ARR No. 3J12
Pt. 2

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

October 1943 as
Advance Restricted Report 3J12

PROTECTION OF NONMETALLIC AIRCRAFT FROM LIGHTNING

II - LIGHTNING CONDUCTOR MATERIALS

High Voltage Laboratory
National Bureau of Standards

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE RESTRICTED REPORT

PROTECTION OF NONMETALLIC AIRCRAFT FROM LIGHTNING

II - LIGHTNING CONDUCTOR MATERIALS

High Voltage Laboratory
National Bureau of Standards

SUMMARY

This report summarizes information of the types of material which can be used for lightning conductors on nonmetallic aircraft and reports the results of experiments on the more important properties of such materials. Tables I and II give the weight per foot and the widths of sheet metal required for certain assumed surge-current carrying capacities. The section on Application gives some preliminary suggestions as to the application of such lightning conductors. The experimental work to date suggests the following tentative conclusions:

1. Aluminum has greater surge-carrying capacity than copper of the same weight.

2. Rolled sheet metal has more surge-carrying capacity than sprayed metal of the same weight.

3. Aluminum strips 0.002 inch thick can be molded in the surface of tego-bonded plywood with excellent mechanical and electrical properties.

4. Metal strips fastened by an elastic cement may give trouble if subjected to alternating strains.

5. Sprayed aluminum adheres well to properly roughened plywood surfaces.

GENERAL ANALYSIS

The function of a lightning conductor is primarily to guide the electric current harmlessly between the points where it enters and leaves the craft. A detailed analysis of this function has been given in reference 1. The purpose of the present report is to summarize available data on the various alternative materials which may be used, singly or in combination, as lightning conductors, and to report the results of some experiments on such materials. This report is by no means exhaustive. Experience in applying these materials should suggest other materials and techniques of application as well as other test procedures for determining their significant properties.

In the following sections the three major classes of material: namely, (1) solid metal, (2) sprayed metal, and (3) conductive paints will be discussed, and the possibilities and limitations of each will be pointed out.

Next to its electrical guiding action, the most important property is probably lightness in weight. Adhesion, durability, applicability to an already completed aircraft are also important. At some locations the conductor may have to carry only the very small charging current of a sideflash while at other locations it will have to carry the full lightning current. Such matters will be treated in the section on Applications.

This investigation was carried on at the National Bureau of Standards under the sponsorship and with the financial assistance of the Bureau of Aeronautics, Navy Department.

SOLID METAL

The most obvious materials for lightning conductors would be wires, tubes or rolled strips, and sheets of a metal such as aluminum or copper which has a high electrical conductivity. The questions which arise in connection with such materials concern the cross section needed, the method of attachment so as to be secure and yet not increase the aerodynamic drag of the craft, the risk of damage at the points of entry of the lightning discharge and the mechanical durability. These will be treated at least partially, in the immediately following paragraphs.

Surge-Current-Carrying Capacity

A rational basis for estimating the surge-carrying capacity of a given wire or strip of solid metal is obtained by computing its momentary temperature rise on the assumption that the surge is of such short duration that all the Joule heat developed in the wire remains in it and goes to raising its temperature. The following notation will be used:

l length of conductor, centimeters

A cross section of conductor, square centimeter

M mass of conductor, grams

γ density, grams per cubic centimeter

ρ volume resistivity, ohm - centimeter

c specific heat, joules per gram

i instantaneous current, amperes

R resistance of conductor, ohms

The heat H developed in the wire in time t is

$$H = \frac{l}{A} \int_0^t i^2 dt \qquad \text{joules} \qquad (1)$$

and the temperature rise T (deg C) is

$$T = \frac{H}{c l A \gamma} \qquad (2)$$

As the metal heats up ρ, and to a lesser extent c, will increase. However, to a satisfactory approximation these quantities may be regarded as constant during the process, provided mean values are used, which correspond to the temperature range covered. Combining equations (1) and (2) gives

$$\int i^2 dt = \frac{c \gamma T}{\rho} A^2 \qquad (3)$$

as the carrying capacity of a conductor of given material and cross section. In terms of the other variables, resistance and mass we have

$$\int i^2 dt = \frac{c\,\gamma\rho T}{(R/l)^2} \qquad (4)$$

and

$$\int i^2 dt = \frac{cT}{\rho\gamma}\left(\frac{M}{l}\right)^2 \qquad (5)$$

respectively. It will be noted that in each of these three equations the surge-carrying capacity is expressed in the form of the product of (1) a factor which is a composite of properties of the material, (2) the permissible temperature rise, and (3) a factor which expresses the size of the conductor in terms either of its area (volume per unit length) or of its resistance per unit length or its mass per unit length. For any given metal and assumed temperature rise T, the combination of quantities

$$F\,(T) = \sqrt{\frac{cT}{\gamma\rho}} \qquad (6)$$

is a measure of the utility of the metal in giving surge carrying ability for a given weight per unit length. The square root is introduced so that the values of F will vary as the first power of the weight of material required or of the current (for a fixed duration) which can be carried. Table I gives values of $F(T)$ for pure aluminum and for copper. It will be seen that even if the copper can be operated up to its melting point, which is materially higher than that of aluminum, its greater density still renders it less effective than aluminum. If operated at the same temperature, aluminum has the advantage by a factor of about 2.2. Aluminum alloys will have somewhat less conductivity than the pure metal, but the difference will not be enough to offset this advantage, unless other considerations such as ease of soldering enter.

To determine the required value of M/l it is necessary to estimate the value of $\int i^2 dt$ for the most intense lightning stroke which is to be guarded against. Unfortunately, adequate statistical data on this quantity are lacking. The best information by McEachron (reference 2) shows that of 36 individual component lightning discharges the most intense had a value of 200,000 amperes squared-seconds and that 50 percent exceeded 10,000 amperes squared-seconds. These values were observed at the Empire State Building on cloud-to-ground strokes. Some authorities suggest that cloud-to-cloud strokes are on the average less intense. If we take 200,000 amperes squared-seconds for the discharge and 200° C for the permissible temperature rise, the value of M/l for aluminum comes out 0.11 grams per centimeter or 0.0075 pound per foot. For copper with the same rise M/l comes out 0.22 gram per centimeter (0.016 lb/ft)(No. 13 AWG). This value gives an interesting contrast with the minimum value of 0.187 pound per foot required by the American Standards Association, Code for Protection Against Lightning. The very heavy conductors specified in this Code for buildings and objects on the ground where weight is of no importance were chosen partly to allow for possible corrosion over long periods of time, partly to insure mechanical strength, and partly because at the time the Code was first written much less was known than at present about the magnitude of lightning currents.

Rolled sheet aluminum can be obtained thinner than 0.001 inch and is usually specified in terms of thickness or gage number. Sheet copper is usually specified in terms of weight in ounces per square foot. Sheet copper made by an electrolytic process is available in weights from 1/2 ounce to 6 ounces per square foot (0.0006 in. to 0.008 in. in thickness). Such copper sheets have a relatively low ultimate elongation (approx. 3 percent) as compared with annealed material.

Table II gives the width required for strips both of aluminum and of copper which would safely carry the indicated surge currents with the stated temperature rises. The values of width (in in.) given in table II correspond to the weights (in lb per linear ft) given at the top of each column, and to the thicknesses indicated (directly or by gage number or by weight) in the first four columns at the left.

Methods of Attachment

Four methods for fastening strip-metal lightning conductors to the plywood aircraft suggest themselves.

1. Cementing to the outer surface.- Such a process would be applicable to an already completed craft. Rubber-base cements

seem to give good adhesion even to smooth metal. Several samples were made up using one of the better grades of Bostik Universal Cement, No. 292 Black (made by the Boston Blacking and Chemical Co., Cambridge, Mass.). These samples showed good adhesion even after severe mechanical treatment but on the repeated flexing tests described below, they developed wrinkles and cracks which rapidly progressed so as to break the electrical continuity of the strip. Figure 1 shows two of these strips after having been subjected to 12,000 cycles of bending (max. elongation about 0.3 percent). It is probable that these effects resulted from the extreme elasticity of this cement and that if the strip were anchored in a more rigid matrix which could force it in compression as well as in tension better results would be obtained. A search for a satisfactory cement remains a difficult problem for the future. Presumably this could be attacked by a competent manufacturing concern. Perhaps some much thinner adhesive applied to the metal strip in the factory as in the manufacture of Scotch tape, may have possibilities.

2. Tacks or staples.- The use of metal fasteners driven into the wood may prove quite satisfactory in the rather common case in which a lightning conductor can be mounted by nailing through the skin into a spar or longeron. Here the tip of the tack would be embedded in dry wood and would be therefore unlikely to start a discharge. A much less desirable situation would exist if the point of the tack projected through the plywood skin of an airfoil. If it ends near some metal such as a wire or control cable, or near another tack which protrudes from the opposite surface of the airfoil, a discharge is likely to occur. If the lightning current happens to be large, the airfoil may be wrecked by the explosive action of the discharge. Experimental trials should be made on this point.

3. Molding (hot-pressing) on the outer surface.- Sheet metal may be attached to cross-laminated plywood by hot-pressure molding with a suitable rosin binder. For a trial of this mode of attachment, a number of hot-pressed (flat) samples were made by the Plastics Section of the National Bureau of Standards. These samples, roughly 0.08 inch thick, were made of eight symmetrically assembled layers of 0.01-inch-thick poplar plies and tego (a paper base containing a phenolic thermosetting resin, approx. 2/3 resin and 1/3 paper). The symmetrical assembly (to avoid warping) was as follows: beginning at the center, two sheets of tego were crossed; the grain of the two wood plies on either side of the

center were run parallel; from those two layers to the outermost layers the grain of each successive wood ply was crossed at 90° to that of its predecessor, and each alternate single layer of tego was similarly crossed.

In some samples the sheet metal-foil strips were surface mounted in the hot-press by placing two crossed sheets of tego between the outer wood ply and the metal strips. In other samples the metal strip was covered by a single sheet of tego, in which case a single sheet of tego crossed with reference to the outer sheet of tego cemented the strip to the outer wood ply.

In some samples the sheet metal-foil strips were surface mounted in the hot-press by placing two crossed sheets of tego between the outermost wood ply and the metal strips. Some of the metal strips were perforated with holes about 1/4 inch in diameter in staggered rows as shown in figure 2. It was thought that this construction might give a better bond and also distribute more uniformly the distortion caused by strain and thermal expansion. Some of the aluminum strips were anodized while others were of plain rolled sheet. This symmetrical construction was used in order to secure as good adhesion of the sheet metal to the laminate as possible. Better adhesion is secured if the coefficients of thermal expansion of any two cemented objects can be made to match. In the case of tego the measured coefficient along the machine direction of the paper was found to be 15.4×10^{-6} per degree while across the machine direction it was 38.4×10^{-6}. For a sample built up with alternate layers of crossed tego the value was 25.7×10^{-6}. Thus the coefficient of crossed tego nearly matches the coefficient of thermal expansion of aluminum which is 22.3×10^{-6}. There is, therefore, very little tendency for differential expansion to separate smooth metal from crossed tego. It may be pointed out that, because of its rough surface, wood bonds well with tego in spite of its smaller average thermal coefficient of expansion.

