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Second Partial Report on the Precipitation-Static Problem

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NAVAL RESEARCH LABORATORY

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NAVY DEPARTMENT

Second Partial Report on the Precipitation-Static Problem

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

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March 7, 1942

Prepared by:

Wayne C. Hall - Senior Physicist

Ross Gunn - Head Physicist

Reviewed by:

Ross Gunn, Technical Adviser

Approved by:

A. H. VanKeuren - Rear Admiral, U.S.N.
Director

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ABSTRACT

A large number of flights were made in snow and ice conditions, both in a C-47 airplane and in a B-24 airplane, with the object of studying the precipitation-static found. While flying in these conditions, instruments were employed to measure the discharge currents of various dischargers attached to the airplane, and the corresponding electrical fields at one location on the airplane. Observations were made of the amount of radio static at such times. Also, the characteristics of the Naval Research Laboratory's liquid-impregnated, wick-type discharger and of various trailing-wire dischargers were obtained. Results are given in this report that show the advantage of preventing discharge from various sharp parts of the airplane other than the dischargers. In particular, the importance of preventing discharge from the antenna and adjacent regions is noted. Recommendations are made which, if followed, will greatly reduce the amount of trouble encountered from precipitation-static.

[redacted]

INTRODUCTION

(A) Authorization

1. Bureau of Aeronautics Project 623/42, authorized March 7, 1942.

(B) Statement of Problem

2. In accordance with the letter of authorization, this project had for its goal the elimination or substantial reduction of precipitation-static encountered on an airplane flying in adverse weather conditions. Because of the great difficulties encountered on the Alaskan route, the Laboratory has directed most of its efforts to the cure and understanding of interference caused by snow.

Known Facts Bearing on the Problem:

3. The First Partial Report O-1919 should be read in connection with this report. The fundamental fact with regard to the problem of precipitation-static in aircraft is that this type of static results from an electrical discharge from the plane. The first report showed that it could be produced artificially in flight. A plane which shows this phenomenon has usually become highly charged by natural processes, such as those encountered while flying in snow or rain. There is no doubt that the peculiar radio static, known as precipitation-static, encountered under such conditions, is a result of the shock-excitation of the radio circuits by the corona discharge from the plane.

4. Attention was at first directed toward the improvement of the radio circuits. It was at first thought that noise-limiting devices ahead of the radio might be helpful. But such was not the case. However, it has been found that high frequency circuits are less affected by precipitation-static than the low frequency circuits used for range reception. Still, the advantage gained by their use is not sufficient for practical purposes.

5. Next, attention was directed to the discharge mechanism on the airplane. Obviously, there is no way to prevent discharge from the plane once it has become highly charged. But, precipitation-static troubles would vanish if, (a) the discharge could be caused to proceed in an interference-free manner, or if (b) an antenna were employed that would discriminate against the unwanted interference. The trailing-wire discharger has been developed with the first need in mind. The metallically-shielded loop came as an answer to the second requirement.

6. Both the anti-static loop, and the trailing-wire with suppressor resistor, are valuable aids in overcoming precipitation-static; but each device has important shortcomings. The anti-static loop, which is at present the best device in use, does not have enough pick-up to provide sufficient range for use on many distant

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routes. Also, the anti-static loop fails to operate through precipitation-static under extreme weather conditions. With regard to the trailing-wire discharger, both experience and our results show that this discharger, while of real service at times, is limited in usefulness to a storm of relatively low intensity. The plane equipped with this discharger will lose all radio reception except that on the anti-static loop in a storm of greater than low intensity, and in a severe storm radio communication will be lost even on the anti-static loop. Another defect of the trailing wire is that it is subject to whipping about in the air stream, and is too frequently lost by breakage. Extra circuits in the plane are necessary to fire the discharger, and operational attention by the pilot is required for types of trailing-wire dischargers which are enclosed until needed. It seems inadvisable to use this type of discharger just anywhere about the plane, because data are at hand [1] to show that trailing-wire dischargers are not effective at other locations than on the tail. This might be expected since, fundamentally, the nature of the discharge from the so-called fine wires used in the dischargers is such as to produce typical precipitation-static, and only the degree of decoupling from the plane offered by the suppressor resistor makes this device operative at all. Whether more than one trailing-wire discharger can be used on the empennage with benefit has not been reported.

Work Done by this Laboratory on the Problem.

7. This Laboratory has been interested in the problems arising from precipitation-static for some time, and has been actively engaged in work in this field since the project was authorized by the Bureau of Aeronautics. An earlier report [2] included a theoretical discussion of the physical causes for corona discharge from the airplane; it also described the experiments to discover a useful discharger and disclosed a new type of liquid-impregnated wick discharger which was developed at this Laboratory. For this first report a study was made of corona discharge from an airplane in flight, with the aid of a charging process which employed a water sprayer and an auxiliary electrical field, thus making it possible to charge the airplane artificially. This charging mechanism can be reversed in direction at will and can be made to overcome a limited charge developed on an airplane flying in snow or rain. A study of a model plane was made to determine the field distribution about a charged airplane with results of practical value in the placement of any discharger.

8. Following the first report the need for data on airplanes flying in actual storm conditions became imperative, particularly in snow, because precipitation-static is reportedly worse and more persistent in snow than in rain. Arrangements were made to conduct experiments in the North during the winter. In cooperation with the Northwest Airlines, a C-47 airplane used for cargo transport by the Army was equipped with various indicating and recording instruments

[redacted]

and with dischargers, both of the trailing-wire type in customary use and of the Naval Research Laboratory type. A flight was made on this airplane from Minneapolis, Minnesota, to Fairbanks, Alaska, and back, during the latter part of December, 1942. It became evident on this flight that special efforts would be needed to find bad weather. Upon returning to Minneapolis, with the full cooperation of the personnel of the NACA Ice Research Project at Minneapolis, the instruments and dischargers were changed to a B-24 airplane attached to that project. On this plane, twelve flights were made in as severe ice and snow conditions as could be found around Minneapolis during the time of the tests which took place in January and February, 1943. Rain, hail, sleet, snow, and ice were all encountered. The B-24 airplane is a good plane for precipitation-static experiments because of its susceptibility to this trouble which results from its large size, relatively high speed, and lack of protection. This report considers the data and results obrained during the above period.

Methods and Results of Observation.

9. A study of precipitation-static on board an airplane in flight requires the use of certain instruments not all of which are now available. Measurements are required of the intensity of the storm, of the nature of the charge upon the precipitation particles, of the relative magnitudes of the precipitation-static, of the electrical field about the airplane, and of the discharge currents. Also, observations of contributing factors, such as air speed, altitude, temperature, and humidity are advisable.

10. The measurement of the relative magnitudes of the precipitation-static requires the use of a portable, field-strength apparatus; but such equipment was not available. Hence, the static observations were made in the following manner: the volume control was set at the same level each time and the relative magnitudes of the signal and precipitation-static were obtained aurally from the receiver under observation. Using this method only two static observations were significant, (a) the point at which static began and, (b) the point at which static prevented the reception of signals.

11. The electric field about a charged airplane in flight is of the utmost significance in precipitation-static research. A type of air-driven induction voltmeter developed at this Laboratory [2] measured the electric field at one point on the airplane; this selected point on the bottom of the fuselage was about one-third of the distance between the tail and the wing. An investigation of a model airplane had disclosed that at such a point the electric field varied slowly along the length of the fuselage. Also, model experiments outlined in the First Partial Report permit one to estimate the electric field at any other selected point on the plane from its value at this reference point.

12. If simultaneous observations of all factors could be re-

corded automatically, such would be the ideal manner of recording data for a study of this nature. Because only one recording instrument was available, this was impossible. However, two trained Naval Research Laboratory observers were on hand at all times to get simultaneous observations of the quantities of importance. Our first estimates of the range needed in the induction voltmeter were low and this resulted in the loss of valuable data on the first flights. After this, the range of the induction voltmeter was increased to a maximum of 550 volts per centimeter.

13. The arrangement of apparatus on the C-47 was quite similar to that on the B-24; therefore, only the setup used on the B-24, which is shown schematically in Plate 1, will be described. It may be seen that lead wires extended from all dischargers to a rotary switch at the control panel, and that it was possible to record any discharge current, or the total current, at will. In addition, the total discharge current was always directly indicated. All of the instruments were located at one point in the airplane as shown in Plate 2. The Plates 3 and 4 show the location of three of the Naval Research Laboratory dischargers on the B-24 airplane; the other three dischargers of the six used were in corresponding locations on the opposite side of the plane. Plate 4 shows the induction voltmeter in place on the fuselage.

14. The dischargers shown in Plates 3 and 4 were insulated from the plane so that the current discharged could be measured. A much better design for ordinary use is sketched in Plate 12. This drawing discloses dimensions and other details of construction; the simplicity of installation of these dischargers is apparent.

15. In the course of many hours of flying through all kinds of weather encountered in the temperate cyclone during the winter, but principally snow and icing weather, many results of interest were obtained. Of perhaps greatest interest is the fact that in all cases the plane developed a negative charge; consequently, the dischargers lost negative charge at all times, except once when the plane was in a strong transverse electric field for a few seconds only. The significant results are given in the tables included in the appendix.

16. A large, fast, four-motored airplane such as the B-24 should experience much precipitation-static and should discharge relatively large currents. Yet, in the adverse weather which was encountered, the maximum total discharge measured in twelve flights was only 330 microamperes from the six Naval Research Laboratory dischargers. Furthermore, in severe icing conditions the maximum discharge measured was only 5 or 10 microamperes. Experience indicated that when flying in the rain, sleet, hail, icing weather, or snow found in a temperate cyclone during the winter, the greatest charge on the airplane was developed by dry snow. Scintillations were visible at times when dry snow struck the stabilizer.

17. In well over thirty hours of flying in winter storm con-

ditions, a transverse electric field was encountered for only a few seconds, and it was only during this time that any of the plane dischargers lost positive electricity. Good measurements were not obtained on this phenomenon because of the speed with which it passed by.

