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# REPORT No. 6.

## IN TWO PARTS.

# INVESTIGATIONS OF BALLOON AND AEROPLANE FABRICS.

By THE UNITED STATES RUBBER COMPANY, GENERAL LABORATORIES.

## Part I.—BALLOON AND AEROPLANE FABRICS.

By WILLIS A. GIBBONS and OMAR H. SMITH.

## Part II.—SKIN FRICTION OF VARIOUS SURFACES IN AIR.

By WILLIS A. GIBBONS.

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# CONTENTS OF REPORT No. 6.

## PART 1.

### BALLOON AND AEROPLANE FABRICS.

Page.

Aeroplane fabric ........ 140
  Materials used ........ 140
  Strength, stretching, and aging tests ........ 142
  Absorption of water ........ 144
  Fireproofing ........ 145
Balloon fabric ........ 145
  Materials ........ 145
  Strength and aging tests ........ 147
  Permeability of balloon fabrics ........ 147
Tests on balloon and aeroplane fabrics ........ 150
  Tearing tests ........ 150
  Surface friction tests ........ 151

## APPENDIX.

Linen fabrics ........ 153
Stretching tests, description, data, and curves ........ 154
Tearing tests, description, data, plates, and curves ........ 160
Cotton fabrics, discussion, data, and curves ........ 166
Permeability tests, description, data, and curves ........ 168
Surface friction tests, data, and discussion ........ 174

## PART 2.

### SKIN FRICTION OF VARIOUS SURFACES IN AIR.

Introduction ........ 176
Experimental ........ 178
Corrections ........ 178
Surfaces ........ 178
Results ........ 180
Values of K and N ........ 181

# REPORT No. 6.

## PART 1.

## BALLOON AND AEROPLANE FABRICS.

By Willis A. Gibbons and Omar H. Smith.

Note.—Although usually associated, for obvious reasons, balloon and aeroplane fabrics have actually become so dissimilar in many respects, such as materials of construction and requirements for satisfactory results, that for the most part the two will be discussed separately. The tearing and surface friction tests, being common to both, are exceptions to this rule. The plan followed as far as possible in this report has been to give first the results of the various parts of the investigation, with such descriptive matter, data, and plates as are necessary to make the results clear. The data and other details are given in the appendix. For convenience the data is grouped somewhat differently in the appendix, without, it is thought, causing any confusion.

## SUMMARY.

The following conclusions are drawn from the results of our tests hereinafter described. It must, however, be remembered that they are based almost entirely on experiment, so care must be used in applying them extensively until they have been tried in actual practice.

### COATING MATERIALS.

(1) By proper treatment fabrics can be made noninflammable even though coated with cellulose nitrate varnish followed by spar varnish.

(2) The ordinary cellulose acetate dopes do not make fabric fireproof, although themselves noninflammable. This applies particularly in the case of fabrics doped, then coated with spar varnish.

(3) Fabrics coated on one side with rubber, with the other side doped, would probably give a satisfactory tightening effect and at the same time resist damp weather better.

(4) Maximum efficiency can apparently be best obtained by not stretching the cloth too tightly on the wings before coating.

(5) Stretching and tearing tests give valuable information regarding the suitability of fabrics and should be considered in addition to the tensile strength. The area inclosed by the stretch-load, curve, representing the work done to break the strip, gives an idea as to its resistance to shocks, etc.

### BALLOON FABRICS.

(1) Permeability increases greatly with temperature—about 4 per cent per degree C. for samples tested.

(2) Tests made on fabrics with varying weights of rubber indicate that permeability is not directly proportional to the thickness of the layer.

(3) Tearing tests show a great superiority of bias over parallel doubled fabrics.

### SURFACE FRICTION TESTS.

(1) For very smooth surfaces the surface friction varies with the 1.8–1.85 power of the velocity; the exponent increases with the roughness, approaching 2 for fabrics with nap on the surface.

(2) Varnished fabrics have nearly as low a resistance as plate glass. The resistance increases greatly as the surface becomes rougher from the presence of loose fibers.