Similar specimens were made up with 0.004-inch copper by the same procedure, but the adhesion was very poor even with the perforated strips. Hence no bending or other tests were made with copper strips. It is, of course, possible that some other bonding conditions might have given better results.

4. Embedding below outermost veneer.- The metal strip (preferably perforated) may be placed between layers of tego in

the mold just below the outermost layer of wood. This construction gives greater mechanical protection to the strip and insures a uniform outer surface appearance which is ideal for later paint and camouflage coatings. However, it is difficult to make connections to such an embedded strip. Also, theoretically, the lightning will surely do a little damage in penetrating the outer layer of wood to reach the metal. Moreover, if any crack or bad joint develops in the metal strip, the arc forming at the bad contact may cause further damage.

Trials of two samples (L-15 and L-16 of table III) showed no signes of deterioration after many repetitions of bending strain. Figure 3 shows the relatively slight splintering which was produced both at (A) where a 22,000-ampere surge penetrated the outer veneer to reach the embedded metal and at (B) where the discharge jumped a gap between two embedded strips. It is planned to make further trials with larger currents as soon as a new current-surge generator is completed.

Mechanical Durability of Sheet Metal

Under service conditions on aircraft, the lightning conductors must stand up well mechanically under extreme fluctuations of temperature and of mechanical stress. Tests were therefore devised to obtain an indication of the effect of such conditions on pieces of plywood to which strips of thin sheet metal had been attached.

1. Temperature cycles.- Two air baths, one heated eloctrically and the other cooled with "dry ice" were arranged so that, by a motor-driven mechanism, a group of specimens could be alternately raised into the heated chamber, held there for a predetermined time and then rapidly lowered into the cold chamber. Figure 4 is a graph which is typical of the temperatures indicated by thermocouples attached to the two ends of such a specimen during a cycle.

Six of the specimens described above, in which metal strips had been molded to 8-ply tego-bonded poplar plywood were tested. Both plain and anodized aluminum strips 2 mils thick and 1 inch wide were used. One strip of each material was perforated. After being subjected to 270 temperature cycles, no sign of deterioration or of loosening could be found. The electrical resistance was found to be practically the same as at the beginning of the test although this measurement is a very sensitive means of detecting cracks. For these particular samples it seems probable that the temperature tests were similar in effect but less severe than the mechanical-strain tests which follow.

2. Repeated mechanical strain.- A number of repeated stress trials were made on metal strips surface-molded to tego-impregnated plywood. The plywood specimens had the shape commonly used for fatigue tests and shown in figure 5. A metal strip 1 inch wide was molded to one side of the 9-inch specimens. When such a triangular cantilever beam is bent, it takes on an approximately uniform radius of curvature and hence a constant strain throughout the length of the beam. The elongation of 0.3 percent used in most of the trials is comparable with the maximum design values of 1 percent and of 0.5 percent given in the A.N.C. Handbook for crosswise and for lengthwise stress, respectively.

Such large values of strain would be expected to occur only rarely and usually would not alternate rapidly. However, it was thought possible that rapid fluttering of thin sections of plywood skin might occur. For this reason and also to make the tests severe enough to distinguish between the various specimens, the flexing tests were continued through several thousand cycles.

The results are shown in table III, in which the specimens are arranged in order of improving quality from top to bottom. This shows, as has already been noted, that the specimens L-1 and L-3, fastened with an elastic cement developed wrinkles and cracks which completely opened the circuit (fig. 1). The thicker (0.004 in.) specimens seem definitely inferior to the thinner (0.002 in.) ones. The anodized specimens appeared to be more brittle and showed on the whole more increase in resistance than the plain aluminum sheet. Since this latter showed no tendency to come loose, there would seem to be no need for the anodized surface which was tried primarily because it was thought that it would be better wetted by tego and consequently would have greater adherence. The perforations seemed to make little difference. The presence of the overlay of tego gave a definite improvement in the performance, and the specimens which had the tego overlay were almost as good as L-15 and L-16, which had a wood-veneer overlay.

The 0.002-inch plain aluminum strips, without the tego overlay, finally developed a curious "crystalline" appearance shown in figure 2. This seemed to be due to the formation of minute wrinkles but did not involve any marked increase in resistance. The anodized strips and the 0.004-inch plain strips without overlay developed fine transverse cracks as shown in figures 6 and 7.

Arc Damage

At the point where the electric discharge passes from the air to a metal object, or vice versa, there is a local concentration of heating which tends to melt and vaporize some of the metal. Lightning conductors on grounded structures are made so heavy that the slight melting by the lightning discharge of the tips of the air terminals is negligible. To make the conductors on an aircraft-protective system thick enough to be immune from such arc damage would require a prohibitive weight of metal. However, the damage done by an arc to a strip of thin sheet metal is very localized and should not be taken too seriously. The melting is not likely to extend completely across the full width of a wide metal strip and even if the conductor is burned in two, the resulting gap is almost sure to be near an extremity of the craft in such a location that the protection of the personnel from a subsequent stroke would not be impaired.

SPRAYED METAL DEPOSITS (METALLIZING)

Sprayed metal has the great advantage of being applicable directly to curved surfaces and to completed aircraft. Therefore considerable time has been spent in studying this material.

Procedure in Spraying

Most of the data on sprayed metal given in this report are for material deposited by a "Mogul Model P" spray gun made by the Metallizing Co. of America. In this gun the metal wire, or rod, to be sprayed is drawn in between two gear-rolls, driven by an air turbine, and fed through the center of an oxyacetylene flame which is surrounded by a concentric jet of compressed air. As the tip of the wire fuses in the flame, it is "atomized" by the air jet and the molten particles are blown against the surface to be coated. (The air pressure was usually about 75 lb/sq in., while both the acetylene and oxygen pressures were about 15 lb/sq in.)

The properties of the deposited material depend somewhat on the conditions of operation, for example, distance from nozzle to work, rates of supply of acetylene, oxygen and air and of metal; time of application and number of applications of the jet to each part, and so forth. The technique of operating the metallizing equipment is not difficult and should be readily learned by a good workman. One should strive for a fine-grained smooth coating. The practice of making repeated light passes over the same area with time allowed for cooling between passes gives best results. A thickness of 0.005 inch to 0.01 inch seems most desirable for this application.

As in the case of stucco, the adherence of the coating depends primarily on the keying quality of the surface to which it is applied. Very little, if any, adherence is obtained if the surface is polished or very smooth. Hence a smooth surface should be scored or roughened, preferably by sand blasting, before spraying. The surface must be absolutely free from grease (even finger prints make trouble). The structure of some woods such as poplar, even when smooth cut, offers a good keying surface and need not be roughened. Others, such as mahogany, are improved by a light sand blasting which removes the softer fibers and leaves a better keying surface. Certain metals such as tin, lead, zinc and aluminum adhere quite well to wood surfaces. In our work copper did not yield such good results, presumably because in the process the wood surface is heated to such an extent that melted or vaporized resins appear and prevent adherence. Copper may, however, be sprayed over an undercoat of sprayed aluminum, and good soldered connections can be made to the copper of such a dual coating. Sand-blasted Lucite plastic may also be sprayed satisfactorily with aluminum. Masking tape, as used in spray painting, was found to be effective in confining the spray to the desired area.

Because aluminum sprays and adheres well, has light weight and high conductivity and incidentally is considerably less toxic than many other metals, it appears to be the most desirable metal for aircraft lightning conductors, at least until tin again becomes available. The data given in this report were obtained on coating sprayed from wire 0.090 inch in diameter, containing 1 percent of zinc (Bur. Aeron. Spec. A-25).

Resistivity

The fundamental properties of sprayed deposit which are important in this application are (a) the longitudinal electrical resistivity (the resistance of a unit length of deposit of unit width, that is, the resistance between opposite faces of a square) which will depend upon (1) the nature of the deposit as well as (2) its thickness; (b) the weight per unit area (surface density) of the deposit, and (c) the mechanical durability of the deposit, which depends in part upon its adherence to the surface coated.

The deposit is always granular so that micrometer measurements of the thickness of thin coatings are of little significance. It is also usually not feasible to weigh the deposit. Hence it happens that the most convenient means for expressing the amount of deposit on a freshly-sprayed surface is to state its longitudinal resistivity (the thicker the deposit the less this resistivity). To determine the quantitative relation between (a) the longitudinal electrical resistivity and (b) the weight per unit area of the deposit, previously weighed, ground-glass plates were sprayed as uniformly as possible, that is, (1) the nature of the deposit and (2) the thickness of deposit were both held as constant as possible. The electrical resistance and the total weight of each was then determined. The results are plotted in figure 8 for aluminum and in figure 9 for tin and copper. Here the abscissas are the surface density and the ordinates are the product of surface density multiplied by the longitudinal resistivity. If the material were uniform this product should be a constant (the "mass resistivity"). Thus a layer twice as thick would be twice as heavy but would have only half the resistance. It is evident from figures 8 and 9 that this product is roughly constant over a considerable range but that for thin film, that is, those weighing less than 0.020 gram per square centimeter for aluminum and 0.030 gram per square centimeter for copper, the resistance is abnormally high, presumably because of gaps between the individual grains of metal. The straight, horizontal lines in figures 8 and 9 indicate the mass resistivity of the metals in bulk. It is evident that even the relatively thick deposits have a materially higher value for this property. This increase is by a factor of 5.6 for aluminum and of 2.2 for copper, and is presumably the result of porosity, incomplete contact between grains, and perhaps of occluded oxide films.

Measurements of the density of the sprayed material by an immersion method gave 2.47 grams per cubic centimeter for aluminum and 8.08 grams per cubic centimeter for copper. These values are about 0.9 of those for the solid metal. In this method the liquid penetrates the pores to a considerable extent. If the volume is obtained from micrometer measurements of thickness over the tops of the granular structure, the apparent density of sprayed aluminum may be in some cases as low as 0.8 gram per cubic centimeter.

Surge-Current-Carrying Capacity

The surge-current-carrying capacity of a strip of sprayed metal might perhaps be calculated from equation (3), (4), or (5) by using appropriate values for mass resistivity (i.e., for the product $\rho\gamma$). However, it was thought desirable to confirm such calculations by direct experiment. The current surge used for this purpose was produced by short-circuiting a 33,000 joule surge-voltage generator through the specimen. The current had a crest value of about 22,000 amperes and decreased in a damped oscillation which had a frequency of about 130 kilocycles and gave a value for $\int i^2 dt$ of 5250 amperes squared-seconds.

