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THE STRUCTURE AND PROPERTIES OF PARACHUTE CLOTHS

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By H. J. McNicholas and A. F. Hedrick.

Abstract

The requisite properties of a parachute cloth are discussed and the methods for measuring these properties described. In addition to the structural analysis of the cloths, the properties measured are weight, breaking strength, tear resistance, elasticity, and air permeability. Thirty-six silk cloths of domestic manufacture, not previously used in parachute construction, are compared with some silk cloths of foreign manufacture which have been proved by trial and extended use to be suitable materials for parachute construction.

Contrary to the belief that domestic woven cloths were not suitable materials for parachute construction, it is shown that many domestic silk cloths are available which in all their properties are entirely satisfactory and in some respects superior to the foreign products.

Based on a comparative study of all the cloths, specifications are drawn for the manufacture of silk parachute cloths, using either the plain or the mock leno weave. These specifications have been accepted by the Navy Department, and service tests on full-sized parachutes made with the domestic woven

cloths have demonstrated the suitability of the specified materials.

The apparatus and methods employed and the information herein obtained are being applied in the development of a parachute cloth woven with some home-grown fiber such as cotton.

I. Requisite Properties of a Parachute Cloth

Along with the size, shape, and other aerodynamical characteristics of a parachute, the physical properties of the cloth used in its construction are of considerable importance in their relation to the performance under the various conditions of service.

As in all aeronautical materials, weight and ultimate strength are of paramount importance. A determination of the stresses in different regions of the parachute envelope is inherently difficult and calculated results are somewhat uncertain. Calculations by Mazer (Reference 1) indicate that the cloth is normally not subjected to excessive stress; yet it is realized that the maximum tensions may vary considerably with variations in the shape of the envelope, with local deformations, and in the region of the points of attachment. A slight deterioration of the thin cloth may decrease in strength considerably. For these reasons the strength requirements in parachute cloths are set to a fairly high value, in order to insure a wide margin of safety.

As part of the strength requirements the cloth must offer a high resistance to the continuation of a tear already started. Whereas breaking strength always applies to the simultaneous breaking of a system of yarns, the tear resistance is the resistance principally of one yarn at a time to a rupture traveling crosswise from yarn to yarn. In the construction of a parachute the gores or panels are usually cut on the bias, so that the warp and filling yarns make an angle with the seams running from the center to the hem of the parachute. In this way, if a tear is started, it follows along the direction of a yarn to the seam where the resistance is sufficient to prevent further rupture. Thus long rips which might run from center to hem of the parachute are prevented.

Other desirable characteristics of a parachute cloth are determined chiefly by its elastic properties. The parachute now universally used is the pack-on-aviator type with manually operated rip cord. Before use it is carefully folded and held compressed in a suitable container. Its quick and positive opening, when released from the container, is deemed to depend largely on the ability of the layers of cloth to spring apart along the folds, thus permitting air to rush in and quickly inflate the envelope. The degree to which a given cloth exhibits this desired property depends on its elastic reaction under flexure. A low permanent set in the folded cloth and a high potential energy of deformation (resilience) are both desirable properties.

The falling parachute opens with a snap followed by a sudden change in the momentum of the system. This change is the result of the impact of air against the parachute envelope with sudden rise in the pressure difference between the under and upper surfaces. We have

$$Ft = MV_1 - MV_2$$

where the right-hand member of the equation is the change in momentum, and the left-hand member is the product of the impulsive force, or "shock," by the time during which it acts. It has been stated by Mazer (Reference 1, page 13) that the magnitude of the opening shock depends chiefly on the shape of the parachute, on the speed with which it opens, and on the speed of the airplane. Definite information is apparently not available regarding the relative importance of some other factors which may contribute appreciably to the reduction of the shock. Obviously, the shock is small when t in the above equation is large; and t depends very much on the elasticity of the system as a whole, including that of the surrounding medium. The time lag in the establishment of the maximum pressure difference between the under and upper sides of the envelope, and in the formation of the steady flight conditions of air flow about the envelope, results in a cushioning action which reduces the magnitude of the shock. Some of the kinetic energy of the falling parachute is transformed into kinetic and potential energy of the surrounding medium. The effect will depend largely on the geometrical form and construction of the envelope. Furthermore, as the pressure difference and air flow are being established, tensions are set up in the parachute structure with resulting stretch of the materials. The stretching of the cloth (and shroud lines) tends to distribute the sudden load more uniformly over the envelope and requires the elapse of a short time interval before the maximum load is taken up. Thus, the elasticity of the cloth may not only assist in the reduction of the opening shock, but it also tends to prevent the development of excessive stresses in any region of the envelope. The expansion of the whole envelope is augmented by the springy action of the vent, which is made flexible and capable of considerable extension under load.

Leakage of air through the cloth has also been regarded as a factor in the reduction of the opening shock, as well as in the determination of the velocity of steady descent. In regard to the latter effect, some experiments to be described definitely indicate that the leakage, or air permeability of the cloth has, within a wide range of permeability, a negligible effect on the velocity of steady descent. This velocity is primarily a function of the size and shape of the envelope. It seems possible, however, that the leakage may appreciably retard the development, and decrease the maximum value, of the pressure difference between opposite sides of the envelope, thus aiding to some degree in the reduction of the shock.

The change in kinetic energy following the opening of the parachute reappears largely as potential energy of strain in the system. Tests have shown (Reference 2) that an ordinary service parachute is sometimes subjected to a shock load of more than 2000 pounds, which may be taken up by the parachute a time interval of less than 1 second (Reference 3). It is probable that the time involved in the reaction of the various elastic forces, and the corresponding capacities for energy absorption, are also pertinent matters for consideration.

In the present status of the parachute problem it is not definitely determined to what degree each of the above-discussed properties of the cloth contributes to the proper performance of the parachute. There is no adequate theoretical or experimental basis for the accurate definition of the limits of tolerance permissible in a specification of the physical properties. In a consideration of these problems it is evident that more reliance must be placed on methodical experiments and successive trials than on calculations. The accurate judgment of the value of any particular material entering into the construction of the parachute may involve numerous tests and expensive experimentation. Little progress in this direction has been made.

Properties of the cloth which may be determined readily and are most likely of importance in their relation to the performance of the parachute, are as follows:

1. Weight
2. Strength
   (a) Breaking strength
   (b) Tear resistance
3. Elastic properties
   (a) Tension - stretch relation
   (b) Recovery from flexure. Permanent set and resilience.
4. Air permeability

II. Purpose and Scope of the Present Investigation

At the beginning of this investigation it was the consensus of opinion in aeronautical circles that domestic woven cloths were not suitable for parachute construction. All the cloths used were of foreign manufacture. Inasmuch as the life of the aviator may depend on the faultless performance of the parachute, there was naturally a reluctance to depart from established usage in this respect. At the request of the Bureau of Aeronautics, Navy Department, the Bureau of Standards undertook the development of specifications for a silk parachute cloth which could be readily manufactured in this country and would compare favorably with the foreign product in all the requisite physical properties.

