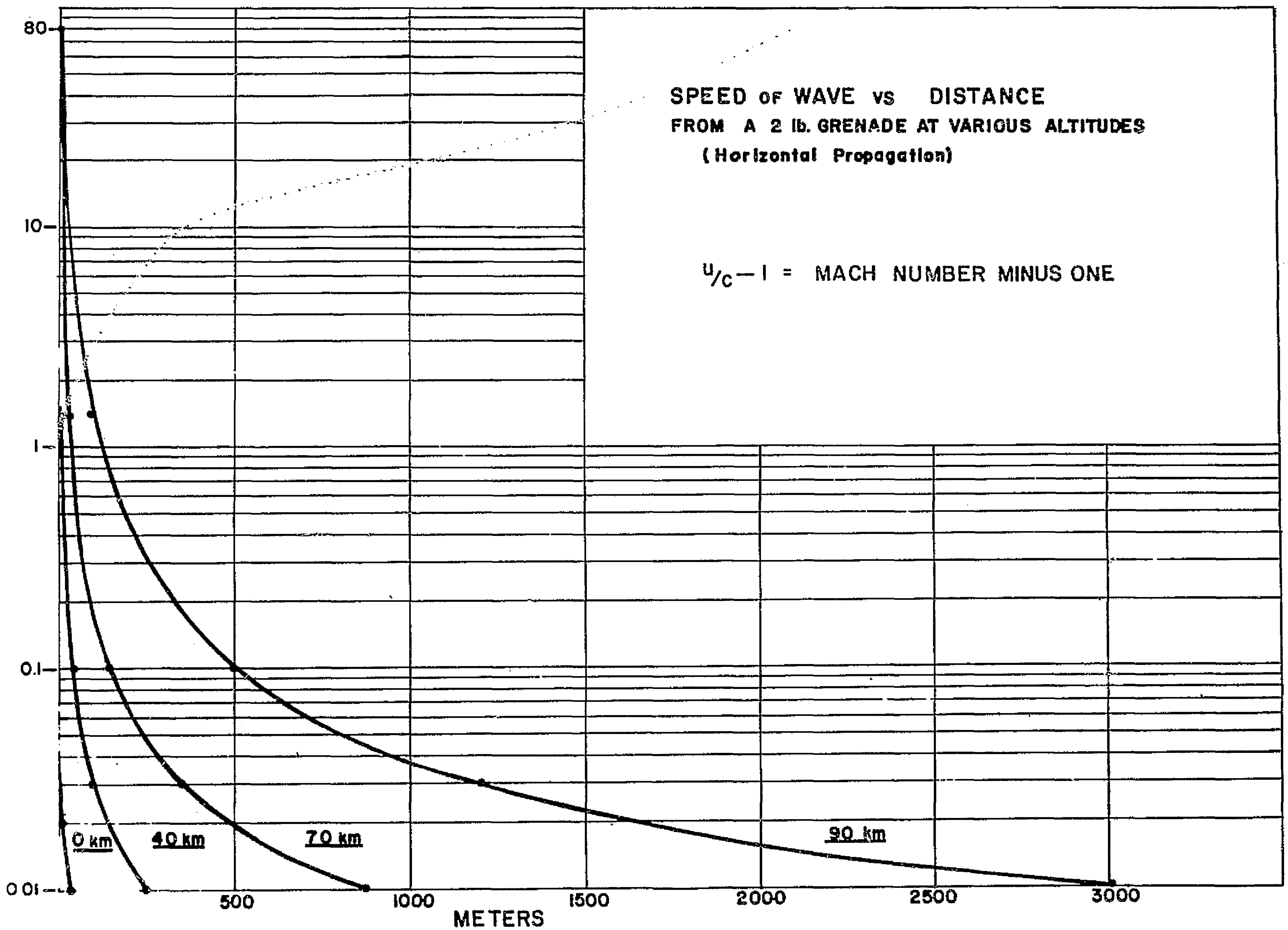

SPEED OF WAVE VS DISTANCE
FROM A 2 lb. GRENADE AT VARIOUS ALTITUDES
(Horizontal Propagation)
u/c − 1 = MACH NUMBER MINUS ONE
80
10
1
0.1
0.01
500
1000
1500
2000
2500
3000
METERS
0 km
40 km
70 km
90 km

FIGURE NO. 7

APPENDIX II

NIKE CAJUN NUMBER: 10.45

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.	BETA ZENITH	BETA DEV. ZEN. DEV.
1	171.315555 158.905186	.001676 .107142	.128972 .933589	.000681 .000231	-.334329 20.998490	.000589 .036965
2	25.081374 152.333501	.001071 .072934	.155382 .942345	.000437 .000139	-.296381 19.550778	.000379 .023866
3	19.318544 146.296294	.000799 .066032	.181434 .945035	.000392 .000123	-.272010 19.084822	.000339 .021619
4	19.170292 140.676539	.001145 .108828	.206349 .945497	.000652 .000207	-.251899 19.003610	.000564 .036435
5	19.212305 136.958235	.001105 .081999	.227791 .942663	.000508 .000167	-.243920 19.496251	.000439 .028748
6	28.413586 132.525189	.000877 .054951	.251247 .940094	.000351 .000120	-.230429 19.932590	.000304 .020175
7	22.902080 130.857758	.000946 .094659	.263125 .937533	.000621 .000217	-.227586 20.358556	.000537 .035859
8	21.651673 128.793705	.001479 .144219	.262240 .941697	.000919 .000312	-.210799 19.661433	.000796 .053144
9	26.075954 122.576493	.002354 .236625	.270475 .947088	.001462 .000477	-.172819 18.721731	.001265 .085189
10	21.776511 125.039934	.002708 .219826	.284524 .937676	.001462 .000518	-.199521 20.335033	.001265 .085558
11	20.373236 126.259725	.002909 .224185	.274754 .940157	.001457 .000504	-.201529 19.921938	.001261 .084836
12	20.891890 131.402834	.002797 .149627	.283956 .925572	.001066 .000411	-.250366 22.245078	.000923 .062310

NIKE CAJUN NUMBER: 10.47

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.	BETA ZENITH	BETA DEV. ZEN. DEV.
1	184.258170 150.413383	.001445 .072369	.206103 .908706	.000544 .000225	- .363005 24.672704	.000471 .030886
2	24.874862 144.839088	.000880 .046242	.234255 .913525	.000342 .000139	- .332559 24.002815	.000296 .019619
3	19.483971 141.094118	.000718 .055952	.255962 .913180	.000419 .000172	- .317151 24.051389	.000362 .024226
4	18.862838 137.411882	.000843 .061006	.279610 .910647	.000467 .000197	- .304200 24.404936	.000404 .027348
5	19.057357 133.485710	.001264 .092861	.304329 .907778	.000729 .000316	- .288653 24.799768	.000631 .043234
6	27.529344 131.090557	.001314 .079418	.325866 .901695	.000647 .000293	- .284176 25.618113	.000560 .038832
7	22.076019 128.427711	.001041 .050098	.333647 .904770	.000404 .000181	- .264708 25.207642	.000350 .024365
8	21.997898 129.475079	.001175 .070064	.330012 .904000	.000566 .000254	- .271799 25.310991	.000490 .034060
9	28.687645 133.790456	.004330 .383653	.325130 .892828	.003234 .001530	- .311684 26.769085	.002799 .194714
10	17.967767 134.816000	.011250 1.164058	.258820 .931063	.007930 .002907	- .257163 21.398801	.006862 .456583
11	20.268635 129.912843	.010959 .332464	.309804 .914800	.002538 .001061	- .259154 23.822530	.002196 .150562
12						

NIKE CAJUN NUMBER: 10.48

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.	BETA ZENITH	BETA DEV. ZEN. DEV.
1	185.648104 125.322361	.000939 .046840	.383397 .882719	.000420 .000214	-.271685 28.027846	.000364 .026148
2	24.745580 120.253204	.000885 .054842	.413395 .878047	.000508 .000267	-.241116 28.592277	.000439 .032082
3	19.471658 117.203927	.000853 .041440	.435712 .871776	.000395 .000216	-.223963 29.334188	.000342 .025320
4	19.626401 114.834422	.001444 .093881	.457085 .863901	.000926 .000528	-.211536 30.242490	.000801 .060076
5	19.266979 113.082306	.001569 .068196	.464127 .863401	.000676 .000387	-.197797 30.299309	.000585 .044029
6	28.202772 109.974004	.001384 .054051	.484880 .856640	.000551 .000327	-.176232 31.058531	.000477 .036356
7	22.907147 108.342377	.001465 .072918	.505061 .846684	.000769 .000477	-.167447 32.147144	.000666 .051444
8	21.985535 108.219900	.002005 .057966	.506909 .845695	.000613 .000382	-.166858 32.253430	.000531 .041079
9	25.054034 107.089044	.001913 .106723	.521982 .837724	.001158 .000747	-.160473 33.099373	.001002 .078391
10	19.197576 105.673668	.002430 .106515	.519383 .842022	.001144 .000726	-.145734 32.645365	.000990 .077192
11	19.963371 104.824316	.002069 .058484	.529594 .836590	.000639 .000415	-.140165 33.218210	.000553 .043418
12	21.372274 107.973241	.012031 .772504	.563092 .805952	.009079 .006588	-.182669 36.297674	.007857 .637716

NIKE CAJUN NUMBER: 10.53

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.		BETA ZENITH	BETA DEV. ZEN. DEV.
1	169.667108 122.151887	.002780 .038794	.476992 .826188	.000421 .000276	-	.299819 34.290854	.000364 .028153
2	23.954756 117.297794	.000962 .038576	.488186 .835581	.000413 .000264	-	.251947 33.323532	.000357 .027565
3	19.198044 114.830036	.001562 .103203	.493454 .839268	.001099 .000696	-	.228322 32.937040	.000951 .073385
4	18.694391 112.456279	.001874 .079087	.514309 .830841	.000866 .000569	-	.212574 33.814686	.000750 .058660
5	18.706106 110.874217	.001828 .089070	.525748 .826674	.000989 .000662	-	.200492 34.241357	.000856 .067505
6	25.904469 108.249513	.001612 .046626	.531364 .828826	.000517 .000345	-	.175212 4.021633	.000448 .035344
7							
8	45.835126 105.128336	.001051 .043731	.567371 .809049	.000512 .000369	-	.153389 35.996810	.000443 .035987
9	26.479488 103.456199	.001696 .096818	.577452 .804648	.001149 .000842	-	.138167 36.423680	.000994 .081260
10	19.380185 103.310080	.001798 .047817	.580726 .802422	.000570 .000421	-	.137385 36.637900	.000493 .040462
11	19.244711 97.265394	.003711 .227886	.564278 .822444	.002607 .001799	-	.071939 34.669736	.002256 .181300
12	18.785324 105.676640	.009520 .591920	.533801 .832233	.006539 .004316	-	.49810 33.671106	.005658 .446072

NIKE CAJUN NUMBER: 10.54

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.	BETA ZENITH	BETA DEV. ZEN. DEV.
1	178.945558	.001430	.356563	.000474	- .310552	.000410
	131.054586	.053228	.881146	.000240	28.219010	.029131
2	24.608467	.000872	.370581	.000404	- .278875	.000350
	126.962742	.045832	.885944	.000202	27.631953	.024965
3	19.127415	.000775	.379625	.000421	- .260523	.000364
	124.460435	.047723	.887700	.000209	27.414254	.026064
4	18.615524	.000761	.388924	.000362	- .242411	.000314
	121.934775	.041070	.888804	.000180	27.276540	.022560
5	18.349803	.001375	.392516	.000955	- .217649	.000826
	119.008287	.109612	.893621	.000465	26.668063	.059409
6	27.072142	.001469	.386158	.000564	- .197374	.000488
	117.072668	.066701	.901068	.000264	25.701083	.034925
7	22.521155	.001134	.386567	.000574	- .194784	.000497
	116.742691	.068007	.901456	.000268	25.649728	.035576
8	21.892011	.001410	.388683	.000458	- .190660	.000396
	116.129288	.054191	.901428	.000214	25.653445	.028423
9	25.479921	.000955	.394814	.000527	- .184353	.000456
	115.029596	.061785	.900075	.000249	25.832046	.032808
10	20.683480	.001326	.407924	.000777	- .159162	.000672
	111.314531	.089983	.899035	.000372	25.968417	.048730
11	21.256507	.001735	.414451	.000988	- .173988	.000855
	112.772895	.111762	.893284	.000488	26.711029	.062210
12	19.780470	.001848	.430293	.000763	- .181082	.000660
	112.823096	.083146	.884339	.000395	27.829617	.048546

