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# DESIGN OF AN AUTOMATIC OCTAVE SOUND ANALYZER AND RECORDER

Research Project under Contract
with the
Office of Scientific Research and Development
Contract No. OEMsr-658
Section C-9, National Defense Research Committee

Report of
November 21, 1942

Submitted by

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from the
Cruft Laboratory
Harvard University
Cambridge, Massachusetts

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ANALYZER AND RECORDER

November 21, 1942

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# DESIGN OF AN AUTOMATIC OCTAVE SOUND ANALYZER AND RECORDER

## I. Introduction

This report describes an automatic apparatus which is suitable for analyzing and measuring sound in combat vehicles. Although it was designed with a specific purpose in mind, its several novel features will make it useful for many types of acoustical measurements.

Since December 1, 1940 a project entitled "Research on Sound Control" has been in progress at Harvard University, under the auspices of the National Defense Research Committee.* One of the major problems of this project has been to measure sound levels in United States military airplanes, and to devise from these measurements suitable techniques for estimating sound levels from blue print and assumed flight data.

At the beginning of the project it was believed that the proper apparatus for measuring sound should include means for analyzing the total noise into its various frequency components. To do this an Electrical Research Products, Inc. RA-277 G sound frequency analyzer was purchased. This instrument, when used with a suitable graphic level recorder, permitted analysis of noise over a frequency range from 40 to 10,000 cycles per second by means of a 5 cycle wide or 200 cycle wide band pass filter. From these early tests it was learned that airplane noise is of three essential types:

(a) that produced by the propeller,
(b) that produced by the engine exhaust, and
(c) that produced by air leaks and aerodynamic flow.

The first type of noise, namely, that produced by the propeller, consists of a fundamental component of 50 to 100 cycles per second and various harmonic components. Usually the fundamental and second harmonic

---

* Until recently this project was under the jurisdiction of the National Research Council Committee on Sound Control. This Committee has been dissolved and the work is now under the jurisdiction of Section C-9 of the N.D.R.C.

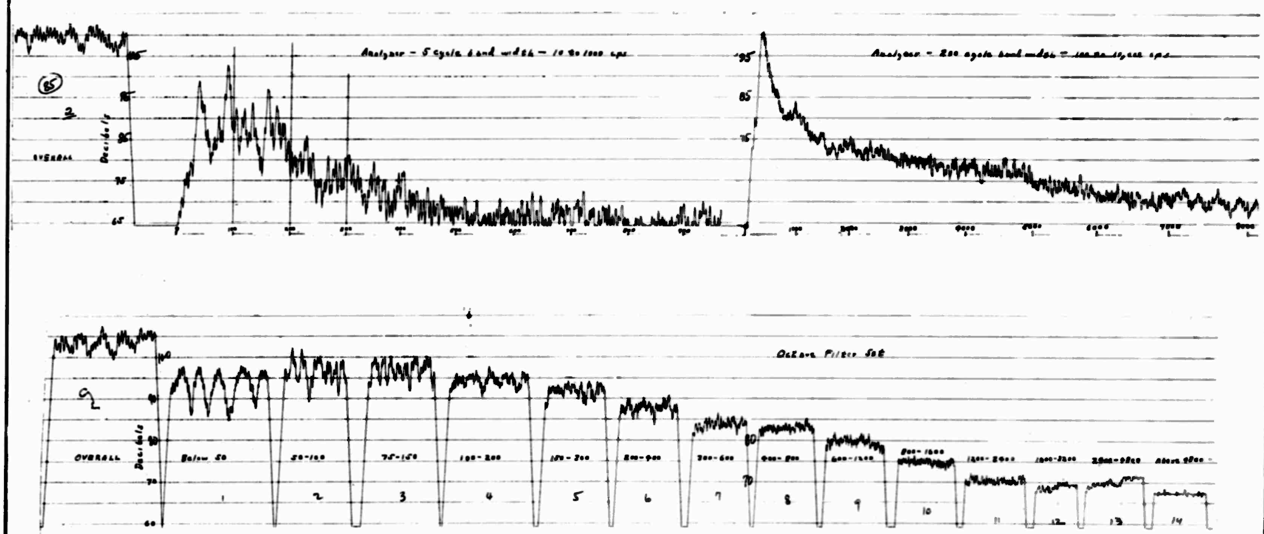
are approximately equal in intensity when measured inside the airplane. The exhaust noise usually has its fundamental below 200 cycles per second and is usually less intense than the propeller noise.

After obtaining a number of curves of sound level vs. frequency in five cycle band widths, it was found that two successive sets of data did not yield exactly the same curves, especially in the frequency region below 200 cycles per second. This was due to "beats" occurring between the tones produced by the two propellers of the airplane. These beats caused variations in intensity of as much as 15 decibels. In the higher frequency region, above 200 c.p.s., the noise was found to result almost entirely from aerodynamic sources and contained all frequencies. In this frequency range it was concluded that 5 cycle band analyses yielded no information that could not be obtained by a wider, say octave, band pass filter. Also, because of the great detail in the 5 cycle band curves, it was found impractical to set up a computational method for estimating sound levels which would yield such a curve in its entirety.

On the basis of the above experience it was decided to measure sound levels in octave bands, and a suitable octave band pass filter set was purchased, an E.R.P.I. RA-243. Comparison between data taken with it, and data taken with the 5 cycle and 200 cycle wide band filters is shown in Fig. 1. In these data it is seen that a total of 14 bands plus an overall band were used. The number of bands was reduced later one-half by choosing the following bands for tests:

| | |
|---|---|
| Below 75 | c.p.s. |
| 75 - 150 | " |
| 150 - 300 | " |
| 300 - 600 | " |
| 600 - 1200 | " |
| 1200 - 2400 | " |
| 2400 - 4800 | " |
| Above 4800 | " |

Much of our data was taken using this apparatus in conjunction with an E.R.P.I. RA-277G sound frequency analyzer and an E.R.P.I. RA-246 graphic level recorder.



PBM-1 | CO-PILOT'S HEAD | R.P.M. 1700 | INDICATED AIR SPEED 130 N.M.P.H. | H.P. 750

AIRPLANE 56P4 | FLAT WEIGHTING NETWORK | M.P. 24" | OUTSIDE T = -8°C | PROPELLER TIP SEP. 17.5"

MARCH 18, 1941 | A.S.A. STANDARDS REF. LEVEL | ALTITUDE 5000 FT. | GEAR RATIO 9/16 | PROPELLER DIA. 14.5'

FIG. 1

These three units were admirably suited for the purposes for which they were intended, but they possessed three characteristics which it was felt were undesirable:

(a) they could not be operated remotely,
(b) they could not be operated on low voltage direct current, and
(c) they were undesirably heavy and bulky.

With these factors as a starting point, new apparatus was then designed using as part of it the E.R.P.I. band pass filter set and graphic level recorder. It accomplished the job of determining, either manually or automatically, sound levels in airplanes by octave bands. The apparatus is reliable, simple to install, and is as compact as possible. In addition, it is flexible in operation in that it can be operated either by the pilot or by an observer stationed in the airplane, and its power supply is completely independent of the plane's supply.

The complete system is composed of the following units which are described in succeeding sections of this report;

(a) a dynamic microphone, the W.E. 630-A or 633-A,
(b) an octave band-pass filter set, the E.R.P.I. RA-243,
(c) a sound level meter, Cruft design,
(d) an automatic graphic level recorder, E.R.P.I. RA-246, modified at Cruft Laboratory,
(e) a battery power supply, and
(f) a hand-held remote control unit, Cruft design.

In its final form it is possible to install the equipment in a rear compartment of an airplane, and to place in the hands of the pilot the simple hand-held control unit. After the pilot has reached his altitude and has set up the flight conditions desired, he then needs only to press the button on the remote control unit. This button sets into operation the automatic apparatus which measures the sound level in each of the frequency bands, and records the information on a wax paper roll. After finishing one complete frequency analysis, namely, the eight bands and an overall position, the apparatus shuts off. The pilot can then set up new flight conditions, change the position of the microphone, and repeat the cycle of measurements.

## II. Operation

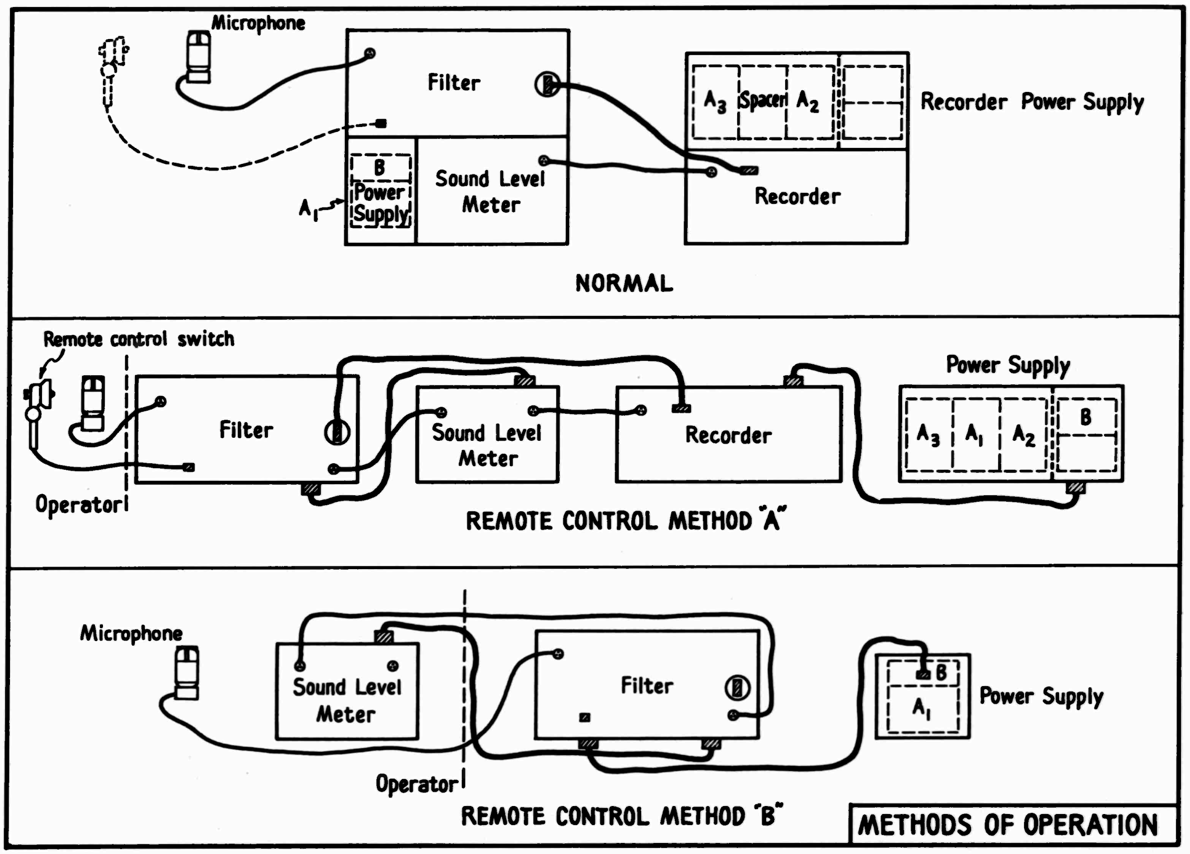
The units which comprise the complete apparatus for analyzing and recording sound levels in airplanes are designed for any one of three methods of operation, depending on space requirements, and whether data are to be recorded automatically or taken manually. These methods are shown schematically in Fig. 2.

The "normal" method of operation is the most efficient electrically and permits automatic recording of data. It consists of a mimimum number of units to be handled as shown in Fig. 3. In this figure, the graphic level recorder and its power supply are coupled together into one unit at the right, while the filter set and the sound level meter with its power supply are connected into one unit at the left. The dynamic microphone is at the left on top of the sound-level meter, and the hand-held remote control unit is in the foreground. By this method of operation it is possible to obtain five hours of continuous analysis and recording, without recharging the 6 volt storage battery.

The space occupied by the sound level meter and filter as one unit is approximately 19" x 18" x 11" high, with a total weight of approximately 124 pounds. Of this, 62 pounds are for the filter set, and 62 pounds for the sound level meter including 15 pounds of batteries -- one "A" battery and two "B" batteries.

The space required by the recorder and the power supply coupled together as one unit is approximately 19" x 18" x 12" high. The power supply with two "A" batteries and a spacer weighs about 55 pounds, plus 50 pounds for the recorder, giving a total weight for this unit of approximately 105 pounds. The total weight of the complete system for "normal" operation with cables, microphone, and remote control unit is approximately 240 pounds.

The microphone on the sound level meter and the remote control unit in the foreground (Fig. 3), are



Microphone
Filter
A3
Spacer
A2
Recorder Power Supply
B
Power Supply
A1
Sound Level Meter
Recorder
NORMAL
Remote control switch
Filter
Sound Level Meter
Recorder
Power Supply
A3
A1
A2
B
Operator
REMOTE CONTROL METHOD "A"
Microphone
Sound Level Meter
Filter
B
A1
Power Supply
Operator
REMOTE CONTROL METHOD "B"
METHODS OF OPERATION


FIG. 2

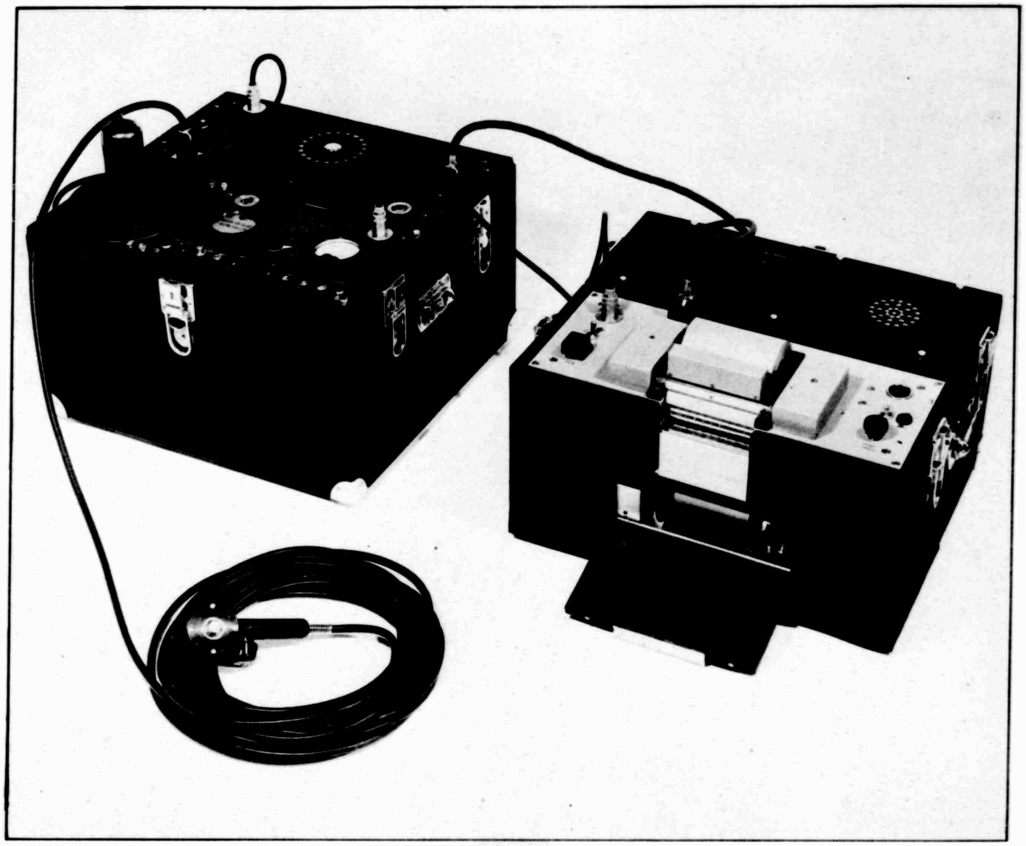


FIG. 3

the two units required by the operator for complete control for automatic recording of sound levels through eight octave bands and an overall position. Once the recorder has been calibrated and adjusted, using the oscillator in the sound level meter, and the microphone position has been determined, the only operations to start a cycle of measurements are to turn the recorder motor switch, which is on the rear of the hand-held remote control unit, to ON, and to depress the push button switch until the light blinks once. Thereupon, the units will continue through one cycle of octave bands, an overall position, and stop automatically. The microphone can then be changed to a different position, and the next cycle of operation begun by depressing the push button switch until the light blinks again.

When space requirements prohibit the use of units as large as in Fig. 3, and recording of data is also required, they may be arranged as shown in Fig. 4 (remote control method "A") with the sound level meter out of its case, and the graphic level recorder and battery supply separated. Due to the losses in the connecting cables, the total time for operation is only about three hours, as compared to the five hours in the "normal" method. The method of control here is exactly as in the above scheme, i.e., the operator needs to handle only the microphone and the small remote hand-held control unit.

The filter, recorder, and power supply in this arrangement each require a space approximately 19" x 9" x 12" high. The sound level meter, as shown in Fig. 4, is approximately 8" x 12" x 6 1/2" high. The total weight is slightly less than that of the first method of operation due to the elimination of one case, and the addition of a number of cables.

For extreme compactness, at the expense of omitting automatic recording of data, it is possible to decrease the total number of pieces to the arrangement shown in Fig. 5 (remote control method "B"). The sound level meter is used as a remote control unit. The filter permits octave band analyses. Both units are supplied power from the small battery box at the right.

In this arrangement, it is necessary to advance the filter manually by means of the push button on

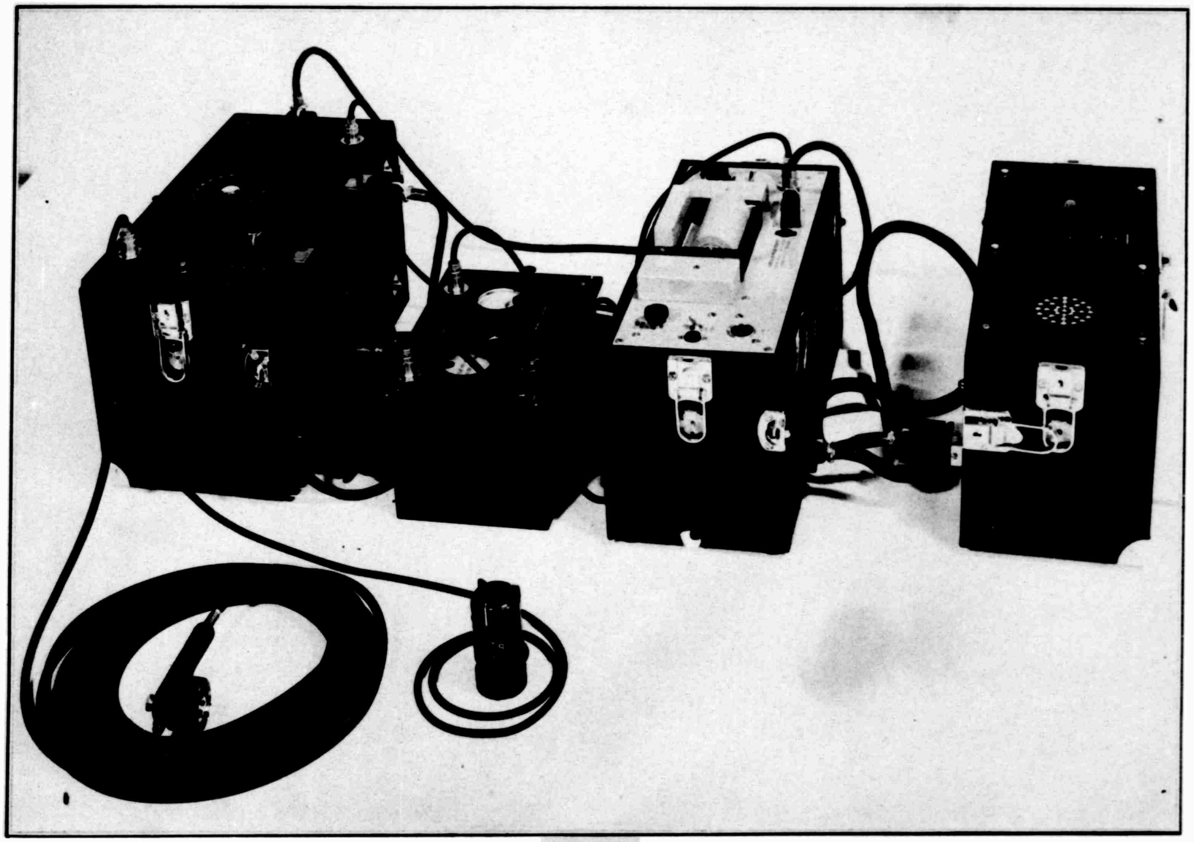


FIG. 4

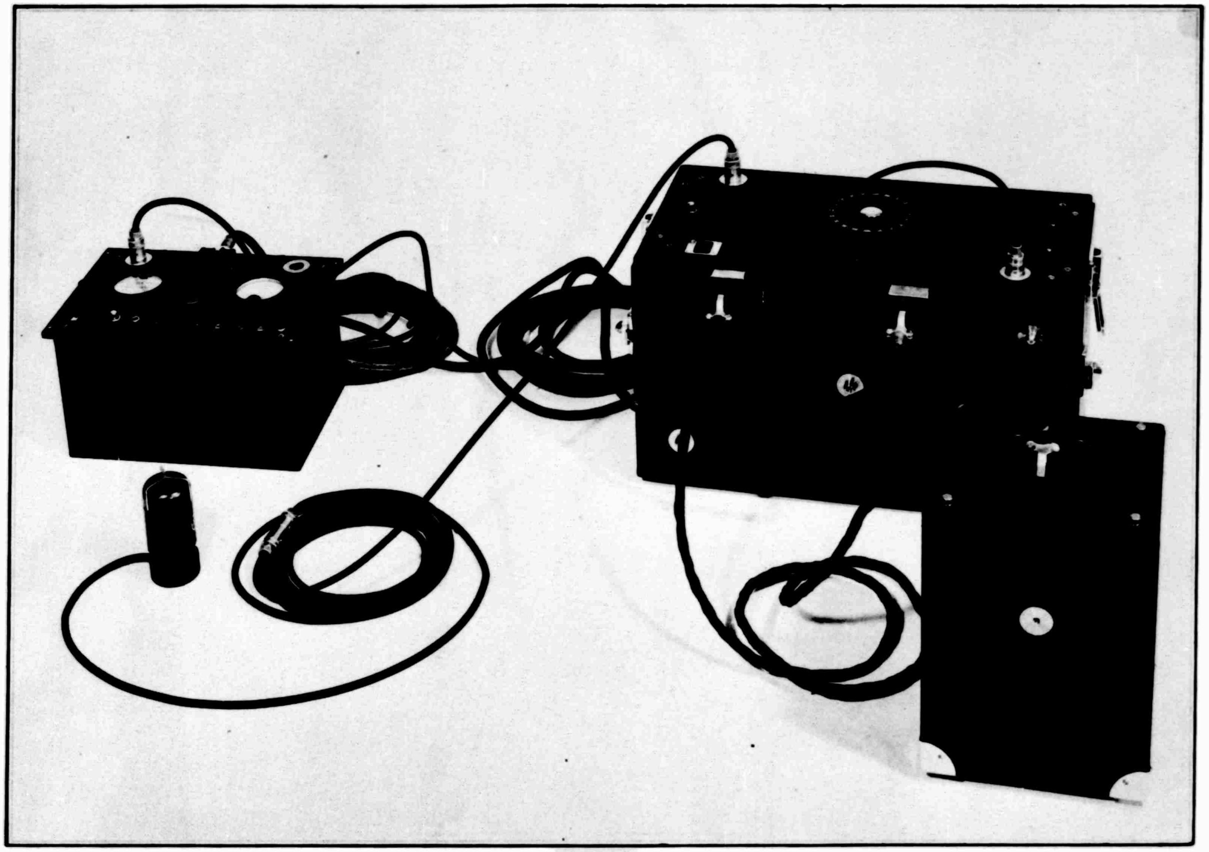


FIG. 5

the sound level meter. The indicator on the left of the sound level meter panel will indicate the position of the filter switch, once the filter is brought into synchronism by advancing the indicator through one complete cycle. Then, the sound level of a particular octave band, or of the complete spectrum can be obtained by adding together the readings of the attenuator, the output meter, and a correction factor.

