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THE TESTING OF AIRPLANE FABRICS

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I. INTRODUCTION

The choice of suitable fabrics for airplane coverings constitutes an ever-recurring problem, the solution of which is often not wholly satisfactory. Hence it seems appropriate to consider the determining factors in the choice of fabrics, to describe the customary methods of testing and to report some of the experimental results obtained with various fabrics, especially as a further revision of fabric standards is about to be published.

During the war, comprehensive tests were conducted in Germany and in other countries, in order to produce covering fabrics which would meet the ever-increasing requirements of military airplanes. (References 1-3.) In making these tests, one naturally had to be assured of the availability, at all times, of a sufficient quantity of the requisite raw materials. This necessarily affected their use in the different countries. Toward the end of the war, coarse materials and substitute fibers were investigated in Germany, while linen was preferred in England and cotton in America.

II. USES AND REQUIREMENTS

The covering fabrics are expected to give the wings smooth surfaces and aerodynamically favorable shapes. Hence they must be strong enough to retain their shape in flight, and their security against failure must equal that of the other structural members.

The stresses will accordingly depend on their use (e.g., as wing or fuselage coverings) and on the character-

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istics of the airplane (speed, wing loading, structure and deformations). Accurate determination of the stresses is very difficult, without any proportionate advantage. A. Pröll attempted to calculate the stresses with the aid of simplifying assumptions. (References 1 and 2.) The description of the tests give an idea, however, of the unreliability of the material characteristics thus obtained. (Reference 3.) For this reason investigators have hitherto foregone the consideration of the assistance of the covering in the wing-truss structure and confined their attention to the requirement that the fabric must transmit the aerodynamic forces to the points of attachment and that the deformations must be small. It also follows that the elastic behavior and the strength are so affected by previous stressing and aging (effects of moisture, light and oxidation), that one can hardly calculate with definite characteristics. However, should greater durability be attained by improved methods of fastening and protecting, the way to a better utilization of the strength of the fabric would then be opened.

In order to meet the above-mentioned requirements, the fabric must be smooth, taut, and air-tight. In the raw state, the fabric possesses these characteristics only in an imperfect degree and therefore require special treatment, which now consists of several coats of cellulose dope. This treatment has the advantage of increasing the strength, elasticity and tautness of the fabric, or in other words, its permanency of form. A suitable dope greatly increases the durability of the fabric by protecting it from the effects of light and weather. The tacit assumption is that, as in all aircraft materials, these properties must entail as little increase in weight as possible. Another requirement, which may be very important under some circumstances, is a certain lack of sensitiveness to mechanical injuries. It is known that the strength of materials is greatly impaired under some circumstances, as soon as the equilibrium of the stresses is disturbed by injury at any point.

In determining the requisite strength of the fabric, it must not be forgotten that under some circumstances it may be impaired with surprising quickness. Very interesting in this connection are the results of weathering tests, which will be more closely considered under the heading of "Tensile Tests." A certain strength reserve must therefore be present from the beginning, in order to avoid the necessity of replacing the fabric soon.

III. RAW MATERIALS.

Aside from metal and plywood, the most important are fibrous materials, and especially vegetable fibers. In a few instances, silk fabrics were used experimentally, but the saving generally failed to compensate for deficiencies in other respects. The two most important vegetable fibers are flax and cotton, since no great progress has been made with artificial silk, especially as regards the effects of moisture.

Flax or linen is the bast fiber from the stalks of the flax plant. (Reference 4.) The stalks are subjected to a bacteriological fermentation (retting), which serves to loosen the fibers. The bast fibers (hackled flax) are then separated from the retted flax by mechanical processes (breaking, swingling, hackling). Usually a fiber consists of several separate cells, so that, in the finished condition, fiber lengths of 30 to 40 cm (12 to 16 inches) are obtained. If the cells are put into a suitable swelling medium, e.g., copper ammonium oxide, the cellulose content swells and puffs out the cell wall. This shortens the fiber and the central canal assumes a spiral form. (Fig. 1.) (Reference 5.)

Cotton is the seed fiber of several plants of the Gossypium genus. (Reference 4.) The fibers do not have to be loosened as in the case of flax, but can be immediately used after removing the seed and cleansing. The cell consists of a rather thick wall and an air-filled cavity (lumen). The outer layer of the cell wall consists of a thin resistant skin (cuticle). (Reference 6.) When soaked in copper ammonium oxide, the cell wall expands greatly, the fiber is shortened, the cuticle bursts open at many points and forms annular rings or spirals. (Fig. 2.) By treating the yarn or cloth in the swollen form with concentrated alkalies (soda lye or the like), the originally flattened form of the fiber is converted into a more cylindrical form. By this treatment (mercerizing) the luster and strength of the fiber are greatly increased. Hence cotton fabrics are used mostly in the mercerized condition.

The yarn is spun from these raw materials by a rather complicated process, which we will not describe here. (Reference 7.) It is then numbered according to its fineness, the number indicating the number of length units in a given weight.

The strength of the yarn depends partly on the strength of the individual cells and partly on the friction between them. If the latter is not great enough, the individual fibers slip on one another without tearing. The friction between the fibers depends on the nature of the surface and on the length of the fibers and also on the number of twists per unit length. Linen fibers acquire a sufficient length by growth, since each fiber consists of several cells. In cotton the length of the staple is the criterion of its excellence, which is the mean length of the longest fibers. High-quality yarns are, of course, made only from long-staple cottons (Sea Island, Egyptian, etc.). The number of twists per unit length depends on the thickness of the yarn and on its use. Warp yarn is generally more closely twisted than filling yarn.

The strength of the fabric depends on the strength of the yarn. It can therefore vary greatly with the selection, treatment and preparation of the yarn. However, the strength of the fabric is not simply the sum of the strengths of the individual pieces of yarn.

Covering fabrics are generally linen, in which the warp and filling are very closely woven, each thread passing alternately over and under the threads of the other system. Each thread may consist of a single strand or of several strands twisted together.