18. Much precipitation-static was encountered when either of the two planes was flying in dry snow. Partial relief was obtained from the Bendix type of trailing-wire discharger. A discharger of this type, attached to the customary long flexible suppressor resistor, was observed to discharge negative electricity quietly up to a maximum of 70 microamperes before the Command receiver on the B-24 was blotted out, and up to a maximum of 85 microamperes before the ADF redeiver on the B-24 was blotted out by precipitation-static. More complete relief was obtained from several Naval Research Laboratory dischargers. It is estimated that approximately two and one-half times as much current was discharged from six Naval Research Laboratory dischargers as from the Bendix discharger before precipitation-static began. The relatively steady nature of the discharge current from an airplane flying in the dry snow of the winter storms encountered is shown by a portion of a typical record included in Plate 5.

Discussion of Results

19. The curves relating the discharge current and the electric field on the airplane, Plates 6 and 7, are of great significance. These show clearly that the electric field at a given point on the plane builds up to a high value and that the discharge current increases, very roughly, in proportion to the electric field. It is believed that the discharge current measured represents the major part of the charging current to the airplane for the following reasons:

(a) It is a known experimental fact that a corona discharge from the airplane of only a few microamperes will cause severe static in the radio [3]. Hence, when no precipitation-static is audible, the corona discharge current from the airplane itself can be at most only a few microamperes. Moreover, estimates in the first report showed that the conduction current from the charged airplane is probably small. Therefore, it is believed that when precipitation-static is inaudible the discharger current represents practically the entire current discharging the airplane.

(b) A consideration of Plates 6 and 7 show that there is no break in the curves when precipitation-static becomes audible. Because of this absence of a break, it is believed that the dischargers handled the major portion of the discharge current throughout the entire considered range.

20. The high values of electric field measured, which were above 440 volts per cemtimeter at the location of the induction voltmeter,

indicate very high potentials exist on the plane flying in snow. A calculation of the approximate potential of the plane must be based on its capacity to its surroundings. Some measurements on a model plane isolated in space show that the plane, has approximately, the same capacity as a sphere of radius equal to one-fifth the wing span of the plane. Hence the capacity of the B-24 airplane in flight, is roughly, 1/5 x 110 x 30 = 660 centimeters. The potential of an isolated sphere of this capacity with a surface field of 440 volts per centimeter is equal to 440 x 660 = 290,000 volts. It is believed that the potential of the airplane probably reaches this value.

21. Although such high values of potential were expected, it seemed of interest to determine experimentally the influence of a relatively high "polarizing potential" on a Naval Research Laboratory discharger. Therefore, a polarizing potential of 20,000 volts was applied to a discharger in such a direction as to promote the discharge. It was found (Table V) that the discharge current was increased threefold without the intervention of noise. Because the increase in current with applied polarizing potential was not phenomenal, further experiments were temporarily discontinued. The special high voltage equipment necessary for such a procedure is not considered very practical on an airplane.

22. A further inspection of Plates 6 and 7 will show that for a given airplane with a given setup, precipitation-static occurred whenever a certain critical electric field was reached. Let this field where precipitation-static begins be called the <u>onset field</u>. The onset field varies with different radios on a given plane, and, in particular, with different planes. For example, the onset field for the Command receiver on the C-47 airplane (frequency about 5.4 megacyles) was between 125-190 volts per centimeter. Yet the onset field for the ADF receiver, either on the loop antenna, the sense antenna, or ADF, was not reached on the range frequency (approximately 250 kilocycles) with certainty, until a field above 320 volts per centimeter was observed. As another example, the onset field for the Command receiver on the B-24 airplane (frequency about 5.4 megacycles) was between 390-430 volts per centimeters with one setup and 235-340 volts per centimeter for another setup.

23. The question immediately arises as to why these differences exist. To arrive at the answer to this question, one must remember, first of all, that precipitation-static arises from a corona discharge on some part of the airplane. Experiments made at this Laboratory in connection with this problem have shown that a corona discharge from the antenna itself of even one-half microampere will produce an extreme type of static, similar to precipitation-static. Hence, a discharge of a microampere or so, from the antenna of the plane would be expected to produce severe precipitation-static. Since the antenna for the Command receiver of the C-47 was on a mast at the top of the rudder (See Plate 8), where it was exposed to the maximum field on the plane, and since it consisted of a relatively

small diameter bare wire, it is believed that the antenna began to discharge long before the other parts of the plane did. Thus, the onset field was exceptionally low, or 125-190 volts per centimeter. This belief is favored by the fact that the sense antenna for the ADF receiver, which was on the bottom of the fuselage in a location of low field intensity, was essentially noise-free to above 320 volts per centimeter. It is believed, therefore, that little discharge was taking place from the plane itself at fields of 125-190 volts per centimeter. The results with the B-24 are parallel in meaning. On this airplane the onset field for the Command receiver was between 235-340 volts per centimeter at first trial. The receiver was identical to the one on the C-47 airplane, but the antenna for the Command receiver on the B-24 airplane was a rubber-covered cable about one-eighth inch in diameter. (See Plate 9 for the location of this antenna). It was suspected that discharge was taking place from the end of the antenna or the supporting hook. To test this belief these parts were covered with a layer or two of rubber tape. As a result, the onset field of the Command receiver rose to a value between 390-430 volts per centimeter. This onset field was very near to the onset field for the ADF receiver using a special whip-type sense antenna. The whip-type sense antenna had been coated on its end with a high dielectric-strength insulating compound to prevent discharge. (See Plate 10). No certain data are at hand relative to the onset field for this whip antenna before treatment because the B-24 airplane was called away before experiments were completed on it; but it is believed that the onset level of the untreated whip antenna was between 220-275 volts per centimeter. (See Table V for these data).

24. These results, although incomplete, show that much can be hoped for in the reduction of precipitation-static by increasing the onset field through a clean-up of the airplane. For example, the prevention of discharge from the antenna, by one means or another, will effectively raise the onset field for the plane and permit the discharge of greater currents from the dischargers without radio static. Also, any means of preventing discharge from the airplane itself, by an electrical clean-up, that is, the removal of such parts as exposed cotter keys, sharp points, and sharp edges, will raise the onset field. A partially effective, electrical clean-up can be accomplished by painting all sharp extremities of the airplane with an insulating paint of high dielectric strength. The wing tips, being in a region of most intense field, must have all sharp edges and points removed. The geared propellers on the modern planes cause less static than the older, faster turning propellers. Nevertheless, the propellers must receive consideration in this clean-up, for the trailing edges, being in a region of low air pressure, are especially liable to be the seat of electrical discharges causing static. A partially effective clean-up of the propellers would result from increasing the radius of curvature of the trailing edge and of the tip of the propeller. A second partial solution, which was tried on the C-47 airplane, is offered by the use of a thick coating (about .030")

of a lacquer or paint of high dielectric-strength along the trailing edges and tips of the propellers. No data were secured on the effect of this treatment, through lack of time. However, it must be pointed out that a solution involving painting the propellers would be only temporary, because of the manner in which propellers are damaged by dirt and gravel during take-offs. The resultant abrasion would undoubtedly break the dielectric coating on the blades, thus rendering the coating useless. As another clean-up measure, the Pitot tubes for the air speed water which sometines extend far out from the plane, should be relocated and designed for the prevention of electrical discharge.

25. It is important to realize that the clean-up of the plane to reduce discharge, although of much value, as is illustrated in Plate 11, is not alone sufficient. This is because the amount of charge collected by the plane in snow or rain is so great that discharge cannot be prevented. Hence, dischargers of a quiet type must also be provided.

26. The question arises as to how many dischargers are required to keep the plane below the onset field. This question can be answered only with respect to the Naval Research Laboratory's discharger. Certainly, one is not sufficient to do the job. Also, the number required will vary with the type of airplane and its speed. Plate 11 shows that the use of more than one is of great advantage; in fact, the upper limit to the number of Naval Research Laboratory dischargers which should be used is based on the practical considerations of drag, installation, and upkeep. Probably, six is the minimum number of these dischargers which may be employed to secure substantial improvement over the present methods of reducing precipitation-static.

27. Considerable experience with the Naval Research Laboratory discharger under winter conditions indicates that no serious difficulties are likely to be encountered in their use. Some misalignment, or breaking of the discharge tubes from the mountings, may result from the use of the canvas wing covers unless slots are provided in the wing covers through which the discharger tubes can extend. Icing difficulties of a serious nature are not expected. Some trouble may be expected through actual saturation of the wicks by the Oleum compound used in cleaning the plane. A wick discharger saturated with Oleum will be useless. Probably the best means of taking care of this trouble is to cut the Oleum-saturated wick off next to the tube, and to pull the clean wick out to the proper length.

28. It has been pointed out by Hucke (1) that the Bendix-type trailing-wire dischargers are of no advantage on the wing tips. Whether two would be of advantage on the tail has not yet been reported. Until the work in progress has been completed this Laboratory cannot supply the information.

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29. But, evidence has been obtained (See Tables IV and V) that the trailing-wire type using a short suppressor resistor (source unknown) introduced recently by the Army as a partial solution to the precipitation-static problem is too closely coupled to the plane, and is not at all satisfactory except, possibly, for very small discharge currents. This unsatisfactory short ype of suppressor resistor was a resistor of one-half megohms enclosed in a plastic case.

30. The data of Table VII, regarding the long trailing-wire with suppressor resistor, are included for completeness. Apparently, the combination of long wire and suppressor resistor can be made to work as an efficient discharge. But, it is not believed that the long trailing-wire is a practical device on an airplane which is flying in storms where strong electric gradients may exist.

CONCLUSIONS

31. The precipitation-static found in the wintertime occurs most commonly in regions where snow and ice crystals are encountered.

32. The onset of precipitation-static is determined by the electric field surrounding the plane.

33. The airplane was negative for all observed conditions.

34. The electric field at onset can be raised by an electrical clean-up of the plane to prevent, insofar as possible, discharge from the plane itself.

35. Antennas can be easily relocated in regions of lower electrical fields and treated to prevent discharge, with little resultant influence on their usefulness in maintaining radio communication in good weather and with much improvement resulting in weather causing precipitation-static.