The minimum space required here is 19" x 9" x 11" high for the filter unit (approximately 62 pounds); a space approximately 7" x 8" x 11" high for the small battery box which weighs 25 pounds with one "A" battery and two "B" batteries; and 8" x 12" x 6 1/2" high for the sound level meter which weighs approximately 21 pounds. The total weight including cables and microphone for this method is approximately 115 pounds.

## III. Band-Pass Filter

The band-pass filter used in this equipment is an E.R.P.I. RA-243 filter, modified by the addition of a specially designed 20 position rotary multiple-bank switch, a solenoid mechanism for advancing the switch, and an automatic attenuator (See Fig. 6). The filter and switch provide a sequence of ten band positions as follows:

Overall
Below 75 c.p.s.
75 - 150 c.p.s.
150 - 300 c.p.s.
300 - 600 c.p.s.
600 - 1200 c.p.s.
1200 - 2400 c.p.s.
2400 - 4800 c.p.s.
4800 and above and a
second overall position

For one complete revolution of the switch, the above sequence occurs twice.

In recording a sequence of filter positions on the graphic level recorder (described in a later section), it is frequently found that the range of levels in the different bands is more than the 50 db range of the graphic level recorder. This is due to the very high levels encountered in the "overall" position and the low frequency octave bands, with respect to the high frequency octave bands. By inserting a resistive network designed to introduce varying steps of attenuation of the signal between the output of the filter and the input of the amplifier, it is possible to obtain a range of signals impressed on the recorder which the recorder can accommodate. This is especially useful in the last two methods of operation discussed in the previous section.

The mechanism for advancing the switch in steps to provide automatic octave band analyses, is a solenoid stepper which is controlled by a relay which receives impulses from a microswitch located in the graphic level recorder. The microswitch closes the relay circuit approximately every six seconds only when the recorder motor is on. The relay can also be operated by push buttons located on the sound level meter, and the band-pass filter.

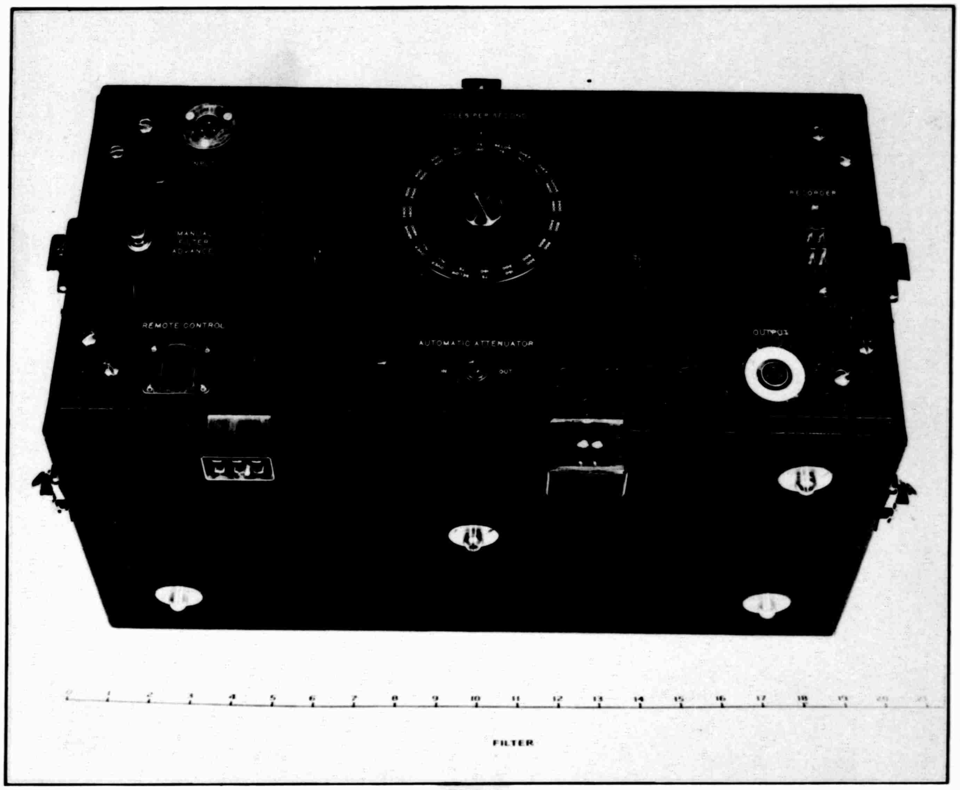



FIG. 6

The schematic diagram of the octave band-pass filter set and the automatic attenuator is shown in Fig. 7. The wiring diagram, also showing in part the control circuits located in the filter, is given in Fig. 8. The complete control circuit is shown in the schematic control circuit diagram Fig. 9.

Automatic Attenuator:

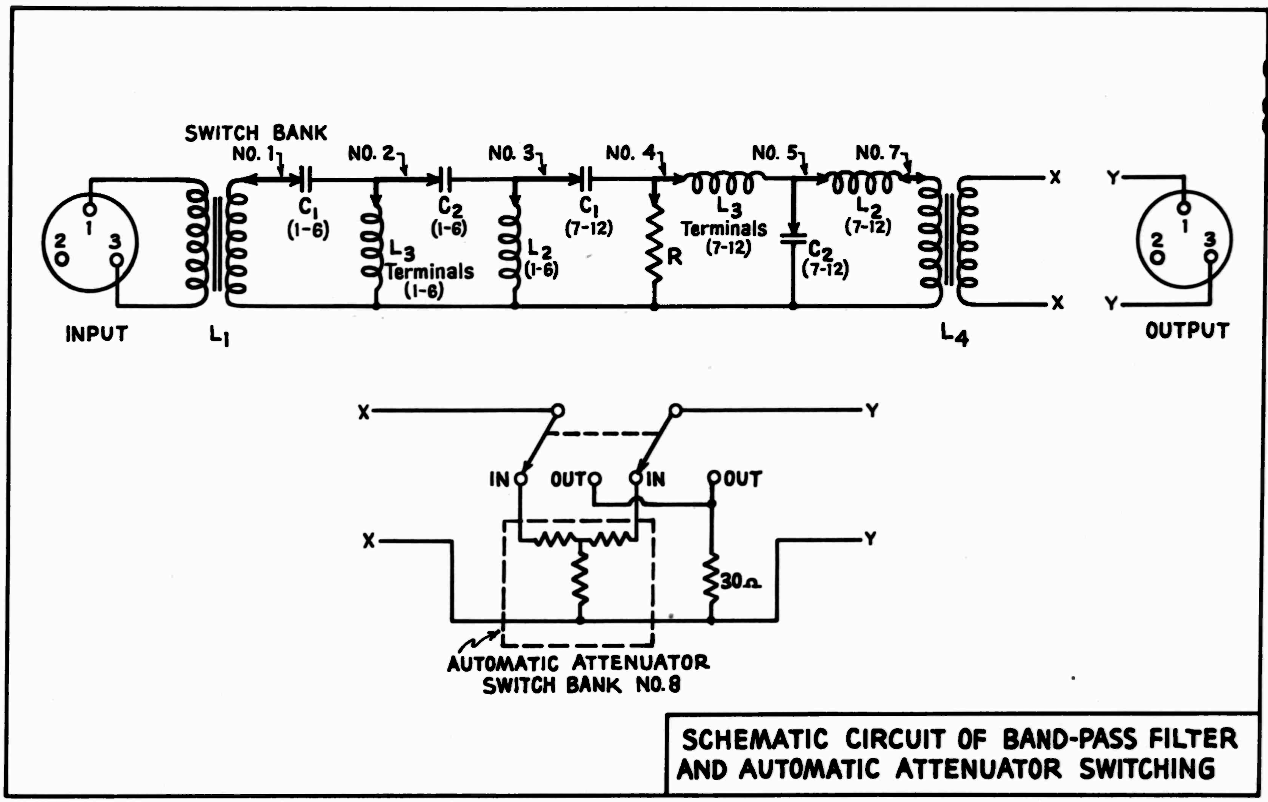
The construction of the attenuator for providing the various insertion losses is shown in Fig. 10 The desired attenuation in decibels in each band to impress a minimum range of signals on the recorder is as follows:

| Band position | | Attenuation |
|---|---|---|
| Overall | - | 30 db |
| Below 75 | - | 20 db |
| 75 - 150 | - | 20 db |
| 150 - 300 | - | 15 db |
| 300 - 600 | - | 10 db |
| 600 - 1200 | - | 5 db |
| 1200 - 2400 | - | 0 db |
| 2400 - 4800 | - | 0 db |
| Above 4800 | - | 0 db |

The various resistors were wound with silk covered manganin wire by a non-inductive (bi-filar) method. To moisture-proof each section, several coats of clear glyptal were applied.

Multiple-Bank Rotary Switch:

The design of a switch for providing the switching sequences required, demanded a compromise between unfailing contacts, (under extreme vibration encountered in planes) therefore, low contact resistances, and low contact pressures in order to reduce to a minimum the torque necessary to rotate the switch. None of the commercially designed switches available was satisfactory from the torque standpoint. Hence, a switch of suitable design was constructed in the Cruft Shop as shown in Fig. 11. All contacts in the switch are solid silver. The stationary contacts are soft silver, and the rotor paddles are cold rolled to provide satisfactory springiness. Each arm of the rotor has two contact paddles, one on each side of the stationary contact. Hence, the contact forces




SCHEMATIC CIRCUIT OF BAND-PASS FILTER AND AUTOMATIC ATTENUATOR SWITCHING

FIG. 7

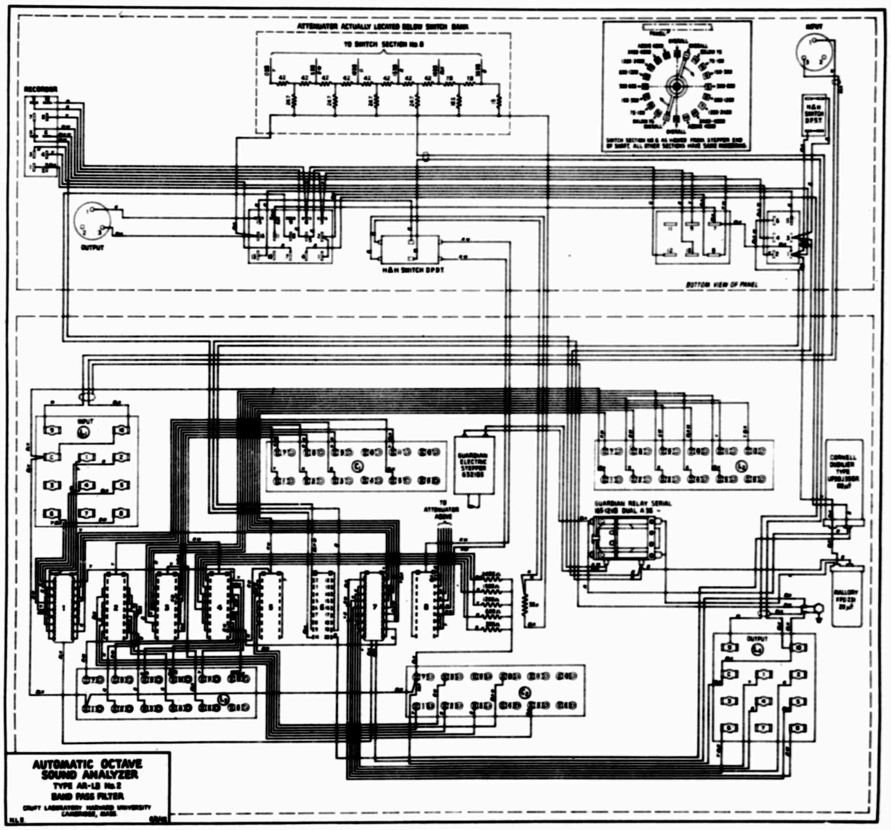

ATTENUATOR ACTUALLY LOCATED BELOW SWITCH BANK
TO SWITCH SECTION No 8
RECORDER
OUTPUT
INPUT
H&H SWITCH DPDT
BOTTOM VIEW OF PANEL
INPUT
OUTPUT
AUTOMATIC OCTAVE
SOUND ANALYZER
TYPE AR-LB No.2
BAND PASS FILTER
CRUFT LABORATORY HARVARD UNIVERSITY
CAMBRIDGE, MASS.

FIG. 8

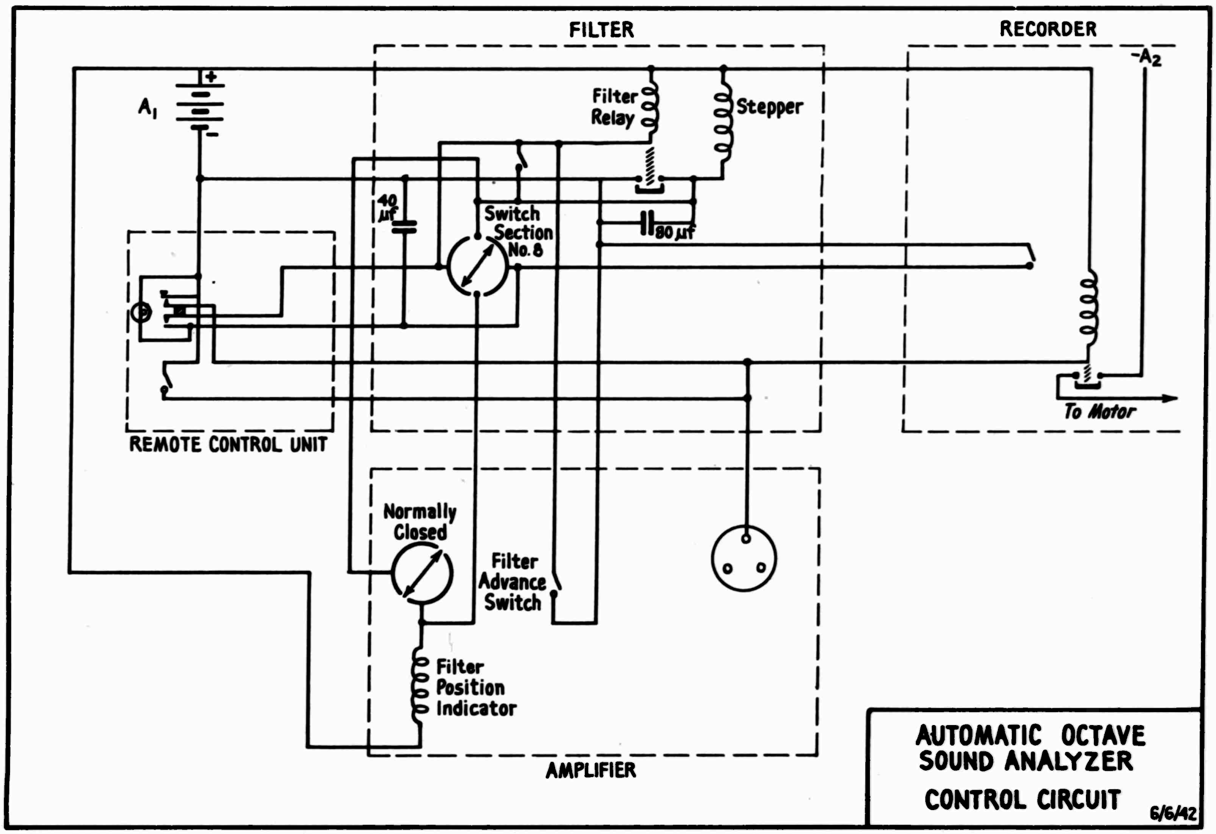
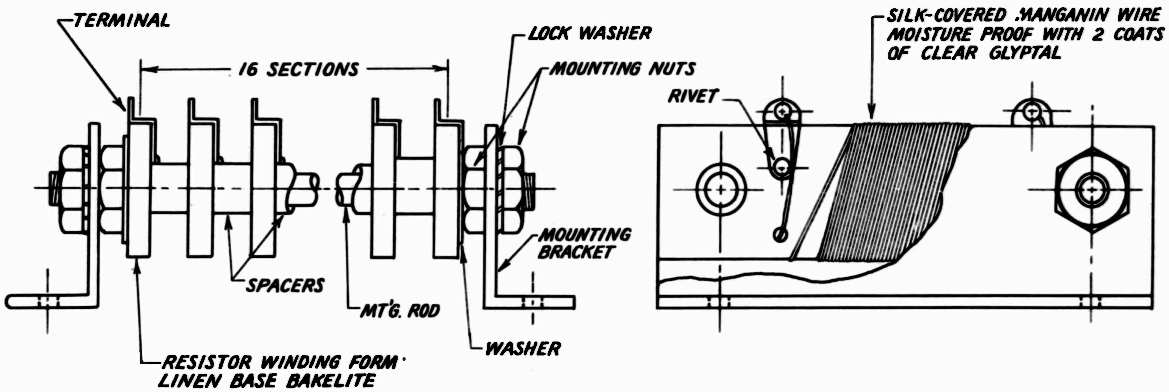

FILTER
RECORDER
$-A_2$
$A_1$
+
−
Filter Relay
Stepper
40 µf
Switch Section No. 8
80 µf
REMOTE CONTROL UNIT
To Motor
Normally Closed
Filter Advance Switch
Filter Position Indicator
AMPLIFIER
AUTOMATIC OCTAVE SOUND ANALYZER
CONTROL CIRCUIT
6/6/42

FIG. 9

38

18




**DETAILS OF ATTENUATOR**
SCALE : 2" = 1"

FIG. 10

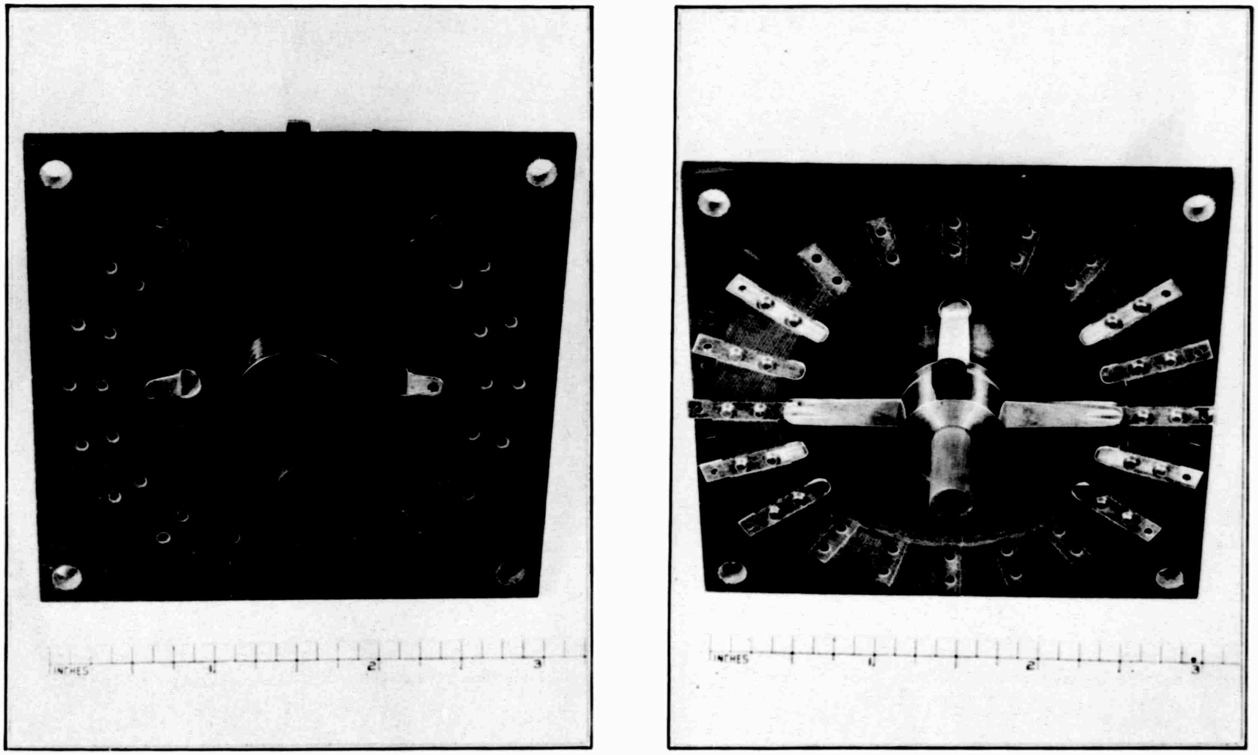



FIG. 11

act in opposite directions and insure that the switch does not open, regardless of which direction vibrational forces act.

