
REPORT No. 22

IN TWO PARTS

FABRICS FOR AERONAUTIC CONSTRUCTION

**By SUBCOMMITTEE ON STANDARDIZATION AND
INVESTIGATION OF MATERIALS**

Part 1.—COTTON AIRPLANE FABRICS

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Part 2.—BALLOON FABRICS

Contributed by Bureau of Standards, Balloon Fabric Committee

REPORT No. 22.

PART I.

COTTON AIRPLANE FABRICS.

By E. D. WALLEN.

PRELIMINARY REPORT.

The work on cotton fabrics as applied to airplane wing coverings has by no means been completed, but certain preliminary investigations have shown useful results, and in the belief that the conclusions already drawn will be of value, the following preliminary report is presented. Time has not been available to put this material into consecutive and strictly logical form. It should be considered as a series of notes containing the salient features of the investigation developed up to this time.

The application of cotton fabrics to airplane wings has long been desired, but the many unsuccessful attempts to substitute this fabric for the highly satisfactory linen have given rise to a general belief that cotton is out of the question.

The objectionable features of the attempted cotton fabrics as compared to linen were:

1. Low tearing resistance.
2. Poor penetration of the dope.
3. Little shrinkage upon the application of dope.
4. Poor restitution properties.
5. Cracking or peeling of the dope during the application of stress to the fabric.

The Bureau of Standards undertook the investigation of airplane fabrics with the view of finding suitable substitutes for the linen fabrics, and it was decided that the fibers to be considered were cotton, ramie, silk, and hemp. Of these, the cotton fiber was the logical one to be given primary consideration.

The long fibers, such as linen, ramie, and hemp, can be grown in this country, but there are no facilities for their spinning. The failure to develop the manufacture of these products has probably been due to the necessarily high labor cost for careful curing of the fibers before manufacture.

Silk has been grown in this country experimentally, but at present the supply is entirely imported. The manufacture, however, has been highly developed and accordingly silk has been given consideration and will be reported on at a later date.

It was decided to study first the physical properties of the satisfactory linen fabrics and the general requirements of fabrics for airplane wing coverings, for the purpose of designing cotton fabrics having the desirable properties of a linen fabric and conforming to the requirements of wing coverings.

FACTORS AFFECTING THE DESIGN OF AIRPLANE FABRICS.

The following is a general consideration of the requirements for a fabric airplane wing covering, together with the factors influencing their attainment:

1. Weight, not more than 4 to 4.5 ounces per square yard.
 - (a) Kind of fiber.
 - (b) Structure of fabric.
2. Tensile strength, 70 to 80 pounds per inch of width.
 - (a) Kind of fiber.
 - (b) Structure of yarn—method of manufacture.
 - (c) Structure of fabric—
 - Threads per inch.
 - Method of interlacing.
 - (d) Treatment of material—
 - Chemical.
 - Finishing process.
3. Smooth surface.
 - (a) Character of fiber.
 - (b) Character of yarn.
 - (c) Structure of fabric.
 - (d) Treatment of fabric.
4. High tearing resistance.
 - (a) Strength of individual yarns.
 - (b) Number of yarns being stressed—
 - Tensibility of yarns.
 - Method of interlacing.
5. Rigidity (compactness).
 - (a) Number and size of yarns.
 - (b) Method of interlacing.
6. Absorption of dope.
 - (a) Kind of dope.
 - (b) Nature of fiber.
 - (c) Twist and size of yarns.
 - (d) Treatment of yarns or fabric.
7. Shrinkage upon the application of the dope.
 - (a) Dependent upon 6.
 - (b) Number of yarns.
 - (c) Tensibility properties of fabric.
8. Permanency of shrinkage.
 - (a) Permanency of the dope.
 - (b) Tensibility properties of the fabric.
9. Advantageous proportion of the tensibility curves of the warp and filling.
 - (a) Analysis of tensible properties of the dope.
 - (b) Analysis of stresses in wing coverings during flights.

LABORATORY EXPERIMENTS.

The tensibility properties of the fabrics were determined in the following manner: Specimens 20 cm. long by 3 cm. wide were raveled to 2.5 cm. wide, exposed to an atmosphere of 65 per cent relative humidity at 70° F. and then stretched at a uniform rate of 13 cm. per minute and the load transmitted by the fabric measured by means of a test-

ing machine of the inclination balance type. The testing machine was arranged to plot autographically the stretch against the load.

The graphs appended are reproductions of the autographic records. In every case the curve showing the greater stretch is the warp direction, and the curve showing the lesser, the filling. No attempt has been made to assign specific reasons for the shapes of the curves, but rather to draw useful conclusions based on marked differences in shape.

The graph PL 30 is typical of the high-grade linen which is considered satisfactory. The loops branching out from the right of the curves show the behavior of the fabric when relieved of the stress at the same rate as for loading and subsequently loaded again. It is observed that the flatter the curve and the smaller the stretch at the low loads the more nearly will the fabric return to its original length.

It was further observed that the condition of the tightness of linen fabrics after doping was dependent upon the shape of the tensibility curve, as the fabrics having flatter tensibility curves, and smaller stretch at the low loads, shrank to a greater degree of tightness than the others.

The fabrics having the above condition of tensibility properties naturally had better restitution properties after doping and could not be permanently dented as easily as the others.

Diagram PL 36 is representative of the linen fabrics now coming from England. Drawn on the same sheet are the tensibility curves of the fabrics after doping.

It will be noted that the filling curve of the doped fabric is very nearly a straight line and that the warp curve shows a marked giving way of the dope at approximately 6 kg. load. This is indicative of a permanent set and although in this instance the dope did not crack or peel off, a less elastic dope would have done so, and thus expose the fabric.

The stretch of the warp should be the same as that of the filling, when the fabric is applied on the bias, in order that the fabric may be the most efficient in resisting uniformly distributed pressure. The type of fabric shown in PL 36 is objectionable from this point of view.

The above types of fabric were taken as a basis for the physical properties which should be embodied in a cotton fabric.

The exact influence of the variables of the construction of cotton yarns and fabrics on the attainment of the desirable features of an airplane wing fabric, as outlined above, were not definitely known. Accordingly, several mills were asked to make samples according to specified constructions which were designed to fix the limits between which suitable properties might be expected to be found.

The resistance to tearing is a function of the strength of the individual yarns and the number of yarns being stressed. Accordingly, the experimental fabrics were constructed of ply yarns varying from 2/40's to 4/100's and having from 50 to 90 threads per inch. The raw cotton in all cases had a staple of about 1½ inches.

The following graphs show the tensibility relations of the more satisfactory cotton fabrics.

Fabric CP 25 when stretched on a frame in the same manner as linen does not possess the necessary shrinkage, and has poor restitution properties. The dope will break when stress is applied to a doped fabric of this nature. These undesirable features can be overcome by stretching the fabric more tightly on a frame. This has many objections considering the practicability of such a procedure. The curves show large stretch at the low loads.

Fabric CP 7 has practically a balanced stretch condition, and if put on a frame properly will show good results. The thread count is low and the yarns fairly coarse, and the sample was observed to have a higher tearing resistance than any of the linens in the undoped condition. Objection has been raised to its open structure, but it was noted that one of the Italian planes was covered with a ramie fabric of a more open structure.

Fabric CP 51 has many of the characteristics of CP 7, but has a better shrinkage upon doping due to the lower stretch in the filling direction. The surface is somewhat smoother and the fabric is more compact, owing to the smaller yarn size and higher thread count.

The graph PC 66 shows the stretch load relation of this fabric after doping. It will be noted that there is a well-defined yield point at the low loads which means poor restitution properties and consequently baggy wings. This condition is due to the larger stretch of the raw fabric at the low loads.

The graph PC 72 shows the load stretch relation of the fabric CP 50 when doped. The yield point at the low loads is not so prominent as was the case in the fabric CP 51. The tightness after doping was much better than in the case of fabric CP 51.

Fabrics CP 22 and CP 26 are practically the same as regards tensibility properties, but are quite different in structure. These fabrics are made of yarns mercerized under tension. Both of these fabrics shrank to a tightness which was much better than the linens.

Graph PC 37 shows the properties of a fabric made of 4/100's. It will be noted that the curves are extremely regular and are very similar to CP 50 and CP 51. This fabric when doped produced the same degree of tautness as the fabric PC 50, but possessed better restitution properties. Graph PC 75 is fabric PC 37 after doping.

Fabric CP 22 was put on a wing section of a JN4 plane at Langley Field. The Italian mission, which was on the field at the time, stated that it was exceptionally good and much better than the cotton which was being used during the recent advance of the Italian Army.

Fabric CP 26 was designed after a study of the many cotton fabrics which had been made in accordance with our instructions and after CP 22 was tried out. The curves were flattened by mercerizing the yarn and this also took out the crimps of the yarns and fibers making very little stretch at the low loads.

Graph PC 74 shows the tensibility properties of CP 26 before and after doping. The close similarity of these curves as compared with those of the linen PL 36 is to be noted. It will be further noted that the filling and warp curves are closer together than are the linen curves. This means that the fabric will withstand more pressure than the linen if each is put on the bias. The nitrate and acetate dopes produced practically the same satisfactory tightness.

Graph PC 70 shows the load stretch relation of the warp of CP 22 when doped with a nitrate dope. This curve shows a distinct yield point, at which the dope cracked.

Graphs PL 38 and PC 74 show the similarity of the restitution properties of cotton CP 26 and linen PL 36.

Graph CP 61 shows the condition of fabric CP 17 after two months continuous exposure to the weather. It was observed that if the dope held up there was very little decrease in the strength of the cotton fabrics.

Graph PX 45 is that of a ramie fabric.

Graph PX 46 shows PX 45 after doping.

FIELD EXPERIMENTS.

Samples of cotton fabric of several classes of tensibility curves were tried on engine sections of airplanes at Langley Field and at Pensacola. The following is a summary of the comments of the commanding officers of these two experimental stations:

LANGLEY FIELD.—The fabrics were put on engine sections as nearly in accordance with the present practice as was possible, and doped with six coats of Dupont No. 20 dope on the bottom side and four coats of Dupont and two coats of varnish on the top side.

Fabric CP 50 dopes well, but is easily and permanently dented.

Fabric CP 22 takes dope beautifully and is considered better than linen.

Fabric P 25 does not absorb the dope and does not shrink well.

All of these fabrics are giving good service.

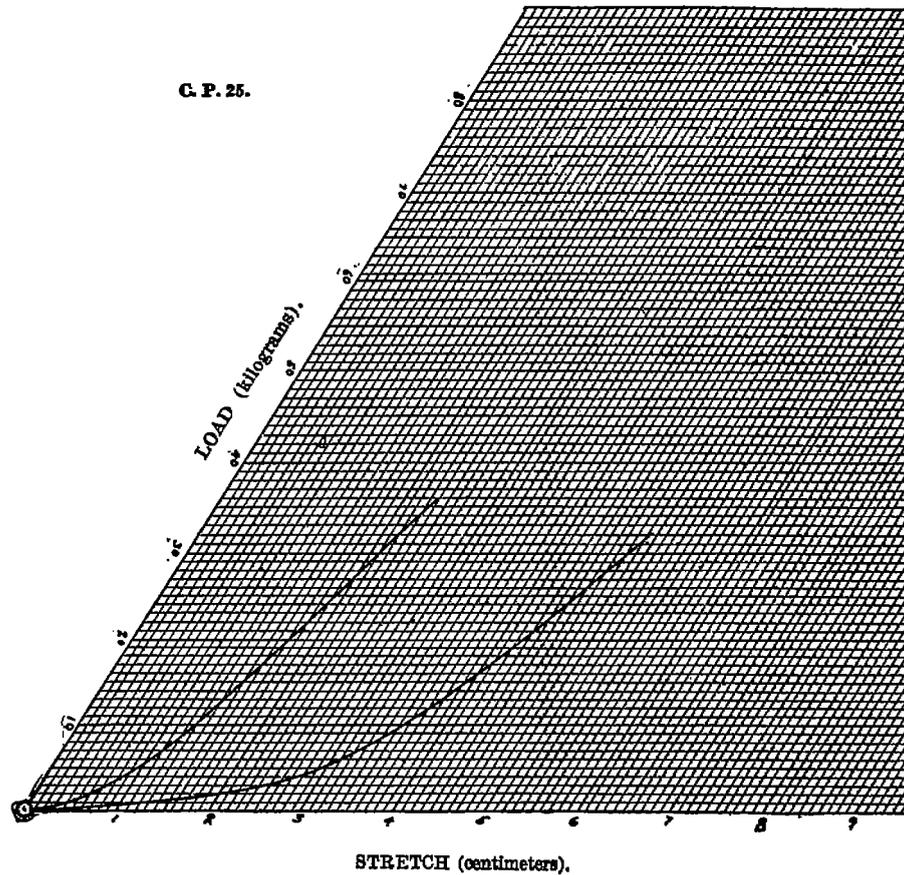
PENSACOLA.—Fabrics were stretched on engine sections as tightly as possible and doped with Emallite dope.

Fabrics P 7, CP 50, and CP 17 were tried. The first application of dope appeared to cause the fabric to slacken, but subsequent coats in every case tauten the fabric, and after five coats it is in as good condition as linen after the same treatment. These samples have been put in actual service, and, although the tests are not concluded, the indications are that they are equally satisfactory with the linens now being used. Fabric CP 17 is the best of the three.

SUMMARY.

1. Cotton fabrics can be made which will be suitable for airplane wings.
2. Cotton fabric CP 26 possesses the same characteristics as a high-grade linen and is the best of the present cotton fabrics. Its resistance to tear is slightly less than that of high-grade linen.
3. Cotton fabrics are as a rule more even in texture than linen.
4. Fabrics made of yarns mercerized under tension and with proper twist and thread count possess the same characteristics as linen.
5. Fabrics made of unmercerized yarns can be used with a fair degree of satisfaction.
6. The restitution properties of a fabric depend upon its tensibility curve, the ply, and the twist of the yarns.
7. The tensibility curve is a valuable basis for specification.
8. The tensibility properties and tearing resistance of cottons can be varied to meet the requirements in any given case, so that a much more satisfactory fabric for any type of airplane can be designed.
9. The tensibility curve is a valuable index in determining the suitability of a particular fabric for wing coverings.