NIKE CAJUN NUMBER: 10.55

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.	BETA ZENITH	BETA DEV ZEN. DEV.
1	158.142051	.001334	.348966	.000435 -	.396900	.000376
	138.677126	.044534	.848936	.000251	31.903827	.027220
2	20.639124	.000946	.378076	.000484 -	.355335	.000419
	133.224014	.049841	.854865	.000276	31.255117	.030520
3	21.081313	.000845	.428339	.000366 -	.325674	.000317
	127.246476	.035790	.842888	.000222	32.553540	.023741
4	20.946399	.000909	.468740	.000537 -	.305558	.000465
	123.099210	.049974	.828804	.000349	34.023868	.035751
5	24.229231	.001187	.498357	.000606 -	.278472	.000525
	119.195600	.054762	.821031	.000409	34.811802	.041057
6	24.020920	.001110	.516874	.000524 -	.262701	.000454
	116.941975	.046389	.814756	.000363	35.436657	.035933
7	27.627635	.001360	.542527	.000858 -	.243058	.000742
	114.132957	.073578	.804106	.000621	36.475951	.059869
8	26.736212	.001383	.562769	.000566 -	.222621	.000490
	111.582838	.047456	.796071	.000423	37.243394	.040076
9	27.099118	.001858	.582985	.001268 -	.211588	.001098
	109.947791	.103410	.784447	.000988	38.330366	.091320
10	25.750585	.002558	.608409	.001367 -	.203907	.001183
	108.528462	.107422	.766980	.001129	39.916456	.100835
11	27.416401	.004049	.621693	.002533 -	.189021	.002192
	106.911517	.196036	.760110	.002142	40.526056	.188930
12						

NIKE CAJUN NUMBER: 10.58

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.	BETA ZENITH	BETA DEV. ZEN. DEV.
1	173.724055 350.888046	.000758 - .055174	.035334 .974790	.000213 .000058	.220304 12.892343	.000256 .015035
2	24.584077 355.538334	.002366 - .272730	.014104 .983425	.000861 .000190	.180762 10.446148	.001035 .060291
3	18.719372 359.258501	.002630 - .183088	.001982 .988198	.000489 .000091	.153165 8.811110	.000588 .034102
4	18.355689 7.226066	.001755 .139245	.016008 .991868	.000308 .000047	.126258 7.311770	.000370 .021343
5	18.006143 14.991551	.001328 .178814	.030500 .993024	.000362 .000051	.113895 6.771377	.000435 .024882
6	17.914868 23.349139	.001340 .155659	.044647 .993634	.000295 .000039	.103425 6.468098	.000355 .020002
7	26.234084 38.185680	.007514 1.744044	.061715 .995004	.002809 .000318	.078466 5.729263	.003376 .182635
8	20.524501 44.265912	.007472 .158433	.064469 .995725	.000231 .000023	.066142 5.299586	.000278 .014764
9	20.311287 52.569153	.001974 .423962	.071433 .995945	.000588 .000057	.054675 5.161063	.000706 .036518
10						
11						
12						

NIKE CAJUN NUMBER: 10.59

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.	BETA ZENITH	BETA DEV. ZEN. DEV.
1	172.703119	.000992	.048621	.000167	.185066	.000200
	14.720372	.050755	.981522	.000038	11.031354	.011608
2	24.869385	.000678	.064071	.000158	.144196	.000190
	23.957069	.059664	.987472	.000029	9.078639	.010775
3	19.284387	.000590	.076672	.000153	.118096	.000184
	32.992917	.066354	.990037	.000024	8.094271	.010162
4	15.934299	.000687	.094889	.000214	.098386	.000257
	43.963314	.099141	.990613	.000032	7.856292	.013770
5	21.775226	.002901	.137395	.001090	.078148	.001310
	60.369507	.456857	.987428	.000183	9.094584	.066628
6	18.389625	.002938	.167770	.000349	.059554	.000420
	70.456377	.132939	.984025	.000064	10.254822	.020867
7	27.036441	.001993	.177432	.000735	.060063	.000958
	71.298234	.286870	.982298	.000145	10.796603	.044422
8	22.285655	.004422	.188494	.001292	.033674	.001553
	79.871105	.462517	.981496	.000253	11.039063	.075966
9	20.637153	.004607	.167821	.000360	.026050	.000433
	81.176463	.145701	.985473	.000062	9.778013	.021081
10	20.428195	.004406	.164497	.000802	.032199	.000963
	78.924549	.327608	.985851	.000137	9.649413	.047001
11	19.872756	.005643	.123199	.000873	.021524	.001050
	80.089510	.478875	.992148	.000110	7.184525	.050798
12						

NIKE CAJUN NUMBER: 10.60

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.	BETA ZENITH	BETA DEV. ZEN. DEV.
1	171.411790	.001564	.015349	.000201	.169912	.000242
	5.162005	.067798	.985339	.000041	9.822950	.014065
2	24.352321	.000669	.037585	.000152	.127594	.000183
	16.413330	.066877	.991114	.000024	7.643802	.010468
3	19.007817	.000684	.056224	.000190	.098871	.000228
	29.625489	.101035	.993510	.000025	6.530909	.012696
4	18.655021	.000721	.077915	.000173	.074593	.000208
	46.247625	.102517	.994165	.000020	6.192267	.011035
5	18.391680	.000857	.095451	.000274	.057544	.000329
	58.915493	.162499	.993769	.000032	6.399196	.016739
6	17.835867	.000842	.102360	.000158	.041436	.000190
	67.961496	.096890	.993883	.000018	6.340035	.009441
7	27.108403	.000850	.112376	.000275	.018011	.000330
	80.894018	.165970	.993502	.000031	6.535023	.015972
8	21.940282	.001161	.123286	.000259	- .012376	.000311
	95.732824	.143783	.992293	.000032	7.117578	.014998
9	21.058629	.002128	.115416	.000689	- .016594	.000828
	98.181853	.405828	.993178	.000081	6.696077	.039956
10	21.280474	.002911	.115274	.000803	- .060260	.000964
	117.598509	.410777	.991504	.000110	7.473904	.048567
11	20.685213	.002628	.105544	.000295	- .052061	.000355
	116.255514	.167845	.993050	.000036	6.758523	.017802
12	16.181098	.002658	.112433	.000658	- .095373	.000791
	130.306707	.287082	.989071	.000106	8.478351	.041545

ROCKET-GRENADE EXPERIMENT: 10.61

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0018-57.254	27.09877	157.10390	.89033	.17724	- .41968
	.00134	.13737	.29342	.00109	.00237	.00208
2	0019-21.933	25.11931	153.81840	.90551	.18731	- .38098
	.00114	.11556	.26643	.00085	.00201	.00177
3	0019-46.055	25.15745	148.10910	.90524	.22460	- .36097
	.00191	.19545	.44023	.00145	.00337	.00296
4	0020-05.009	24.77291	144.02170	.90807	.24619	- .33912
	.00040	.04125	.09299	.00030	.00070	.00062
5	0020-28.574	24.58291	141.21470	.90945	.26061	- .32731
	.00099	.10253	.23034	.00074	.00175	.00154
6	0020-51.603	25.04129	138.24840	.90610	.28188	- .31581
	.00077	.08045	.17470	.00059	.00136	.00119
7	0021-13.764	25.50812	136.59040	.90262	.29597	- .31287
	.00216	.22751	.48018	.00171	.00381	.00336
8	0021-43.996	25.14533	133.81780	.90533	.30663	- .29423
	.00355	.37425	.79314	.00277	.00626	.00551
9	0022-14.328	26.54359	132.73850	.89471	.32825	- .30331
	.00387	.41330	.81913	.00322	.00681	.00599
10	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.62

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0148-43.855	29.00049	138.85580	.87476	.31904 -	.36515
	.00093	.10025	.18397	.00084	.00163	.00144
2	0149-08.616	28.10269	134.13980	.88223	.33809 -	.32809
	.00114	.12304	.22953	.00101	.00200	.00176
3	0149-32.780	27.53007	127.21360	.88689	.36815 -	.27958
	.00095	.10360	.19209	.00083	.00167	.00147
4	0149-52.118	27.90778	123.57240	.88383	.39003 -	.25886
	.00167	.18316	.32914	.00149	.00292	.00257
5	0150-15.604	28.14707	120.07100	.88186	.40830 -	.23640
	.00196	.21654	.37989	.00178	.00343	.00301
6	0150-33.346	28.81672	117.79630	.87630	.42645 -	.22481
	.00235	.26271	.44438	.00221	.00412	.00362
7	0151-02.893	29.93449	117.36600	.86659	.44316 -	.22938
	.00123	.13880	.22395	.00120	.00215	.00189
8	0151-32.996	29.92686	112.91410	.86681	.45960 -	.19427
	.00166	.18869	.29993	.00164	.00290	.00255
9	0152-01.769	30.52907	112.45560	.86137	.46945 -	.19403
	.00564	.64449	.99853	.00571	.00985	.00867
10	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	[illegible]

ROCKET-GRENADE EXPERIMENT: 10.63

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0322-51.901 .00026	24.02937 .02782	138.72270 .00343	.91342 .00019	.28836 – .00047	.30605 .00041
2	0323-16.474 .00063	23.03002 .06617	131.33720 .15316	.92037 .00045	.29376 – .00111	.25841 .00098
3	0323-40.436 .00095	23.58684 .10035	126.12080 .22110	.91653 .00070	.32325 – .00167	.23589 .00147
4	0323-59.259 .00111	24.32217 .11879	124.01170 .25061	.91133 .00085	.34144 – .00195	.23040 .00172
5	0324-22.841 .00197	24.96703 .21355	120.46480 .43115	.90664 .00157	.36386 – .00348	.21402 .00306
6	0324-46.366 .00049	26.32547 .05482	117.54800 .10302	.89639 .00042	.39323 – .00087	.20512 .00077
7	0325-08.784 .00574	26.93750 .63599	115.71970 1.15603	.89162 .00502	.40819 – .01011	.19362 .00890
8	0325-39.793 .00200	26.49502 .22207	113.35010 .40822	.89507 .00172	.40962 – .00353	.17683 .00310
9	0326-09.656 .00366	24.44737 .39877	113.17990 .80329	.91042 .00288	.38048 – .00645	.16291 .00567
10	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
11	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
12	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000

NIKE CAJUN NUMBER: 10.66

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.	BETA ZENITH	BETA DEV. ZEN. DEV.
1	169.953758	.000874	.048640	.000188	.197010	.000226
	13.868593	.053770	.979194	.000046	11.708080	.013107
2	24.602791	.000771	.063418	.000223	.144043	.000268
	23.762653	.084105	.987537	.000041	9.055197	.015164
3	18.763681	.000913	.071120	.000253	.113143	.000304
	32.152966	.115159	.991029	.000039	7.679958	.016805
4	18.073218	.000995	.082311	.000280	.079549	.000336
	45.977492	.155507	.993426	.000035	6.573003	.017807
5	17.339967	.001004	.083413	.000265	.055764	.000319
	56.235997	.173317	.994953	.000028	5.758534	.016304
6	16.968442	.000985	.081846	.000268	.038420	.000323
	64.853758	.198964	.995904	.000025	5.187502	.016076
7	25.531733	.001066	.074415	.000289	.013778	.000347
	79.510447	.261876	.997132	.000022	4.340307	.016748
8	20.988043	.001100	.065659	.000303	.004962	.000364
	85.677676	.317122	.997829	.000020	3.775445	.017453
9	20.876318	.001222	.068038	.000352	-.006686	.000423
	95.613007	.354457	.997660	.000024	3.920107	.020288
10	20.904076	.001437	.074529	.000405	-.017402	.000487
	103.142840	.361980	.997066	.000031	4.389323	.023576
11	19.713251	.001782	.091854	.000505	-.038962	.000607
	112.985483	.340807	.995009	.000052	5.726231	.030103
12	15.419116	.001627	.100951	.000318	-.053020	.000382
	117.708956	.185709	.993477	.000038	6.547536	.019221