IV. TEST CONDITIONS

1. Moisture Content

Like most animal and vegetable materials, the textile fabrics are hygroscopic, i.e., they absorb moisture from the surrounding medium to the saturation point of the fibers and give out this moisture again to a dry surrounding medium. The moisture content affects both the weight and the strength of the fibers. Hence, when it is desired to obtain comparable experimental results, the moisture content of the fibers must be determined. In standard tests, it is considered sufficient, however, to let the fabric hang for a long enough time in air of known humidity. The air, according to its humidity, imparts more or less moisture to the fibers, so that the moisture content of the latter can also be determined. In Germany and in many other countries, a humidity of 65 per cent at 20° C (68°F.)

is considered standard. The requisite time for the fabric to hang to absorb the corresponding amount of moisture depends partly on the humidity of the air and partly, of course, on the difference between the humidity of the air and the moisture content of the fabric. If this difference is great, the time of suspension must be relatively long; otherwise, it may be quite short. Data concerning the requisite time differ greatly. According to American experiments, three hours suffice, while according to more recent Russian experiments the fibers have to be exposed a month to acquire the same moisture content. Unless conditions are very abnormal, the minimum period of 24 hours, as given in "DIN L 21," may be considered sufficient, provided care is taken that the air circulates freely about the samples.

Figures 3 and 4 show the rates of giving off and of absorbing moisture for airplane linen. Figure 3 shows the moisture losses of a sample which, after drying in the air, was dried in an oven at 98° until its weight became constant. The loss in weight was determined every half-hour and therefrom the percentage loss as compared with the original moisture content was calculated. At the end of three hours 99 per cent of the original moisture content had been expelled and the curve in the half-logarithmic diagram was practically straight. This sample was then suspended in air of 63 per cent relative humidity and the gain in weight determined. After an hour and a half, as shown in Figure 4, the sample had regained 90 per cent of its original moisture content. Beyond this point the gain was very slow. At the end of 20 hours the fabric weighed exactly the same as before drying. The second curve in Figure 4 shows the results with wet fabric. The sample was soaked in water for half an hour, lightly dried between blotting papers and suspended with a moisture content of 60 per cent. The air in the room was kept constantly in motion by a small fan, though the air current from the fan was not directed at the fabric. The dash-dot line ascends steeply, showing a more rapid loss than in the case of the dry fabric. After about an hour, 95 per cent of the absorbed water had been again lost to the air and after six hours, 98.5 per cent.

The difficulty of obtaining and maintaining a definite moisture content during the test is avoided in many countries by testing the saturated fibers. The samples are soaked half an hour in water and tested wet. Their strength is considerably greater than that of air-dried samples, which must be taken into consideration in comparing strength data from different sources. The defects of this method are that the strength in the air-dry condition can be determined only from "a posteriori" conclusions and that the elongation characteristics of the fabric are also different.

The effect of the moisture content on the course of the curves can be estimated from Figure 5. This figure shows the curves for a standard linen, a light cotton and a viscose artificial silk. The strength of the linen increases with the moisture content, especially at the higher degrees. The "Mako" (Egyptian) cotton also shows an increase in strength, while the artificial silk shows a considerable loss. This is probably the chief reason it has not been used for airplane coverings. If the strength at normal atmospheric humidity is put at 100, we then obtain the percentage variation in the tensile strength of the first two fabrics, as shown by the curves in Figure 6. In the most important region between 60 and 70 per cent relative atmospheric humidity, a change of about 1 per cent in the strength corresponds to a change of 2.5 per cent in the moisture content.

Even doped fabric is sensitive to humidity, although the rapidity with which its moisture content follows the humidity of the surrounding air is considerably less, according to the kind and degree of doping. The effect of the moisture absorbed is the same as on undoped fabric. Increased moisture content increases the strength, but decreases the tautness. No thorough investigation has yet been made, but only a few preliminary tests, as reported by Barr and Wilson. (Reference 9.)

In order to determine the moisture content of the fibers, the sizing in the fabric must first be removed. This is accomplished by boiling the sample for a short time and then letting it stand two hours in a dilute solution of diastase at 60 to 65° C (140 to 149° F.). It is then washed, boiled again for an hour and rinsed. The quantity of the sizing is the difference between the dry weights before and after this treatment. The drying is done in an oven at 105 to 110° C (221 to 230° F.) until the weight becomes constant, i.e., until two weighings one-fourth hour apart show less than 0.03 per cent loss in weight. According to British and American specifications, the sizing must not exceed 3.5 per cent, while French specifications allow only 1.5 per cent for linen fabric.

The moisture content is similarly determined.

$$\frac{G_n - G_2}{G_2} 100 = \% \text{ moisture content,}$$

where G_n = weight of unsized air-dried sample,

G_2 = " " " oven-dried " .

This definition corresponds to the method employed with wood. In the textile industry, however, according to Heermann (reference 6), the moisture content is understood as being based on G_n, while the here-defined expression is considered as the moisture increase.

2. Rate of Loading

Aside from the moisture content, a whole series of other factors also affects the strength. Since the strength of the yarn, as already mentioned, is intermediate between the strength of the fibers and the friction between the fibers, all factors affecting the friction also affect the strength of the yarn. This statement applies particularly to the rate of loading. At a high rate of loading the strength is greater, because the friction between the fibers increases with the rate. According to American data (reference 10) there is a logarithmic relation between the tensile strength and the loading time, somewhat as follows:

$$P_t = P - \frac{P}{8} \log t,$$

in which P_t denotes the breaking load for the loading time t in minutes, and P the breaking load in a standard tensile-strength test. This relation is naturally valid only within certain limits. One-half of the breaking strength, as determined by the tensile test, is considered as the permanent strength, i.e., as the load which the fabric can withstand for a long time.

V. TESTING METHODS

1. Unit Weight and Number of Threads

After the fabric has been reduced to normal moisture content, a piece of at least 0.25 m^2 (2.7 sq.ft.) is cut out parallel with the threads and is accurately measured and weighed to within one gram (0.035 oz.).

The number of threads per unit length is determined either by pulling them out for a distance marked on the fabric or better, for fine-threaded fabrics, with the aid of a thread counter (a lens under which a glass scale is laid on the fabric). The mean of at least five counts at different places, 15 cm (about 6 in.) or more apart, is taken as the number of threads.