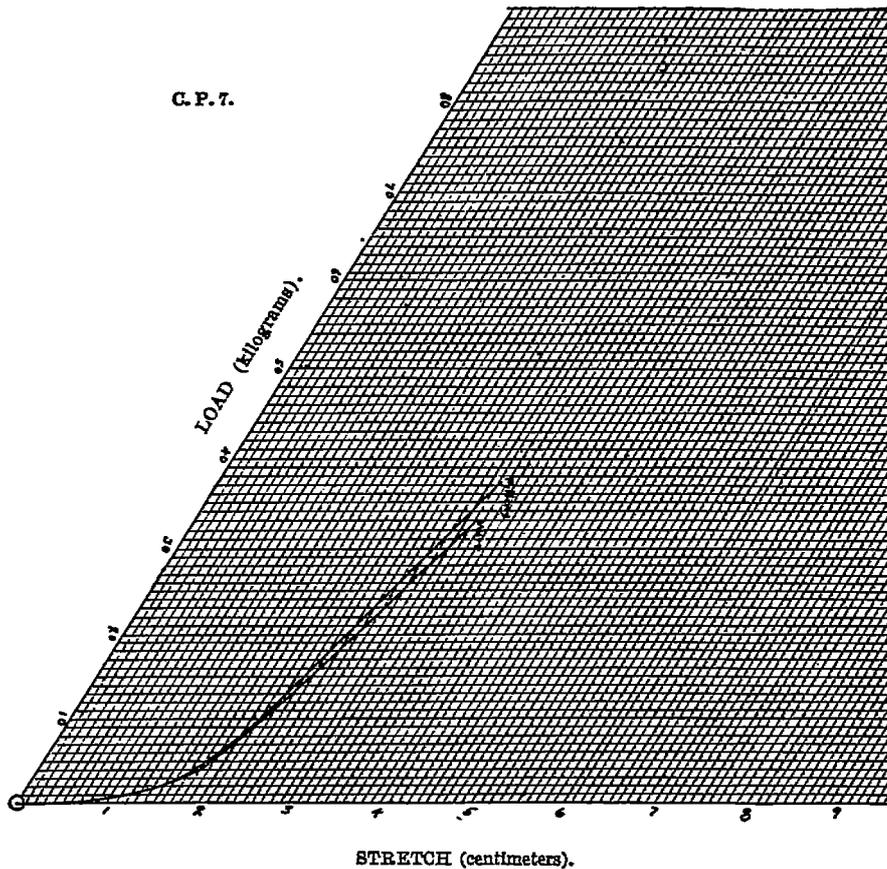
WASHINGTON, October 12, 1917.



Laboratory No. C. P. 25.
 Date, June, 1917.
 Kind, fine Sea Island.
 Condition, 65 per cent; relative humidity, 70° F.

	Warp.	Filling.
Threads.....	88	87
Yarn No.....	2/70	2/70
Twist per inch.....singles..	34-38	34-38
Twist per inch.....doubling..	24-28	24-28

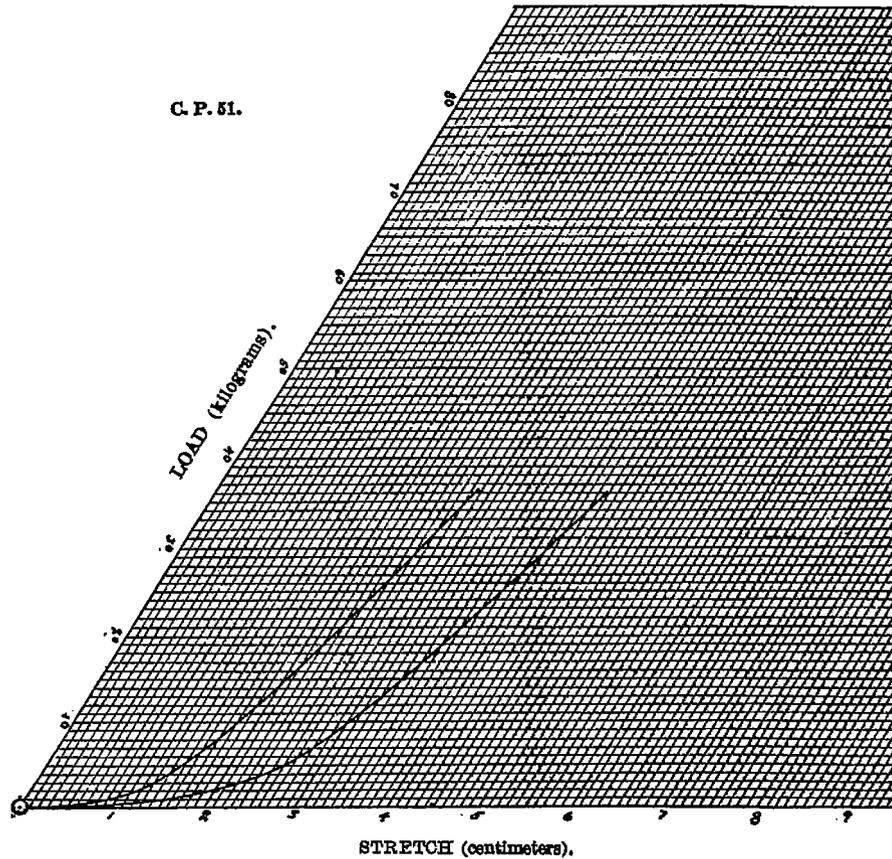
Specimen dimensions, 20 by 2.5 centimeters.
 Speed, 13 cm. per minute.
 Weight per square yard, 5.3 ounces
 Weave, plain.



Laboratory No. C. P. 7.
 Date, June, 1917.
 Kind, cotton, fine Sea Island.

	Warp.	Filling.
Threads.....	56	58
Yarn No.....	2/40	2/40
Twist per inch... singles...	24	20
Twist per inch... doubling...	17-18	16

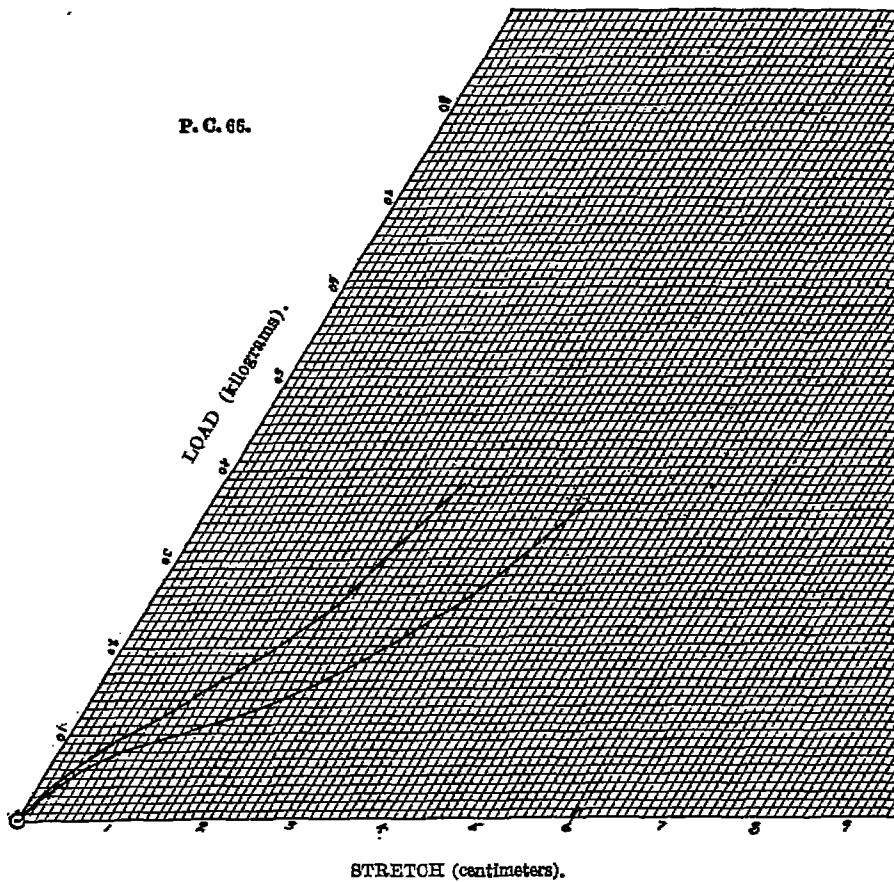
Specimen dimensions, 20 by 2.5 centimeters.
 Weight per square yard, 4.2 ounces.
 Weave, plain.



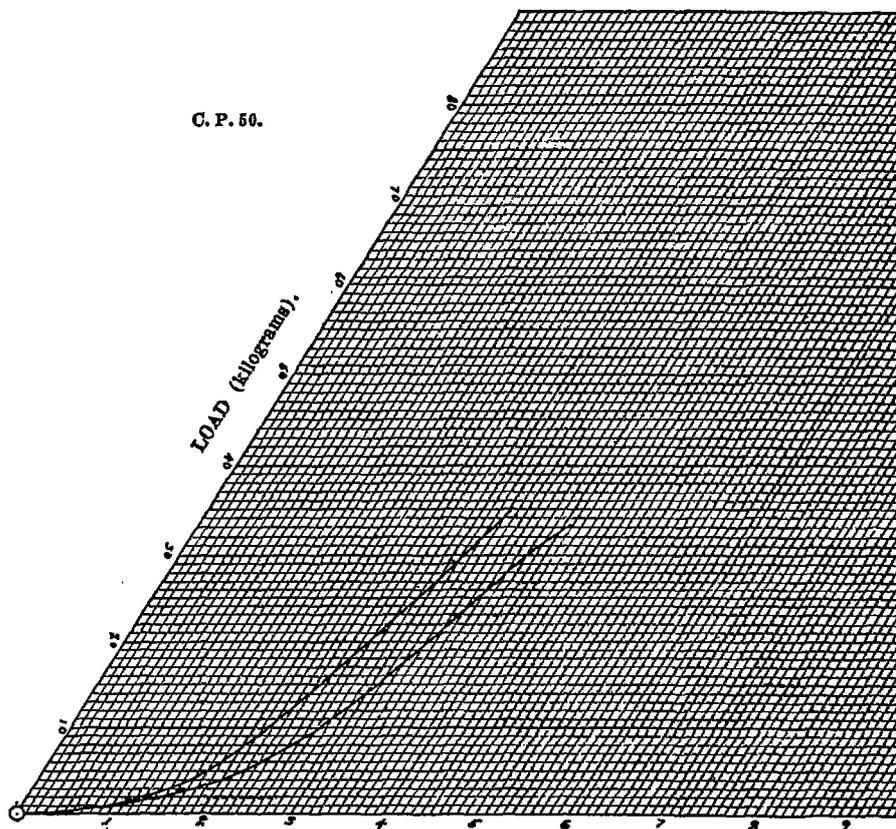
Laboratory No. C. P. 51.
 Date, August, 1917.
 Kind, fine Sea Island.
 Condition, 65 per cent; relative humidity, 70° F.

	Warp.	Filling.
Threads.....	68	71
Yarn No.....	2/50	3/50
Twist per inch...single..	28-32	36-40
Twist per inch...doubling..	16-20	18-22

Specimen dimensions, 20 by 2.5 centimeters.
 Weight per square yard, 4.2 ounces.
 Weave, plain.



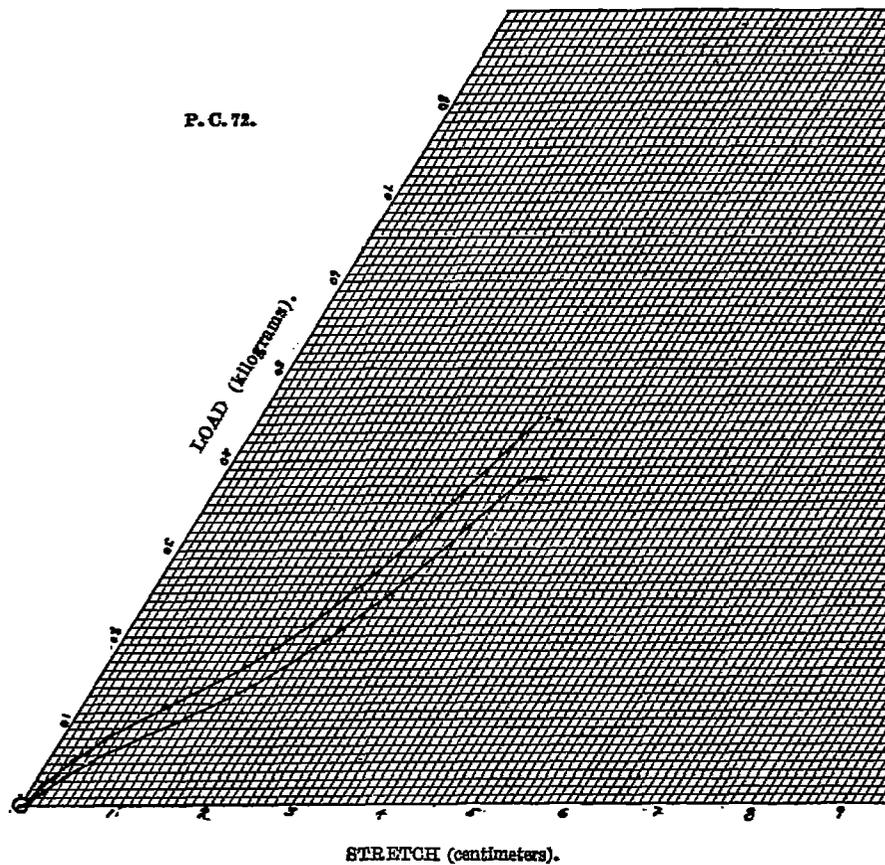
Laboratory No., P. C. 66.
Date, September, 1917.
Condition, 4 coats Perry Austin.
Specimen dimensions, 20 by 2.5 centimeters.
Weight, _____.
Weave, plain.
Dope in good condition; fabric, tight.