The switch shaft is of linen base bakelite coupled to a steel driving shaft with a universal joint. The driving end of the switch is a revised Guardian Electric Stepper Type G-32185. The adjustment of the stop for the ratched wheel is very critical, and one type of adjustable, frictionless, non-overthrow stop is shown in Fig. 12. The shock of stopping is taken by the lower set-screw and the ratchet arm, while the upper set-screw is adjusted for a slight amount of clearance in the normal released position to effectively prevent overthrow due to the inertia of the shaft, rotors, etc. The tension of the return spring is determined by the minimum voltage at which the stepper is to fail and the minimum energy to be stored in it on the closing of the solenoid.

It will be noted that switch sections 1 and 7 (Fig. 8) have double the number of contacts of the other sections. These extra contacts are provided to ground the input and output circuits between switch positions. Section 8 of the switch is for the automatic attenuator. Section 6 (Fig. 8) provides a normally open S.P.S.T. switch for the interlock circuit to keep the auxiliary filter position indicator in the sound level meter in step with the position dial on the filter set panel, and also a normally closed S.P.S.T. switch to stop the automatic filter advance mechanism at the end of a sequence of bands.

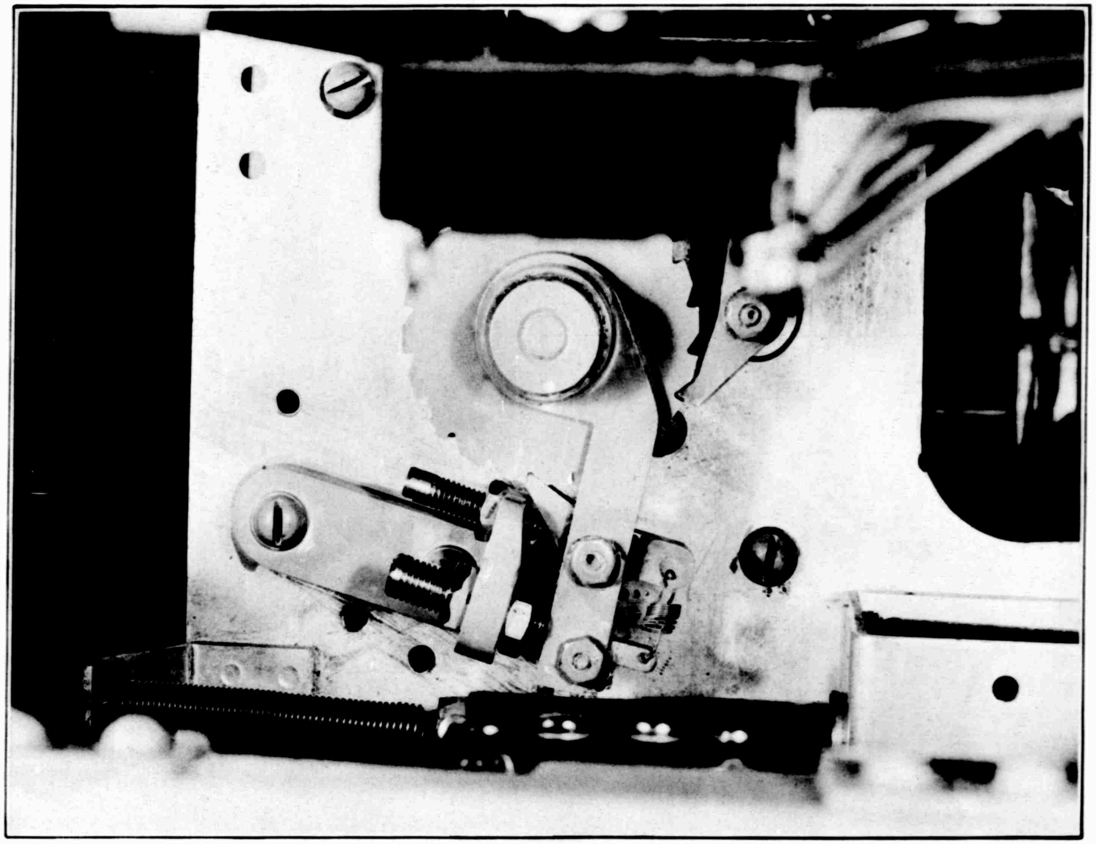


FIG. 12

## IV Sound Level Meter

The sound level meter consists of a five-stage amplifier stabilized with degenerative feedback, and is designed to operate out of the revised RA-243 band pass filter, or the W.E. type 633-A (or 630-A) microphone.* The amplifier is calibrated to read average sound pressures in decibels (with a reference pressure of 0.000204 dynes/cm.$^2$) when the proper corrections have been made as described in a later section. The output circuit is also provided with a Cannon plug to operate into the graphic level recorder.

A total gain of approximately 110 db is obtained with the circuit arrangements as shown in Fig. 13. The input and output stages are coupled with U.T.C. transformers LS-14X and A-26 respectively, giving 30 ohms input impedance, and 500 ohms output impedance. It will be observed that all the tubes employed are of the 6.3 volt filament type. These were chosen because all lower voltage types were too microphonic. Extreme stability is obtained by use of negative feedback circuits which takes care of, in addition to the variations in tube characteristics, a wider range of battery voltages than will be obtained in service. Control for various gains is by a Daven CP - 350Y attenuator with 5 db steps, and a total attenuation of 70 db.

To provide a signal for calibration of the graphic level recorder, an oscillator (R-C circuit) is built into the last two stages of the amplifier, and is controlled by an on-off toggle switch on the panel. Power (at 90 v., 67-1/2 v., 22-1/2 v., and 6 v.) is obtained through the 15-terminal Jones plug which is supplied either from the power supply adjacent to the graphic level recorder, or the power supply adjacent to the sound level meter.

---

*Information from the manufacturer indicates that the W.E. 630-A microphone is no longer being manufactured or is procurable. This explains the reason why the 633-A was selected for use with the sound level meter.

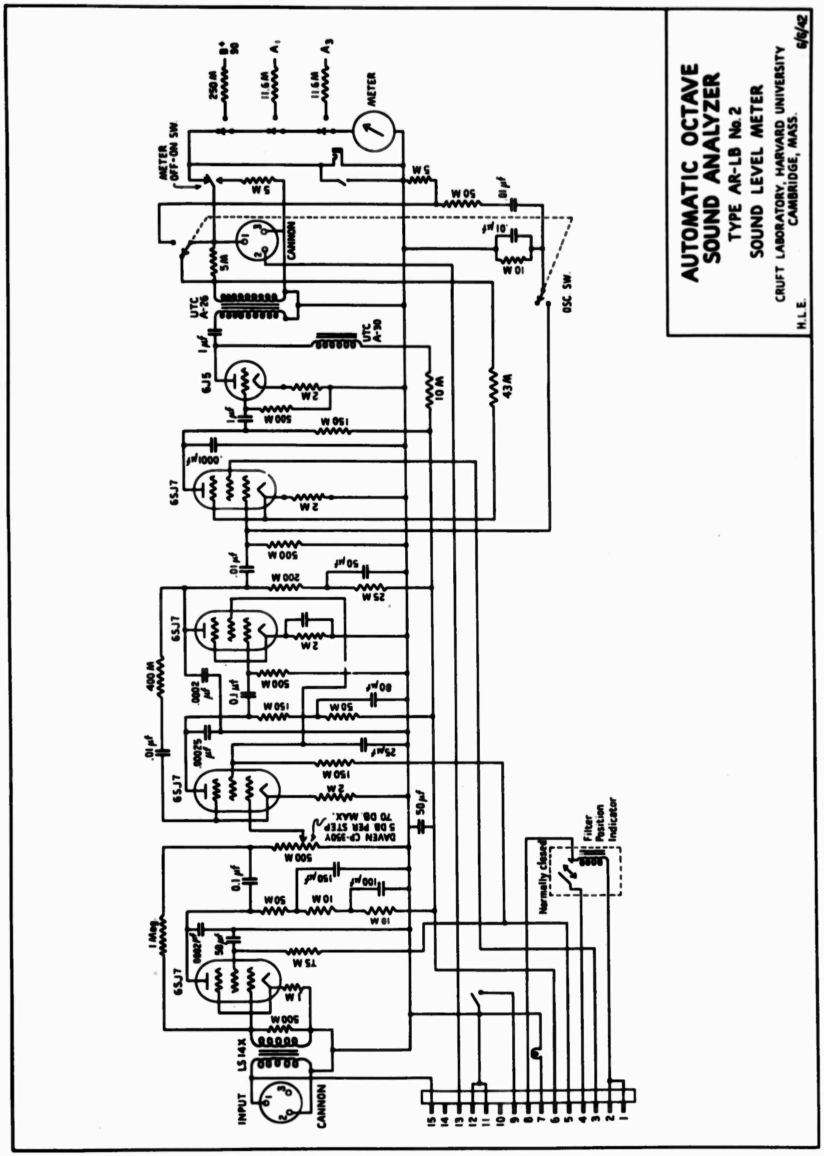

AUTOMATIC OCTAVE
SOUND ANALYZER
TYPE AR-LB No. 2
SOUND LEVEL METER
CRUFT LABORATORY, HARVARD UNIVERSITY
CAMBRIDGE, MASS.
H.L.E.
6/8/42
INPUT
CANNON
LS14X
6SJ7
6J5
UTC A-26
UTC A-30
METER
METER OFF-ON SW.
OSC SW.
DAVEN CP-350Y
5 DB PER STEP
70 DB. MAX.
Normally closed
Filter Position Indicator
B+ 90
A1
A3

FIG. 13

The output meter is a standard Weston model 301 type 20. This meter also serves to read the voltages of the "A" and "B" supply for the amplifier, as well as the "A" supply for the recorder. The meter deflection is so determined that batteries must be replaced when the meter reads below "0" db in the various positions. In order to permit a check between the recorder and the output meter, the circuit has been designed to permit the meter to be left on when the recorder is operating.

A monitoring jack is also provided in the output circuit to permit either phones or cathode ray oscilloscope to be used.

Since in one of the methods of operation the amplifier is also used as a remote control unit, the amplifier case must be extremely rugged and well shielded to permit mounting in a pilot's cockpit. In Figs. 14, 15, and 16 the assembly of the chassis into the housing and then into the case can be seen.

To permit the observation of the filter position when the sound level meter is used as a remote control unit, it was necessary to design an auxiliary dial indicator (Fig. 17) which would automatically remain in step with the filter set dial. For an advance mechanism, a Western Electric message register (Type 5-L) was revised mechanically and electrically.

The indexing of the cam was reversed so that the shaft was indexed on the release stroke of the clapper. The 5-L type Western Electric register was designed originally to index on the closing of the magnetic circuit.

Because of the limited force which the magnetic circuit will exert, the bearings for the shaft must provide an easy running fit for the shaft, on which are mounted three cams and a dial plate. These parts possess considerable inertia, and overtravel prevents exact indexing. To overcome this, a double acting pawl is employed which strikes on a cam, the same as the driving cam, except having teeth pointing in the opposite direction of the driving cam. This permits accurate location of each advance of the shaft without the use of friction.

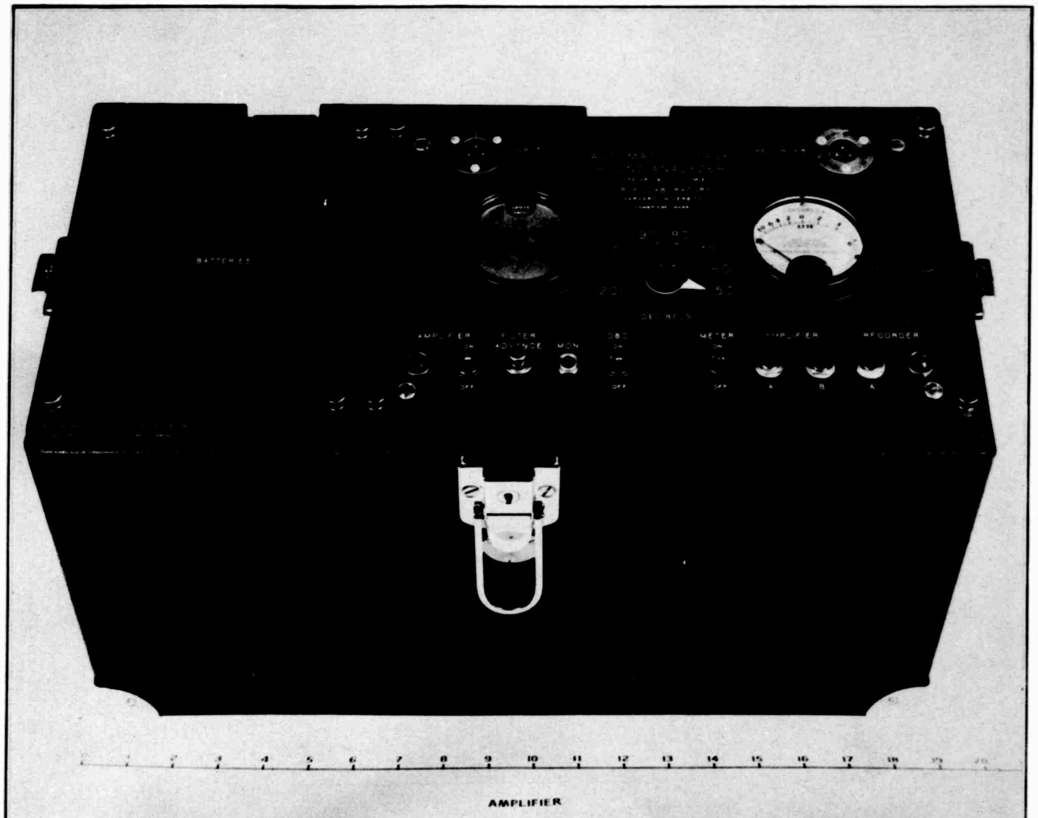



FIG. 14

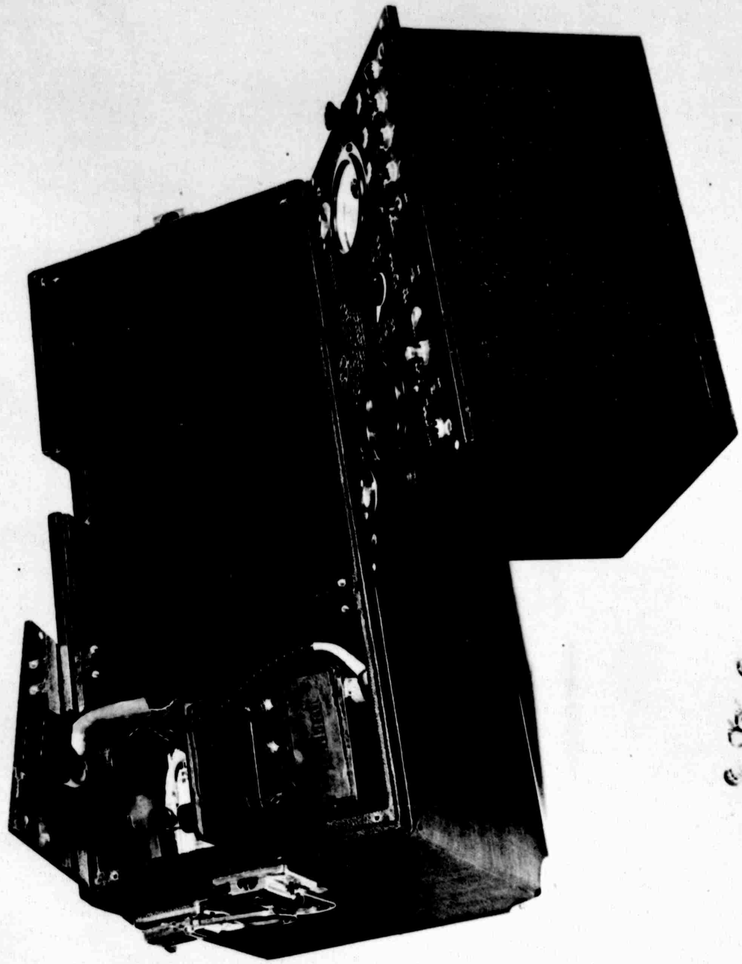


FIG. 15

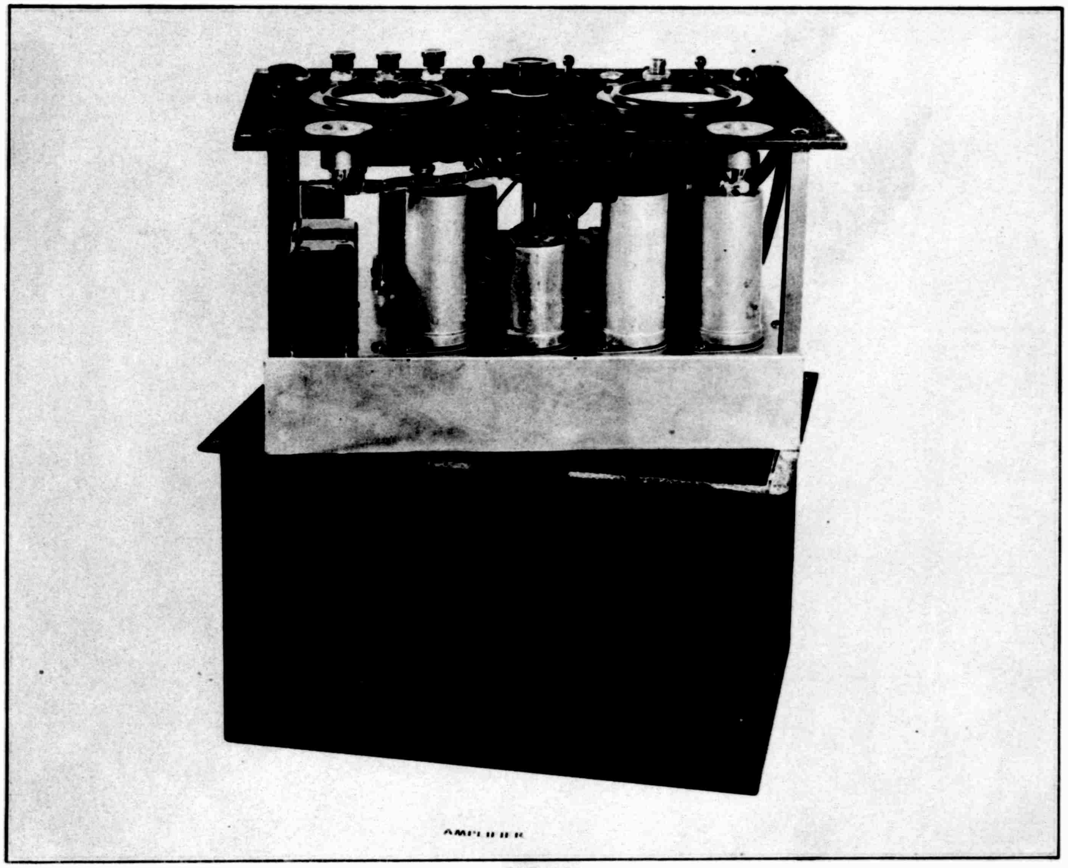


FIG. 16

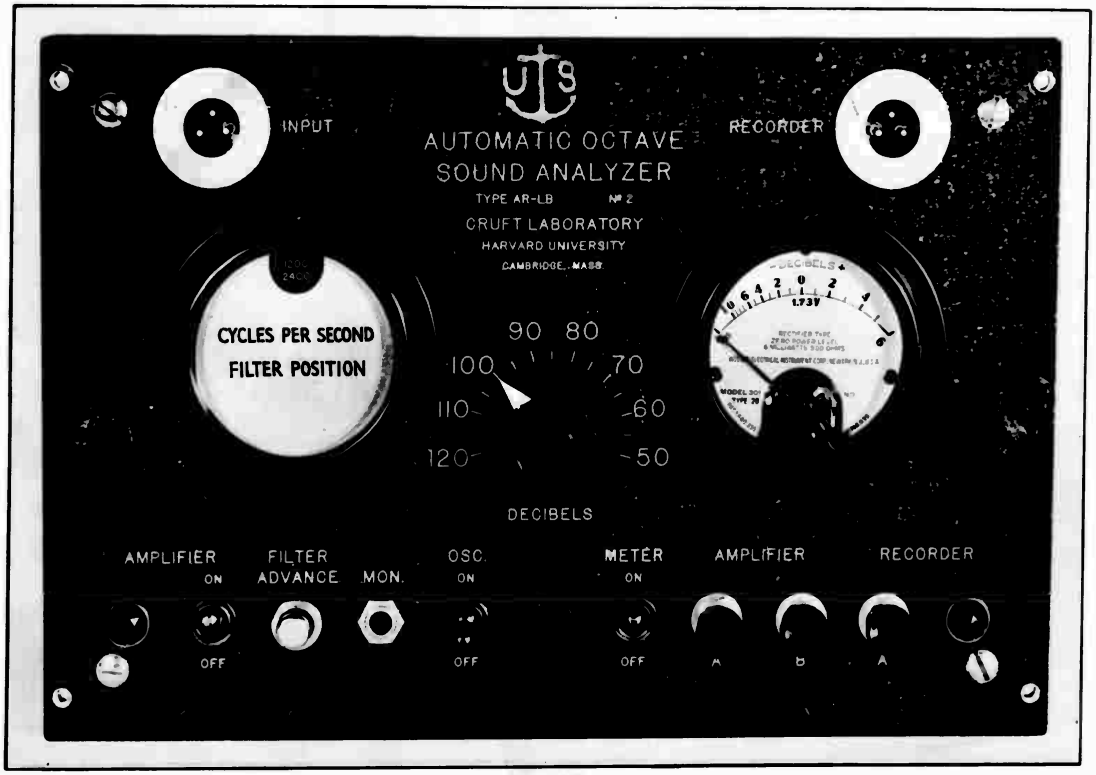

INPUT
RECORDER
AUTOMATIC OCTAVE
SOUND ANALYZER
TYPE AR-LB
Nº 2
CRUFT LABORATORY
HARVARD UNIVERSITY
CAMBRIDGE, MASS.
CYCLES PER SECOND
FILTER POSITION
90 80
100
70
110
60
120
50
DECIBELS
DECIBELS
AMPLIFIER
ON
OFF
FILTER
ADVANCE
MON.
OSC.
ON
OFF
METER
ON
OFF
AMPLIFIER
RECORDER

FIG. 17

A circular metal cam with an insulated segment is also mounted on the dial shaft which provides a normally closed S.P.S.T. switch to complete the interlock scheme with the normally open S.P.S.T. switch in section 6 of the rotary switch bank in the filter set. All of these details may be seen in Figs. 18 and 19.