## Part I.—AEROPLANE FABRIC.

### I. MATERIALS USED.

By far the greater part of the aeroplanes in use to-day have wings made of a textile fabric, usually linen, coated with a more or less waterproof, practically nonelastic varnish. This is ordinarily some form of cellulose acetate, or less frequently cellulose nitrate, with more or less softening material added, and some suitable solvent.

It is ordinarily the practice to apply three or more coats of this varnish, rubbing down with sandpaper after the coating is dry, after which one or two coats of high-grade linseed oil varnish, preferbly a spar varnish, are applied.

#### 1. COATINGS.

The cellulose acetate or nitrate lacquer is chiefly useful because it acts as a sort of waterproof sizing, which shrinks the cloth more or less, and prevents it from changing in tension with the hygroscopic conditions of the atmosphere. The spar varnish protects this layer, which often shows a tendency to peel, and makes the wing more waterproof.

This form of treatment is convenient, and the materials fairly easy to obtain. On the other hand it could hardly be called permanent; the varnish or dope, as it is commonly called, must be applied to the wings of a machine every few weeks, if the machine sees much service.

Another defect noted probably more by the United States military branches than abroad, is that due to deterioration of the underside of the fabric from moisture and bacteria. The dopes owe their shrinking action to the fact that they are colloids, and as such, when applied to the cloth, do not penetrate but remain on one side. As the solvent evaporates, the gel decreases in volume. The most evident decrease is of course in the thickness of the layer, but there is naturally a tendency for the other two dimensions of the layer of drying varnish to decrease, causing the well known shrinking effect. Other colloids produce the same effect; for example, glue. Another example is the common gummed label, which being unable to shrink, curls up. At Vera Cruz it was found that there was considerable tendency for the uncoated side of the wings to rot, owing to this lack of penetration. On the other hand, those varnishes which penetrate do not produce the shrinking effect.

## 2. FABRICS.

Of the fabrics linen is the most satisfactory. Ramie and cotton have been used to some extent, but the former is difficult to obtain and the latter does not take the varnish so well as the linen and tears much easier.

Practically all of the linen suited for this purpose comes from abroad, chiefly from Ireland. An investigation of the relative weights and strengths obtainable is, particularly at the present time, rather difficult to make complete. Added to this there is the difficulty of obtaining material of exactly the same grade from time to time. The fabrics in general use weigh 3¾ to 4¾ ounces per square yard, and have a tensile strength, tested at about 65 per cent humidity, of from 60 to 70 pounds per inch for the lighter weight to 100 pounds per inch for the heavier weight.

In the following experiments we have used two grades of linen, No. 1, called high grade, being about the best material immediately obtainable in sufficient quantities for our work, and No. 2, medium grade. The No. 1 weighs 4.6 ounces per square yard and has a tensile strength of about 90–95 pounds per inch warp and 60 pounds filling. The No. 2 medium grade weighs about 3.8 ounces per square yard and has a strength of about 65 pounds warp, 50 pounds filler.

## DOPES.

The varnishes or dopes used were three representative products obtained in this country. The cellulose acetate varnishes are probably far from perfect, owing to the difficulty of obtaining a satisfactory product in this country. We understand that the latest European material of this sort is a vast improvement on anything heretofore produced.

The solvents for cellulose acetate commonly used are acetone or tetrachlorethane. The latter is said to be rather dangerous on account of its poisonous properties, and care should be used to allow the vapors, which are heavier than air, to pass through ventilating openings in the floor.

Mention must also be made of a material, the use of which in Europe has been mentioned in news reports. This is a transparent celluloid made of cellulose acetate compounded with a camphor substitute and used in the form of a thin, transparent, noninflammable sheet. These are used for wings instead of cloth, and are said to be very difficult to see at a height of a few thousand feet. Whether this is so or not there is of course this advantage, that the pilot can have a much wider field of view than with ordinary wings.

We were fortunate in obtaining sheets of this material. They are of practically the same strength in both directions.

| Thickness. | Weight (ounces per square yard). | Tensile strength (pounds per inch), about— |
|---|---|---|
| 10/1000 | 9.33 | 55 |
| 64/1000 | 59 | 325 |

Complete data are given elsewhere.

While the thickest sheets are of course too heavy for wings, they might be used for other purposes as, for example, flooring.

