THE PRACTICAL DETERMINATION OF STRENGTH OF DOPED FABRIC

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Technical Development Report No. 129

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TECHNICAL DEVELOPMENT AND
EVALUATION CENTER
INDIANAPOLIS, INDIANA
November 1950

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Manuscript received, April 1950

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SUMMARY

Fabric coverings still are extensively used on airplanes, and the safety and maintenance of such coverings will constitute a problem for some years to come This report discusses some characteristics of aircraft fabric and some appropriate test methods for doped fabric An analytical method for determining minimum tensile strength requirements for doped fabric is presented

A portable impact fabric tester developed at the Technical Development and Evaluation Center is described By means of several test methods, data were obtained for the strength of fabric on various parts of the control surfaces of a DC-3 airplane The accuracy of the test methods and the uniformity of the doped fabric material were considered The data also correlate the fabric tester settings with the strength of the doped fabric These data indicate that the tester may be used in the maintenance of minimum strength standards for doped fabric If the impact fails to penetrate the dope and fabric, the tensile strength of the combination exceeds a certain minimum value for which the tester was set The emphasis of the operation is to determine without penetration that portion of the fabric in which the strength of the fabric-dope combination is equal to, or greater than, a certain minimum value A survey of the entire doped fabric surfaces of the airplane without damage to acceptable fabric is thus possible The data indicate that doped fabric is a very nonuniform material as concerns its strength

From the survey of the DC-3 airplane, it is concluded that fabric from one part of a covering may have less than one half the strength of fabric from another part It is also concluded from an examination of typical support and loading conditions, and from calculations, that the elasticity of the doped fabric is an important factor in determining the tension of the fabric during flight It is demonstrated that the portable impact tester is a convenient, useful and nondestructive tool for assisting in the determination of the condition of the doped fabric on an airplane

INTRODUCTION

Fabric-covered airplanes are sustained in flight by a combination of dope and fabric The function of the fabric is to provide a covering for the structure with a surface having adequate strength The function of the dope is to tauten and protect the fabric It also provides considerable additional strength.

Existing civil air regulations prescribe minimum tearing and tensile strengths for new undoped fabric and minimum tensile strengths for deteriorated fabric from which the dope has been removed Approval or disapproval of the airplane's doped fabric covering, under existing civil inspection procedures, is based mainly upon a visual and tactile examination The inspector examines the dope coating for smoothness, flexibility, adherence, thickness, evidence of rejuvenation, and especially for cracking He examines the fabric for indications of discoloration, abrasion, mildew or other clues to fabric deterioration or weakening

In cases of approval, based upon the visual and tactile examinations outlined previously, tests of the fabric are seldom made In cases of disapproval, however, and only when his decision is challenged, the inspector resorts to the regulation covering minimum tensile strength of deteriorated fabric from which the dope has been removed In such cases, the owner is permitted to cut a tensile test strip from one or more areas selected by the inspector If the strips with dope removed do not show a strength at least equal to the required minimum strength, the fabric must be replaced

These practices assume that the strength of deteriorated fabric from which the dope has been removed is an appropriate measure of the strength of the dope-fabric combination on the airplane Also they assume that in most cases the strength of the fabric less dope can be estimated with sufficient accuracy by the inspector such that no tests are necessary Where disagreement requires tests, they assume that the inspector can select the weakest areas, and that tests of one or a few strips provide an adequate indication of the strength of the airplane covering

The wide variation in strength of deteriorated fabric over different portions of the same area is well known Tests of a few samples, therefore, do not provide an adequate determination of its strength It is necessary to make a thorough survey of the entire area by conducting a large number of tests on the various surfaces of the airplane This precludes the application of any testing method that damages good fabric

A portable impact tester, for use by inspectors in the field, for testing doped fabric covering without removing it from the airplane, was developed It was designed to reveal areas having less than prescribed minimum strengths without injury to acceptable dope or fabric

One method of determining minimum tensile-strength requirements for doped fabric is based upon an estimate of the load to be sustained by the material in service, allowing an ample margin of safety. As a first step to convert this value of tensile strength to a tester setting, it was necessary to calibrate the tester to determine the impact energy over the range of tester settings, and to check the reproducibility of the impacts in successive trials at a given fixed tester setting In the calibration, the rate of energy release was not considered, but rather the total energy of impact was considered The rate is a factor determined by the specific tester and the fabric The fabric reaction was simulated in the calibration by the use of aluminum foil After calibration, the tester was used in an experimental inspection procedure to determine (at many points on the airplane surfaces) the settings necessary to cause the tester to penetrate the fabric The general methods of measurement and the relative effects on the data, of variations in the tester, variations in the fabric strength and variations due to sampling were considered The data obtained with the portable tester were compared with data obtained by standard tensile-strength and burst-strength tests, and a method of correlating the data was developed A fixed setting was selected to permit the tester to penetrate, with certainty, all test areas of doped fabric below an assumed minimum allowable tensile strength

GENERAL CONSIDERATIONS OF FABRIC STRENGTH

Aircraft fabric is a textile cloth used to cover various parts of an airplane It is usually cut in appropriate shapes, sewed into an envelope to form the airplane surfaces and fastened securely to the structure of the airplane in a manner to leave no free edges of fabric

Several coats of airplane dope are applied to the weather-exposed side of the fabric to provide a suitable finish and to shrink the fabric into a smooth taut surface The use of fabric complying with certain textile specifications is required by the Civil Aeronautics Administration [1,2] Fabric strength may be measured by various methods [3] The tests most commonly used in connection with aircraft fabric are the tear test (Elmendorf), the burst test (Mullen) and the tensile test (Scott) The tests and values discussed previously pertain only to new, undoped fabric

Testing the strength of doped fabric introduces new considerations for interpreting the data Here a textile backing and an interpenetrating plastic dope coating are tested simultaneously Considered as separate materials, the textile is relatively strong in tearing, bursting and breaking, while the plastic dope is very weak in tearing and quite strong in bursting and tension The changes in the properties with extremes of low and high temperature are quite different in the

[1]Aeronautical Material Specification AMS 3804 and AMS 3806, January 1, 1946, Society of Automotive Engineers, Inc , New York City

[2]Technical Standard Order TSO-C14 and TSO-C15, September 1, 1948, Department of Commerce, Office of the Administrator of Civil Aeronautics, Washington 25, D C

[3]Textiles, General Specifications Test Methods CCC-T-191a, April 23, 1937, and CCC-T-191A Supplement October 8, 1945 Federal Standard Stock Catalog, Section IV, Part 5, Superintendent of Documents, U S Government Printing Office, Washington 25, D C

two materials In general, the dope material becomes soft and ductile at very high atmospheric temperatures, and is hard and brittle at very low temperatures The textile material is less susceptible to changes in temperature, but probably more susceptible to changes in humidity, and certainly more susceptible to deterioration by fungus infection

The combination of plastic and textile in doped fabric does not permit a simple addition of the values of the properties of the separate materials Under ordinary conditions of temperature, the tearing strength of doped fabric, for instance, may be approximately equal to, or even less than, the tearing strength of the fabric before the dope is applied The burst strength and the tensile strength of the fabric are increased by applications of dope In failures under tension, good fabric with brittle dope will show successive failure, first by cracking of the dope, and finally by breaking of the fabric Poor fabric with soft dope may fail in quick succession by breaking of the fabric and by severance of the dope film It is almost as if the strengths of the two materials in the combination were being tested in series if either material is faulty, and in parallel if neither material is faulty

The properties exhibited in burst tests and tensile tests apparently are more closely associated with each other than they are with the properties exhibited in tear tests A satisfactory portable tester should obtain an indication of the properties of the doped fabric combination as associated with its resistance to failure in service

In a service failure, tearing can occur only from an existing free edge or after a free edge has been created by some previous failure No free edge normally exists in the fabric surface of an airplane, so it appears reasonable to assume that initial failure probably will occur from a splitting, bursting or penetration of the fabric The resistance of a plastic film to initial tearing is illustrated by the familiar difficulty of opening a cellophane wrapper without first finding or creating a free edge to begin the tear In flight, if no cracks, cuts or edges are present, conditions are somewhat analogous to this example It is believed that the strength of doped aircraft fabric on the airplane is measured more appropriately by the tensile test or burst test than by the tearing test

Assuming the use of tensile strength as a criterion for determining the airworthiness of doped fabric, it is necessary to consider the tensile loads actually experienced in flight An analytical method for determining such loads is presented here The calculations are based on the assumption that the fabric is installed on a small, high-performance airplane, and that the relatively high lift area, on the upper surface of the wing at approximately ten per cent of the chord, is critical The wing is assumed to have a Clarke Y airfoil For purposes of illustration, the method includes certain representative data and a calculation, first, of the airfoil pressure differential under maximum lift conditions, and second, of the tension produced in the fabric by this pressure differential