The specimens for this purpose were of aluminum sprayed on a plywood backing. Each deposit was tapered either in width or thickness, so that at some intermediate position the deposit would just fail to carry the particular test surge. Before the test each specimen was "surveyed" by measuring the electrical resistance of successive portions each 3 centimeters long. After the test the width or the longitudinal resistance at the boundary of the undamaged region was taken as an index of the performance of the deposit. Specimens of this type are shown in figure 10.

In figure 11 this width (in in.) at the boundary is plotted as abscissa and the longitudinal resistivity (in ohms between opposite sides of a square) for the particular part of the deposit which was on the point of failure is plotted as ordinate. The observed points lie fairly close to the straight line which corresponds to a longitudinal resistivity of 0.005 ohm for a width of one inch. This is, of course, equivalent to a linear resistance of the strip of 0.005 ohm per linear inch or 0.06 ohm per linear foot (0.002 ohm per cm). It is interesting to note that if this value of linear resistance and the value of mass resistivity (40×10^{-6} ohm gram cm^{-2}) or 0.40 ohm (meter, gram) shown for sprayed aluminum in figure 8 are inserted in equation (4) as the value of the product "$\rho\gamma$", the corresponding crest temperature comes out at 610° C, which is in fair agreement with the melting point of aluminum of 660° C. The difference may perhaps result from lack of uniformity but more probably is caused by the heat of the arc at the overstressed parts of the specimen. This arc tends to spread and damage the immediately adjacent wider or thicker portions which could carry the surge, but with only a slight margin.

Mechanical Durability of Sprayed Deposits

Tests to obtain an indication of the mechanical ruggedness of sprayed deposits were made with the same apparatus and in much the same way as with the sheet metal conductors.

1. Temperature cycles.- A number of sprayed deposits were subjected to 270 cycles of temperature in much the same way as described for the sheet-metal specimens. The results are summarized in table IV. The values of resistance are the average over the length of the sample of a number of short sections. It will be noted that the increase in resistance is very slight (about 20 percent). It was fairly uniform over the length of each specimen. No tendency for the deposit to flake off could be detected and it would appear that even extreme and fairly sudden temperature changes do not have any deleterious effect on the deposit.

2. Repeated mechanical strain.- A considerable number of specimens of sprayed aluminum deposits on plywood of various thicknesses and origins were subjected to repeated flexing tests similar to those described above for the sheet-metal strips. Two sizes of specimens were used. Their dimensions are shown in figure 5. The resistances per unit length of successive portions (1 cm long) of each specimen were measured before they were subjected to the flexing and at intervals during the run. The flexing occurred at the rate of 150 cycles per minute. In most cases the outermost wood ply ran crosswise to the length of the sample so that the maximum strain was across the grain of the wood.

None of the coatings showed any visible signs of deterioration nor any tendency to peel off as a result of these tests. However, it was found that the electrical resistance increased with the number of cycles of bending. As might be expected the increase was much more marked in those specimens which were the more severely strained. The results are shown in table V. The values given in this table are the factors by which the average resistance across a unit square, measured after the number of bending cycles given at the top of the column, exceeded the initial resistance of the same portion. Specimen G-3 after 10,000 cycles of a strain of 0.05 percent showed an increase of 15 percent in resistance. On the other hand, with specimen M-6, after the same number of cycles of the much greater strain of 0.71 percent, the increase was by a factor of 65.

When interpreting these increases in resistance into decreases in surge-carrying capacity, it should be noted that the factors in table V indicate changes in the resistivity ρ of equations (3) and (5). Since no appreciable metal is removed as a result of the flexing test the mass of metal to be heated by the surge is not reduced. Hence if the resistance per unit length has been increased by a factor of 4, the surge-carrying capacity is theoretically reduced to the same extent as by the removal of half the width (or half the thickness) of the strip.

Actually the performance of sprayed deposits which have been increased in resistance by repeated flexing seems to be sometimes even better than this analysis would indicate. Perhaps the surge current produces a coherer action and restores conducting paths which had been broken by the bending. This effect is exemplified in table VI, which gives values of the measured resistance per unit length of several specimens of sprayed aluminum. The fifth column gives the initial resistance r_1, the seventh column gives the resistance r_f after flexing. The values of r_c in the sixth column are the critical values of resistance per unit length which would on the foregoing theoretical assumption be expected to barely carry the test surge ($\int i^2dt = 5250$ (ampere)^2 sec). The value of r_c for this particular surge is given by the formula

$$r_c = (0.005)^2/r_1 \text{ ohms/inch} \tag{7}$$

The values in the tenth column are the resistances measured after a single test surge had passed through the specimen.

It will be noted from table VI that after 129,000 cycles of flexing specimen H-11 had a resistance (r_f) which was not only greater than the limiting value of 0.005 ohm per inch but also considerably greater than the values of r_c given in the sixth column. Accordingly, the deposit was wrecked over its whole length by the surge. As shown in figure 12, specimen G-32, on the other hand, had a deposit which was so heavy that the initial values (r_i) are less than the limit of 0.005 ohm per inch and if tested before flexing it would have survived. After flexing the resistance (r_f) was materially higher than the 0.005 limit but was less (except at the top point) than the critical value (r_c). Hence it survived the surge and surprisingly enough showed, after the test, values of resistance almost as low as before flexing. A similar reduction in resistance is shown by G-3 and by G-31 except at its narrow end (fig. 10). It may be noted that the top point of G-32 and the bottom two points of H-7 survived in spite of the fact that their resistances after flexing were somewhat greater than the computed critical values. These instances lend support to the idea that by coherer action the surge reduces the resistance from its higher flexed value.

3. Camouflage paint.- Some concern was entertained as to the possible detrimental effect of camouflage paint on the sprayed metal if it were later flexed. Sprayed metal specimens were, therefore, painted with one coat of blue Navy camouflage paint and subjected to flexing tests. The results included in table V, based on resistance measurements, indicate little or no detrimental effect from the painting. These samples were not tested with a current surge.

4. Air blast.- The jet of air supplied at 90 pounds per square inch to the nozzle of the spray gun was used in attempts to blow the sprayed aluminum deposit off from its backing. In all cases where the backing had been cleaned and reasonably rough before spraying no loosening occurred.

Arc Damage

The effect of the arc at the points of contact of the lightning path and a sprayed metal coating is much the same as that with rolled sheet metal. Figure 13 shows two sprayed aluminum deposits which have been subjected to a 30-coulomb arc. Even in nominally still air the arc moved about during its 1-second duration and burned a path which had a total length of 14 inches. Sample E-7 had been scored with a knife prior to the discharge. The heat of the arc at this gap has burned back the deposit and has slightly scorched the wood beneath. It is very unlikely that the wood of an airplane in flight would catch fire from such an arc because the air stream would probably blow the arc along the surface and also cool both the arc gases and the wood.

CONDUCTING PAINTS

Preliminary trials showed that the presence of a strip of conducting paint served to guide an electrical surge so that the current passed in an arc in the air adjacent to the painted strip. This seemed to offer possibilities which might be of use in certain cases when it is important to keep the discharge from shattering wooden members but where the presence of the flash and of the ionized path which may be blown about by the air stream would do little harm. It was later found that strips of nonconducting aluminum paint, or lines of discrete patches of conducting paint showed a similar guiding property.

Such painted strips have the advantages of ease of application and of lightness. A strip $1\frac{1}{2}$ inches wide of the type used (Ohio Brass Co. No. 608) weighs only 0.0026 pounds per foot (0.01 gram/cm^2) per coat. The longitudinal resistivity is about 300 ohms.

The use of painted guiding strips has at least two serious disadvantages. The first of these arises from the fact that the resistivity is so high that the voltage gradient along the length of the strip rises to a high value. It is, of course, this gradient which establishes the arc in the air adjacent to the strip. For this reason painted strips should <u>not</u> be used in the protection of the fuselage or of any other part of the aircraft where personnel may be stationed.

It might be thought that the process by which the arc forms along a strip of, say, aluminum paint is a progressive one, so that the gradient, although high enough at the one location when the arc is developing, might be low at other parts of the path, with the result that the total voltage drop across a considerable distance would not be excessive. An experiment to check on this point was made by sending the discharge through (and over) a layer of paint applied to the outer surface of a cardboard mailing tube, shown at A B C figure 14. A metal sphere S, 4.92 centimeters in diameter, was centered in the tube by an insulating washer W and connected by a metal rod D, to a copper cap C at one end of the tube and thus to the paint and to the surge circuit. The measured peak voltage (60 cycle a-c) required to spark from the sphere through the cardboard to the painted layer was later found to be about 16,300 volts. The sphere is almost perfectly shielded electrostatically so that there should have been no tendency for electrostatic sideflash. If the discharge had been localized in an arc one millimetor in diameter extending from B to C, the electromagnetically induced voltage should have been only about 3300 volts. Yet, when the experiment was tried the discharge passed along the central rod, jumped the gap from S to B puncturing the tube and continuing in an arc outside the tube from B to A. This seems to indicate that the longitudinal voltage drop between B and C was greater than 16,000 volts and that the theory of progressive development of the arc is incorrect. The same result was obtained with a tube coated with aluminum paint, but when a control experiment was tried using a tube coated with a layer of sprayed aluminum, no puncture of the tube took place.

The second disadvantage of painted strips arises from the "blast effect" of the arc. The sudden liberation of energy in the discharge heats the air and develops a very considerable momentary pressure wave. In cases where the conducting (or aluminum) paint is open to the air, the blast from the laboratory test discharge which had a crest current of about 25,000 amperes was not enough to damage any of the plywood tested, even the two-ply material 0.088 inch thick. However, if the conducting paint is covered with a layer of camouflage paint, not only is the latter blown off by the discharge (fig. 15) but the added mass of the outer paint layer may cause the blast to develop more pressure and to damage the plywood. With the larger crest currents which might occur occasionally in natural lightning this blast effect would be correspondingly worse.

APPLICATIONS

With the three types of material which have been discussed above to choose from, the next question is which to use and in what location. The detailed answers to such questions must await the results of further laboratory studies on actual aircraft parts. Certain general principles, however, seem already fairly evident and lead to the following suggestions:

1. For the protective Faraday cage around personnel and sensitive cargo:

   (a) Metal sheet screening or sprayed deposits should be used and conductive paint should <u>not</u> be relied upon.

   (b) Joints between adjacent conducting strips should be such as to minimize the development of an air gap of appreciable length and should preferably be bonded by a clamped or soldered connection.

2. For the main conductors to the wing tips and tail surfaces:

   (a) Solid metal or sprayed metal is preferable.

   (b) Conductors should be run as directly as possible from one extremity to the other.