NIKE CAJUN NUMBER: 10.67

GRENADE	TIME (DIFF) AZIMUTH	TIME DEV. AZ. DEV.	ALPHA GAMMA	ALPHA DEV. GAMMA DEV.	BETA ZENITH	BETA DEV. ZEN. DEV.
1	172.327964 13.233524	.000906 .053090	.061808 .962860	.000247 .000082	.262828 15.664168	.000297 .017546
2	23.573221 19.929441	.000861 .060689	.074568 .975777	.000225 .000059	.205663 12.636435	.000271 .015659
3	17.969026 27.443921	.000828 .070314	.086811 .982100	.000220 .000049	.167162 10.857058	.000265 .014978
4	16.817695 35.733564	.000857 .095125	.092567 .987358	.000245 .000044	.128661 9.119845	.000294 .016179
5	16.799370 45.773009	.000909 .096891	.097515 .990697	.000207 .000031	.094919 7.821291	.000249 .013244
6	16.395585 55.221416	.000960 .157113	.099973 .992564	.000292 .000038	.069428 6.991170	.000351 .018080
7	24.867481 72.614055	.000989 .148136	.108473 .993518	.000248 .000028	.033964 6.526703	.000298 .014582
8	20.505025 81.145055	.001089 .152426	.109583 .993830	.000240 .000027	.017072 6.367476	.000296 .014282
9	20.163941 87.212172	.000940 .148976	.120517 .992693	.000261 .000031	.005868 6.930184	.000313 .015083
10	19.659213 93.260901	.000939 .130688	.132205 .991193	.000251 .000033	-.007532 7.609403	.000302 .014548
11	19.034576 99.413062	.001221 .187270	.145833 .989013	.000403 .000060	-.024176 8.500841	.000485 .023530
12	14.679526 103.828770	.001513 .141377	.158562 .986577	.000338 .000056	-.039031 9.398207	.000406 .019896

ROCKET-GRENADE EXPERIMENT: 10.71

GRENADE	ZULU TIME / TIME DEV.	ZENITH / ZEN. DEV.	AZIMUTH / AZ. DEV.	GAMMA / GAMMA DEV.	ALPHA / ALPHA DEV.	BETA / BETA DEV.
1	0413-43.868	25.15754	140.55620	.90524	.27011	- .32832
	.00107	.11040	.24090	.00081	.00187	.00165
2	0414-08.437	23.41363	134.51000	.91774	.28339	- .27859
	.00059	.06060	.13966	.00042	.00102	.00090
3	0414-32.096	22.93741	127.08420	.92100	.31092	- .23501
	.00144	.15052	.34355	.00102	.00252	.00222
4	0414-51.038	23.44477	121.93110	.91752	.33769	- .21044
	.00084	.08925	.19459	.00061	.00147	.00129
5	0415-14.398	23.98148	116.79070	.91375	.36284	- .18321
	.00134	.14355	.29920	.00101	.00234	.00206
6	0415-37.178	25.00342	113.73580	.90637	.38695	- .17015
	.00067	.07298	.14357	.00053	.00117	.00103
7	0415-59.654	25.25128	110.39860	.90453	.39987	- .14870
	.00047	.05216	.10041	.00038	.00083	.00073
8	0416-30.974	26.68275	105.24330	.89360	.43329	- .11807
	.00079	.08821	.15724	.00069	.00138	.00122
9	0417-01.942	29.18841	103.70460	.87314	.47386	- .11555
	.00378	.43072	.68843	.00366	.00660	.00581
10	0417-22.410	29.30099	102.68780	.87218	.47751	- .10750
	.00144	.16430	.26087	.00140	.00251	.00221
11	0417-42.267	31.03439	101.06970	.85685	.50596	- .09898
	.00366	.42536	.62807	.00382	.00638	.00562
12	0418-00.723	29.68878	101.13710	.86886	.48603	- .09568
	.00409	.46902	.73096	.00405	.00714	.00628

ROCKET-GRENADE EXPERIMENT: 10.73

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0041-37.867 .00076	14.79680 .03745	7.65356 .14179	.96686 .00016	.03401 .00063	.25312 .00063
2	0042-01.385 .00114	11.63690 .05551	10.11127 .26962	.97945 .00019	.03541 .00094	.19857 .00094
3	0042-19.551 .00187	10.06554 .09019	13.40984 .50820	.98461 .00027	.04053 .00155	.17001 .00155
4	0042-37.481 .00134	8.88824 .06447	16.07610 .41233	.98799 .00017	.04278 .00111	.14846 .00111
5	0042-55.157 .00023	7.84888 .01104	20.30794 .08011	.99063 .00002	.04739 .00019	.12807 .00019
6	0043-12.777 .00009	7.24052 .00465	23.88462 .03662	.99202 .00001	.05103 .00008	.11524 .00008
7	0043-34.866 .00019	6.10149 .00904	30.59382 .08463	.99433 .00001	.05409 .00015	.09149 .00015
8	0043-56.364 .00089	5.35119 .04237	40.12383 .45244	.99564 .00006	.06010 .00073	.07131 .00073
9	0044-17.609 .00284	4.94240 .13499	39.11857 1.56111	.99628 .00020	.05435 .00234	.06684 .00234
10	0044-38.510 .00241	4.97152 .11470	45.45297 1.31859	.99623 .00017	.06176 .00199	.06079 .00199
11	0045-01.066 .00267	4.70724 .12705	53.16193 1.54297	.99662 .00018	.06567 .00221	.04920 .00220
12	0045-18.436 .00051	4.56368 .02446	54.86268 .30652	.99683 .00003	.06506 .00042	.04579 .00042

ROCKET-GRENADE EXPERIMENT: 10.78

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.		DETA DETA DEV.
1	0102-47.013	22.16785	150.72330	.92615	.18453	-	.32915
	.00132	.15263	.37461	.00100	.00246		.00246
2	0103-10.147	19.86599	148.76880	.94054	.17620	-	.29059
	.00087	.09893	.27380	.00058	.00162		.00162
3	0103-32.335	18.15424	145.46730	.95026	.17663	-	.25668
	.00064	.07263	.22150	.00039	.00120		.00120
4	0103-49.659	17.09549	142.84200	.95585	.17756	-	.23429
	.00045	.05071	.16489	.00026	.00084		.00084
5	0104-11.058	16.30540	141.61710	.95980	.17433	-	.22008
	.00013	.01506	.05149	.00007	.00025		.00025
6	0104-32.276	15.52062	141.52340	.96356	.16649	-	.20948
	.00187	.20774	.74805	.00097	.00349		.00349
7	0104-53.965	14.60708	139.60570	.96770	.16343	-	.19207
	.00297	.32787	1.25808	.00144	.00553		.00553
8	0105-23.302	13.84407	135.52940	.97096	.16762	-	.17075
	.00037	.04086	.16581	.00017	.00069		.00069
9	0105-50.565	13.95290	131.69580	.97051	.18004	-	.16039
	.00206	.22642	.91134	.00095	.00383		.00383
10	0106-10.712	14.42248	127.21900	.96850	.19834	-	.15065
	.00290	.31987	1.24381	.00139	.00540		.00540
11	0106-30.422	14.41634	124.68040	.96853	.20473	-	.14166
	.00470	.51728	2.01236	.00224	.00874		.00874
12	0106-48.813	16.11365	124.27300	.96073	.22935	-	.15629
	.00404	.44863	1.55297	.00217	.00752		.00752

ROCKET-GRENADE EXPERIMENT: 10.78A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0102-44.254	18.11461	205.81080	.95044 –	.13537 –	.27990
	.00049	.05269	.16436	.00028	.00089	.00086
2	0103-07.064	15.46862	201.66520	.96378 –	.09846 –	.24787
	.00063	.06632	.24542	.00030	.00114	.00111
3	0103-28.980	12.76456	197.04610	.97528 –	.06476 –	.21123
	.00040	.04196	.19031	.00016	.00073	.00071
4	0103-46.160	11.70433	192.92010	.97920 –	.04535 –	.19772
	.00095	.09798	.48704	.00034	.00172	.00167
5	0104-07.438	11.17168	189.50090	.98105 –	.03198 –	.19109
	.00132	.13557	.70801	.00045	.00239	.00231
6	0104-28.631	9.65620	185.41100	.98583 –	.01581 –	.16698
	.00028	.02937	.17825	.00008	.00052	.00050
7	0104-50.217	9.53397	181.86520	.98618 –	.00539 –	.16554
	.00106	.10800	.66433	.00031	.00192	.00185
8	0105-19.443	8.55283	176.67740	.98888	.00861 –	.14847
	.00092	.09406	.64603	.00024	.00167	.00162
9	0105-46.107	7.75579	164.49080	.99085	.03608 –	.13003
	.00151	.15363	1.16001	.00036	.00273	.00265
10	0106-05.723	7.48517	152.11350	.99148	.06092 –	.11514
	.00334	.34089	2.64256	.00077	.00605	.00585
11	0106-25.027	8.89580	149.72550	.98797	.07795 –	.13354
	.00508	.51963	3.37356	.00140	.00917	.00888
12	0106-43.155	8.63326	146.78600	.98867	.08222 –	.12558
	.00155	.15930	1.06302	.00041	.00281	.00272

ROCKET-GRENADE EXPERIMENT: 10.81

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0420-38.231 .00268	11.75165 .37711	204.80620 2.65521	.97897 − .00134	.08544 − .01009	.18486 .00534
2	0421-03.366 .00481	10.97354 .51301	213.73930 2.82846	.98166 − .00170	.10572 − .00985	.15828 .00826
3	0421-22.252 .00118	11.91087 .12871	219.36110 .63138	.97839 − .00046	.13088 − .00242	.15956 .00203
4	0421-40.770 .00569	12.07921 .61293	215.36580 3.03371	.97778 − .00223	.12111 − .01167	.17063 .00979
5	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
6	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
7	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
8	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
9	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
10	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
11	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
12	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000

ROCKET-GRENADE EXPERIMENT: 10.82

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0457-39.068	7.89429	229.69770	.99049 -	.10474 -	.08883
	.00213	.23747	1.66464	.00056	.00438	.00367
2	0457-54.387	7.87248	232.56190	.99055 -	.10875 -	.08326
	.00123	.13859	.95778	.00033	.00253	.00212
3	0458-09.247	8.56556	235.24770	.98881 -	.12236 -	.08489
	.00360	.40743	2.54490	.00105	.00739	.00620
4	0458-23.577	8.73232	238.73070	.98837 -	.12976 -	.07880
	.00163	.18627	1.11899	.00049	.00334	.00280
5	0458-37.123	8.21180	242.31250	.98971 -	.12647 -	.06636
	.00259	.29752	1.86689	.00074	.00531	.00445
6	0458-50.377	8.00256	238.72740	.99024 -	.11898 -	.07226
	.00263	.28621	2.32299	.00069	.00448	.00601
7	0459-03.967	7.57618	242.14780	.99125 -	.11656 -	.06159
	.00096	.10294	.90987	.00023	.00164	.00220
8	0459-21.688	7.92457	235.80930	.99042 -	.11403 -	.07747
	.00141	.15947	1.07441	.00038	.00289	.00242
9	0459-34.745	6.90505	231.37650	.99273 -	.09392 -	.07504
	.00338	.37721	2.99732	.00079	.00694	.00582
10	0459-47.905	6.73828	231.46620	.99307 -	.09178 -	.07309
	.00175	.19550	1.59141	.00040	.00360	.00302
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.83

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0102-00.581	23.78794	142.87730	.91512	.24345 -	.32164
	.00069	.07167	.16830	.00050	.00123	.00108
2	0102-24.824	22.56953	138.23700	.92348	.25565 -	.28630
	.00032	.03328	.08124	.00022	.00057	.00050
3	0102-48.378	21.50567	134.46250	.93044	.26165 -	.25679
	.00079	.08293	.20998	.00053	.00142	.00125
4	0103-06.793	20.84254	132.33470	.93462	.26303 -	.23963
	.00055	.05750	.14927	.00035	.00099	.00087
5	0103-29.712	20.58670	130.08000	.93619	.26906 -	.22640
	.00022	.02336	.06085	.00014	.00040	.00035
6	0103-52.663	20.05512	128.20160	.93941	.26949 -	.21208
	.00036	.03755	.09984	.00022	.00064	.00056
7	0104-15.235	19.92109	126.39470	.94021	.27428 -	.20217
	.00203	.21252	.56474	.00126	.00363	.00319
8	0104-45.530	19.68945	123.44360	.94158	.28115 -	.18569
	.00169	.17844	.47436	.00104	.00303	.00267
9	0105-16.461	19.91465	120.79910	.94025	.29259 -	.17441
	.00255	.27071	.70334	.00160	.00458	.00403
10	0105-37.913	20.82790	119.74410	.93470	.30873 -	.17641
	.00332	.35484	.87437	.00220	.00595	.00524
11	0105-58.401	21.80735	120.26250	.92850	.32088 -	.18723
	.00478	.51275	1.20370	.00332	.00855	.00753
12	0106-16.427	18.52117	117.52640	.94824	.28170 -	.14681
	.00313	.33103	.91863	.00183	.00561	.00494