36. Suitable dischargers must be employed on an airplane if any reduction of precipitation-static is to be obtained, irrespective of other treatments.

37. The Naval Research Laboratory's liquid-impregnated wick-type discharger is thought to offer a satisfactory discharger for the reduction of precipitation-static troubles because of its simplicity and other good characteristics. It is believed that a minimum of six Naval Research Laboratory dischargers will afford a substantial reduction in precipitation-static troubles.

38. Since simplicity is a prime consideration for any discharger, only the Naval Research Laboratory-type and the trailing-wire type merit serious attention at present. The Naval Research Laboratory discharger is believed to be superior to the

trailing-wire type under operating conditions.

39. The best solution now available for the reduction of precipitation-static may be found by a combination of clean-up of the plane, and the use of several dischargers. These dischargers should be located on wing tips, stabilizer tips and rudder tips.

40. The anti-static loop will benefit from the use of dischargers and a clean-up of the plane.

41. No complete solution to the problem of precipitation-static is at hand. Because of the extent and complexity of the problem, more work is necessary.

RECOMMENDATIONS

Because the above report indicates that real progress has been made toward a solution of this problem,,and because one may reasonably expect a substantial reduction in the "outrage" caused by precipitation-static, the following recommendations are made with regard to all military planes operating in zones were precipitation- static is common:

1. That all planes be provided simultaneously with

(a) NRL dischargers mounted in accordance with the requirements herein set forth,

(b) Treatment to eliminate or cover with an insulating material having a high dielectric strength all sharp points on antenna supports, air speed tubes, or other parts of the airplane exposed to high electrostatic fields,

(c) treatment to insure that no insulated antenna sections, or other objects or surfaces, be left without a suitable high resistance leakage path to the ships ground.

2. That the location of aircraft antenna be considered in relation to the precipitation-static problem. The preferred location is not on the extremity of a mast of a part of a plane, but is inboard in a region of lower electric field.

3. That the "Whip" antenna be abandoned, or, at least, that its tip be covered with an insulating cap having a high dielectric strength.

ACKNOWLEDGEMENT

The experimental work in the northern winter storms disclosed in this report has been made possible through the full cooperation extended by the Northwest Airlines Corporation, and by the National Advisory Committee for Aeronautics. Officials and others of the above corporation, especially in the Radio Communication Division, were unfailing in their efforts to aid this research project. The director and other personnel of the NACA Ice Research Project at Minneapolis have been especially helpful. Much of the data contained herein could not have been obtained at this early date without their hearty cooperation.

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APPENDIX A

MISCELLANEOUS INFORMATION

A. Data on the B-24 Airplane (Approximate):

Wing Span	110 ft.
Length	66 ft.
Height	16 ft.
Effective frontal area, flying position with landing gear retracted, flaps up, cowl flaps closed is	31 to 35 sq. ft.

Command Receiver

Antenna-	1/8" diameter rubber-covered control cable about 32 ft. long from left vertical fin forward to top of cabin.
Frequency-	5.37 megacycles, usually, or Range frequency of 266 kilocycles.

ADF Receiver antennas:

Loop on top of cabin near mid-section
Whip-type sense antenna on top of cabin, 5-1/2 ft. long.

Precipitation-Static Protective Devices - None.

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APPENDIX B

C - Clear reception with no precipitation-static.
V - Precipitation-static is audible, but signal comes through above the static.
S - Loud precipitation-static; signal does not come through above the static.
ES - Extreme precipitation-static present.

TABLE I

Data on the C-47 Airplane
Date: December 24, 1942

Weather: Snow

Remarks: One NRL discharger on each wing tip.

Approximate: Altitude Feet	Speed m.p.h.	Air Temp. °F
6,500	155	0

Time	Command Receiver	ADF Receiver	Electric Field Volts/cm	NRL Discharger Currents Right Wing Microamperes	NRL Discharger Currents Total Microamperes	Cartridge type trailing wire current	Remarks
4:30							Take-off from Edmonton, Alberta.
5:10	U	C	-51*	-3	[-6]+	Not out	Beginning of snow
5:12	"	"	-96	-4	[-8]	" "	Snow
5:15	"	"	-128	-9	[-18]	" "	"
5:16	ES	"	-192	-20	[-40]	" "	"
----	"	"	-290	-35	[-70]	" "	"
5:35	"	"	-270	-34	-66	" "	"
5:37	"	U	>-320	-35	-82	" "	"
5:40	"	"	>-320	-50	-100	" "	"
5:45	"	"	>-320	-60	-110	" "	"
5:50	"	"	>-320	-55	[-110]	" "	" Moderate to heavy
----	"	"	>-320	-64	-120	" "	"
----	ES	----	----	-33	-60	Out-0μA	No difference was noted on firing the cartridge either in static or current discharged. Reason for failure unknown.
----	"	----	-130	-20	-46	Out-0μA	
6:05	C	C	0	0	0	Out-0μA	Plane in clear sky.

Notes: * The negative field denotes that the plane was negative.
\+ The values in parenthesis were estimated.

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TABLE II

Data on the B-24 Airplane
Date: January 15, 1943

Weather-Snow, no icing
Location-North of Minneapolis and within 40 miles.

Remarks: Bendix discharger available only.

Approximate: Altitude 2000 ft. Speed 190m.p.h. Air Temp. 18°F.

Time	Command Receiver	ADF Receiver	Electric Field Volts/c m	Discharger Current Microamperes	Remarks
2:05	ES	ES	-320	0	No discharger; Light snow
----	C	C	-192	-50	Bendix trailing-wire out with suppressor resistor
----	ES	C	>-320	-70	" " " " " " "
----	" "	ES	>-320	-85	" " " " " " "
2:14	" "	Loop-C	"	-85	" " " " " " "
----	" "	" "C	"	-100	" " " " Moderate" snow
2:50	" "	" "	----	-40	" " " "
----	" "	" "	>-320	0	No discharger
2:51	" "	" "	----	-62	Bendix trailing-wire out with suppressor resistor
----	" "	" "	----	0	No discharger
2:52	" "	" "	----	-60	Bendix trailing-wire out with suppressor resistor
----	C	ADF-C	-172	-35	" " " " " "
3.00	U	------	>-320	-84	" " " " " " Observation right over field*

*Landed 3.01 P.M.

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TABLE III

Data On the B-24 Airplane

In Icing Conditions.

Remarks: No precipitation-static encountered on these flights

Date	Weather	Electric Field Volts/cm	Discharger Currents Microamperes	Remarks	Altitude	Speed m.p.h.	Air Temp. °F.
1/8/43	Overcast	-19 -32	-----	Nothing but overcast encountered.	8,000	180	0
1/14/43	Moderate icing	-30 to --55	-----		-----	---	-
1/24/43	Light to moderate icing	-22 to --55	0 to -2		3,200	177	+ 16
2/5/43	Light icing	-44(maximum)	0 to -2(maximum)				
2/8/43	Moderate to heavy icing	-10 to -55	0 to -5		10,000	160	+ 15
2/9/43	Heavy icing	-0 to -22	0 to -5				

Note: The icing observations were made by NRL observers untrained in making such observations, but were checked against the reports of trained observers.

TABLE IV

Data on the B-24 Airplane
Date: January 29, 1943

Weather: Snow
Location: East of Minneapolis about 80 miles

Remarks: [a] 6 NRL dischargers on plane.
[b] Insulating composition on end of whip-type, sense antenna used by ADF receiver.
[c] Command Antenna untreated,

Time	Command Receiver	ADF Receiver	Electric Field Volts/cm.	Discharger Currents Total (Microamperes)	Discharger Currents Other* (Microamperes)	Remarks	Altitude. Feet	Speed m.p.h.	Air Temp. °F.
2:00	C	C	-44	-5	Not out	Overcast			
2:01	"	"	-66	-12	" "	Beginning of snow			
2:08	"	"	-154	-70	" "				
2:10	"	"	-132	-50	" "		6300	152	23°
2:19	"	"	---	-110	-30	Bendix discharger in use on tail.			
2:25	"	"	-165	-105	-25	" " " " "			
----	S	--	-220	-120	Not out				
2;30	"	U	-330	-200	" "		11,000	---	---
2:35	U	--	-220	-155	-35	Bendix discharger in use on tail.			
2:37	S	C	-264	-210	-50	" " " " " "			
2:40	S	U	-198	-200	-60	Trailing-wire discharger with special suppressor supplied by Army.			
----	--	--	-264	-235	-75	" " " " " " " "			
2:50	S	C	-352	-225	Not out				
2:50	C	C	-286	-180	" "				
3:01	C	--	-198	-130	" "		11,000	183	14
3:07	S	C	>-440	-245	" "				
3:10	"	U	>-440	-260	" "				
3:11	ES	(ADF-S Loop -U)	>-440	-330	" "				
3:14	""	U	>-440	-290	" "				
----	""	C	-440	-240	" "				
----	""	U	>-440	-295	" "				
3:17	""	C	---	-260	" "	ADF Receiver is clear below 260 μa discharge			
3:20	U to S	"	-396	-200	" "	Command Receiver is usable up to 200 μa discharge			

TABLE IV (continued)

Time	Command Receiver	ADF Receiver	Electrical Field	Discharger Currents Total	Discharger Currents Other	Remarks	Alti-tude	Speed	Air Temp.
3:21	C	C	-44	-10	Not out	In heavy overcast at lower elevation, little snow is present			
3:35	"	"	-220	-112	" "	Snow			
3:36	"	"	-198	-100	" "				
3:55	"	"	---	-32	-10	Trailing-wire discharger with special suppressor supplied by Army.			

4:05 Landed at Minneapolis.

* The "Other" discharger, when used was one of the trailing-wire type.

[redacted]

TABLE V

Data on B-24 Airplane
Date: January 31, 1943

Remarks: [a] NRL dischargers on plane; "other" dischargers where noted.
[b] Insulating tip on whip antenna
[c] Insulating tape on exposed metal parts of Command receiver antenna installation.