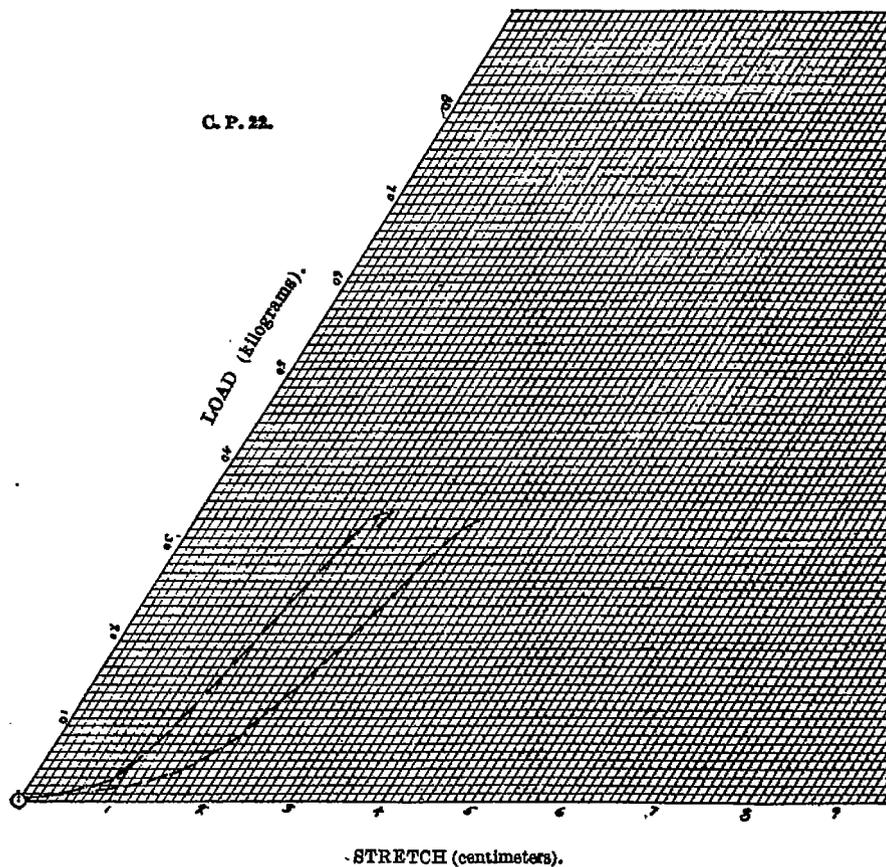
Laboratory No., C. P. 50.
 Date, August, 1917.
 Kind, fine Sea Island.
 Condition, 65 per cent; relative humidity, 70° F.

	Warp, Filling.	
Threads.....	70	70
Yarn No.....	3/80	3/80
Twist per inch..... singles..	36-40	36-40
Twist per inch..... doubling..	18-22	18-22

Specimen dimensions, 20 by 2.5 centimeters.
 Weight per square yard, 4.2 ounces.
 Weave, plain.



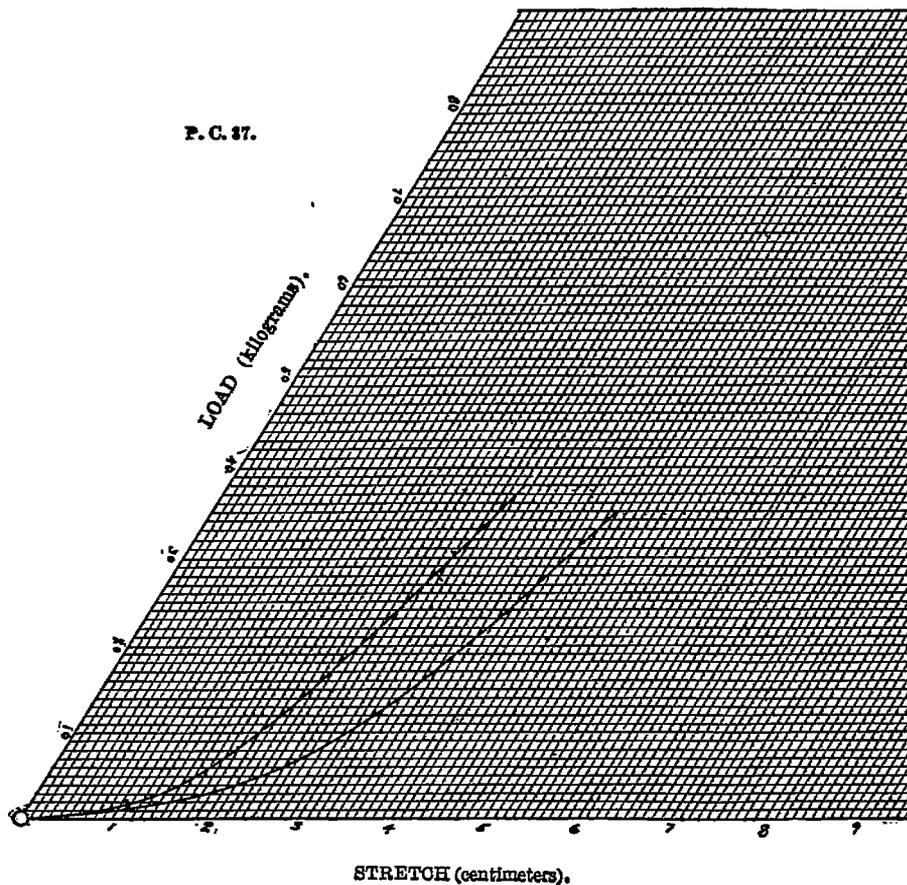
Laboratory No., P. C. 72.
Condition, 4 coats Perry Austin.
Specimen dimensions, 20 by 2.5 centimeters.
Weave, plain.
Dope in good condition; fabric, tight.



Laboratory No., C. P. 22.
 Date, August, 1917.
 Kind, fine Sea Island, mercerized in yarn.

	Warp. Filling.	
Threads.....	68	70
Yarn No.....	3/80	3/80
Twist per inch... singles..	38-40	.....
Twist per inch... doubling..	18-22	.....

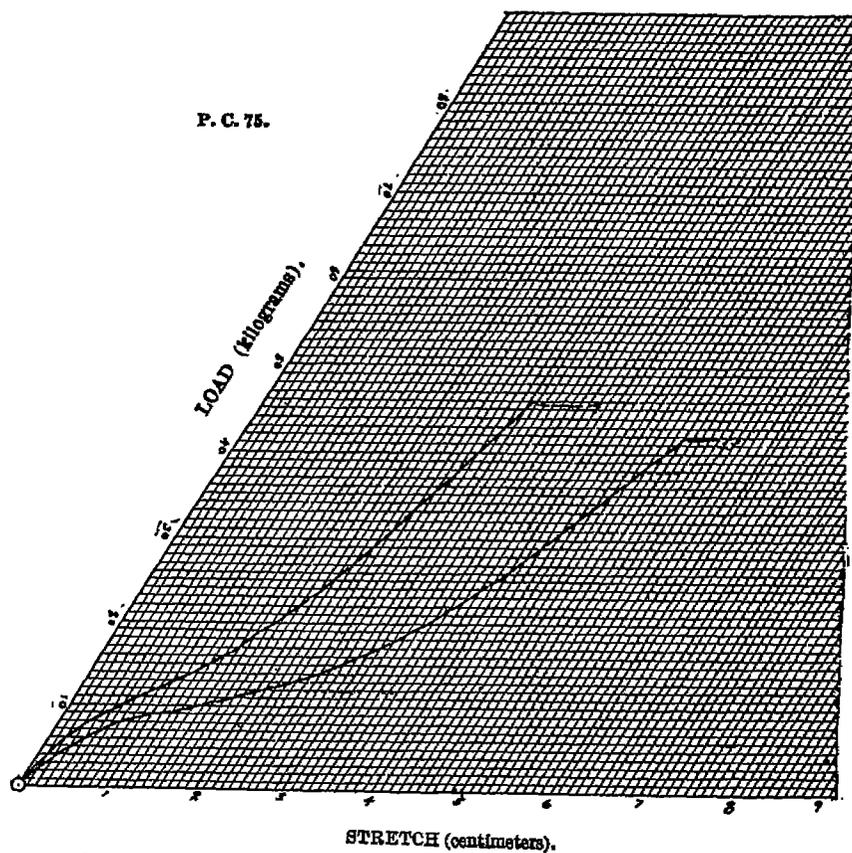
Dimensions, 20 by 2.5 centimeters.
 Weight per square yard, 3.80 ounces.
 Weave, plain.



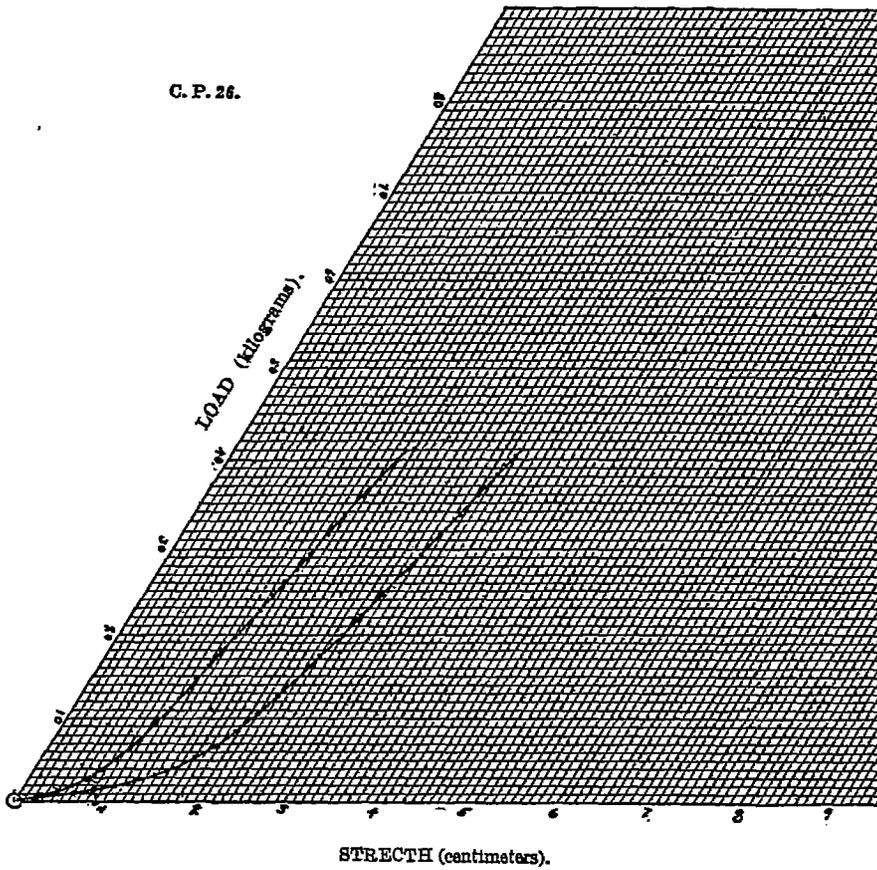
Laboratory No., P. C. 37.
 Date, September, 1917.
 Kind, fine Sea Island.

	Warp. Filling.	
Threads.....	76	75
Yarn No.	4/100's	.....
Twist per inch...singles..	41	.....
Twist per inch...doubling..	20	.....

Specimen dimensions, 20 by 2.5 centimeters.
 Weight, 5 ounces per square yard.
 Weave, plain.



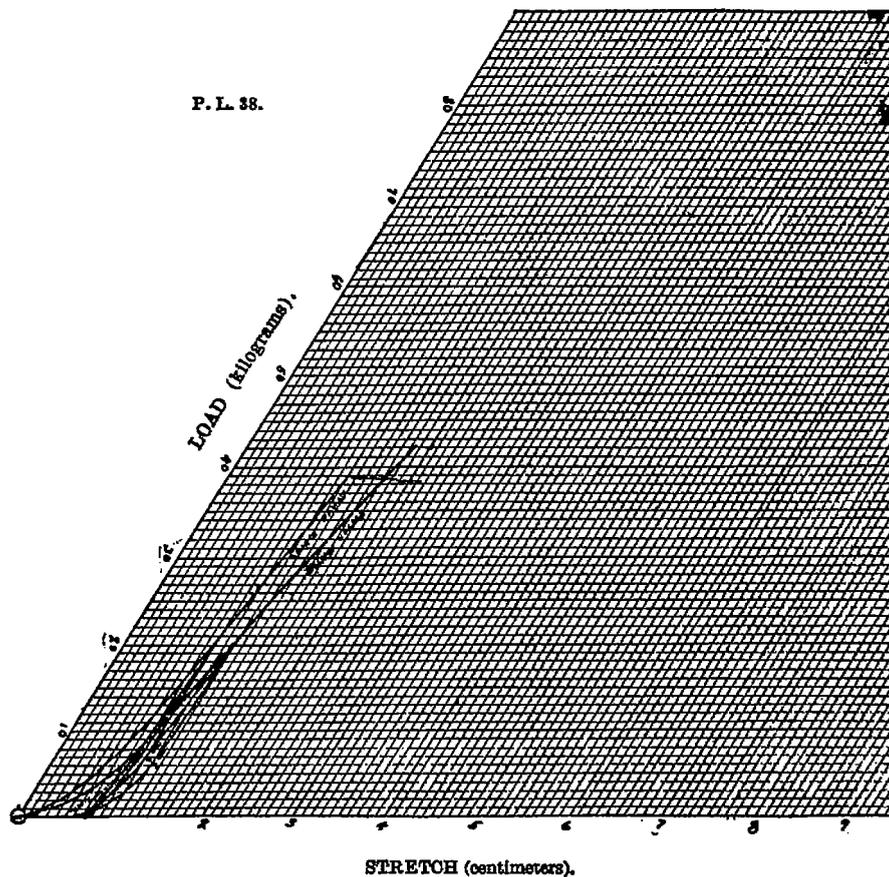
Laboratory No., P. C. 75.
Date, September, 1917.
Condition, doped, Parry Austin. 4 coats.
Specimen dimensions, 20 by 2.5 centimeters.
Weight, 7.3 ounces per square yard.
Weave, plain.



Laboratory No., C. P. 26.
 Date, September, 1917.
 Kind, Georgia, I.S.
 Condition, mercerized in yarn.