As a basis for the development of tentative specifications, a study was made of the degree to which the requisite properties were exhibited by the cloth which had been proved by trial and extended use to be suitable materials for parachute construction. With this approximate specification of the physical properties, thirty-six different silk cloths of domestic manufacture were examined to ascertain as nearly as possible their suitability for parachute construction. It will be shown that domestic woven fabrics are available which are entirely satisfactory and in some respects superior to the foreign product.

As a raw material for the construction of parachute cloths, silk exhibits to a higher degree than other natural fibers all the desirable properties. Its greatest disadvantage lies in the matter of cost and in the availability of the raw materials. Although several attempts have been made to cultivate the silk worm in this country, the high labor costs involved in handling the cocoon have prevented the rapid advancement of the industry. The methods of measurement to be described herein are being applied (with some improvements) in the development of a suitable cloth woven from a home-grown fiber, thus obtaining eventually an entirely domestic product. It has been found, for instance, that cotton may be treated to enhance some of the desired qualities. The progress of this work will be given in a future report.

III. Description of Cloths and Their Construction

The materials studied, with their constructional features, are listed in the accompanying table. Sample A is the Japanese Habutai cloth which has been generally used in parachutes of the U.S. Air Services. Sample B is material taken from a "Guardian Angel" parachute (foreign cloth). Samples C and D are domestic woven cloths used for repairing the Navy parachutes. These four materials, then, give some indication of the requisite properties of a parachute cloth. Although used with a certain degree of satisfaction, they have been regarded as possessing certain weaknesses wherein improvement could probably be made. Samples A and B have a rather low breaking strength in the warp direction, and samples C and D have a low warp stretch. Up to the time of this investigation the remaining samples had never been used in parachute construction; they were submitted by various domestic manufacturers in the interest of the present investigation. In this connection appreciation is expressed for the cooperation of the Belding Mills; Cheney Brothers; the Duplan Silk Corporation; Follmer, Clogg and Company; Julius Kayser and Company; the Russell Parachute Company; Schwartzenbach, Huber and Company; and also for the assistance of the Bureau of Foreign and Domestic Commerce, and the Bureau of Aeronautics in obtaining these cloths.

Five different weaves are represented in the group. The plain weave is the simplest type of weave wherein each yarn goes alternately over and under the cross yarn. The cross-barred weave is the plain weave with a cross-bar effect introduced by extra heavy yarns spaced about 1 inch both in the warp and in the filling directions. The warp-knit cloth differs from the ordinary knit in that it is made from a series of yarns forming a warp and knitted in such a way that these yarns run lengthwise in the fabric, whereas the yarns in the ordinary cloth run crosswise. The cloth is actually a series of chains, so bound together that it cannot ravel from a dropped or broken stitch. In the mock leno* weave the center yarn of each group of three yarns goes over three cross yarns and under one; whereas the two outer yarns of each group go under one and over one as in the plain weave. The pattern is thus complete in six warp ends and six filling picks and is symmetrical with respect to the warp and filling directions. Each group of three yarns is woven close to the next without being separated by small intervening spaces, as is done in some mock leno weaves by leaving a certain number of dents empty in the loom when an open effect is desired. The letter "a" in the table indicates the original mock leno weave, and variations are denoted by letters "b" to "e." A photomicrograph of the mock leno weave, closely woven for parachute use, is shown in Figure 2.

*This weave has sometimes been referred to erroneously as a basket weave. Even the term "modified basket weave" is mesleading. It is essentially the mock leno weave which has been extensively used in the manufacture of cotton dress goods, men's shirts, curtains, imitation gauze, etc.

The procedure followed in the analysis of the cloth structure is described in U.S. Government General Specifications No. 345-a. It is found that a uniformly low twist is used in all the cloths tested, both in the binding of the individual silk filaments in the single thread and in the binding together of the threads in the yarn. Only enough twist is used, apparently, to keep the yarns from separating into the component filaments. The size of each single thread is given in the table and expressed in terms of a definite length of thread (denier measure). It was not considered necessary to extend the yarn analysis to all the cloths. All measurements were made on the degummed silk. To estimate the weight of silk before the gum was removed, 25 per cent of the given weight should be added. The degumming of the silk, and in general, the absence of any weighting or sizing, improves the quality of the material especially with respect to the elastic properties.

IV. Measurement of Physical Properties

The methods employed in the determination of weight, breaking strength, tear resistance and stretch, are standard test procedures used by the Bureau of Standards in the general testing of all kinds of cloths. Special methods have been devised for measuring the air permeability and elastic properties under flexure. All tests were made on material having a normal moisture content, obtained by proper exposure to atmospheric conditions of 65 per cent relative humidity and 70°F.

1. Weight

In weight determinations a sample 2 inches square is cut with a die and weighed on an analytical balance. The weight is then expressed in ounces per square yard.

2. Strength

(a) Breaking strength.- Rectangular specimens, approximately 6 by 1-1/4 inches, are cut with the long edge either in the warp or in the filling direction, as desired. The specimens are then frayed to exactly 1 inch in width.

An inclination-balance type of testing machine is employed, having an autographic recording device which plots the tension-stretch curve up to the breaking point. The specimen is clamped between the jaws of the machine, which are each 3 inches in width and are initially separated by a distance of 3 inches (initial length of specimen under stress). When the machine is in operation the lower or pulling jaw moves at a uniform speed of 12 inches per minute (under no load), and the rising arm of the pendulum applies an increasing tension in the cloth until it breaks.

In the case of three cloths, which were knitted instead of woven and consequently could not be frayed at the edges, the "grab" method of test was employed. In this method the operation of the machine is the same as described above. The test procedure differs only in the method of mounting the specimen. The specimen is 6 inches long and 4 inches wide. The width of the back jaw of each set of jaws is 3 inches, as before, but the width of the front jaw of each set is now only 1 inch. Although the load is thus applied only over a 1-inch width of the specimen, there is a certain amount of "cloth assistance" contributed by the remainder of the specimen.

Ten warp tests and ten filling tests were made on each sample. The average breaking load per inch width of specimen is recorded in the table.

