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NAVY DEPARTMENT

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NAVY DEPARTMENT

FOURTH PARTIAL REPORT ON
THE PRECIPITATION STATIC PROBLEM,

FR-2271

BEING A PROGRESS REPORT ON MINNEAPOLIS INVESTIGATIONS

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Personnel Attached to the Joint Army-Navy Precipitation-Static
Project.

Plates 1 through 18.

ABSTRACT

The influence of previously recommended antenna treatments in improving radio communications are expressed in quantitative terms and shown to be very important in reducing precipitation-static. Similarly, the performance of the NRL liquid type dischargers are evaluated and it is shown that by their use an airplane can acquire free charge about three times as fast as it could without these dischargers and still produce about the same precipitation-static interference.

The performance of an artificial charger for producing precipitation-static interference in flight is given. Its approximate equivalence to natural static charging is discussed. The artificial charger is found to be an excellent discharger of natural electrical static charges. A complete cure for precipitation-static in a form suitable for military application is not yet in sight but a substantial reduction in such interference can be achieved by rather simple recommended means.

INTRODUCTION

A. Authorization

1. This problem was authorized under Bureau of Aeronautics project order 623/43, dated 7 March 1942. In the army it is known as Aircraft Radio Laboratory No. 742-301-E. The work is carried forward under the jurisdiction of the Joint Army-Navy Precipitation-Static Committed consisting of:

Commander L. V. Berkner	- Bureau of Aeronautics
Major T. S. Banes	- American Air Forces
Captain C. I. Stafford	- Office, Chief Signal Officer
Lt. J. H. Willox	- Bureau of Aeronautics
Joseph Weichbrod, Sec.	- Office, Chief Signal Officer

B. Statement of Problem

2. The principle object of this investigation is to develop equipment or treatments for airplanes permitting them to operate their radio equipment under all weather conditions, particularly under so-called precipitation-static conditions. In order to guide the technical developments and, in order to achieve a reasonable solution to the urgent phases of the problem in the shortest possible time, it is absolutely essential that the natural physical processes responsible for the production of precipitation-static be thoroughly understood. Moreover, it is essential that this understanding be put on a quantitative basis so that the various factors may be properly analyzed and evaluated. The work of the Minneapolis and Naval Research Laboratory groups has been organized with this guiding principle in mind, and all flight data and experiments have been carefully maintained on a quantitative basis. The leader of the project has systematically avoided experiments leading to great masses of data that cannot be directly correlated with the project or can not be safely interpreted. One of the objectives of this investigation is to secure in flight, data on the static electricity deposited on the airplane in relation to the exciting cause, together with an evaluation of various methods for the discharge of the accumulated electricity. With the object of expediting the work and completing many preliminary tests under fair weather flying conditions, considerable attention has been given to an artificial charger capable of putting large amounts of free electrical charge of selected sign on the airplane. This apparatus has worked well both as a charger and as a discharger and it seems of interest to report its performance.

C. Known Facts Bearing on the Problem

3. The various technical matters considered in this report have been evaluated in a B-25 assigned to the project flying under precipitation-static conditions for about 12 hours. Operations were carried on in the states near Minneapolis, and at Billings, Montana, where the airplane was transferred in its search for suitable precipitation-static weather. The observational data considered in this report were secured by the use of a photo recorder, each set of data being identified by a code number carefully coordinated with a notebook statement of the exact experiments being

conducted. The complete recorded data may therefore be rechecked at a later date for any desired new correlations.

4. As the result of work reported earlier and new information just obtained, as well as qualitative determinations made by others, it is believed to be well established that most of the charging that occurs on an airplane in snow is due to frictional phenomena. A snow flake presumably strikes the airplane at an angle and, in scraping along the metallic surface, transfers a charge of one sign to the airplane while the snow flake carries away the other. In this way, snow flakes behind the plane systematically acquire charges opposite in sign to the plane itself. Except in crossed electric fields commonly encountered in thunderheads, an airplane flying through snow normally acquires a negative charge. This implies that the snow flakes left behind the airplane carry a positive charge. Consider a snow flake approaching the wing and deflected by the moving air so that it strikes the wing a glancing blow. The force between the snow flake and the metallic surface is low and a relatively low charge is transferred to the wing. On the other hand, if the snow flake strikes the leading edge normally, then as it is deflected along the wing surface its direction is greatly changed and the accelerating force urging the snow flake against the metallic wing is relatively much larger and the frictional forces are larger. Therefore, if frictional phenomena is responsible for the charging process, one would expect the leading edge to be the area of the most intense electrification. Such, indeed, is found to be the case. Because of this fact, frictional currents to nose patches on the B-25 have been determined in actual bad weather flight.

D. Original Work

Characteristics of Unmodified B-25 Airplane

5. The B-25 airplane assigned to this project is painted with standard desert camouflage paint and when first received, it had a standard army installation of antennae and radio equipment. In order that the scientists responsible for this work would have a measure of the increase in performance of the airplane when treated, a careful analysis of the original airplane was undertaken. It was found that the command and liaison antennae of the original unmodified plane broke into corona as soon as the electric field at the belly of the plane exceeded about 260 volts per centimeter. Appreciable radio noise did not set in, however, until the discharged antenna currents exceeded about 5 microamperes. In a snow storm over Waukesha, Wisconsin, at an air temperature of -6° C, data were collected to determine the relationship of antenna current versus electric field. These data are plotted in Figure 1 and show that for electric fields greater than 400 volts per centimeter, the corona current increases very rapidly indeed with the electric field. Because normally, the discharge from the antenna is coupled directly into the radio receiver, it is a self-evident fact that antenna corona will produce very severe precipitation static noise. The relationship secured under natural conditions between a 300 kc noise signal as measured on an RCA 312B noise meter connected to the command antenna and the electric field is given in Figure 2, marked "untreated." It will be noticed that the noise increases very rapidly as the electric field increases beyond 400 volts per centimeter.

6. Employing an artificial charger described in the First and Third Partial Reports, it is possible to measure the current flowing away from the airplane in flight, as a function of the electric field. Further, with the knowledge of the approximate geometry of the plane and its effective capacity (as a rule of thumb we have found that the capacity of an airplane is 20% of the wing span expressed in centimeters) it is possible to determine the approximate potential of the airplane with respect to space several ship radii away. Thus, with a knowledge of both the potential and current the effective discharge resistance may be evaluated. This resistance is the order of 10^9 ohms and depends rather critically upon the maximum electric field existing on the plane and hence is related to the electric field at the belly of the plane. Further, with a knowledge of the effective discharge resistance and the approximate capacity of the airplane, one may evaluate the relaxation times of the airplane in actual flight. Table I below gives the relaxation times so estimated. The relaxation time for the airplane may be defined as the time it takes for the airplane to reduce by conductive discharge a given initial quantity of free electricity down to a value of $\frac{1}{e}$ of the original amount, where e is 2.718.

Table I
Electric Field - Relaxation Time
at Low Altitude

volts/cm	seconds
0	(400) (calculated)
100	1.7
200	1.5
300	1.1
400	.9
500	.7

7. It may be seen from the table that at low altitude the B-25 will adjust itself to surrounding electrical conditions in a time approximating 1-1/2 seconds at low fields and a fraction of a second at relatively high fields. Therefore, when one examines the relationship between the processes producing electrification on a plane and the resultant electrical state; differences of time phase between these two quantities may be expected to be an appreciable part of a second. It may be remembered further that the installation of dischargers of various types on the airplane will systematically reduce the relaxation times given in Table I. Moreover, from Figure 10 it follows that the relaxation times will be much less at great altitudes.

Performance of the Artificial Charger on the B-25

8. NRL Confidential Report No. O-2243, being the third partial report on the Precipitation-Static Problem, outlined in some detail the

theory underlying an artificial charger for aircraft. Figure II of that report showed how the performance factor of the discharger increased with the speed of the incident air jet. In an analogous manner, the increase in performance of the charger on the B-25, as its air speed increases, is given in Plate 3. The shape of the curve is uncertain but it does show that artificial charger performance increases steadily with increased air speed, at least over the studied range.

9. In order to investigate the characteristics of the untreated airplane, the artificial charger was arranged so that the convected current could be measured on a microammeter as charge is lost by the airplane. Then the potential of the airplane builds up steadily, until conduction processes set in to discharge currents equal to that being charged. In this case an equilibrium is reached and the equivalent electric field at the belly of the plane is measured on the generating voltmeter. Two independent determinations of the relationship between charging current and equilibrium electric field are plotted in Plate 4. It is evident that the current discharged by the airplane in the untreated state is actually the same function of the electric field as plotted in Plate 4, because the charging and discharging rates are equal when equilibrium is reached. The relaxation times given in Table I are derived from the curve of January 25, 1944, in Figure 4.

10. The 30 jet artificial charger installed on the B-25 will put out over 100 microamperes at the highest inducing voltage used (15,000 volts) and at about 60 gallons per hour. When used as a discharger under natural charging conditions a maximum current of 250 microamperes has been produced.

11. The behavior of the artificial charger when used to discharge naturally acquired static charge in an actual snow storm is shown in Plate 5. In this plate are plotted patch current, artificial charger current, wick current, noise meter reading in microamperes and electric field in volts per centimeter. A curve for converting noise current in microamperes to noise in microvolts is given in Plate 6. The changes in the reading of the charging current in Plate 5 are due to an unsuccessful attempt of the operating personnel to reduce the electric field on the belly of the plane to zero as the incoming natural charge to the airplane is varied. It is thought probable that the values of the patch current at a constant speed are roughly proportional to the natural charging processes but this is not yet certain. It will be noted that, due to the operation of the artificial charger, the electric field could actually be reversed in flight and therefore the charger is also an effective discharger. Moreover, an examination of the curve will show that when the electric field reversed, so also did the current from the liquid dischargers mounted on the wing tips. Unfortunately the magnitude of the negative currents could not be read on the meter because of the stop, but in Plate 5 these negative currents are indicated by small arrows pointed below the axis. The simultaneous reversal of electric field on the belly of the plane and current from the discharger shows that the field at the wing tip and just behind it rises and falls with the electric field on the belly of the plane and not with a local electric field due to the free charge on the snow in that area. The curves of Plate 5 show that when the charge induced on the liquid droplets is the same sign as that produced on the plane by natural charging processes the artificial charger makes a very useful electric discharger.