Weather-Snow

Time	Command Receiver	ADF Receiver	Electric Field Volts/c m	Discharger Current Total (Microamperes)	Discharger Current Other (Microamperes)	Remarks
10:40	C	C	-77	-21	Not out	Snow
10:43	"	"	-77	-26	" "	
10:50	"	"	-99	-36	" "	
10:51	"	"	-110	-45	" "	
11:00	"	"	-198	-115	" "	
11:02	"	"	-220	-120	" "	
11:03	"	"	-209	-116	" "	
11:04	U	"	-275	-150	" "	
11:05	S	S	-176	-140	-35	Trailing-wire discharger with special suppressor supplied by Army.
11:10	ES	ES	-187	-130	-40	" " " " " "
11:12	C	S*	-297	-144	Not out	
11:17	C	S*	-275	-140	" "	
11:30	C	C	-220	-130	-20	NRL discharger in tail tube.
11:33	--	--	-187	-135	-60	NRL discharger in tail tube at -15,000 to -20,000 volts with respect to plane
11:44	U	C	-77	-75	-60	400 feet #24 Cu D.C.C. wire out of tail tube. No suppressor
11:44	"	"	-77	-95	-78	" " " " " " " " "
11:52	C	C	-44	-40	-35	200 ft. #24 Cu D.C.C. wire out of tail tube. No suppressor.
11:55	C	C	-66	-60	-50	" " " " " " " "

Time	Command Receiver	ADF Receiver	Electric Field Volts/cm	Discharger Currents Total (Microamperes)	Discharger Currents Other (Microamperes)	Remarks
11:58	C	C	-88	-95	-75	200 ft. #24 Cu D.C.C. wire out of tail tube. No suppressor.
12:03	ES	ES	-44	-22	-17	" " " " " " " " " "
12:09	C	C	-11	0	0	Pulled wire in
12:35						Landed at Minneapolis.

* It is believed that the insulating tip on the whip antenna partly broke away at this time. Inspection at the end of the flight showed the insulation to be broken.

[redacted]

TABLE VI

Data on B-24 Airplane

Weather: snow, hail, sleet, rain, and severe icing

Date: February 3, 1943

Remarks: Set-up on plane described in Table V.

Time	Command Receiver	ADF Receiver	Electric Field Volts/cm	Discharger Currents Total (from 6 NRL Type)	Remarks	Altitude Feet	Speed m.p.h.	Air Temp. °F
3:30	C	C	-66	----	Severe icing			
3:40	"	"	-66	----	" "	4,000	169	26.5°
4:05	"	"	-99	----				
4:20	"	"	-110	-33	Light snow			
4:21	"	"	-165	-65	Visible scintillations on stabilizer from striking snowflakes.			
4:25	"	"	-22	-3				
4:35	"	"	-275	-120	" " " " " "			
-----	"	"	-297	-170	" " " " " "			
----	U to S	--	-440	-270	Command receiver noisy above -270 μA.			
4:40	C	C	----	-240				
4:45	ES	C	----	-270 to below -200	Plane in transverse electric field. Right wing discharged over +30 μA. for few seconds.			
5:00					Landed			

[redacted]

TABLE VII

Data on B-24 Airplane

Weather: Snow Date: February 12, 1943

Remarks: Trailing wire (#24 Cu D.C.C.) 200 feet long attached to tail of plane through 1 megohm suppressor resistor. No noise from either Command or ADF receiver at any time during flight.

Time	Total Discharge Current	Trailing wire discharger	Electric Field	Remarks	Approximate: Altitude	Speed	Air Temp.
	Microamperes	Microamperes	Volts/cm				
2:05	--	-10	---	Light snow	7,700ft	180 mph	6°F
2:10	-38	-30	(-40)*	"	"		
2:26	-61	-50	---	"	"		
2:27	-120	(-95)*	(-95)*	"	"		
2:30	-73	-60	---	"	"		
----	-105	-85	---	"	"		
2:35	-75	-60	---	"	"		
3:05				Landed at Minneapolis			

Note: * These values are estimated.

[redacted]

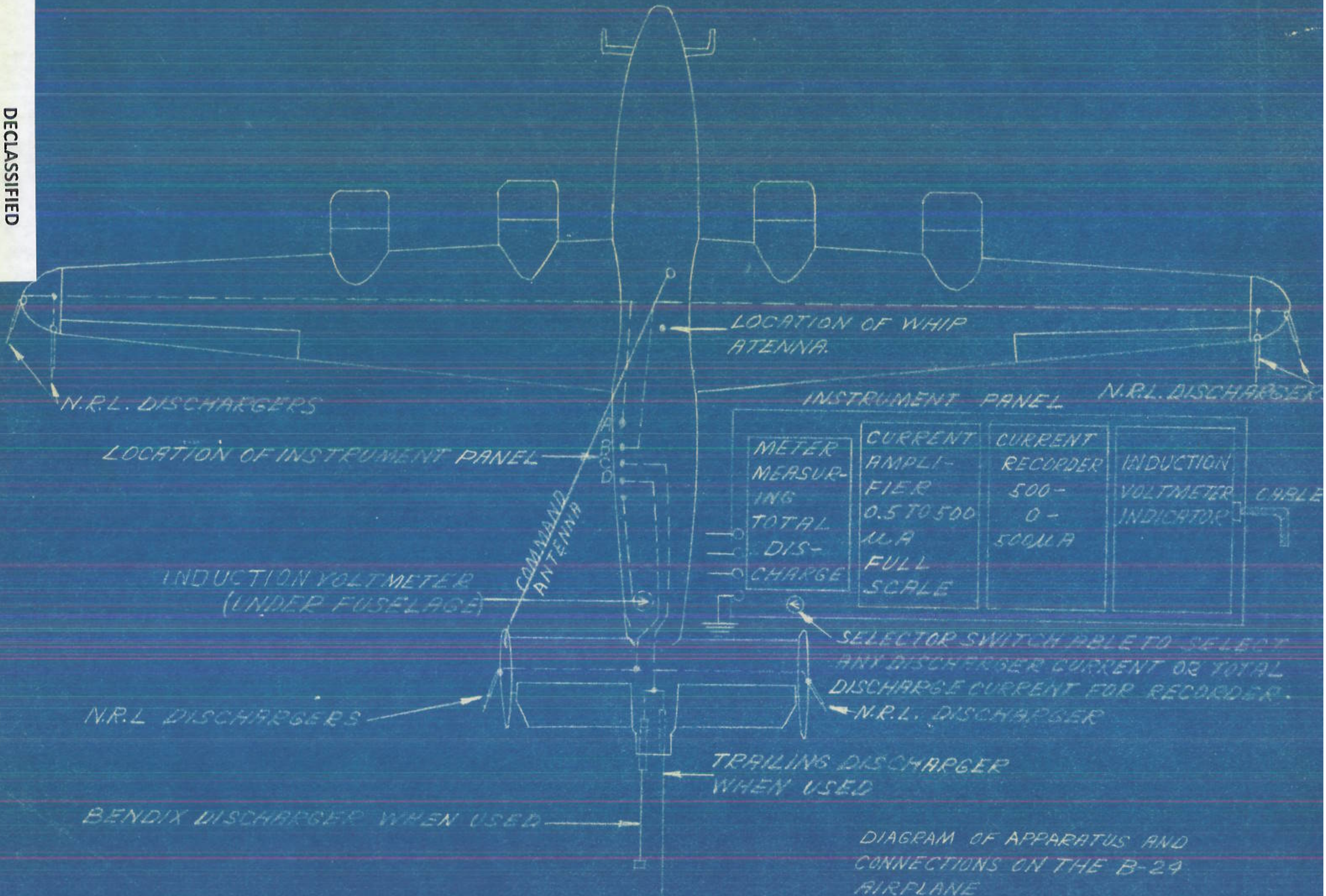
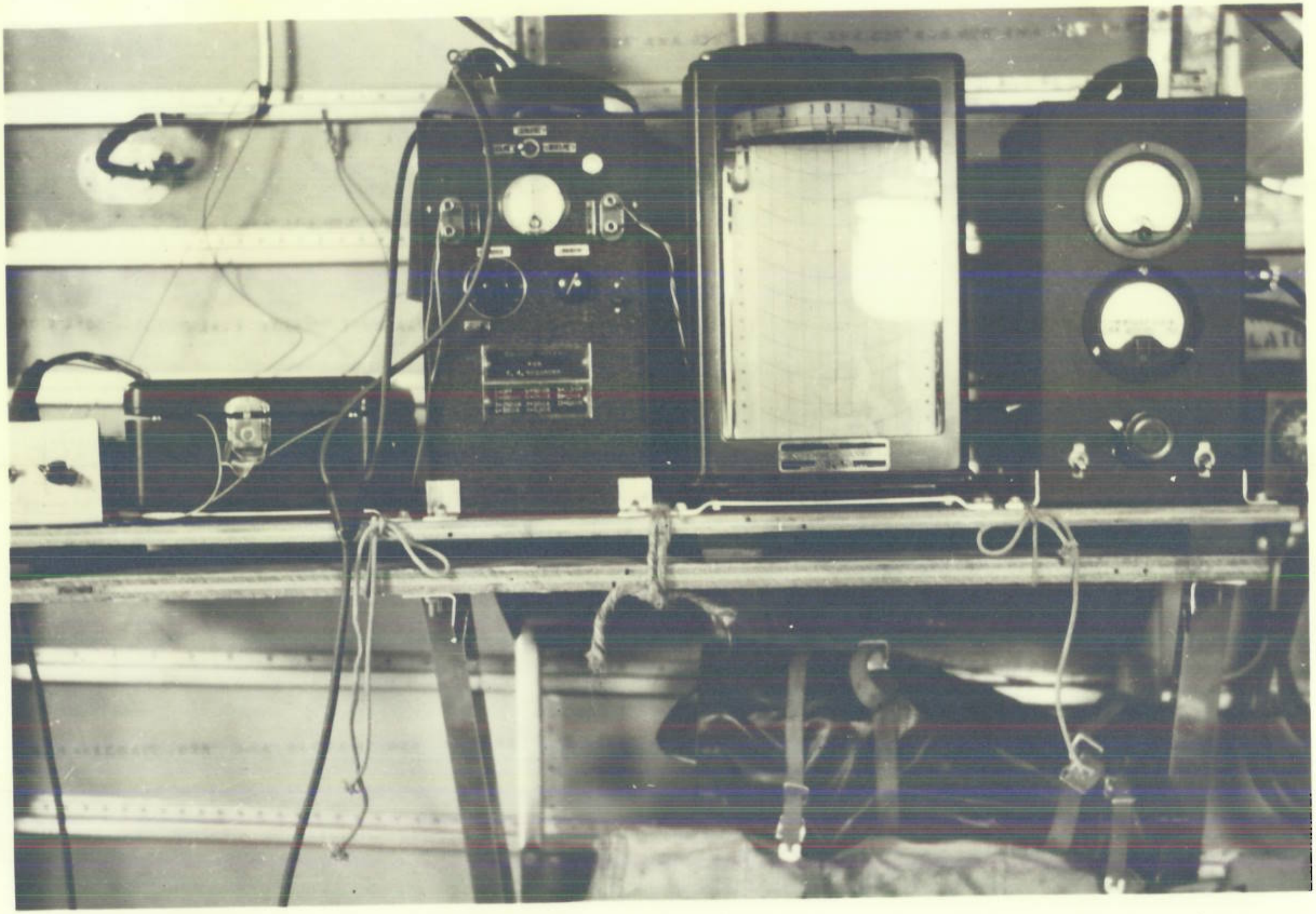
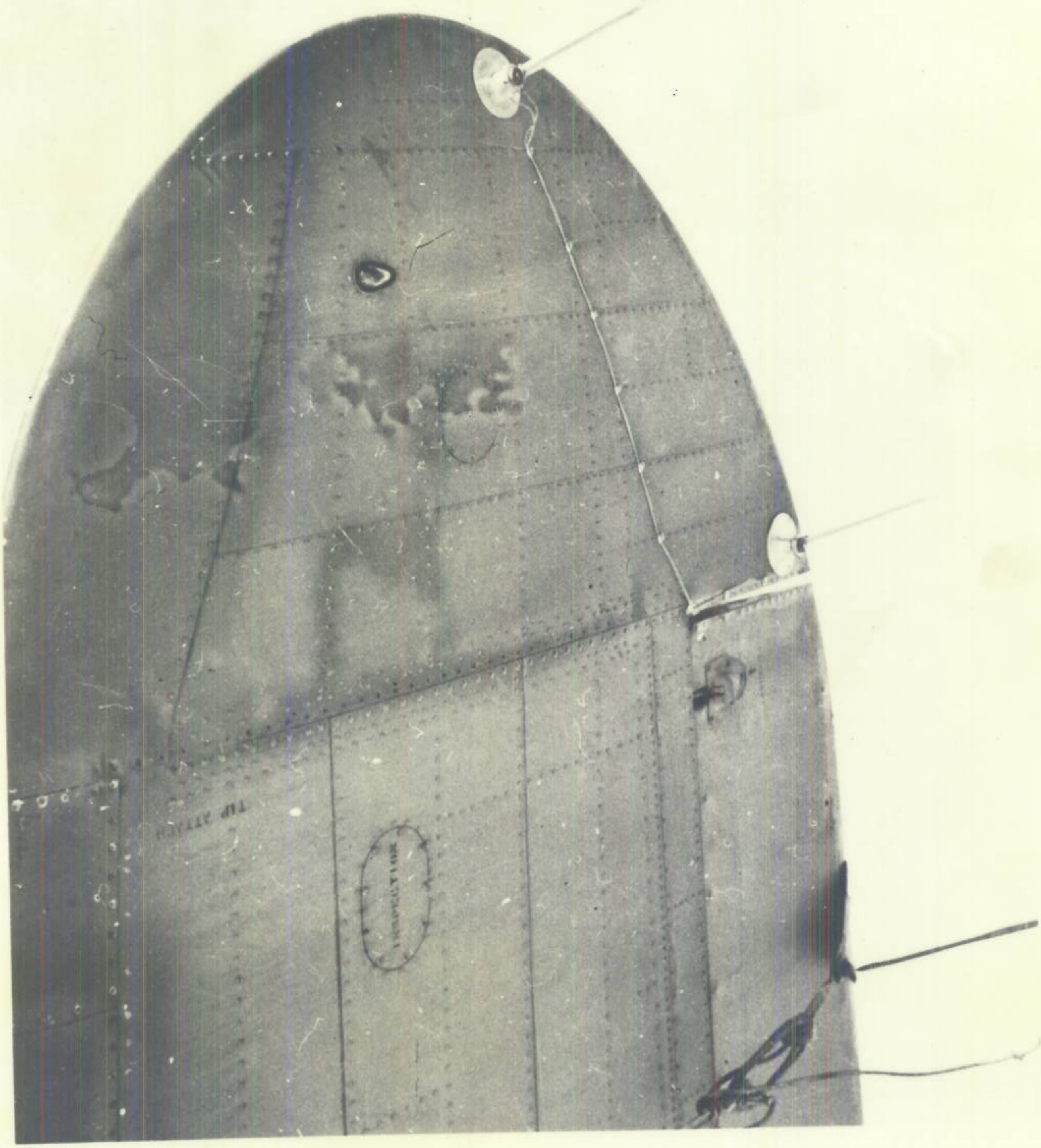