## II. STRENGTH, STRETCHING, AND AGING TESTS.

### 1. STRENGTH.

The samples on which these tests are based were made in two ways: (1) The method used in most cases, except when otherwise specified: The linen was stretched moderately on a frame about 3 by 4 feet, and fastened by tacking. The dopes, etc., were applied to this. (2) The second way (used only in special cases): The linen was doped without first being stretched on a frame.

(1) In general there is a gain in tensile strength due to the dope. No added effect was observed from the varnish.

(2) With a high-grade linen No. 1, the increase in strength amounted to about 10 to 15 per cent. With a medium grade, the increase, particularly in the filler, was much higher, about 40 to 60 per cent.

(3) Tests made on high-grade linen No. 1, coated without being stretched on a frame, showed a much higher tensile increase—in the neighborhood of 40 per cent in some cases. In the first samples, stretched fairly tight before coating, there was evidently not much shrinkage, in the latter samples the cloth shrunk at will, in some cases 3 or 4 per cent. In specifying the increase in strength due to dopes, the method of coating is therefore of importance. The first tests probably approach more nearly the conditions of use on the aeroplane.

(4) Linen coated with rubber, with or without dopes, is stronger than uncoated linen.

(5) Medium-grade linen shows a greater increase in tensile than high-grade linen, in some cases about twice as great an increase being observed.

### 2. STRETCH.

The stretch at different loads was measured for several different samples and curves plotted. The following points were noted:

(1) The stretch is less up to a certain load with coated fabrics than with the same fabric uncoated.

(2) There is no decided difference between cellulose acetate and cellulose nitrate dopes. The latter is usually supposed to give less shrinking than the acetate. It is possible that this view arises to some extent at least from the fact that fabrics coated with the

nitrate varnish are often more flexible than the others, and therefore appear, on a frame, less taut.

(3) Spar varnish slightly decreases the stretch.

(4) Linen coated with rubber has a greater stretch than the linen without rubber, the latter being, for example, 13 per cent at 96 pounds break, the former 16½ per cent at 100 pounds.

(5) Medium-grade linen, while it acquires a relatively greater strength increase due to coating, has both coated and uncoated a lower ultimate stretch.

| | Break. | Stretch. |
|---|---|---|
| | *Pounds.* | *Per cent.* |
| High-grade linen No. 1 | 90–95 | 13¼ |
| High-grade linen No. 1 coated with varnish 1877 | 100 | 14½ |
| Medium-grade linen No. 2 | 65 | 11 |
| Medium-grade linen No. 2 coated with varnish 1877 | 78 | [1] 10.7 |

[1] By extrapolation.

### 3. EFFICIENCY.

While it is desirable to have a wing material which will not easily sag, at the same time it is also important to have a fabric yield rather than break under load. A material which has this ability will often by yielding reduce the stress, and so stand usage which would otherwise be disastrous.

A convenient index of this, which for want of a better term we call the efficiency of the fabric, is the work required to break a piece say 1 inch wide and 12 inches long. This is represented by the area included by the stress-stretch curve. We have calculated this value for the various materials examined. The details and data are given elsewhere, but the following points may be mentioned here, observations being based on breaking in the direction of the warp, since the fillers do not show such marked differences.

(1) When the linen is fastened to a frame under fairly strong tension, as would ordinarily be done in covering a wing surface, and then coated, the work required to break a piece of given dimensions is not sensibly greater than that to break the uncoated material, in spite of the fact that the actual tensile strength of the linen seems to be higher after coating. This holds for high and medium grade linens.

(2) Linen coated under no tension required about two and one-half times as much work to break as uncoated linen. The greater stretch and increased tensile strength are both responsible for this.

In view of this the suggestion is made that there is probably some advantage in not using any more tension than is necessary in fastening the fabric to the frames before coating. The dopes have considerable shrinking power, measured linearly, and by allowing the cloth to shrink a certain amount the slack will be taken up and at the same time a greater efficiency obtained. A stress from collision, etc., will then have a chance to exhaust itself without breaking the cloth, since the cloth can "give" and thus adjust itself to decrease the amount of the stress.