(b) Tear resistance.- In the measurement of tear resistance the specimens are cut as shown in Figure 1, with the long edge either in the warp or in the filling direction, as desired. A slit approximately 3/8 inch in length is cut in the specimen at the point S. With the jaws of the testing machine horizontal and separated by a distance of 1 inch, the test specimen is clamped on the diagonals AB and A'B'. The left-hand edge of the specimen is thus held taut between the jaws, but the remaining portion lays in folds. As the jaws of the machine are separated, then, with the customary speed of 12 inches per minute, the tear continues from the initial slit horizontally across the specimen.

The test is made on a sensitive autographic breaking strength machine, with the pawls of the pendulum fastened up so that the pendulum is free to move up or down in accordance with the load required to continue the tear. The automatic record of this varying load is given on a chart attached to the machine. Five tests were made across the warp system of yarns and the same number across the filling yarns. The average resistance of each sample is recorded in the table.

3. Elastic Properties

(a) Stretch.- The stretch is recorded in the test for breaking strength, by means of the autographic device previously described. The stretch at any tension up to the breaking load may be read directly from the chart. Inasmuch as the stretch is not proportional to the load applied, it is convenient to compare the values at some definite load. The maximum stretch at the breaking load is perhaps not a fair means of comparison, because the cloth in service is not usually subjected to such extreme conditions. A load of 20 pounds was chosen as being more representative of actual service conditions. The stretch at this load, in both the warp and the filling directions, is recorded in the table.

(b) Recovery under flexure.- In the following measurements it is only intended to simulate roughly actual service conditions in which a parachute is folded and compressed in a container and then released for use. With the release of the parachute the folds spring apart, permitting air to enter between the folds and rapidly inflate the envelope.

The device employed is shown in Figure 3. A fold of the cloth F is placed upon a horizontal platform, which may be raised or lowered by means of a rack-and-pinion arrangement and its vertical position read on a suitable scale. The upper part of the fold bears against the circular weight holder C, which is 5/8 inch in diameter and hangs freely from the balance arm D. Under the initial conditions of the test, the weight holder is balanced by the counterpoise, and its under surface is just in contact with the fold of the cloth. A load is applied by moving the rider R or by adding weights to the holder, thus destroying the balance of the arm. By raising the platform, then, the radius of the fold is decreased until the balance of forces is again restored. The various heights of the platform are recorded as definite increments of load are added until the fold is bent flat on itself. Weights are then removed, again in definite steps, and the degree of return of the fold to its initial state is recorded. A uniform procedure in loading and unloading was employed for all the specimens.

The standard size of sample adopted is a rectangular strip 9 inches long and 3 inches wide, the long edge being cut in either the warp or the filling direction. The fold is carefully formed by laying the specimen on the platform and bringing it back on itself until the ends are even. The specimen is adjusted with the center of the fold approximately under the center of the weight holder.

Some illustrative data obtained in this way are given in Figure 4. Two silk cloths, one a plain weave and the other a mock leno weave, are chosen to represent the maximum variation among the silks. Comparative data are also given on a cotton cloth of approximately the same weight and yarn count. Only the parts of the compression and return curves between loads of 0 and 2.2 grams are presented in the figure, although the loading process was continued until the fold was flat on itself. The plain weave cloth (Curve B B') shows a 67 per cent recovery from the compression. The mock leno weave cloth (Curve C C') shows a 61 per cent recovery, whereas the recovery of the cotton cloth is only 40 per cent. It may be noted that at return loads down to approximately 0.6 gram the force tending to open the cotton fold is comparable with that of the silks; but there is a considerable permanent set in the cotton yarns which prevents a return to the original form proportionate to that shown by the silks. The potential energy of strain, or resilience, of the deformed cloth is represented by the area under the return curve. In general the animal fibers are more elastic and pliable than the vegetable fibers. Thus silk and wool are easily bent under a small load and recover readily, whereas cotton is stiff, requiring a greater load to bend it and remaining creased when the load is removed.

The apparatus described was assembled from parts conveniently at hand. It is not applied in this work for differentiating definitely between various silk cloths, or for use in specifying the elastic properties. Improved equipment for these purposes is planned. Owing to the inherent and characteristic elasticity of silk, all the silk cloths herein compared are presumably satisfactory in this respect for parachute use. Hence no results of this test are included in the table. The apparatus has served a useful purpose as an aid in the development of a suitable parachute cloth woven from cotton yarn. Relations which may be obtained between the load, deformation, and permanent set, furnish a basis for comparing in different cloths the effect of various chemical treatments and other factors which may prove of interest. The ability to recover from long-continued flexure is also a desirable characteristic of parachute cloths which may be investigated in like manner. Again silk leads the other natural fibers in this respect.

4. Air Permeability

The apparatus used for the air permeability measurements is shown in Figure 5. Air from the compressed air line L passes through the gas meter M into the box A, and thence through the specimen which is mounted over an opening S in the top wall of the box. By means of an arrangement of clamps and spring balances (not shown in the figure), the specimen is held over the opening under a tension of approximately 0.2 lb. per sq.in., both in the warp and in the filling directions. An annular-shaped metal plate, held by the clamps C_1 and C_2, presses the cloth gently against the edge of the opening, thus forming an approximately air-tight junction between the cloth and the box. To keep the flow of air through the system always within the capacity of the gas meter (600 cu.ft. per hr.), the diameter of the outlet may be changed from 6 inches to 2 inches, as required.

The pressure take-off P is mounted just below the edge of the 6-inch outlet and is connected directly to a water manometer. A cathetometer K is used to read the water level in the manometer tube G. The cross section of the reservoir W is so large in comparison with that of the tube G that the variations in the water level of this reservoir are negligible.

After a steady flow of air at a chosen pressure difference has been established, the rate of flow is determined by readings of the gas meter and a stop watch. The air permeability at the given pressure difference is expressed in cubic feet per minute per square foot area of the specimen. For permeability values greater than 30, the 2-inch opening was used. The measurements were made over a pressure range (in Box A) of from 0.1 to 5.0 pounds per square foot.

Data on samples A, C, S, and Q are shown in Figure 6. The high permeability of sample Q is the result of its porous construction. Curves for samples B, D, E, F, G, I, J, K, L, M, N, O, and W if plotted, would lie between the curves for samples A and C; curves for samples U, V, X, and Y would lie only slightly above the curve for sample A.

Air permeability, as above defined, may depend not only on the pressure difference between both sides of the cloth, but also on the absolute pressure (or density) on either side. In the present apparatus the pressure on the emergent side of the cloth is that of the surrounding atmosphere and is considered constant. As shown by the curves in Figure 6, the permeability is not strictly proportional to the pressure difference. Hence, for convenience in the comparison of the different cloths, only the permeability for a pressure difference of 1 pound per square foot is recorded in the table.