DIAGRAM OF APPARATUS AND CONNECTIONS ON THE B-29 AIRPLANE

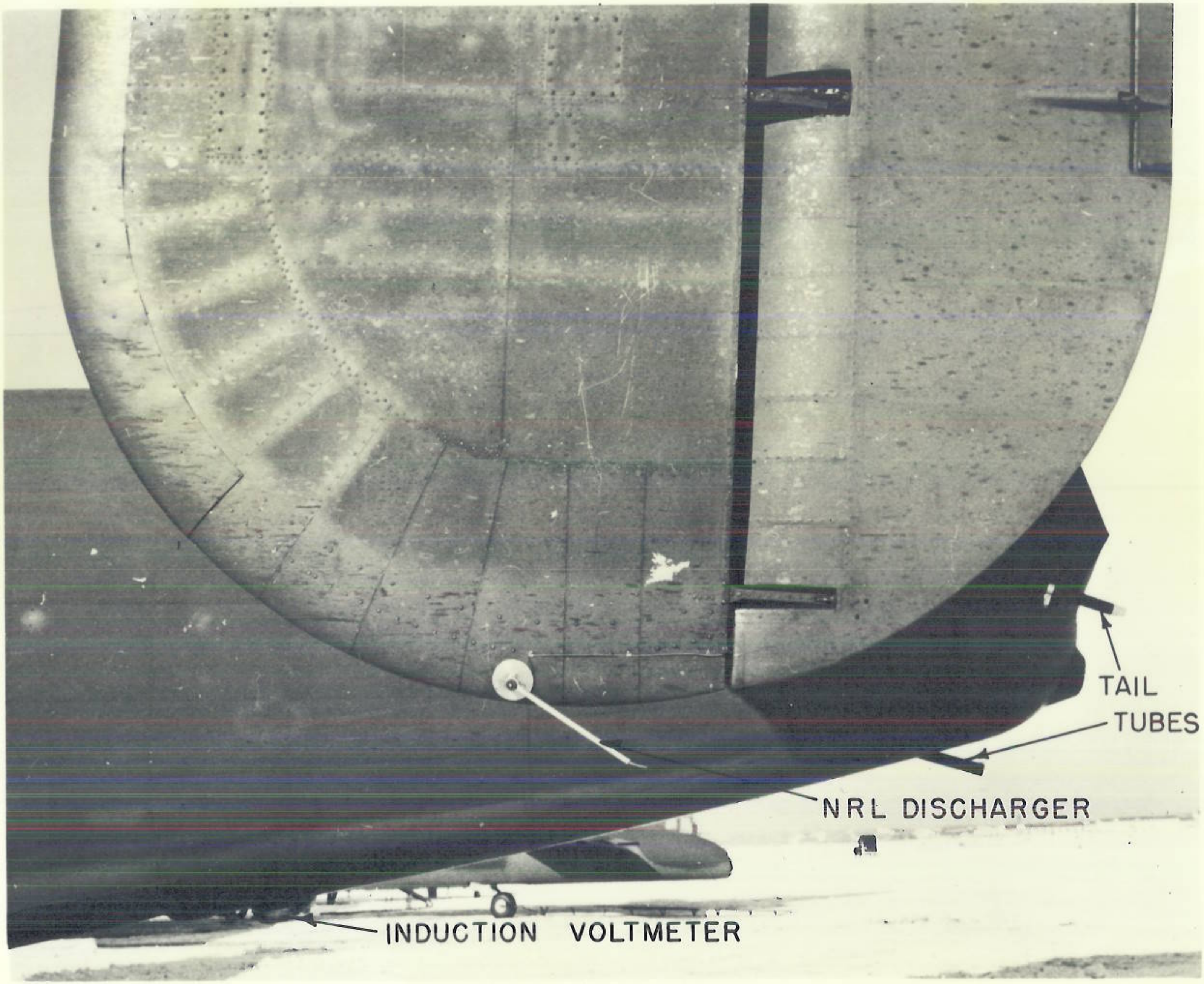
PLATE 1



INSTRUMENT PANEL FOR PRECIPITATION - STATIC RESEARCH ON THE B-24 AIRPLANE



UNDER-SIDE OF WING TIP ON THE B-24 SHOWING TWO NRL DISCHARGERS



EMPENNAGE OF THE B-24 AIRPLANE

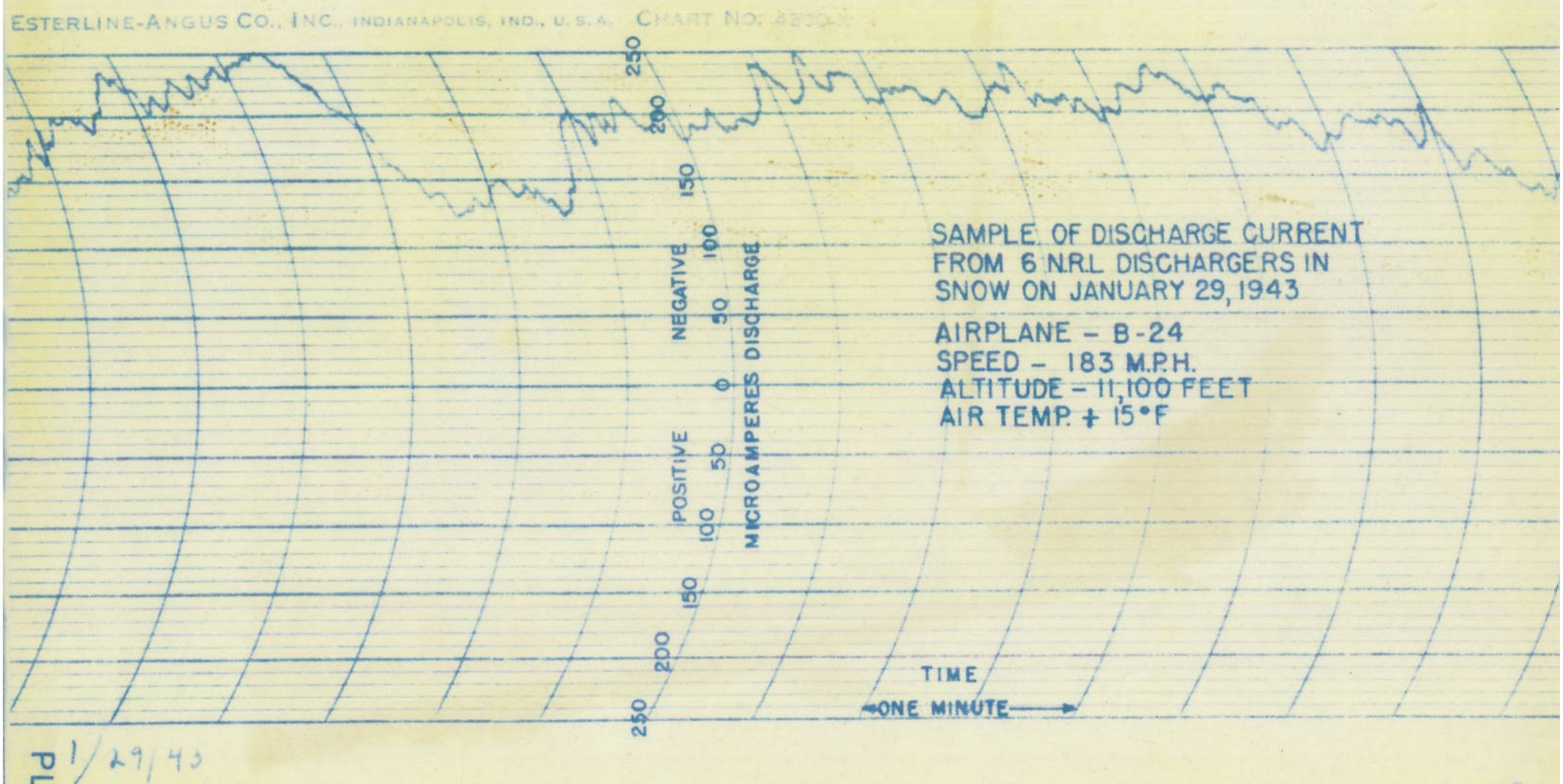
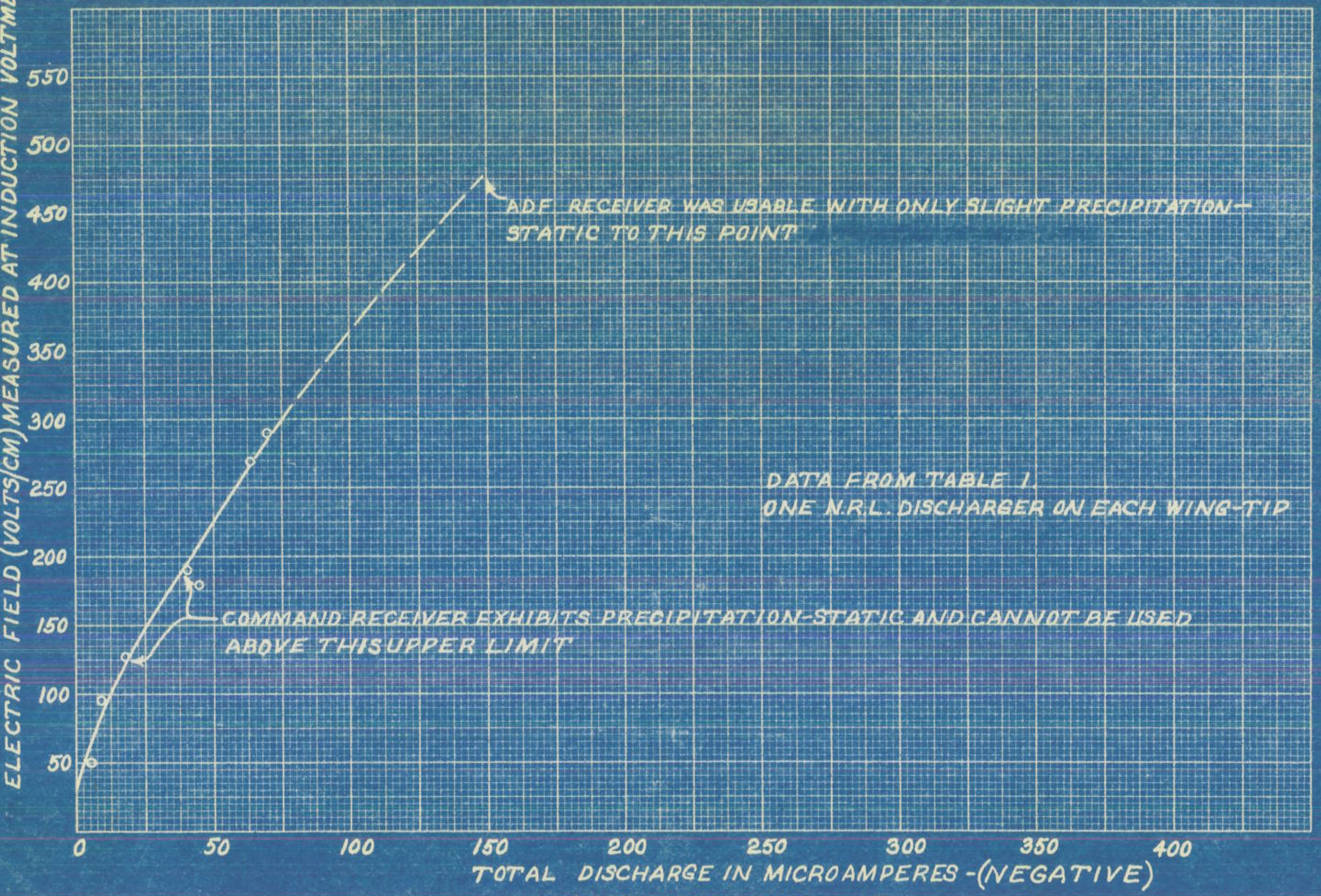