ROCKET-GRENADE EXPERIMENT: 10.83A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0101-55.890	16.56478	193.06940	.95850 -	.06447 -	.27771
	.00113	.11663	.40376	.00058	.00201	.00194
2	0102-19.395	13.95370	182.81760	.97049 -	.01185 -	.24084
	.00143	.14593	.60670	.00061	.00255	.00247
3	0102-42.368	12.40883	173.34130	.97664	.02491 -	.21343
	.00175	.17738	.83221	.00066	.00312	.00302
4	0103-00.455	11.98563	166.48340	.97820	.04853 -	.20191
	.00164	.16594	.80474	.00060	.00292	.00282
5	0103-22.947	12.12824	158.06930	.97768	.07846 -	.19489
	.00172	.17455	.83158	.00064	.00306	.00296
6	0103-45.592	12.39042	154.42830	.97671	.09261 -	.19355
	.00093	.09492	.44103	.00035	.00166	.00160
7	0104-08.045	12.35150	151.31990	.97685	.10265 -	.18766
	.00124	.12631	.58709	.00047	.00220	.00213
8	0104-37.896	11.91580	145.55460	.97845	.11678 -	.17027
	.00181	.18457	.88502	.00066	.00322	.00311
9	0105-08.156	12.70826	138.53920	.97550	.14565 -	.16486
	.00050	.05130	.22843	.00019	.00088	.00086
10	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.84

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0151-48.374	24.53986	138.04930	.90975	.27766 -	.30891
	.00350	.33727	.72082	.00244	.00464	.00586
2	0152-11.407	22.50293	134.99440	.92392	.27067 -	.27062
	.00339	.31785	.76728	.00212	.00449	.00568
3	0152-33.517	21.29354	131.81570	.93178	.27066 -	.24213
	.00364	.33390	.87893	.00211	.00482	.00610
4	0152-50.679	20.38920	130.17160	.93739	.26622 -	.22475
	.00368	.33314	.93171	.00202	.00487	.00616
5	0153-11.429	19.57811	127.91600	.94222	.26436 -	.20592
	.00314	.28018	.83363	.00163	.00416	.00526
6	0153-32.308	19.44770	126.80050	.94298	.26661 -	.19945
	.00256	.22712	.68662	.00131	.00339	.00428
7	0153-53.550	19.03599	126.39640	.94536	.26255 -	.19354
	.00396	.35003	1.08630	.00199	.00524	.00663
8	0154-22.381	19.10320	122.67990	.94497	.27547 -	.17671
	.00594	.51745	1.64545	.00295	.00787	.00995
9	0154-51.194	20.55414	121.42480	.93639	.29961 -	.18306
	.00731	.63925	1.89494	.00391	.00968	.01225
10	0155-12.204	20.30953	118.25630	.93787	.30574 -	.16432
	.00349	.30075	.92361	.00182	.00462	.00584
11	0155-32.104	22.02890	119.06550	.92705	.32786 -	.18222
	.00826	.72241	2.01805	.00472	.01093	.01383
12	0155-51.087	22.68472	116.87070	.92270	.34404 -	.17432
	.00957	.83377	2.28839	.00561	.01267	.01603

ROCKET-GRENADE EXPERIMENT: 10.84A

GRENADE	ZULU TIME / TIME DEV.	ZENITH / ZEN. DEV.	AZIMUTH / AZ. DEV.	GAMMA / GAMMA DEV.	ALPHA / ALPHA DEV.	BETA / BETA DEV.
1	0151-42.607	14.92546	186.98730	.96626 –	.03133 –	.25565
	.00029	.03088	.11960	.00013	.00053	.00052
2	0152-05.372	13.21476	178.61880	.97352	.00551 –	.22853
	.00029	.03096	.13624	.00012	.00054	.00052
3	0152-27.261	11.85381	171.03950	.97867	.03199 –	.20290
	.00049	.05130	.25211	.00018	.00090	.00087
4	0152-44.345	11.32052	165.79000	.98054	.04818 –	.19029
	.00118	.12200	.62719	.00041	.00215	.00208
5	0153-04.980	10.54357	159.27960	.98311	.06474 –	.17114
	.00034	.03576	.19689	.00011	.00063	.00061
6	0153-25.573	10.24108	150.27890	.98407	.08814 –	.15440
	.00056	.05781	.32535	.00017	.00101	.00098
7	0153-46.612	10.24497	146.92210	.98405	.09707 –	.14903
	.00024	.02527	.14170	.00007	.00044	.00042
8	0154-14.944	10.07452	138.25280	.98458	.11647 –	.13051
	.00086	.09012	.50916	.00027	.00157	.00152
9	0154-41.852	11.47871	131.42920	.98000	.14920 –	.13168
	.00088	.09271	.45474	.00032	.00160	.00155
10	0155-03.136	13.28703	127.32690	.97323	.18275 –	.13936
	.00404	.42700	1.79264	.00171	.00733	.00710
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0155-40.994	14.57528	130.74610	.96782	.19065 –	.16425
	.00099	.10546	.40366	.00046	.00180	.00174

ROCKET-GRENADE EXPERIMENT: 10.85

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0317-48.553 .00202	23.02808 .21502	134.83880 .50550	.92039 .00146	.27740 - .00366	.27585 .00322
2	0318-11.814 .00262	20.70082 .27709	130.56900 .71905	.93549 .00170	.26853 - .00475	.22991 .00418
3	0318-34.323 .00170	19.20476 .17938	127.01160 .49726	.94439 .00102	.26268 - .00308	.19802 .00271
4	0318-51.790 .00267	17.94840 .28082	124.46830 .82821	.95137 .00151	.25407 - .00484	.17441 .00426
5	0319-13.386 .00215	16.86068 .22525	122.97610 .70566	.95704 .00114	.24332 - .00389	.15787 .00342
6	0319-35.005 .00233	16.58690 .24523	121.98550 .77858	.95841 .00122	.24213 - .00423	.15121 .00372
7	0319-56.492 .00259	15.98648 .27243	119.57290 .89082	.96135 .00130	.23953 - .00470	.13592 .00413
8	0320-25.639 .00300	15.69409 .31688	115.98550 1.04266	.96274 .00149	.24316 - .00544	.11852 .00479
9	0320-54.453 .00467	16.97487 .49854	113.06920 1.49516	.95646 .00254	.26861 - .00847	.11440 .00745
10	0321-15.296 .00666	16.94049 .71218	110.98600 2.12635	.95664 .00362	.27215 - .01206	.10412 .01061
11	0321-35.492 .00558	18.49377 .60324	109.68460 1.63420	.94839 .00333	.29867 - .01011	.10685 .00890
12	0321-54.818 .00418	16.86601 .44790	109.08410 1.33639	.95701 .00226	.27419 - .00757	.09486 .00666

ROCKET-GRENADE EXPERIMENT: 10.85A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0317-42.989	12.47460	189.75530	.97639 -	.03660 -	.21288
	.00023	.02385	.11118	.00008	.00041	.00040
2	0318-06.105	10.25742	179.70190	.98401	.00092 -	.17806
	.00030	.03113	.17777	.00009	.00055	.00053
3	0318-28.457	9.01049	169.11680	.98766	.02956 -	.15379
	.00010	.01055	.06863	.00002	.00018	.00018
4	0318-45.888	8.34521	161.95220	.98941	.04496 -	.13799
	.00042	.04279	.29952	.00010	.00076	.00073
5	0319-07.595	7.73761	154.50070	.99089	.05796 -	.12152
	.00104	.10602	.79652	.00024	.00188	.00182
6	0319-29.130	7.77183	149.11330	.99081	.06941 -	.11605
	.00079	.08084	.60156	.00019	.00143	.00138
7	0319-50.534	7.79949	143.97490	.99075	.07981 -	.10975
	.00071	.07294	.53793	.00017	.00128	.00124
8	0320-19.312	8.26302	133.44680	.98962	.10434 -	.09883
	.00087	.08972	.61675	.00022	.00157	.00152
9	0320-47.424	9.03048	123.09480	.98760	.13149 -	.08570
	.00178	.18456	1.14613	.00050	.00321	.00310
10	0321-07.650	10.44336	115.05880	.98343	.16420 -	.07677
	.00160	.16741	.88948	.00052	.00288	.00279
11	0321-27.435	10.92449	116.11980	.98188	.17016 -	.08343
	.00317	.33038	1.67788	.00109	.00569	.00551
12	0321-46.344	12.21177	116.98730	.97737	.18849 -	.09598
	.00317	.33193	1.50458	.00122	.00569	.00551

ROCKET-GRENADE EXPERIMENT: 10.87

GRENADE	ZULU TIME	ZENITH	AZIMUTH	GAMMA	ALPHA	BETA
	TIME DEV.	ZEN. DEV.	AZ. DEV.	GAMMA DEV.	ALPHA DEV.	BETA DEV.
1	0042-45.595	14.25170	38.71326	.96924	.15397	.19209
	.00131	.06491	.25559	.00027	.00109	.00109
2	0043-10.187	11.70994	49.82919	.97919	.15508	.13092
	.00074	.03647	.17598	.00012	.00062	.00062
3	0043-29.738	10.59242	56.90934	.98296	.15400	.10036
	.00075	.03679	.19676	.00011	.00063	.00063
4	0043-49.701	10.18154	63.42129	.98425	.15808	.07909
	.00055	.02690	.14981	.00008	.00046	.00046
5	0044-10.076	10.54747	68.60054	.98310	.17043	.06678
	.00203	.09877	.53041	.00031	.00169	.00169
6	0044-29.037	10.23144	72.58644	.98410	.16948	.05315
	.00138	.06736	.37316	.00020	.00115	.00115
7	0044-53.080	11.19795	77.87151	.98096	.18986	.04080
	.00243	.11858	.59893	.00040	.00203	.00203
8	0045-16.093	11.84989	81.40734	.97869	.20304	.03068
	.00047	.02335	.11128	.00008	.00039	.00039
9	0045-37.043	12.35169	83.87206	.97685	.21269	.02283
	.00351	.17177	.78433	.00064	.00292	.00292
10	0045-57.982	12.06880	85.97633	.97790	.20857	.01467
	.00499	.24385	1.14033	.00088	.00416	.00416
11	0046-19.477	11.43992	79.46000	.98013	.19499	.03628
	.00185	.07678	.52146	.00026	.00129	.00182
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.88

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0432-46.386	12.56011	32.66304	.97608	.11736	.18307
	.00208	.10015	.44954	.00038	.00170	.00170
2	0433-11.385	10.59576	41.85881	.98295	.12270	.13695
	.00078	.03748	.20038	.00012	.00064	.00064
3	0433-30.742	9.68680	51.21537	.98574	.13116	.10539
	.00146	.06972	.40845	.00020	.00119	.00119
4	0433-49.522	9.01575	61.52802	.98764	.13775	.07470
	.00343	.16303	1.02747	.00044	.00281	.00281
5	0434-07.846	7.99560	75.64657	.99028	.13475	.03448
	.00110	.05236	.37274	.00012	.00090	.00090
6	0434-25.703	7.41126	82.68052	.99164	.12793	.01643
	.00263	.12484	.95965	.00028	.00216	.00216
7	0434-47.926	6.87849	90.63299	.99280	.11975	-.00132
	.00159	.07527	.62393	.00015	.00130	.00130
8	0435-09.328	6.24190	97.76393	.99407	.10772	-.01468
	.00500	.23643	2.16141	.00044	.00410	.00410
9	0435-30.237	6.48630	99.19760	.99359	.11151	-.01805
	.00210	.09922	.87265	.00019	.00172	.00172
10	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0436-29.016	6.24425	100.65330	.99406	.10689	-.02010
	.00280	.13227	1.20878	.00025	.00229	.00229

ROCKET-GRENADE EXPERIMENT: 10.89

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0419-44.285	17.45227	37.90970	.95400	.18427	.23663
	.00147	.07166	.22795	.00037	.00119	.00119
2	0420-10.740	16.29718	49.13918	.95984	.21223	.18359
	.00099	.04809	.16448	.00023	.00080	.00080
3	0420-31.240	15.74420	56.49081	.96250	.22625	.14980
	.00143	.06913	.24519	.00032	.00116	.00116
4	0420-51.524	14.91677	62.27163	.96631	.22785	.11977
	.00094	.04558	.17111	.00020	.00076	.00076
5	0421-08.896	13.78142	66.04460	.97122	.21770	.09672
	.00092	.04449	.18138	.00018	.00075	.00075
6	0421-26.921	13.24730	69.24621	.97340	.21428	.08120
	.00110	.05271	.22390	.00021	.00089	.00089
7	0421-49.338	12.16505	72.59894	.97755	.20108	.06302
	.00028	.01356	.06290	.00004	.00023	.00023
8	0422-11.130	11.65667	74.41214	.97938	.19461	.05429
	.00073	.03469	.16815	.00012	.00059	.00059
9	0422-31.796	11.53778	73.75505	.97979	.19202	.05595
	.00844	.40069	1.96264	.00139	.00685	.00685
10	0422-52.445	11.66844	75.37560	.97934	.19569	.05106
	.00169	.08034	.38899	.00028	.00137	.00137
11	0423-12.161	11.35052	74.89634	.98044	.19001	.05128
	.00298	.14175	.70609	.00048	.00242	.00242
12	0423-31.266	11.67480	78.47651	.97931	.19827	.04042
	.00357	.16985	.82189	.00059	.00290	.00290