2. Tensile Tests

Due to the simplicity of the testing method, the standard tensile test is also applicable to covering fabrics, although the stressing conditions, for the most part, do not correspond to those of actual practice. In order to obtain a closer approximation to the actual stressing conditions, one must use the simple or multiple cross test introduced by Haas and Dietzius (reference 11), in which the fabric is simultaneously stressed in both warp and filling. This method is much more troublesome, however, so that it is worth using only for very fundamental tests and in cases where the fabric serves as an element of the static structure (e.g., in nonrigid airships). Even the results of the simple tensile test, however, enable instructive conclusions on the behavior of the fabric on an airplane.

In cutting the test samples, the lack of uniformity of the strength characteristics of the yarn must be taken into account. The samples must be cut in such a way that the largest possible number of different threads will be included. They must be so distributed over the fabric that each sample will contain different threads in the direction to be stressed. Generally at least five samples are taken parallel to the warp and a like number parallel to the filling. The warp samples are distributed in several groups over the width of the fabric. The filling samples should include threads from several different spools, so that the interval between the different groups is determined according to the distance covered by a spool. An interval of 15 to 20 cm (about 6 to 8 in.) should suffice for fabric 130 cm (about 51 in.) wide. In "DIN L 21" an example is given for taking samples. If the piece of fabric is not large enough for this scheme, the more economical method according to Figure 7 may be employed. By this method considerably smaller pieces will suffice, which is advantageous, e.g., in cutting samples from airplane coverings.

According to "DIN L 21" the standard tensile sample is 5 cm (about 2 in.) wide and 30 cm (about 12 in.) long. Test samples of doped fabric can be cut just the right width, while samples of undoped fabric must have a margin of about 5 mm (0.2 in.) on each side, so that the transverse threads can project beyond the longitudinal threads. Otherwise the outside threads of the sample would not be uniformly stressed. The superfluous longitudinal threads may either be pulled out or cut at several points. In testing smaller pieces, these measures may be omitted. Foreign test specifications all call for shorter test samples and in some cases narrower. Dutch specifications, e.g., call for samples 20 by 5 cm (8 by 2 in.), British 7 by 2 in., American 6 by 1 in., and French only 10 by 5 cm (4 by 2 in.). The sample is given a certain preliminary tension in the clamping frame, and the load is very gradually increased. According to "DIN L 21" an advance of the lower clamp of 10 cm (4 in.) per minute is prescribed as the rate of loading. The load-elongation diagram is plotted either from the elongation read at definite degrees of loading or automatically by the testing mechanism itself. The breaking load of the sample is reduced to that of a strip 1 m (3.28 ft.) wide and designated as the tensile strength (kilograms per meter).

Failure normally occurs in the free portion of the test sample. A lateral tear indicates lack of uniform preliminary stressing. The corresponding breaking load is then generally much smaller than in a normal test. The results of such tests are not to be used in determining the mean value. In homogeneous fabrics, failure may occur simultaneously at several points, e.g., on both edges, but at different heights. Such tests yield good strength and elongation data and indicate uniform strength and clamping. In especially sensitive doped fabrics, failure occasionally occurs at the clamping points. This can be avoided by the interposition of strips of soft fabric next to the clamp cheeks.

For comparing different fabrics with one another, the "breaking length" (km) is introduced as the criterion. For woven fabrics this means the quotient of the tensile strength (kg/m) divided by the unit weight (kg/m²). In judging the fabric, care must therefore be taken that the breaking length in both directions is as high as possible, because, by a corresponding choice of the yarn, the breaking length can be increased in one direction at the expense of the other.

The tensile strength is also the criterion for the deterioration of the fabric characteristics from weathering. Here two factors should be distinguished, the effect of light and the effect of moisture in the presence of air. These two effects are superposed in the case of an unprotected fabric. Either effect may exceed the other according to climatic conditions. Hence a medium, which affords excellent protection against light but not against moisture, may succeed in one vicinity and fail in another. The British experiments under greatly differing climatic conditions are interesting in this connection. (Reference 12.) For German conditions, Sommer's experiments yield interesting conclusions. (Reference 13.) It was found that cotton is more durable than linen, which is comprehensible from the production processes of the two materials. In Figure 8 the loss in tensile strength is plotted against the exposure time. The effect of the light is shown more clearly, however, when the loss in strength is plotted against the number of hours of exposure to sunlight. (Fig. 9.) (In comparing the curves, however, it must be borne in mind that the cotton and silk fabrics used in the tests were of lighter weight than the linen fabric.) The most harmful wave lengths of the sun's spectrum are between 3,100 and 3,900 angstrom. (References 17 and 18.) The light protection must therefore be especially effective against these wave lengths. According to British and German tests, we can figure for our climate an annual strength loss of about 10 per cent in well-protected fabrics. With transparent varnishes or dopes an annual strength loss of 50 per cent and more has been observed.

3. Testing the Tautness, Elastic Behavior and Bursting Strength

The testing of these characteristics avails only for doped fabrics, in which the characteristics of the fabric and dope cooperate. The tautness can be determined in various ways, two of which are described by Pröll. (Reference 2.) One method is based on the height of rebound of a small steel ball which is dropped on the fabric from a given height in a glass tube. The other is a pressure method, in which a rounded stamp is pressed against the taut fabric. An instrument developed during the war by Bayer and Company of Elberfeld is based on a similar principle. The fabric is clamped between two conical rings with a given preliminary tension. By additional loading the same impression is produced in the doped fabric as in the undoped fabric and the ratio of the two loads is taken as the measure of the tautness. This method is suitable for comparative tests, because it is simple and quick.

The British specifications for airplane doping (reference 14) utilize an experimental arrangement in which the samples are stressed by air pressure and the deflection is determined by a "test clock." A negative pressure of 1 inch water column (0.0025 atm. gauge pressure) is produced under the fabric and the radius R of the resulting concavity in the fabric is measured with the help of a superposed ring. The radius R is calculated on the assumption of a spherical depression according to the simplified formula $R = D^2/8f$, in which D is the diameter of the ring and f is the central depression. The tautness T is obtained from the formula $T = Rp/2$, in which p is the test pressure.