We understand that one manufacturer of the varnish at least recommends this. We have also been told that in some cases, as when a wing collides with an obstruction in landing, a dent may be formed in the fabric without breaking, this dent later disappearing. Since the varnish coating is noncrystalline, and can really be considered in a sense a supercooled liquid, it seems quite likely that there may be some flowing action permitting a slow readjustment of this sort.

(3) The use of spar varnish seems to have no decided effect on the efficiency.

(4) Rubber on one side of the linen with various coatings showed an efficiency about 75 per cent higher than that of linen without rubber, coated on frames. This is of course partly due to the greater stretch of such a fabric, as already noted. It would be interesting to find by practical experiment whether a fabric with rubber on one side can be made to shrink sufficiently for use on a wing. From our small experiments it seems likely that it would be satisfactory. If so, it would have the advantage of being protected on the under side, a matter of consequence in certain localities, as already shown.

### 4. AGEING.

Samples subjected to continuous exposure for three weeks in a location such that the material felt the full effect of sun and weather throughout the day gave the following results on tests:

(1) The tensile strength was 66 to 75 per cent of the original.

(2) In all cases samples had been greatly affected by the weather, in appearance and feeling. Spar varnish coatings cracked and pealed; samples doped but not coated with spar were more or less scrubbed off by the weather and had evidently deteriorated.

(3) In several cases samples doped and varnished with spar varnish showed a smaller decrease in tensile than those unvarnished, but the effect was not so pronounced as would be expected.

(4) Cellulose acetate coatings seemed more affected by the ageing than cellulose nitrate. This is probably due to the hygroscopic character of the former material, and to the ease with which oils are blended with the latter, making it more waterproof.

## III. ABSORPTION OF WATER.

Samples were first weighed, then dried at 95–100° C., and reweighed, after which they were tested. One piece of each was soaked in water at an average temperature of 25° C., another was hung in a saturated atmosphere at the same temperature—for two weeks in both cases. The samples were removed, surface water wiped off the ones that had soaked, after which they were weighed in a weighing bottle. They were then dried at 95–100° C., and reweighed. These data gave the amount of moisture normally present, the amount of water taken both by soaking, and by standing in moist air, and the amount of material washed out by soaking in water. The following results were obtained:

(1) Loss from soaking amounts to 3 to 7½ ounces of the weight of the sample.

(2) Compared with dried samples, fabrics exposed to saturated atmosphere showed 6 to 13 per cent moisture.

(3) Soaking caused the samples to take up 30 to 60 per cent of water.

(4) Cellulose acetate coatings suffer more from soaking than cellulose nitrate.

(5) Fabrics coated with rubber on one side, and doped on the other side, show a smaller absorption of water on soaking, and a smaller increase in weigh due to moisture taken up on standing in a saturated atmosphere than unrubberized fabrics. The effect of spar varnish, in preventing the absorption of water was here very apparent.

### IV. FIREPROOFING.

Tests on fire resisting properties of various fabrics were made, to find the effect of the different coatings, and to investigate the possibility of impregnation of fabric with fireproofing materials.

*Method of test.*—A strip of the fabric ¾ inch wide, was held horizontally, coated side up, and the end touched to a Bunsen flame for a distance just sufficient to ignite. The time required to burn back for a distance of 3½ inches was observed; in cases where the flame was extinguished before this point was reached, the actual distance was noted. Care was taken to avoid drafts.

(1) All coated fabrics not otherwise treated were inflammable; that is, the piece continued to burn after the source of heat was removed.

(2) Spar varnish seemed to retard the burning of fabric coated with cellulose nitrate, and to accelerate it in the case of fabric coated with cellulose acetate.

(4) Fabrics impregnated with ammonium chloride and ammonium phosphate were more fireproof than those impregnated with boric acid. In every case the first two prevented the flame from being self-propagating even when the fabric was doped with cellulose nitrate.

(5) It is interesting to note (see appendix) that fabric impregnated with ammonium chloride has an increased initial tensile strength, but deteriorates more rapidly on exposure. This is probably on account of hydrolysis of the cellulose (fabric). These experiments lead one to believe that by further investigation a thoroughly statisfactory material may be found, which will make fabric fireproof and at the same time not injure it.