Although the conditions under which the permeability is herein measured are not strictly comparable with actual service conditions, the results, nevertheless, provide an adequate comparison of the different cloths with respect to the degree of porosity in their structure. In a direct application of the numerical results to any phase of parachute performance, these differences would perhaps demand further consideration.

V. Discussion of Data

Specifications for Parachute Cloth

A comparison of the structure and properties of the cloths brings out several points of interest.

As may be expected, the heavier cloths in general exhibit a higher breaking strength, although the latter property is also dependent on the quality of the fiber, on the type of weave, and on other constructional features such as relative size, count and twist of the warp and filling yarns. Cloths weighing more than 2 ounces per square yard are considered unnecessarily heavy for parachute use, because sufficient strength can readily be obtained in the lighter cloths.

The effect of weave on the tear resistance is graphically illustrated in Figure 7. For samples having the same breaking strength, the tear resistance of the mock leno weave is far above that of the plain weave. Only cloths woven with yarns of uniform size are included in this comparison; for the presence of an extra heavy yarn, for example, at definite intervals in the cloth, would considerably increase the average tear resistance and the effect would be confused with the true effect of the weave.

All cloths have been assigned to groups in accordance with their estimated suitability for parachute use. In Group I are included the cloths A, B, C, and D previously used in parachute construction. The cloths in Group II are considered too heavy. Those in Group III have a breaking strength below 40 pounds per inch, either in the warp or in the filling direction, or both, and are for this reason discarded. Exception is made, however, in the case of samples 2B and 2K. Although their warp breaking strength is low, their high filling strength makes them appear at least as satisfactory as sample A. In Group IV are cloths of low elasticity, having a stretch of less than 5 per cent under a load of 20 pounds. In Group V the air permeability is so high that these cloths would undoubtedly be unsatisfactory for this reason alone. All remaining cloths are placed in Group VI and are considered suitable materials for parachute construction. The large number of cloths thus obtained, all comparing favorably with the Japanese Habutai silk (sample A), shows conclusively that a satisfactory material can be woven in domestic mills.

Careful comparison of all the cloths with respect to breaking strength, tear resistance, and balance in strength and elasticity between the warp and filling directions, shows the superiority of the mock leno weave cloths over the imported and other domestic materials. Specifications were accordingly drawn for the construction of two cloths, one using the mock leno weave and the other the plain weave. These specifications* were based

*Material Specification for Silk Parachute Cloth. Revised edition C-37, December 11, 1928. Copies of the specification may be obtained by application to the Bureau of Aeronautics, Navy Department, Washington, D. C.

on the measured properties of all the cloths and have been accepted by the Navy Department.

The essential elements of the specifications are as follows (as per revision of December 11, 1928):

(1) The material used in the manufacture of the cloths shall be a natural unbleached white Japan, or the equivalent grade of China or Italian silk. Only one grade, known as firsts may be used in either the plain or the mock leno weave (called also the modified basket weave. See footnote, page 10). The cloth shall be thoroughly boiled to remove gums and greases and there shall be no sizing or weighting materials of any description present in the finished cloth. Excessive heating must not be applied in the finishing process, and in general the cloth shall be free from all imperfections affecting its strength or durability.

(2) The weight per square yard of the finished cloth shall be 1.55 ounces for the plain weave and 1.70 ounces for the mock leno weave, with a tolerance of ±10 per cent in each case.

(3) The yarns per inch in the warp and filling directions shall be 120 and 90, respectively, for the plain weave, with corresponding values of 96 and 105 for the mock leno weave. A tolerance of ±10 per cent is allowed for each of the counts.

(4) The minimum breaking strength in pounds per inch width shall be the same in the warp and filling directions. The permitted values are 45 pounds for the plain weave and 53 pounds

for the mock leno weave.

(5) The minimum tear resistance in the warp and filling directions shall be 3 and 5 pounds, respectively, for the plain weave, with corresponding values of 7 and 9 for the mock leno weave.

Other properties of the cloth are not specified. The prescribed methods for making the physical tests are essentially the same as described in Section IV of this paper.

Service tests were made on full-sized parachutes constructed of the mock leno weave (sample 5) cloth. A 200-pound lead weight was used in these tests, which were conducted by the Bureau of Aeronautics, Navy Department, at the Naval Air Station, Anacostia, D. C., on March 23, 1927. The tests included drops of 600 feet, at flying speeds of 60, 80, and 100 miles per hour. The parachutes withstood all the tests successfully and the velocity of descent was comparable with that of parachutes of the same type made of the Japanese Habutai cloth.

It may be noted (see table) that sample S has about twice the air permeability of sample A. The service tests showed, however, that the rate of descent of the parachutes constructed of these cloths is approximately the same. It thus appears that a considerable variation in the air permeability is permissible without appreciably affecting the velocity of steady descent. This conclusion is in agreement with some laboratory tests by Jones and Williams (Reference 4). These investigators conducted wind-tunnel experiments with plane models of the same size and shape (6-inch circular plates) but made of materials varying widely in the porosity of their structure. Tin, longcloth, muslin and silk (doped and undoped) were tried with no appreciable differences among the various materials in the "drag" for air speeds up to 60 feet per second.

The further development and refinement of the parachute involves problems which are essentially aerodynamical. The manufacture of suitable cloths for the envelope will progress on a more intelligent basis with more definite knowledge of the requisite properties of the cloth. The development of uniform and accurate specifications is of particular concern to the cloth manufacturer, who is obliged to supply materials with properties limited by the specifications. At present these specifications are not the same in the different Air Services, although each service uses the same type of parachute. The active cooperation of all interested parties would be advantageous in a methodical study of the performance of parachutes, using different experimental cloths in their construction. In conjunction with full-scale observations in the field, valuable information undoubtedly would accrue from well-designed experiments with models in the wind tunnel. To gain needed information on the requisite properties of the cloth, some work along this line would indeed seem imperative.