Antenna Modification and Treatment

12. As soon as it was established that appreciable currents flowed to the antenna from the charged airplane the importance of suppressing corona discharge from the circuit was appreciated, for obviously a noisy corona coupled directly to the antenna will cause much more disturbance than the same discharge from a wing tip located many feet away and relatively uncoupled to the antenna and receiving systems. The antennae on the B-25 have been reworked and modified to reduce such generated static noise. The antennae as now constructed are made up of the Navy type Model J phosphor bronze wire especially covered with polyethylene plastic without breaks and carefully insulated and covered at the antenna posts in such a way that no free conducting surface is exposed to the area of high electric field. Polyethylene is used because of its very low dielectric loss and its high insulating qualities. Because of its low loss, the resistance of the antenna is not much greater than that of a bare antenna employing the same wire. In accordance with the practices outlined in earlier reports of this series, the antennae were always connected to ground through the receiver or through a high resistance. No completely insulated guy sections are permitted. Employing this type of careful clean up, Plate 1, which was obtained for the untreated plane, is modified in such a way that no D.C. currents to the antenna are measured up to the limit of electric field of the curve of Plate 1. The profit that accrues from this antenna treatment may be evaluated by referring to Plate 7, which gives a time plot of electric field versus noise meter current for the B-25 with the command antenna untreated and an exactly similar plot for the antenna treated, all obtained in natural snow at about 0° centigrade. It may be noticed that although the electric field in the treated case averaged more than 100 volts per centimeter above the value for the untreated case the noise is reduced by more than 400 microvolts. The improvement in the noise produced under natural charging conditions when the plane is treated and untreated, is given in Plate 2. This curve shows that the performance of the treated antenna is notably superior to that of an untreated one.

Performance of Liquid Dischargers in Flight

13. The B-25 assigned to this project has been fitted with six retractable dischargers. These dischargers are operated by a piston driven by air pressure from the cabin of the airplane which permits the extension or the retraction of any selected wick discharger in flight as required by the operator. A wick saturated with a glycerine mixture as recommended in earlier reports was attached to the end of the piston and extends through the discharger holder which is terminated by a well-designed corona shield. The currents to these extended corona shields are vanishingly small up to about 550 volts per centimeter as measured on the belly of the plane. Two of these dischargers are located on each wing tip trailing backward from the center of the section and from the trailing edge of the wing tip. Two of them are mounted at the top of the vertical stabilizers. Under normal conditions the currents from the two wing tip dischargers are approximately the same and each discharges about 25% more current than each discharger located on the vertical stabilizers. The influence of the liquid dischargers in modifying the charging current to the airplane as a function of the electric field is clearly shown in Plate 8. These curves are obtained by

employing the artificial charger as previously disclosed. It may be seen from these curves that the total current that may be discharged from the airplane when the belly field is 300 volts per centimeter, is only 50 microamperes when no dischargers are in operation, rises to 125 microamperes with two dischargers in operation, increases still further to about 160 microamperes with four dischargers in operation and probably registers more than 180 microamperes with all six dischargers in operation. Thus, since by Plate 12 moderate interfering noise does not set in until the electric field approximates 300 volts per centimeter, it is clear that this plane provided with dischargers may, under many conditions, operate with a charging current more than three times larger than it would operate with, were it not provided with suitable glycerine dischargers. It is not contended that this is true under all conditions but perhaps in a majority of conditions it is true. Under artificial charging conditions both the charging current to the plane and the discharging current from the liquid dischargers may be measured and these are given in Plates 8 and 9. The difference between charging and discharging current must flow away from the airplane by ordinary conduction and, therefore, the differences of the currents for given electric field (for the same number of operating dischargers) might be expected to lead to the charging current versus electric field curve for the airplane having no dischargers at all. This latter current - electric field relation is given in Plate 8 and in Plate 10 for two different altitudes. Within the experimental error amounting to about 10 microamperes the prediction is found to be true. Plate 11 gives the relation between charging and discharging currents with six dischargers in operation.

Comparison of Natural and Artificial Charging Processes on the B-25 in Flight

14. Plate 12 summarizes the observational data taken on the B-25 in actual flight under both artificial and natural charging conditions. The dashed curve gives the relationship between noise meter voltage measured on the RCA 312B noise meter as a function of the electric field for the command antenna in the original untreated condition. The solid curves give the same data for the same airplane, but with the antenna treated. As outlined in earlier sections, it is to be noted in Plate 12 that two curves were secured under natural charging conditions and two others were obtained using the artificial charger under fair weather conditions. It may be noted that the threshold of effective noise occurs at the same value of the electric field employing either method of charging. The artificial and natural curves overlap and appear to show that small alterations in the airplane surface produce differences between the measured noise larger than those due to the two different methods of charging.

15. Plate 9 gives a plot of the electric current discharged from two glycerine dischargers mounted on the B-25 under artificial charging conditions. This curve, obtained by using two dischargers, may be compared directly with an analogous curve secured in a snow storm of February 26, 1944, and plotted in Plate 13. Except for an appreciable difference in slope of the two curves, they are similar and show that artificial and natural charging processes are nearly equivalent.

16. In view of the practically equivalent performance of artificial

and natural charging methods achieved in flight on the B-25, it is thought that a great deal of valuable preliminary work can be done on the plane under fair weather conditions, leaving the final check of exact equivalence of the two methods to later determination. The group has not yet seen any case where the artificial and natural methods were in practical disagreement although it is recognized that the two methods are probably not exactly identical.

17. Attention is drawn to the fact that when the artificial charging equipment is employed in natural precipitation-static conditions the artificial charger can and does reverse the electric field surrounding the plane. It may also be noted that the direction of the electric field and the current discharged by the glycerine dischargers simultaneously reverse. This is interpreted to mean that the discharge current is related to the free charge actually resident on the plane and not due to any special distribution of free charge carried by the snow adjacent to the discharger.

MISCELLANEOUS RESULTS

18. With the idea of obtaining a measure of the intensity of the charging phenomena of an airplane in flight we have investigated quantitatively the charging produced on aluminum and chromium patches in various types of snow. These patches are all protected from stray charge by a conducting guard surrounding the patch and connected to the airplane ground. Plate 14 gives a plot of the patch current on the nose of the B-25 and the electric field at its belly in an actual snow storm as a function of the time. Close examination of these curves will show that there exists a definite correlation between patch current and electric field. The relationship between patch current density and electric field under natural charging conditions is further elucidated in Plate 15, which gives the negative current produced by an aluminum alloy patch as shown. In studies of contact electromotive forces, it has been observed that chromium is the most stable of all the easily available metals. Thus, because frictional processes are probably related to contact electrical phenomena, a chromium patch was mounted on the nose of the B-25 for the purpose of measuring the frictional charge generated thereon. In a snow storm occurring on February 22, 1944, at temperatures near 0°C, the chromium patch produced negative free electrical charge as shown in Plate 16. On the other hand, in another snow storm occurring on February 17, 1944, at a lower temperature, the chromium patch produced a positive current which was related to the electric field on the belly of the plane as shown in Plate 17. The electric field at the belly is usually due to a negative charge on the airplane and therefore we have the unusual condition of having a plane which is normally charged negative (perhaps resulting from the painted surface of the ship) while the current supplied by the patch is of opposite sign. This is a most interesting circumstance that shows that the patch charging process is casually connected with the amount of snow encountered by the patch and by the detailed characteristics of the snow flakes. It is probable that the sign of the charge produced depends on the crystal structure and the detailed frictional processes between the plate and the ice crystal. Perhaps, therefore, a reversal of sign may be a very important guide to the study of the charging processes.

These results suggest that further study should be made of various painted surfaces but it should be noted that the charging process under various meteorological conditions may be very complicated and non-reproducible. If this is so, then solution of the precipitation-static problem by a simple means probably will be very difficult.

19. The idea has often been advanced that in flight the motion of the propeller through the dry snow is largely responsible for the charging process. In the hope that more reliable data might be obtained, an experiment was run in which the aircraft engine speed was changed systematically from 2000 to 2500 rpm, then down to 1600 rpm, returning finally to 2000 rpm. Measurements of patch current and electric field were made simultaneously and plotted in Plate 18. It will be seen from Plate 18 that there is no apparent connection between the superposed variation of the engine speed and resulting electric field or patch current. Unfortunately in this test the pitch of the propeller was changed to effect the change in speed and the resulting projected propeller area changed accordingly. These data are for an isolated case and should not be interpreted to mean that all propellers do not contribute appreciably to aircraft charging processes, but all the data available to this group suggest that the propellers on the B-25 do not appreciably contribute to its charging.

20. At the request of the Aircraft Radio Laboratory two standard SCR-269-G loop compasses were installed, one in which the housing was painted with slightly conducting paint and the other being untreated. The performance of these two compasses was checked under natural static conditions and as far as experiments have proceeded to date, no appreciable difference in performance is apparent. It appears that the position of the loop on the plane has more influence on its performance than any other factor.

CONCLUSIONS AND RECOMMENDATIONS

21. An evaluation of the results observed on this investigation to date warrants the following recommendations:

a. It is recommended that every effort be made to clean up military aircraft as follows:

- (1) Provide high resistance leaks to the ground of the airplane for all antennae, guy wires and other exposed insulated surfaces.
- (2) Install insulated antenna wire having low dielectric loss and high dielectric strength in such a way that appreciable corona current from the antenna cannot be discharged to the free air.
- (3) That all sharp metallic projections sticking out from the plane be covered with a highly insulating plastic material in order to suppress corona discharge therefrom.

(4) When facilities permit, to suspend various types of aircraft clear of the ground in a suitable hangar and, by applying very high voltage, determine the points of corona discharge and suppress them as much as practicable by application of highly insulating plastic material.

b. Because the deposited electrostatic charge on the airplane must be dissipated in one way or another, it is recommended:

(1) That dischargers be systematically installed on aircraft as far as practicable. The NRL type liquid discharger employing glycerine and water at ordinary temperatures and Ethylene glycol at low temperatures have been well tested and are the only proven quiet dischargers known to this Group.

22. When flying conditions are otherwise equal at all levels, it is recommended the pilots encountering precipitation-static fly at the highest practicable level. This is because an airplane discharges itself at high levels more easily than at low levels.