## Part II.—BALLOON FABRIC.

### I. MATERIALS.

Cotton is the most widely used fabric for balloons, in spite of the fact that it is one of the weakest textile fabrics. Silk, the strongest textile fabric, is used to some extent in France and Italy, when lightness is the most important feature. In Germany, it is usually considered dangerous, owing to its electrostatic properties. Its high cost is another objection, when large amounts are needed, as in a Zeppelin type dirigible.

Ramie has been used, but is reported to be unsatisfactory, owing to the difficulty in rubberizing.

Linen has been used, with success, and on account of its greater strength possesses considerable advantage over cotton. The greater tearing resistance of this material as compared with cotton is particularly important. On the other hand, as already stated, it is more difficult to obtain, made according to specifications, than cotton.

In large balloons, rubber is used almost without exception. Other materials are less permeable to hydrogen, but none possess the same properties of adhesion, ease of working, and flexibility. Several layers of fabric can be used, thus increasing the strength and gas-tight properties of the material, whereas oiled fabrics are ordinarily used in a single layer, and to keep this tight a thin closely woven fabric must be used. Furthermore, oiled fabrics are subject to change from heat and cold and must be handled with care. They are, however, cheaper than rubberized fabrics.

We have obtained various cotton fabrics suitable for use in balloon cloth, and from the tests on these, and also from published data of tests made in Europe, have endeavored to establish some relation between the weight and maximum strength obtainable at that weight. Differences in testing conditions, such as humidity and method of testing, not usually specified, cause a certain variation, so the probable limits of strength of each weight are given.

Until recently it was very difficult to obtain a satisfactory fabric made in this country. Labor and other conditions in Europe have permitted a greater concentration upon the spinning and weaving of such fabrics. The results have been that until recently no cotton fabrics comparable to those made in Europe could be obtained.

Recently there have been produced in this country fabrics which from the standpoint of weight and strength are probably as good as those made in Europe. It is to be hoped that the same perfection in spinning and weaving may also be obtained.

In the former operation cotton manufacturers usually admit the superiority of European material, but probably in time this can be met. This point is important, in order to get a fabric as free from flaws as possible.

The mean results of our tests and those from abroad would indicate the following:

| Weight of fabric. | Strength warp and filler. |
|---|---|
| *Ounces per square yard.* | *Pounds per inch.* |
| 2 | 30 |
| 2½ | 42 |
| 3 | 53 |
| 3½ | 65 |
| 3¾ | 74 |

## II. STRENGTH AND AGEING TESTS.

(1) *Effect of structure.*—Ordinarily balloon fabrics are made of two or more cloth layers, one of these usually on the bias. A layer of rubber is between each ply of fabric and a layer on the face of the fabric which comes in contact with the gas. The outside surface may or may not be coated with rubber and is sometimes treated after the balloon is made with cellulose acetate varnish. Parallel fabrics—that is, two or more layers of fabric with the warp threads all running in the same direction—have been used to some extent in France. They are supposed to be stronger, but tear more easily. Since cotton tears quite easily under ordinary conditions, it seems highly desirable to adopt some such method as biasing to prevent tearing. While the biased fabric does not show so high a tensile strength test, it must be remembered that the stresses on a dirigible balloon which cause trouble are not the simple ones due to internal pressure, weight of load, etc., but those localized in one area due to sudden pulls on ropes, etc. It is important to have a fabric that will not continue to tear after a tear is once started.

Tensile strength tests made on 1-inch strips showed that the strength of a 2-ply parallel fabric was not necessarily twice that of the single ply of uncoated fabric. On the other hand, double bias fabrics show a greater strength than that of the single ply of fabric when the stress is parallel, for example, to the warp of the unbiased piece.

| | Balloon cloth made from— | |
|---|---|---|
| | Fabric No. 1. | Fabric No. 2. |
| Strength of fabric, uncoated warp | 70 | 50 |
| Strength of 2-ply parallel fabric warp | 125.5 | 92.6 |
| Strength of fabric 2-ply bias warp of unbiased ply | 85 | 66 |
| Tensile strength by bursting test, 2-ply bias | 100 | 85 |

Ageing for 13 weeks, the samples being continuously exposed to the weather, caused a decrease in tensile strength of about 5 per cent. The samples were exposed during the winter months, from January 1 to about April 1.