For computations of pressure, the following symbols are used

α = angle of attack in degrees

C = rib spacing in airplane wing in inches

C_L = coefficient of lift

hp = horsepower

K = gust factor (See CAM-04) [4]

m = slope of lift curve C_L per radian corrected for aspect ratio (See CAM-04)

n = limit load factor (See CAM-04)

Δn = limit load factor increment (See CAM-04)

Pav = average pressure or wing loading in lb /ft ^{2}

P = static pressure in lb /ft ^{2} (Pressure differential supported by wing covering)

Q = dynamic pressure in lb /ft ^{2}

[4] "Airplane Airworthiness," Civil Aeronautics Manual 04, Revised July 1, 1944, Superintendent of Documents, U S Government Printing Office, Washington 25, D C

S = effective area of lifting surface of airplane in square feet

U = gust velocity (See CAM-04) in ft /sec

Vmax = maximum speed of airplane for given rib spacing in mph

W = gross weight of airplane in pounds

The data assumed for the airplane are as follows

W = 2, 200 pounds

Vmax = 150 mph

Pav = W/S = 14 lb /ft ^{2}

Power loading = 14 lb /hp

C = 15 inches

The data for the Clarke Y airfoil[5] are as follows

C_L max = 1 5

α = 20 degrees

P/Q at 10 per cent of chord = 2 5

m (no aspect ratio correction required) = 4 01

From the aerodynamic relations for level flight,

$$Pav = W/S = C_L Q = 1\ 5Q \qquad (1)$$

and from the data

$$P = P/Q \times Q = 2\ 5Q \qquad (2)$$

By combining and evaluating equations (1) and (2)

$$P = 1\ 67\ Pav = 23\ 3 \text{ lb /ft}^2 \qquad (3)$$

Appropriate load factors representing gust loads and maneuvering accelerations will be applied to this value

In determining limit load factor increments Δn, to allow for increases in load due to maneuvers and gusts, the maneuver increment and the gust increment both are determined,[6] and the larger of the two values is used For an airplane of 2,200 pounds gross weight and a power loading of 14 lb /hp , the maneuver increment is

$$\Delta n = 3\ 68 \qquad (4)$$

The gust increment is given by the equation

$$\Delta n = \frac{KUVm}{5\ 75\ W/S} \qquad (5)$$

For a wing loading of 14 lb /ft ^{2}, the value K = 0 97 is obtained The value U = 30 ft /sec is specified in Table II for condition I, CAM-04 page 27, and the value m = 4 01 is given in the airfoil data

Substituting in equation (5)

$$\Delta n = \frac{0\ 97 \times 30 \times 150 \times 4\ 01}{5\ 75 \times 14} = 2\ 17 \qquad (6)$$

Using the larger value, Δn = 3 68, in conjunction with Table II, the limit load factor n is given by

$$n = 1 + \Delta n, \text{ or,} \qquad (7)$$

$$n = 1 + 3\ 68 = 4\ 68$$

When this is applied to the value of P in equation (3),

$$P \times n = 23\ 3 \times 4\ 68 = 110 \text{ lb /ft}^2 = 0\ 764 \text{ lb /in}^2 \qquad (8)$$

Having arrived at this value of the pressure on the fabric, it is desired to calculate the tension in the fabric which supports the pressure For this purpose, consideration will be given to a strip of the fabric one inch wide secured at its ends to the ribs of the wing at ten per cent of the chord and extending spanwise from one rib to the next In the original (unloaded) condition, the strip is

[5] "Airfoil Pressure Distribution Investigation in the Variable Density Wind Tunnel," NACA Report No 353, Page 10, Fig 7, Superintendent of Documents, U S Government Printing Office, Washington 25, D C

[6] See footnote 4

taut and straight In its loaded condition, it is acted upon by the difference in air pressure on its upper and lower surfaces due to the aerodynamic properties of the wing surfaces of which it is a part It is assumed that the pressure is uniform spanwise along its length, and that the strip is flexible enough to make the bending moments negligible Under these conditions, the strip adjusts itself to the pressure in the form of a circular arc Referring to the diagram in Fig 1,

C = rib spacing = length of unloaded strip

L = circular arc = length of loaded strip

It will be noted that the value of L approaches C as the load is decreased

ΔL = change in length of strip due to loading

R = radius of circular arc

A = vertical projection of arc, L/2

c/2 = horizontal projection of arc, L/2

θ = angle corresponding to arc L/2 in radians

T = tension in fabric in pounds per inch width

$E = \frac{L}{\Delta L} \times T$ = modulus of elasticity for a 1-inch strip of doped fabric

F = vertical reaction at rib

Consider the equilibrium conditions for the shaded area under the arc L/2 Using the vertical force equivalent, produced by multiplying the force normal to the arc by the area of the arc projected on the horizontal, the vertical forces are

$$F = \frac{PC}{2} = T \sin \theta$$

whence

$$\theta = \sin^{-1} \frac{PC}{2T} \tag{9}$$

Similarly, for the horizontal forces

$$T = PA + T \cos \theta$$

Substituting in this equation the value

$$A = R (1 - \cos \theta)$$

the equation becomes

$$PR (1 - \cos \theta) = T (1 - \cos \theta)$$

and

$$R = \frac{T}{P} \tag{10}$$

Since θ is expressed in radians

$$L = 2 R\theta \tag{11}$$

By equating two expressions for the change in length of the fabric strip

$$L - C = \frac{T}{E} \times C \tag{12}$$

Substituting the value for θ from equation (9), and the value of R from equation (10), in equation (11)

$$L = \frac{2T}{P} \sin^{-1} \frac{PC}{2T} \tag{13}$$

Substituting the value of L from equation (13) in equation (12)

$$\frac{TC}{E} = \frac{2T}{P} \sin^{-1} \frac{PC}{2T} - C$$

whence

$$\sin^{-1} \frac{PC}{2T} = \left(\frac{TC}{E} + C\right) \frac{P}{2T} \tag{14}$$

Substituting the force of reaction at the rib,

$$F = \frac{PC}{2}$$

and simplifying, equation (14) becomes

$$\frac{F}{T} = \sin\left(\frac{F}{E} + \frac{F}{T}\right) \tag{15}$$

Equation (15) was initially solved by plotting a combination of trial values These solutions are rearranged in Fig 2, which provides a convenient means for obtaining values of T when F and E have been determined. F is obtained from the relationship $F = \frac{PC}{2}$, and E is determined by actual tests of doped fabric

The factor of safety is the ratio of the ultimate tensile strength of the fabric to the tension produced in the fabric by the maximum loading pressure Some typical data and cal-