	Warp.	Filling.
Threads.....	79	84
Yarn No.....	2/50	2/80
Twist per inch.....singles	28-34	28-32
Twist per inch doubling	15	15

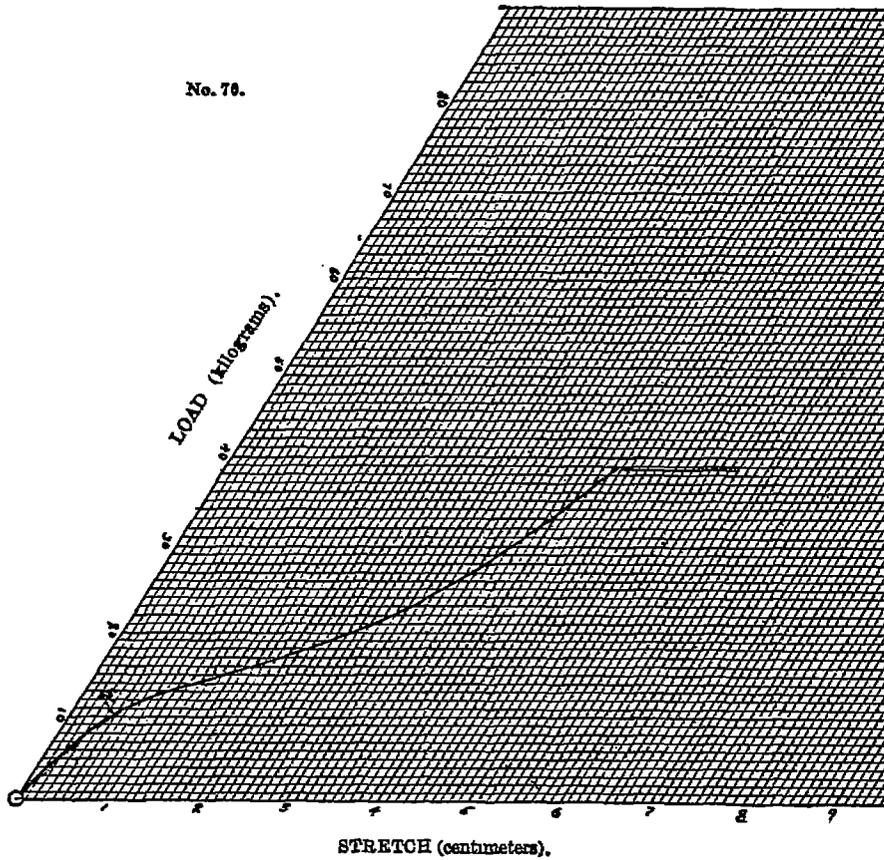
Specimen dimensions, 20 by 2.5 centimeters.
 Weight per square yard, 4.2 ounces.
 Weave, plain.



Laboratory No., P. L. 38. Filling, P. C. 74 filling.
 Date, September, 1917.
 Kind: Cotton, P. C. 74; linen, P. L. 36.
 Condition, undoped.

	Warp.	Filling.
Threads.....	.....	.....
Yarn No. ....	.....	.....
Twist.....	.....	.....

Specimen dimensions, 20 by 2.5 centimeters.
 Weight, _____
 Weave, plain.

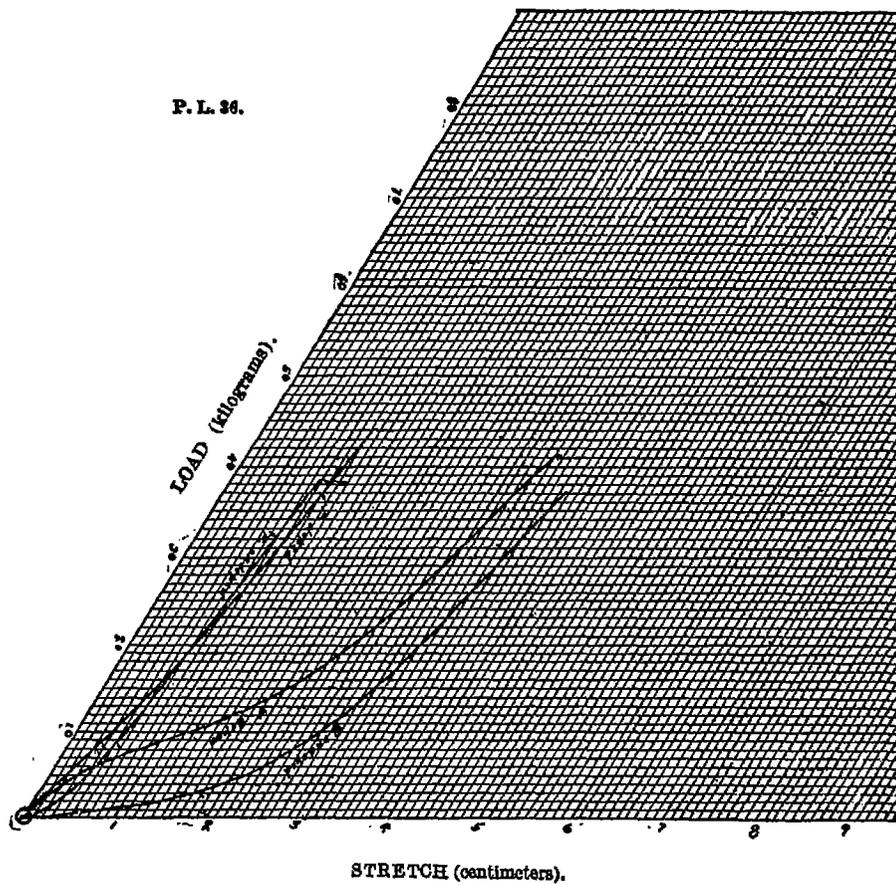


Laboratory No., 78.
 Date, September, 1917.
 Kind, _____
 Condition, 4 coats Dupont No. 20.

	Warp.	Filling.
Threads.....	.....	.....
Yard No. ....	.....	.....
Twist.....	.....	.....

Specimen dimensions, 20 by 2.5 centimeters.
 Weight, _____
 Weave, plain.

Note.—Dope cracked at "a." Fabric tightened on frame.

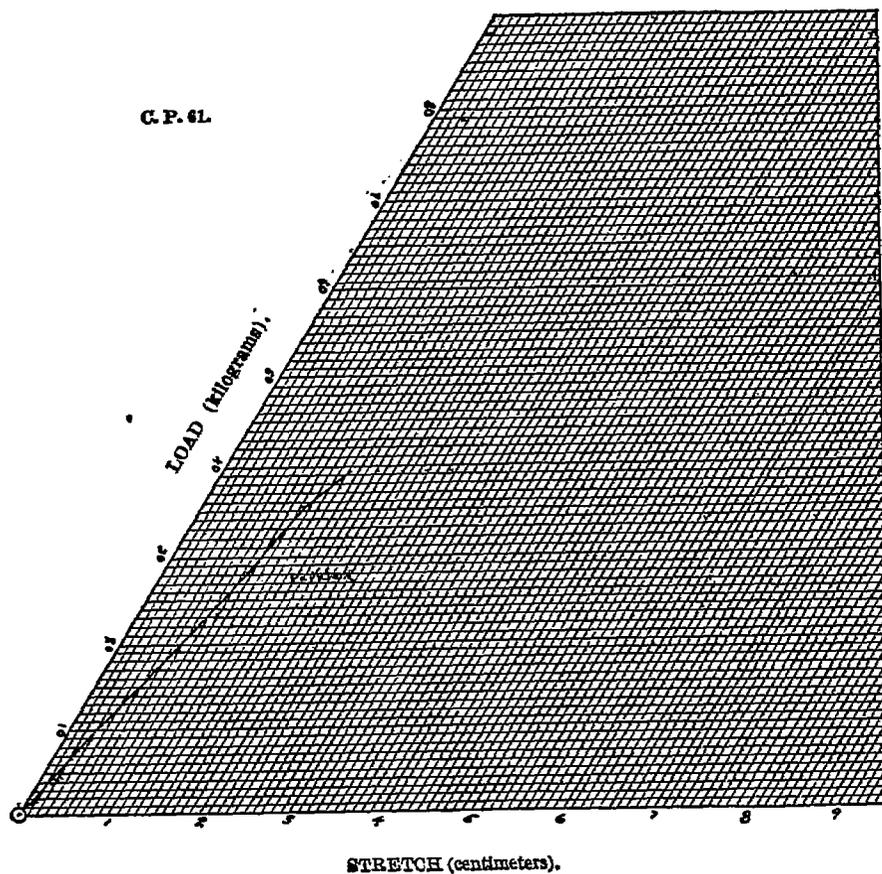


Laboratory No., P. L. 36.
 Date, September, 1917.
 Kind, linen.
 Condition, Parry Austin; 4 coats; no dope.

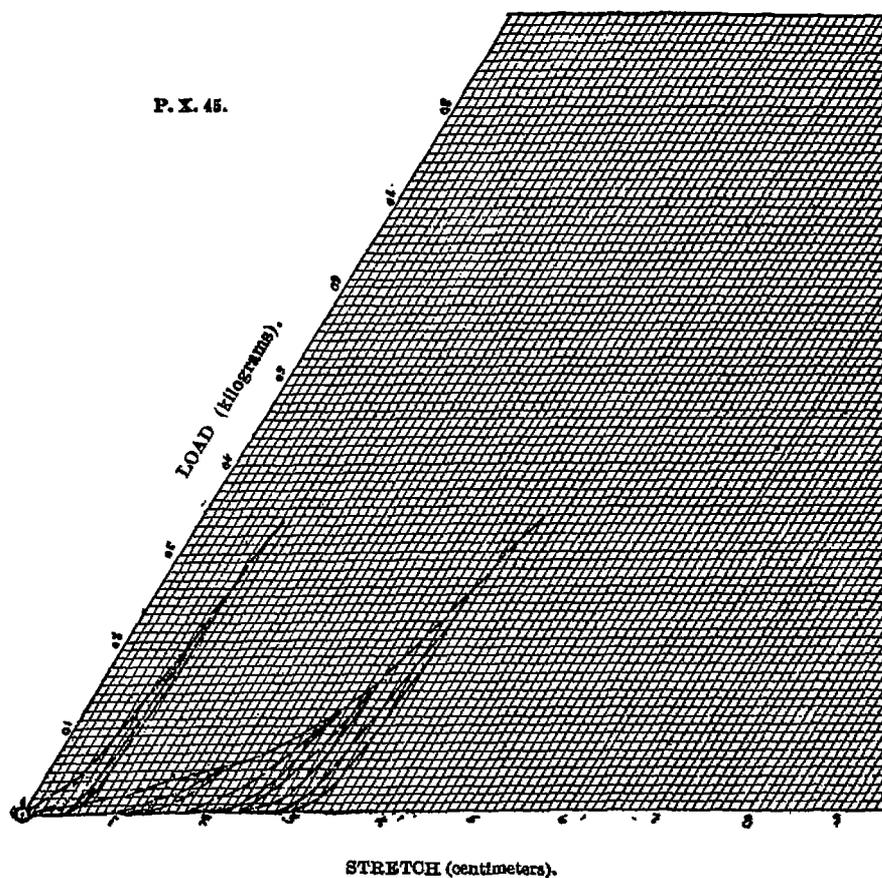
	Warp.	Filling.
Threads, .....	.....	.....
Yarn No. ....	.....	.....
Twist, .....	.....	.....

Specimen dimensions, 20 by 2.5 centimeters.
 Weight: Undoped, 3.5 ounces per square yard; doped, 5.4 ounces per square yard.
 Weave, plain.

NOTE.—Clean break; no peeling of dope.



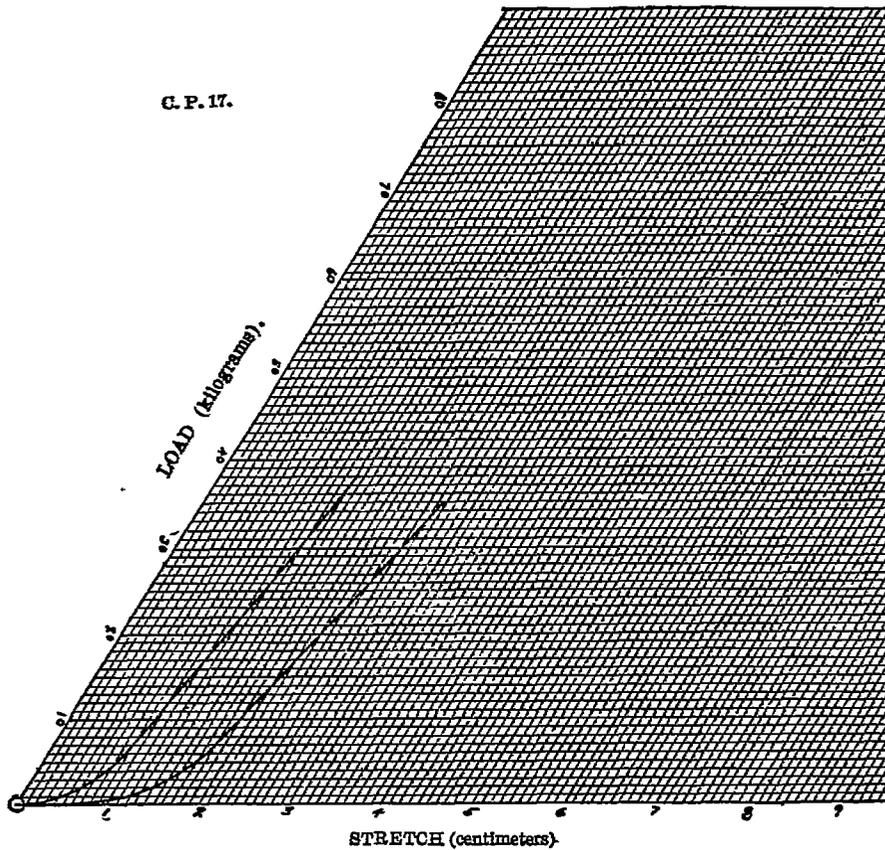
Laboratory No., C. P. 6L.
Date, August, 1917.
Kind, mercerized 423.
Condition, 5 coats, Celestron; 2 months exposure.
Specimen dimensions, 20 by 2.5 centimeters.



Laboratory No., P. X. 45.
 Date, August, 1917.
 Kind, ramie.

	Warp.	Filling.
Threads.....	97	96
Yarn No.,	60/1	60/1, metric.