For air-dried samples the tautness should be between 0.45 and 0.89 kg/cm (2.52 and 5 lb./in.). After the sample has been kept two hours in air having a relative humidity of 95 per cent, the tautness should be at least 0.36 kg/cm (2 lb./in.). This method seems to be based on the experiments of Aston. (Reference 15.)

The apparatus shown in Figure 10 for the determination of the elasticity and bursting strength is based on the same principle. It consists of a square iron pressure basin with connections for compressed-air pipes and manometer. The frame, over which the doped fabric is stretched, is secured to the top of this basin (with the interposition of packing) by strong screw clamps. The load is produced by compressed air in definite stages. The deflections in the middle of the frame are recorded by a test clock. By using indicators for different pressures (water, mercury, and spring manometers), tautness, elastic behavior and bursting strength can be successively determined with one and the same frame.

The elasticity of the doped fabric is tested by graduated loading and unloading on a definite fundamental tension. The difference between the total and permanent deflections gives the elastic or temporary deformation. On account of the temporary after-effects, the readings are made only after the pointer of the test clock has come to rest. The tautness of the fabric is proportional to the total deflection and its elasticity to the temporary component of the deflection. In a good covering, the elongation characteristics of the fabric and of the dope film must be similar. If, for example, the fabric is too extensible as compared with the dope, a noticeable increase in the permanent elongation will occur under relatively small stresses. In brittle films small cracks will form, and the covering fabric will become permeable to air. If the adhesion is poor, the film will separate from the fabric in many places.

After the conclusion of the elasticity test, a thin rubber membrance was laid under the fabric and the pressure was gradually increased until the fabric burst, the bursting pressure, course of the tear and the adhesion of the dope film being noted. Good fabrics usually tear in both directions, and good dope does not separate from the fabric after bursting. This method is particularly adapted for investigating the effect of moisture and weathering on the tautness.

4. Tearing Tests

Tensile and bursting tests determine to a certain degree the strength of the fabric as a whole. For practical use, however, there must be a certain local strength, to enable the transmission of the stresses at the seams and points of attachment. Moreover, as already mentioned, there must be some security against the tearing of the wing or fuselage covering in case of accidental injury during flight. On military airplanes where such injuries are very liable, the tearing strength is very important.

According to Turner (reference 16), a tear, once started, may be propagated by the surface pressure or by local stresses. In the first case, the resistance of the fabric is principally a function of the stress distribution at the edges of the tear. If the threads next to the tear are relieved by threads farther away, the tearing strength is correspondingly higher. It corresponds, in this case, to the strength and elasticity of the yarn. In the second case, the shearing strength of each thread and its position in the fabric are involved, in so far as a certain movability of the threads permits them to be torn in groups instead of singly. Any displacement of the threads is largely prevented, however, by the tension of the fabric and by the dope film.

The testing methods correspond to these two possibilities of tearing. The bursting test of a framed piece of fabric with slits cut in it corresponds to the first case. In this test, slits of a given length and arrangement (simple or cross slits) are cut in the fabric and the reduction in the bursting pressure, as compared with the undamaged fabric, is determined. The loss in strength naturally depends on the ratio of the size of the injury to the size of the sample. According to the tests of Walen (reference 8) with grade A American cotton fabric, the bursting pressure was reduced from 1.3 to 0.4 atm. gauge pressure by cross slits 1 inch long, and to 0.22 atm. by simple slits 2 inches long.

The "wound test" followed the normal tensile test. In this test a slit was previously cut in the center of the test strip perpendicular to the line of pull. (Fig. 11.) The tearing strength, defined as the breaking load with respect to the supporting width, depends on the ratio of the length of the slit s to the width of the strip b, that is, for very wide strips and short slits a limit is reached, below which the tearing strength is not affected by the length of the slit. The fabric widths used in airplane coverings and the possible injuries from projectiles are below this limit. In this connection, it is advisable to test various ratios of $s : b$.

The strength characteristics of the separate threads are exhibited still more clearly in the following methods of testing than in this one, the simplest method being the one which imitates the tearing of the fabric by hand. For this purpose the sample is cut a certain distance (fig. 12) and the two ends are pulled apart. This method has the advantage of simplicity. On the other hand, it has the defect that the transverse threads are without tension and can be somewhat displaced under some conditions.

For this reason the wound test has been quite commonly replaced by another form of the tearing-strength test, called the "tongue test." In this test a rectangle is cut on three sides at or near the center of the sample. (Fig. 13.) The lateral tension can be obtained either by stretching the sample on a frame or by some special device during the test. The forces required to continue the tear are then recorded and the mean tearing strength thus determined. The samples are so selected that in some of them the warp is torn and in the others the filling is torn.

The two tests can be combined by cutting the tongue diagonally to the direction of the threads. Figure 14 shows an apparatus which can be used both for the normal and the diagonal tongue test. It consists of an angle frame, in which the fabric is clamped parallel to the threads. The free edges are looped and the fabric is given a certain preliminary tension by means of weights. Slits 5 cm (2 in.) long are cut in the sample at a certain distance from the clamped edges, and the corresponding triangular tip is held in a clamp. The force required to break the threads is measured with a spring balance and plotted graphically. The diagonal test is based on the viewpoint that injuries often take a triangular course, showing that the warp and filling in doped fabric support each other to a certain degree. Subsequent values for the tearing strength of different samples are determined in this manner. If it is desired to test the warp or filling separately, the frame is rotated 45°.

5. Other Testing Methods

Among the initial requirements there were some which are now fully met by the dopes and covering fabrics, so that no special test is necessary. This applies especially to air and water-tightness. The air-tightness can be judged by the bursting test. It can now be required of good dopes that, when newly applied, they shall show no appreciable lack of tightness up to 2.5 m (8.2 ft.) water column.

The roughness or smoothness is preeminently a question of the dope used and the manner of its application. Accurate measurements have hitherto been made in only a few cases, one being generally satisfied to judge from superficial appearances.