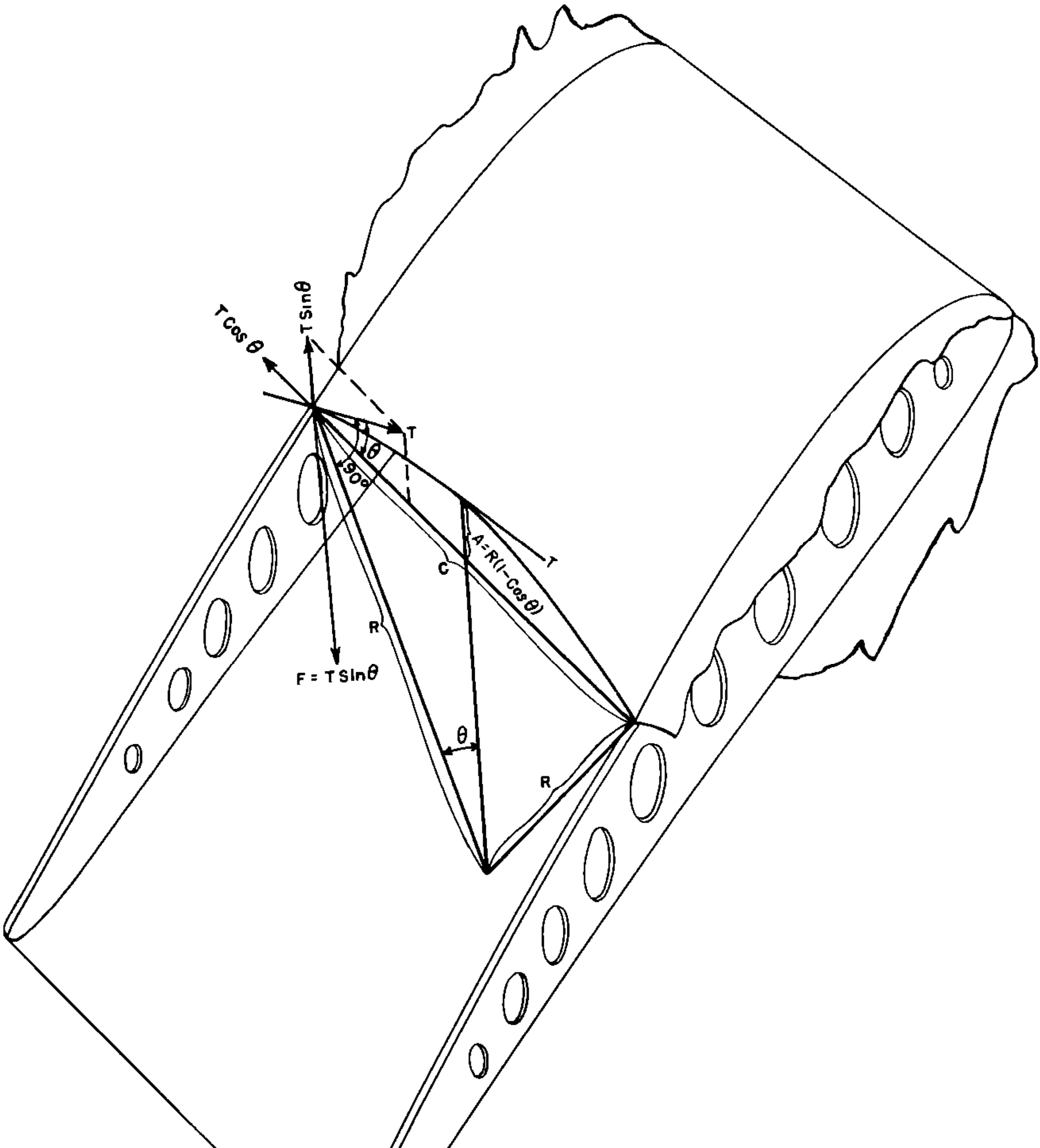


Fig 1 Fabric Loading Diagram

TABLE I

Data And Calculated Values For Individual Strips

Sample Designation	Tensile Strength Breaking lb /in *	Modulus E*	Tension-lb for F = 5 73 lb	Factor of Safety
No. 88-8 (weakest individual strip)	41 5	2000	22 4	$\frac{41\ 5}{22\ 4}$ = 1 54
No 64-2 (intermediate individual strip)	84 0	3030	25 6	$\frac{84\ 0}{25\ 6}$ = 3 28
No 80-2 (strongest individual strip)	146 0	4800	30 1	$\frac{146\ 0}{30\ 1}$ = 4 85

* These values of tensile, breaking strength and modulus are for Grade A doped fabric at temperatures from 60° to 80°F

culated values are given in Table I

An examination of the physical concept of the problem illustrated in Fig 1 shows that the tension could be considered to vary as cosecant θ Thus, if no stretch occurred, θ is zero and an infinitely large tension would be called into play to resist a small pressure on the fabric If the angle θ increases slightly due to some stretch, the cosecant θ drops very rapidly, as does the tension The modulus of elasticity of the fabric within the range of tension met in practice is, therefore, an important factor in determining the probability of fabric failure, as sufficient stretch within the elastic limit will allow the fabric to adjust itself to a relatively small tension

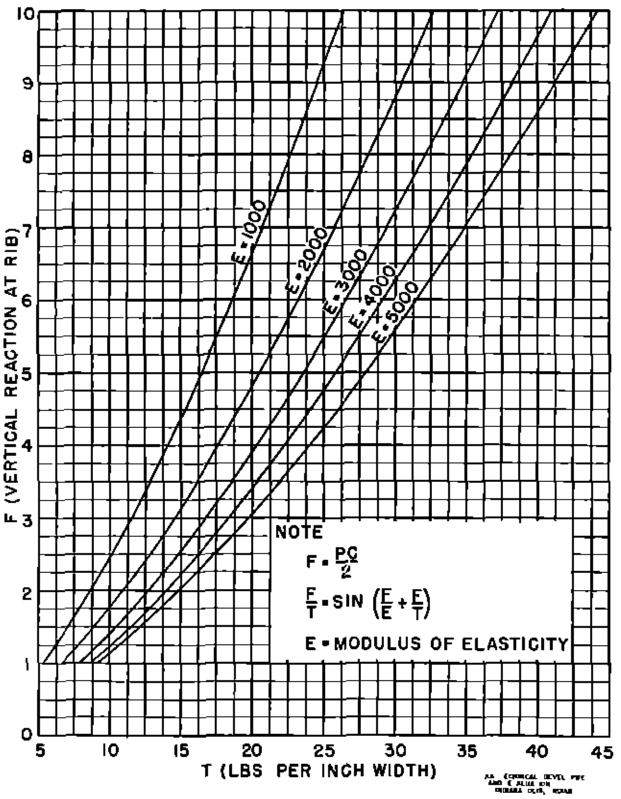
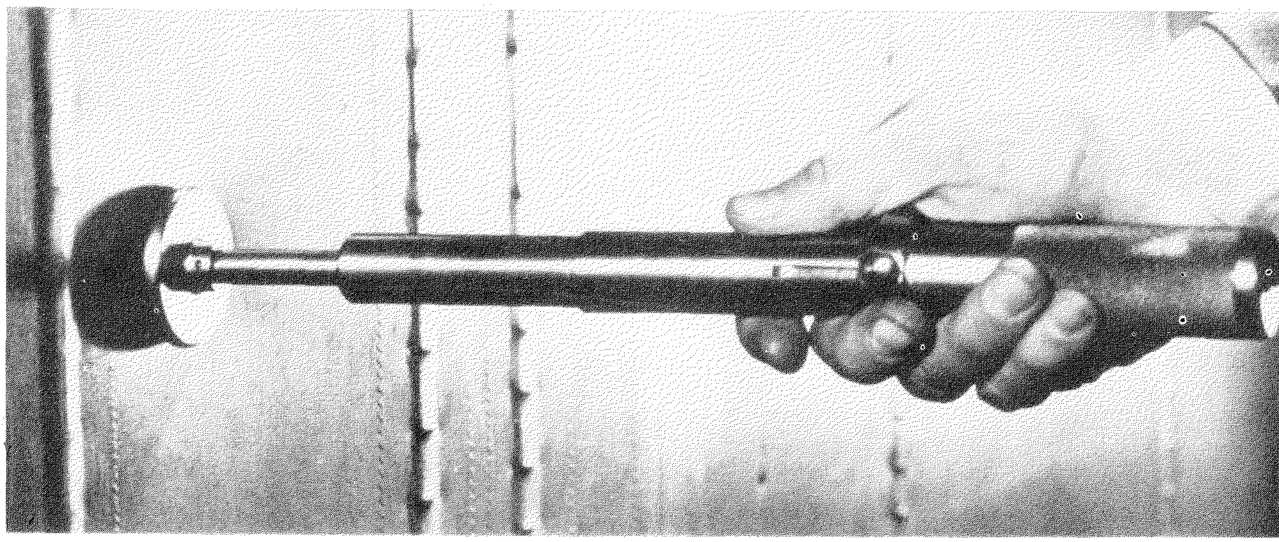
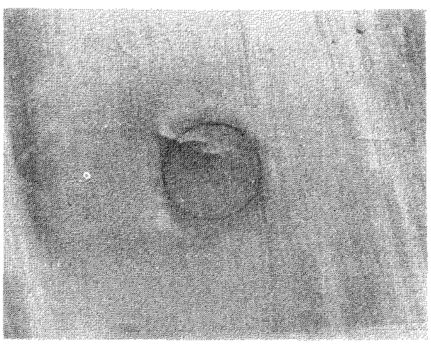


Fig 2 Graph for Solving Tension Equation

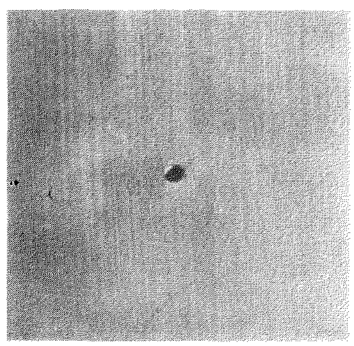
DESCRIPTION OF A FABRIC TESTER

Illustrated in Fig 3 is a portable impact-type fabric tester developed at the Technical Development and Evaluation Center and samples of fabric which have been subjected to impact tests For experimental purposes, the tester was made adjustable with respect to the force of impact For inspection purposes, a nonadjustable tester would be used Fig 4 shows an exploded view of the tester It consists of two nonseparable telescoping tubes The smaller tube is a cylindrical guide terminating in a disk or foot at its outer end Sliding within the guide is a long cylindrical plunger pin, the outer end of which normally is held flush with the outer face of the foot by a buffer spring and stop The larger tube, closed at its outer end to provide a handle, is a cylindrical barrel enclosing a firing spring to actuate a sliding piston-type hammer, and a cocking spring to return the telescoped tubes to a fully extended position A spring-restrained trigger is provided