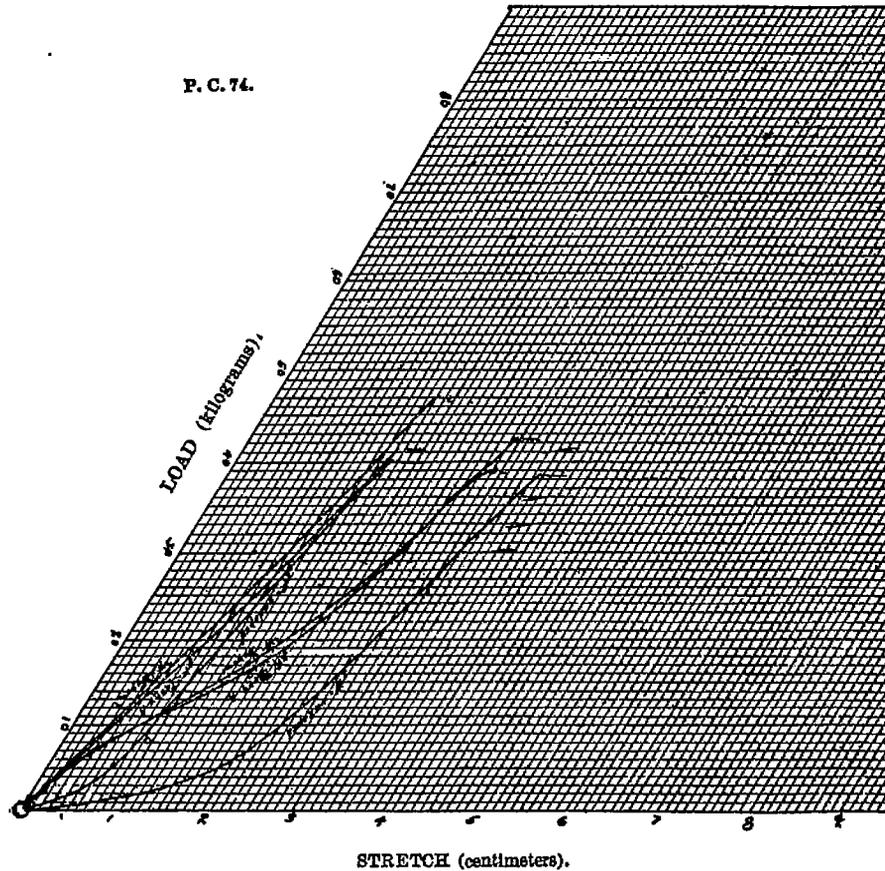
Specimen dimensions, 20 by 2.5 centimeters.
 Weight, 4.6 ounces per square yard.
 Weave, plain.



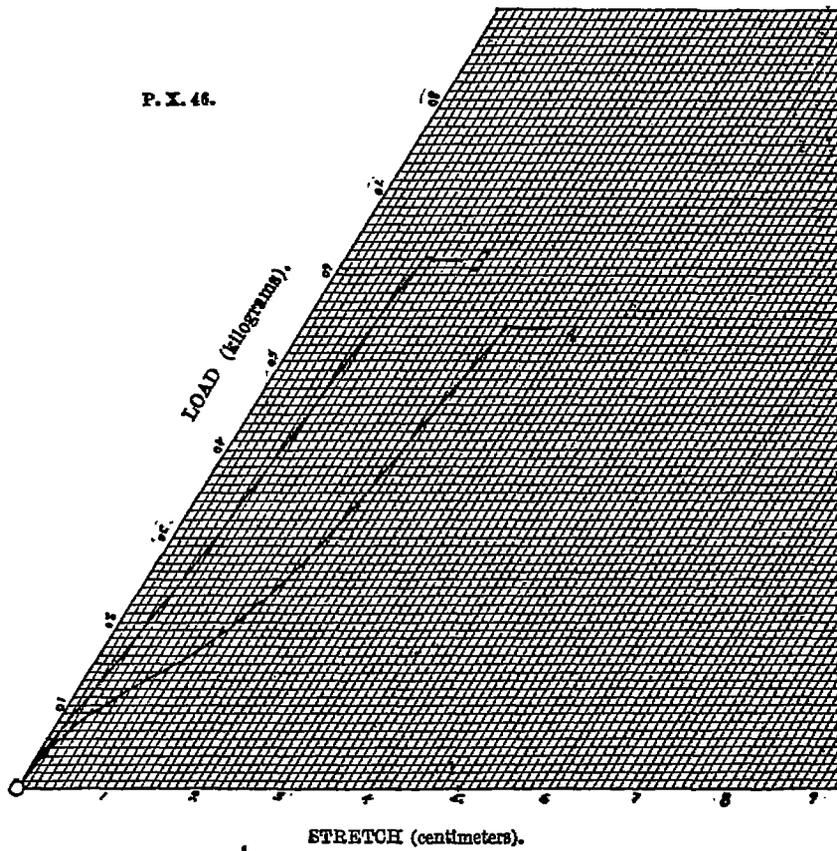
Laboratory No., G. P. 17.
 Date, June, 1917.
 Kind, No. 417, mercerized in the yarn.
 Condition in the yarn, relative humidity, 70 per cent.

	Warp.	Filling.
Threads.....	56	56
Yarn No.,	2/40	2/40
Twist per inch... singles	20	18
Twist per inch... doubling	13	12

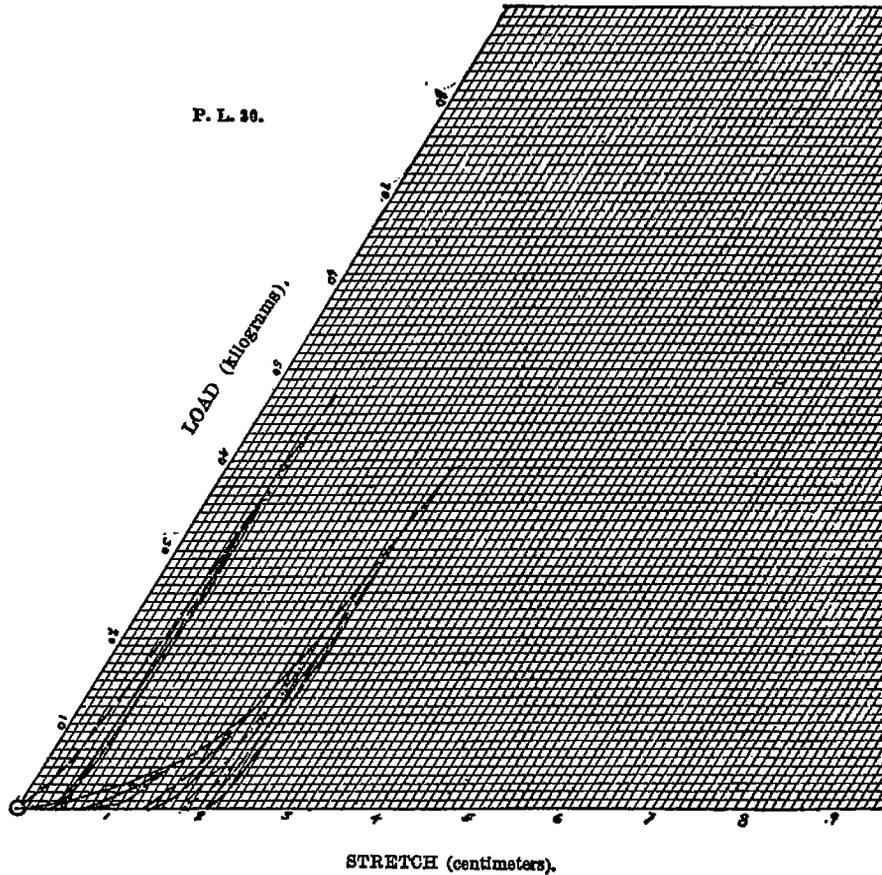
Dimensions, 20 by 2.5 centimeters.
 Weight, 4.2 ounces.
 Weave, plain



Laboratory No., P. C. 74.
 Date, September, 1917.
 Condition:
 Undoped, doped 4 coats.
 Dupont No. 22A, doped 4 coats.
 Ferry Austin B.
 Specimen dimensions, 20 by 2.5 centimeters.
 Weight:
 Undoped, 4.0 ounces per square yard.
 Ferry A, 6.1 ounces per square yard.
 Drysuit, 6.0 ounces per square yard.
 Weave, plain.
 NOTE.—Clean break—no peeling.



Laboratory No., P. X. 46.
Date, September, 1917.
Condition: Doped. Perry Austin, 4 coats.
Specimen dimensions, 20 by 2.5 centimeters.
Weight, 6.5 ounces per square yard.
Weave, plain.



Laboratory No., P. L. 30.
 Date, August, 1917.
 Kind, linen.
 Condition,

Warp. Filling.

Threads..... 92 99
 Yarn No.
 Twist.....
 Specimen dimensions, 20 by 2.5 centimeters.

Weight, 4.0 ounces per square yard.
 Weave, plain.

REPORT No. 22.

PART 2.

BALLOON FABRICS.

BY BUREAU OF STANDARDS BALLOON FABRIC COMMITTEE.

INTRODUCTION.

The life of a balloon fabric in service is important from the standpoint of efficiency, safety, and economy. It is therefore highly desirable to be able to determine quickly, in advance of balloon construction, the probable useful life of a fabric. As a contribution toward the solution of this problem the Bureau of Standards has undertaken to correlate with the actual usefulness of the fabric in service the results of various laboratory tests after exposure to conditions intended to accelerate the ageing of the material. The following reports give in a preliminary way the progress made in a typical series of life tests.

For these tests five samples of dirigible fabric and three samples of ballonnet fabric were used. The physical characteristics of these materials, such as weight and construction of the plies, are given in the following table. The weights of fabric and rubber are those given by the manufacturers.

TABLE 1.—Description of balloon fabrics.

Number of fabric.	Description.	Construction (weight in ounces per square yard).					
		Outside rubber coat.	Straight fabric.	Rubber between plies.	Bias fabric.	Inside rubber coat.	Total weight.
10850	Dirigible body.....	0.5	4.25	3.9	2.55	0.5	11.7
10852	Dirigible lower body.....	.5	2.67	3.14	2.67	.3	9.28
10853	Dirigible upper body.....	.5	4.7	3.45	2.67	.5	11.3
22151	.....do.....	.45	4.5	3.30	2.5	.25	10.25
22152	Dirigible lower body.....	.45	2.5	3.30	2.5	.25	8.25
10851	Ballonet.....	Nons.	2.05	3.0	2.05	Nons.	7.1
22150	.....do.....	Nons.	2.5	3.30	2.5	Nons.	7.5
22785	.....do.....	[Single ply of fabric; one coat of rubber.]					6.8

METHODS OF EXPOSURE AND PERMEABILITY TESTS.

By JUNIUS DAVID EDWARDS, Assistant Chemist.

(a) *Methods of exposure.*—The effect of exposure to weather (sun and rain), the effect of exposure to heat alone, and the effect of exposure to ultra-violet light are being studied. The effect of weather and heat will be reported at this time; the work on the effect of the

ultra-violet light has not yet progressed far enough for definite report.

For exposure to the weather, samples of the fabric 5 yards long were mounted on wooden frames. The frames were placed running east and west, so that the fabric had a southern exposure, with a slope of about 10 degrees, which allowed rain to drain off quickly. A good idea of the weather conditions existing during the period of exposure can be obtained from the weather records taken at the American University, Washington, D. C., and which the U. S. Weather Bureau has kindly furnished. These data are summarized in Table 2, and the number for each period will be used later in referring to this table for weather conditions. The ballonnet and dirigible fabrics were exposed over different 30 and 60 day periods; the periods for the ballonnet fabrics are numbered 5 and 8 while the same length periods for the dirigible fabric are numbered 2 and 4.

The heat exposure was made in electric ovens maintained at a temperature of 70° centigrade. The air in the ovens was kept in circulation by a fan, and it was possible to maintain the temperature approximately constant and the same within a few degrees in all parts of the oven occupied by the samples. The ovens had ventilating ports open to the air in the room; no attempt was made to regulate the humidity of the air in the oven. That the conditions in the oven were not strictly uniform, was shown by the uneven appearance and stiffness of the fabrics after several weeks' heating.

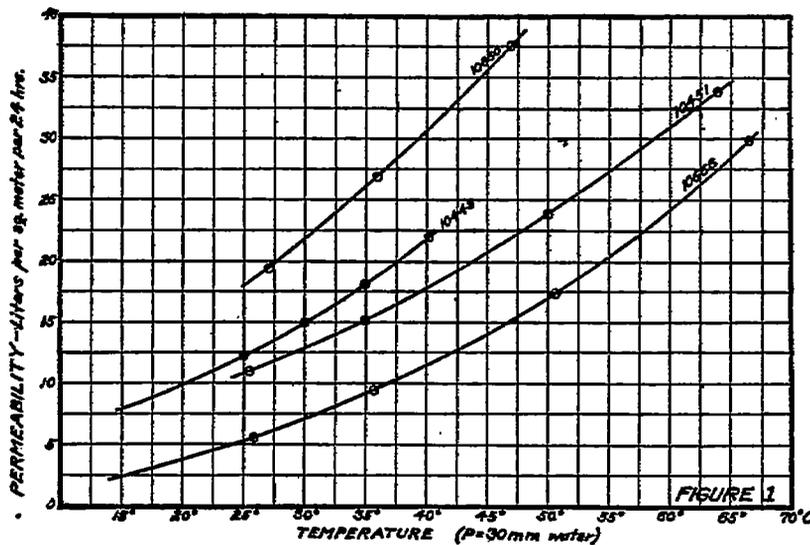
TABLE 2.—Weather conditions—Observations made at the American University, Washington, D. C.

Period.	Number of days.	Total radiation gram calories per square centimeter.	Precipitation.		Average mean temperature.
			Inches of rain.	Days on which it rained.	
(2) July 17-Aug. 15.....	30	13,684	4.65	14	77.5
(3) July 17-Aug. 30.....	45	20,635	4.90	21	78.9
(4) July 17-Sept. 14.....	60	25,320	5.92	29	74.0
(7) July 17-Oct. 14.....	90	34,809	6.24	42	68.9
(5) Aug. 18-Sept. 15.....	30	11,736	1.35	16	70.0
(8) Aug. 16-Oct. 15.....	60	19,635	2.58	28	64.0
(6) Aug. 16-Aug. 31.....	15	7,053	.24	8	79.0

(b) *Method of determining permeability.*—The apparatus designed at the Bureau of Standards for determining the permeability of fabrics to hydrogen consists of a cell divided by the fabric into two gas chambers. In one of these chambers is maintained an atmosphere of hydrogen and through the other chamber a slow current of air is passed. The hydrogen diffusing through the fabric is carried by the stream of air into a gas interferometer where the percentage of hydrogen in the air is determined by an optical method. From this percentage and the total volume of air, as determined by a meter, the rate of passage of the hydrogen through the fabric is computed. This method is the same as that used by American and English manufacturers for testing purposes except that the hydrogen is here determined by means of an interferometer instead of by combustion with subsequent weighing as water.

The permeability cell is immersed in a constant temperature water bath in order to keep the temperature of the fabric during test at the standard temperature of 25° C. The pressure of hydrogen is 30 mm. of water above atmospheric pressure. The results are calculated in liters (at 0° C. and 760 mm.) of dry hydrogen diffusing per square meter of fabric per 24 hours.