Other samples exposed for one month, from August 20 to September 20, showed a decrease of about 8 to 10 per cent in tensile strength in the warp and from 0 to 6 per cent in the filling. The rubber was apparently unaffected.

## III. PERMEABILITY OF BALLOON FABRICS.

The permeability was measured by the chemical method similar to that used at the National Physical Laboratory of Great Britain. In this method the fabric is held in a cell, which is divided by the fabric into two compartments. Dry purified hydrogen at a pressure of 70 millimeters of water is passed through one side, while air is drawn through the other, dried and passed through an electric furnace, which burns the hydrogen present in the air from diffusion to water, which is absorbed and weighed. The cell is kept at constant temperature by immersion in a thermostatic bath. The permeability is expressed in liters of hydrogen, measured at 0° C., 760 millimeters per square meter of fabric per 24 hours.

In France the Renard-Sourcouf balance is ordinarily used. This measures the net volume of gas lost by diffusion through the fabric. It does not in reality measure the loss of hydrogen, since air passes in while hydrogen passes out. According to T. Graham,[1] the relative rates of diffusion of nitrogen, air, and hydrogen are as follows:

*Diffusion through rubber.*

| | |
|---|---|
| Nitrogen | 1 |
| Air | 1. 149 |
| Hydrogen | 5. 5 |

With the Renard balance, while 5.5 volumes of hydrogen pass out, according to the above figures, 1.149 volumes of air pass in, giving a net change of 4.351 volumes. In other words, for an apparent loss of 10 liters per 24 hours per square meter, we should have an actual loss of 12.6 liters, as measured by the chemical method. (We have not had an opportunity to test fabrics measured by the gas balance method.) The volume loss is of course important, and if on further investigation it is found that there is much variation in the ratios given by the Graham experiments for different kinds of rubber it would be well to make both tests standard. In fact, the introduction of auxiliary coatings of cellulose esters, etc., makes this of immediate interest.

### (1) EFFECT OF VARYING AMOUNTS OF RUBBER.

The permeability decreases with increasing weight of rubber as a general rule, but does not seem to be proportional to it.

| Weight of rubber between plies (ounces per square yard). | Permeability at 15° (by extrapolation). |
|---|---|
| 1. 65 | 50 |
| 3. 11 | 9 |
| 5. 11 | 9 |

This is in accord with the observation of Austerweil,[2] who found that the permeability of two rubber membranes, 918 and 1,675 grams per square meter respectively, was practically the same for the first 100 hours. The rates diverged up to 400 hours, after which they were again constant. This, according to Austerweil, marked the point when both membranes were saturated. Between 100 and 400 hours the thinner membrane became saturated more rapidly than the other, and so showed a greater rate of diffusion.

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[1] Phil. Trans., 1866, p. 399.

[2] Die Angewandte Chemie in der Luftfahrt, p. 67.

### (2) EFFECT OF TEMPERATURE.

Experiments conducted in England at the National Physical Laboratory[1] show that the permeability rises rapidly with the temperature. For two samples they found the following results:

| | |
|---|---|
| Diagonally doubled, 3 layers rubber | 15.5° C.— 6.71 1 |
| | 22.1° C.—10.84 1 |
| Parallel doubled, 2 layers rubber | 15.5° C.—12.3 1 |
| | 22.1° C.—21.5 1 |

These figures show more than 9 per cent increase in permeability per degree.

We have made tests at approximately 20, 30, and 40° C., and found in every case a marked temperature coefficient. If the values of permeability and temperature are plotted, it will be noted (fig. 9, appendix) that the curve rises more rapidly with increasing temperature. Our results show a temperature coefficient about one-half that given in the data just cited. It may be that the nature of the rubber compound has considerable bearing.

This high temperature coefficient is of peculiar importance in this country, where the aeronautic activities of both Army and Navy are centered in the South. It seems advisable that this be considered in specifying the minimum gas leakage allowable when contracting for dirigible balloons, and that some temperature be stated, since a balloon tested at Pensacola would, without extra precautions, show a higher loss than one in the vicinity of New York. A correction to a standard temperature could probably be made.