   (c) Unless interior metal such as wiring and control cables are bonded into the lightning-conductor system, (1) a good clearance (preferably 8 in.) should be maintained between the lightning conductor and the interior metal; (2) some of the main conductors must run roughly parallel to the interior metal so as to intercept any stroke which might otherwise strike through to the interior metal; (3) strips or areas of conductive paint may prove useful in intercepting strokes and guiding them to the nearest main conductors and would be much lighter than metal.

3. Sprayed metal should be located so far as possible at places free from flutter and with a minimum of strain (i.e., near the neutral axis of the member).

4. Conducting paint should be applied preferably at locations where the skin is braced by ribs, spars, or other solid material in order to minimize the danger that the "blast effect" will damage the unsupported skin adjacent to the discharge.

5. Where explosive vapors (gasoline fumes) may be present <u>every</u> piece of metal should be bonded to avoid side-flash sparks.

6. Small (i.e., less than 1 ft long) pieces of metal need not be bonded purely for lightning protection provided sparks to them from the conductor system will not pass through explosive vapor. However, such bonding is usually needed to reduce precipitation static. The question whether or not conducting paint will give a bond which is satisfactory for this latter purpose remains for future investigation.

7. Local melting and burning of the lightning conductor at the points of entrance of the discharge must be expected and should not be regarded as an indication of failure of the protective system.

National Bureau of Standards,
Washington, D. C., June 30, 1943.

REFERENCES

1. High Voltage Laboratory, National Bureau of Standards: Protection of Nonmetallic Aircraft from Lightning. I - General Analysis. NACA ARR No. 3I10, Sept. 1943.

2. American Institute of Electrical Engineers. Transactions. Vol. 60, (fig. 9), 1941, p. 889.

TABLE I.– SURGE-CARRYING PROPERTIES OF SOLID METAL CONDUCTORS

Maximum Temperature		100	200	660	1080	
Resistivity at Mean Temperature	(Al	3.3×10^{-6}	4.0×10^{-6}	7.1×10^{-6}		ohm-cm
	(Cu	2.0×10^{-6}	2.4×10^{-6}	4.0×10^{-6}	5.7×10^{-6}	Do.
Specific heat at Mean temperature	(Al	.91	.94	1.1		joules/g
	(Cu	.39	.39	.42	.44	Do.
Density	(Al	2.7	-----	-----		g/cm^3
	(Cu	8.9	-----	-----		Do
F (T)	(Al	2800	4000	6100		
	(Cu	1300	1800	2700	3000	
Linear weight for $\int i^2 dt$–200,000	(Al	.0106	.0075	.0049		lb/ft
	(Cu	.022	.016	.011	.0099	Do.
Linear weight for $\int i^2 dt$–20,000	(Al	.0034	.0024	.0016		lb/ft
	(Cu	.0071	.0052	.0035	.0031	Do.

TABLE II.- WIDTH OF STRIP (IN IN FOR VARIOUS STANDARD WEIGHTS AND THICKNESSES)

				Aluminum				Copper					
i^2dt (amperes^2 sec)				20,000		200,000		20,000			200,000		
Max. temp. (°C)				200	660	200	660	200	660	1080	200	660	1080
M/l (lb per linear ft)				0.0024	0.0016	0.0075	0.0049	0.0052	0.0035	0.0031	0.016	0.011	0.0099
Gage number	Weight (oz/sq ft)	Thickness (mils)											
(A.W.G.)	Cu	Al	Cu										
	½		0.68					1.98	1.34	1.20	6.26	4.25	3.80
		1		2.02	1.33	6.40	4.21						
	1		1.35					.99	.67	.60	3.13	2.12	1.90
	1½	2	2.03	1.01	.67	3.20	2.12	.66	.44	.40	2.08	1.41	1.26
	2		2.70					.49	.33	.30	1.56	1.06	0.95
40		3.14	3.14	.64	.42	2.03	1.34	.43	.29	.26	1.35	.91	.82
38*	3	4	4.06	.50	.33	1.60	1.05	.33	.22	.20	1.04	.71	.63
36		5	5	.41	.27	1.29	.85	.27	.18	.16	0.84	.57	.51
		6		.34	.22	1.06	.70						
34		6.30	6.30	.32	.21	1.02	.67	.21	.14	.13	.67	.46	.41
32*	6	8	8.12	.25	.17	.80	.53	.16	.11	.10	.52	.35	.32
30		10	10	.20	.13	.64	.42	.13	.09	.08	.42	.29	.26

*Thicknesses given correspond approx. to diam. for this gage.

TABLE III.- EFFECT OF REPEATED FLEXING ON ALUMINUM FOIL STRIPS ATTACHED TO PLYWOOD

Specimen	Reference	Plywood Base	Elongation (f)	Size (in.)	Foil data Perforations	Anodizing	Attachment	Overlay	Ohms per linear inch Initial, R_0	Ohms per linear inch Final, R	R/R_0	Cycles (g)	
L-1	Fig.1	(a)	.003	.002 x 1	(c)	None	"Bostick"	None	.0008	(open)	----	10,600	Poorest
L-3	Fig.1	(a)	.003	.002 x 1	(c)	Yes	do.	None	.005	(open)	----	12,500	
L-9		(b)	.003	.004 x 1	(c)	Yes	Tego	None	.0005	0.32	640	10,000	
L-14	Fig.6	(b)	.003	.004 x 1	None	Yes	Tego	None	.0003	.16	530	9,600	
L-13		(b)	.003	.002 x 1	None	Yes	Tego	None	.00075	.014	19	9,600	
										.031	41	14,000	
L-12		(b)	.003	.004 x 1	(c)	None	Tego	None	.00043	.00163	3.8	8,500	
L-11	Fig.7	(b)	.003	.004 x 1	None	None	Tego	None	.00029	.00095	3.3	8,500	
L-8		(b)	.003	.002 x 1	(c)	Yes	Tego	None	.0011	.00305	2.8	10,000	
L-5		(b)	.003	.002 x 1	None	Yes	Tego	(d)	.0013	.0027	2.1	9,100	
L-7	Fig.2	(b)	.003	.002 x 1	None	None	Tego	None	.0006	.00165	2.7	22,300	
										.0093	15.5	96,000	
L-2	Fig.2	(b)	.003	.002 x 1	(c)	None	Tego	None	.00083	.00162	2	23,000	
L-4		(b)	.003	.002 x 1	(c)	Yes	Tego	(d)	.00097	.00155	1.6	25,000	
L-10		(b)	.003	.002 x 1	(c)	None	Tego	(d)	.00082	.00098	1.2	46,400	
L-6		(b)	.003	.002 x 1	None	None	Tego	(d)	.00056	.00057	1.0	42,500	
										.00235	2.4	115,000	Best
L-16		(e)	.0015	.002 x 1	None	None	Tego	(e)	.00056	.00057	1.0	41,500	
L-15		(e)	.0015	.002 x 1	(c)	None	Tego	(e)	.00081	.00082	1.0	41,500	

Reference Notes:

(a) Plywood cut from wing section received from Wright Field; mahogany, two-ply diagonal, specimen 0.078 inch thick.
(b) Plywood made by N.B.S. Plastics Section; eight-ply, layers crossed at 90°; bonded with Tego (pp. 6 and 7); over-all thickness 0.075 inch.
(c) Perforations: two staggered rows of 1/4 inch holes; holes 1/2 inch apart in rows; rows 7/16 inch apart on centers.
(d) Overlay: foil covered by a single sheet of Tego (crossed with reference to single sheet which cemented foil to plywood base).
(e) Plywood made similar to (b), but foil buried beneath two plies of wood, putting foil midway between center and surface.
(f) Elongation computed as ratio t'/R where t' is distance from central plane (assumed neutral axis) to foil, and R = bending radius.
(g) Each cycle represents a double flexure, putting foil once in tension and once in compression for each cycle.

TABLE IV.- EFFECT OF CYCLIC CHANGES ON RESISTANCE OF SPRAYED ALUMINUM DEPOSITS

Specimen	Plywood thickness (in.)	Base number plies	Mean Longitudinal Resistivity (Ohms for a unit square)					
			Initial Ro	R at 170 cycles	R at 270 cycles	R/Ro at 170 cycles	R/Ro at 270 cycles	Approx. temp. range
J-4	.075	2	0.0096	0.0110	0.0112	1.15	1.17	(-20° to 83°C)
J-6	.038	3	.0075	.0089	.0093	1.19	1.24	
J-9	.038	3	.0087	.0099	.0102	1.14	1.17	
J-10	.038	3	.0102	.0132	.0134	1.29	1.31	
J-12	.038	3	.0053	.0064	.0068	1.31	1.28	
J-13	.038	3	.0045	.0054	.0055	1.20	1.22	
J-15	.10	3	.0046	.0053	.0054	1.15	1.17	
J-16	.10	3	.0040	.0043	.0044	1.05	1.10	
K-1	.038	3	.0047	.0055	.0056	1.17	1.19	(-12° to 76° C)
K-2	.038	3	.0114	.0145	.0158	1.27	1.39	(-12° to 76° C)
N-7	.10	3	.0039	------	.0045	-----	1.15	(-48° to 97° C)
N-8	.038	3	.0040	------	.0054	-----	1.35	(-48 to 97° C)
N-9	.038	3	.0053	------	.0061	-----	1.15	(-40° to 95° C)
					Av. R/Ro	1.18	1.22	

Note: Samples J-15, J-16, and N-7 approximately 9 in. long cut from stock supplied by Philadelphia Navy Yard, April 4, 1943; remainder, $2\frac{1}{2}$ in. long, cut from wing to tail sections sent from Wright Field.

TABLE V.- EFFECT OF REPEATED FLEXING ON RESISTANCE OF SPRAYED ALUMINUM DEPOSITS

Specimen	e	Length (in.)	Thickness (in.)	Plies	Av. Long Res. ohm per unit square	Factor of increase in resistance					
						10,000 cycles	20,000 cycles	50,000 cycles	75,000 cycles	100,000 cycles	150,000 cycles
G-3	.0005	9	.25	[2]3(L)	.00193	1.15	1.17	1.21	1.21		1.25
G-4	.0007	9	.073	2(D)	.0227	1.36	1.46	1.58	1.65		1.90
[1]0-4	.0015	9	.037	3(L)	.0132	4.2	5.2	7.1			
M-3	.0025	2½	.037	3(T)	.0089	3.8	4.3	5.2	5.7	6.4	
[1]0-1	.0035	9	.090	3(L)	.0010	13	17	22	32		
M-4	.004	2½	.037	3(T)	.0070	7.0	12	19	21.5		
[1]0-3	.0048	9	.125	3(L)	.002	28	34	38	50	75	
M-2	.005	2½	.037	3(T)	.0086	38	38	66	68		
M-5	.0063	2½	.037	3(T)	.0123	53	100	170	280		
M-1	.0071	2½	.037	3(T)	.0104	70	80	180	260		
M-6	.0071	2½	.037	3(T)	.0283	65	120	(500)			

[1]Specimens 0-1, 0-3 and 0-4 were sprayed aluminum covered with 1 coat of blue Navy camouflage paint.