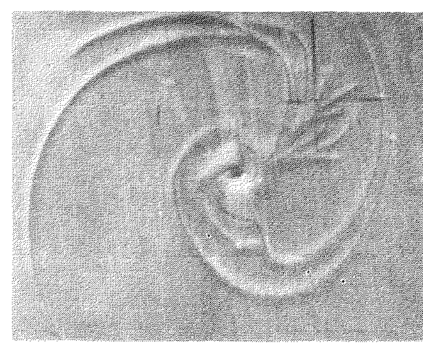




SLIGHT DAMAGE TO GOOD FABRIC AFTER 50 IMPACTS WITHIN ONE INCH CIRCLE



PENETRATION OF WEAK FABRIC



CRACKING OF BRITTLE DOPE

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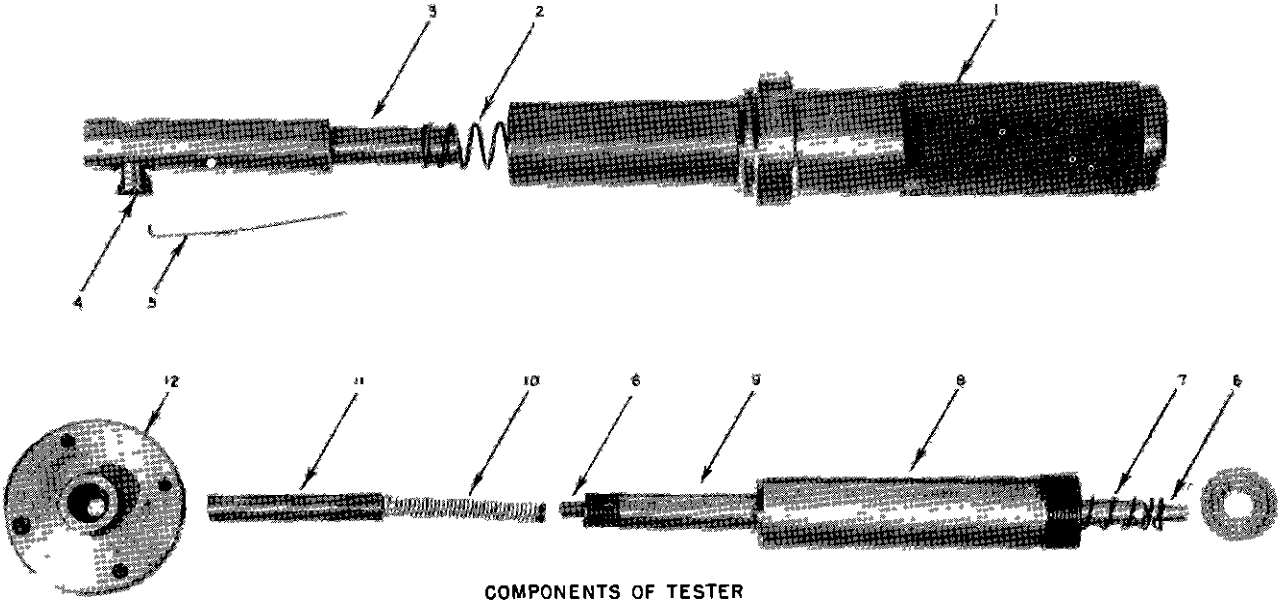
Fig. 3 Fabric Tester and Impact Test Samples

to hold the hammer in the cocked position during the first part of the operating stroke while the foot is supported against the fabric and the handle is pushed to cause the barrel to slide down the guide tube and compress the firing spring. At a predetermined position in the operating stroke, a reduction in the internal diameter of the barrel causes the trigger to move laterally within the hammer. This releases the hammer which is then driven down the barrel by the firing spring until it strikes the inner end of the plunger. The outer end of the plunger is projected out of the foot suddenly and stopped by an external resistance like a taut fabric surface, or in the absence of sufficient external resistance, until stopped by the buffer spring and stop. When the tester is removed from the fabric, the cocking spring extends the tubes and cocks the hammer to complete the cycle of operations necessary for another test.

CALIBRATION OF THE IMPACT TESTER TO DETERMINE ENERGY OF IMPACT

First attempts at calibration, based on measurements of the indentations produced by the impact of the tester pin against lead and tin blocks, showed that lead was too soft and tin was too hard to cover the range of impact adjustment satisfactorily. However, alumi-



COMPONENTS OF TESTER

1 HANDLE	5 TRIGGER SPRING	9 CYLINDRICAL GUIDE
2 FIRING SPRING	6 PLUNGER PIN	10 BUFFER SPRING
3 HAMMER	7 COCKING SPRING	11 STOP
4 TRIGGER	8 TELESCOPING TUBE	12 FOOT

Fig 4 Exploded View of Tester

num strips held in a special clamping fixture allowed the entire range to be covered and the procedure to be improved, although erratic frictional and rebound effects in the tester mechanism, and the necessity for extreme precision in measurements of the small indentations made good reproducibility unattainable Next, a ballistic pendulum device designed to absorb the energy of impact over the necessary range was used The accuracy of measurement was improved, but the method did not reduce the erratic rebound and frictional effects sufficiently In an effort to eliminate the rebound and to absorb the energy of impact in approximately the same way that it would be absorbed by the fabric during actual use of the tester, a new method was devised

By use of the special clamping fixture for holding a sample of aluminum foil in contact with the tester shown in Fig 5, and a dial gage for measuring the depth of the dimple or indentation produced in the foil by the impact of the tester pin, satisfactory results were obtained By producing similar indentations in the aluminum foil by means of measured impacts from a ballistic pendulum, as illustrated in Fig 6, the foil was standardized and the depth of the indentations was interpreted in units of energy absorbed This standardization was reproducible to better than plus or minus one per cent Tester impacts were reproducible to better than plus or minus five per cent For checking the calibration in the field, a simple clamp-on attachment is used to hold a sample of foil against the tester The foil is provided in two thicknesses, one of which will be penetrated, and another which will not be penetrated when the tester is operating with the standard impact

USE OF THE FABRIC TESTER

In use, the tester is applied to the fabric on the airplane so that the axis of the barrel (and guide) is perpendicular to the fabric surface The foot with flush-positioned plunger must be in good contact with a corresponding area of freely supported fabric and an inch or more from any solid support The tester handle is pushed toward the fabric with a smooth, gradual motion The resulting compression of the firing spring forces the foot against the fabric and gradually increases the tautness of the fabric At the triggering point, the hammer strikes the plunger, driving its smooth rounded end out of the foot against