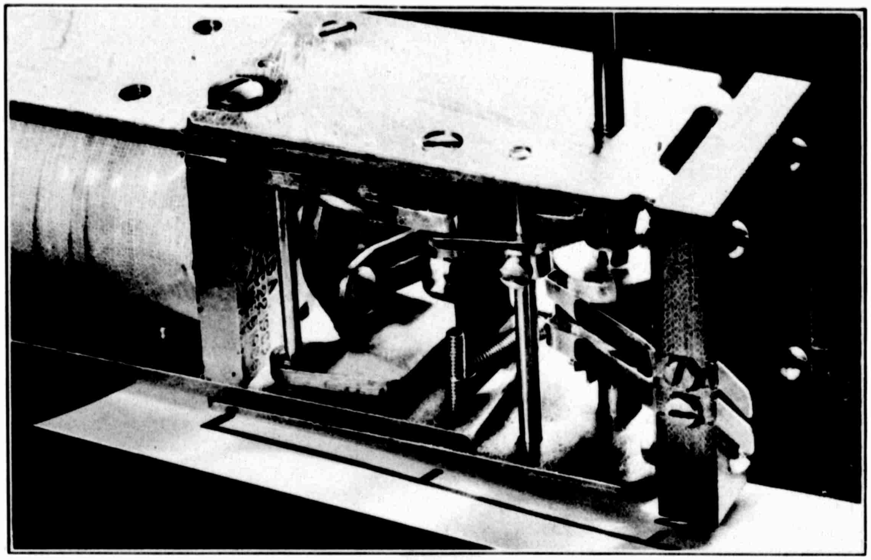


FIG. 19

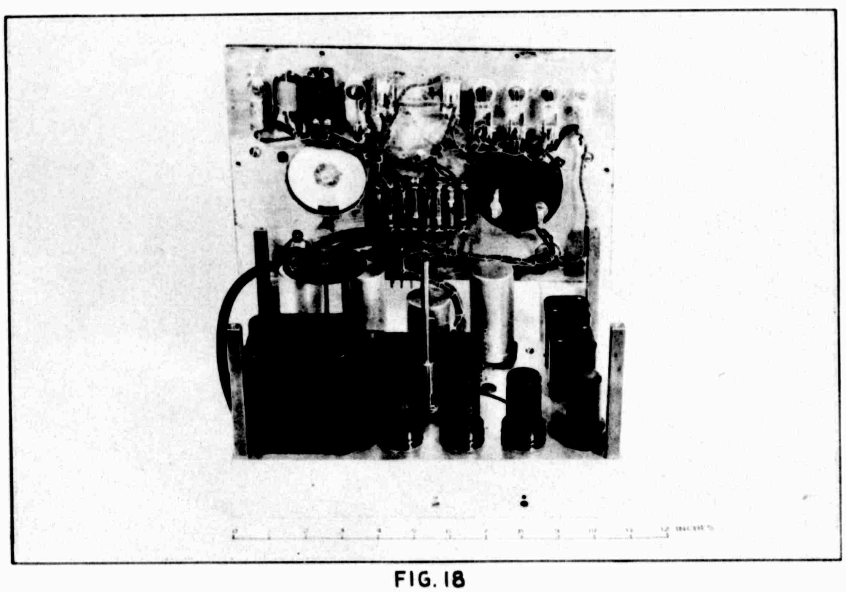


FIG. 18

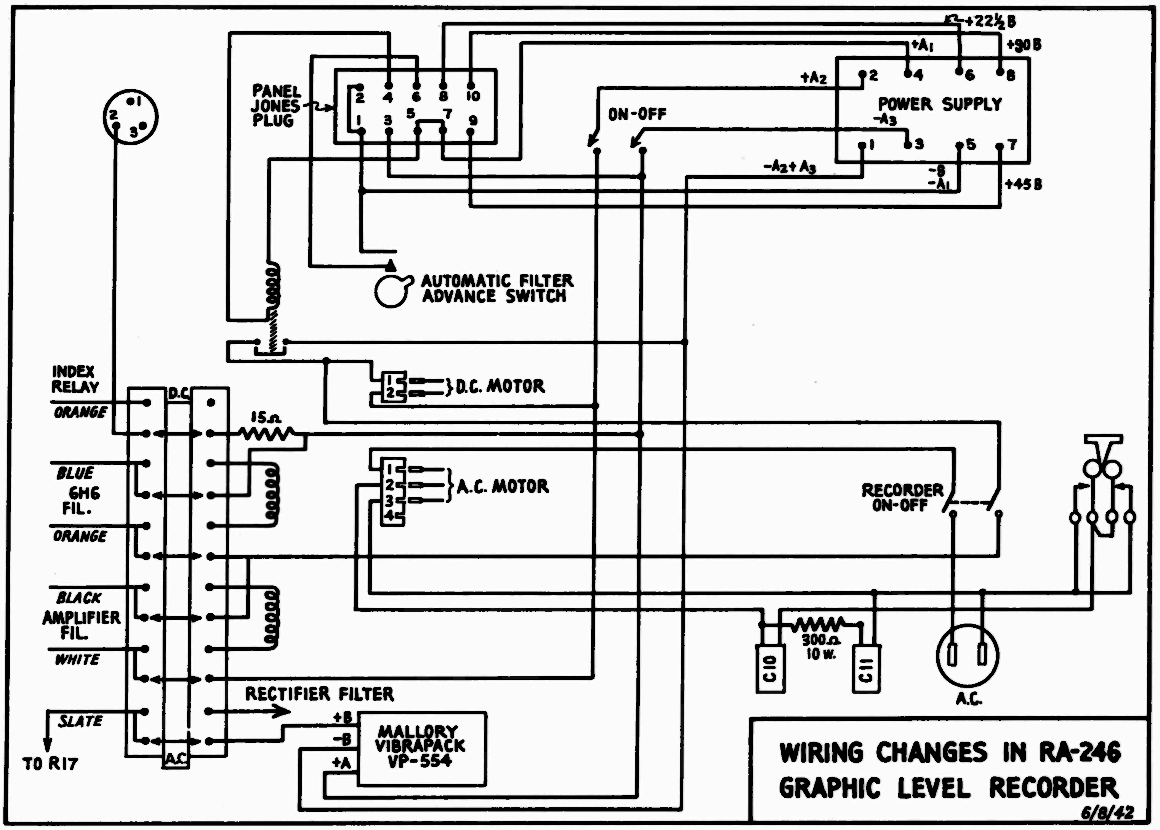
## V. Modified RA-246 Graphic Level Recorder

The major deficiencies of the standard E.R.P.I. RA-246 Graphic Level Recorder for the purposes it was to serve in this equipment, were its lack of D.C. operation and lack of rewinding facilities for the wax-paper tape. To keep the recorder available for possible A.C. operation, the changes from A.C. to 6 volt D.C. operation were accomplished by installing a simple switching unit, a Mallory Vibrapack, and replacing the A.C. motor with a D.C. motor (a Delco Service Part 5047473) in the same mounting frame. The schematic diagram in Fig. 20 shows the circuit additions and changes made in the recorder.

The 8 prong Jones plug at the rear of the chassis (Fig.21) connects to the large battery box adjacent to it in normal operation (or connected with a cable), and provides power to operate the Mallory VP-554 Vibrapack, the filaments and B supply for the amplifier, as well as power for the automatic filter advance in control method "A".

In order to accommodate the rewind mechanism, a number of the recorder elements had to be shifted as shown in Figs. 21 and 22. The drive for the rewind spool was obtained by mounting a split pulley on the upper shaft which drives the metal marking roll (Fig. 22). A 1" diameter V-grooved pulley on this shaft transmits sufficient torque through a spring belt to a 3/4" dia V-pulley on the spool to wind very nearly a full roll of tape with reasonable tightness. Removal and insertion is fool-proof and simple as is evidenced in Figs. 22, 23, and 24. An apron (Fig. 22) was added to permit clearance for the index relay as well as to provide a surface for making notations on the tape. To permit access to the tape without removing the recorder from the case, a small double-hinged door was built into the case as shown in Fig. 3.

The idler shaft in the gear-change box of the recorder was found to have a period of approximately six seconds under load conditions, which proved to be an ideal source for a positive impulse to advance the filter from band to band. This period allowed sufficient time for the recorder to obtain a reading.



PANEL JONES PLUG
+22½ B
+A1
+30 B
+A2
POWER SUPPLY
-A3
ON-OFF
-A2+A3
-B
-A1
+45 B
AUTOMATIC FILTER ADVANCE SWITCH
INDEX RELAY
ORANGE
D.C.
15Ω
D.C. MOTOR
BLUE
6H6 FIL.
ORANGE
A.C. MOTOR
RECORDER ON-OFF
BLACK
AMPLIFIER FIL.
WHITE
300Ω 10 W.
C10
C11
A.C.
RECTIFIER FILTER
SLATE
TO R17
A.C.
+B
-B
+A
MALLORY VIBRAPACK VP-554
WIRING CHANGES IN RA-246 GRAPHIC LEVEL RECORDER
6/8/42


FIG. 20

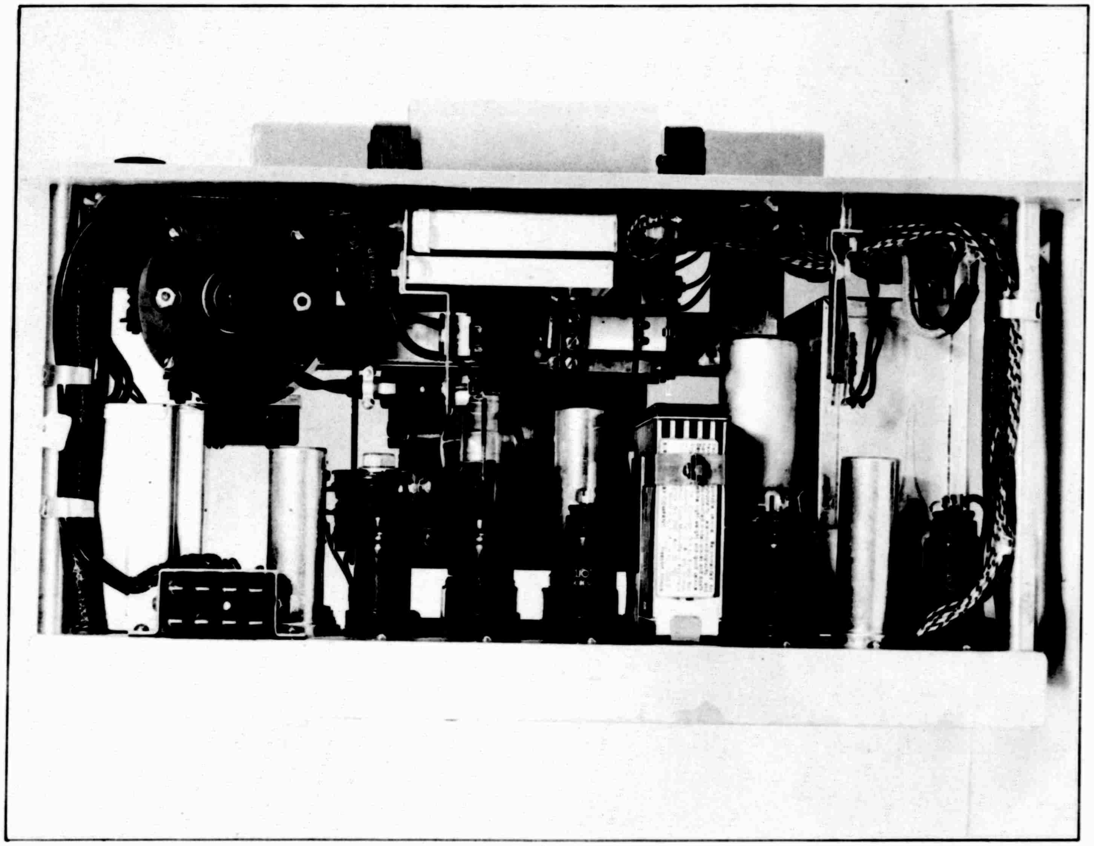


FIG. 21

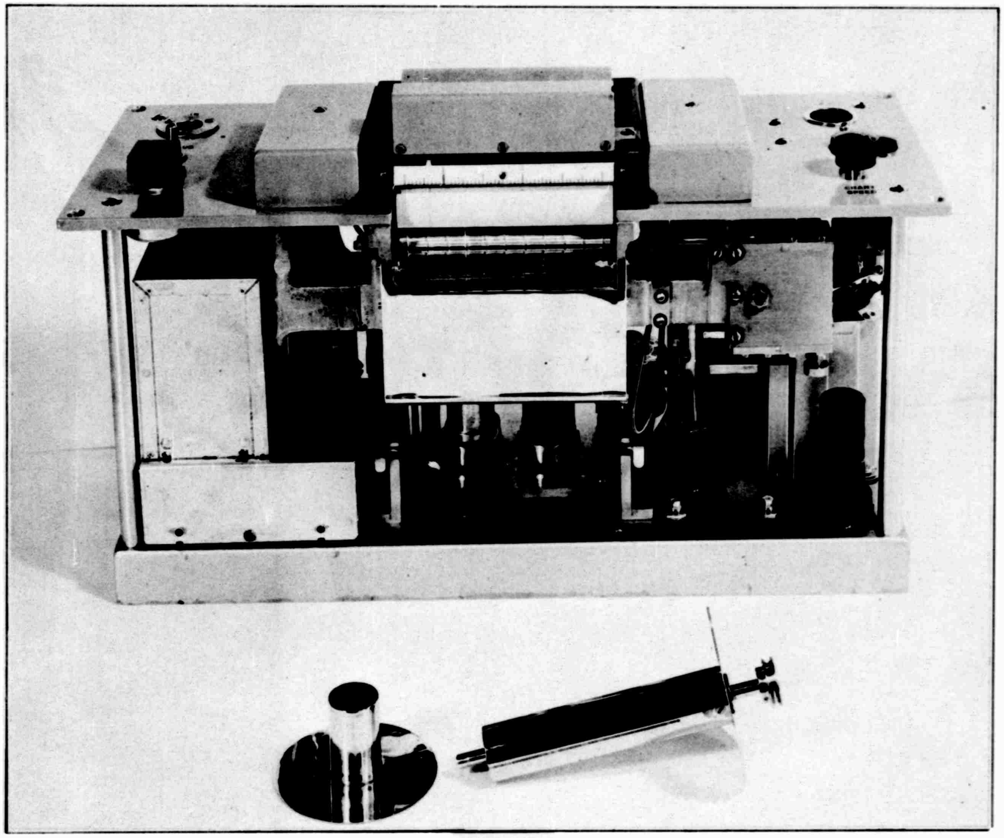


FIG. 22

3 19

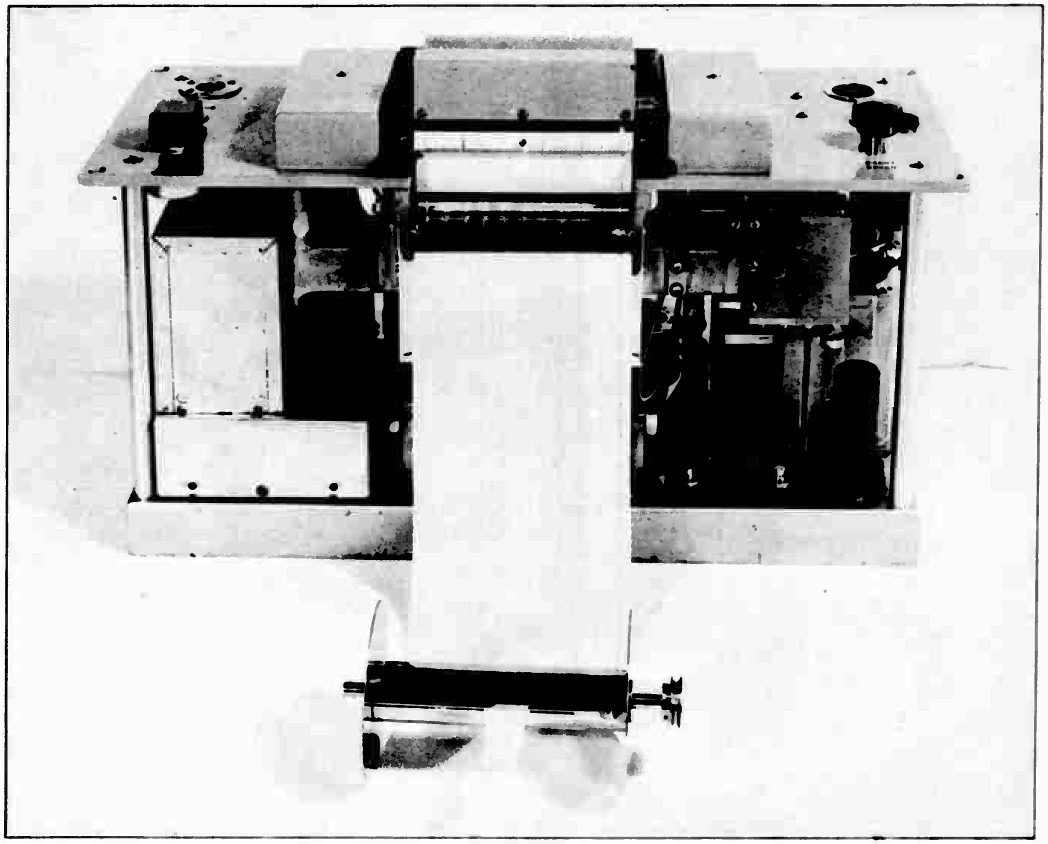


FIG. 23

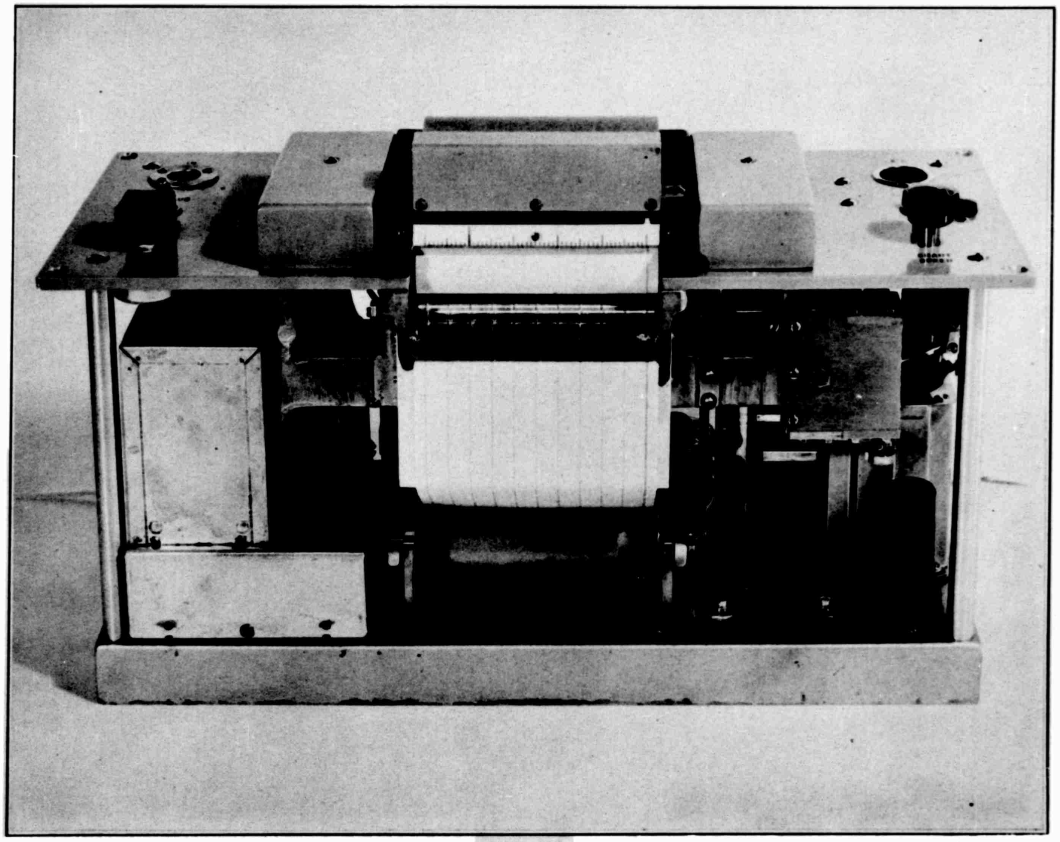


FIG. 24

A normally open S.P.S.T. microswitch was mounted to operate from a cam on the idler shaft. The microswitch controls the automatic filter-advance circuit by closing the relay which in turn controls current through the stepper solenoid. For a complete schematic diagram of the control circuit see Fig. 9.

To convert the recorder from A.C. to D.C. operation, the two changes required are removal of the A.C. motor by the four screws which hold it against the panel and to replace it with the D.C. motor; and to shift the switch located in the bottom of the recorder sub-panel (Fig. 25) by removal of the nuts retaining the terminal strip so that the letters "D.C." are visible.