PERSONNEL ATTACHED TO THE JOINT ARMY-NAVY

PRECIPITATION-STATIC PROJECT

Ross Gunn - Head Physicist - Senior Technical Director - NRL

James P. Parker - Associate Physicist - Civilian Officer-in-Charge - NRL

Ronald G. Stimmel - Associate Physicist - Aircraft Radio Laboratory

Franklin E. Waterfall - Assistant Physicist - Naval Research Laboratory

John W. McGee - Asst. Radio Engineer - Aircraft Radio Laboratory

John R. Galt - Chief Pilot - Northwest Airlines

K. C. James - Co-pilot - Northwest Airlines

J. Earl Jones - Chief Maintenance Crew - Northwest Airlines

Henry W. Dyche - Chief Storekeeper, USNR - Naval Research Laboratory

Mary R. Davis - Yeoman 2nd Class, USNR - Naval Research Laboratory

At the Naval Research Laboratory:

Wayne C. Hall - Senior Physicist

R. C. Waddel - Physicist

Emery Rogers - Junior Physicist

J. R. Clement - Ensign, USNR

SUM OF CORONA CURRENTS FROM LIAISON AND COMMAND ANTENNAS



FLIGHT DATA FOR B-25 DECEMBER 12, 1943
OVER WAUKESHA, WISCONSIN

AIR TEMPERATURE = -6°C .
ALTITUDE = 2700 FT.