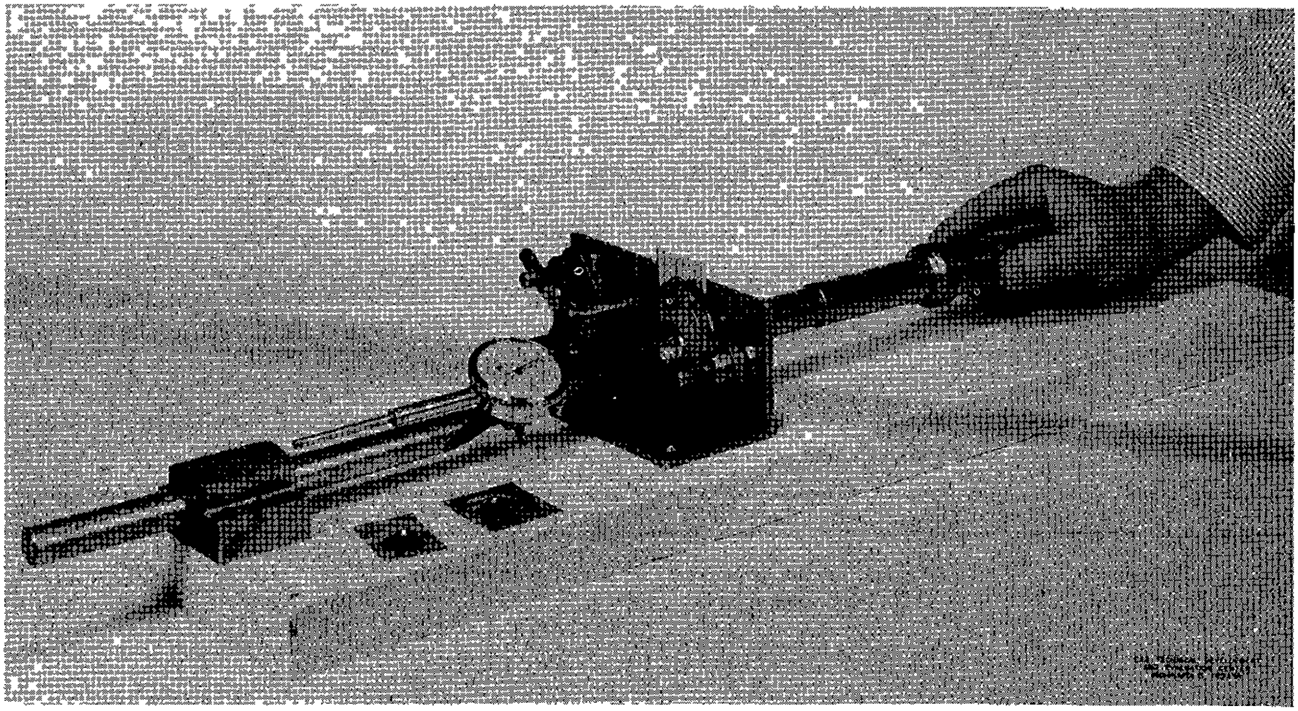


Fig 5 Calibrating Fabric Tester

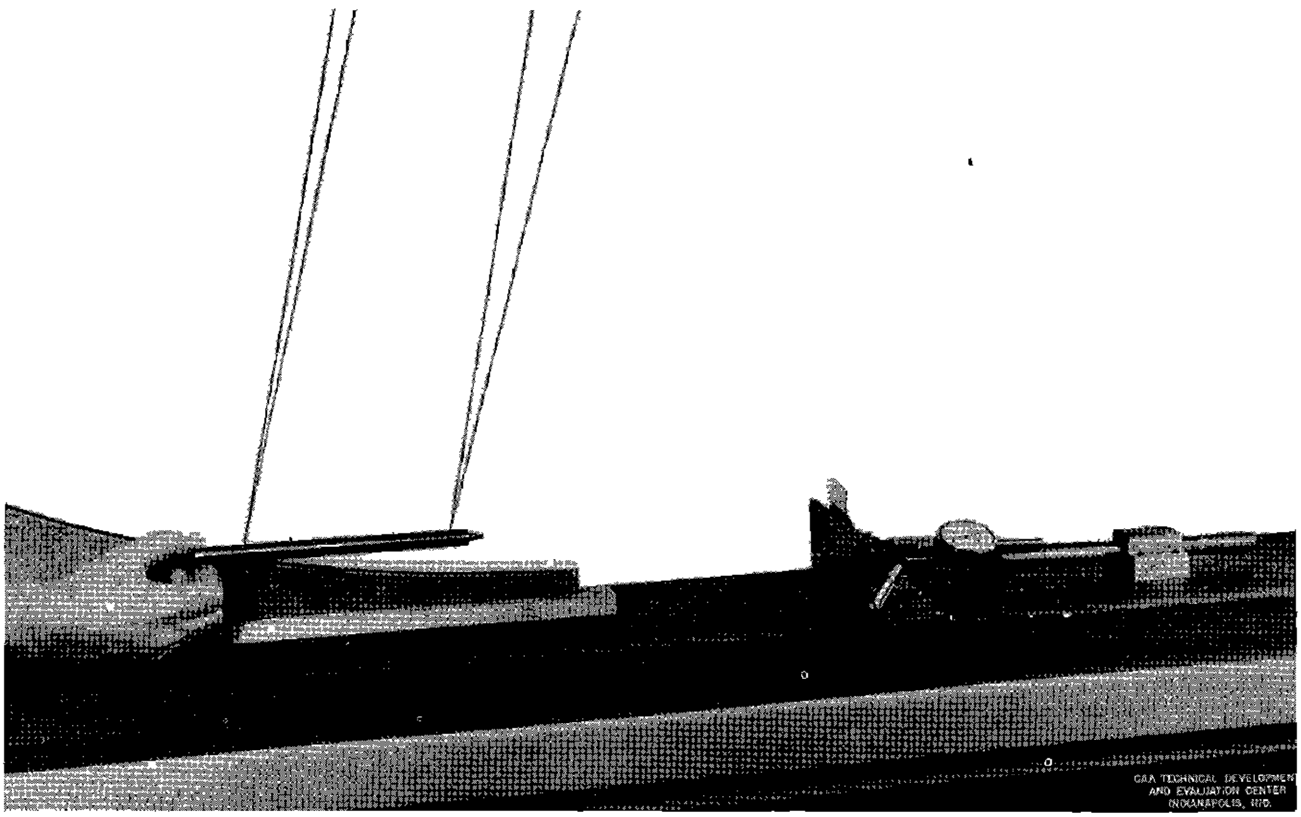


Fig 6 Standardizing Aluminum Foil With Ballistic Pendulum

the taut fabric surface with a sharp measured impact to give a determination of the fabric strength

If the quality or condition of the fabric covering is dangerously below standard, either the dope will be cracked or the fibers of the textile backing will be ruptured by the force of the impact, as illustrated in Fig 3 No penetration of the fabric indicates that the material of the covering is equal to, or exceeds, the standard set by the measured impact The material will not be overstressed, and no damage will occur

DETERMINATION OF STRENGTH OF FABRIC ON AN AIRPLANE

Shortly before the control surfaces of a DC-3 airplane were to be recovered with new material, a survey was made to determine the strength of the fabric This was accomplished by applying several methods of test to a large number of areas located on various parts of the control surfaces The control surfaces were removed from the airplane and tested with the portable tester in the hangar at temperatures ranging from 60° to 80°F

In Figs 7A, B, C, D and E, are shown the locations of more than 100 test areas The pattern shown in Fig 7F was stamped at each location alternately, either directly on the doped surface or on the surface of the fabric from which the dope has been removed with a solvent At each location where the test pattern was stamped directly on the dope, approximately 25 determinations were made with the fabric tester All samples containing the test patterns and sufficient adjacent fabric were then cut out and removed to the laboratory Approximately eight determinations of tensile strength and ten determinations of burst strength were made on each of the doped and the dope-removed samples The average results of the tests made on the various areas by the different test methods are charted in Fig 7 at the appropriate locations

DISCUSSION OF THE ACCURACY AND CORRELATION OF TEST RESULTS

A wide range of variation in strength was revealed by the results of the survey of the strength of fabric on the airplane It was desired to determine whether the variation is due chiefly to the lack of accuracy in the various test methods, or to the nonuniformity of the fabric This will be considered briefly

The accuracy of a test method is usually demonstrated by using the method to determine, in a series of measurements under carefully controlled conditions, the magnitude of a standard which is assumed to be fixed and accurate A sufficiently large number of observations by the most precise method will never give a series of identical values for the standard magnitude As the number of observations increases, the frequency with which certain magnitudes appear will increase The frequency of occurrence may be expressed as a per cent of the total number of trials The results may be plotted to locate a distribution curve showing the magnitudes and the frequency with which they appear

A minimum value, a mean value and a maximum value may be determined on this curve The difference between the minimum value and the maximum value represents the range of dispersion in the results A "standard deviation" or a simpler "per cent deviation" may be computed as a measure of the accuracy of the measuring process The per cent deviation is taken to be one half the range of dispersion divided by the mean value The accepted value of the measurement obtained in the series of trials is taken to be the mean value plus or minus the per cent deviation Figs 8, 9 and 10 show graphically the steps in the processes of establishing the degree of accuracy of measurement and the quality of uniformity in samples of material

Figs 8A, B and C suggest that a measuring process begin originally with the defined perfect accuracy of a primary unit of measurement, such as a standard meter bar for example The vertical line in Fig 8A represents a fixed magnitude No observations are involved, so no frequency scale need be shown Fig 8B represents what might be expected from observations of the length of the standard meter made with a precision instrument under carefully controlled conditions The very small dispersion reveals excellent control of the conditions, and very small errors in the measuring instrument Fig 8C represents an increased dispersion which might result from a technique including a less accurate test device, a less accurate