[2]L indicates grain of surface ply was longitudinal, that is, in direction of bending.

D indicates grain of surface ply was diagonal to direction of bending.

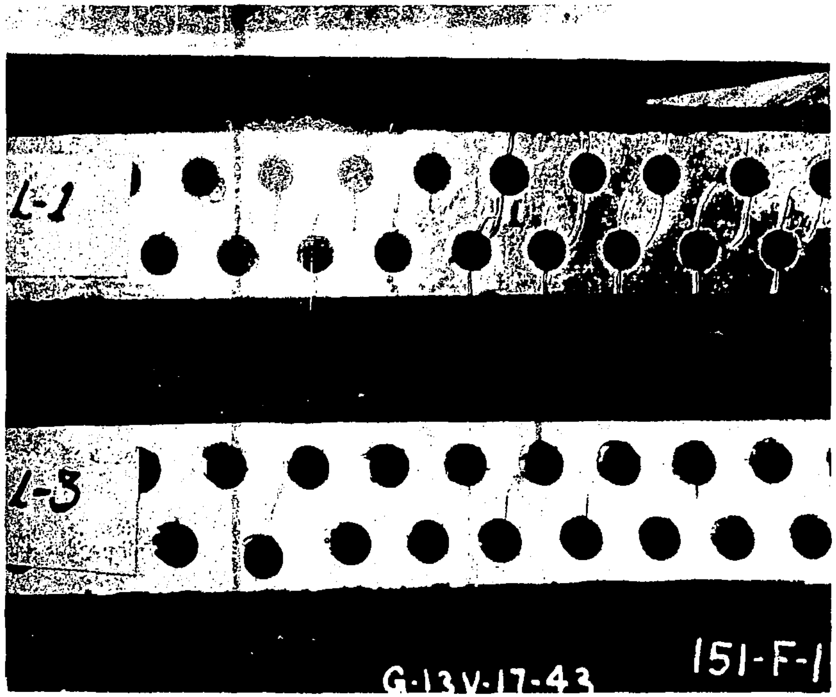
T indicates grain of surface ply was transverse to direction of bending.

TABLE VI.- EFFECT OF SURGE CURRENT ON SPRAYED ALUMINUM DEPOSITS AFTER REPEATED FLEXING

Specimen	Plywood Thickness (in.)	Plies	Grain[1]	Initial resistance(r_i) (ohms/in.)	Computed critical resistance (r_c) (ohms/in.)	Final Resistance after flexing (r_f) (ohms/in.)	Flexing cycles for final resistance	Elongation	Resistance[2] after 1 surge (ohms/in.)	
H-7	0.038	3	(L)	0.0081	-------	0.071	129,000	0.002	x	Figure 10
				.0053	-------	.058			x	
				.0043	0.0061	.038			x	
				.0051	(.0051)	.041			x	
				.0025	.0100	.025			0.0033	
				.0025	.010	.025			.0033	
G-32	.038	3	(L)	.0036	.0074	.0076	5,300	.002	.0033	
				.0025	.0100	.0064			.0028	
				.0020	.0130	.0069			.0025	
				.0020	.0130	.0099			.0028	
				.0018	.0140	.012			.0031	
G-3	.025	3	(L)	.0028	.0092	.0046	150,000	.0005	.0025	
				.0023	.011	.0030			.0023	
				.0020	.013	.0025			.0020	
				.0015	.017	.0018			.0018	
				.0015	.017	.0018			.0015	
G-31	.038	3	(T)	.0068	-----	.0014	540	.002	x	
				.0023	.011	.0033			.0023	Figure 10
				.0023	.011	.0038			.0023	
				.0023	.011	.0066			.0023	
				.0015	.017	.0061			.0023	
H-11	.038	3	(L)	.0051	(.0051)	.0396	129,000	.0016	x	Figure 12
				.0033	.0079	.0221			x	
				.0033	.0079	.0254			x	
				.0036	.0074	.0262			x	
				.0036	.0074	.0305			x	
				.0043	.0061	.0415			x	

[1]L indicates grain of surface ply longitudinal in direction of bending. T indicates grain of surface ply transverse to direction of bending.

[2]X indicates that this portion of sample failed on surging. Resistance of unflexed sprayed aluminum which will just break down under the test surge was about 0.005 ohms/in. length.



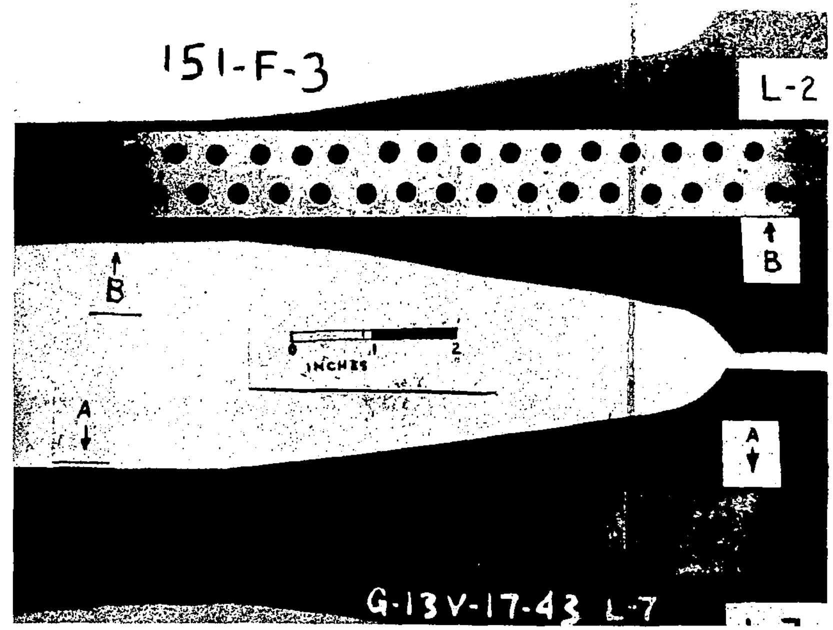


Figure 1.- Anodized (L-3) and plain (L-1) aluminum strip cemented with Bostik, after 10,000 cycles of bending with an elongation of 0.3 per cent.

Figure 2.- Plain aluminum strips without tego overlay after 23,000 cycles of flexing with elongation of 0.3 per cent. Note frosted "crystalline" appearance between AA and BB. Outside these limits the area under the clamp at the wide end and a considerable part of the narrow end were subjected to less or to no elongation and do not show this appearance.

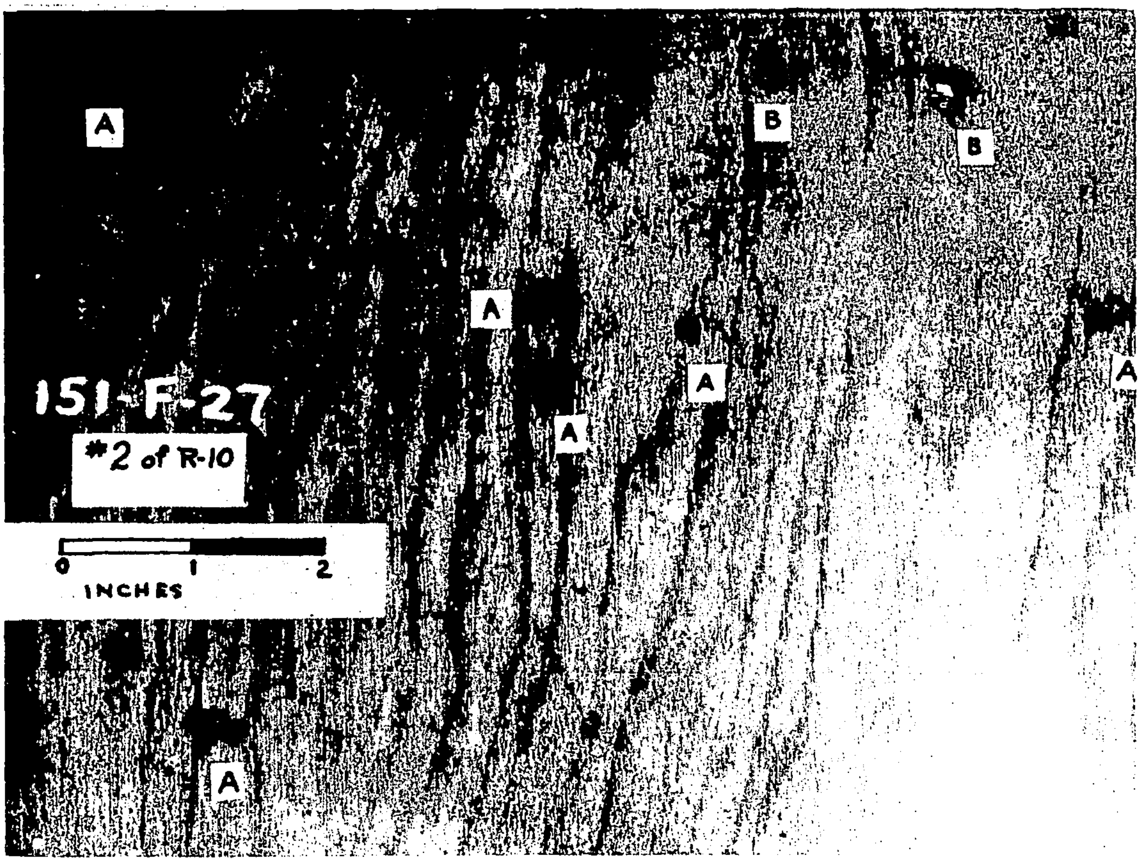


Figure 3.- Specimen containing strips of 0.002" aluminum covered with 2 layers of wood veneer, after a 25,000-ampere surge. Damage at A is where arc penetrated to strip; at B is where discharge passed from one strip to the adjacent one 1 1/4 inch away.