ROCKET-GRENADE EXPERIMENT: 10.104

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
2	0404-09.735	10.51505	9.81513	.98321	.03111	.17982
	.00047	.02415	.13017	.00007	.00041	.00041
3	0404-28.109	8.50369	8.69945	.98901	.02236	.14617
	.00110	.05586	.37371	.00014	.00096	.00096
4	0404-46.099	7.02221	9.77190	.99250	.02074	.12048
	.00072	.03654	.29670	.00007	.00063	.00063
5	0405-03.526	5.71948	12.19644	.99502	.02105	.09740
	.00113	.05688	.56803	.00009	.00098	.00098
6	0405-20.917	4.84865	13.31369	.99642	.01946	.08225
	.00177	.08870	1.04584	.00013	.00154	.00154
7	0405-42.870	4.20138	9.26778	.99731	.01179	.07230
	.00125	.06282	.85539	.00008	.00109	.00109
8	0406-04.563	3.40698	358.05510	.99823	-.00201	.05939
	.00214	.10692	1.79633	.00011	.00186	.00186
9	0406-25.871	2.73207	1.68974	.99886	.00140	.04764
	.00270	.13492	2.82775	.00011	.00235	.00235
10	0406-47.286	1.69037	11.25066	.99956	.00575	.02893
	.00164	.08228	2.78849	.00004	.00143	.00143
11	0407-08.269	1.26035	30.99755	.99975	.01132	.01885
	.00271	.13549	6.15904	.00005	.00236	.00236
12	0407-28.553	3.21773	91.70823	.99842	.05610	-.00167
	.01016	.50777	9.03085	.00049	.00884	.00884

ROCKET-GRENADE EXPERIMENT: 10.105

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0217-37.145 .00153	14.38554 .07935	8.44796 .30944	.96866 .00034	.03650 .00134	.24575 .00134
2	0218-01.010 .00121	11.18144 .06172	11.49784 .31229	.98102 .00020	.03865 .00105	.19002 .00105
3	0218-19.413 .00050	9.13764 .02559	15.01905 .15915	.98731 .00007	.04115 .00044	.15338 .00044
4	0218-37.314 .00053	7.52932 .02712	18.05245 .20522	.99138 .00006	.04060 .00046	.12458 .00046
5	0218-54.976 .00014	6.22620 .00712	21.53473 .06534	.99410 .00001	.03980 .00012	.10088 .00012
6	0219-12.388 .00128	5.16514 .06458	23.57010 .71458	.99594 .00010	.03599 .00112	.08251 .00112
7	0219-34.426 .00193	3.85891 .09684	28.95317 1.43581	.99773 .00011	.03257 .00168	.05888 .00168
8	0219-56.388 .00094	2.66396 .04731	31.39401 1.01695	.99891 .00003	.02421 .00082	.03967 .00082
9	0220-18.255 .00199	2.37871 .09961	41.88250 2.39805	.99913 .00007	.02770 .00173	.03090 .00173
10	0220-40.539 .00046	1.87458 .02312	60.68769 .70659	.99946 .00001	.02852 .00040	.01601 .00040
11	0221-02.175 .00209	2.42806 .10483	95.09930 2.47209	.99910 .00007	.04219 .00182	-.00376 .00182
12	0221-23.249 .00210	2.96670 .10508	104.65180 2.02740	.99865 .00009	.05007 .00183	-.01309 .00183

ROCKET-GRENADE EXPERIMENT: 10.106

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	DETA DETA DEV.
1	0117-33.782 .00024	15.25313 .01293	7.93704 .04745	.96480 .00005	.03632 .00021	.26057 .00021
2	0117-57.805 .00101	11.75107 .05162	11.02950 .24820	.97905 .00018	.03896 .00088	.19990 .00088
3	0118-16.185 .00091	9.47832 .04644	14.37053 .27819	.98635 .00013	.04087 .00079	.15952 .00079
4	0118-34.286 .00056	7.82279 .02853	17.75205 .20774	.99069 .00006	.04149 .00049	.12962 .00049
5	0118-51.977 .00069	6.17751 .03491	21.20909 .32259	.99419 .00006	.03893 .00060	.10032 .00060
6	0119-09.478 .00041	4.95199 .02084	25.84909 .24055	.99626 .00003	.03763 .00036	.07768 .00036
7	0119-31.398 .00074	3.95525 .03740	33.84684 .54107	.99761 .00004	.03841 .00065	.05728 .00065
8	0119-53.229 .00110	3.03465 .05548	41.25012 1.02971	.99855 .00005	.03548 .00096	.04045 .00096
9	0120-15.325 .00085	2.39385 .04293	47.96245 .91247	.99889 .00003	.03490 .00074	.03147 .00074
10	0120-37.791 .00104	1.97216 .05218	54.28689 1.51546	.99940 .00003	.02794 .00091	.02008 .00091
11	0121-00.936 .00218	1.30334 .10917	84.70485 4.79808	.99974 .00004	.02264 .00190	.00209 .00190
12	0121-22.436 .00213	.95774 .10682	103.34200 6.38939	1.00000 .00003	.01626 – .00186	.00385 .00186

ROCKET-GRENADE EXPERIMENT: 10.107

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	1703-03.638	21.20029	142.82180	.93238	.21854	- .28815
	.00111	.11543	.30798	.00072	.00202	.00178
2	1703-28.195	20.95620	135.27310	.93391	.25170	- .25411
	.00123	.12946	.33845	.00080	.00224	.00197
3	1703-52.075	20.81492	130.42930	.93479	.27051	- .23046
	.00088	.09309	.23999	.00057	.00159	.00140
4	1704-10.903	20.72684	126.90570	.93533	.28301	- .21253
	.00141	.15074	.38449	.00093	.00256	.00225
5	1704-33.946	20.24050	123.48020	.93830	.28857	- .19086
	.00247	.26442	.68229	.00159	.00448	.00394
6	1704-56.516	20.04133	119.62260	.93949	.29792	- .16940
	.00120	.12931	.33215	.00077	.00218	.00191
7	1705-18.893	20.85747	117.58240	.93452	.31559	- .16486
	.00081	.08787	.21446	.00054	.00146	.00129
8	1705-47.870	19.33781	115.80680	.94363	.29812	- .14416
	.00426	.45971	1.21034	.00265	.00773	.00681
9	1706-15.634	18.60569	109.52530	.94777	.30071	- .10663
	.00473	.51303	1.38022	.00285	.00859	.00756
10	1706-35.213	17.87330	111.43540	.95177	.28569	- .11216
	.00712	.76594	2.16331	.00410	.01291	.01136
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.107A

GRENADE	ZULU TIME / TIME DEV.	ZENITH / ZEN. DEV.	AZIMUTH / AZ. DEV.	GAMMA / GAMMA DEV.	ALPHA / ALPHA DEV.	BETA / BETA DEV.
1	1702-59.452	14.55682	196.34060	.96790 –	.07071 –	.24118
	.00078	.08102	.32069	.00035	.00141	.00136
2	1703-22.953	11.95961	184.28030	.97829 –	.01546 –	.20664
	.00070	.07233	.35269	.00026	.00127	.00123
3	1703-45.916	10.86199	170.85670	.98208	.02994 –	.18605
	.00124	.12651	.68008	.00041	.00223	.00216
4	1704-04.141	10.33632	160.99620	.98377	.05842 –	.16964
	.00154	.15674	.88180	.00049	.00277	.00268
5	1704-26.655	10.36442	148.29830	.98368	.09454 –	.15306
	.00242	.24799	1.37589	.00077	.00435	.00421
6	1704-48.735	10.65050	138.04830	.98277	.12355 –	.13745
	.00108	.11222	.59882	.00036	.00195	.00189
7	1705-10.635	10.41704	133.91460	.98351	.13025 –	.12540
	.00259	.26763	1.45400	.00084	.00466	.00451
8	1705-39.398	11.02074	126.34220	.98155	.15398 –	.11328
	.00780	.81026	4.12022	.00270	.01403	.01358
9	1706-07.194	10.51193	118.01730	.98321	.16105 –	.08569
	.00355	.36955	1.95564	.00117	.00638	.00618
10	1706-26.729	11.77286	122.49330	.97896	.17209 –	.10960
	.00397	.41442	1.96120	.00147	.00714	.00691
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.113

GRENADE	ZULU TIME / TIME DEV.	ZENITH / ZEN. DEV.	AZIMUTH / AZ. DEV.	GAMMA / GAMMA DEV.	ALPHA / ALPHA DEV.	BETA / BETA DEV.
1	0128-03.381	20.50267	146.61510	.93671	.19274 -	.29247
	.00138	.15679	.41929	.00095	.00256	.00256
2	0128-26.147	18.62829	142.95210	.94765	.19245 -	.25495
	.00035	.03946	.11705	.00022	.00065	.00065
3	0128-48.419	17.84654	142.00880	.95192	.18865 -	.24154
	.00027	.03045	.09457	.00016	.00050	.00050
4	0129-06.132	17.08139	141.05750	.95592	.18462 -	.22846
	.00210	.23386	.76104	.00119	.00390	.00390
5	0129-27.968	16.72079	141.25020	.95775	.18008 -	.22438
	.00161	.17951	.59754	.00090	.00300	.00300
6	0129-49.395	16.26548	140.95760	.96000	.17643 -	.21754
	.00309	.34264	1.17436	.00167	.00574	.00574
7	0130-10.767	15.91172	139.69280	.96171	.17735 -	.20907
	.00219	.24177	.84807	.00115	.00405	.00405
8	0130-40.526	15.88357	135.11400	.96184	.19314 -	.19391
	.00215	.23840	.83784	.00113	.00400	.00400
9	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
10	0131-31.720	17.04630	135.73930	[illegible]010	.20460 -	.20995
	.00512	.56950	1.85739	.002[illegible]1	.00950	.00950
11	0131-50.762	18.30587	137.36980	.94944	.21273 -	.23111
	.00609	.68164	2.06037	.00373	.01129	.01139
12	0132-08.657	16.24495	124.08000	.96010	.23170 -	.15676
	.00327	.36199	1.24239	.00176	.00606	.00606

ROCKET-GRENADE EXPERIMENT: 10.113A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0128-00.129	15.12617	200.11040	.96535 –	.08972 –	.24503
	.00070	.07319	.27759	.00033	.00126	.00122
2	0128-22.631	13.19337	195.32600	.97360 –	.06032 –	.22012
	.00046	.04780	.20973	.00019	.00083	.00081
3	0128-44.678	12.00336	190.25570	.97813 –	.03702 –	.20464
	.00062	.06392	.30998	.00023	.00112	.00109
4	0129-02.207	11.39520	186.65180	.98029 –	.02288 –	.19624
	.00058	.05987	.30664	.00020	.00105	.00102
5	0129-23.925	11.09689	183.00140	.98130 –	.01007 –	.19220
	.00098	.10034	.52846	.00033	.00177	.00171
6	0129-45.243	10.83115	178.60500	.98218	.00457 –	.18786
	.00062	.06386	.34485	.00020	.00113	.00109
7	0130-06.440	10.57558	175.79520	.98301	.01345 –	.18303
	.00047	.04799	.26550	.00015	.00085	.00082
8	0130-35.624	10.29285	166.25290	.98390	.04246 –	.17356
	.00176	.17909	1.01515	.00055	.00317	.00306
9	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
10	0131-25.414	13.44859	157.29600	.97258	.08976 –	.21455
	.00727	.75023	3.21003	.00304	.01309	.01267
11	0131-44.081	12.13894	153.57930	.97764	.09356 –	.18831
	.00539	.55468	2.63011	.00203	.00971	.00940
12	0132-01.651	9.10205	148.44120	.98741	.08279 –	.13479
	.00547	.49969	3.13527	.00137	.00881	.00853