The methods thus far described are only for laboratory tests and are not so suitable for testing coverings on airplanes. They require the removal of samples and considerable time for their execution. It would pay to develop devices for testing in a simple manner the tautness and strength of fabrics on airplanes. The method proposed by Schubert (reference 19) appears quite feasible. The A. J. Amsler Testing-Machine Factory is making a machine for determining the strength of airplane fabrics according to Breuil, under the designation "Perforameter," with which a small spherical stamp is pressed through the fabric and the required force is recorded on a spring balance. This machine can also be used to determine the tautness.

VI. RESULTS OBTAINED WITH VARIOUS COVERING FABRICS

We will give a few of the results obtained with various covering fabrics and especially with linen fabrics. The experiments were made for the purpose of obtaining data on fabrics lighter and heavier than standard linens according to DIN L 21.* The characteristic data of the fabrics are given in Table I. All the fabrics were unbleached.

1. Delivery Condition

Sample 1 (fig. 15) corresponds to the standard airplane linen according to DIN L 21. It is rather closely woven. Its unit weight is a little greater than the maximum standard weight, but this can be disregarded in view of its great tensile strength, which is much greater than the stipulated minimum strength. The mean breaking length of about 11,000 m (36,089 ft.) is to be designated as the standard for linen fabrics.

Sample 2 is a similar linen whose unit weight has been reduced to about 110 g/m² (3.24 oz./sq.yd.) without diminishing the tensile strength. This was accomplished by using finer yarn, specially selected for its strength. The breaking length was thus increased to over 13,000 m (42,651 ft.). For quantity production, however, this fabric is of less importance, because of the limited supply of such high-

*The linen samples came from the A. W. Kisker Company, Bielefeld, Germany, which has taken an active part in the development of airplane fabrics.

grade yarn. In appearance, it is chiefly distinguishable from sample 1 by the greater uniformity of the yarn. Sample 3 represents the same fabric made from standard yarn. It weighs the same as sample 2. Its strength is smaller as compared with sample 2, corresponding to its reduction in weight as compared with sample 1, so that an intermediate breaking length of 11,300 m (37,073 ft.) is obtained. The weave seems a little lighter than that of sample 1.

Another way to reduce the unit weight was adopted with sample 4, in which the thread number per centimeter was reduced about 20 per cent in both directions as compared with the standard fabric, the same size of yarn being used. Though the weight was not reduced in the same ratio, this was due to the fact that the yarn was woven in the raw condition, while the yarn for the previous samples had been boiled. Therefore its tensile strength was relatively somewhat greater. This fabric, notwithstanding its being 25 g/m² (.737 oz./sq.yd.) lighter than the standard fabric, still satisfies the standard strength requirements. The smaller number of threads, as compared with the other samples, produces a more open weave. (Fig. 16.)

The next two samples belong to the category of heavy fabrics. Sample 5 is a fabric of the kind somewhat used in Germany toward the end of the war and which is even now prescribed in many countries. (See Table V.) Its mean tensile strength is about 2,000 kg/m (112 lb./in.) and its elongation is less than that of the standardized fabric, due to the smaller number of threads. Sample 6 is more than twice as strong as the standard fabric. In order not to be obliged to use still coarser yarn and thus produce a thicker and rougher fabric, the Panama weave was adopted, in which the threads are used in pairs. It was thus possible to increase the number of threads to 40/cm (about 100/in.). Despite its great strength, this fabric weighs only 223 g/m² (6.58 oz./sq.yd.).

Sample 7 represents the fine light cotton fabrics much used for the coverings of sport airplanes with low wing loading. Its strength is only about half that of the standard fabric, but its weight is not proportionately less, so that its breaking length is less than 7,000 m (22,966 ft.). This is rather small, since ordinary cotton fabrics have breaking lengths of 9,000 to 12,000 m (29,527 to 39,370 ft.). This fabric has therefore not been developed to its maximum strength. In contrast with linen fabrics, the elongation is greater in the direction of the filling than in that of the warp.

The last sample, an artificial viscose silk, is really not a covering fabric. It was included in the tests, however, in order to discover how it is affected by doping. The fabric is still lighter than cotton fabric, weighing only 85 g/m² (2.51 oz./sq.yd.), but somewhat stronger than sample 7. In contrast with the other fabrics, the slight twist of the yarn and the smoothness of the surface are noticeable. The fabric is consequently very soft.

2. Characteristics after Doping

It is interesting to note how differently the fabrics are affected by doping. All the fabrics were treated alike and simultaneously. Stretched on wooden frames with about 10 kg/m (6.72 lb./ft.) preliminary tension, they were painted with two coats of "Perluco Red" (undiluted) and two coats of "Perluco Silver." This method was adopted first, because it afforded a good protection and secondly, because the layer of dope is not so thick as seriously to affect the properties of the fabrics.

All the fabrics were perfectly doped, the thin ones being thoroughly impregnated, while the thicker ones were not impregnated to the same degree. The strength tests were made about three weeks after the application of the last coat, the samples having been kept at normal humidity for a long time before the beginning of the tests. Tables II and III contain the results obtained with the doped fabrics, while Table IV summarizes the changes in weight and strength. The tearing-test data, as already mentioned, are the results of diagonal stressing.

The standard linen is made about 84 g/m² (2.48 oz./sq.yd.) heavier by doping and weighs about 225 g/m (6.64 oz./sq.yd.). The strength increment due to doping is not the same in both directions, being about three times as great in the direction of the filling as in that of the warp. It may be noted, however, that the increment in the strength of the filling is not normally so high. The strength increment does not correspond perfectly to the weight increment, for which reason the breaking length is reduced about 12 per cent by the doping. The breaking elongation is not affected in either direction by the doping, the tearing load having a mean of 4 kg (8.82 lb.) and a maximum of 6 kg (13.23 lb.).

In the doped condition, sample 2 does not retain its superiority with respect to the other samples. To be sure the finer yarns absorb less dope, and the doped fabric is therefore 42 g/m^2 (1.24 oz./sq.in.) lighter than sample 1, for which reason, however, the strength is increased only 24 to 27 per cent. Its breaking length of 10,000 m (32,808 ft.) is the same as for the other samples. Its tearing strength is about 1 kg (2.2 lb.) less than that of the standard fabric. This fabric shows that the evaluation of the fabrics must be on the basis of their properties in the doped condition. It is obviously purposeless to increase the cost by using specially selected yarns, when the finished covering is no better than other coverings made from standard yarns.