PLATE 5

DECLASSIFIED

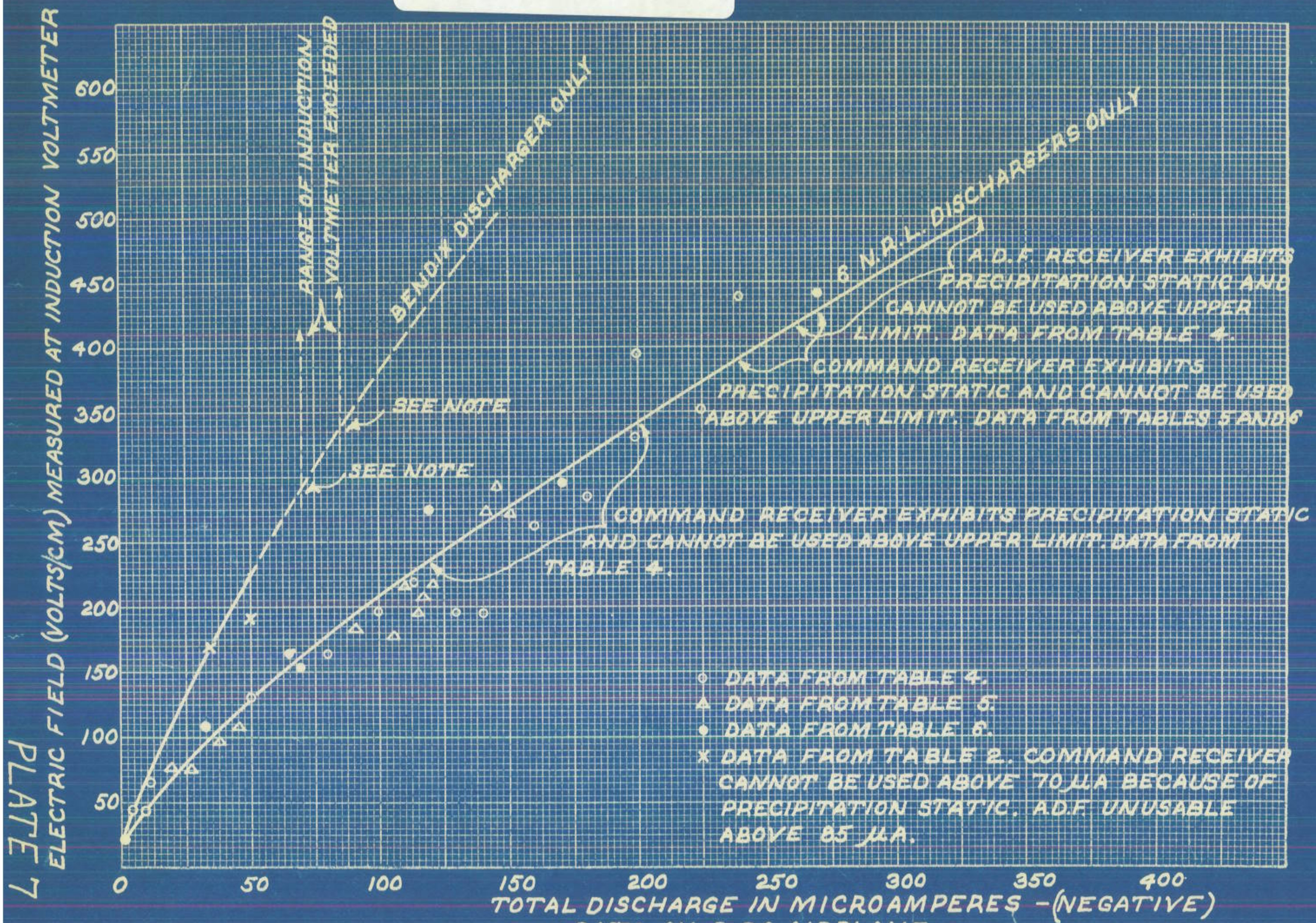


DATA ON C-47 AIRPLANE

PLATE 6

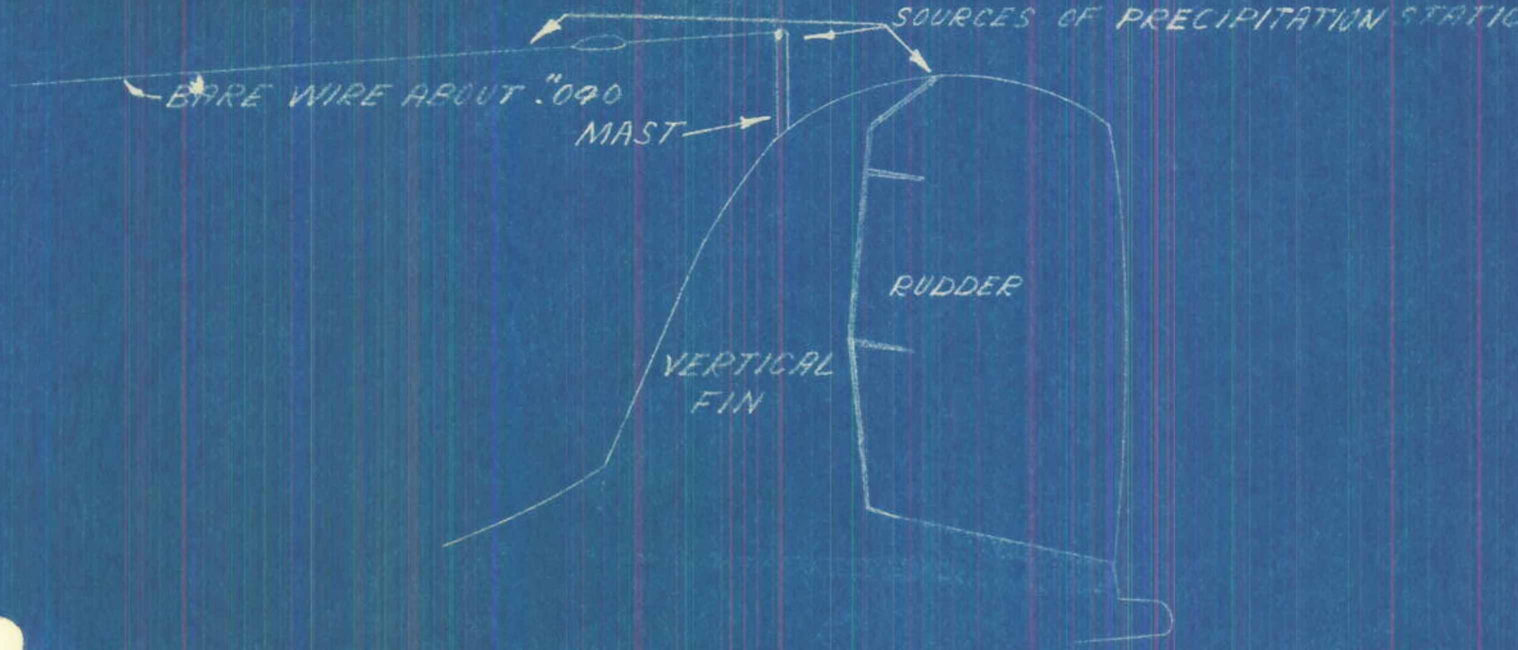
U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