ROCKET-GRENADE EXPERIMENT: 10.115

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0555-26.936	7.50550	198.92870	.99142 –	.04237 –	.12355
	.00063	.06433	.56073	.00014	.00129	.00108
2	0555-47.955	7.69198	204.14420	.99098 –	.05474 –	.12213
	.00019	.01951	.16229	.00004	.00038	.00032
3	0556-02.835	7.49352	200.52950	.99144 –	.04573 –	.12213
	.00070	.07099	.61593	.00016	.00142	.00119
4	0556-26.704	7.47074	202.57540	.99149 –	.04991 –	.12005
	.00158	.16170	1.39506	.00036	.00323	.00271
5	0556-40.600	7.49011	199.48620	.99145 –	.04348 –	.12288
	.00084	.08576	.74748	.00019	.00172	.00145
6	0556-54.343	7.68262	195.15130	.99101 –	.03494 –	.12903
	.00010	.01024	.08833	.00002	.00020	.00017
7	0557-08.208	8.19827	191.27270	.98975 –	.02787 –	.13984
	.00000	.00000	.00000	.00000	.00000	.00000
8	0557-21.660	7.77096	189.45280	.99080 –	.02220 –	.13337
	.00143	.14267	1.23454	.00033	.00292	.00245
9	0557-39.559	6.92384	182.86270	.99270 –	.00602 –	.12039
	.00651	.64304	6.30790	.00135	.01327	.01113
10	0557-57.713	7.88088	179.75200	.99054	.00059 –	.13711
	.00162	.16035	1.38121	.00038	.00330	.00277
11	0558-15.534	7.63829	178.71280	.99112	.00298 –	.13288
	.00139	.13734	1.22079	.00031	.00283	.00237
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.116

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	1257-49.077 .00051	11.83207 .05397	209.18410 .28235	.97869 – .00019	.09997 – .00104	.17900 .00087
2	1258-08.640 .00162	11.26618 .17094	210.08560 .93595	.98067 – .00058	.09793 – .00331	.16903 .00278
3	1258-22.744 .00272	11.37137 .28762	209.90870 1.56132	.98031 – .00098	.09830 – .00558	.17089 .00468
4	1258-45.660 .00024	11.24937 .02618	208.03390 .14515	.98073 – .00008	.09168 – .00051	.17218 .00042
5	1258-59.089 .00295	11.18907 .30890	207.24330 1.72840	.98094 – .00104	.08882 – .00604	.17251 .00506
6	1259-12.341 .00358	11.15503 .37336	206.44230 2.10397	.98105 – .00126	.08614 – .00732	.17321 .00614
7	1259-25.727 .00164	11.19824 .16975	203.51300 .96606	.98091 – .00057	.07747 – .00335	.17807 .00281
8	1259-38.946 .00343	11.00808 .35616	204.48000 2.05364	.98155 – .00118	.07912 – .00702	.17377 .00589
9	1259-56.082 .00410	10.66290 .42337	203.03030 2.53882	.98269 – .00136	.07238 – .00839	.17027 .00703
10	1300-13.810 .00081	10.44867 .08294	198.30790 .51769	.98338 – .00026	.05696 – .00166	.17216 .00139
11	1300-31.270 .01296	13.02802 1.33464	198.13400 6.64349	.97419 – .00525	.07015 – .02652	.21421 .02224
12	1300-43.736 .00384	11.35699 .39260	197.91310 2.25313	.98037 – .00134	.06056 – .00785	.18736 .00658

ROCKET-GRENADE EXPERIMENT: 10.117

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	1905-09.461 .00112	19.76581 .11875	128.53380 .32119	.94113 .00070	.26455 - .00204	.21068 .00179
2	1905-36.684 .00119	19.17893 .12738	119.85380 .34345	.94454 .00073	.28493 - .00216	.16354 .00190
3	1905-56.216 .00172	19.57528 .18658	114.69050 .48293	.94225 .00109	.30443 - .00313	.13996 .00275
4	1906-18.007 .00153	19.56119 .16694	109.87950 .42595	.94233 .00097	.31487 - .00278	.11385 .00244
5	1906-39.786 .00142	19.66586 .15556	105.75000 .39040	.94171 .00091	.32391 - .00257	.09135 .00226
6	1907-08.508 .00134	20.45206 .14820	101.85290 .35356	.93701 .00090	.34199 - .00243	.07177 .00214
7	1907-37.044 .00151	21.15666 .16818	100.16440 .38551	.93264 .00105	.35527 - .00274	.06369 .00241
8	1908-07.425 .00291	20.80727 .32201	99.33349 .75078	.93482 .00199	.35054 - .00526	.05761 .00463
9	1908-29.715 .00477	22.09259 .53268	98.96651 1.16212	.92663 .00349	.37153 - .00863	.05862 .00760
10	1908-49.991 .00713	20.98404 .78973	100.38450 1.82725	.93373 .00493	.35226 - .01291	.06455 .01136
11	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
12	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000

ROCKET-GRENADE EXPERIMENT: 10.117A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	1905-04.165	8.93185	186.39160	.98787 -	.01728 -	.15429
	.00100	.10161	.66743	.00027	.00180	.00175
2	1905-30.237	7.42289	159.29750	.99162	.04567 -	.12084
	.00138	.13983	1.09987	.00031	.00248	.00240
3	1905-49.143	7.98289	142.73540	.99031	.08408 -	.11052
	.00084	.08555	.61543	.00020	.00150	.00146
4	1906-10.405	8.27939	129.36110	.98957	.11133 -	.09132
	.00174	.17928	1.22419	.00045	.00313	.00303
5	1906-31.731	8.44092	117.94470	.98916	.12967 -	.06878
	.00269	.27831	1.84146	.00071	.00483	.00468
6	1907 00.225	10.42234	105.84490	.98350	.17402 -	.04939
	.00117	.12277	.64921	.00038	.00211	.00204
7	1907-27.751	11.01706	99.04555	.98157	.18872 -	.03004
	.00105	.11027	.54912	.00036	.00189	.00183
8	1907-57.782	10.75343	104.61500	.98243	.18054 -	.04707
	.00688	.71980	3.68368	.00234	.01236	.01197
9	1908-19.755	14.21678	96.86224	.96937	.24383 -	.02934
	.00649	.68893	2.63445	.00295	.01166	.01128
10	1908-40.192	13.23065	99.46698	.97345	.22575 -	.03764
	.00572	.60467	2.49368	.00241	.01028	.00995
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.118

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	2226-52.449	27.30509	125.70990	.88870	.37253	- .26778
	.00065	.06971	.12968	.00055	.00112	.00099
2	2227-12.846	26.83968	121.21860	.89238	.38616	- .23404
	.00110	.11703	.21806	.00092	.00188	.00165
3	2227-32.896	28.06852	116.24790	.88251	.42207	- .20812
	.00160	.17336	.30086	.00142	.00273	.00240
4	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
5	2228-05.831	29.65453	109.22330	.86916	.46725	- .16292
	.00089	.09996	.15889	.00086	.00153	.00135
6	2228-35.001	31.14717	106.09390	.85584	.49696	- .14338
	.00194	.21971	.32632	.00198	.00331	.00291
7	2229-07.029	32.97750	102.93510	.83888	.53049	- .12184
	.00095	.11040	.15168	.00104	.00162	.00143
8	2229-38.177	35.37413	100.10030	.81538	.56994	- .10152
	.00113	.13517	.16888	.00136	.00193	.00169
9	2230-03.061	36.64654	99.71922	.80233	.58831	- .10076
	.00234	.28456	.33911	.00296	.00399	.00351
10	2230-21.423	37.84076	98.83064	.78971	.60619	- .09417
	.00392	.48484	.55261	.00519	.00670	.00589
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.118A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	2226-40.999 .00026	13.53815 .02524	161.22140 .10759	.97221 .00010	.07535 .00044	-.22163 .00042
2	2227-02.410 .00089	13.37085 .08747	147.78160 .37321	.97289 .00035	.12329 .00152	-.19564 .00147
3	2227-21.226 .00044	14.33479 .04373	132.68690 .17071	.96887 .00018	.18199 .00075	-.16786 .00072
4	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
5	2227-52.389 .00330	16.44449 .33136	119.37200 1.10381	.95910 .00163	.24669 .00558	-.13884 .00541
6	2228-20.177 .00178	19.16221 .18206	111.19230 .51144	.94460 .00104	.30605 .00301	-.11866 .00291
7	2228-50.879 .00043	22.13628 .04524	106.93330 .10826	.92631 .00029	.36048 .00073	-.10975 .00070
8	2229-20.921 .00503	24.49799 .53588	102.40390 1.14169	.90999 .00387	.40499 .00852	-.08907 .00825
9	2229-45.001 .00157	26.71288 .17026	101.50210 .32832	.89330 .00133	.44050 .00265	-.08963 .00257
10	2230-02.778 .00086	28.17498 .09547	100.45470 .17289	.88154 .00078	.46434 .00147	-.08568 .00142
11	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
12	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000

ROCKET-GRENADE EXPERIMENT: 10.119

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0512-48.796	18.91953	130.11590	.94602	.24797 –	.20892
	.00041	.04150	.11851	.00023	.00071	.00063
2	0513-16.102	25.15594	123.12850	.90525	.35602 –	.23234
	.00080	.08414	.17023	.00062	.00137	.00121
3	0513-32.602	25.41405	116.83570	.90332	.38298 –	.19375
	.00082	.08826	.17226	.00066	.00142	.00125
4	0513-47.043	25.56202	113.13340	.90221	.39683 –	.16953
	.00108	.11678	.22356	.00087	.00187	.00164
5	0514-07.097	25.96363	110.40290	.89917	.41037 –	.15264
	.00037	.04053	.07557	.00030	.00064	.00056
6	0514-30.569	25.24972	105.53360	.90454	.41102 –	.11424
	.00100	.10872	.20666	.00080	.00173	.00152
7	0514-56.269	26.03850	104.31720	.89859	.42538 –	.10856
	.00129	.14102	.25806	.00108	.00222	.00196
8	0515-23.447	25.53428	103.24180	.90241	.41963 –	.09874
	.00196	.21288	.39752	.00160	.00337	.00296
9	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
10	0516-03.191	25.32306	102.10290	.90399	.41825 –	.08968
	.00152	.16480	.30999	.00123	.00261	.00229
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0516-44.813	26.07056	98.74016	.89834	.43441 –	.06678
	.00291	.31798	.57538	.00243	.00499	.00439

ROCKET-GRENADE EXPERIMENT: 10.119A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0512-41.574	12.97826	179.36420	.97445	.00249	- .22456
	.00053	.05219	.23397	.00020	.00091	.00088
2	0513-07.455	11.34964	156.80850	.98044	.07749	- .18089
	.00076	.07430	.37863	.00025	.00130	.00126
3	0513-23.013	11.53678	142.93620	.97979	.12053	- .15959
	.00092	.08980	.44390	.00031	.00156	.00151
4	0513-36.829	11.97895	135.95670	.97822	.14429	- .14919
	.00129	.12694	.59896	.00045	.00220	.00213
5	0513-56.341	12.15880	123.63270	.97757	.17536	- .11665
	.00079	.07854	.35996	.00028	.00135	.00130
6	0514-19.198	12.76698	112.59700	.97528	.20402	- .08491
	.00122	.12150	.52406	.00046	.00207	.00201
7	0514-44.335	14.10091	107.95960	.96987	.23176	- .07512
	.00144	.14470	.56104	.00061	.00245	.00237
8	0515-11.448	14.29348	104.54780	.96905	.23897	- .06201
	.00023	.02405	.09177	.00010	.00040	.00039
9	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
10	0515-51.000	15.69507	103.49130	.96272	.26305	- .06311
	.00180	.18289	.63224	.00086	.00307	.00297
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0516-32.047	18.57613	99.88526	.94791	.31384	- .05469
	.00544	.56038	1.61702	.00311	.00927	.00898