INDICATED AIR SPEED = 245 M.P.H.
AIRPLANE - NEGATIVE
CODE # 6006

MICROAMPERES

10

20

30

0

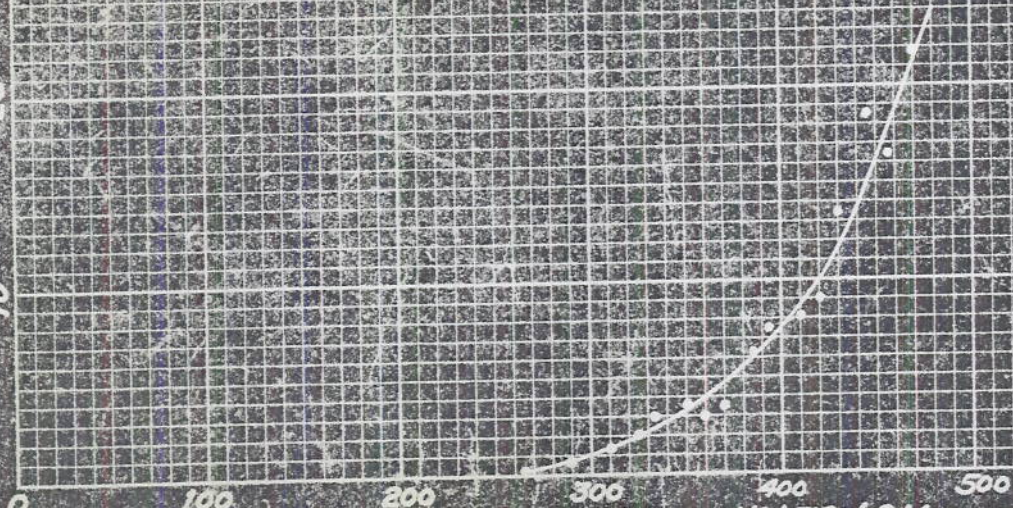
100

200

300

400

500

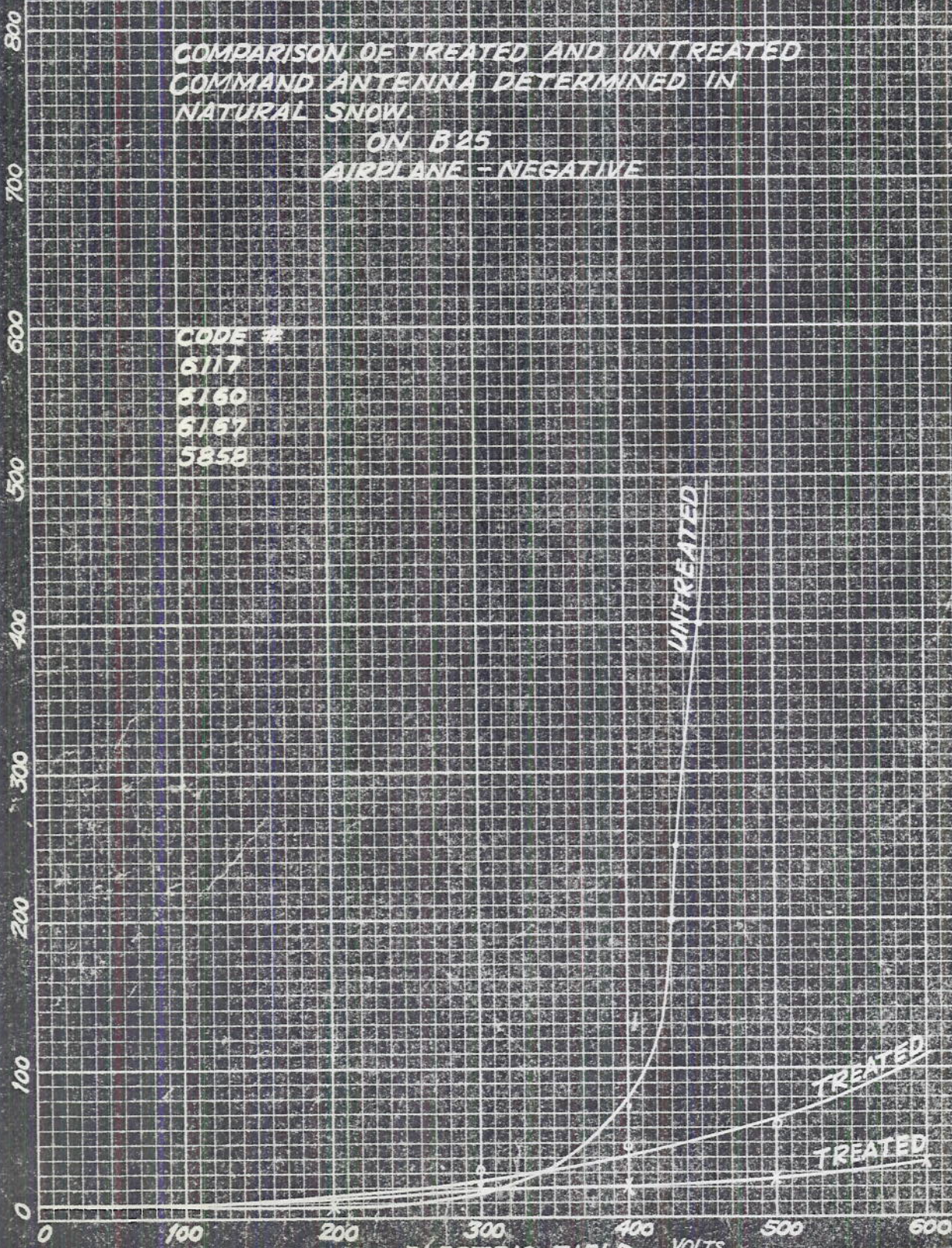


COMPARISON OF TREATED AND UNTREATED
COMMAND ANTENNA DETERMINED IN
NATURAL SNOW

ON B25
AIRPLANE - NEGATIVE

CODE #
6117
6160
6167
5858

NOISE - MICROVOLTS



CHARGING CURRENT - MICROAMPERES

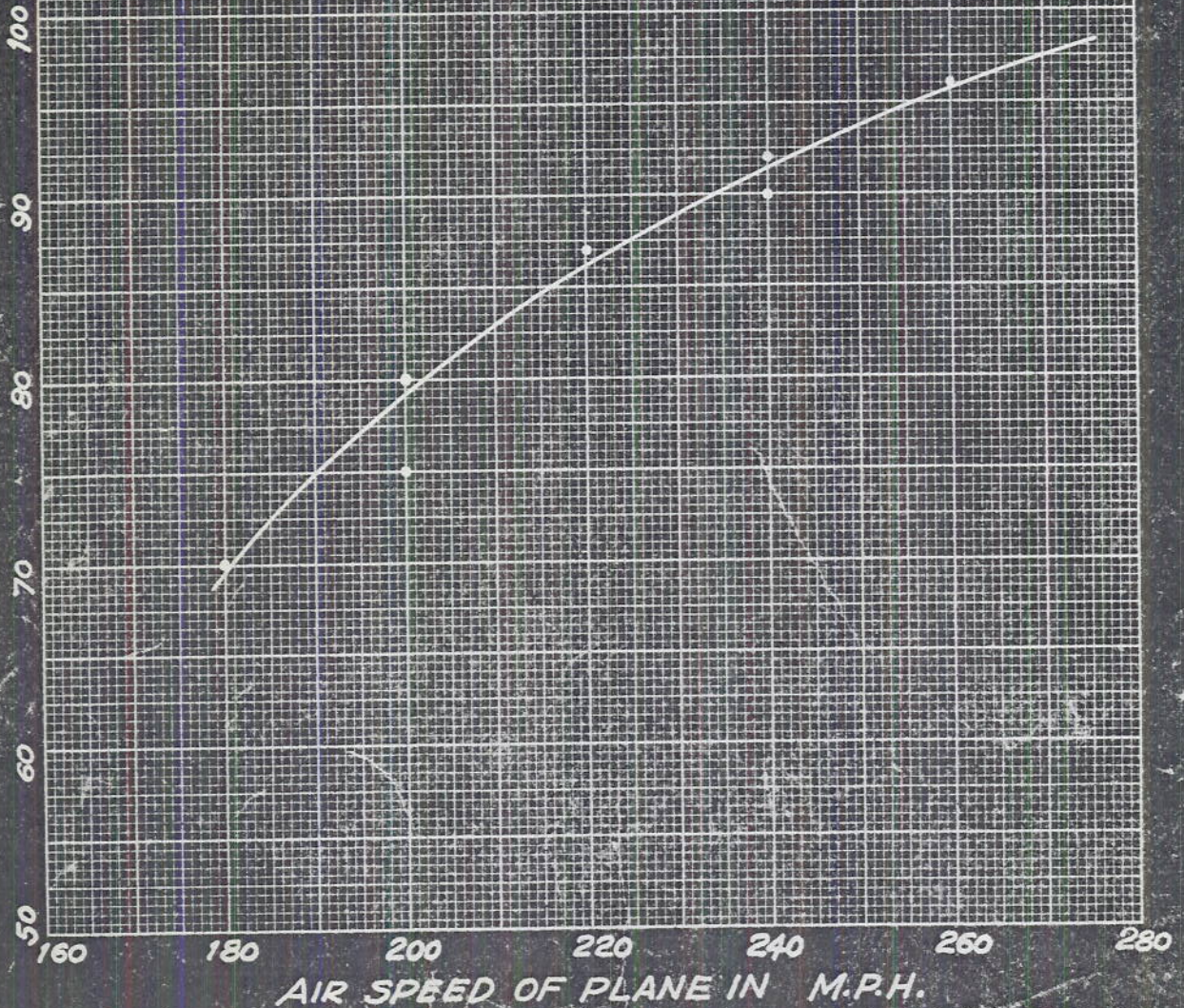
CHARGING CURRENT VS AIR SPEED

INDUCING VOLTAGE = 16 KV

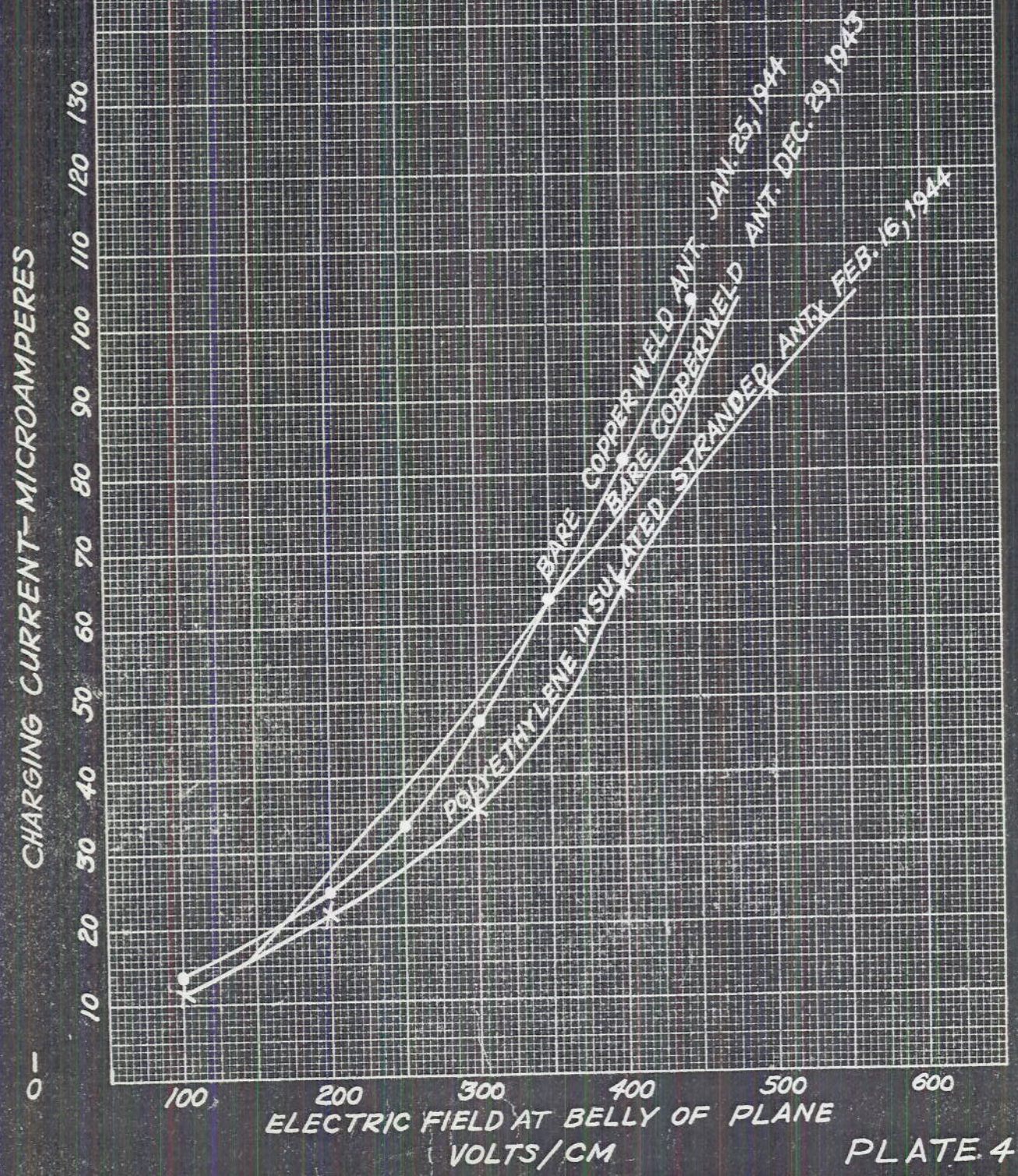
FIELD ON BELLY = 330-350 V/CM

30 NOZZLE CHARGER

SEPARATION OF NOZZLE FROM INDUCING
PLATE = 3/4"



FAIR WEATHER DATA, B-25 AIRPLANE
USING ARTIFICIAL CHARGER



STANDARD CROSS SECTION
NEW YORK
POLICE DEPARTMENT

11:51:00

52:00

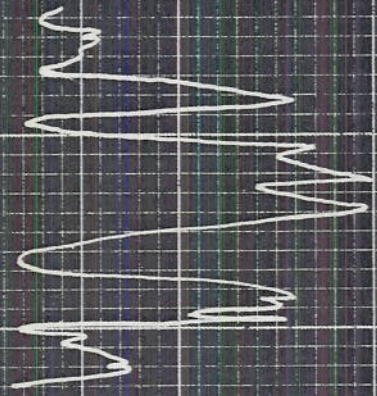
TIME

53:00

54:00

ELECTRIC FIELD VOLTS/CM.

+100 0 -100 -300 -500 -700 0



POSITIVE

AIRPLANE

NEGATIVE

NOISE METER MICROAMPERES

WICK CURR

100

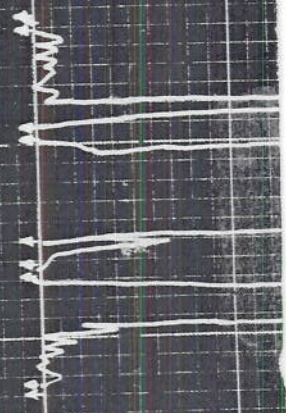
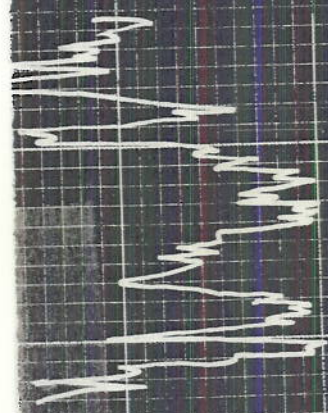
200