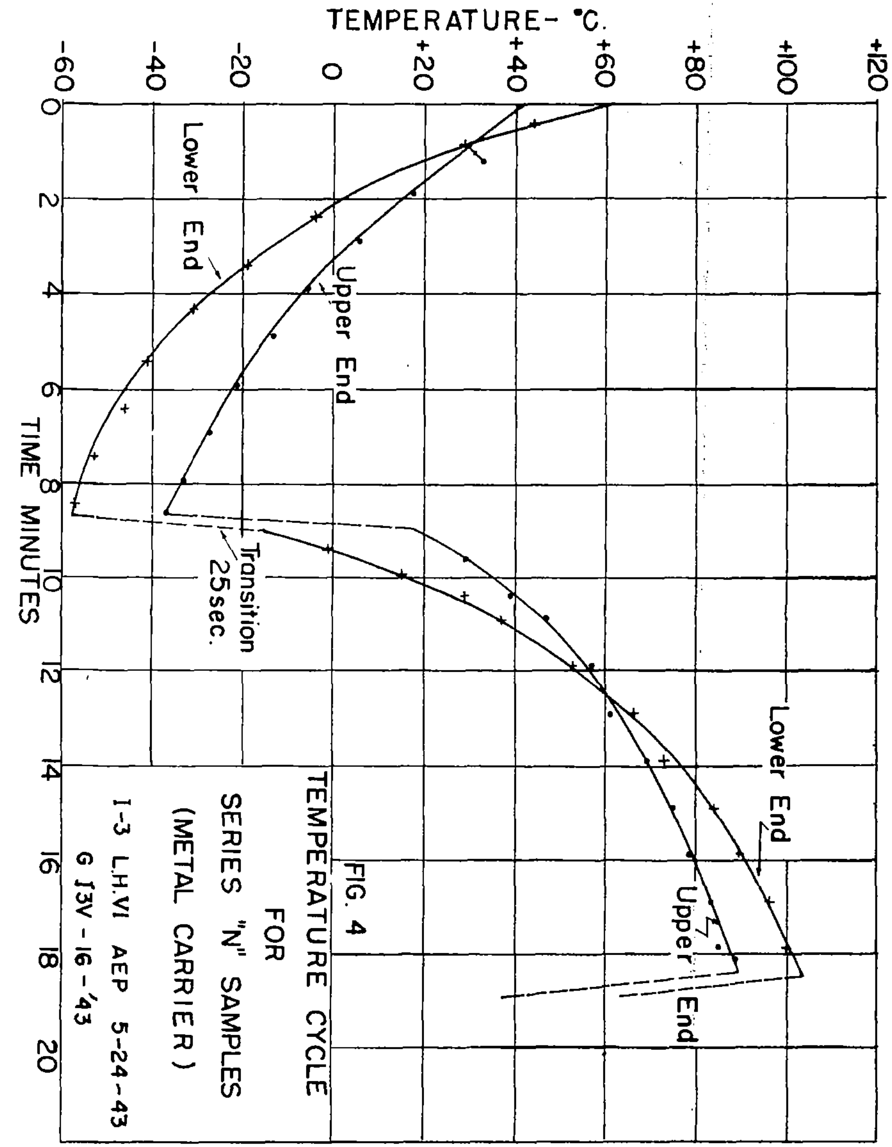
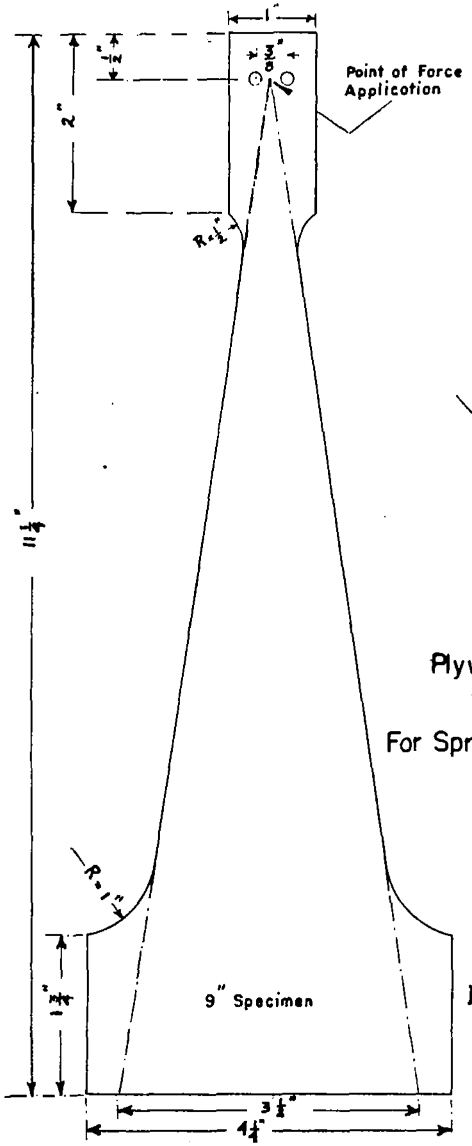
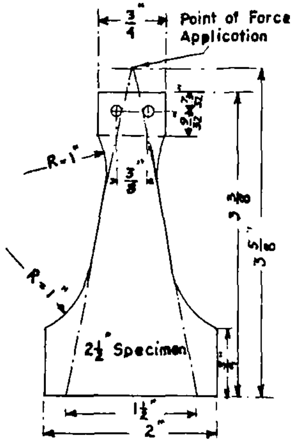


FIG. 4
TEMPERATURE CYCLE FOR SERIES "N" SAMPLES (METAL CARRIER)
I-3 L.H.VI AEP 5-24-43
G I3V-16-'43





Plywood Flexing Specimens For Sprayed Aluminum
Scale: 3/4" = 1"

NATIONAL BUREAU OF STANDARDS
I-3 L.H.VI AEP 6-10-43
G I3 V-18-'43

FIG 5

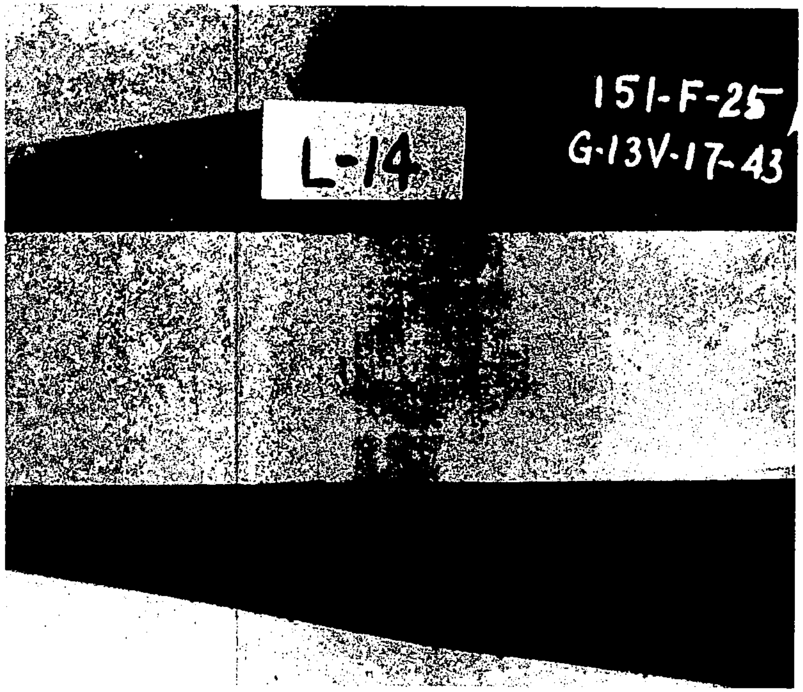


Figure 6.- Anodized aluminum strip, 0.004" thick, without tego overlay after 9600 bending cycles with elongation of 0.3 per cent. Note hair cracks in anodized surface layer.

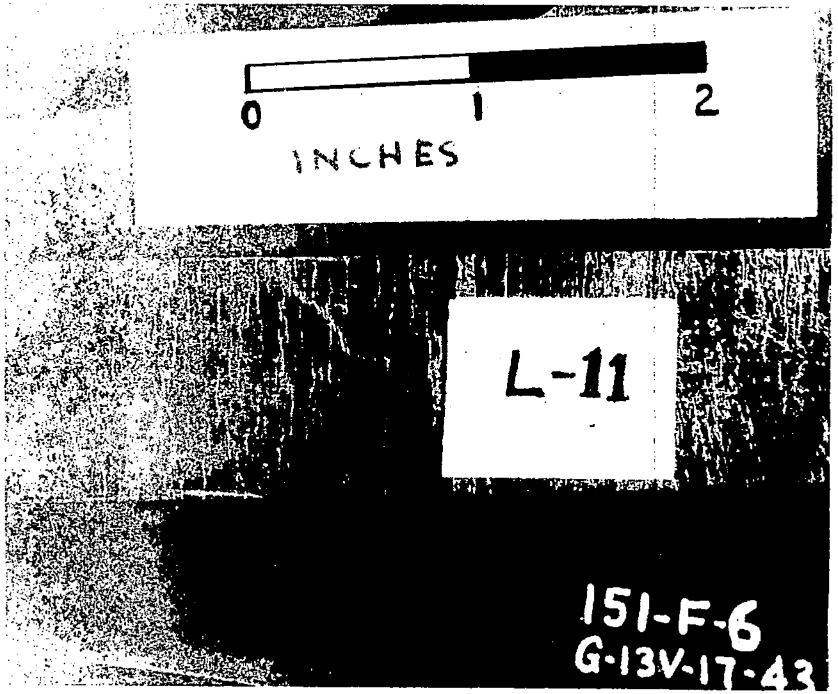


Figure 7.- Plain aluminum strip, 0.004" thick, without tego overlay after 8500 bending cycles with elongation of 0.3 per cent. Note cracks.