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Washington, D. C.,

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TABLE I. Structure and Properties of Parachute Cloths

Sample	Weave	Weight oz. per sq.yd.	Yarns per inch		Group*
			W	F	
A	plain	1.45	134	94	I
B	"	1.76	115	106	I
C	"	1.53	75	101	I
D	"	1.63	75	102	I
E	"	2.58	96	78	II
F	"	1.79	77	94	VI
G	"	1.64	75	99	III
H	"	2.09	76	86	II
I	"	2.71	93	74	II
J	"	2.73	94	78	II
K	"	2.53	95	70	II
L	"	2.67	97	77	II
M	"	1.30	141	86	III
N	"	1.30	139	92	III
O	"	1.50	121	91	VI
P	warp knit	1.86	–	–	V
Q	" "	1.67	–	–	V
R	" "	1.85	–	–	V
S	mock leno – a	1.99	–	–	VI
T	" "	1.84	–	–	VI
U	serge	1.73	–	–	VI
V	"	1.92	–	–	VI
W	plain	1.82	–	–	VI
X	"	1.86	–	–	VI
Y	cross-barred	1.64	–	–	III
Z	plain	1.58	75	97	IV
2A	"	1.53	–	–	VI
2B	"	1.87	96	99	VI
2C	mock leno – a	1.30	–	–	III
2D	" "	1.74	96	105	VI
2E	mock leno – b	1.92	104	112	VI
2F	plain	1.91	103	112	VI
2G	mock leno – c	1.75	–	–	IV
2H	mock leno – d	1.79	–	–	VI
2I	mock leno – e	1.77	–	–	IV
2J	plain	1.38	127	84	VI
2K	"	–	111	87	VI
2L	mock leno – a	1.66	94	93	VI
2M	" "	1.67	95	92	VI
2N	plain	1.52	130	104	III

*Explanation of groups: I. Previously used for parachutes; II. Too heavy; III. Low breaking strength; IV. Low stretch; V. High air permeability; VI. Compare satisfactorily with sample A.

TABLE I (Cont.)

Structure and Properties of Parachute Cloths.

Sample	Filaments per thread		Threads per yarn		Twist of yarns Turns per inch		Denier of thread (degummed)		Group*
	W	F	W	F	W	F	W	F	
A	14	20	2	3	0.2	1.3	14.9	24.5	I
B	16	16	2	5	–	–	–	–	I
C	10	10	7	5	0.1	1.5	12.6	13.7	I
D	14	14	7	5	2.3	2.3	11.7	11.8	I
E	10	10	10	9	0.2	2.3	12.0	10.8	II
F	10	10	7	6	0.2	2.2	13.6	13.2	VI
G	10	10	7	5	0.1	1.4	14.1	14.9	III
H	10	10	7	9	0.4	2.6	13.9	13.8	II
I	18	10	5	9	0.2	3.4	29.0	13.4	II
J	10	10	10	9	0.1	2.8	14.7	14.4	II
K	20	8	5	9	0.1	3.0	28.3	11.7	II
L	20	10	5	9	0.1	0.6	29.2	14.8	II
M	12	12	2	5	0.0	2.0	16.0	14.0	III
N	12	10	3	4	0.1	2.6	15.1	12.6	III

*See footnote, page 26.

TABLE I (Cont.)

Structure and Properties of Parachute Cloths

Sample	Breaking strength lb. per inch		Tear resistance lb.		Stretch at 20 lb. load per cent		Air permeability cu.ft. per min. per sq.ft. area for pressure difference of 1 lb. per sq.ft.	Group*
	W	F	W	F	W	F		
A	39	67	1.8	4.3	11.4	5.4	62.9	I
B	31	64	-	-	8.7	8.3	36.6	I
C	43	31	3.8	2.1	3.4	8.7	24.2	I
D	57	57	4.3	3.2	3.4	11.4	57.7	I
E	88	70	6.0	4.9	8.0	9.4	27.7	II
F	52	52	-	-	5.4	8.6	24.2	VI
G	44	38	-	-	3.2	9.2	28.9	III
H	57	63	-	-	5.4	8.6	19.1	II
I	88	62	-	-	13.3	9.9	28.5	II
J	101	76	-	-	12.3	9.4	29.6	II
K	109	65	-	-	9.1	11.5	25.6	II
L	99	72	-	-	10.4	7.9	27.9	II
M	25	33	-	-	18.0	9.0	45.5	III
N	42	29	-	-	6.7	7.3	27.3	III
O	44	45	-	-	9.0	6.0	34.3	VI
P	52	41	10.7	7.8	51.0	91.0	-	V
Q	43	32	7.6	12.0	47.0	88.0	383.5	V
R	55	39	-	-	38.0	94.0	-	V
S	45	69	10.2	13.2	8.0	7.0	125.4	VI
T	45	58	10.6	11.1	8.0	8.0	-	VI
U	42	52	7.4	7.9	8.0	7.0	68.2	VI
V	40	48	7.2	10.2	9.0	9.0	88.3	VI
W	43	56	4.8	7.3	10.0	9.0	57.9	VI
X	43	68	4.4	7.5	11.0	8.0	69.2	VI
Y	25	41	3.4	9.6	15.9	4.3	78.1	III
Z	42	54	-	-	4.3	7.7		IV
2A	46	41	-	-	7.0	5.0		VI
2B	32	65	-	9.5	8.0	6.0		VI
2C	45	28	12.9	5.7	6.0	10.0		III
2D	54	56	11.5	12.7	6.0	5.0		VI
2E	53	67	7.1	8.8	13.0	8.7		VI
2F	58	67	6.6	6.5	11.3	9.7		VI
2G	49	61	7.9	11.3	4.0	7.7		IV
2H	49	49	4.9	7.0	5.0	9.7		VI
2I	49	61	6.6	9.0	4.7	7.7		IV
2J	40	51	3.0	8.0	8.3	7.7		VI
2K	38	71	-	-	9.4	6.6		VI
2L	58	53	-	-	6.2	7.4		VI
2M	60	57	-	-	6.0	8.0		VI
2N	35	52	4.0	5.3	-	-		III

*See footnote, page 26.