300

400

0

10

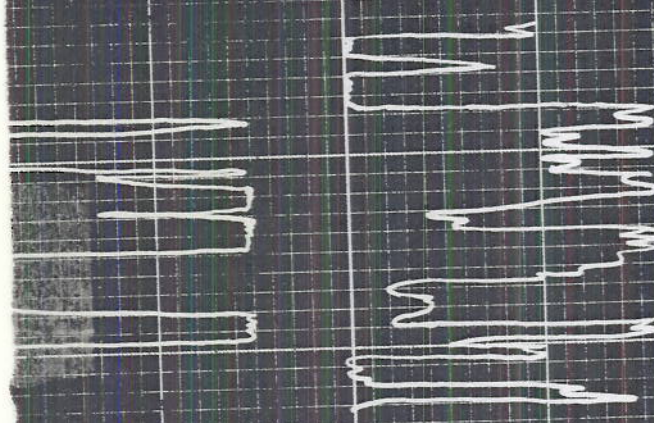


CURRENT MICROAMPERES CHARGE CUL

20

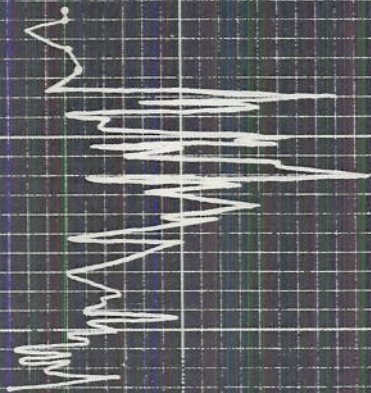
0

50



CURRENT MICROAMPERES PATCH CURRENT MICROAMPERES

100 0 0.20 0.40



CODE # 6173
ACTUAL SNOW
FEB. 17, 1944

PLATE 5

page 4 of plate 5

NOISE IN MICROVOLTS



MICROAMPERES ON NOISE METER PLATE 6

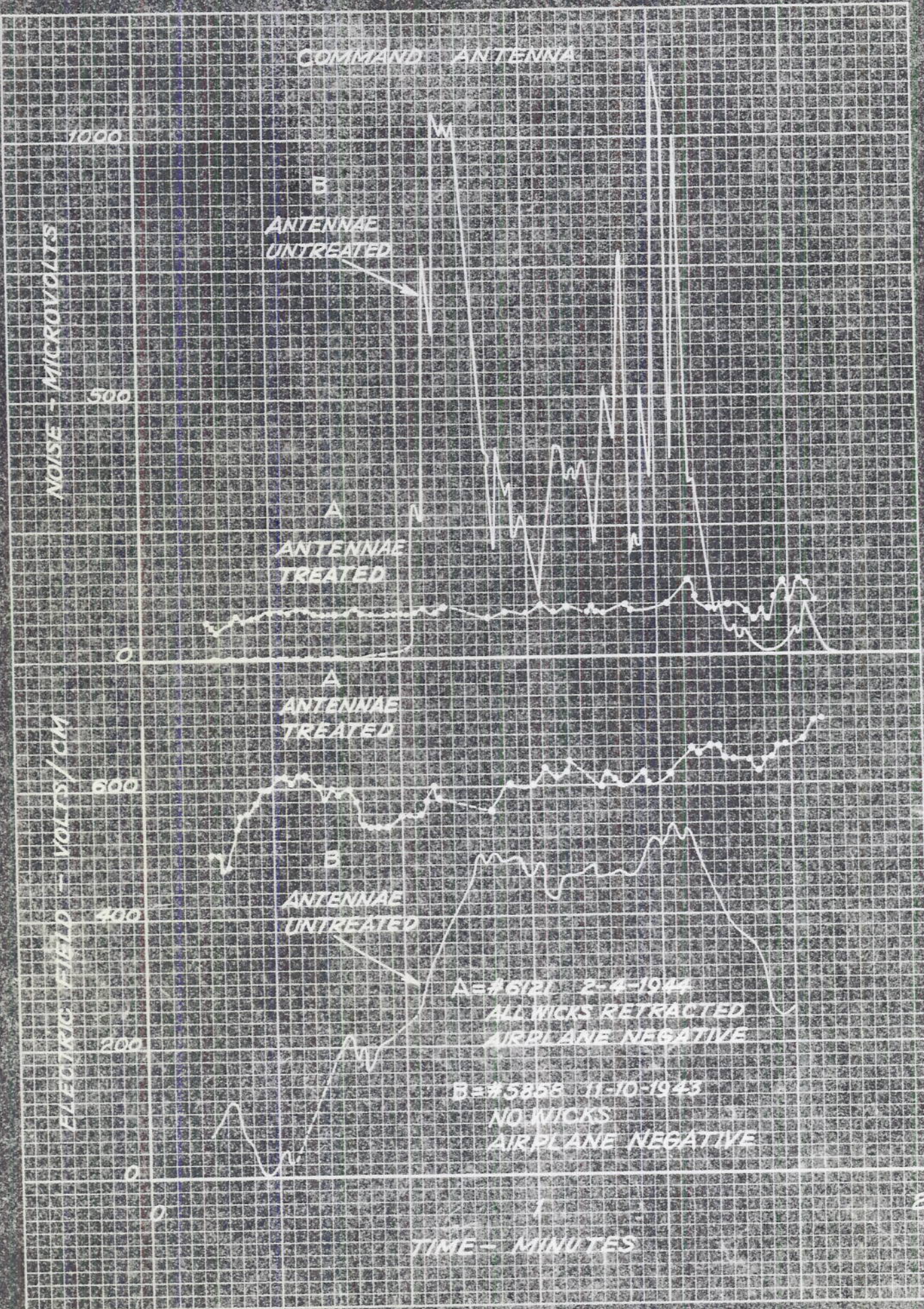
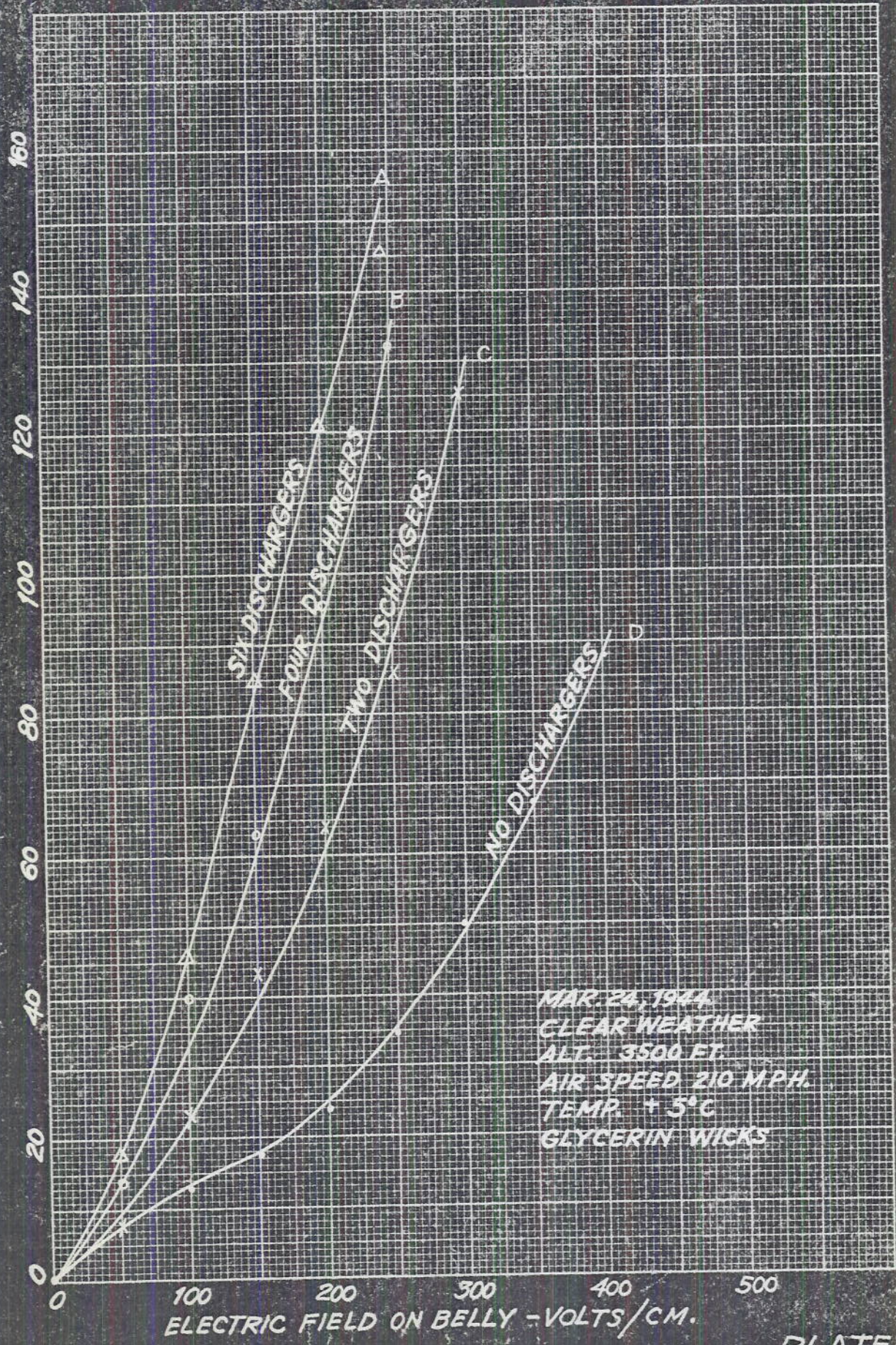


PLATE 7

CHARGING CURRENTS MICROAMPERES

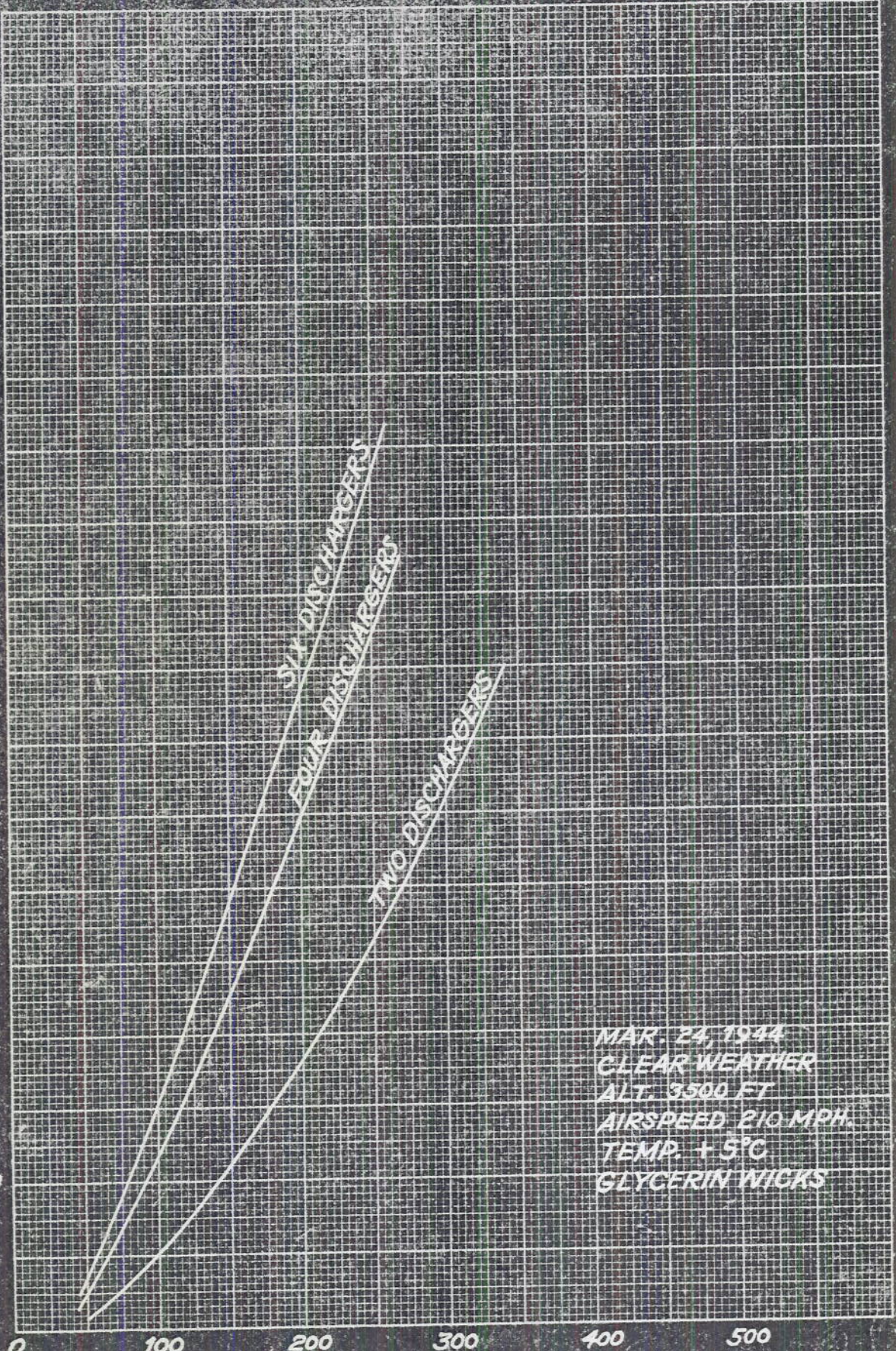


MAR. 24, 1944
CLEAR WEATHER
ALT. 3500 FT.
AIR SPEED 210 MPH.
TEMP. + 5°C
GLYCERIN WICKS

ELECTRIC FIELD ON BELLY - VOLTS/CM.