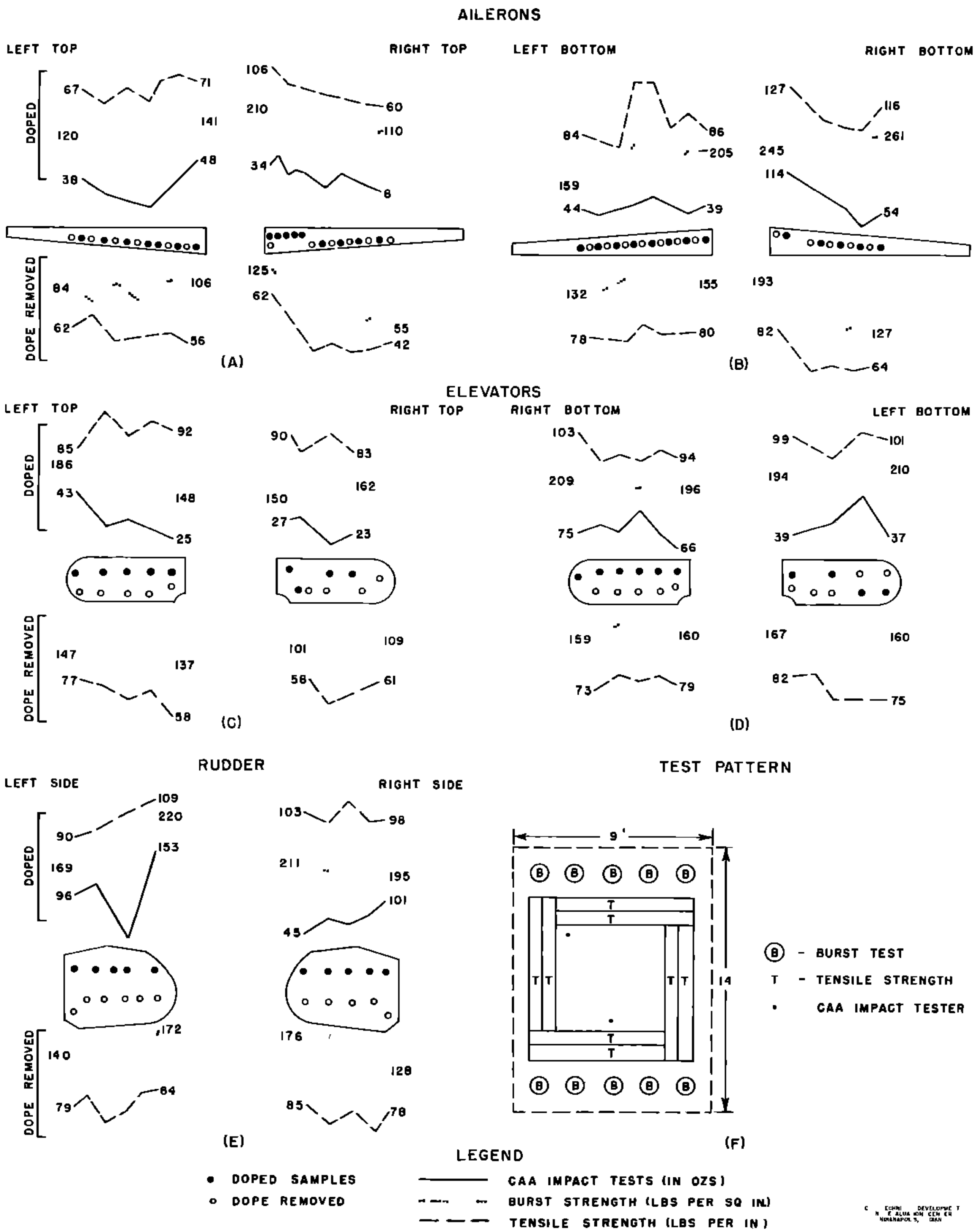


Fig 7 Test Pattern Locations and Average Strength of Samples

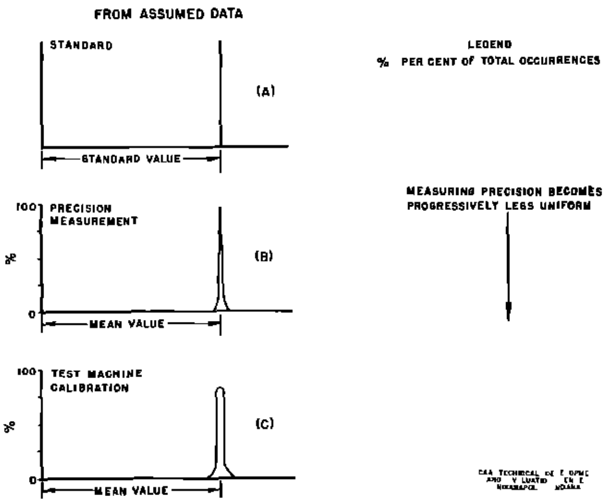


Fig 8 Distribution Curves of Hypothetical Dispersion in Measurements

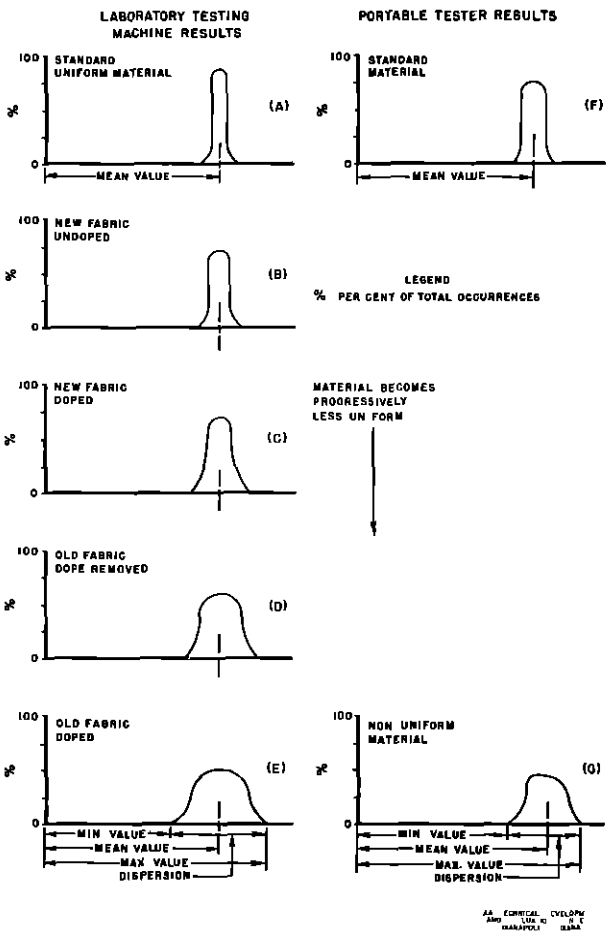


Fig 9 Distribution Curves of Hypothetical Effect of Nonuniformities in Material

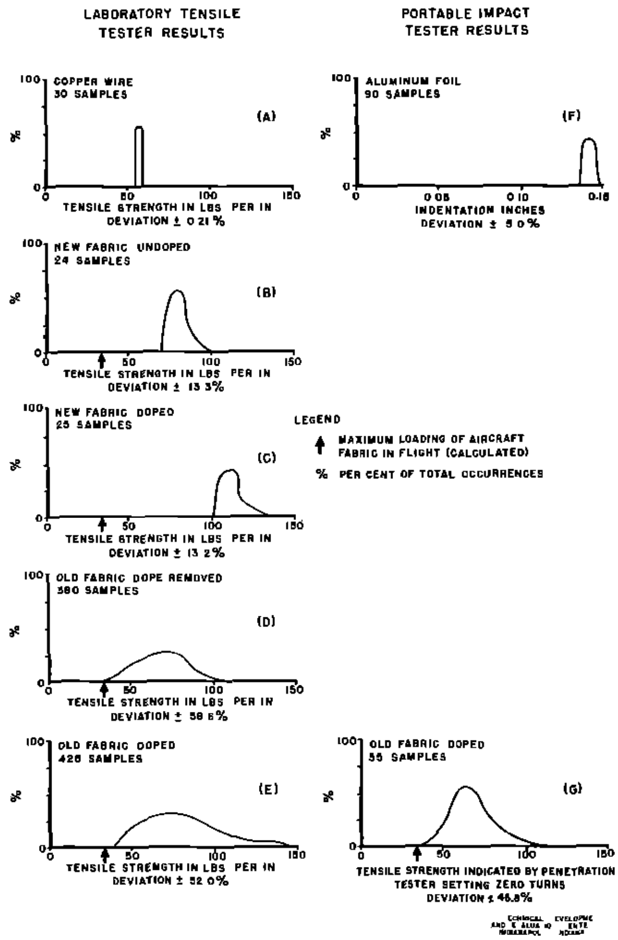


Fig 10 Actual Distribution Curves Plotted From Calibration and Test Data

standard (secondary), and less effective control Figs 9A, B, C, D and E show a sequence of hypothetical curves representing what would be expected of a test machine such as a laboratory tensile tester when used to test samples of various materials In Fig 9A, the samples of the material are assumed to be very uniform in quality, so that a number of samples may perform the function of a single standard (standard samples) As the sample is assumed to represent the standard of accuracy, the dispersion in this case is taken as an over-all measure of the accuracy of the measuring process, i e , accuracy of the test machine as used The increasing dispersions shown in Figs 9B, C, D and E, therefore, can be attributed to the increasing nonuniformity of the materials Tests of a standard material made with a less accurate tester would probably be indicated by a plot as in Fig 9F The increase in dispersion between the condition shown in Fig 9A representing a test machine and that shown in Fig 9F representing a portable tester (assuming equally good standard samples) can be attributed to the lower accuracy of the portable tester Fig 9G represents the greater dispersion in results to be expected from using the moderately accurate portable tester on a very nonuniform material To be compared with the foregoing hypothetical cases, Figs 9A, B, C, D and E, show a sequence of curves plotted from actual data derived from tensile tests of various materials by means of a laboratory tester As this tester is demonstrated to be very accurate when used to test a uniform material such as copper wire as in Fig 10A, the increases in per cent deviation shown in Figs 10B, C, D and E are a measure of the increases in nonuniformity of the material Figs 10F and G are plots of data obtained with the portable fabric tester Fig 10F shows a distribution curve for values of the depth of dimpling produced in standardized aluminum foil in 90 determinations with a fixed setting of the tester The overall accuracy of the tester in terms of the standard sample is shown to be relatively good It may be assumed that, were the strength of fabric as uniform as the strength of standardized aluminum, the limits of variations in using the tester to determine fabric strength would be similar to those obtained with the aluminum Fig 10G represents the variation in the tensile strengths associated with the average penetration values obtained with 25 impacts on each of 55 samples of doped fabric from the same airplane It will be observed that this figure is the first to involve both a correlation and a distribution Each value of fabric