As was to be expected, sample 3 absorbed the same amount of dope, since it closely resembled sample 2. Likewise in this case the increase in the strength of the filling considerably exceeded that of the warp. The tensile strength in the direction of the filling approximates that of sample 2, while the tearing strength of sample 2 is somewhat greater, due to the better quality of yarn.

Sample 4 behaves better in this respect, the strength increment from doping being 30 to 48 per cent. Unfortunately the weight increment is likewise quite high, so that the difference, as compared with the standard fabric, is relatively less than in the original state. It is uncertain whether the condition of the yarn is affected by this relatively large absorption of dope. Judging from experiments with other fabrics, the effect is hardly worth considering. It is advisable, however, not to reduce the number of threads too much, both in consideration of the weight increment and of the danger of permeability of the dope film.

The thick heavy samples 5 and 6 have relatively the most favorable dope consumption. The impregnation is not so complete as in fine-threaded fabrics, but the strength increment corresponds approximately to the weight increment. Consequently, the breaking length is hardly reduced, contrary to the case with the previous samples. As regards tearing strength, samples 5 and 6 far surpass all the others. With sample 6 the peak loads exceeded the measuring limit of the apparatus, so that the mean tearing strength could be only approximately determined.

Both cotton and artificial silk can be readily doped. The increase in the strength of the Mako fabric is very pronounced, but it must be remembered that its original strength was rather small. The dope consumption is great with both these samples. It is surprising to find that these originally lighter fabrics are as heavy after doping as the corresponding samples 2 and 3. Despite this increase, their tensile strength is still considerably below that of the linen fabrics. The elongation, especially of sample 8, is considerably less than in the original condition, an indication that the stress preliminarily imparted to the fabric largely eliminated the shrinkage of the yarn. This is also manifest in the tautness of the doped fabric. Likewise the tearing strength of these samples is rather small, approaching the lowest permissible limit with the usual methods of sewing and attaching. In many cases it is advisable to reinforce the fabric at these points. The behavior of the fabric is shown by the difference between the mean and maximum tearing loads in Table III, as also by the course of the curves in Figure 17. The standard linen offers considerable resistance to tearing, while the cotton fabric behaves much like paper.

To sum up briefly the results obtained with these different fabrics, it may be said that increasing the strength of covering fabrics by using coarser yarns ordinarily offers no difficulty, because the weight increment from doping is relatively smaller. The case is different, however, when it is desired to use the lightest possible fabric with small strength requirements. With standard fabrics, the limit set by the requisite tearing strength is then soon reached. Some improvement can perhaps be attained by using doubled yarn instead of simple yarn, or by other methods of weaving. Otherwise these peculiarities of the fabric must be taken into account in attaching the coverings.

TABLE I. Properties of Undoped Fabrics (mean values)

Sample	Material	No. of threads per cm		Weight g/m^2	Tensile strength kg/m		Elongation per cent		Breaking length m		Mean
		warp	filling		warp	filling	warp	filling	warp	filling	
1	Linen	33	35	141	1470	1620	12.5	7.0	10,400	11,500	11,000
2	"	35-36	33-35	109	1440	1460	7.5	6.7	13,200	13,400	13,300
3	"	33	33-35	109	1165	1290	8.4	6.0	10,700	11,900	11,300
4	"	27	30	114	1285	1570	8.1	5.2	11,300	13,800	12,600
5	"	23	22	173	2170	1920	7.1	7.0	12,500	11,100	11,800
6	"	20x2	20x2	223	2650	3025	9.0	6.2	11,900	13,500	12,700
7	Mako cotton	41	44-46	97	660	665	8.3	17.0	6,800	6,900	6,800
8	Artificial silk	33	26	85	890	715	19.1	15.1	10,500	8,400	9,500

(g/m^2 x .029493 = oz./sq.yd.) (kg/m x .0559977 = lb./in.) (cm x .3937 = in.) (m x 3.28083 = ft.)

TABLE II. Properties of Doped Fabrics (mean values)

Dope: 2 priming coats of "Perluco Red"; 2 finishing coats of "Perluco Silver"

Sample	Material	Weight g/m^2	Tensile strength kg/m		Breaking elongation per cent		Breaking length m		Mean
			warp	filling	warp	filling	warp	filling	
1	Linen	225	1780	2565	12.5	6.5	7,100	11,400	9,700
2	"	183	1830	1815	7.9	6.5	10,000	9,900	10,000
3	"	181	1460	1840	8.5	5.9	8,100	10,200	9,200
4	"	200	1665	2315	6.8	6.8	8,300	11,600	10,000
5	"	250	2665	2660	8.1	8.4	10,600	10,600	10,600
6	"	297	3150	4010	10.8	11.2	10,600	13,500	12,000
7	Mako cotton	199	1405	1270	10.6	13.8	7,100	6,400	6,800
8	Artificial silk	183	1245	1115	12.1	10.5	6,800	6,100	6,500

TABLE III. Tearing Strength of Doped Fabrics

Sample	Material	Load in kg maximum	Load in kg mean	Resulting tear
1	Linen	6.2	4.4	Chiefly in warp
2	"	5.1	3.4	Chiefly in filling
3	"	4.1	2.8	In both directions
4	"	5.0	3.0	Chiefly in warp
5	"	9.6	6.8	Diagonally
6	"	10.0	9.5	Chiefly in warp
7	Mako cotton	2.8	2.2	In both directions
8	Artificial silk	3.2	2.4	In both directions

TABLE IV. Change of Properties from Doping (mean values)

Sample	Material	Weight increase		Increase in tensile strength warp		filling		Decrease in mean breaking strength	
		g/m²	%	kg/m	%	kg/m	%	m	%
1	Linen	84	60	310	21	950	59	1,300	12
2	"	74	68	390	27	350	24	3,300	25
3	"	72	66	300	26	550	43	2,100	19
4	"	86	75	390	30	750	48	2,600	20
5	"	77	45	490	23	740	38	1,200	10
6	"	74	33	500	19	990	33	700	5
7	Mako cotton	102	105	750	113	610	92	0	0
8	Artificial silk	98	115	360	40	400	56	3,000	32