DISCHARGED CURRENT - MICROAMPERES

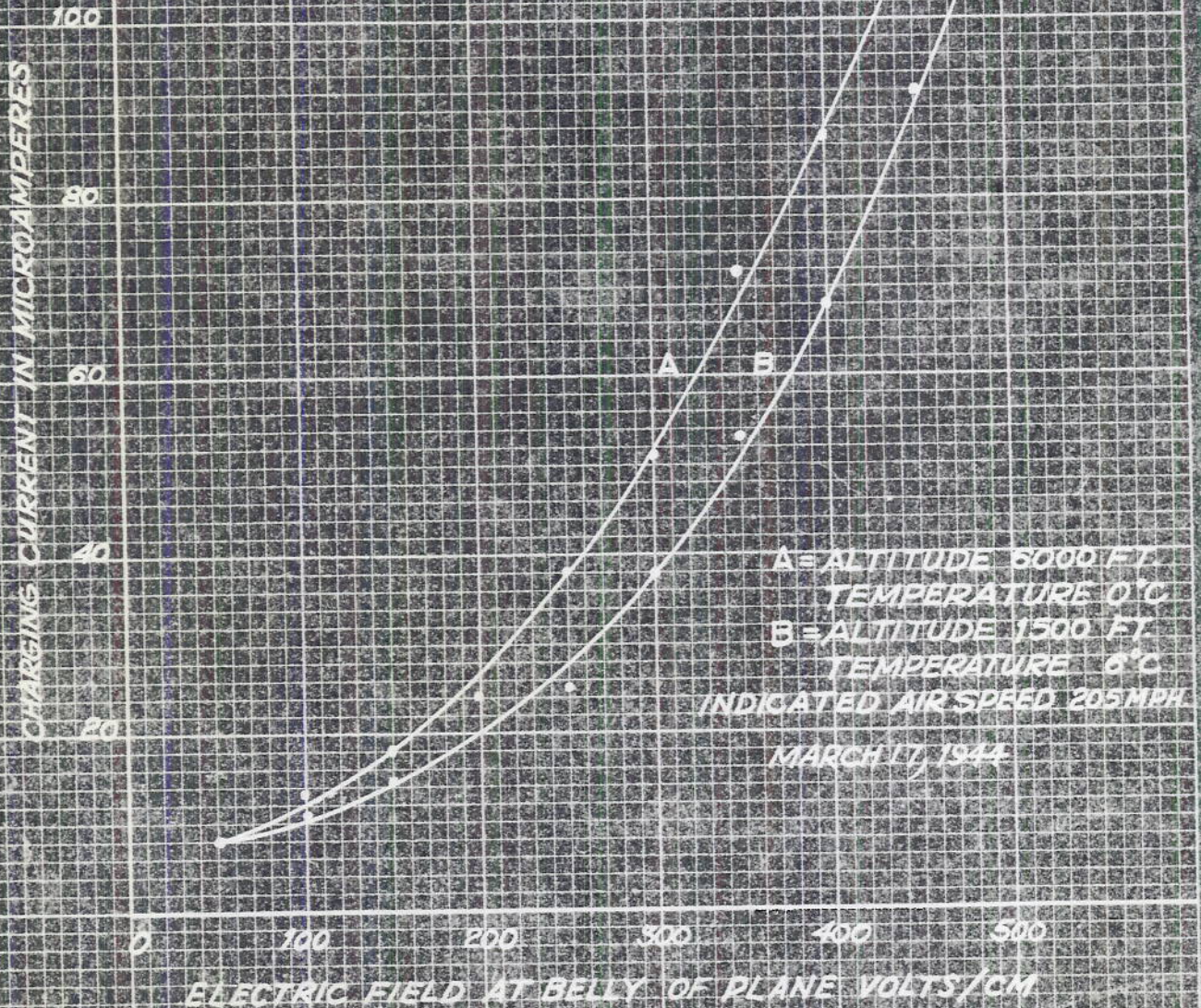
140
120
100
80
60
40
20



MAR. 24, 1944
CLEAR WEATHER
ALT. 3500 FT
AIRSPEED 210 MPH
TEMP. +5°C
GLYCERIN WICKS

ELECTRIC FIELD ON BELLY OF AIRPLANE VOLTS/CM.

CURRENT-ELECTRIC FIELD
CHARACTERISTIC FOR BARE B-25



CURRENT IN MICROAMPERES

160

140

120

100

80

60

40

20

CHARGING
CURRENT

DISCHARGING
CURRENT

ALTITUDE 1500 FT.
TEMPERATURE 0°C
INDICATED AIR SPEED 205 MPH
SIX DISCHARGERS OPERATING
PLANE NEGATIVE
MARCH 17 1944

0

100

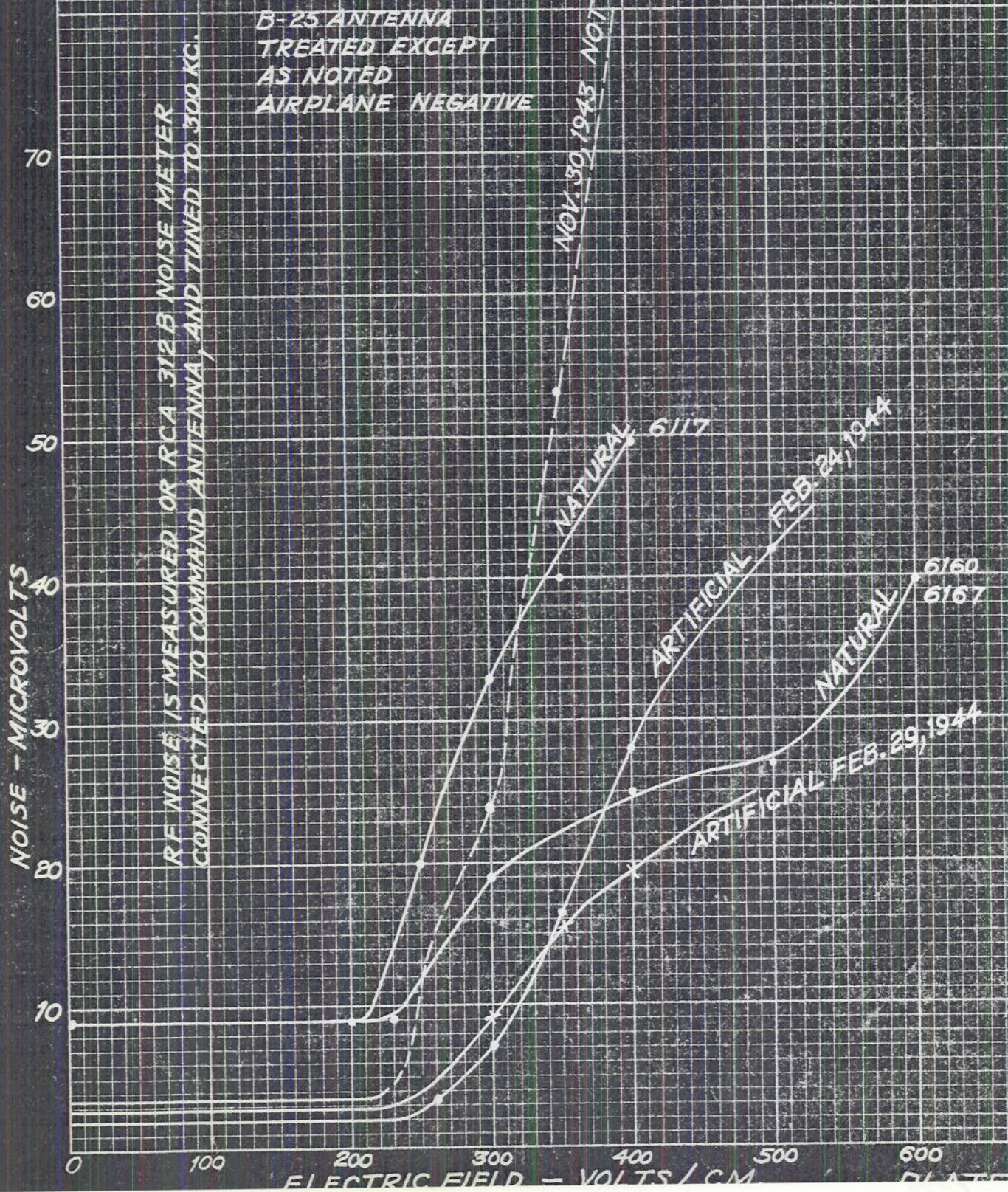
200

300

400

500

ELECTRIC FIELD VOLTS/CM



SNOW, FEB 26
AIRPLANE NEGATIVE

CODE #
6192
6193
6196

DISCHARGE CURRENT FROM TWO GLYCERIN WICKS ON WING TIPS (REF LR)