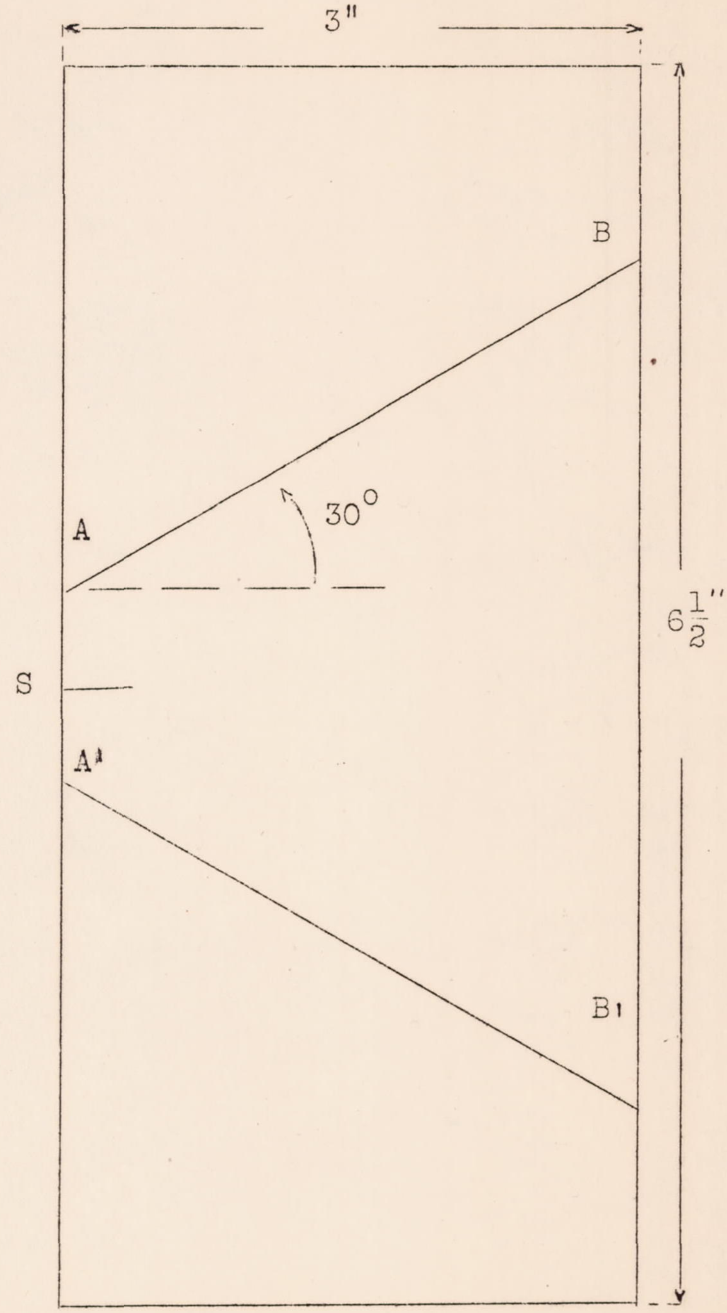


Fig.1. Test specimen for tear resistance measurements.

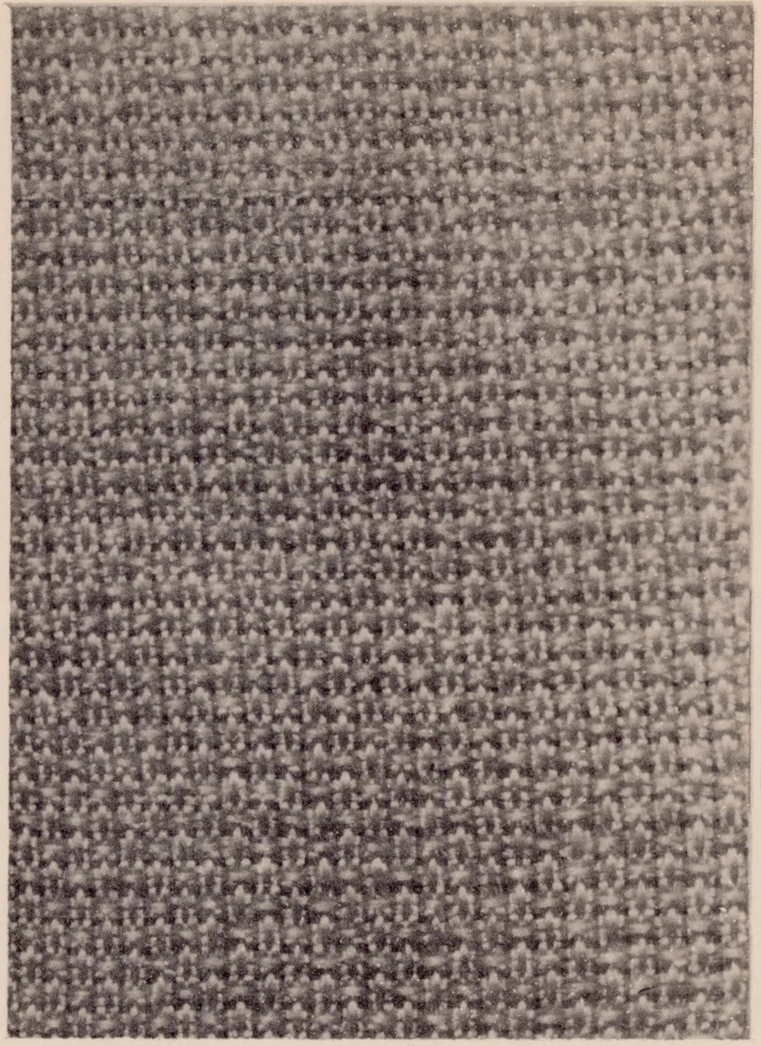
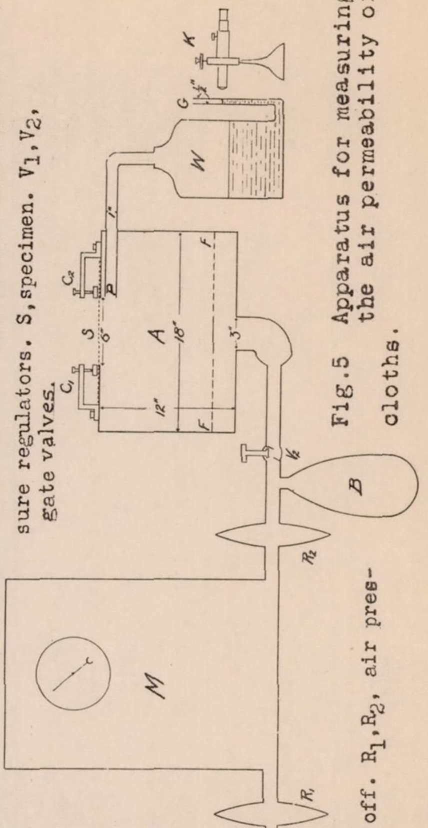


Fig.2 Photomicrograph of the mock leno weave cloth, closely woven for parachute use.



A, air-tight box. B, balloon. C_1, C_2, clamps. F, baffle. G, manometer tube. W, water reservoir. K, cathetometer. L, compressed air line. M, gas meter. P, pressure take off. R_1, R_2, air pressure regulators. S, specimen. V_1, V_2, gate valves.

Fig.5 Apparatus for measuring the air permeability of cloths.