TABLE V. A Few Specifications for Covering Fabrics

Source	Fabric	Material and treatment	Yarn number (British) warp	Yarn number (British) filling
DIN L 21 Germany	Airplane linen	Linen yarn, lightly boiled	80-90	100-110
Air 5010 Specifications of French Air Ministry	Linen M (medium strength) H (high ") T (very high ")	Linen	- - -	- - -
Br. Eng. Stand. Assoc. 5 F 1	4-oz. linen grade 1	Linen lightly boiled	80-90	95-105
4 F 8 Great Britain	Mercerized cotton airplane fabric, grade 1	long-staple cotton yarn, mercerized	2-57	2-57
Dutch military specifi- cations for military airplanes C1	Linen	Linen	-	-
U.S. Army Signal Corps 16,003-B, U.S.A.	Airplane linen Grade A " B	Unbleached linen	- -	- -
U.S. Army Specifications No. 6-97-A	Airplane fabric mercerized cotton, Grade A	Long-staple cotton yarn, mercerized	2-60 ±4	2-60 ±4

TABLE V. A Few Specifications for Covering Fabrics (Cont'd)

Source	No. of threads per cm		Weight g/m²		Tensile strength (kg/m)					
					air-dry		wet		doped	
	warp	filling	dry	air-dry	warp	filling	warp	filling	warp	filling
DIN L 21 Germany	30-35	33-38		140	1200	1350			1600	1800
Air 5010 Specifications of French Air Ministry	28-31	28-31	140	154			2000	2000		
	28-31	28-31	190	210			3000	3000		
	21-24	21-24	270	300			4000	4000		
Br. Eng. Stand. Assoc. 5 F 1	31	35		136			1600	1600		
4 F 8 Great Britain	31-33	31-33		153			1425	1425		
Dutch military specifications for military airplanes Cl	20-30	20-30	160				1600	1600	1600	1600
U.S. Army Signal Corps 16,003-B, U.S.A.	35-41	35-41		153	1340	1340				
	23-35	23-35		153	1160	1160				
U.S. Army Specifications No. 6-97-A	31-33	31-33		153	1425	1425				

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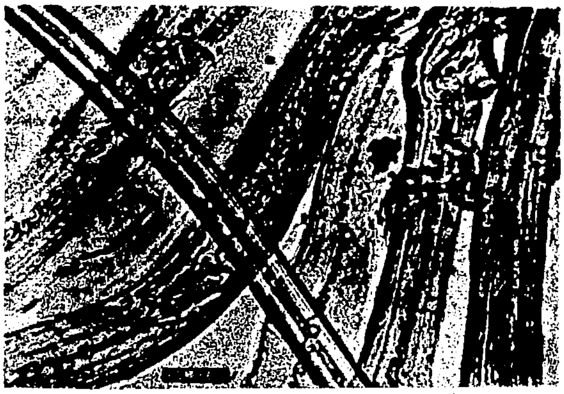

Fig. 1 Flax fibers swollen in copper ammonium oxide. V = 400.

Fig. 2 Cotton fibers swollen in copper ammonium oxide. V = 400.

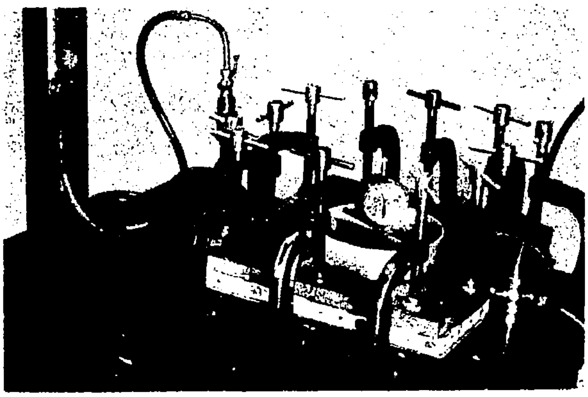

Fig. 10 Apparatus for determining tautness, elasticity, and bursting strength of fabric.

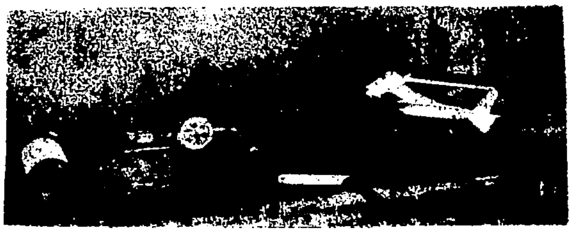

Fig. 14 Apparatus to determine tearing strength.

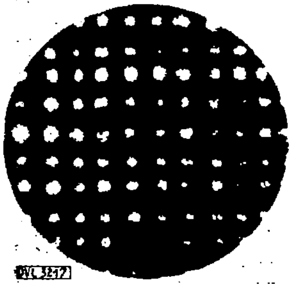

Fig. 15 Structure of sample 1 (standard linen) V = 25.

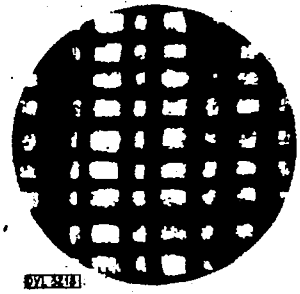

Fig. 16 Structure of sample 4 (linen) V = 25.

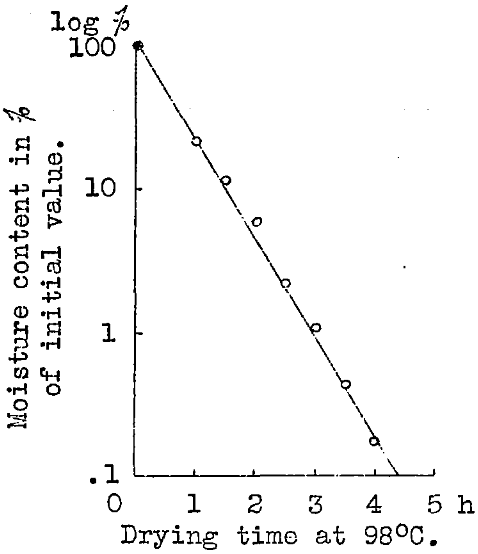

Fig. 3 Loss of moisture of a linen fabric from artificial drying.