MICRO AMPERES

100

80

60

40

20

0

100

200

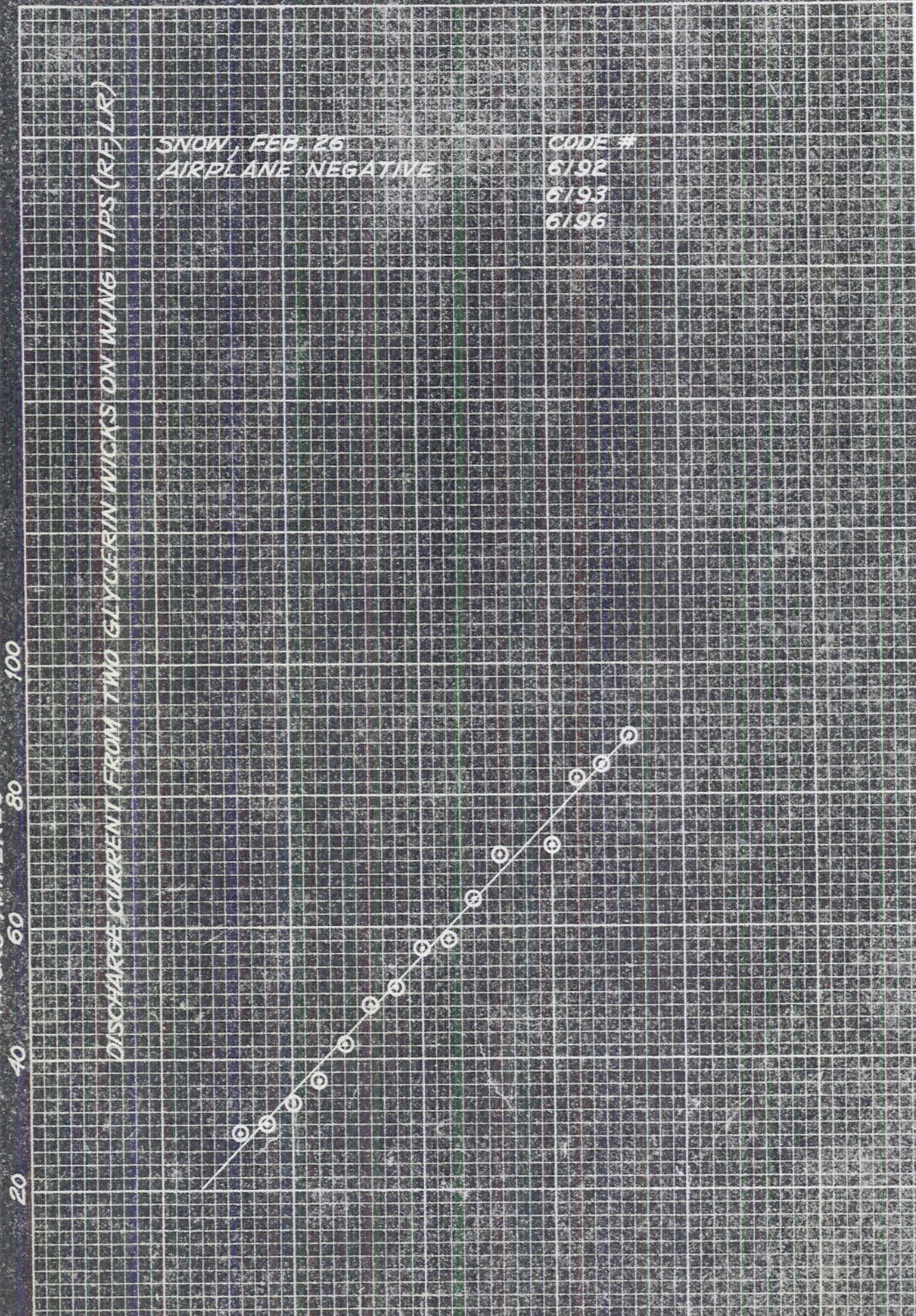
300

400

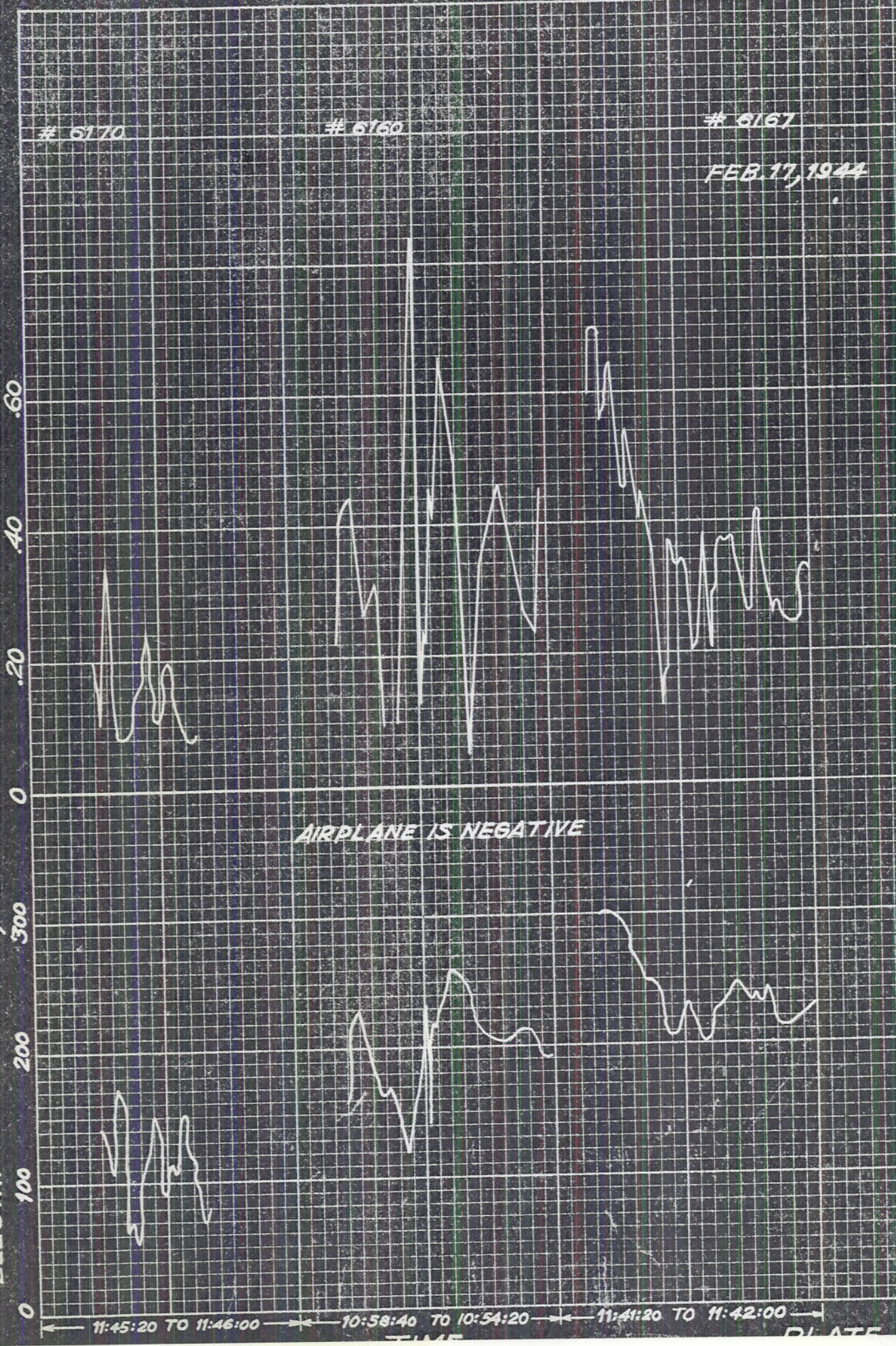
500

ELECTRIC FIELD - VOLTS/CM

PLATE



PATCH CHROMIUM CURRENT IN MICROAMPERES (POSITIVE)



PATCH CURRENT DENSITY MICROAMPERES/SQ.FT.

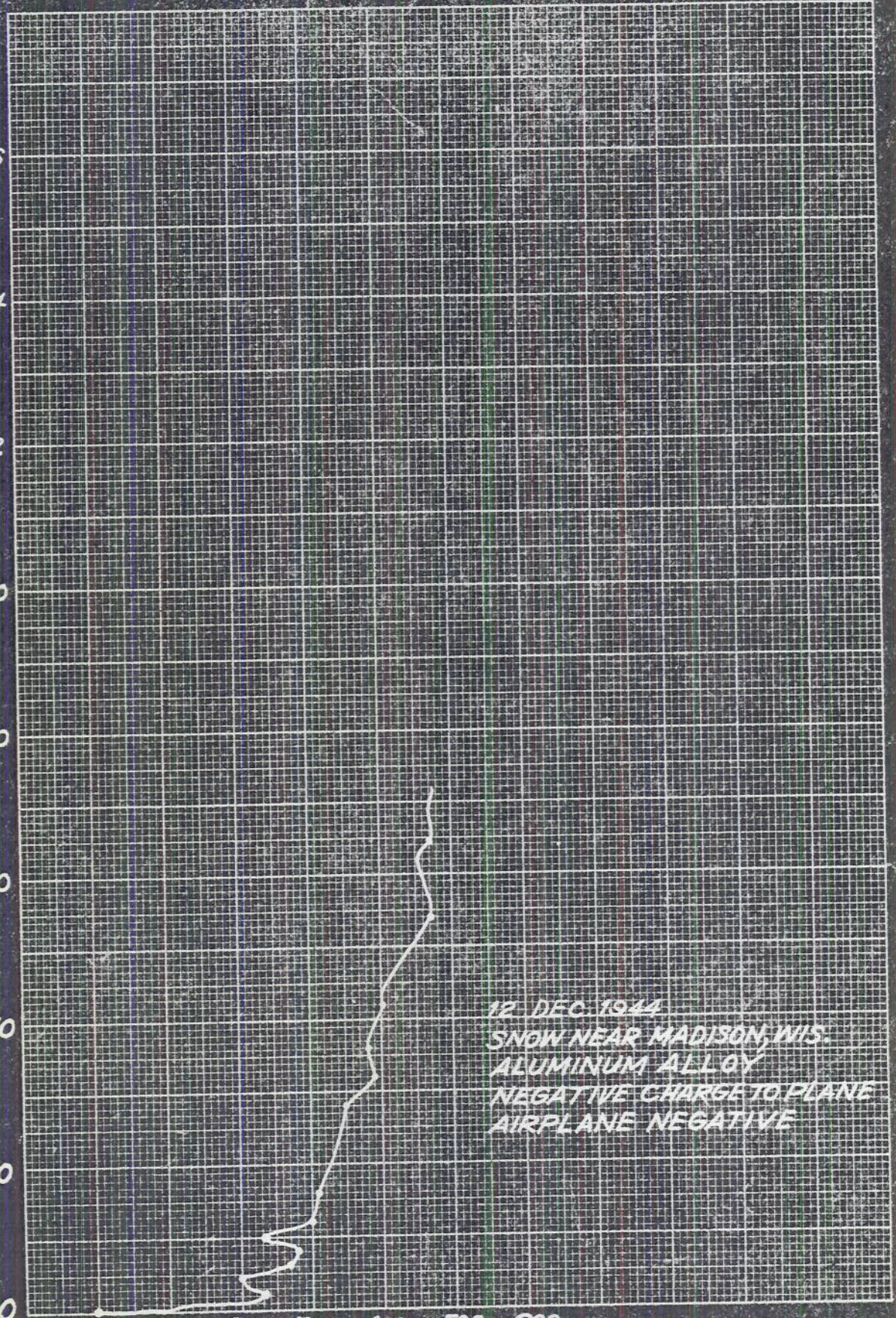
1.6
1.4
1.2
1.00
.80
.60
.40
.20
0

0 100 200 300 400 500 600

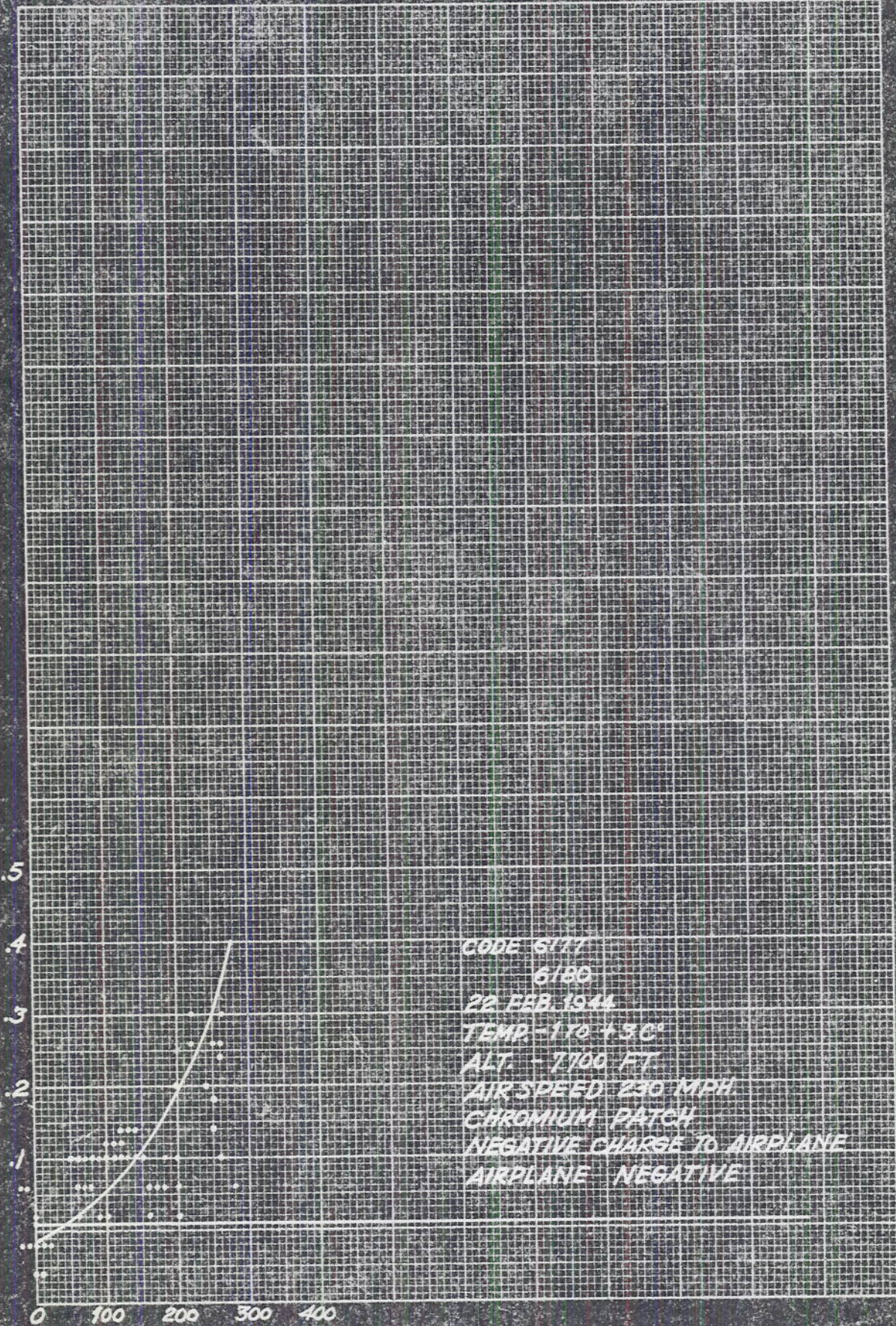
ELECTRIC FIELD - VOLTS/CM.