This also shows the advisability of providing adequate arrangements to prevent too high a temperature in hangars. I understand that in Europe double roofs, with fans and other suitable cooling devices are used.

### (3) EFFECT OF COATING CLOTH WITH CELLULOSE ESTER LACQUERS.

It has been the practice in Europe for some time, apparently, to coat the outside of balloons with some sort of varnish. These are sold under various names, but in general are cellulose acetate lacquers. They are used to cut down wind resistance, to protect the fabric, and to render it gas tight in cases where the rubber has deteriorated.

Samples were given four coats of cellulose nitrate and cellulose acetate lacquers 1876 and 1877, respectively, the lacquer being applied to the cloth. In both cases the improvement in permeability was definite, though small, amounting to from 1 to 1½ liters per square meter per 24 hours.

### (4) EFFECT OF COATING RUBBER WITH CELLULOSE ESTER LACQUERS.

It seemed likely that the small improvement noted above was due to the fact that cloth offers a poor surface for obtaining a tight coat, at least for a thin film. To verify this tests were made with the same

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[1] Tech. Report Adv. Committee for Aeronautics, 1910-11, p. 60.

materials in the same amounts on the rubber side. The improvement was very marked here, amounting to 50 per cent or more of the value found for the same fabric uncoated. In one case there was a reduction from 11 liters at 20° C. to 4 liters at the same temperature. Unfortunately these lacquers are not suited for use on rubber surfaces since they peel off. It is to be hoped that a marked improvement may be made in them, since their use for this purpose seems very promising. The inflammability of cellulose nitrate is of course a drawback, but obviously a balloon filled with hydrogen must be carefully protected from fire, however noninflammable the material used in its construction. It is, moreover, a simple matter to obtain cellulose nitrate blended with oil to give a flexible coating.

### (5) EFFECT OF COATING RUBBER WITH GELATIN COMPOUNDS.

A flexible gelatin compound on the rubber surface in about the same amounts as the coatings used in (4) and (5) was tested and found to give a very low permeability:

Original permeability at 20° C., 11 liters per square meter per 24 hours.
Permeability after coating with gelatin compound at 20° C., .8 liter approximately per square meter per 24 hours.

## Part III.—TESTS ON BALLOON AND AEROPLANE FABRICS.

### I. TEARING TESTS.

To obtain some knowledge of the behavior of aeronautic fabrics under stresses somewhat similar to those existing in aeroplanes and balloons, the test used by the National Physical Laboratory[1] was employed.

*Method.*—A piece of fabric is clamped in the jaws, and in the center of this a slit of definite length is cut perpendicular to the line of pull. When stress is applied, the cut opens, and if the load is increased the tear widens in a direction perpendicular to the stress and the sample finally breaks. The threads parallel to the line of stress bend inward on either side of the slit; those perpendicular to the strain bend away from the cut. The localization of strain on the thread at the ends of the slit is evidently caused by the pull being transmitted from the longitudinal threads to the transverse threads, due to the take-up in weaving. The general effect of stretching coated and uncoated fabrics is shown in the photographs taken of tests. (Appendix, Plates I–VI.) The wrinkling of the coated fabric around the cut, producing a poor impression, is particularly of interest, showing how the disturbance is more localized than in the case of uncoated fabric.

A fair index of the ability of fabrics to resist tearing may be obtained by plotting the results for the point at which the tear starts to widen and where rupture occurs against the size of cut. The factor found by dividing the breaking load by the width of slit gives a means of comparison which seems to have some value. (See appendix for data and curves.)

(1) The load to break falls off more rapidly with increasing size of slit in the case of a doped fabric than with an undoped fabric.

(2) Cotton is much inferior to linen.

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[1] Tech. Report of Adv. Com. for Aeronautics, 1910–11, p. 72.

(3) Parallel double balloon fabric tears more easily than bias doubled fabric, particularly for small cuts. Furthermore, a parallel fabric tears evenly in a straight line, while in the case of the bias a general rending of one layer occurs, while the other is distorted rather than torn. It can be readily seen that the effect of tearing on the parallel fabric in a balloon would be much more disastrous.