The standard temperature of test abroad is approximately 15° C. and for purposes of comparison it may be stated that the permeability of most rubberized fabrics at 15° C. is approximately 65 per cent of the permeability at 25° C.; this holds only for fabrics of moderate permeability, i. e., 10 to 20 liters. The rate of change of permeability with change of temperature for a number of fabrics, foreign and domestic, is shown in Figure 1. Fabric No. 10568 was a French fabric; the others were manufactured recently in this country.



(c) *Effect of weathering on permeability.*—After the exposure tests had proceeded for a number of weeks it was observed that the permeability of several samples had decreased considerably. This decrease was accompanied by an increase in the hardness and brittleness of the gas film which rendered it particularly susceptible to cracking. In order to detect this brittleness, which is an obvious sign of deterioration, a method of wrinkling before testing was devised. The fabric was attached to two parallel clamps and wrinkled by drawing over a metal edge at an angle of 90 degrees, ten times under a tension of 179 grams per centimeter (1 pound per linear inch). This wrinkling was without effect on the permeability of a sound fabric but was useful in detecting any hardening of the gas film (the gas tight rubber coating) where deterioration had commenced. All test pieces which were wrinkled before testing are designated in the following tables by the letter "w."

Five samples of dirigible fabric and three samples of ballonnet fabric were tested in one series, for which results are given as typical of those being secured in this work. The dirigible fabrics were rubberized on the inside, outside, and between the plies; the ballonnet fabrics were only rubberized between the plies with the exception of No. 22795 which was a single-ply fabric. Although the ballonnet fabrics are not exposed to the weather under service conditions, they were exposed in these tests to determine the effect of weathering on the gas film.

The results of the permeability tests after different periods of exposure are given in Table 3. It seems apparent from these data that the aging of the fabric usually results in a decrease in permeability. Similar observations have been made by other investigators.¹ The permeability after reaching its lowest value rises rapidly again, particularly if the fabric is wrinkled, and this point marks the end of the period of usefulness of the fabric as a gas container.

Examination of the exposed fabric frequently showed a marked increase in stiffness even to the point of brittleness. Fabrics 22151 and 22152 for example showed this very markedly after thirty days. Other evidences of weathering noted on different fabrics were the disappearance of the outside rubber films, bleaching of the fabric or rubber compounds, separation of outer fabric from the gas film, failure of seams on the bias fabric.

TABLE 3.—Effect of exposure to weather on permeability.

Fabric No.	Description.	Permeability of fabric at 25° C. (liters, per square meter per 24 hours).						
		Unexposed.	30 days (period 2).	45 days (period 3).	60 days (period 4).	90 days (period 7).	30 days (period 6).	60 days (period 8).
10650	Dirigible body.....	17.1	7.5	1.4 105.0w	1.3	3,750.0w	.....	.....
10652	Dirigible lower body.	13.6	17.6	6.3 12.6w	3.0	115.0w	.....	.....
10653	Dirigible upper body.	16.7	14.4	6.9 9.6w	11.0	16.5w	.....	.....
22151	.....do.....	15.3	25.7	55.0 2,700.0w	114.0	.....	.....	.....
22152	Dirigible lower body.	15.3	79.0	70.0 2,000.0w	33,000.0	.....	.....	.....
10651	Ballonnet.....	15.0	.....	.....	.....	.....	23.7 424.0w	44,500.0w 7,230.0w
22150	.....do.....	13.5	.....	.....	.....	.....	3.3 9.9w	15.8w 44.8w
22795	.....do.....	17.4	.....	.....	.....	.....	14.6	240.0w 1,525.0w

NOTE.—Where two values are given in the table it indicates that two test pieces were run.

From the standpoint of permeability the five dirigible fabrics may be ranked in the following order: 10653, 10652, 10650, 22151, 22152. At the end of 90 days fabric No. 10653 was still in good condition; No. 10652, although of the same composition, was of lighter weight and showed signs of deterioration at the 90-day period. Fabric No. 10650 began to show excessive leakage after wrinkling at the end of 45 days. Fabrics Nos. 22151 and 22152 failed completely under the same conditions within 30 days.

¹ Barr and Thomas, British Advisory Committee for Aeronautics, vol. 3, 197, 1912.

d. *Effect of exposure to heat on permeability.*—The results obtained after heating in an electric oven at 70° C. are given in Table 4. The results after 60 days' heating show no great differences in permeability of the five dirigible fabrics and are therefore without value as a criterion of the aging properties of these materials; indeed they are misleading. For example, fabrics 22151 and 22152, which gave evidence of rapid deterioration after only one week's exposure to the weather, were pliable and practically as gas tight as the original material even after 60 days' heating, whereas fabrics 10652 and 10653 were very stiff after 60 days' heating but still showed no excessive leakage. These differences were noticed on all test pieces and could not be attributed to unequal heating.

TABLE 4.—*Effect of exposure to heat on permeability.*

Fabric No.	Description.	Permeability of fabric at 25° C. (liters, per square meter per 24 hours).			
		Unexposed.	7 days at 70° C.	23 days at 70° C.	60 days at 70° C.
10650	Dirigible body.....	17.1	16.9	13.1w	4.1w
10652	Dirigible lower body.....	18.6	11.9	8.7w	17.2w
10653	Dirigible upper body.....	16.7	10.6	13.8w	8.8w
22151	do.....	15.8	11.0	12.8w	3.5w
22152	Dirigible lower body.....	15.8	15.5	19.9w	11.4w
10651	Ballonet.....	15.0	9.5	2.3w	60.0w
22150	do.....	18.5	11.8	12.5w	1.5w
22795	do.....	17.4	54.0	13.1w	634.0w

The permeability test after heating appears to be without value as a means of judging fabrics from different manufacturers; it may be positively misleading. This test may find some use, however, in comparing fabrics having rubber compounds of similar composition. The deterioration after heating is in some cases not as severe as after exposure in summer weather in Washington for a similar period, and it appears certain that the effect of light in the aging of the fabric can not be neglected. Any accelerated test should make use of light as one of the deteriorating elements.

The greater part of the work involved in exposing the samples and making the permeability tests was performed by Messrs. P. G. Ledig, I. L. Moore, and F. A. Smith, to whom credit should be given for the efficient performance of these tests.

CHEMICAL TESTS OF BALLOON FABRICS.

By J. B. TUTTLE, Associate Chemist.

Rubber, both crude and vulcanized, is insoluble in acetone. All crude rubber contains, however, more or less of other substances, called resins, which are soluble in acetone. In all of the high-grade rubbers this amount is small, usually from 3 to 4 per cent of the total. When rubber breaks down through aging, oxidation, etc., the decomposition products are soluble in acetone. We may therefore look upon this test as one indication of the life of rubber goods; a slight increase in acetone extract from time to time would show normal aging, while a rapid increase would indicate that the life of the rubber was practically at an end.

The method employed at the Bureau of Standards for making extractions with acetone, is as follows:

Place a 2-gram sample in an acetone-extracted S. & S. paper thimble and extract continuously with acetone for eight hours, unless the

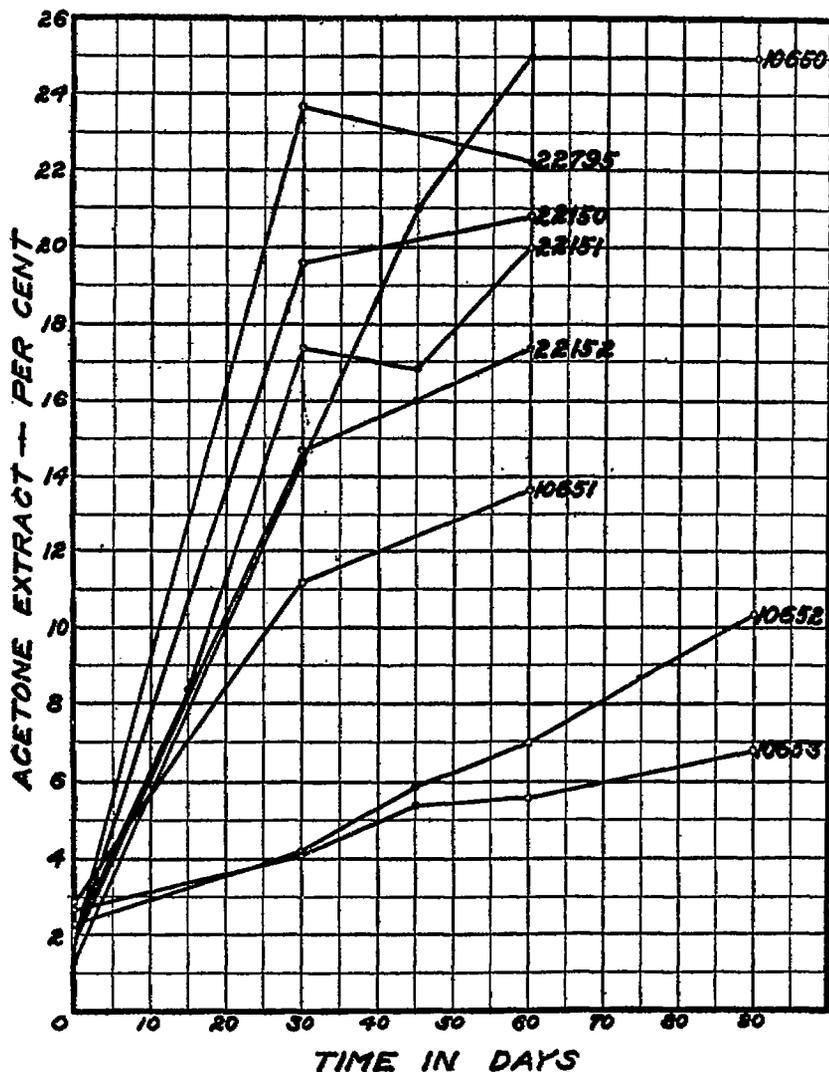


Fig. 2. EXPOSURE TO WEATHER

solution in the thimble is still colored at the end of that time, when the extraction shall proceed the next day for a further period of four hours. Transfer the extract to a tared 100 or 150 c. c. Erlenmeyer flask, using chloroform or benzene for dissolving any material which may have separated from the solvent during the course of the ex-

traction. Drive off the solvents at as low a temperature as possible, using a gentle current of air. Care must be taken to avoid allowing the flasks to stand on the steam bath after the solvent is removed, and while the air is still passing through it, since appreciable quantities of free sulphur may be lost by so doing. Dry the flask and contents in an air bath at 90° to 95° C., cool and weigh. Calculate the results to percentage.

The acetone extract thus determined always contains the free or uncombined sulphur. The amount of this sulphur is determined, and the proper correction made. The method for determining the free sulphur is as follows:

Add to the flask containing the acetone extract 50 to 60 c. c. of distilled water and 2 or 3 c. c. of bromine. Heat gently on the steam

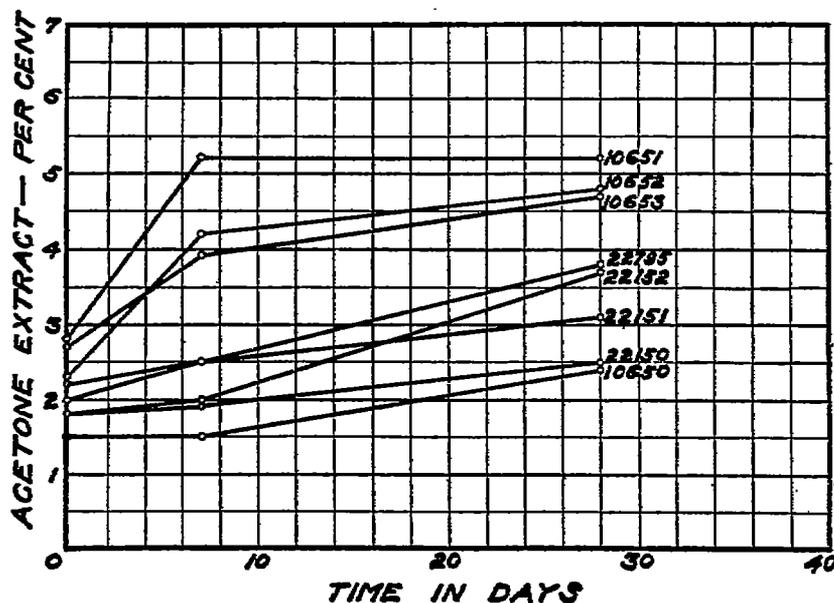


Fig. 3. EXPOSURE TO HEAT—OVEN AT 70° C.

bath until the solution is practically colorless and filter into a 250 c. c. beaker. Cover the beaker with a watch glass, heat to boiling on the steam bath, add 10 c. c. of 10 per cent barium chloride solution, and allow the precipitate to stand overnight. The next day filter the precipitate on 11-cm. 590 S. & S. filter paper. Ignite in a small porcelain crucible, using a small Bunsen flame, and not allowing the paper to inflame; cool and weigh. Calculate the barium sulphate to sulphur by means of the factor 0.1372, and calculate the percentage of free sulphur.

The amount of sulphur thus determined is deducted from the total amount of the acetone extract, and the difference is usually reported as "acetone extract—corrected."

Figure 2 gives a comparison of the rate of change in acetone extract of the various fabrics when exposed to the weather, and figure

3 gives the same comparison when the fabrics are heated in the dark. The weather exposure test closely approximates service conditions and we may therefore look upon the curves showing the rate of deterioration as an indication of the relative life of the fabrics. This has been confirmed by actual experience. It will be noted, however, in comparing figure 2 with figure 3 that the curves are not identical for the various fabrics. In the dry-heat test the most rapid change occurred in fabrics which withstood the weather exposure the best. It is obvious from this that the dry heat, or oven test, does not give any accurate data as to the probable life of balloon fabrics.

There is still a possibility that when exposed to the weather, rubberized balloon fabrics may decompose to such an extent as to lose their valuable properties (impermeability, strength, etc.) without the decomposition products being soluble in acetone. This, however, is an extremely remote possibility, and we may say, in general, that a slow rate of change in the acetone extract indicates a long life, and a rapid change indicates a short life.

PHYSICAL TESTS OF BALLOON FABRICS.

By E. D. WALLEN, Assistant Physicist.

In the study of the deterioration of balloon fabrics it is of importance to consider the change in the physical properties upon which depends the life of a balloon as regards its resistance to stresses.

The conventional balloon fabric is made up of two cotton fabrics or plies, termed "raw fabrics," cemented together by a film of rubber compound called the "gas film." The function of the raw fabric is to resist stresses and to protect the gas film from exposure to abrasion and weather.