ROCKET-GRENADE EXPERIMENT: 10.120

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	2255-46.372	18.07343	146.16060	.95069	.17276 -	.25769
	.00078	.07789	.25050	.00042	.00140	.00123
2	2256-08.080	22.41375	142.70650	.92452	.23104 -	.30335
	.00049	.05096	.12781	.00033	.00088	.00078
3	2256-27.872	21.46259	139.71120	.93072	.23661 -	.27912
	.00110	.11345	.29463	.00072	.00197	.00174
4	2256-41.387	21.38117	137.16680	.93124	.24787 -	.26737
	.00044	.04600	.11864	.00029	.00079	.00070
5	2256-58.072	21.24871	134.00510	.93207	.26069 -	.25179
	.00048	.05050	.12931	.00031	.00087	.00076
6	2257-19.715	21.19721	130.13010	.93240	.27647 -	.23306
	.00127	.13345	.33680	.00084	.00228	.00200
7	2257-45.427	21.07749	125.77970	.93315	.29177 -	.21027
	.00054	.05712	.14237	.00035	.00096	.00085
8	2258-08.808	21.07938	124.22250	.93314	.29740 -	.20228
	.00188	.19931	.49347	.00125	.00336	.00296
9	2258-28.686	20.96460	123.43220	.93385	.29860 -	.19713
	.00325	.34503	.85659	.00215	.00582	.00512
10	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
11	2259-18.074	20.62885	119.33820	.93593	.30714 -	.17263
	.00474	.50581	1.25759	.00311	.00849	.00747
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.120A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	DETA BETA DEV.
1	2255-42.496	18.00227	201.02450	.95104 -	.11087 -	.28848
	.00105	.10986	.34637	.00059	.00187	.00181
2	2256-03.555	15.51642	193.50030	.96355 -	.06245 -	.26012
	.00095	.09730	.36083	.00045	.00168	.00163
3	2256-22.819	13.68328	186.30540	.97161 -	.02598 -	.23512
	.00203	.20600	.87352	.00085	.00360	.00349
4	2256-35.800	13.10807	179.95980	.97394	.00015 -	.22678
	.00194	.19651	.87192	.00077	.00345	.00334
5	2256-51.878	12.38583	171.66020	.97672	.03111 -	.21222
	.00121	.12302	.57797	.00046	.00216	.00209
6	2257-12.775	11.79689	159.89450	.97888	.07027 -	.19198
	.00038	.03898	.19139	.00013	.00068	.00066
7	2257-37.648	11.90668	149.15550	.97848	.10578 -	.17713
	.00089	.09100	.43830	.00032	.00159	.00154
8	2258-00.693	12.15348	145.26290	.97759	.11996 -	.17301
	.00067	.06851	.32182	.00025	.00119	.00115
9	2258-20.611	12.32507	140.70090	.97695	.13519 -	.16518
	.00277	.28385	1.30753	.00105	.00493	.00477
10	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
11	2259-09.501	12.86376	134.89260	.97490	.15772 -	.15713
	.00088	.09099	.39839	.00035	.00157	.00152
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.121

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	2226-40.354 .00082	10.82531 .03919	33.11754 .20496	.98221 .00012	.10261 .00067	.15730 .00067
2	2227-06.464 .00198	8.12190 .09287	48.40923 .65079	.98997 .00022	.10566 .00160	.09378 .00160
3	2227-26.681 .00083	7.06715 .03889	60.14353 .31372	.99240 .00008	.10670 .00067	.06124 .00067
4	2227-46.471 .00125	7.07845 .05886	71.64603 .47398	.99237 .00012	.11695 .00101	.03880 .00101
5	2228-05.796 .00074	6.90970 .03487	76.57229 .28775	.99273 .00007	.11701 .00060	.02793 .00060
6	2228-24.605 .00019	6.71999 .00911	85.10381 .07737	.99313 .00001	.11659 .00015	.00998 .00015
7	2228-47.756 .00082	6.42803 .03842	98.91189 .34104	.99371 .00007	.11060 .00066	-.01734 .00066
8	2229-10.020 .00212	7.59923 .09965	117.61510 .74692	.99121 .00023	.11717 .00172	-.06129 .00172
9	2229-31.967 .00359	8.17614 .16833	122.39380 1.17157	.98983 .00041	.12008 .00290	-.07619 .00290
10	2229-53.066 .00311	9.35785 .14634	126.26830 .88802	.98668 .00041	.13109 .00252	-.09618 .00252
11	2230-13.814 .00309	10.04724 .14558	126.42000 .82164	.98466 .00044	.14038 .00250	-.10357 .00250
12	2230-33.885 .00586	10.81742 .27710	127.99190 1.45017	.98222 .00090	.14790 .00475	-.11552 .00474

ROCKET-GRENADE EXPERIMENT: 10.122

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	1737-26.415 .00145	14.65845 .06975	55.33353 .26665	.96746 .00030	.20813 .00117	.14394 .00117
2	1737-52.193 .00182	11.94069 .08673	76.61236 .41010	.97836 .00031	.20127 .00148	.04790 .00148
3	1738-12.187 .00090	10.88812 .04262	94.18741 .22154	.98199 .00014	.18838 .00073	-.01379 .00073
4	1738-31.955 .00122	10.61178 .05757	110.25590 .30725	.98289 .00018	.17276 .00098	-.06375 .00098
5	1738-50.567 .00146	10.43997 .06913	119.34680 .37515	.98344 .00021	.15795 .00118	-.08880 .00118
6	1739-09.052 .00274	10.33555 .12957	122.81970 .71045	.98377 .00040	.15077 .00222	-.09724 .00222
7	1739-32.161 .00054	11.07773 .02574	127.05240 .13148	.98136 .00008	.15334 .00044	-.11577 .00044
8	1739-54.364 .00260	10.84478 .12283	129.31990 .64119	.98213 .00040	.14555 .00210	-.11922 .00210
9	1740-16.175 .00303	10.56813 .14292	131.71750 .76608	.98303 .00045	.13689 .00245	-.12204 .00245
10	1740-37.875 .00292	9.81975 .13750	136.25260 .79443	.98534 .00040	.11793 .00236	-.12320 .00236
11	1740-58.703 .00783	10.03660 .36878	137.22080 2.08369	.98469 .00112	.11836 .00633	-.12791 .00633
12	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000

ROCKET-GRENADE EXPERIMENT: 10.123

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	2302-45.982	12.23580	37.85059	.97729	.13004	.16734
	.00092	.04369	.20150	.00016	.00074	.00074
2	2303-10.583	10.02736	48.07581	.98473	.12955	.11633
	.00100	.04751	.26872	.00014	.00081	.00081
3	2303-29.978	9.00078	54.30497	.98769	.12705	.09128
	.00148	.06973	.44021	.00019	.00120	.00120
4	2303-49.145	8.45074	60.69268	.98914	.12814	.07193
	.00158	.07445	.50113	.00019	.00128	.00128
5	2304-07.882	8.42542	67.45149	.98921	.13532	.05618
	.00095	.04457	.30089	.00011	.00076	.00076
6	2304-26.308	8.03833	73.11059	.99017	.13380	.04062
	.00121	.05689	.40281	.00013	.00098	.00098
7	2304-49.454	8.28140	77.38199	.98957	.14055	.03146
	.00076	.03570	.24524	.00008	.00061	.00061
8	2305-12.062	9.06763	80.20880	.98750	.15530	.02680
	.00218	.10279	.64402	.00028	.00177	.00177
9	2305-34.476	9.55742	81.99203	.98612	.16441	.02313
	.00116	.05497	.32648	.00015	.00094	.00094
10	2305-55.687	9.95882	83.57816	.98493	.17185	.01934
	.00404	.19041	1.08431	.00057	.00327	.00327
11	2306-16.209	10.08919	84.02874	.98453	.17423	.01822
	.00225	.10641	.59795	.00032	.00182	.00182
12	2306-36.486	9.89516	95.83341	.98512	.17095	.01746
	.00168	.07924	.45423	.00023	.00136	.00136

ROCKET-GRENADE EXPERIMENT: 10.124

GRENADE	ZULU TIME / TIME DEV.	ZENITH / ZEN. DEV.	AZIMUTH / AZ. DEV.	GAMMA / GAMMA DEV.	ALPHA / ALPHA DEV.	BETA / BETA DEV.
1	2134-51.441	16.39235	87.44561	.95934	.28192	.01257
	.00276	.19080	.79052	.00093	.00319	.00389
2	2135-12.712	17.66762	90.61218	.95282	.30347	-.00324
	.00331	.23062	.88310	.00122	.00383	.00467
3	2135-39.000	19.65121	96.37310	.94174	.33421	-.03732
	.00259	.18315	.62247	.00107	.00300	.00366
4	2135-59.210	19.88333	101.02460	.94038	.33383	-.06503
	.01165	.86689	1.40374	.00514	.01441	.00801
5	2136-23.335	20.83137	100.89310	.93461	.34920	-.06720
	.00102	.07204	.36801	.00044	.00111	.00231
6	2136-50.277	20.44423	99.93733	.93700	.34405	-.06027
	.00098	.07006	.22648	.00042	.00113	.00138
7	2137-11.987	20.52345	102.59440	.93651	.34215	-.07644
	.00245	.17558	.56116	.00107	.00283	.00346
8	2137-33.344	19.90662	99.07520	.94024	.33622	-.05370
	.00289	.20513	.68398	.00121	.00334	.00408
9	2137-55.262	18.65880	97.04863	.94742	.31750	-.03925
	.01159	.81399	2.92225	.00454	.01341	.01635
10	2138-17.233	20.31556	100.70970	.93778	.34113	-.06451
	.00062	.04430	.14393	.00026	.00071	.00087
11	2138-43.044	18.26394	93.41968	.94962	.31283	-.01869
	.00276	.19338	.71371	.00105	.00320	.00390
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.125

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0447-47.885	13.84061	96.28600	.97096	.23778	- .02619
	.00240	.16426	.80929	.00068	.00277	.00338
2	0448-07.616	13.88854	98.16548	.97076	.23759	- .03409
	.00206	.14129	.69128	.00059	.00238	.00290
3	0448-31.324	13.59437	99.01872	.97198	.23214	- .03684
	.00134	.09206	.45974	.00037	.00155	.00189
4	0448-50.067	13.48229	100.06550	.97243	.22955	- .04074
	.00218	.14965	.75194	.00060	.00252	.00307
5	0449-13.774	13.36174	102.11150	.97292	.22595	- .04848
	.00094	.06402	.32696	.00025	.00106	.00132
6	0449-41.350	13.44599	103.79050	.97258	.22582	- .05542
	.00266	.18316	.91315	.00074	.00306	.00374
7	0450-03.535	13.68350	103.12300	.97161	.23037	- .05370
	.00235	.16181	.79384	.00066	.00271	.00330
8	0450-25.466	13.74228	103.36360	.97137	.23112	- .05490
	.00186	.12806	.62500	.00053	.00214	.00261
9	0450-47.211	14.25285	103.81730	.96921	.23907	- .05879
	.00239	.16519	.77504	.00070	.00275	.00336
10	0451-10.765	14.56550	101.01680	.96785	.24685	- .04805
	.00434	.29892	1.38253	.00131	.00500	.00610
11	0451-33.166	15.01825	97.49875	.96584	.25691	- .03381
	.00168	.11580	.52284	.00052	.00194	.00237
12	0451-52.072	15.02671	100.85790	.96580	.25462	- .04883
	.00230	.15856	.71014	.00071	.00264	.00323

ROCKET-GRENADE EXPERIMENT: 10.126

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	2217-51.000	12.14527	92.30240	.97761	.21022	- .00645
	.00149	.09931	.56249	.00036	.00169	.00206
2	2218-11.875	12.21766	93.07133	.97734	.21132	- .01133
	.00160	.10621	.59764	.00039	.00181	.00220
3	2218-36.861	11.87852	94.41649	.97858	.20522	- .01585
	.00203	.13480	.77982	.00048	.00229	.00280
4	2218-56.284	11.65800	93.80873	.97936	.20162	- .01342
	.00219	.14506	.85607	.00051	.00247	.00302
5	2219-20.004	11.47965	93.64526	.97999	.19861	- .01265
	.00222	.14705	.88179	.00051	.00251	.00306
6	2219-47.874	11.23918	91.50879	.98082	.19483	- .00513
	.00214	.14152	.86843	.00048	.00242	.00295
7	2220-10.869	11.22612	90.92597	.98086	.19465	- .00314
	.00164	.10885	.66891	.00036	.00186	.00227
8	2220-33.122	11.63367	89.95376	.97945	.20165	.00016
	.00442	.29267	1.73392	.00103	.00500	.00610
9	2220-54.465	12.45856	92.92016	.97645	.21545	- .01099
	.00550	.36576	2.01719	.00137	.00622	.00759
10	2221-19.690	12.62539	90.91305	.97581	.21854	- .00348
	.00548	.36389	1.98139	.00138	.00619	.00755
11	2221-43.739	13.53595	86.83356	.97222	.23369	.01292
	.00092	.06172	.31236	.00025	.00104	.00127
12	2222-02.884	14.31020	86.50227	.96896	.24671	.01507
	.00436	.29245	1.39629	.00126	.00494	.00602

ROCKET-GRENADE EXPERIMENT: 10.133

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0005-01.157	22.51146	135.00210	.92387	.27074	- .27076
	.00049	.05253	.12676	.00035	.00089	.00079
2	0005-24.768	21.72374	128.53310	.92905	.28955	- .23059
	.00196	.20876	.50926	.00134	.00354	.00311
3	0005-47.862	20.88507	123.87530	.93436	.29600	- .19871
	.00246	.26243	.65545	.00163	.00443	.00390
4	0006-06.171	21.05116	120.38420	.93331	.30988	- .18169
	.00198	.21304	.52016	.00133	.00357	.00314
5	0006-28.796	21.46243	117.13760	.93071	.32563	- .16690
	.00120	.13082	.30891	.00083	.00217	.00191
6	0006-51.153	22.19973	115.13030	.92593	.34209	- .16047
	.00181	.19864	.44869	.00131	.00327	.00288
7	0007-13.427	22.44540	111.76280	.92430	.35461	- .14156
	.00215	.23747	.52411	.00158	.00389	.00342
8	0007-42.397	23.06934	106.07140	.92009	.37655	- .10848
	.00327	.36465	.76851	.00249	.00590	.00519
9	0008-10.924	23.10534	106.26880	.91984	.37673	- .10994
	.00433	.48263	1.01586	.00330	.00781	.00687
10	0008-30.179	23.63711	105.54650	.91617	.38630	- .10747
	.00297	.33200	.68005	.00232	.00535	.00471
11	0008-48.475	23.11593	105.27790	.91977	.37874	- .10345
	.00303	.33824	.70991	.00231	.00547	.00481
12	0009-06.643	24.44098	102.77730	.91045	.40354	- .09151
	.00358	.40480	.79378	.00292	.00646	.00569