strength is taken from the value on line B-B in Fig 13A corresponding to an average impact value, as will be explained in discussing the correlation of the values of tester settings and tensile strength By comparison with Fig 10F, the wide variation in strength and the large percentage deviation are seen to be a measure chiefly of the quality of the fabric and the operation of sampling An examination of the operation of sampling is given in Fig 11 This compares average results from different parts of the same sample by the same test method Doubtless, the dispersion thus created is attributable not to a lack of correlation between two test methods, but rather to differences in strength in the immediate areas compared The dotted line in Fig 11 represents a theoretically perfect correlation With the given accuracy of the test and the given uniformity of the fabric, a decrease in dispersion could be expected from a method of correlation which permitted a nearer approach to tests of exactly the same spot of fabric

The correlation of the results from different methods of test are given in Figs 12 and 13 Fig 12 shows the comparison of tensile and burst strengths obtained by accurate laboratory test methods It is obviously impossible to test exactly the same area by two destructive tests, so here again the dispersion is due chiefly to the combination of this fact and the nonuniformity within the sample area

Fig 13 shows the value of the tester setting averaged from 25 attempts to just penetrate the sample, plotted against the value of the tensile strength averaged from eight determinations on other parts of the same fabric sample Again the dispersion is attributable to relatively small variations in the tester and relatively larger variations introduced by nonuniformities in the strength of fabric within the sample area

The test pattern shown in Fig 7F determines the proximity of the various test areas within the sample The average of data for a given sample of fabric is represented by one point on the plot in Fig 13 Each point is to be considered as a result of certain specific operations established in the routine of testing and sampling In a plot of many such points, the scattering of tensile strength values for a given tester setting, or the scattering of tester setting values for a given tensile strength represents a probability of occurrences in the given routine As has been previously pointed out, an increase in the range of dispersion or scattering is an inescapable feature of a combination of nonuniformity within the sample and noncoincidence of the test areas used in the different methods of test Presumably, other methods of sampling might be devised to improve the factor which depends on the close proximity of the test areas, and thus reduce the scattering attributable solely to this proximity factor

A practical application of the results is made possible, however, by using the cor-

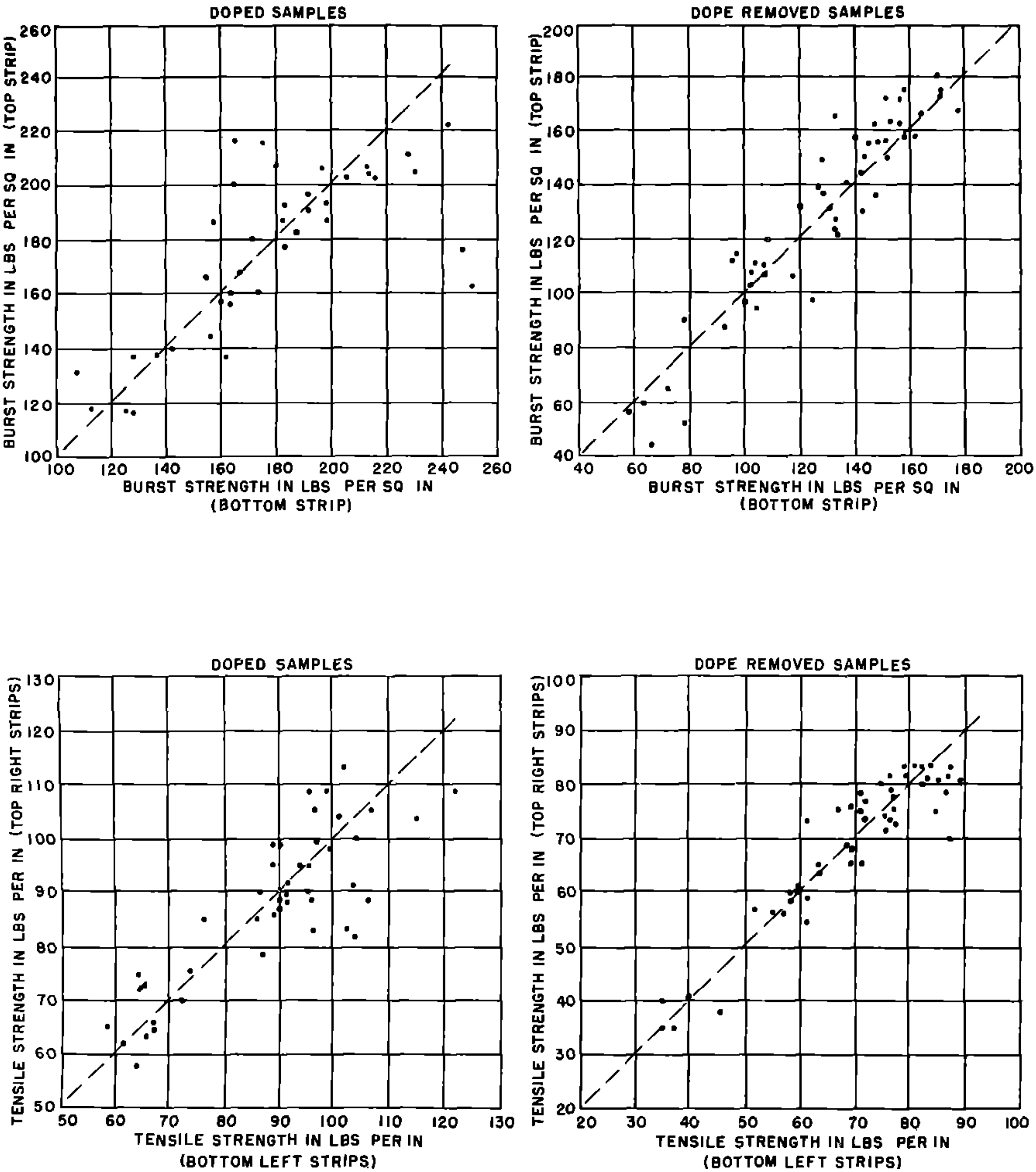


Fig 11 Comparison of Data Obtained on Different Parts of the Same Sample by the Same Test Method