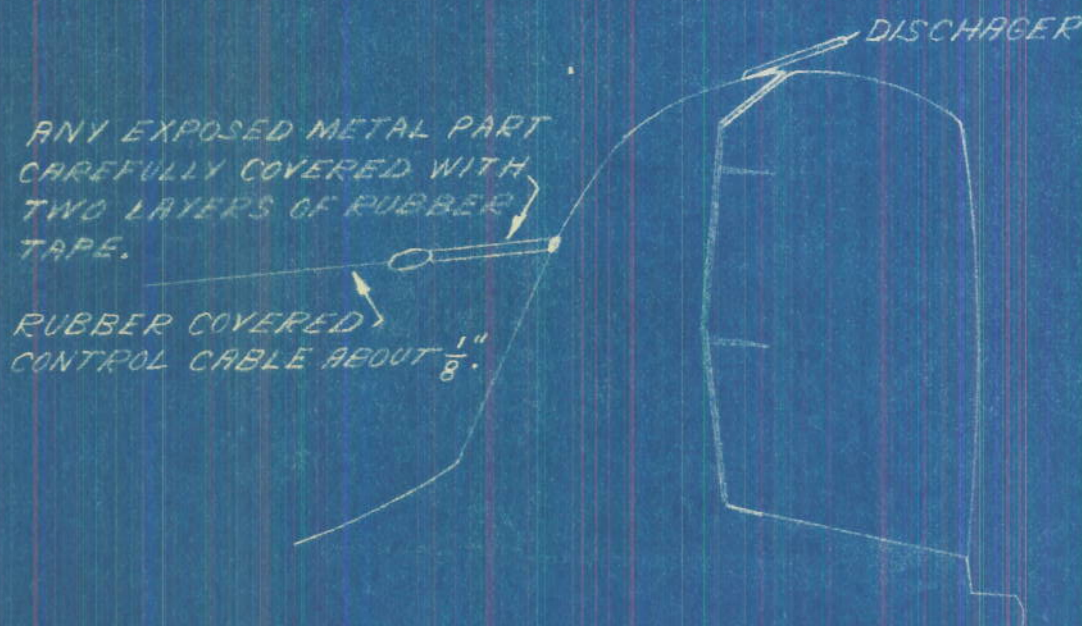


DATA ON B-24 AIRPLANE

PLATE 7



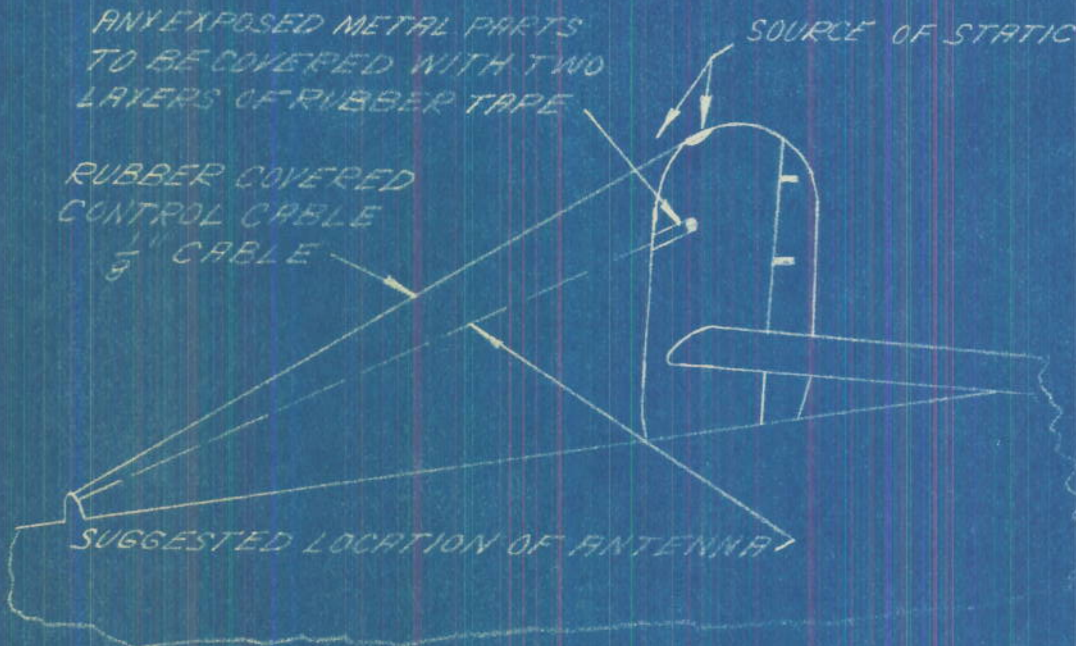
COMMAND ANTENNA INSTALLATION ON C-47



SUGGESTED CLEAN-UP OF COMMAND ANTENNA ON C-47 AIRPLANE

ANTENNA INSTALLATION OF COMMAND RECEIVER ON THE C-47

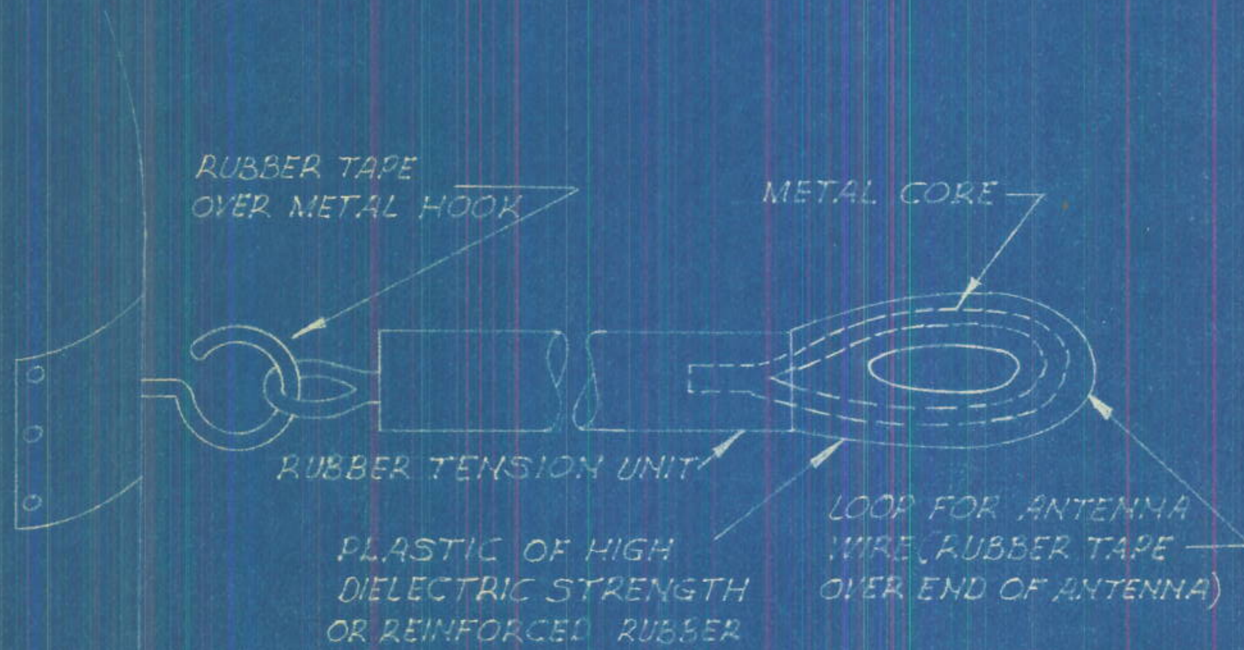
PLATE 8



ANTENNA INSTALLATION OF THE COMMAND
RECEIVER ON THE B-24