One raw fabric, the "bias," has its systems of yarns, warp and filling, at 45° to the warp and filling, respectively, of the other raw fabric, termed the "parallel" fabric.

It has been maintained that the tearing resistance of a balloon fabric made of a parallel and bias ply is greater, and that there is a more equable distribution of stresses in the systems of yarns than with one which is made of two plies having the systems parallel to each other.

Rubber is sometimes placed on each side of the plied material to protect the raw fabric from acids which might form on the inside of the balloon, and from weather conditions, when the outside of the gas bag is not protected by an exterior protective coating.

METHODS OF TESTING.

TENSIBILITY PROPERTIES.—The tensibility properties may be best expressed in the form of a load-stretch diagram which is a graphical representation of the manner in which the fabric stretches when tension is applied in the direction of one of the systems of yarns.

The curves were obtained in the following manner:

Samples 2.5 centimeters (.985 inches) wide and 18 centimeters (7.1 inches) long were cut out of the fabric in each of the four directions of the systems of yarns and placed in the clamps of a conventional testing machine of the inclination balance type. The distance between the clamps was 10 centimeters (3.9 inches). The

fabric was then stretched at the rate of 13 centimeters (5.1 inches) per minute, and the load (or resistance of the fabric to being stretched) was drawn autographically against the stretch.

The slow speed was used in order that the results might be reasonably free from any inertia effects existing in this type of testing machine while in operation. It was observed that the variation in the breaking load of the fabric was very small when the material was tested at this speed, and that the breaking loads or tensile strengths given on the graphs are within the average variations of the individual tests. The absolute form of the curves varied even less than the breaking load.

The autographic device used consists of a light drum and an intermittent pen moving along the axis of the drum. The drum is operated by the motion of the balance arm of the testing machine and the pen by that of the pulling clamp. The correction for the motion of the clamp attached to the balance arm was made by the use of skew coordinate paper having a reference line which subtracted graphically the motion of this clamp. These correction values are proportional to the loads and were obtained by calibration. The dots produced by the intermittent pen were then connected by solid lines.

The stretch may be read at any load, either in centimeters or percentage, directly from the graphs.

BURSTING TEST.—In the bursting test the material was subjected to uniformly distributed pressure in the following manner:

Samples were clamped in a circular container of 21.6 centimeters ($8\frac{1}{2}$ inches) diameter so arranged that the fabric could be subjected to air pressure on the inside and would be free to deflect by reason of the action of the pressure. The inside edge of the clamping ring next the fabric was chamfered to a radius of 3.2 millimeters ($\frac{1}{8}$ inch) to prevent cutting of the material at the ring.

The fabric container was connected to an air reservoir in which was maintained a pressure of 150 pounds per square inch (10.6 kg. per sq. cm.). A valve in the connecting line was opened a very small and like extent for each test. This appeared to be the most feasible method of controlling the time element, since, as has been shown, if a fabric is stressed at very slow rates it makes little difference whether the fabric is stressed in equal increments of load or in equal increments of stretch. In this method of applying air pressure there is little flow and consequently the pressure may be considered as being equally distributed. The air pressure under the deflected fabric was drawn autographically against the deflection of the center point of the fabric by means of an ordinary steam indicator.

The contour of the inflated fabric at several sections perpendicular to the original plane of the fabric was determined by measuring the vertical displacement of small rods held at known and constant distances on centers. Displacements were measured to the nearest hundredth of an inch at points distributed over the surface of the fabric.

The results obtained with this improvised apparatus were such as to warrant the construction of a similar though more refined apparatus.

TEARING RESISTANCE.—Inasmuch as this discussion has to do with the deterioration of balloon fabrics whose plies are of practically the same construction, it is reasonable to assume that the change in tearing resistance may be deduced from a consideration of the change in the tensibility properties, keeping in mind that the tearing resistance is a function of the strength of the individual yarns and the number being stressed.

WEIGHT.—The weight was determined by weighing four samples of 4 square inches (25.8 sq. cm.) taken from various places in the fabric.

VALUE OF TESTS.

TENSIBILITY.—In many instances in the determination of the deterioration of balloon fabrics the tensile strength does not change materially, although a change occurs in the general shape of the load-stretch diagram. In other cases it is difficult to determine the exact point of rupture of one raw fabric, since after exposure some fabrics appear to give way slowly while being supported by the rubber film.

The tensibility curves show graphically what is actually taking place in the raw fabrics when they are stressed and, in some cases, the condition of the rubber film in its relation to the properties of the fabric.

BURSTING.—It is very difficult to visualize the resultant effect of a difference in the tensibility properties determined in the direction of the systems of yarns when these yarns are acting in conjunction with each other. For this reason it was thought advisable to subject the fabric to uniformly distributed pressure to show more readily the resultant deterioration of the material.

WEIGHT.—The change in weight of an exposed balloon fabric is apt to lead to conclusions which are not correct, since the state of the rubber films may influence the moisture content of the fabric and there may be soluble substances in the rubber compound which may be washed out.

KINDS OF EXPOSURE.—The samples were exposed to weather and oven conditions as outlined in part 2. The same tests were applied to all samples.

RESULTS OF TESTS.

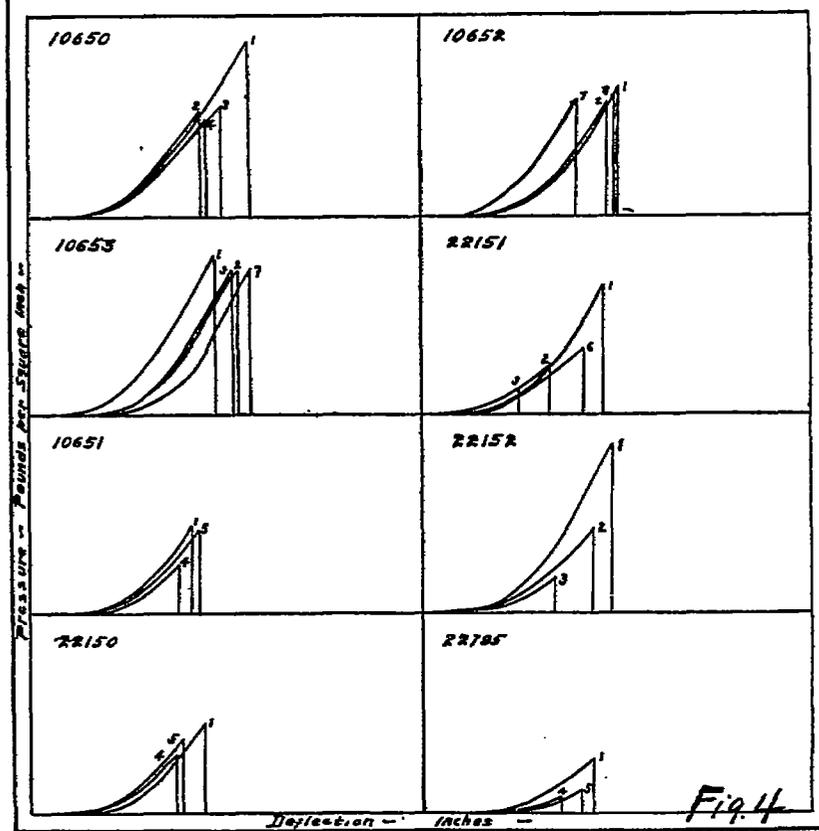
The tensibility properties are shown in the load stretch diagrams figures 5 to 12, inclusive.¹

The graphs, figure 4, show the relations between the air pressure and deflection of the center point of the fabric when the material is subjected to the bursting test, and the system of yarns which gave way first.

¹ Inasmuch as the exact designation of the system of yarns has no bearing on the purpose of this paper, the warp and filling of the several fabrics may be reversed, but the same system of threads bears the same name throughout.

BURSTING TESTS

1, No	Exposure	5, 30 Days Exposure
2, 30 Days	"	6, 15 "
3, 45 "	"	7, 90 "
4, 60 "	"	8, 60 "