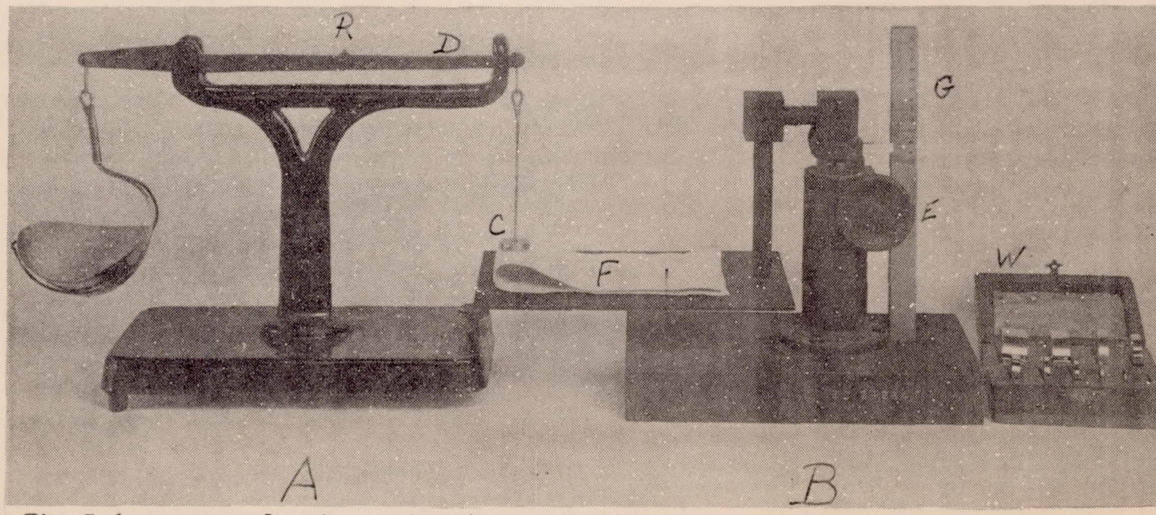


Fig.3 Apparatus for investigating the elastic properties under flexure. A, balance. B, movable platform. C, foot of weight holder. D, arm of balance. E, rack and pinion. F, fold of cloth. G, scale. R, rider. W, weights.

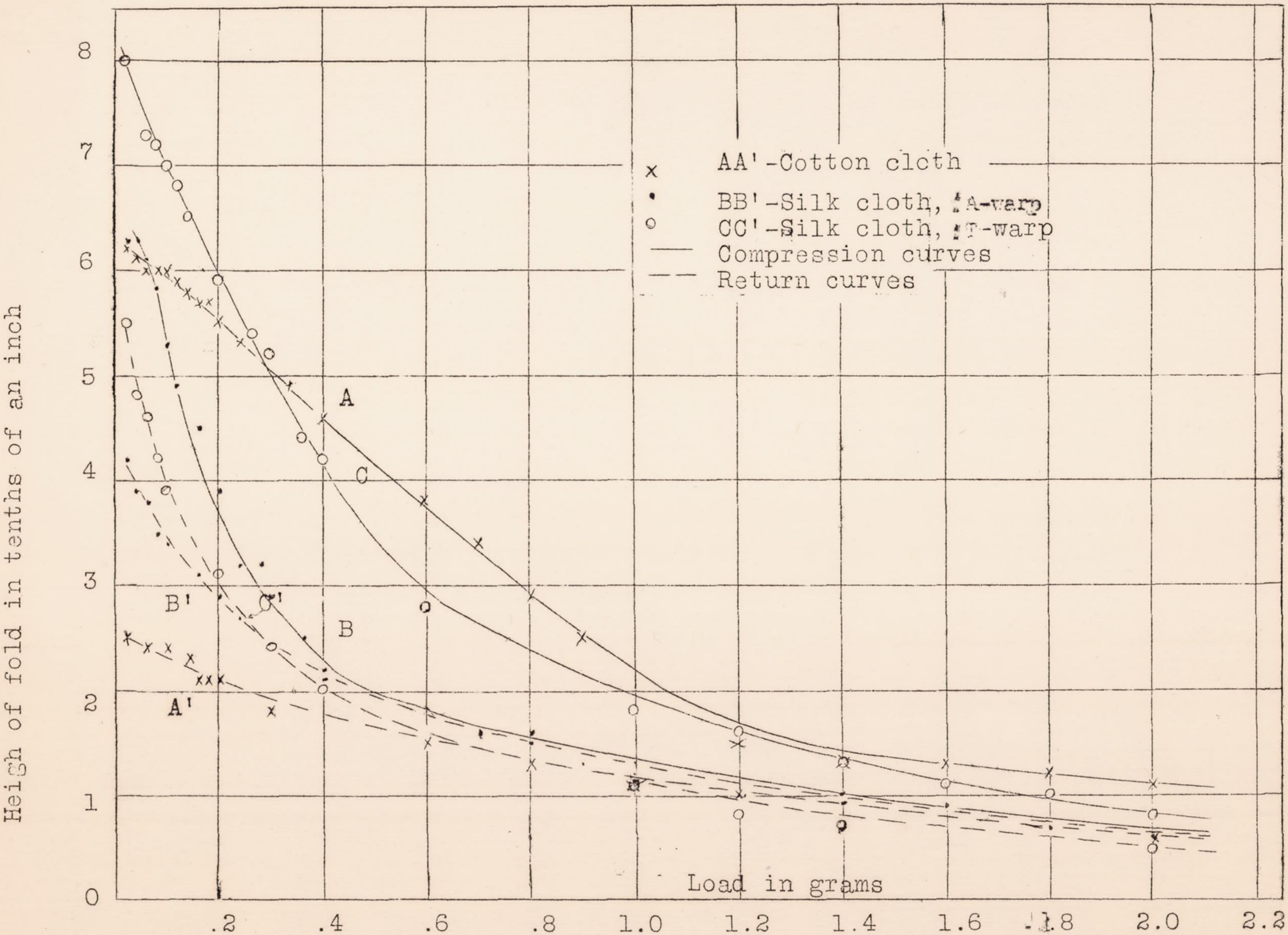


Fig.4 Characteristic stress- deformation curves for silk and cotton cloth under flexure.