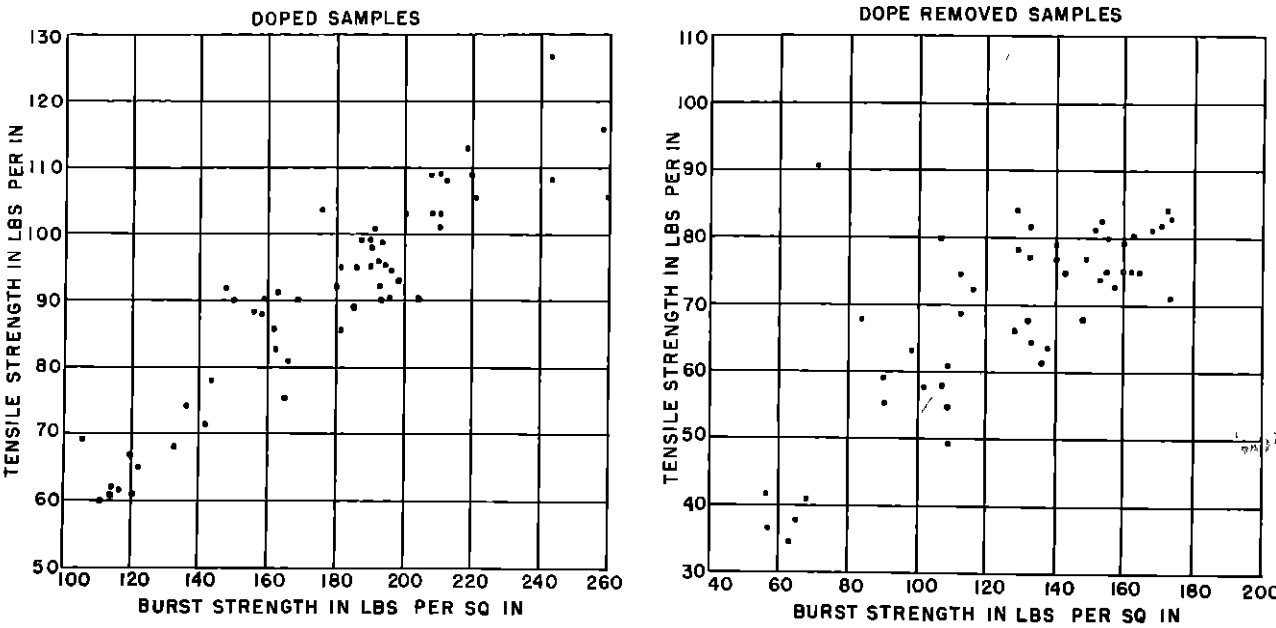


Fig 12 Relationship Between the Tensile Strength and Burst Strength of Fabric

relation established on the line B-B On this line is established a relationship such that fabric having a given strength will never be penetrated by the impact having a value corresponding to this strength The actual strength of the fabric at the point of the impact is established within a much narrower range than is indicated between the lines B-B and A-A, which represent a correlation based on a routine providing the necessarily imperfect correlation previously explained

Of course, in using the line B-B, a small additional, but not completely determined, margin of safety has been added as a more perfect correlation of results in the sampling and testing routine undoubtedly will raise the line B-B and lower the line A-A

The experimental variation in the range of fabric strengths at the point of impact will be greatly reduced when thus considered on the basis of the actual accuracy of the impact tester, as demonstrated in Fig 10F In practice, the strength of the fabric at the precise spot at which the impact occurs is the actual correlative value

TESTER SETTING AND PROCEDURE FOR FABRIC INSPECTION

Table II lists tester setting values based on these considerations

TABLE II

Experimental Tester Setting And Grade A Fabric Strength Established For Temperatures Ranging From 60° To 80° F

Tester Setting Turns	No Penetration Indicates the Strength Equal to or Greater Than Minimum Strengths Listed Below — Tensile lb /in	Burst lb /sq in
0	47	73
5	51	80
10	58	94
15	68	115

In Table I, the maximum load in tension is shown to be 30 lb /in With a factor of safety of 1 5, this gives a maximum required tensile strength of 45 lb /in A tester setting of zero turns gives an equivalent minimum tensile strength for the fabric-dope combination of 47 lb /in , or higher This is equivalent to a mean value of about 70 lb /in This

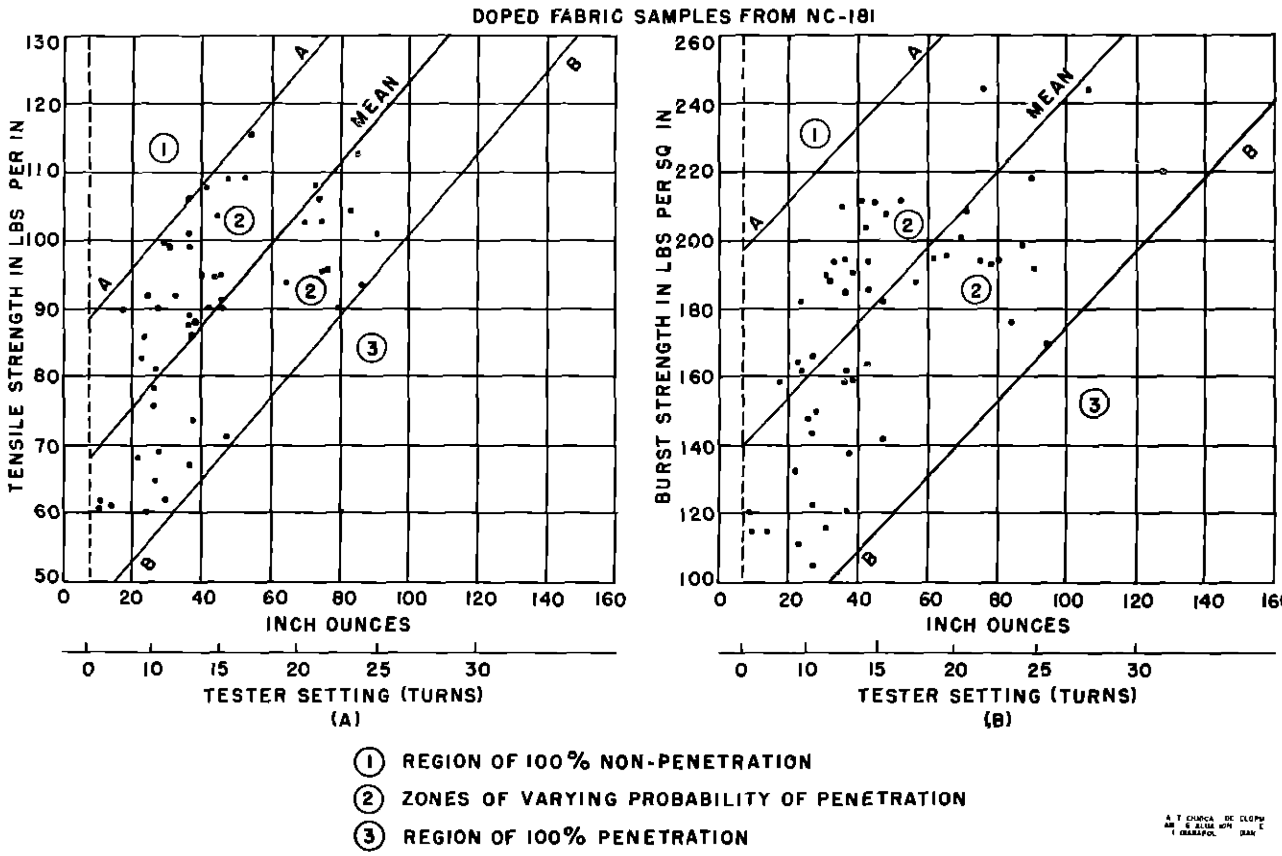


Fig 13 Relationship Between Penetration Setting for CAA Tester and the Tensile Strength and Burst Strength of Fabric

seems to be a reasonable requirement for using the impact tester to determine dangerously weak areas of fabric

The inspection procedure based on this setting will be of a survey nature, and the tester, which is preset and nonadjustable, may be used on various locations over the whole surface If no penetrations occur, the wide areas of fabric tested will be above a required minimum value If occasional penetrations occur, they may be patched If small areas are delineated by penetrations, they may be replaced, and if large areas show many penetrations, the surface should be recovered For this survey, no test patterns or any adjustments are required, simply an observation of whether or not penetration occurs or whether the dope cracks The use of the tester will permit a more uniform maintenance of a reasonable minimum standard strength of doped fabric on the airplane

CONCLUSIONS

It is concluded that

1 The strength of new undoped airplane fabric is not uniform for different samples from the same bolt The nonuniformity is made progressively greater in service use on an airplane by the processes of doping, deterioration, maintenance and repair

2 The average tensile strength of a sample of apparently airworthy doped fabric from one part of an airplane may be less than one half as much as the strength of a similar sample from a near-by area

3 The modulus of elasticity of the dope-fabric combination is an important factor in determining the tension in the fabric under flight conditions

4 The portable impact-type fabric tester is suitable for use in surveying the dope-fabric covering on an airplane to determine whether or not its strength has been reduced below an established minimum value