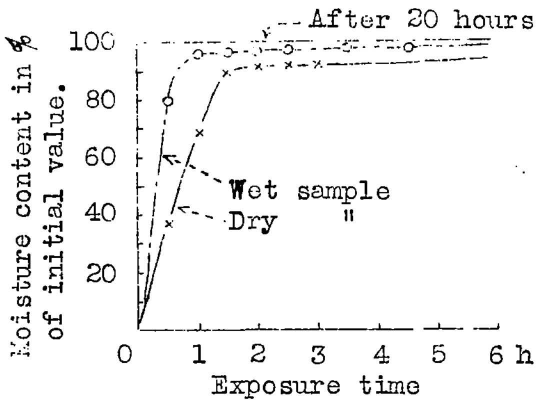

Fig. 4 Loss of moisture of a wet and of a dry linen sample at standard atmospheric humidity.

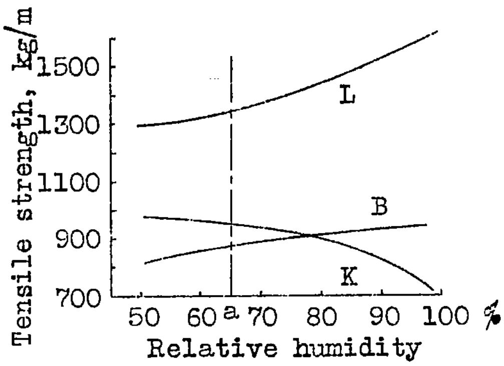

Fig. 5 Tensile strength (kg/m) of a linen (L), a Mako cotton (B) and a viscose artificial silk (K) plotted against the relative atmospheric humidity.

a, Normal humidity

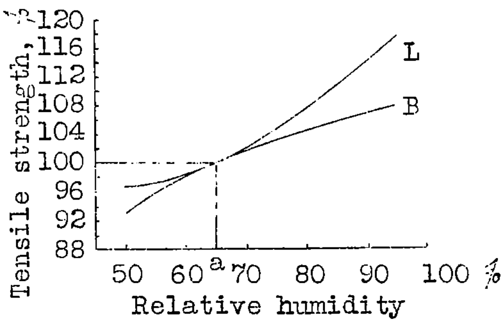

Fig. 6 Percentage variation in tensile strength of linen (L) and Mako cotton (B) at various atmospheric humidities.

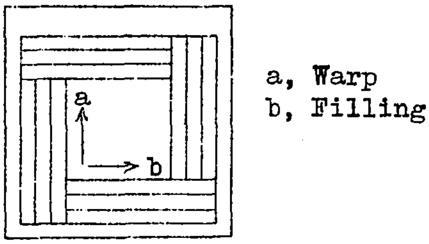

Fig. 7 Most economical method of cutting fabric samples.

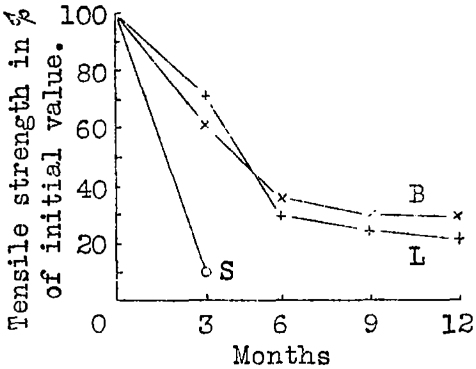

Fig. 8 Percentage loss in tensile strength of a linen (L), a cotton (B) and a natural silk (S) from weathering (according to Sommer).

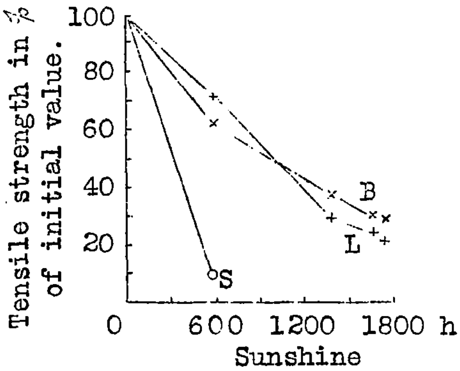

Fig. 9 Percentage loss of tensile strength of fabrics plotted against hours of sunshine (according to Sommer).

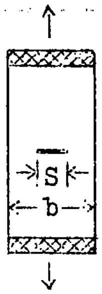

Fig. 11

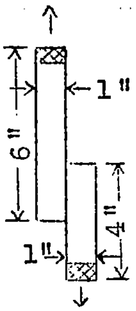

Fig. 12

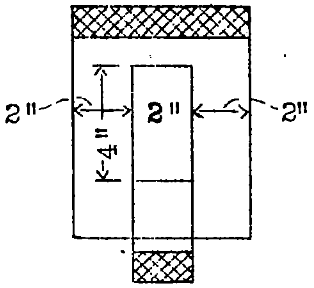

Fig. 13

Fig. 11 Form of sample to determine tearing strength. (Slit test)
Fig. 12 Form of sample to determine tearing strength (Tearing test)
Fig. 13 Form of sample to determine tearing strength (Tongue test)

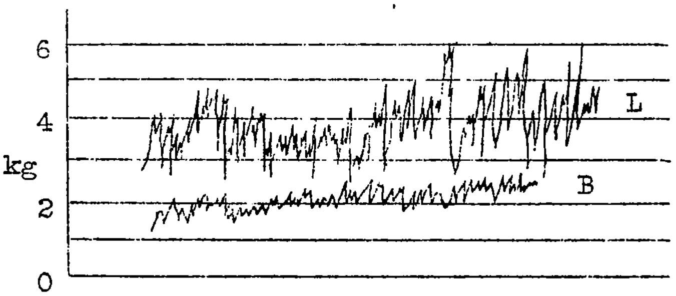

Fig. 17 Tearing curves for sample 1 (L) and sample 7 (B)