Several other minor revisions were made as follows:

A ten-terminal Jones socket was mounted on the panel for the control and power circuits to the filter set, and sound level meter (Fig. 26)

When the hand-held remote control is used to turn the recorder motor on and off, considerable loss occurs in the cable, and consequently, it was found advisable to operate the recorder motor through a relay (Guardian Electric Serial 165-12VB Dual A 36) properly compensated to operate in any position and against any gravitational forces encountered in flight. This relay is mounted below the panel near the roll of waxed-paper tape.

For connecting the power supply and the recorder into one unit locating bushings were mounted as shown in Fig. 26 on the back side of the recorder.

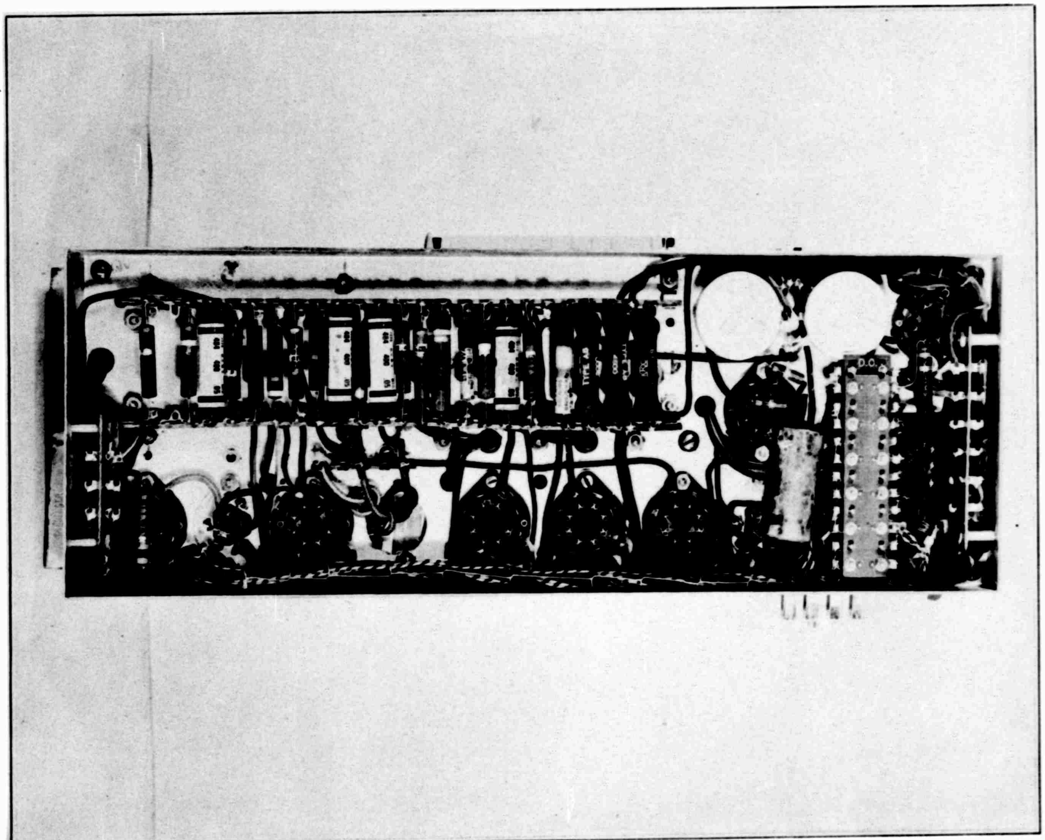


FIG. 25

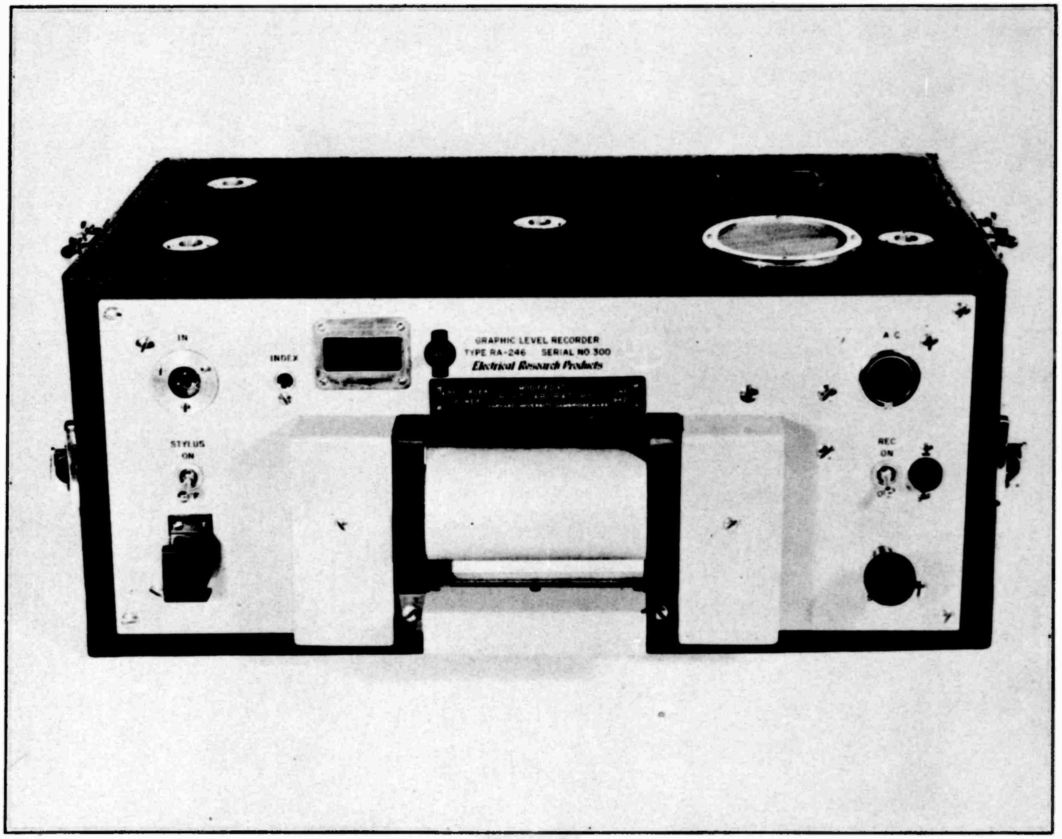

GRAPHIC LEVEL RECORDER
TYPE RA-246 SERIAL NO. 300
Electrical Research Products
IN
INDEX
STYLUS
ON
A C
REC
ON

FIG. 26

## VI. Hand-Held Remote Control Unit

To control the entire system from a remote position the operator need only operate the compact switching unit shown in Fig. 27. This instrument houses a switch to start and stop the recorder motor, an indexing switch for recording code on the edge of the recording tape, and a switch to begin an automatic cycle of band positions. The indexing switch, when fully depressed, begins the cycle of operation from an overall band through all the octave bands, and stops on the overall position. A small pilot light indicates to the operator the beginning of each cycle, and each filter advance. When the cycle is completed the light goes out. For each filter advance the light extinguishes. momentarily.

By virtue of the indexing switch always closing ahead of the starting switch there is always a record on the tape where the beginning of each cycle is. This, of course, can also be determined by the pattern of the levels of the octave bands on the wax tape. It is possible to record code, by means of the indexing switch, on the recording tape without interfering with a sequence of switching.

A schematic diagram of the switching within this unit is shown in Fig. 28, and the complete control circuit in Fig. 9.

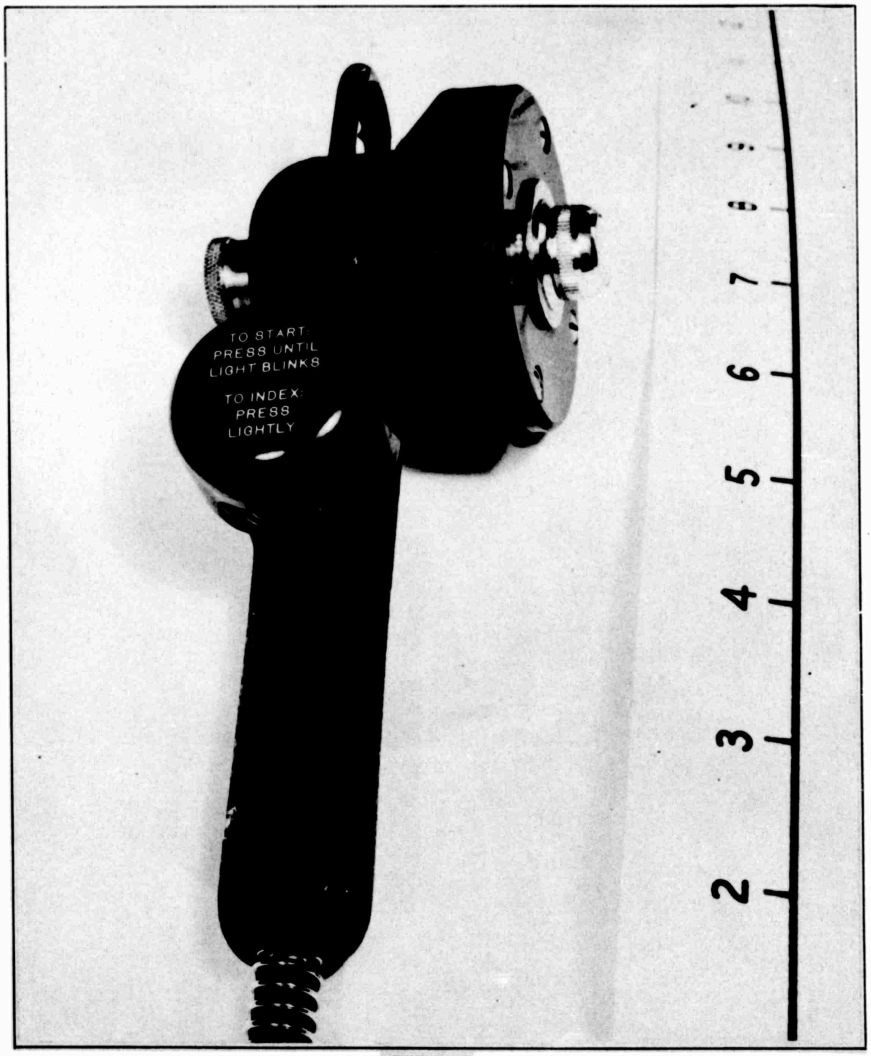
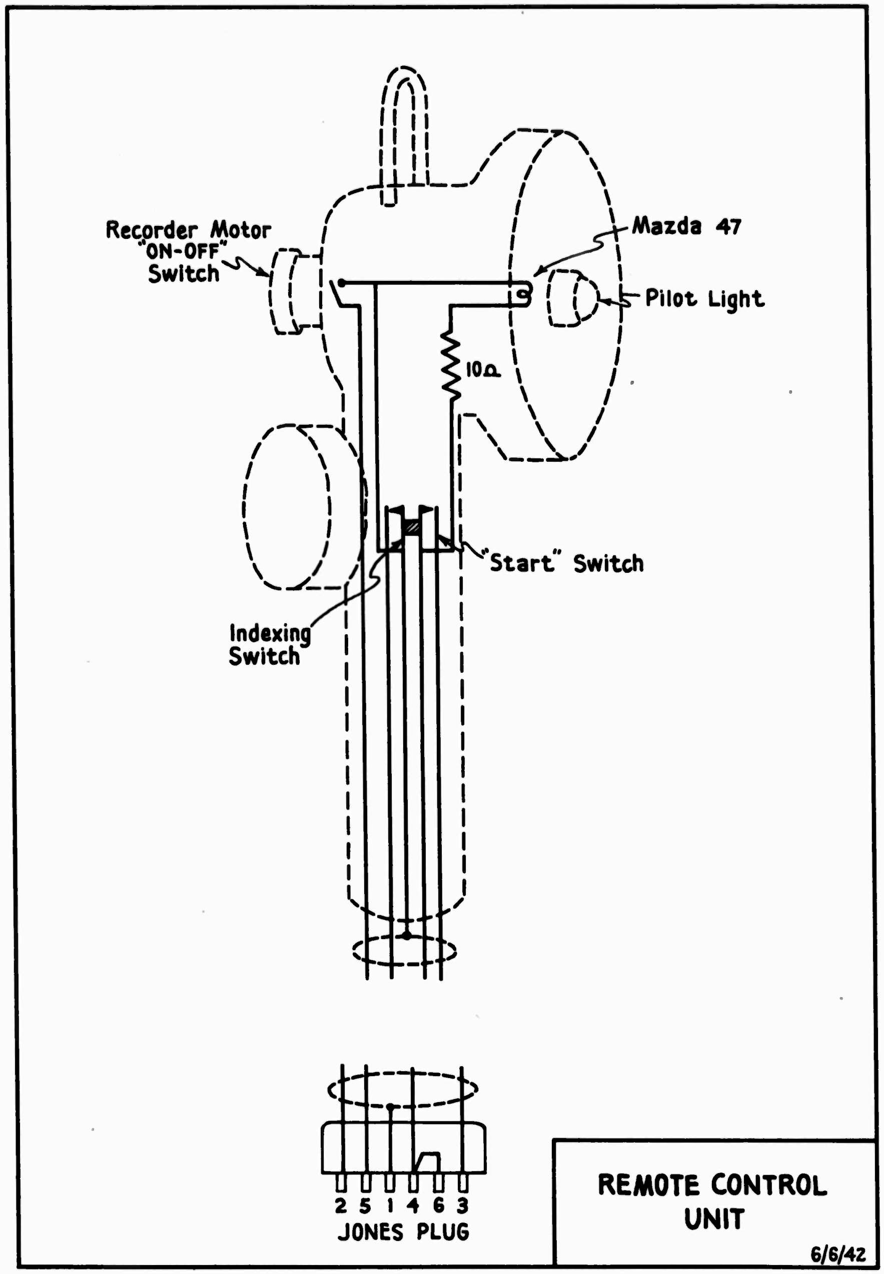

TO START:
PRESS UNTIL
LIGHT BLINKS
TO INDEX:
PRESS
LIGHTLY
2
3
4
5
6
7

FIG. 27



Recorder Motor
"ON-OFF"
Switch
Mazda 47
Pilot Light
10Ω
"Start" Switch
Indexing
Switch
2 5 1 4 6 3
JONES PLUG
REMOTE CONTROL
UNIT
6/6/42


FIG. 28

## VII. Power Supply Units

The maximum time of operation in any flight determines the total ampere hours required for the storage battery capacity. The system with all the extension cables in use as in control method "A" (Figs. 2 and 4) will operate continuously for three hours. Without the cable from the power supply to the recorder the time can be increased to four hours. "Normal" operation will permit five hours of continuous analysis and recording.

The space and load requirements excluded most types of batteries except one which was designed for motorcycles, such as the Willard MFW-5-3, a six volt, 3 cell, storage battery. Three of these batteries are used for the whole system in three schemes of supply as shown in the methods of operation, Fig. 2.

The main battery box which houses the three Willard storage batteries, and the two Burgess Z-30-N for the "B" supply is shown in Figs. 29 and 32. Terminals for the batteries are provided with bakelite cap screws. To secure the three batteries in the case against vibration, cleats are mounted lengthwise on the sides near the bottom, and an adjustable panel compresses the batteries end-to-end which permits accommodation of variations in batteries. The whole case is lined with tinned sheet iron for shielding and protection against spillage of acid.

The ventilating holes in the side of the case and the panel of the battery box provide circulation for the recorder motor.

If the power supply is divided between this source and the one adjacent to the sound level meter, (See Fig. 15) then one of the 6 volt storage batteries is replaced by a dummy spacer, and the leads to the "B" supply are terminated in a terminal block to prevent short-circuiting (Fig. 32).

An auxiliary battery box for remote control method "B" is also provided, and is shown in Fig. 30. This box is sufficiently large enough to hold one 6 volt storage battery and the two Burgess Z30N's. The cable for this supply is interchangeable with the cable from the supply adjacent to the sound level meter to the filter.

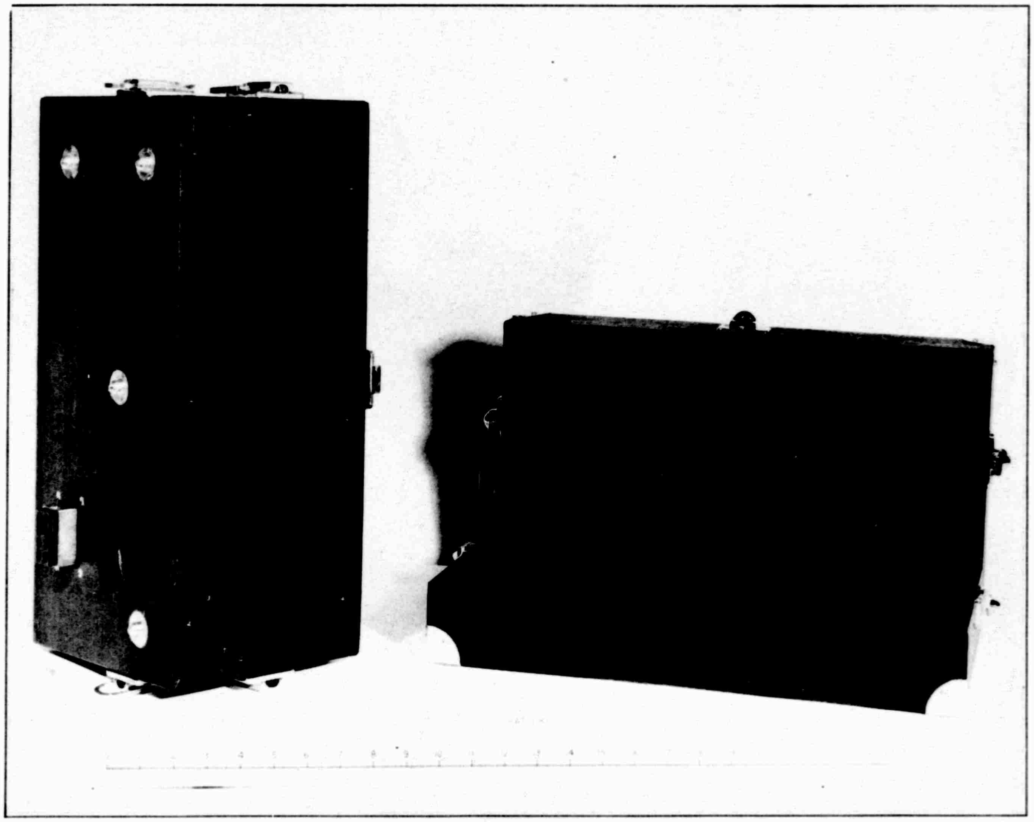


FIG. 29

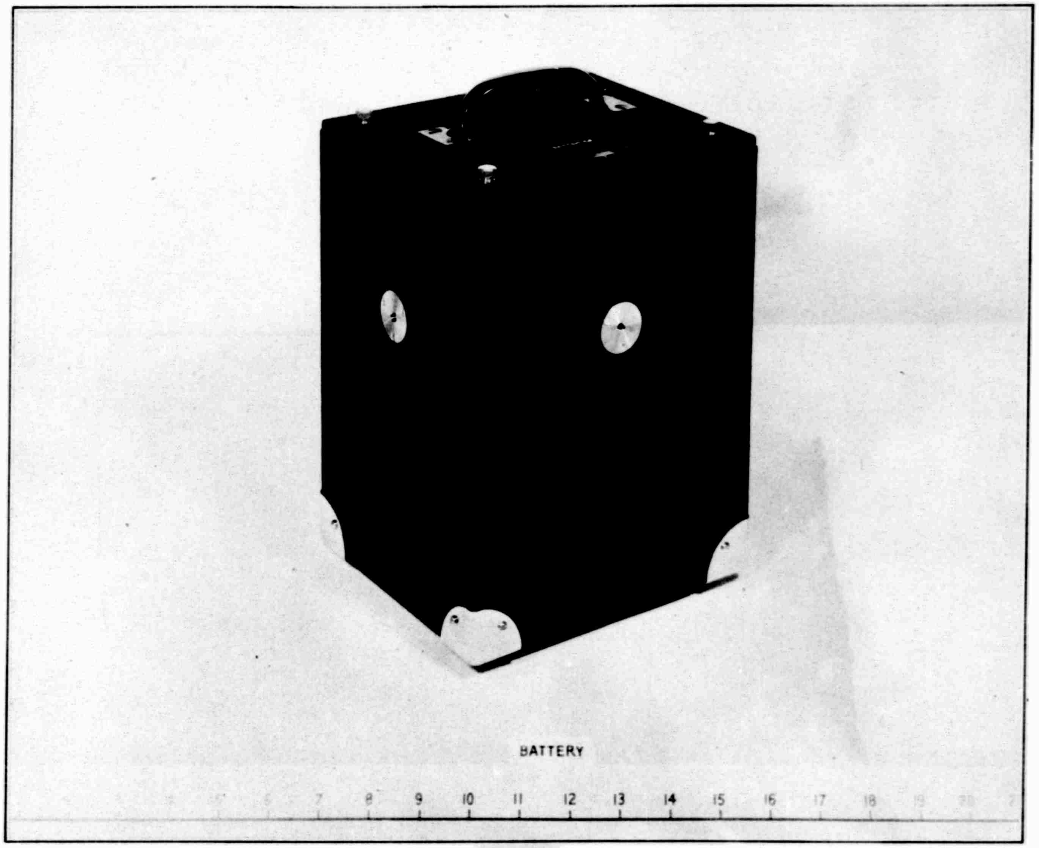



**FIG. 30**

## VIII. Cases

In order to obtain speed in installation of this equipment in planes, as test flights are usually available on extremely short notice, it was paramount that the number of pieces to be installed be an absolute minimum, yet be small enough and flexible enough to be mounted in almost any available space. This resulted in a design of carrying cases which combined an extremely efficient compromise between portability and number of pieces, as well as providing space for all the cables, microphone, and remote control unit without increasing the number of cases to be carried. The carrying cases are shown complete in Fig. 31.