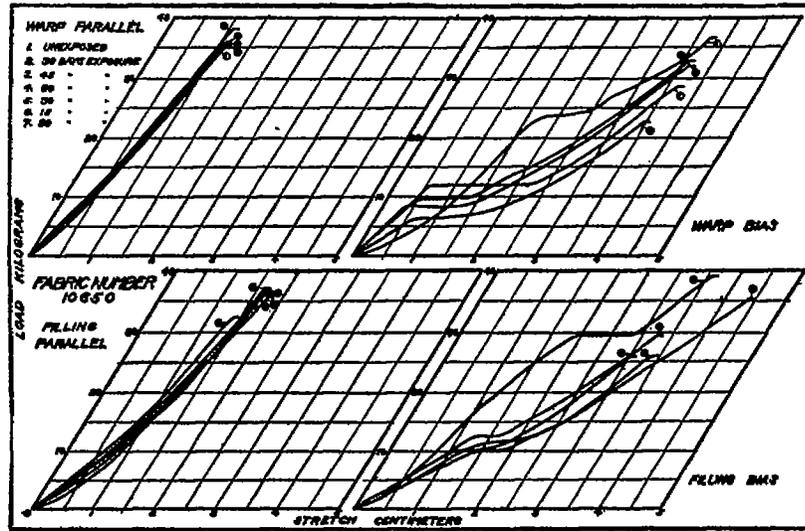


Fig. 6. LOAD-STRETCH DIAGRAM



Fig. 6. LOAD-STRETCH DIAGRAM

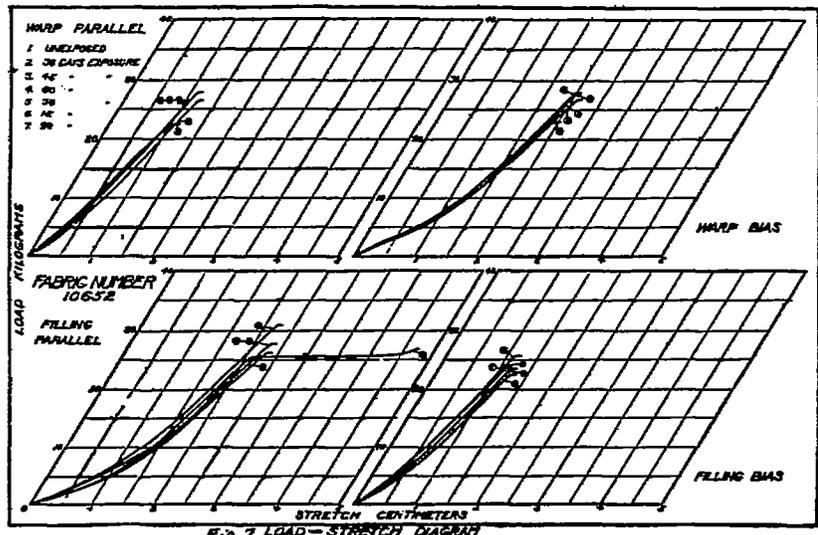


FIG. 7 LOAD-STRETCH DIAGRAM

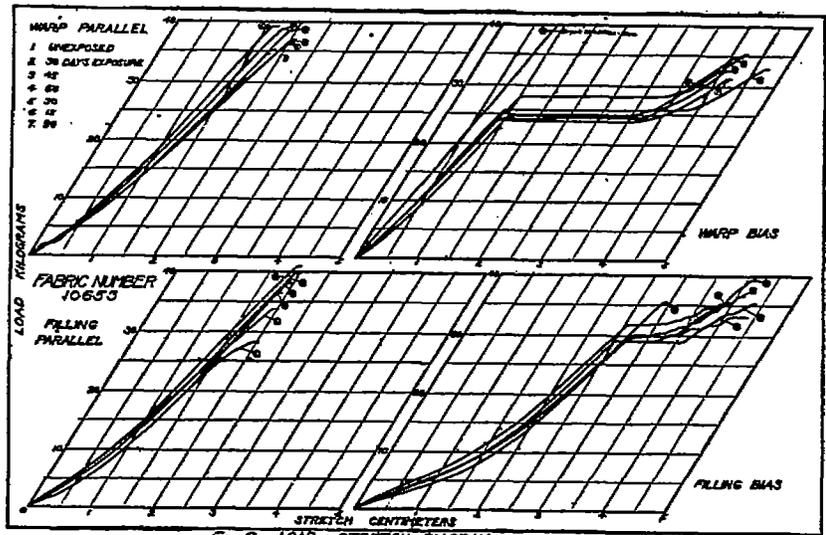


FIG. 8 LOAD-STRETCH DIAGRAM

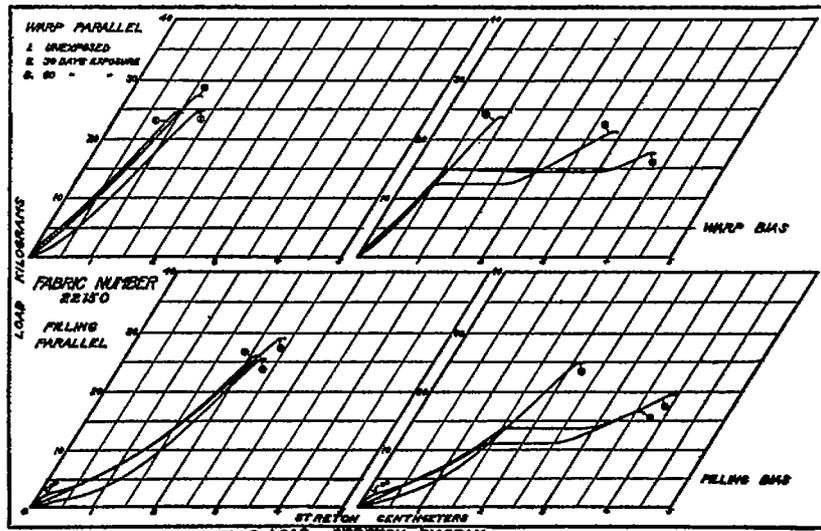


Fig. 9. LOAD-STRETCH DIAGRAM

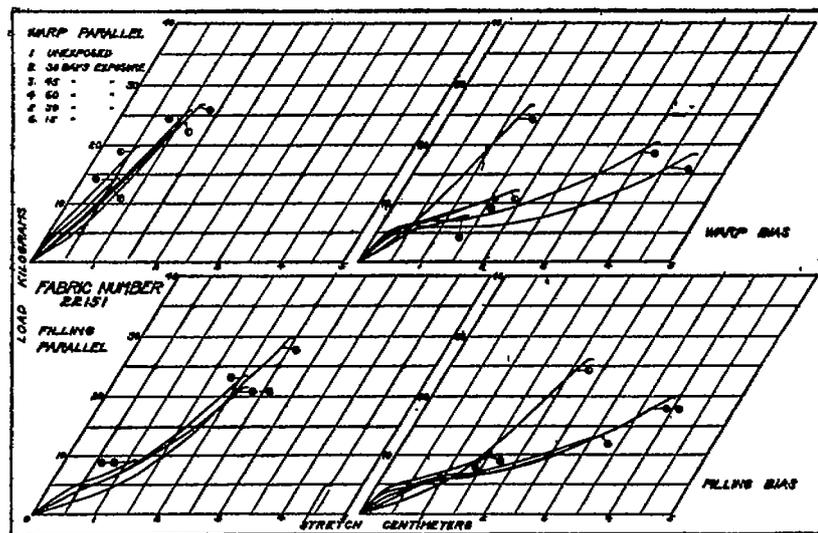


Fig. 10. LOAD-STRETCH DIAGRAM

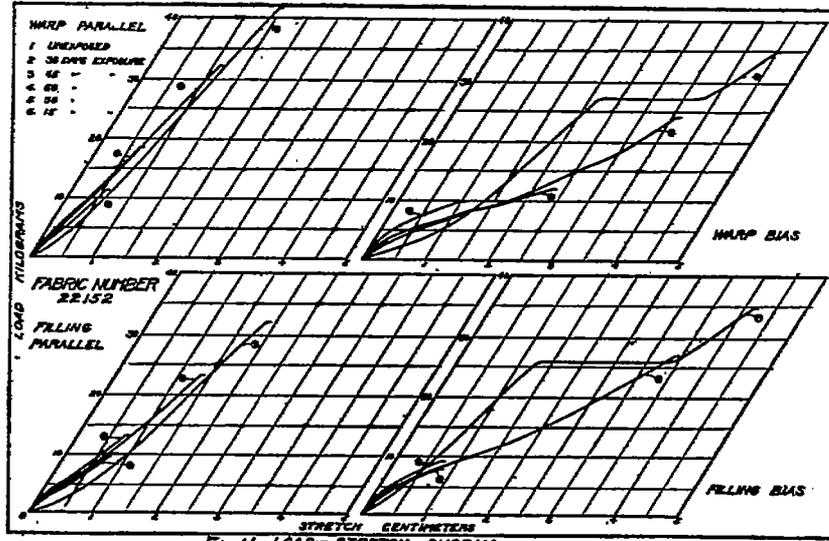


Fig. 11. LOAD-STRETCH DIAGRAM

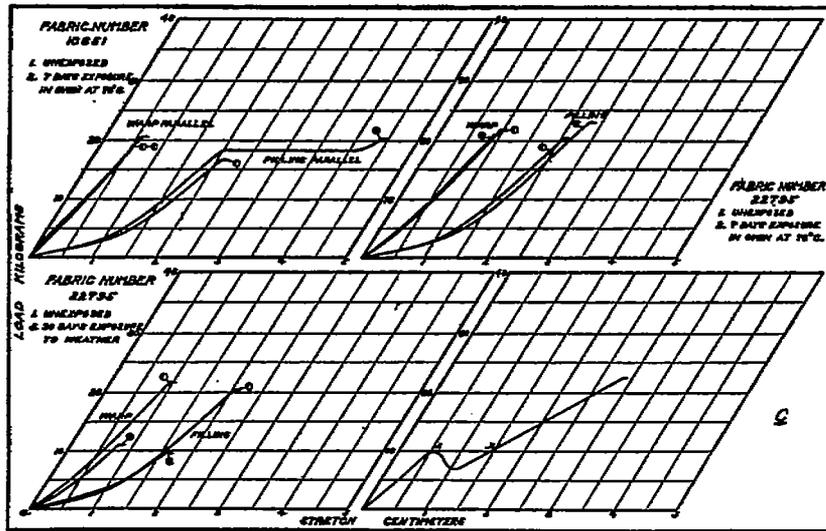


Fig. 12. LOAD-STRETCH DIAGRAM

Table 5 gives the maximum values of deflection and pressure obtained from the bursting test.

Table 6 gives the approximate calculated tension in the material at the time of bursting.

TABLE 5.—*Dirigible fabric.*

[W.—B=Warp bias; W.—P=Warp parallel; S=System of yarns giving way first; P=Pressure pounds per square inch; D=Deflection of center point inches.]

LOWER BODY.						
Fabric No.....	10652			22152		
Days exposure.	P.	D.	S.	P.	D.	S.
0.....	23	1.7	F. B.	30	1.6	W. S.
15.....	22	1.7	F. B.			
30.....				15	1.5	W. S.
45.....	20	1.6	F. B.	6	1.1	W. S.
60.....						
90.....	18	1.2				

UPPER BODY.									
Fabric No.....	10653			22151			10650		
Exposure.	P.	D.	S.	P.	D.	S.	P.	D.	S.
0.....	28	1.6	W. B.	22	1.6	W. S.	31	1.8	W. P.
15.....	25	1.8	W. B.	12	1.4	W. S.			
30.....	25	1.8	W. B.	8.5	1.1	W. S.	19	1.5	W. P.
45.....	25	1.8	W. B.	8.6	.65	W. S.	20	1.7	W. P.
60.....	25	1.8	W. B.				17	1.5	W. P.
90.....	25	1.9	W. B.				16	1.3	W. P.

BALLONET.									
Fabric No.....	22150			22795			10651		
Exposure.	P.	D.	S.	P.	D.	S.	P.	D.	S.
0.....	16	1.5	F. B.	10	1.5	W.	16	1.5	W. P.
15.....									
30.....	13	1.3	W. F.	4.5	1.4	W.	15	1.4	W. P.
45.....									
60.....	10.5	1.3		3.5	1.2		3.5	1.3	
90.....									

TABLE 6.—*Dirigible fabric.*

[T=lbs. tension per inch of width; Tm=Kg. tension per 2.5 cm. of width.]

LOWER BODY.						
Fabric No.....	10652			22152		
Exposure days.	T.	Tm.	Per cent decrease.	T.	Tm.	Per cent decrease.
0.....	233	104	0	320	143	0
15.....	220	98	5.6			
30.....	214	96	8.0	171	76	46.0
45.....				92	41	77.0
60.....						
90.....	250	112	17.0			

¹ Increase over original.

TABLE 6.—Dirigible fabric—Continued.

UPPER BODY.

Fabric No.....	10653			10650			22151		
	T.	Tm.	Per cent decrease.	T.	Tm.	Per cent decrease.	T.	Tm.	Per cent decrease.
0.....	300	134	0	300	134	0	235	105	0
15.....	242	108	20	216	97	28	144	64	39
30.....	242	-----	20	203	91	32	130	58	45
45.....	242	-----	20	194	87	35	142	63	40
60.....	242	-----	20	208	93	31	-----	-----	-----
90.....	225	108	25	-----	-----	-----	-----	-----	-----

BALLONET.

Fabric No.....	22150			22795			10651		
	T.	Tm.	Per cent decrease.	T.	Tm.	Per cent decrease.	T.	Tm.	Per cent decrease.
0.....	183	82	0	114	51	0	183	82	0
15.....	-----	-----	-----	55	25	52	180	80	2.0
30.....	170	75	7	-----	-----	-----	-----	-----	-----
45.....	-----	-----	-----	49	22	57	110	49	40.0
60.....	150	67	18	-----	-----	-----	-----	-----	-----

DISCUSSION OF THE RESULTS OF THE TESTS.

Tensibility.—It will be noted that some of the curves of the load-stretch diagrams are not continuous, but have an abrupt change indicating the breaking of the systems of yarns being tested. This is followed by a straight line which terminates at another point of abrupt change. The balance arm of the testing machine is held at the position of the maximum load, between the two points of abrupt change, and hence does not show the manner in which the biased systems of yarns adjust themselves. The true shape of the curve is shown in diagram (C) figure 12. Points A and B in all other diagrams are connected with a straight line. The part of the curve above the point A has no value except for checking the strength of the ply cemented to and lying at 45° with the system of yarns being tested. For this reason only the part of the curve below the point A will be discussed.

The lower part of the load-stretch diagram of the raw fabric up to about 5 kg. is very nearly a straight line, and beginning at this point and extending to about 10 kg. there is a rapid change in the rate of curvature; beyond the termination of this part of the curve the change in the rate of curvature is again very small. Thus, a load-stretch diagram or tensibility curve may be spoken of as consisting of three sections to be known as 1, 2, and 3, respectively.

The shape of section 1 is influenced almost entirely by the fabric characteristics, and is a function of the diameter and number of yarns, the resistance of the yarns to bending, and the relation of the one system of yarns to the other. The result of these relations,

commonly termed "crimp," may be expressed as the increased length of the yarns due to interlacing.

At the end of section 1, the crimp has been taken out to such an amount that the characteristic of the yarn has begun to predominate, and there is at the end of section 2 an adjustment of the fabric.

The shape of section 3 is influenced by the yarn characteristic in its constrained position. If the crimp is very small in one direction, this portion of the curve will be parallel to the load-stretch diagram of an equal number of unwoven yarns, and there is a divergence from the diagram of the yarns as the crimp of the fabric is increased. Hence it is possible to assign reasons for the change in the sections as compared with the diagram of the fabric before exposure.

If, as cited below, there is a radical change or reversal in the curvature of section 1, and a slight change in the other sections, or more particularly in section 3, the cause must lie in certain constraining forces which are not existent in the raw fabric. This condition is shown in the 60 days' exposure curve of fabric 10651. In this case the rubber film was found to be cracked at the reversal of the curvature of the lower portion of the curve, and it is logical to assume that the constraint was due to stiffening of the rubber.

Sometimes there is a merging of the three sections, as in the diagram of the 30-days exposure of fabric 10651. It is probable that this is caused by constraining forces of the same nature as those just referred to, which persist throughout the entire lower portion of the curve, unaccompanied by any noticeable deterioration of the raw fabric.

A consideration of the load-stretch diagrams of the warp parallel of fabric 22151 and 22152 and the warp and filling of 22150 and of fabric 22795 before and after exposure, would appear to demonstrate that the deteriorations of the raw fabric were made evident only by the decrease in the tensile strength, since no change is evident in shape of the curves.

There are four types of deterioration which might exist in the balloon fabric and which may appear in the load-stretch diagram:

1. One ply deteriorating.
2. Two plies deteriorating.
3. The rubber film deteriorating to such an extent that its stretch fails to follow that of the fabric.
4. Combinations of three with either one or two.

Deterioration of one ply is shown in the curves of fabric 22150, 30 days exposure, where the bias ply has lost considerable strength and the parallel fabric has remained constant. In every case an unprotected ply which has been exposed to the weather and directly to the sun has deteriorated rapidly.

The condition of the two plies deteriorating without an apparent deterioration of the rubber film was not observed in these experimental fabrics.

An instance of two plies deteriorating accompanied by a discernible deterioration of the rubber film is shown in the curves of fabrics 22151 and of 22152. In the bias curve of these fabrics, it is difficult to determine the breaking point of the system of yarns being tested, since there appears to be an incipient breaking down of this system of yarns at the lower portion of the load application.

The deterioration of the rubber film as discussed in this portion of the paper has bearing on the permeability only in so far as

change in the lower portion of the load-stretch diagram may be taken as an index of the state of the film as regards its ability to remain intact up to the breaking point of the fabric.

BURSTING TESTS.—The determination of the contour surface of the fabric at the time of the bursting leads to the conclusion that any vertical section taken through the center point conforms very nearly to an arc of a circle, or that the curvature of the surface is the same throughout. In some instances slight deviations from this condition were noted.

The tension in the fabric may be approximately calculated by the use of the simple formula for the tension in a hollow sphere of thin walls which is subjected to uniformly distributed pressure from the inside.

$$T = \frac{P R}{2}$$

When T = tension in pounds per linear inch.
 R = radius of curvature in inches.
 P = pressure in pounds per square inch.

The bursting tests show that there are three general cases to be considered.

1. A decrease in the tension of the fabric at the time of bursting during the early part of the exposure followed by a condition of equilibrium which may be caused by the following conditions:

(a) One ply deteriorating and the other remaining constant.

(b) Both plies deteriorating very rapidly at first, followed by a gradual decrease which may be due to the changed condition of the rubber film.

2. A steady decrease which is probably caused by a deterioration of the entire balloon fabric. This is probably the result of the liberation of a free acid from the rubber films.

3. No apparent change in tension.

The condition of 1-a is shown in the bursting tests of fabric 10650, which apparently has lost considerable of its life at the end of 45 days, and at the end of 90 days is somewhat better. In this case it is probable that the condition of the rubber film is playing an important part in the increase in strength.

Fabric 22151 is a case of 1-b in which both of the plies are very rapidly decreasing up to 30 days, while after time there appears to be an increase. From the load-stretch diagrams of this fabric it is quite evident that the condition of the rubber film is increasing the strength of the material.

A steady decrease of tension of the fabric, as noted in case 2, is clearly shown in the fabric 22152.

The condition of 3 is shown in the fabric 10652, which is not suffering from exposure to the weather and is apparently growing better with age. In this case it is probable that the rubber film is increasing the strength.

SUMMARY.

From a study of the results obtained on fabrics exposed to weather conditions, given in the body of this report, it will be seen that the changes in values obtained in testing vary in the same way in permeability, acetone extract, bursting strength, and the curvature of

the tensibility curves. Thus, the smallest changes occur in those fabrics which in actual service show the longest life, and the greatest changes in those which show the most rapid deterioration. We may therefore look upon any or all of these tests as reliable indications of the changes which would take place under service conditions.

The results after exposure to dry heat fail to show any great differences between the various fabrics, although as stated above, we know that in actual service these differences exist. The curves plotted from these results do not correspond to the tests obtained on samples exposed to the weather. From this it is obvious that the dry heat test is of little or no value as a means of predicting the life of balloon fabrics. It is possible that the introduction of moisture in these tests would so change conditions as to afford a means of determining the relative life of the fabrics. Experiments along this line are now under consideration and the results will be reported at some future date.

There still remains the possibility that artificial light, containing a large percentage of the ultra-violet rays, either with dry samples or where an excess moisture condition is maintained, will give results closely approximating weather conditions. If this proves to be true, it is probable that this test will be of considerable value, since it would make possible the obtaining of results in a much shorter time than at present.