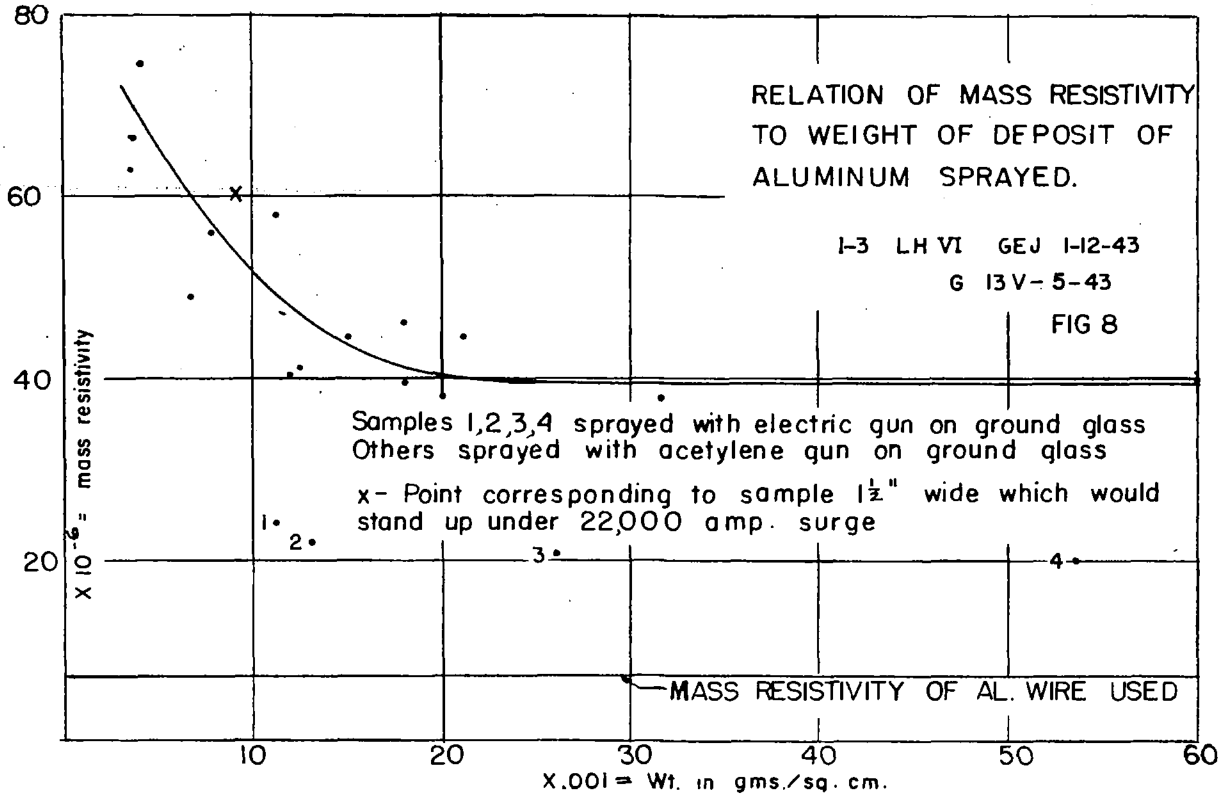

RELATION OF MASS RESISTIVITY TO WEIGHT OF DEPOSIT OF ALUMINUM SPRAYED.
1-3 LH VI GEJ 1-12-43
G 13 V- 5-43
Samples 1,2,3,4 sprayed with electric gun on ground glass
Others sprayed with acetylene gun on ground glass
x- Point corresponding to sample 1½" wide which would stand up under 22,000 amp. surge
MASS RESISTIVITY OF AL. WIRE USED
X 10^-6 = mass resistivity
X .001 = Wt. in gms./sq. cm.
80
60
40
20
10
20
30
40
50
60

FIG 8

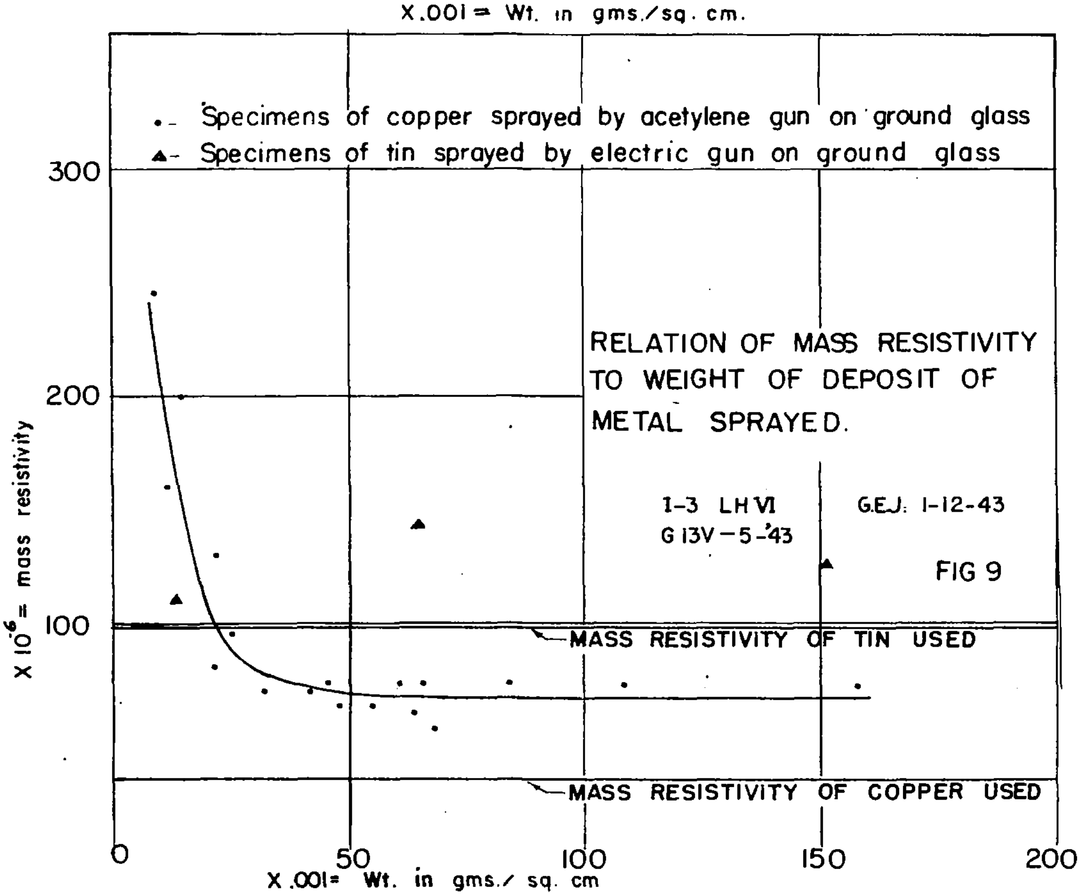

• - Specimens of copper sprayed by acetylene gun on ground glass
▲ - Specimens of tin sprayed by electric gun on ground glass
RELATION OF MASS RESISTIVITY TO WEIGHT OF DEPOSIT OF METAL SPRAYED.
1-3 LH VI G.E.J. 1-12-43
G 13V-5-43
MASS RESISTIVITY OF TIN USED
MASS RESISTIVITY OF COPPER USED
X 10^-6 = mass resistivity
X .001 = Wt. in gms./ sq. cm
300
200
100
0
50
100
150
200

FIG 9

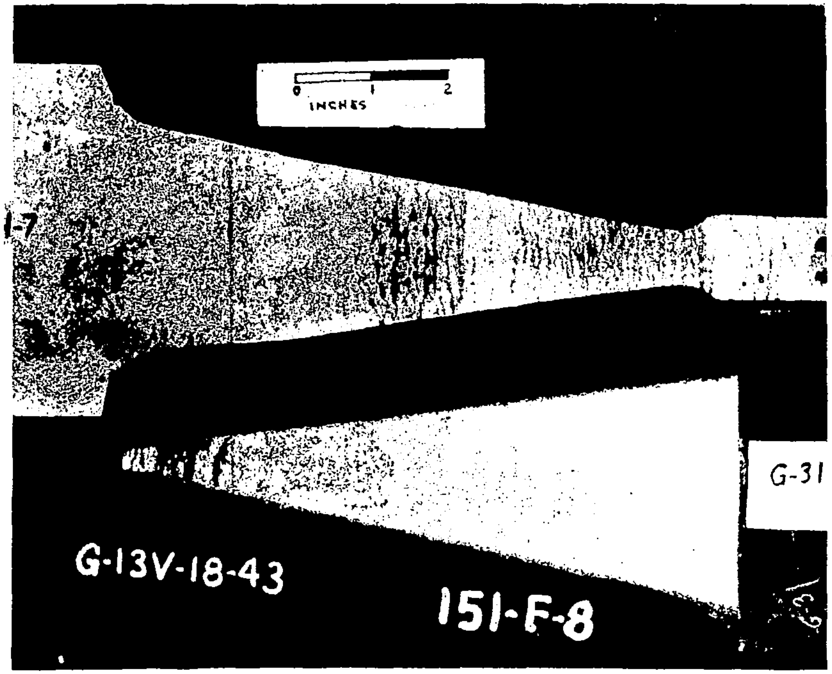


Figure 10.- Wedge specimens of sprayed aluminum after surge test at 22,000 amperes.

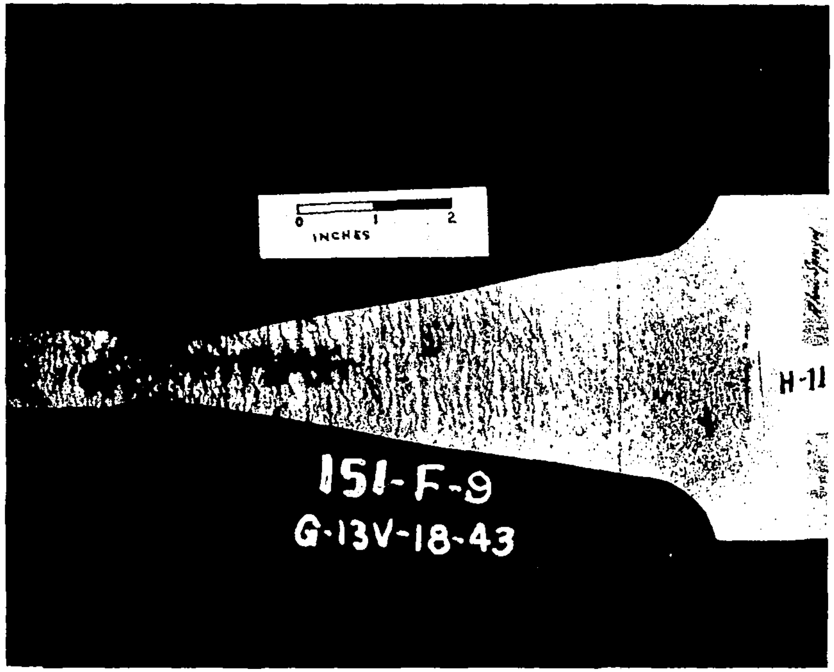


Figure 12.- Sprayed aluminum specimen after exposure to surge current which exceeded its carrying capacity.