The four units, recorder, filter, sound-level meter, and power supply can be used separately, or can be clamped together to form two units which can be strapped into the plane by means of shock cords fastened to screw eyes which can be screwed into tapped bushings which are located on every side of each case.

Where two units are to be mounted together extremely accurate alignment is required in view of the Jones plug connections which must be made. Four locating studs and bushings, which are mounted with very close tolerances, are provided on the sides which are face to face, thus relieving the Jones plug connections of any stresses (See Figs. 6 and 32 for details). The bushings located in the center of the sides are also tapped to receive screw-eyes in case individual mounting is required. Clamping the two units together is accomplished with Eagle Auto-trunk locks which also serve to secure the lids when the instruments are to be carried (See Figs. 31 and 32.

The filter case, Fig. 33, is shielded with thin copper sheet, and it was found necessary to prevent electrical contact between the two cases (filter and amplifier) by insulating all the bushings and hasps which were in common between the two cases. This prevented the existence of ground loops and consequent hum pick-up by removing the multiple sources of ground in the two units.

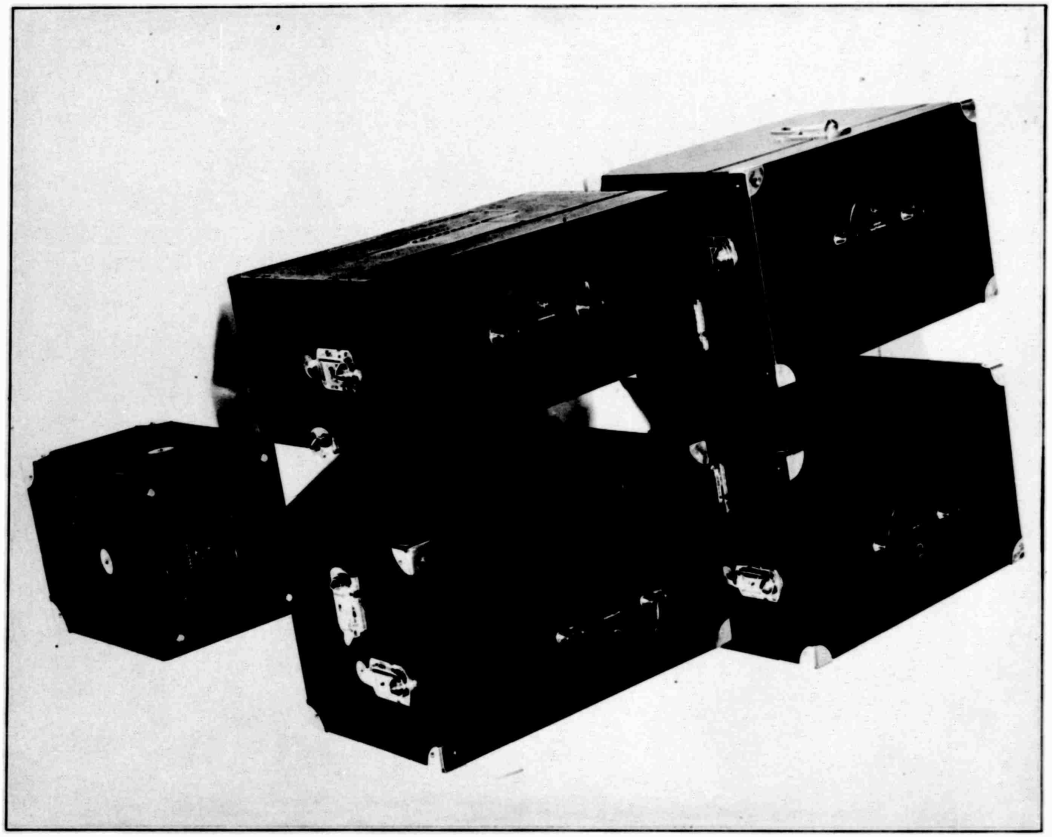


FIG. 31

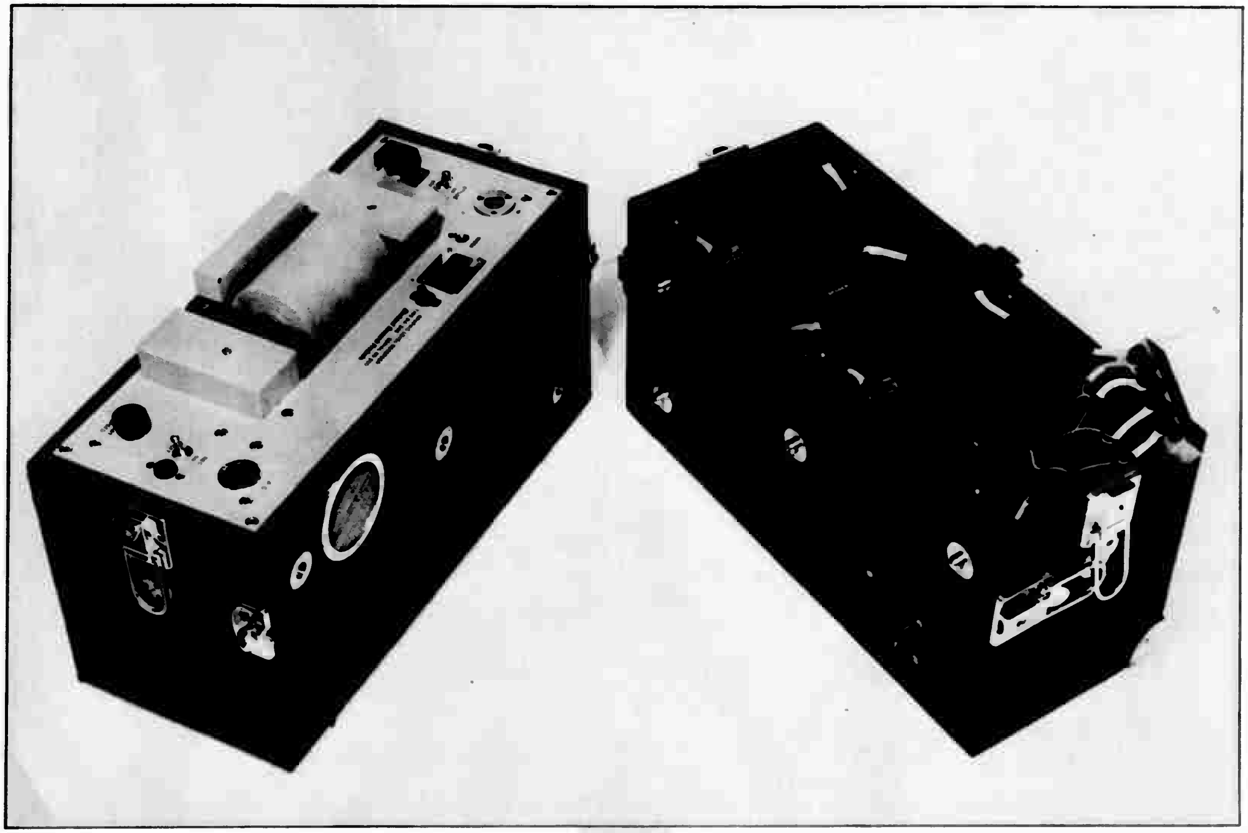


FIG. 32

3 29

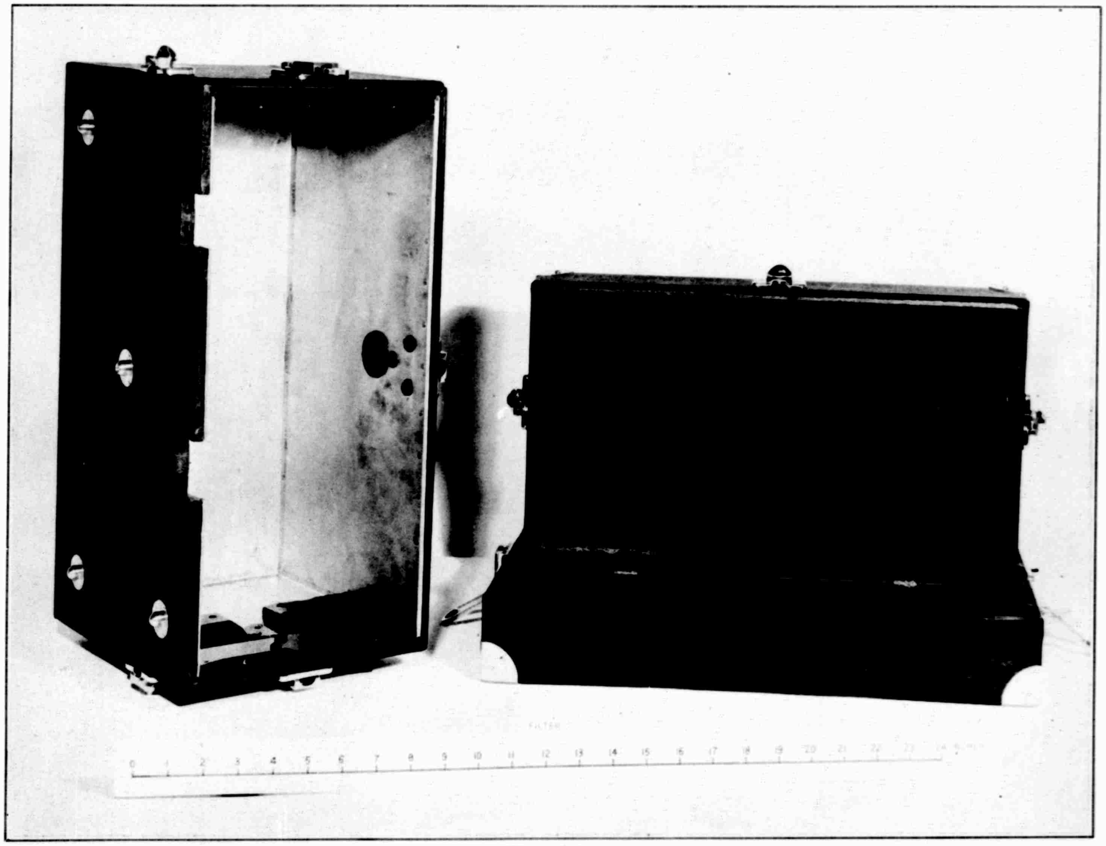


FIG. 33

The covers for the cases were designed to accommodate all the cables, microphone, and remote control, as well as serving to protect the locating bushings from being mutilated in transportation. Special brackets and clamps were installed to secure the cabling as shown in Figs. 33 and 34.

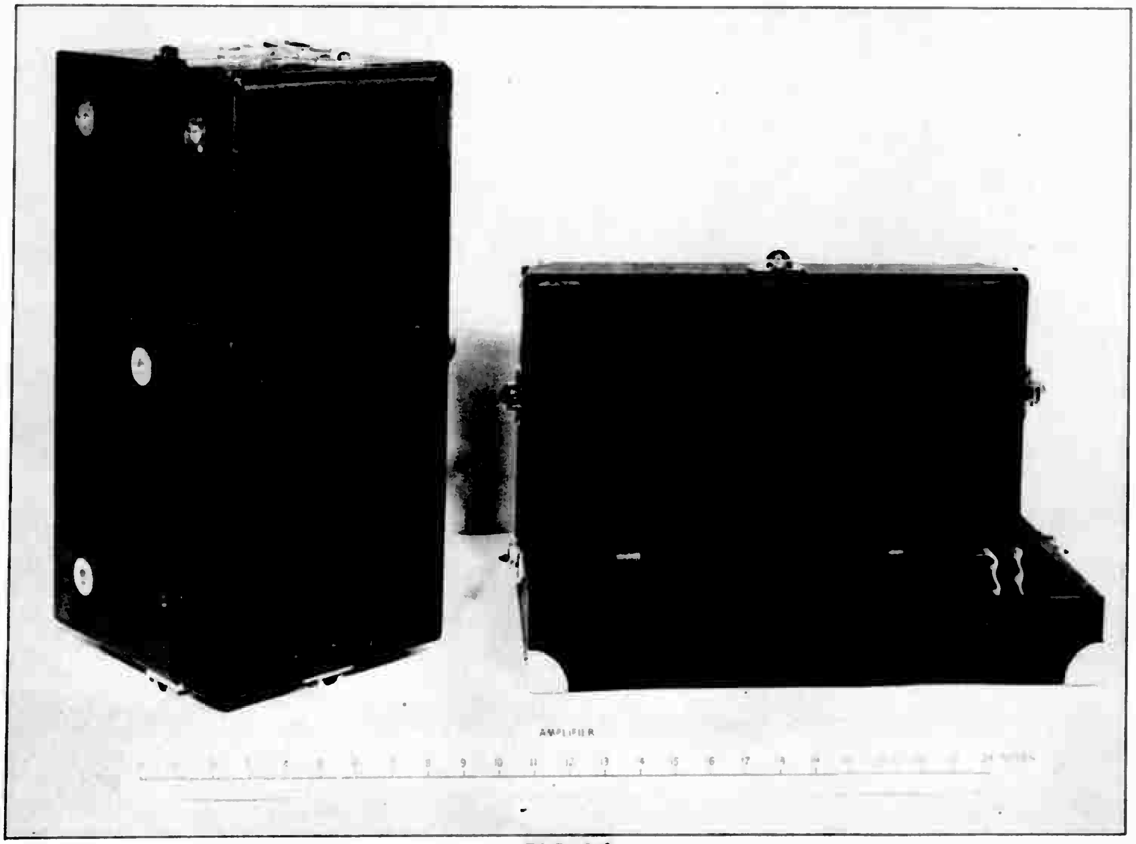



FIG. 34

## IX. Calibration of Equipment

To obtain readings on this equipment which indicate reliably the sound levels of the noise under investigation, the whole system must be carefully calibrated. This requires acoustic and electric calibration techniques.

For the Western Electric type 633-A microphone, a free field, open circuit, random incidence calibration is given in Fig. 35.

The electrical calibration of the filter set and the sound level meter is obtained by inserting a known signal from a standard type beat frequency oscillator in series with the microphone while the filter and sound level meter are properly connected. The output of the oscillator is measured with an accurately calibrated high impedance voltmeter. The schematic circuit showing all the elements used for calibration is in Fig. 36. The battery voltages for the sound level meter should all be checked before calibration is attempted. For the different bands, the automatic attenuator is thrown in and out to obtain its insertion loss. The position of the attenuator in the sound level meter should be adjusted to give a reading on the output meter between -2 and +3 db when calibrating. This is advisable because of the slight difference one obtains from reading the meter at the low end of the scale as compared to the high end.

The high impedance voltmeter was calibrated with an accuracy of ±0.1 db by use of a Weston Model 341 AC-DC voltmeter and a precision voltage divider.

The response of the amplifier alone, and the insertion loss of the filter for all positions is given in Fig. 37. The insertion loss for the automatic attenuater is also tabulated in this figure.

In order for the whole system to be calibrated acoustically it is necessary to compute a correction factor for each point on the overall response curve, as well as the individual octave bands. These are computed as follows:

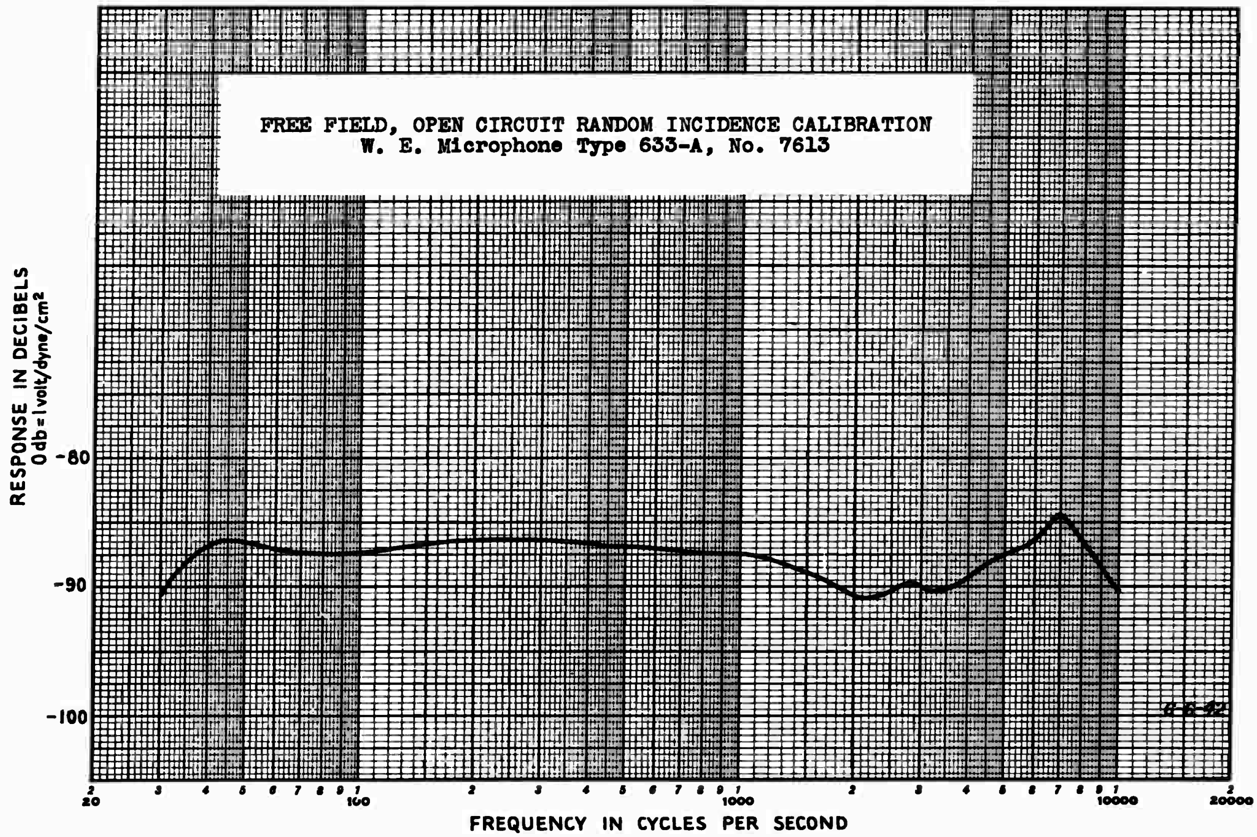
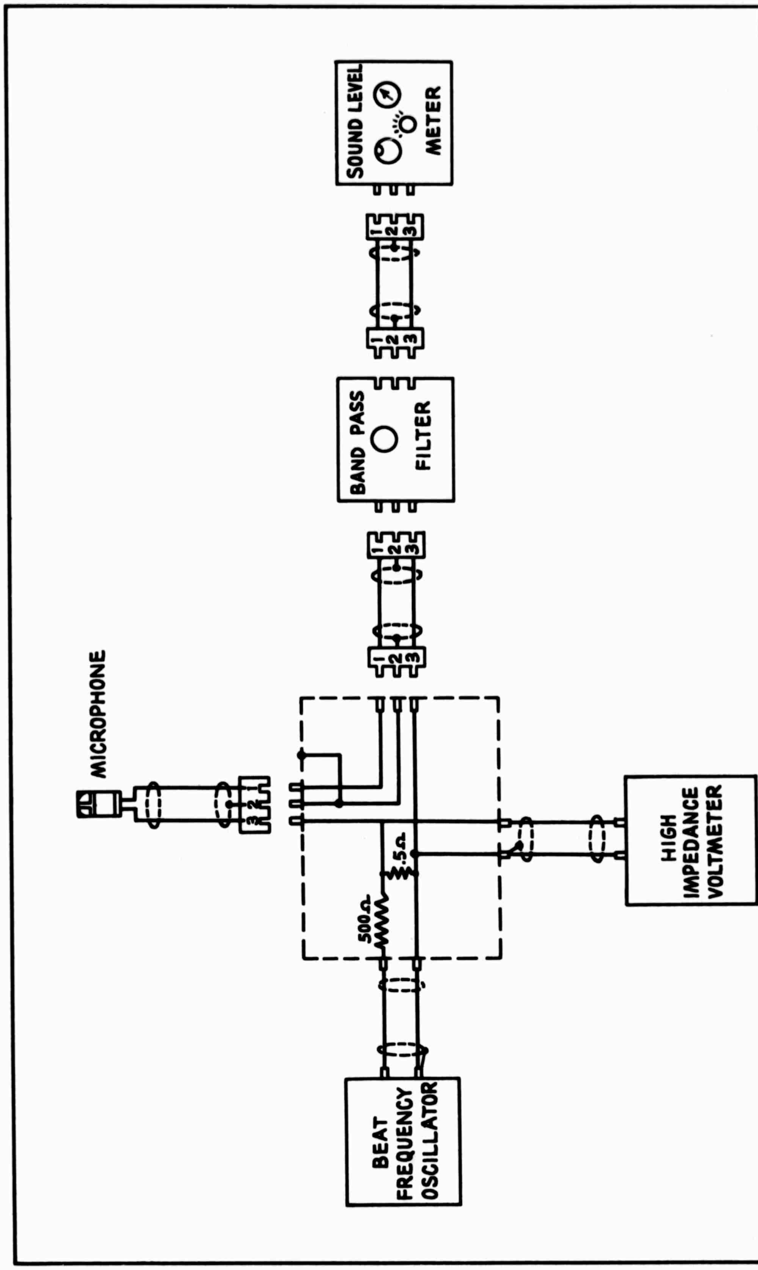

FREE FIELD, OPEN CIRCUIT RANDOM INCIDENCE CALIBRATION
W. E. Microphone Type 633-A, No. 7613
RESPONSE IN DECIBELS
0 db = 1 volt/dyne/cm²
-80
-90
-100
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