12 DEC 1944
SNOW NEAR MADISON, WIS.
ALUMINUM ALLOY
NEGATIVE CHARGE TO PLANE
AIRPLANE NEGATIVE

PLATE 15



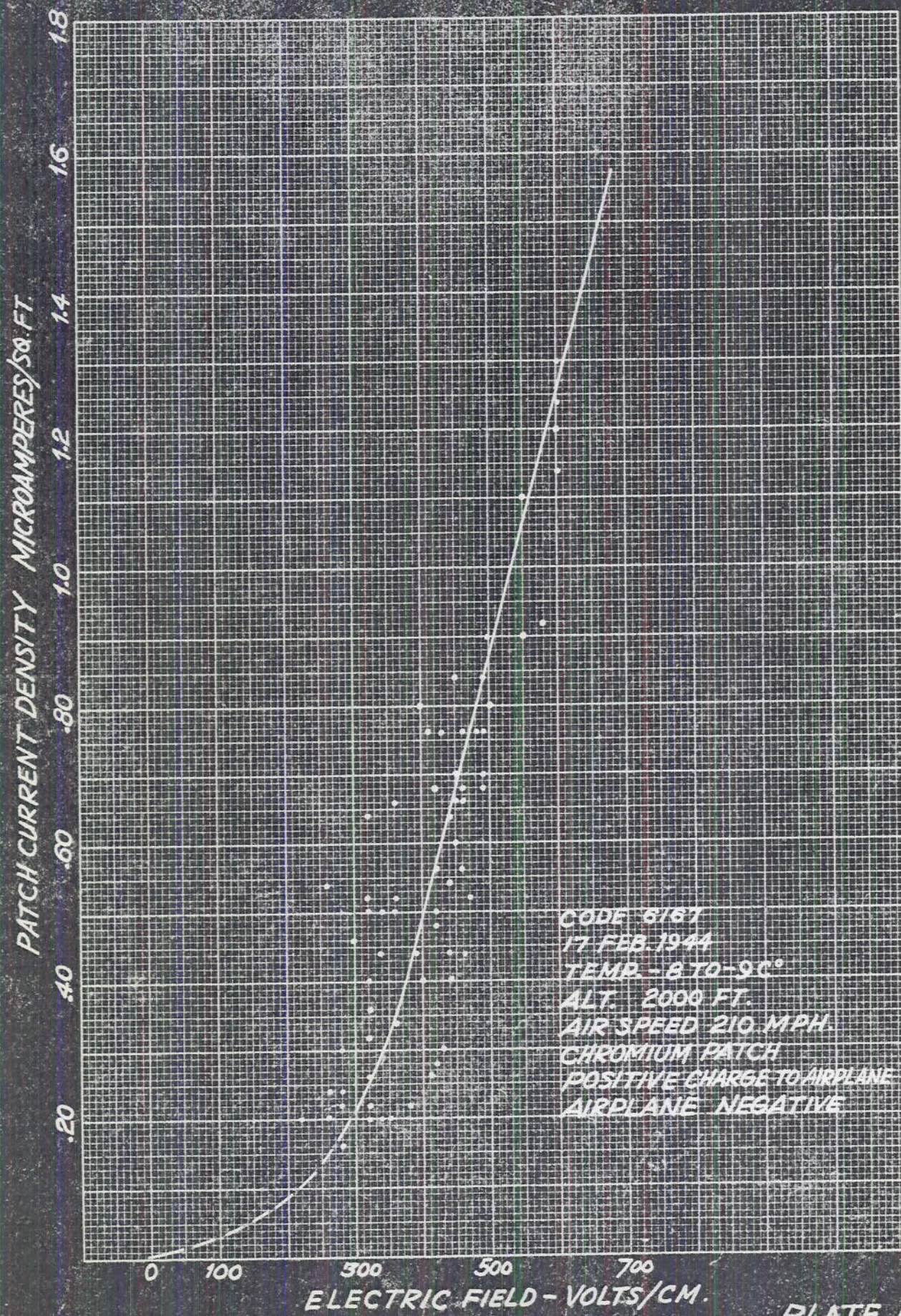
CURRENT TO PATCH - MICROAMPERES / SQ. FT.



CODE 6177
6180
22 FEB. 1944
TEMP - 110 ± 5 C
ALT - 7100 FT
AIR SPEED 230 MPH
CHROMIUM PATCH
NEGATIVE CHARGE TO AIRPLANE
AIRPLANE NEGATIVE

0 100 200 300 400

ELECTRIC FIELD - VOLTS/CM.



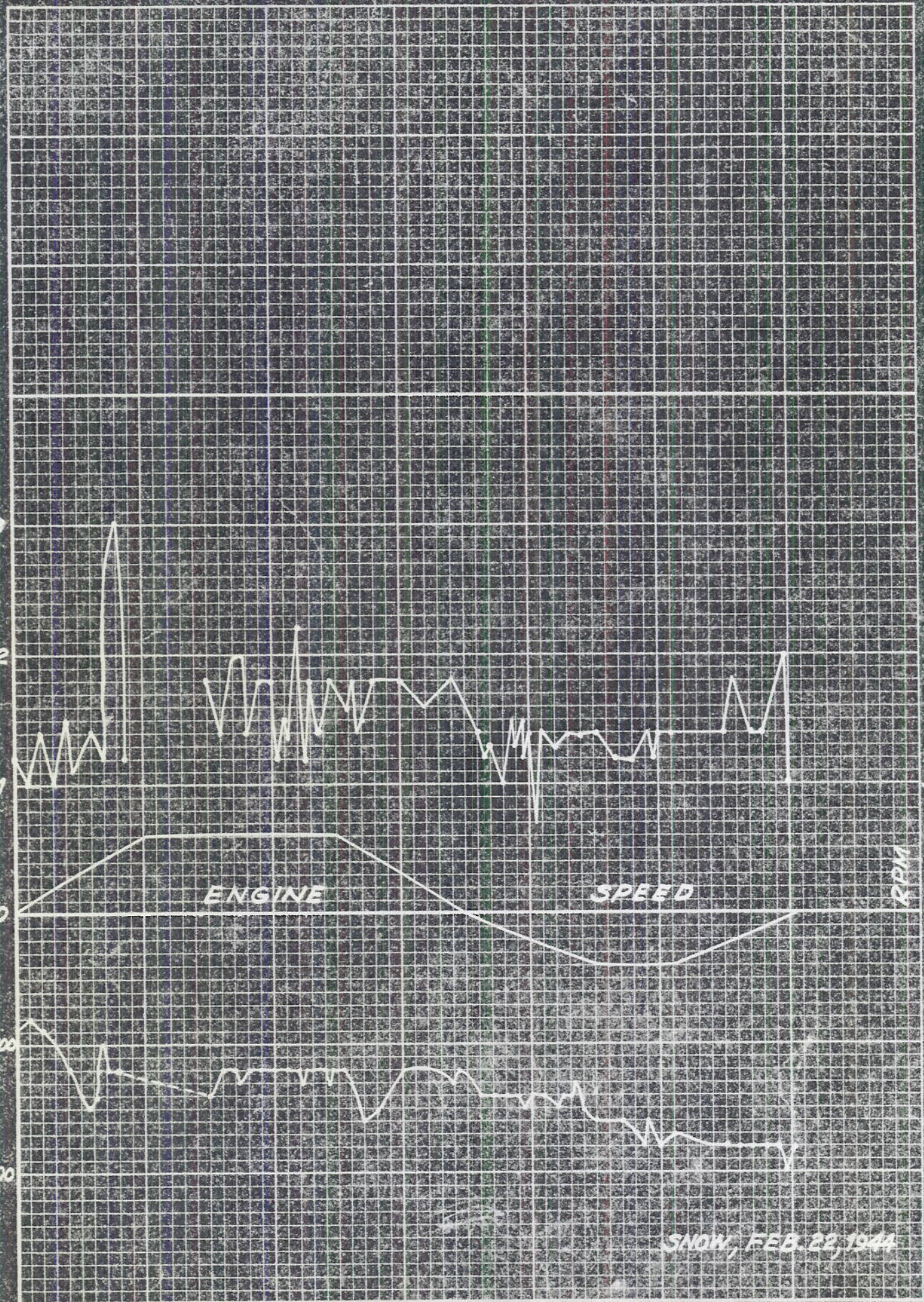
CODE 6167
 17 FEB 1944
 TEMP -8 TO -9C°
 ALT. 2000 FT.
 AIR SPEED 210 MPH.
 CHROMIUM PATCH
 POSITIVE CHARGE TO AIRPLANE
 AIRPLANE NEGATIVE

ELECTRIC FIELD - VOLTS/CM.

PLATE 17

PATCH CURRENT - MICROAMPERES

ELECTRIC FIELD - VOLTS/CM.



11:54:45

11:55:00

11:55:15

11:55:30

SNOW, FEB. 22, 1944

PLATE 18