ROCKET-GRENADE EXPERIMENT: 10.133A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0004-55.536 .00126	13.13000 .12869	186.09830 .56961	.97385 - .00051	.02413 - .00225	.22587 .00218
2	0005-18.232 .00065	10.97188 .06631	172.12990 .35298	.98172 .00022	.02606 - .00117	.18853 .00113
3	0005-40.587 .00170	10.28306 .17214	158.45000 .97170	.98393 .00053	.06556 - .00304	.16603 .00294
4	0005-58.317 .00148	10.31475 .15088	146.14800 .83937	.98384 .00047	.09974 - .00264	.14870 .00256
5	0006-20.223 .00073	11.10478 .07544	135.13560 .38445	.98127 .00025	.13586 - .00131	.13651 .00127
6	0006-41.929 .00162	11.78001 .16843	125.51110 .79915	.97894 .00060	.16618 - .00290	.11858 .00281
7	0007-03.526 .00215	13.23208 .22518	120.36090 .94252	.97345 .00089	.19750 - .00385	.11569 .00373
8	0007-31.844 .00620	14.68810 .65257	116.18430 2.44047	.96732 .00288	.22753 - .01108	.11188 .01072
9	0007-59.958 .00406	16.00565 .43117	114.22350 1.47094	.96124 .00207	.25145 - .00727	.11313 .00703
10	0008-19.011 .00690	15.13150 .72873	111.55330 2.63148	.96533 .00332	.24278 - .01233	.09589 .01193
11	0008-37.226 .00133	17.22019 .14240	108.98760 .44779	.95518 .00073	.27993 - .00238	.09632 .00230
12	0008-55.213 .00536	16.51591 .57139	104.73750 1.87307	.95874 .00283	.27493 - .00958	.07231 .00927

ROCKET-GRENADE EXPERIMENT: 10.134

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0523-01.825	25.91236	139.39540	.89957	.28444 -	.33181
	.00402	.42828	.89882	.00326	.00720	.00634
2	0523-26.079	24.53902	135.00800	.90977	.29365 -	.29374
	.00114	.12117	.26542	.00087	.00204	.00179
3	0523-49.328	24.24199	128.60420	.91191	.32090 -	.25621
	.00159	.17108	.36939	.00122	.00285	.00250
4	0524-07.947	23.66229	126.61720	.91601	.32216 -	.23941
	.00146	.15746	.34640	.00110	.00262	.00230
5	0524-31.159	24.06778	123.41680	.91314	.34043 -	.22461
	.00125	.13555	.28866	.00096	.00223	.00196
6	0524-54.312	24.00726	120.11750	.91358	.35196 -	.20416
	.00213	.23292	.49095	.00165	.00382	.00336
7	0525-16.747	24.46713	118.16730	.91028	.36515 -	.19552
	.00293	.32268	.66081	.00233	.00526	.00462
8	0525-47.669	24.93491	115.67670	.90688	.37999 -	.18269
	.00249	.27630	.54884	.00203	.00446	.00393
9	0526-17.823	25.93217	113.13490	.89942	.40218 -	.17183
	.00612	.68659	1.29289	.00524	.01097	.00965
10	0526-37.999	25.13319	112.18550	.90541	.39332 -	.16039
	.00343	.38266	.74462	.00283	.00614	.00540
11	0526-57.204	26.35555	110.62850	.89616	.41552 -	.15642
	.00259	.29295	.53724	.00227	.00464	.00408
12	0527-14.634	24.87072	115.51080	.90736	.37961 -	.18115
	.00821	.90882	1.80954	.00667	.01470	.01293

ROCKET-GRENADE EXPERIMENT: 10.134A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0522-55.431 .00681	16.14705 .69850	186.63590 2.49041	.96056 - .00339	.03213 - .01209	.27624 .01170
2	0523-18.720 .00064	15.02109 .06537	171.98740 .25139	.96583 .00029	.03612 - .00113	.25664 .00110
3	0523-41.309 .00102	14.22778 .10501	158.46360 .42415	.96933 .00045	.09022 - .00182	.22861 .00176
4	0523-59.307 .00176	14.05221 .18105	151.03070 .73598	.97007 .00076	.11760 - .00314	.21242 .00304
5	0524-21.860 .00342	14.54176 .35197	143.69730 1.37019	.96796 .00154	.14865 - .00607	.20235 .00587
6	0524-44.277 .00169	15.53272 .17592	136.55470 .63407	.96348 .00082	.18414 - .00300	.19442 .00291
7	0525-06.192 .00091	16.08993 .09565	131.55370 .33033	.96083 .00046	.20739 - .00162	.18383 .00157
8	0525-36.291 .00304	16.57093 .31884	128.15970 1.06331	.95847 .00158	.22425 - .00539	.17621 .00522
9	0526-06.821 .00845	18.88080 .90135	119.67710 2.59206	.94620 .00509	.28115 - .01500	.16022 .01452
10	0526-27.017 .00525	16.44903 .55102	126.26470 1.84814	.95907 .00272	.22831 - .00932	.16749 .00902
11	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
12	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000

ROCKET-GRENADE EXPERIMENT: 10.135

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	1003-22.823	24.27769	140.62320	.91165	.26087 -	.31785
	.00159	.16533	.37575	.00118	.00282	.00248
2	1003-46.288	23.43894	134.55930	.91756	.28344 -	.27911
	.00159	.16652	.38335	.00115	.00282	.00248
3	1004-09.441	23.22029	130.05780	.91907	.30179 -	.25375
	.00147	.15551	.35466	.00107	.00261	.00230
4	1004-27.980	22.94232	127.00430	.92097	.31132 -	.23463
	.00218	.23130	.52763	.00157	.00387	.00341
5	1004-50.646	22.47796	123.44090	.92409	.31905 -	.21070
	.00192	.20514	.47164	.00136	.00342	.00301
6	1005-12.718	23.05814	119.02690	.92018	.34249 -	.19006
	.00253	.27334	.60032	.00186	.00451	.00397
7	1005-34.700	22.91969	116.48820	.92112	.34858 -	.17371
	.00089	.09635	.21105	.00065	.00158	.00139
8	1006-03.529	22.68245	115.42080	.92273	.34831 -	.16554
	.00531	.57460	1.26856	.00386	.00945	.00831
9	1006-31.502	23.07488	117.52150	.92007	.34761 -	.18112
	.00811	.87636	1.91236	.00599	.01442	.01269
10	1006-49.831	21.09737	113.30020	.93302	.33061 -	.14238
	.00792	.84919	2.01651	.00533	.01407	.01239
11	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000
12	0000-00.000	.00000	.00000	.00000	.00000	.00000
	.00000	.00000	.00000	.00000	.00000	.00000

ROCKET-GRENADE EXPERIMENT: 10.135A

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	1003-16.725 .00057	15.76562 .05816	181.51830 .21285	.96238 − .00027	.00719 − .00100	.27160 .00097
2	1003-39.374 .00281	13.97111 .28416	169.61610 1.17754	.97042 .00119	.04351 − .00496	.23747 .00480
3	1004-01.856 .00142	13.13429 .14320	159.01860 .62876	.97384 .00056	.08136 − .00250	.21216 .00242
4	1004-19.760 .00174	12.66388 .17640	148.39260 .79669	.97567 .00067	.11489 − .00307	.18671 .00297
5	1004-41.808 .00203	13.05859 .20717	141.47660 .89975	.97414 .00081	.14072 − .00359	.17677 .00347
6	1005-03.283 .00186	13.46341 .19067	135.43010 .79685	.97252 .00077	.16339 − .00328	.16586 .00318
7	1005-24.798 .00180	13.94972 .18497	131.94970 .74211	.97051 .00077	.17929 − .00317	.16115 .00307
8	1005-53.521 .00561	14.34778 .57861	127.62500 2.24340	.96881 .00250	.19626 − .00990	.15128 .00958
9	1006-21.075 .00316	16.47172 .33000	122.83870 1.10120	.95897 .00163	.23823 − .00557	.15376 .00539
10	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000
11	1006-57.121 .00748	15.49067 .78158	108.74020 2.74802	.96368 .00364	.25292 − .01318	.08580 .01276
12	0000-00.000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000	.00000 .00000

ROCKET-GRENADE EXPERIMENT: 10.136

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0432-52.551 .00112	21.75337 .11120	143.15560 .28883	.92885 .00071	.22225 - .00194	.29661 .00171
2	0433-16.737 .00118	20.04895 .11718	137.21080 .32428	.93945 .00070	.23289 - .00205	.25159 .00180
3	0433-40.262 .00092	20.16220 .09391	128.93000 .24902	.93877 .00056	.26814 - .00161	.21659 .00141
4	0433-59.295 .00240	20.54451 .24558	124.63990 .62645	.93645 .00150	.28874 - .00416	.19949 .00366
5	0434-22.597 .00085	21.07223 .08848	119.80120 .21531	.93318 .00055	.31201 - .00148	.17870 .00130
6	0434-45.808 .00595	21.70413 .62358	115.18610 1.44440	.92917 .00402	.33468 - .01032	.15739 .00908
7	0435-08.879 .00154	22.70127 .16320	113.05270 .35712	.92260 .00109	.35513 - .00267	.15113 .00235
8	0435-40.507 .00155	24.07148 .16709	109.34980 .33860	.91311 .00118	.38487 - .00269	.13515 .00237
9	0436-10.228 .00826	25.65604 .90311	105.85810 1.68677	.90150 .00682	.41653 - .01433	.11832 .01261
10	0436-30.083 .00068	25.35192 .07436	106.65810 .14107	.90378 .00055	.41024 - .00118	.12275 .00104
11	0436-49.278 .00545	25.79177 .59639	106.31400 1.10838	.90046 .00452	.41762 - .00945	.12223 .00832
12	0437-07.684 .01019	26.90855 1.12997	101.79810 1.98058	.89184 .00892	.44306 - .01767	.09254 .01555

ROCKET-GRENADE EXPERIMENT: 10.137

GRENADE	ZULU TIME TIME DEV.	ZENITH ZEN. DEV.	AZIMUTH AZ. DEV.	GAMMA GAMMA DEV.	ALPHA ALPHA DEV.	BETA BETA DEV.
1	0247-46.880	26.21397	143.02590	.89726	.26570 -	.35294
	.00059	.06141	.12920	.00047	.00103	.00091
2	0248-10.133	23.99583	140.39780	.91366	.25925 -	.31336
	.00122	.12568	.28915	.00089	.00215	.00189
3	0248-32.497	22.76736	139.21060	.92216	.25283 -	.29302
	.00157	.16103	.39091	.00108	.00277	.00244
4	0248-50.121	22.15362	138.29020	.92624	.25092 -	.28153
	.00191	.19451	.48476	.00128	.00336	.00295
5	0249-12.114	21.78754	137.27010	.92863	.25187 -	.27266
	.00097	.09960	.25171	.00064	.00172	.00151
6	0249-34.015	21.85549	136.00760	.92819	.25858 -	.26784
	.00054	.05561	.13927	.00036	.00095	.00084
7	0249-54.824	21.84261	133.67830	.92827	.26910 -	.25696
	.00093	.09614	.23846	.00062	.00164	.00145
8	0250-23.778	21.75638	130.97970	.92883	.27984 -	.24309
	.00214	.22100	.54401	.00142	.00377	.00331
9	0250-51.569	22.31111	125.85540	.92520	.30771 -	.22238
	.00203	.21262	.49786	.00140	.00357	.00314
10	0251-11.781	22.46275	125.15310	.92420	.31242 -	.22000
	.00491	.51513	1.19365	.00343	.00863	.00760
11	0251-30.861	23.86209	123.89710	.91461	.33581 -	.22563
	.00561	.59604	1.28419	.00420	.00986	.00868
12	0251-48.811	23.43376	125.20710	.91760	.32497 -	.22930
	.00613	.64817	1.43299	.00449	.01079	.00949