FIG. 35

3 40

54

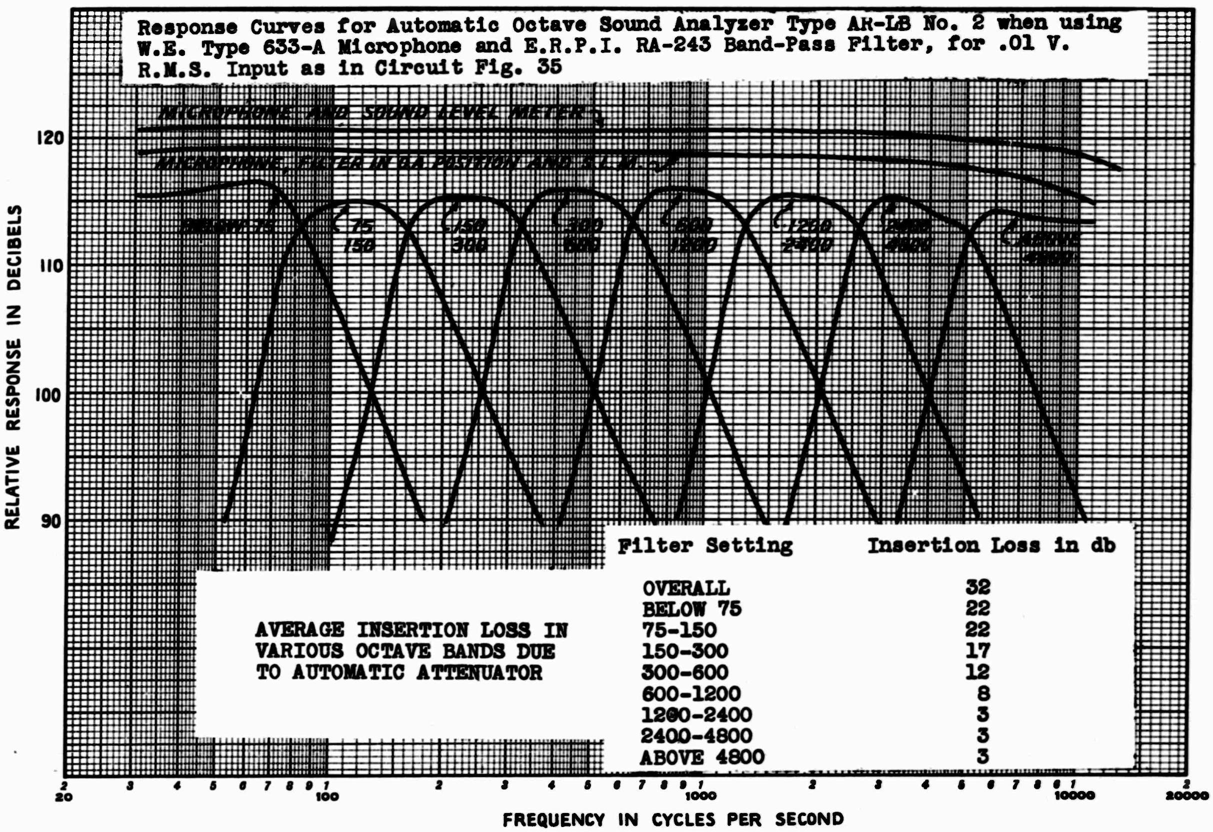
3 42




CIRCUIT FOR ELECTRICAL CALIBRATION

FIG. 36

Response Curves for Automatic Octave Sound Analyzer Type AR-LB No. 2 when using W.E. Type 633-A Microphone and E.R.P.I. RA-243 Band-Pass Filter, for .01 V. R.M.S. Input as in Circuit Fig. 35




AVERAGE INSERTION LOSS IN VARIOUS OCTAVE BANDS DUE TO AUTOMATIC ATTENUATOR

| Filter Setting | Insertion Loss in db |
|---|---|
| OVERALL | 32 |
| BELOW 75 | 22 |
| 75-150 | 22 |
| 150-300 | 17 |
| 300-600 | 12 |
| 600-1200 | 8 |
| 1200-2400 | 3 |
| 2400-4800 | 3 |
| ABOVE 4800 | 3 |

FIG. 37

From the calibration curve (Fig. 35) of the microphone we find that the microphone has a sensitivity at 1000 c.p.s. of -87.6 db relative to 1 volt per dyne/cm$^2$. In other words, the microphone will develop an open circuit voltage of 87.6 db below 1 volt for a sound pressure of 1 dyne/cm$^2$. Using a reference level 0.000204 dyne/cm$^2$. as 0 db, this represents a sound pressure of +73.8 db. The signal introduced into the input was held constant at .01 volt which is 40 db below 1 volt. In order for the microphone output to be .01 volt a certain sound pressure is required. This at 1000 cycles per second is equal to 73.8 + (87.6-40) = 121.4 db.

However, at 1000 cycles the sound level meter reads only 118.7 db with the filter in the "overall" position (calibration in Fig. 37), and therefore, it reads 121.4-118.7 = 2.7 db too low. To read r.m.s. sound pressures accurately, 2.7 db must be added to the "overall" reading at 1000 cycles. Other points are obtained similarly which gives the correction curves in Fig. 38. It must be kept in mind that these corrections are for pure tones only as indicated on the curves.

When the noise being measured is more or less continuous such as is encountered in aircraft spectra, then "average" corrections must be applied. This "average" correction factor can be explained as follows:

The indicators used for the sound level meter and the graphic level recorder possess rectification characteristics which are not only dissimilar, but also have characteristics dependent on the complexity of the impressed wave form. Thus, if one chooses factors for the individual bands, as well as the overall position, to make the two systems agree for, say a square wave signal, then this factor will not hold for a signal such as thermal noise. It is, therefore, necessary to make a comparison of results obtained by the two indicators for a range of typical airplane spectra, and choose a factor to make them agree. It has been found in general that if the recorder is adjusted to read the same as the sound level meter for a single frequency, the recorder will read 1 to 2 db lower when the two indicators are subjected to a typical airplane spectra.

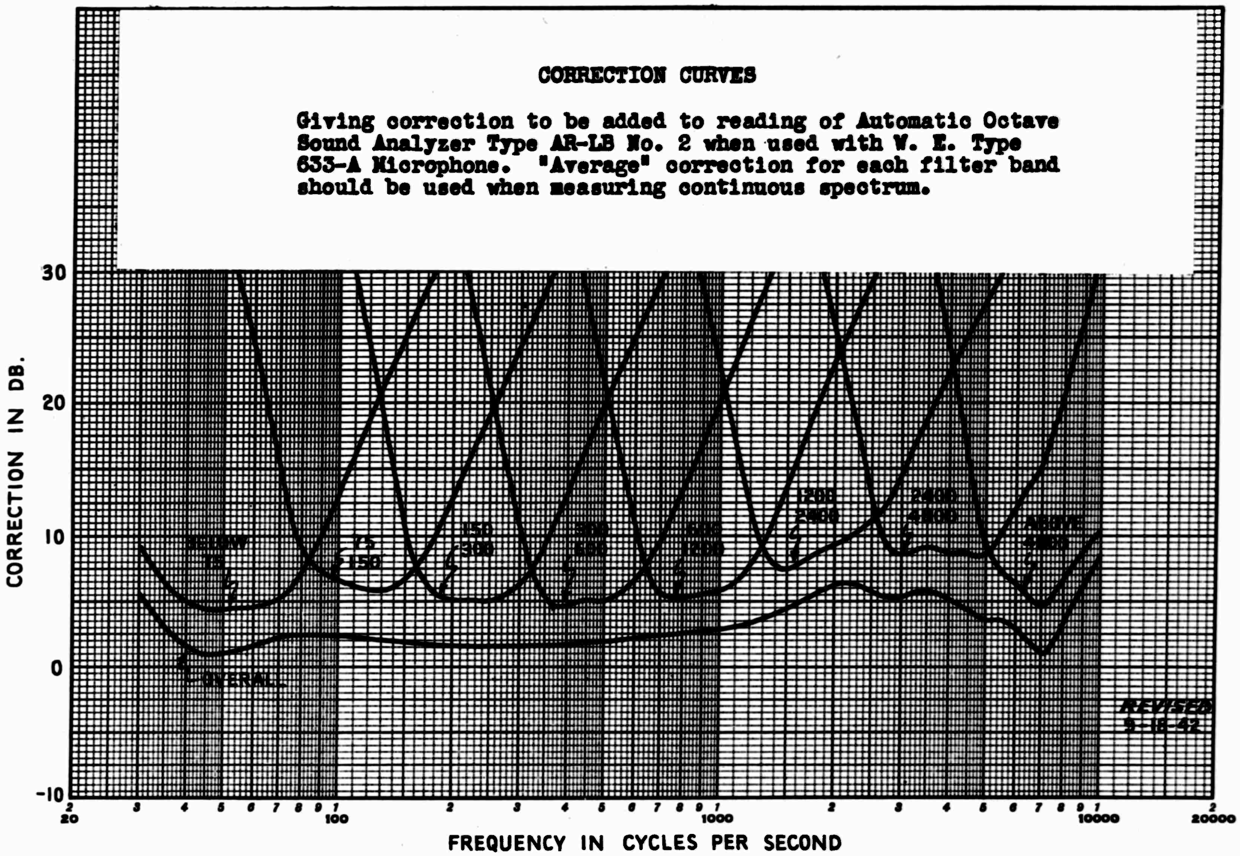

CORRECTION CURVES
Giving correction to be added to reading of Automatic Octave Sound Analyzer Type AR-LB No. 2 when used with W. E. Type 633-A Microphone. "Average" correction for each filter band should be used when measuring continuous spectrum.
CORRECTION IN DB.
30
20
10
0
-10
75
150
150
300
1200
2400
2400
4800
OVERALL
REVISED
9-18-42
20
100
1000
10000
20000
FREQUENCY IN CYCLES PER SECOND

FIG. 38

Most military organizations in the United States use the E.R.P.I. RA-277G Sound Frequency Analyzer in conjunction with the 630-A, i.e., "8" ball, type of microphone instead of the 633-A type. Correction factors - to meter readings obtained on the apparatus described in this report - for giving results equal to corrected meter readings obtained with the 630-A microphone are tabulated below.

| Filter Setting (Attenuator Out) | | Correction in db to be added |
|---|---|---|
| Overall | - | 3 |
| Below 75 | - | 6 |
| 75 - 150 | - | 7 |
| 150 - 300 | - | 5 |
| 300 - 600 | - | 5 |
| 600 - 1200 | - | 7 |
| 1200 - 2400 | - | 9 |
| 2400 - 4800 | - | 9 |
| Above 4800 | - | 6 |

A fuller discussion of the correction factors for several types of . systems was contained in a previous report "Sound Levels in U. S. Military Airplanes" May 20, 1942, by H. W. Rudmose, R. L. Wallace, Jr., H. L. Ericson, and L. L. Beranek, Director. For ease of reference this discussion is reprinted with slight deletions in the Appendix.

# APPENDIX *

## 1. Apparatus

The data presented in this report* were taken with several different sets of apparatus, all of which, however, were composed of basic units purchased from one manufacturer. Similar apparatus is possessed by the Army Air Forces Materiel Division, Wright Field, the Naval Aircraft Factory, the Aberdeen Proving Ground and several of the leading aircraft companies. Each of these sets of apparatus should be equally reliable if carefully calibrated against the same standard and if the calibration is carefully and frequently checked in the field.

The question of careful and frequent calibration tion is so important that some space will be devoted to this subject in the next section.

Briefly described, the apparatus consists of a dynamic type microphone, an octave band pass filter set, and an automatic graphic level recorder. The sound frequency analyzer when used with the dynamic microphone enables one to read on its output meter the root-mean-square sound pressure at the microphone in decibels with respect to a reference level of 0.000204 dynes per $cm^2$. This is the sound pressure which would be measured in a plane traveling wave along which $10^{-16}$ watt per $cm^2$ is being transferred. In all of the measurements the amplifier characteristic was maintained "flat" since the characteristic of the ear at the high sound levels encountered in airplanes is very nearly that way.

For convenience in referring to the apparatus the following tabulation is made:

System No. 1 -- Cruft Laboratory

E.R.P.I. [1] Type 277-G Sound Frequency Analyzer Serial No. 241

[1] Electrical Research Products Co. Inc., 300 Central Avenue, Kearny, New Jersey

* Excerpt from National Research Council Committee on Sound Control report entitled "Sound Level Measurements in U. S. Military Airplanes" dated May 20, 1942.

W. E. Type 630-A Microphone Serial No.AR-LB

E.R.P.I. Type RA-246 Graphic Level Recorder

E.R.P.I. Type RA-243 Octave Filter Set
Serial No. 8

System No. 2 -- Cruft Laboratory

E.R.P.I. Type Ra-273 Industrial Noise
Analyzer, Serial No. 256

W. E. Type 630-A Microphone Serial No. 2826

System No. 3 -- Cruft Laboratory

Cruft Automatic Octave Sound Analyzer Type
AR-LB Serial No. 1

W. E. Type 630-A Microphone Serial No. 3547

E.R.P.I. Type RA-246 Revised Graphic Level
Recorder

System No. 4 -- Naval Aircraft Factory

E.R.P.I. Type 277 G Sound Frequency
Analyzer Serial No. 238

W. E. Type 630-A Microphone Serial No. 3127

E.R.P.I. Type RA-246 Graphic Level Recorder

E.R.P.I. Type RA-243 Octave Filter Set
Serial No. 19

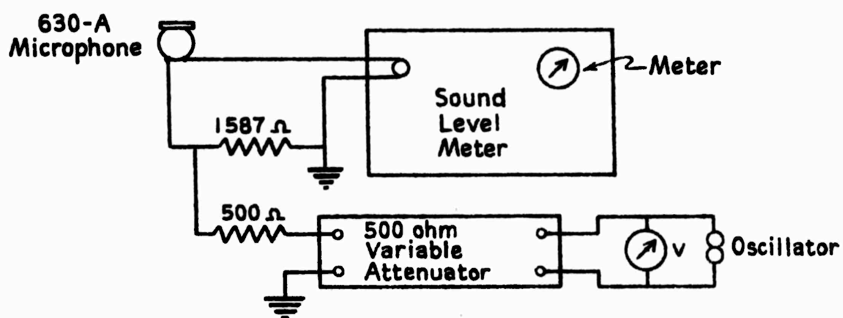
## II. Calibration of the Apparatus

The microphone is calibrated in a plane wave sound field by comparison with a secondary standard. For our purposes a W. E. 640-A condenser microphone was sent to the National Bureau of Standards for comparison against their primary standard. This same microphone was also calibrated by a reciprocity method in our own laboratories. These two calibrations are in good agreement.

The open circuit, free field calibration of a microphone at a given frequency is defined as the ratio of the open circuit voltage generated by the microphone to the sound pressure at the microphone position prior to its insertion into the progressive plane wave sound field.

Since the readings of the sound analyzers are given in terms of the Acoustical Society of America's reference level of 0.000204 dyne per $cm^2$, one dyne per $cm^2$ corresponds to a sound pressure level of 73.8 decibels. Usually the open circuit voltage generated is expressed in decibels below one volt. If, for example, according to the calibration curve, at 1000 c.p.s. the sensitivity is -50 db; this means that the microphone will produce an open circuit voltage 50 db below one volt for an impressed sound pressure level of 73.8 db. For a sound pressure level of 100 db the microphone will produce an open circuit voltage of -23.8 db (re one volt) or .065 volts.

To check the calibration of the sound analyzer, the circuit shown here is employed.



The oscillator generates a voltage which is reduced 50 db by the fixed pad and an additional number of db by the variable attenuator. If the voltage V is set at 1.0 volt and the attenuator reading plus 50 db is set equal to the number of negative decibels given on the calibration curve of the microphone, then the meter on the analyzer should read 73.8 decibels. This assumes, of course, that the microphone calibration is given in db above one volt with respect to a sound pressure of one dyne per $cm^2$. If the meter does not read 73.8 db at all frequencies then a correction curve should be plotted and all data taken with the instrument corrected accordingly. (See pages 66 through 72)

It is usually found that the calibration of the type 630-A microphone is quite stable over a period of time. Hence, in practice, it is sufficient to perform an electrical calibration on the apparatus as described above. The microphone with careful handling should be calibrated about once a year. If subjected to rough handling, its calibration should be checked more often.

If an octave filter set is built into the analyzer or is connected between the analyzer and the microphone, the same method of calibration should be use. It is necessary, however, to perform the calibration as a function of frequency for each band pass setting of the octave filter.

On the following pages calibrations are given for three of the microphones listed above. Relative response curves are also given for the sound analyzers.

In flight, data were obtained either from direct observation of the output meter or from records of the graphic level recorder. The observed or recorded readings were then corrected with certain established correction factors, and these corrected data then plotted.

In choosing correction factors to the data as obtained from the meter reading or from wax tape records several things must be considered. First, it is not sufficient to use a calibration of the microphone for a sound traveling parallel to the plane of the diaphragm. Noise in airplanes usually strikes the microphone at random angles of incidence. Hence, a calibration curve for the microphone in randomly incident sound must be obtained. This was done in our case by averaging the calibration curves obtained for a large number of angles of incidence according to conventional methods. Secondly, the choice of correction factors obtained from pure tone calibration of the apparatus depends upon the law of summation of the instrument from which the data are obtained. The indicating device should sum voltages according to a square law characteristic in order that its readings be proportional to energy. If the instrument has a square law characteristic, then the insertion losses can be chosen from the single frequency calibration curves of the equipment.

The meters used in systems 1, 2, and 4 are essentially "square law" meters; whereas, the meter in system 3 and the recorders used for all of the systems are not.

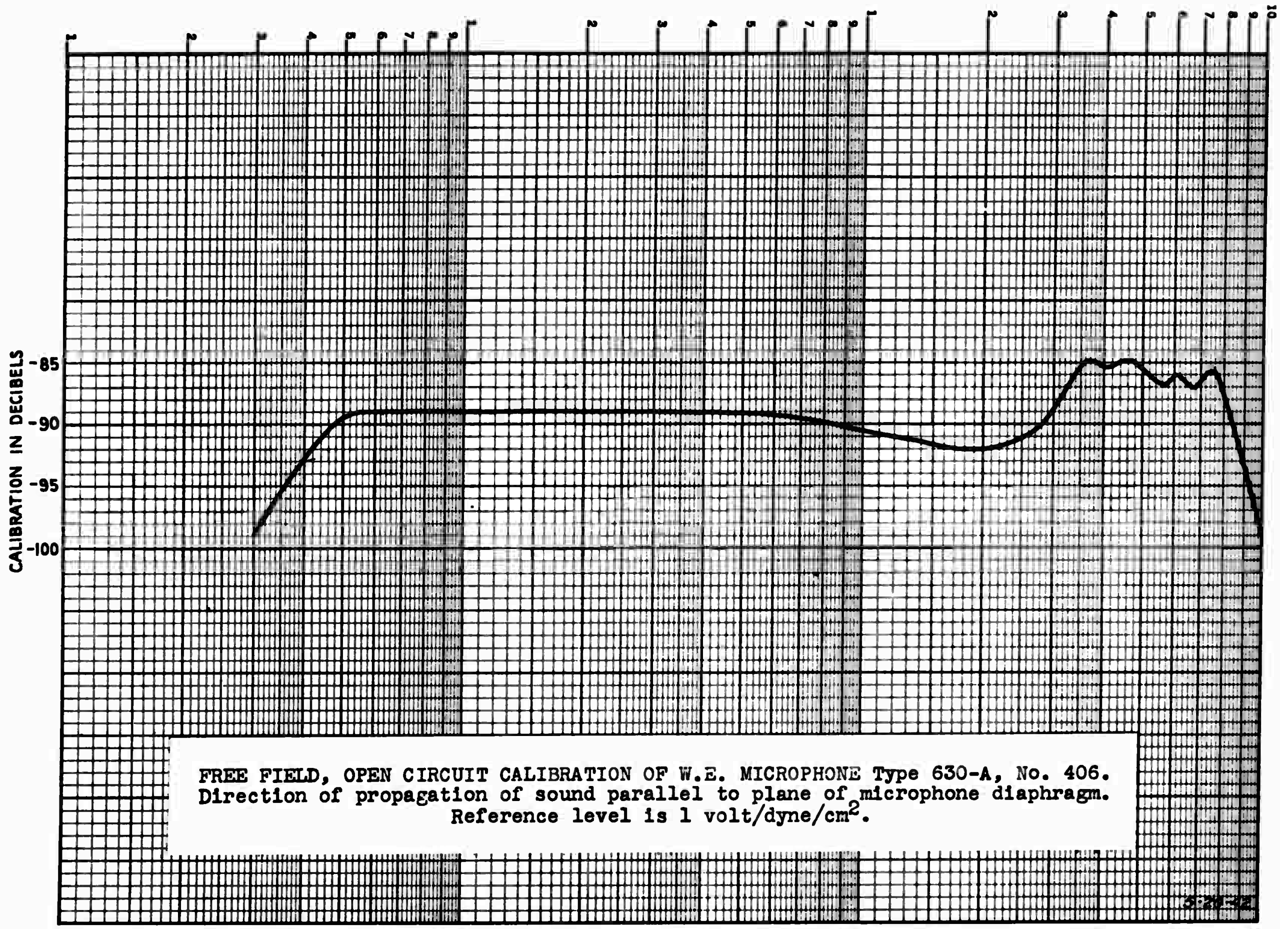
A comparison of the results obtained when a wide range of typical airplane spectra are measured by the two systems indicates that correction factors can be chosen which will make the data obtained from the two systems agree. These correction factors are listed in Table 1, page 72.

It should be pointed out that the gain of the recorder can be adjusted so that its readings will agree with those of the meter only if it is calibrated against a complex tone or noise. If the gain of the recorder is set so that the data from the meter and recorder agree for single frequencies (such as a local internal oscillator), then the recorder will read from one to two decibels lower than the meter when an airplane noise is applied to the microphone.