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Fig. 6

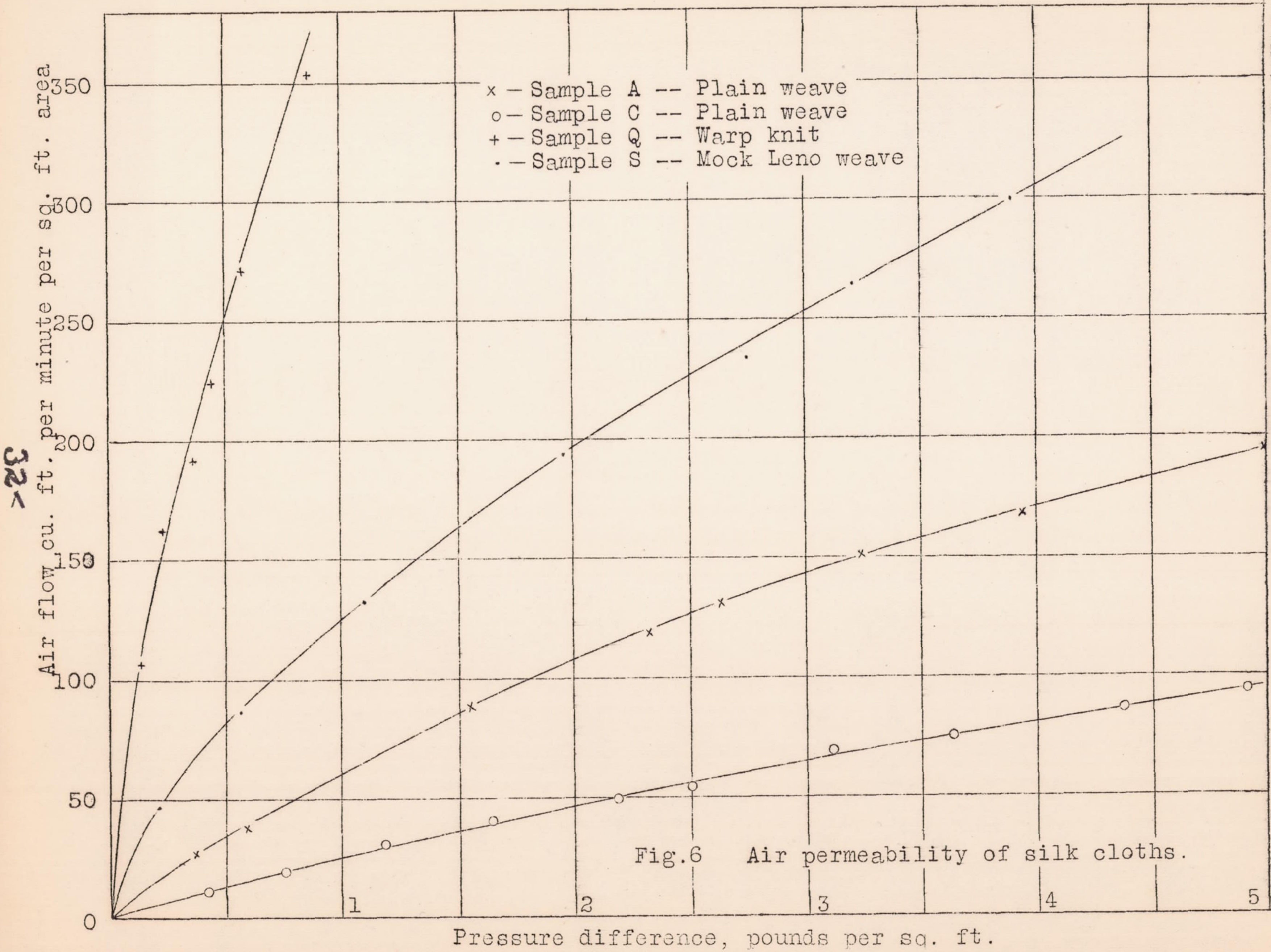

Fig. 6 Air permeability of silk cloths.

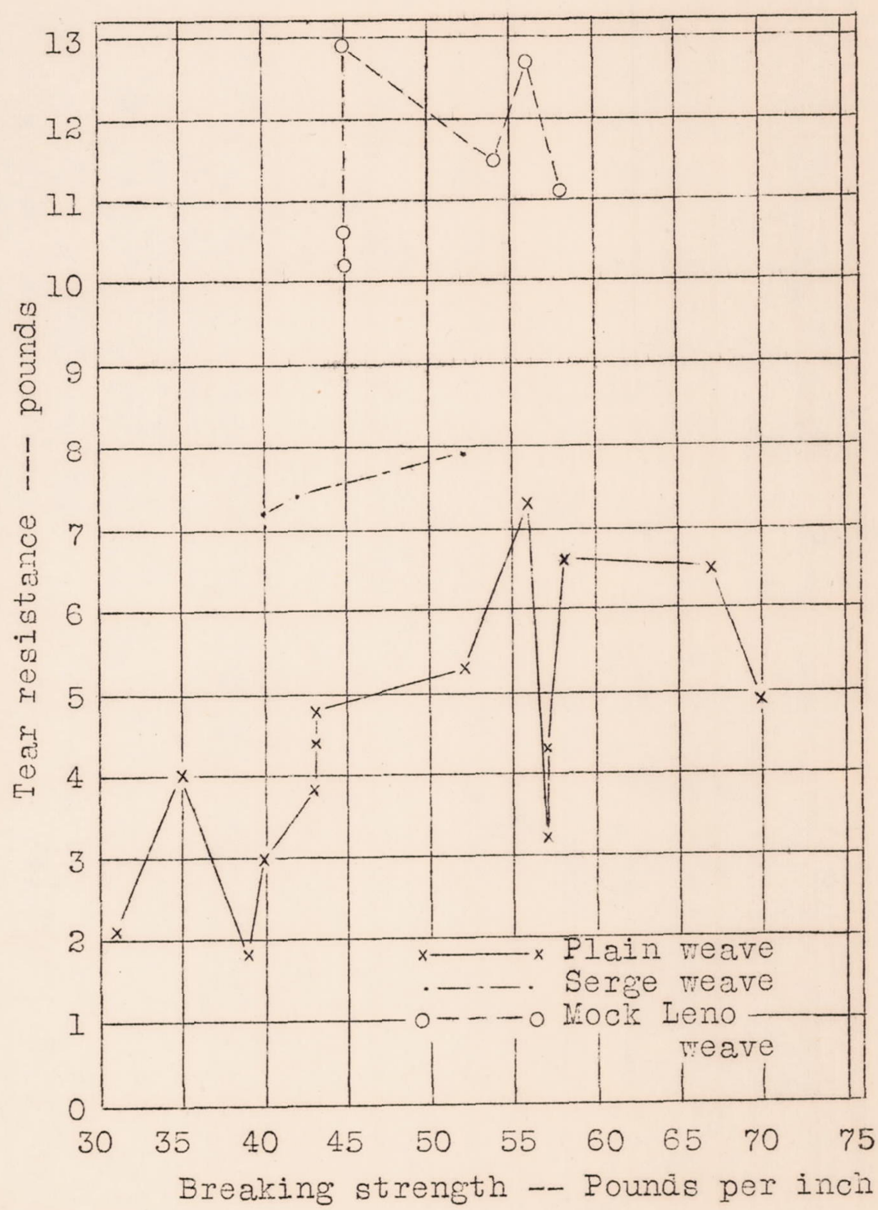

Fig.7 Effect of weave on the tear resistance.