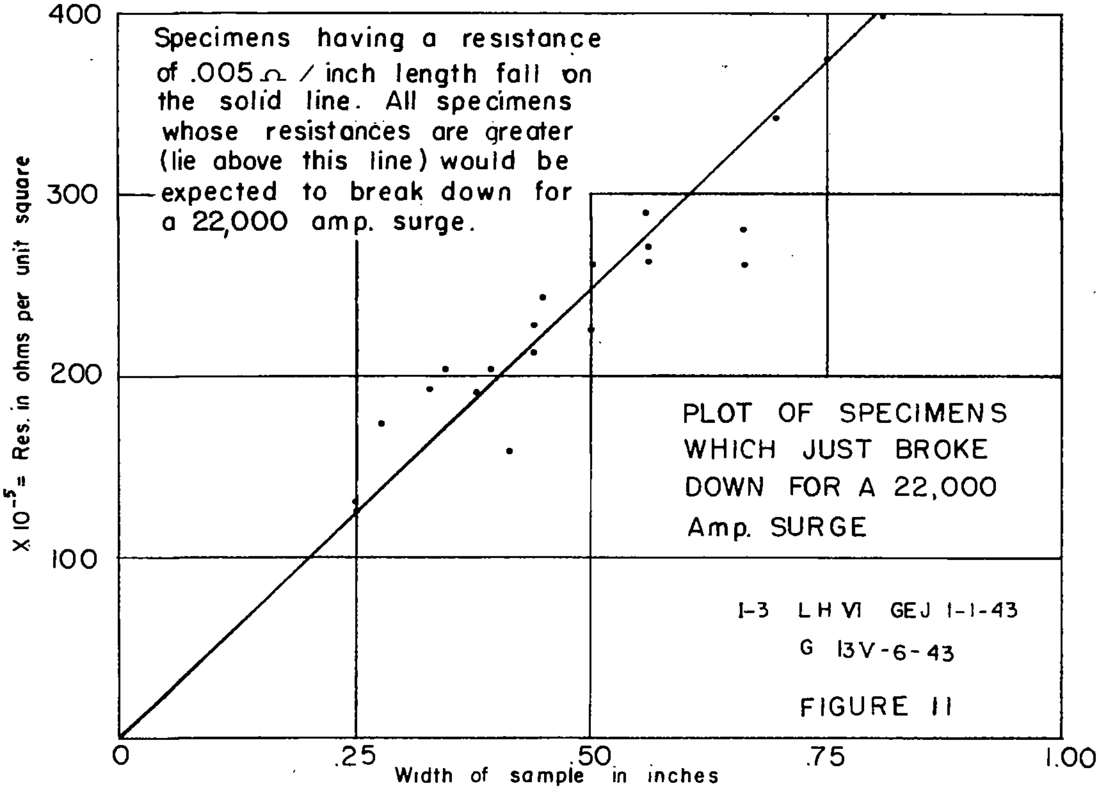


FIGURE 11

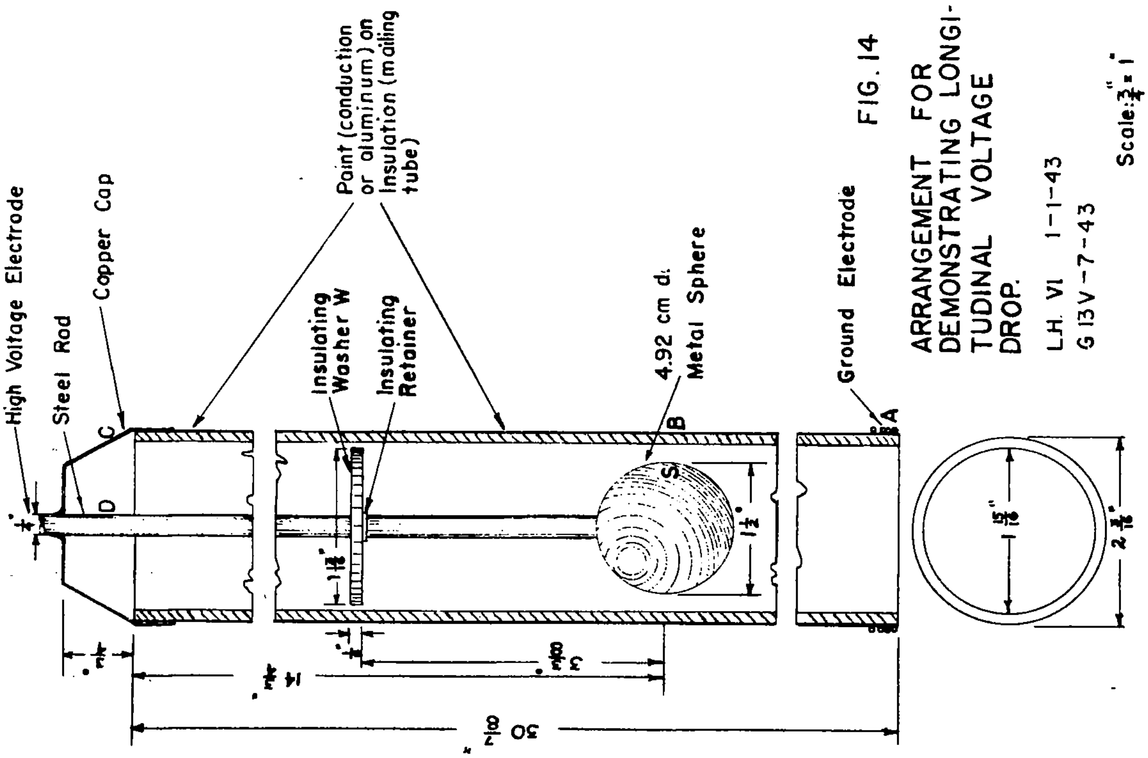


FIG. 14

ARRANGEMENT FOR DEMONSTRATING LONGITUDINAL VOLTAGE DROP.

L.H. VI 1-1-43
G 13V-7-43

Scale: 3/4" = 1"

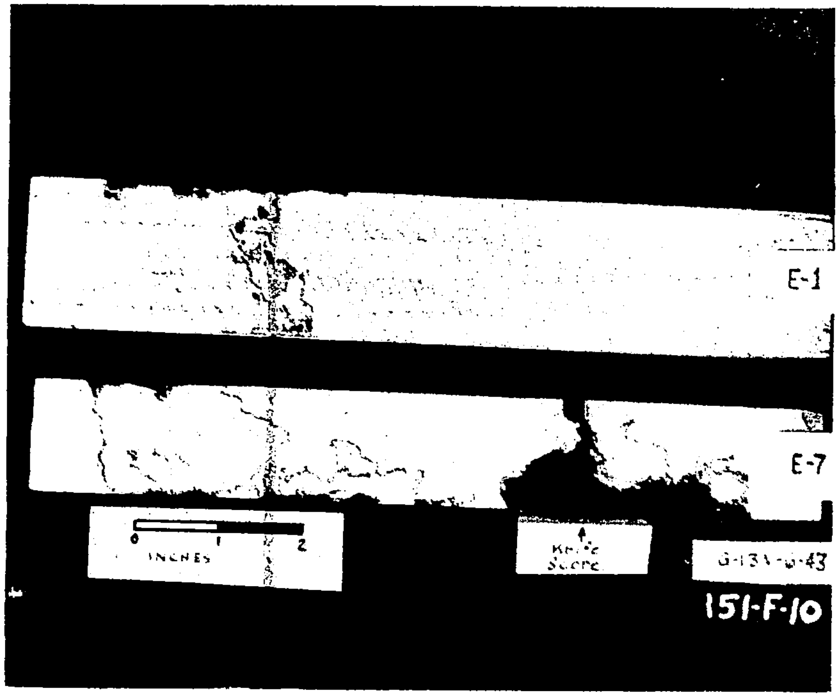


Figure 13.- Two sprayed aluminum deposits after carrying a surge followed by a current of 30 amperes lasting 1 second. The discharge passed to the deposit as an arc which moved about erratically burning the "trails" shown. Specimen E-1 was scarified before metallizing to improve adherence of the sprayed metal.

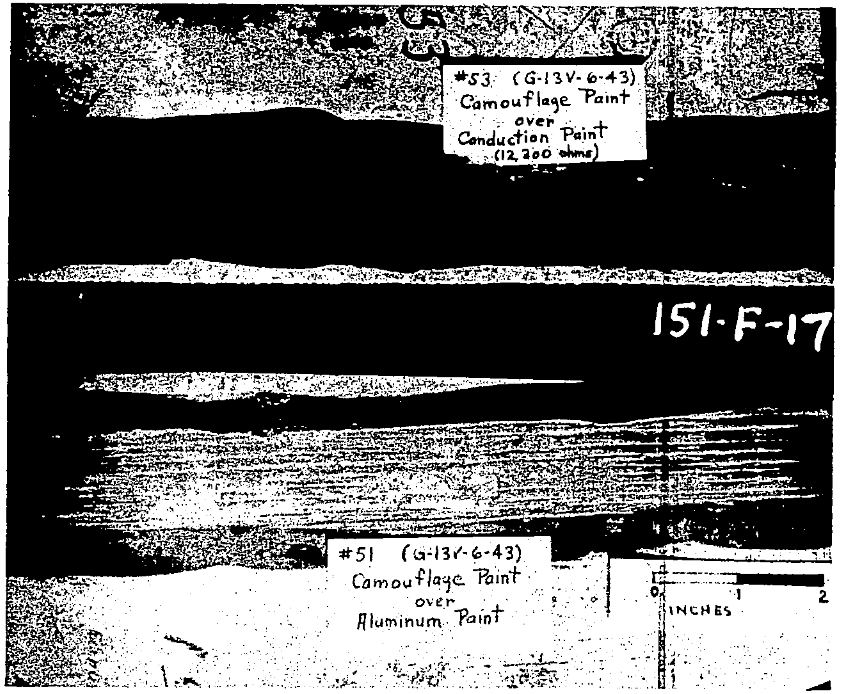


Figure 15.- These two samples of thin plywood were painted first with a strip about 1-inch wide of (on #51) aluminum paint or (on #53) conductive paint. On top of these were painted strips about two-inches wide of blue Navy camouflage paint. The surge current (22,000 amperes) was then passed from end to end of the strips. The discharge blew off the central portions of the paint so that the grain of the wood is exposed. The dark overlap where the insulating camouflage paint was not underlain by conducting material remains. The blast action blew a small hole in #53 and cracked it for about 5 inches.

TITLE: Protection of Nonmetatitc Atrcraft from Lightning - II - Lightning Conductor Matertais AUTHOR(S): (Not known) ORIGINATING AGENCY: Nattonat Advisory Committee for Aeronautics, Washington, D. C. PUBLISHED BY: (Same)	ATI- 7769 REVISION (None) ORIG. AGENCY NO. ARR-3J12 PUBLISHING AGENCY NO.

DATE	DOC. CLASS.	COUNTRY	LANGUAGE	PAGES	ILLUSTRATIONS
Oct '43	Unctass.	U.S.	Eng.	35	photos, tabies, diagrs, graphs

ABSTRACT:

Three major classes of materiai, namely, solid metal, sprayed metal, and conductive paints are discussed with timttations and possibiiities of each as types of materiat, whtch can be used for itghtning conductors on nonmetallic aircraft. Tables gtve weight per ft and wtdth of sheet metal required for certain assumed surge-current carrying capacities. Atuminum was found to have greater surge-carrying capacity than copper of same wetght; rolled sheet metat, more than sprayed metal of same weight. Aiuminum strips of 0.0002-in. thickness can be motded tn surface of tego-bonded plywood with excellent mechaotcat and etectrtcat properttes.

DISTRIBUTION: Request copies of this report only from Originating Agency

DIVISION: Materiais (8) SECTION: Generat Data (15) ATI SHEET NO.: R-B-15-4	SUBJECT HEADINGS: Materiats - Electric properties (60487); Airpianes - Lightning protection (08470.7); Metals - Electrtc conducttvity (61040)