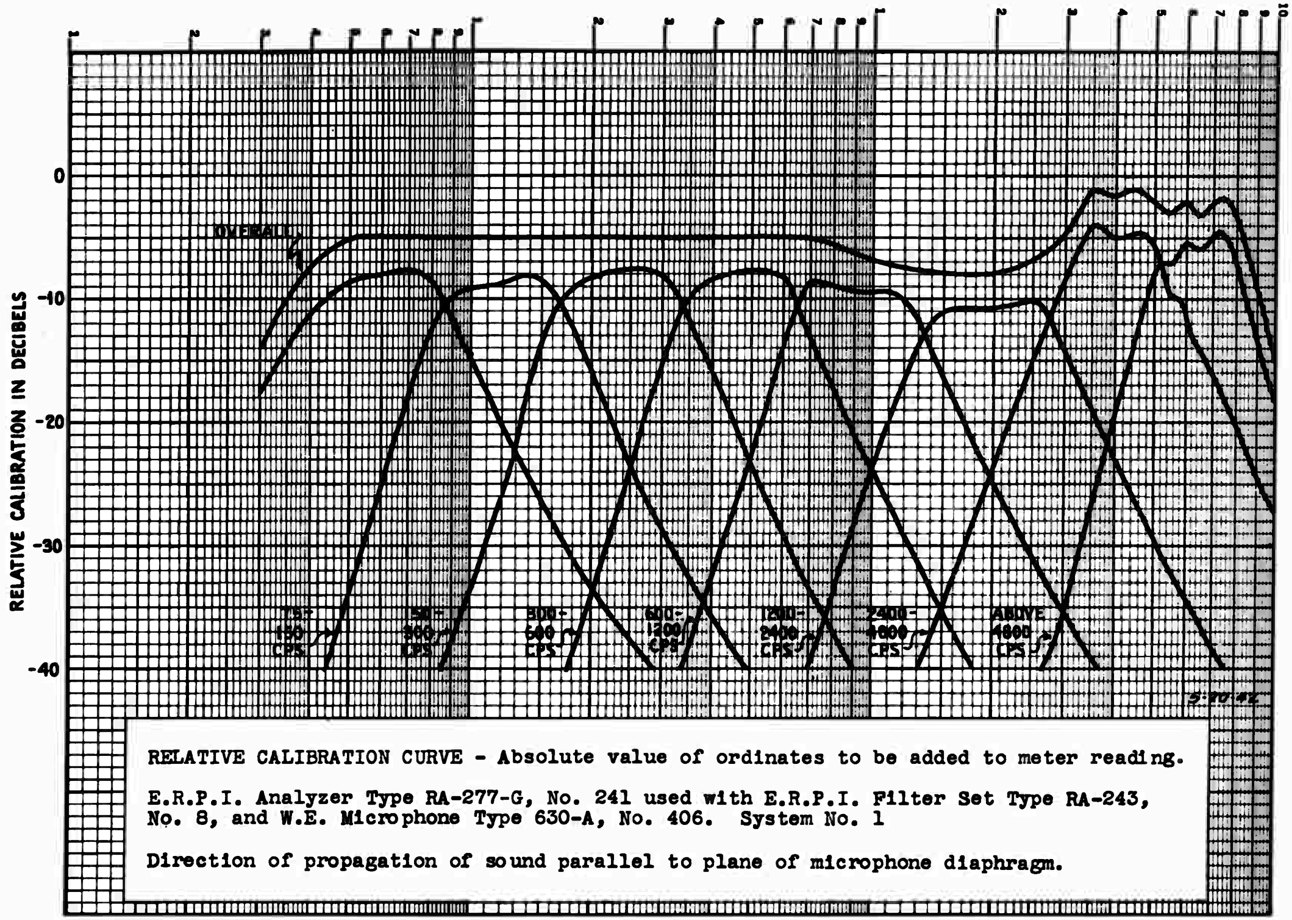
It is also true that if the correction factors for the square law and non-square law instruments are chosen to make the systems agree for single frequency inputs, then the non-square law system will indicate one to two decibels too low when airplane noise is being measured. This difference of one or two decibels applies <u>only</u> when the non-square law instrument is measuring airplane spectra. For other types of noise, entirely different results, depending upon the character of the spectrum, may be expected.

E.R.P.I.'s usual practice seems to be to calibrate their equipment approximately two decibels too sensitive. This has also been observed by P. Huber and J. Whitmore in the Journal of the Acoustical Society of America, Vol. 12, page 168, Fig. 2, July, 1940. We have checked three different systems here and have found in each case that they indicate one to three decibels too high for pure tone inputs.

Two reasons can be advanced for the E.R.P.I. calibration being too sensitive. In the first place, they have used the thermophone method of calibration as a means of determining the absolute reference level of their standards. This method has been shown to yield results 1.5 db different from those yielded by the reciprocity method of calibration. Both the Bureau of Standards and the Cruft Laboratory have adopted the reciprocity method of calibration as standard. For further information on this subject, refer to National Bureau of Standards research paper RP 1341 entitled Absolute Pressure Calibrations of Microphones by Richard K. Cook. This was also printed in the Journal of Research of the National Bureau of Standards, Volume 25, November, 1940.



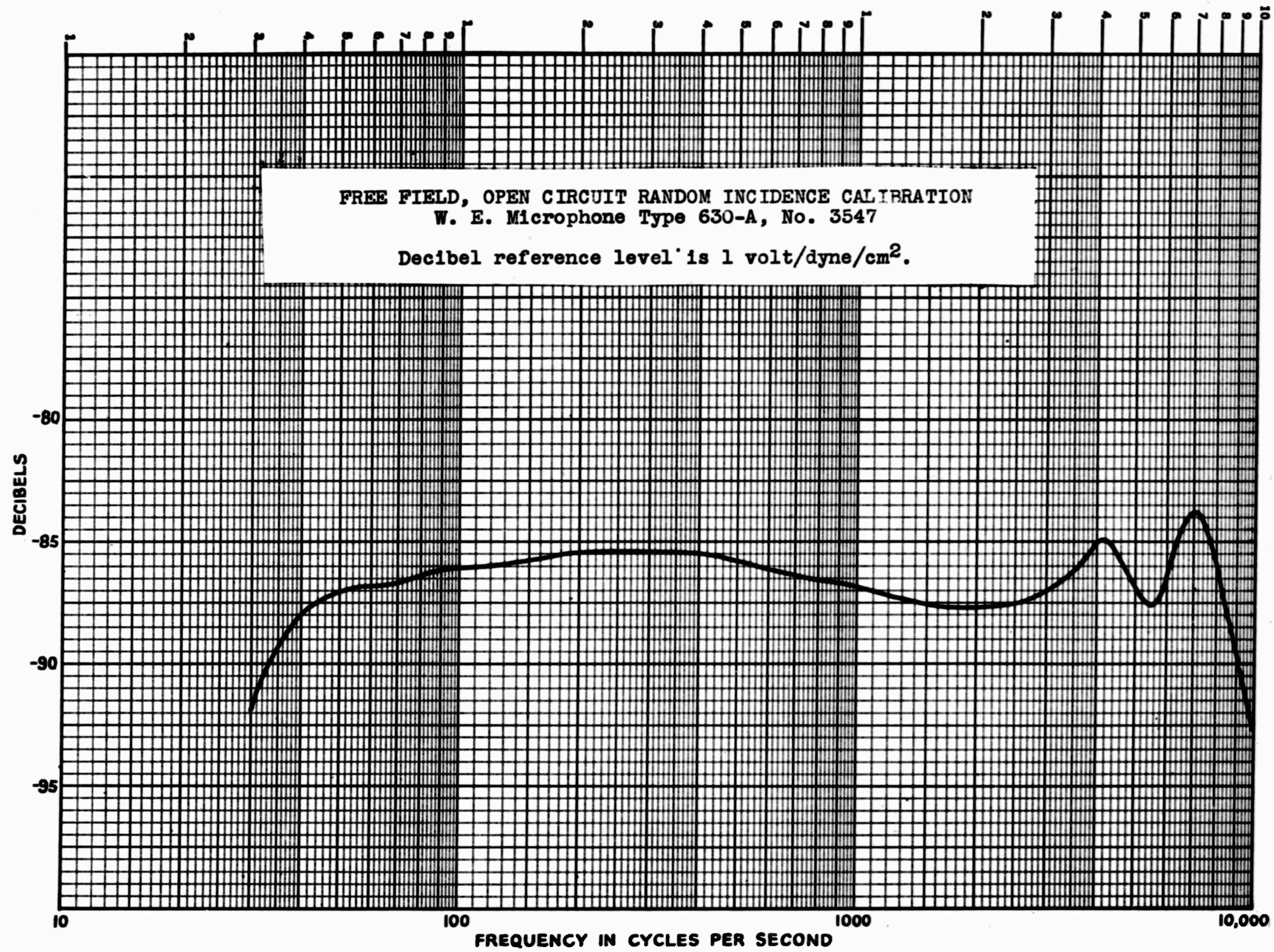

FREE FIELD, OPEN CIRCUIT CALIBRATION OF W.E. MICROPHONE Type 630-A, No. 406.
Direction of propagation of sound parallel to plane of microphone diaphragm.
Reference level is 1 volt/dyne/cm$^2$.



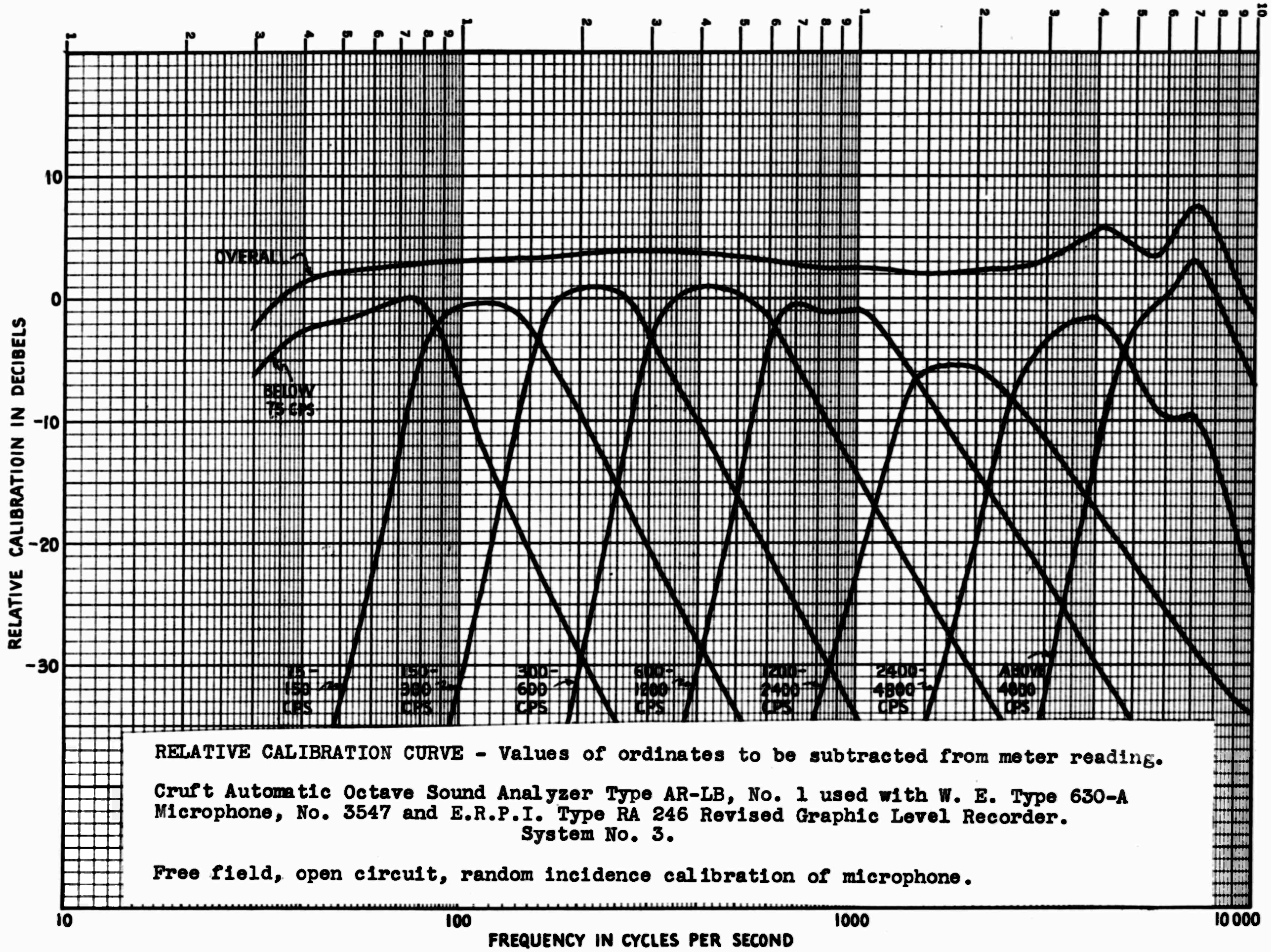

RELATIVE CALIBRATION CURVE - Absolute value of ordinates to be added to meter reading.

E.R.P.I. Analyzer Type RA-277-G, No. 241 used with E.R.P.I. Filter Set Type RA-243, No. 8, and W.E. Microphone Type 630-A, No. 406. System No. 1

Direction of propagation of sound parallel to plane of microphone diaphragm.


FREE FIELD, OPEN CIRCUIT RANDOM INCIDENCE CALIBRATION
W. E. Microphone Type 630-A, No. 3547
Decibel reference level is 1 volt/dyne/cm2.
-80
-85
-90
-95
DECIBELS
10
100
1000
10,000
FREQUENCY IN CYCLES PER SECOND

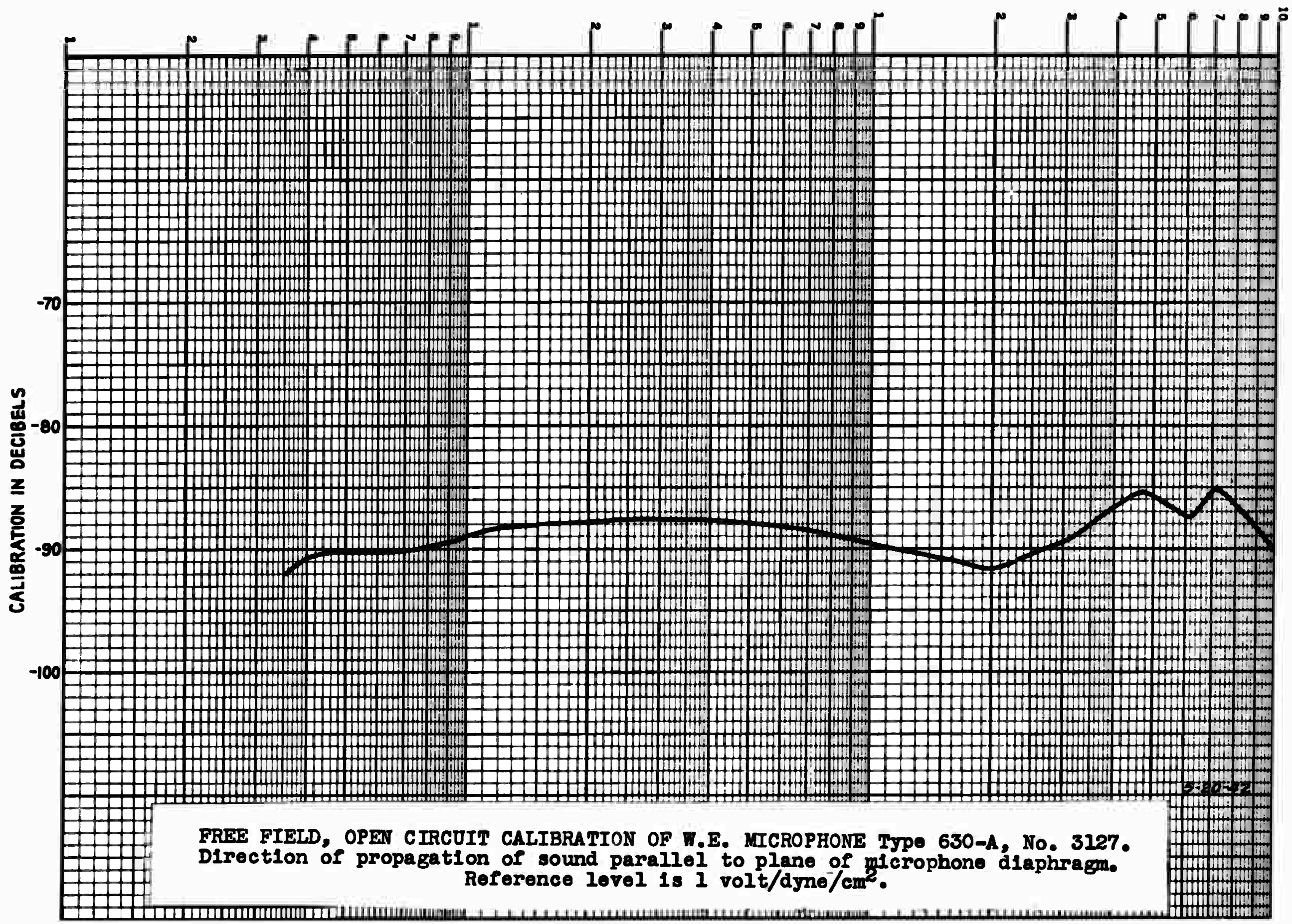
3 36




RELATIVE CALIBRATION CURVE - Values of ordinates to be subtracted from meter reading.

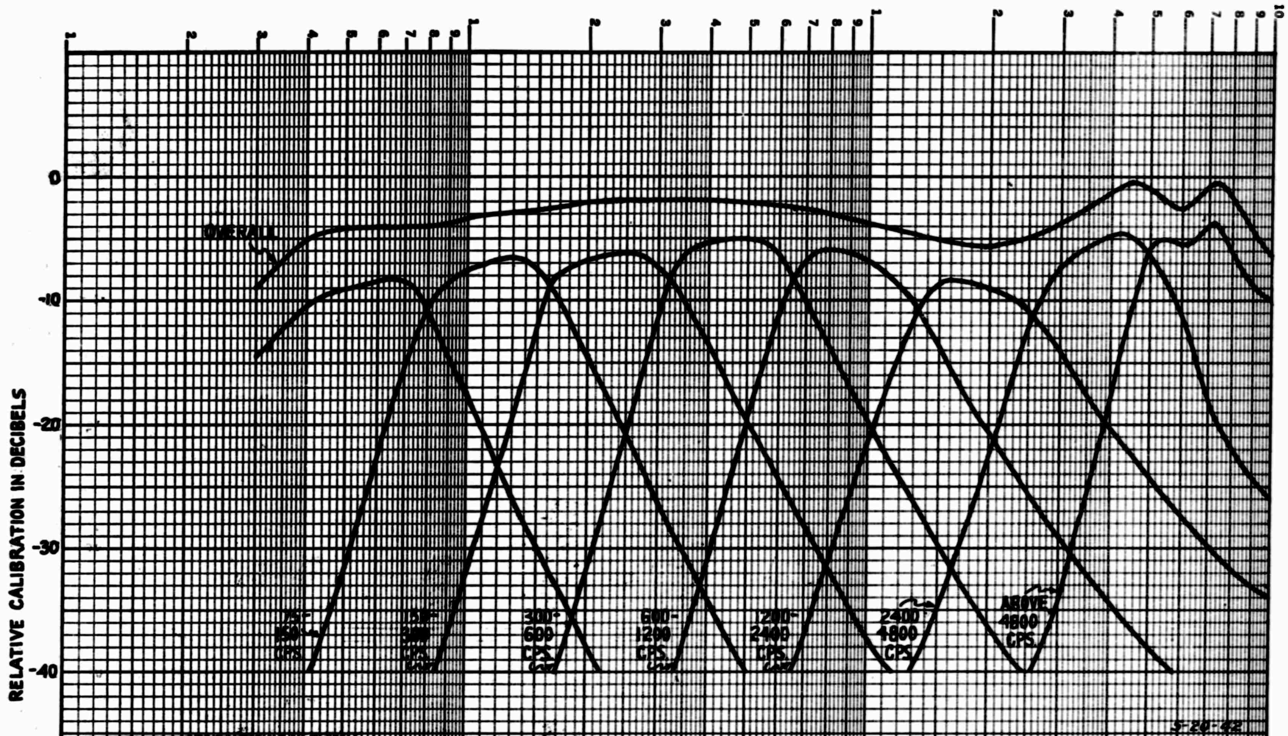
Cruft Automatic Octave Sound Analyzer Type AR-LB, No. 1 used with W. E. Type 630-A Microphone, No. 3547 and E.R.P.I. Type RA 246 Revised Graphic Level Recorder.
System No. 3.

Free field, open circuit, random incidence calibration of microphone.




FREE FIELD, OPEN CIRCUIT CALIBRATION OF W.E. MICROPHONE Type 630-A, No. 3127.
Direction of propagation of sound parallel to plane of microphone diaphragm.
Reference level is 1 volt/dyne/cm$^2$.

3 34




**RELATIVE CALIBRATION CURVE - Absolute value of ordinates to be added to meter reading.**

**E.R.P.I. Analyzer Type RA 277G, No. 238 used with E.R.P.I. Filter Set Type RA 243, No. 19, and W.E. Microphone Type 630-A, No 3127. System No. 4**

**Direction of propagation of sound parallel to plane of microphone diaphragm.**

Table I

Correction Factors
To Be Added To Meter Reading

| Octave | System No. 1 Random Incidence Insertion Losses | System No. 3 Random Incidence Insertion Losses | System No. 4 Random Incidence Insertion Losses |
|---|---|---|---|
| Overall | 5 | -2 | 4 |
| Below 75 | 9 | 2 | 9 |
| 75-150 | 9 | 2 | 8 |
| 150-300 | 9 | 1 | 7 |
| 300-600 | 9 | 1 | 6 |
| 600-1200 | 10 | 2 | 7 |
| 1200-2400 | 10 | 7 | 9 |
| 2400-4800 | 5 | 3 | 5 |
| Above 4800 | 6 | 0 | 5 |

REEL – C

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A.T.I.

27410

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|---|
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ABSTRACT:

An automatic octave sound apparatus is described which is suitable for analyzing and measuring sound in combat vehicles. An RA-277 G sound frequency analyzer when used with a suitable graphic level recorder, permitted analysis of noise over a frequency range from 40 to 10,000 cycles per second by means of a 5-cycle wide or 200-cycle wide band pass filter. It was learned that airplane noise was produced by the propeller, by the engine exhaust, and by air leaks and aerodynamic flow. A complete system composed of a dynamic microphone, an octave band-pass filter set, a sound level meter, an automatic graphic level recorder, a battery power supply, and a hand-held remote control unit is described that determines either manually or automatically, sound levels in airplanes by octave bands.

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