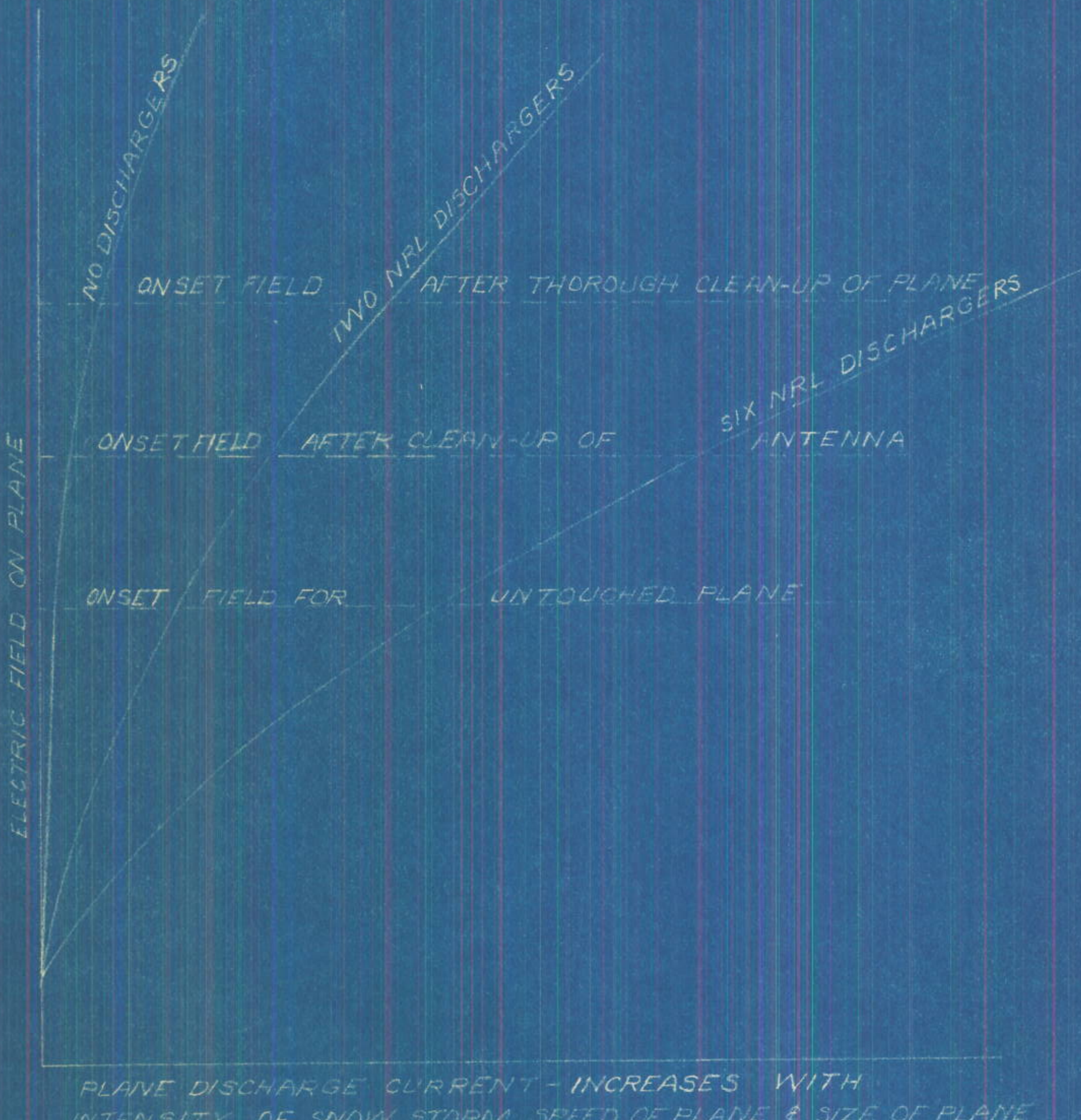
DECLASSIFIED

(A) ANTI-STATIC TIP FOR WHIP TYPE ANTENNA



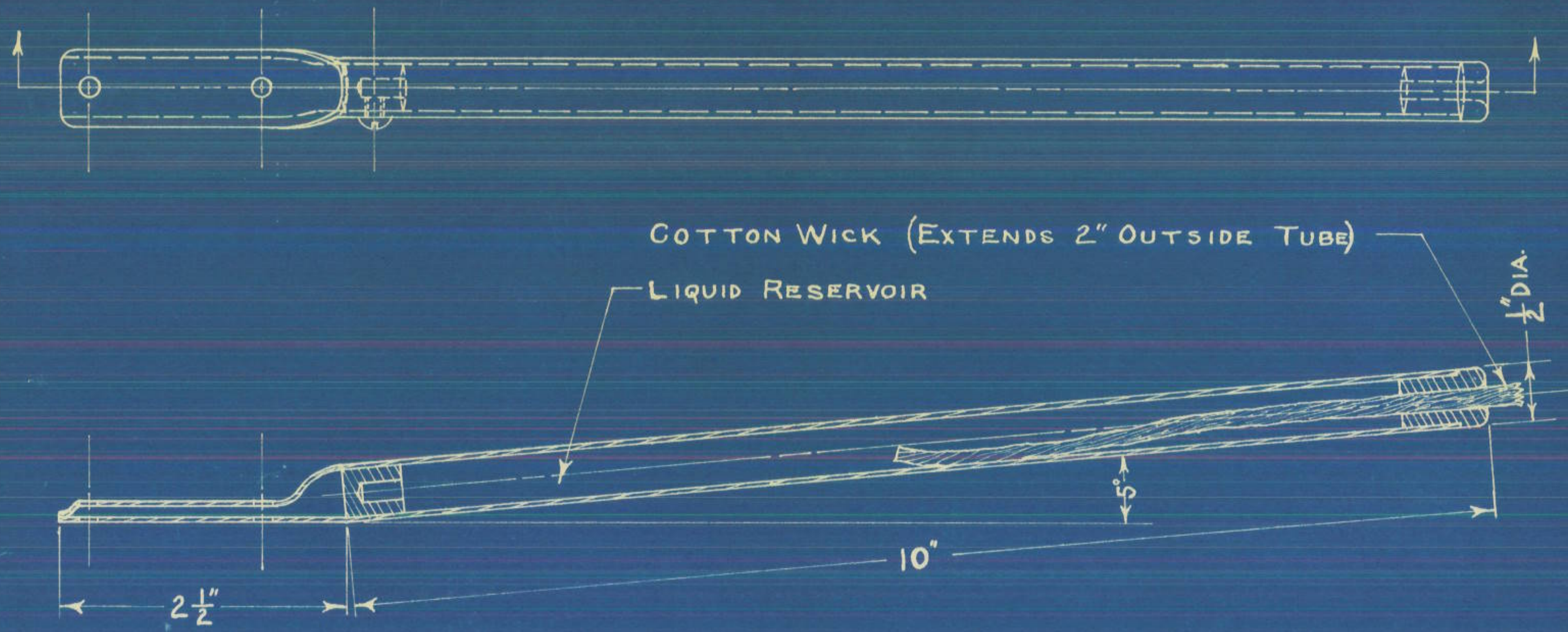
(B) ANTI-STATIC ANTENNA TENSION UNIT

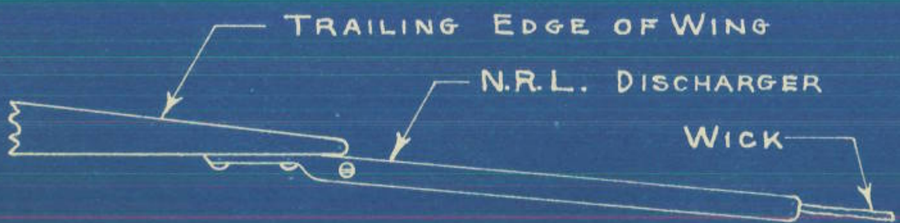
ON METHODS FOR CLEAN-UP ANTENNAS



THE RELATIVE EFFECTIVENESS OF THE DIFFERENT METHODS FOR THE REDUCTION OF PRECIPITATION STATIC.

PLATE 11





Example of Mounting

N.R.L. DISCHARGER

PLATE 12