## II. SURFACE FRICTION TESTS.

Tests on the resistance of various fabrics were made in the wind tunnel at the Washington Navy Yard.

The method used was to suspend vertically a glass plate about 34 inches wide and 9 feet long so that its long edge is in the direction of the air flow. The following edge of the plate is connected with the balance, allowing the horizontal moment about one knife edge to be measured.

Corrections were found and used for the wires suspending the plate. The ends of the plate fitted into slots in struts of stream line form. The wind passing the slot into which the leading edge fitted caused a diminution in pressure, giving the effect of a thrust on the plate against the wind. The wind caused a compression in the slot in which the following edge fitted, likewise giving the effect of a thrust against the wind. The amount of pressure developed in each slot was observed with a hook gauge manometer, and from this and the area of the edges could be calculated the correction to be added for each speed.

The resistance of the plate glass was taken as standard and found at 30, 40, 50, 60, and 70 miles per hour. Various samples of fabric were then attached, covering both sides of the glass completely in each case, and the resistance measured at different speeds.

Complete data will be found elsewhere, but the following general points may be mentioned here. Taking, for example, the resistance of plate glass as 1, at 70 miles per hour, we have the following comparative resistances at this velocity:

*At 70 miles per hour.*

| Experiment No. | | |
|---|---|---|
| 1 | Plate glass | 1.000 |
| 5 | Linen No. 1 (high grade) | 1.362 |
| 2 | Linen No. 1 (high grade), 1 coat varnish No. 1876 | 1.162 |
| 3 | Linen No. 1 (high grade), 3 coats varnish No. 1876 | 1.108 |
| 4 | Linen No. 1 (high grade), 3 coats varnish No. 1876, 1 coat spar varnish | 1.061 |
| 6 | Linen No. 1 (high grade), 3 coats varnish No. 1877 | 1.085 |
| 7 | Linen No. 1 (high grade), 3 coats varnish No. 1877, 1 coat spar varnish | 1.081 |
| 8 | Linen No. 1 (high grade), 3 coats varnish No. 1877, 2 coats spar varnish | 1.078 |
| 9 | Balloon fabric No. 3, cloth outside, double parallel | 1.965 |
| 10 | Balloon fabric No. 3, cloth outside, double parallel, freshly singed | 1.654 |
| 11 | Balloon fabric No. 3, cloth outside, double parallel, singed and coated once, No. 1876 | 1.345 |
| 12 | Balloon fabric No. 3, cloth outside, double parallel, singed and coated three times, No. 1876 | 1.107 |
| 13 | Balloon fabric No. 3, cloth outside, double bias | 1.902 |
| 14 | Balloon fabric No. 3, cloth outside, double bias, freshly singed | 1.762 |
| 15 | Balloon fabric No. 6, cloth outside (specially woven fabric), double bias | 1.528 |
| 16 | Balloon fabric No. 6, cloth outside (specially woven fabric), double bias, freshly singed | 1.372 |
| 21 | Aeroplane fabric, rubberized, No. 23 | 1.079 |
| 22 | Aeroplane fabric, aluminum coated, No. 24 | 1.101 |

I. From these figures it will be seen that we may roughly divide surfaces into groups as to wind resistance.

(1) Those which are what might be called continuous; in this case the resistance probably increases simply as the surfaces deviate from a true plane due to lumps and other unevennesses. Plate glass, doped, varnished, and rubberized fabrics come in this class. The resistance does not exceed 1.20, glass being 1.

(2) Those which have a discontinuous surface, i. e., such as would be presented by a perfectly smooth woven material, as a wire gauze; linen and singed cotton approach this. Here the resistance is between 1.35 and 1.7.

(3) Those which have a discontinuous surface to which is added other roughnesses, such as arise from nap. Unsigned cotton is in this class, and the resistance is 1.5 or more.

II. It is interesting to note the great improvement produced on balloon fabric by the use of one or more coats of some sort of varnish.

III. The *difference* in resistance between an uncoated fabric of class (3) and plate glass is very appreciable at high speeds, being about 0.013 pound per square foot at 70 miles per hour. This would mean a total head resistance in a large machine of about 18 pounds, or a decrease in lifting power of 150–180 pounds. However, as can be seen from the list, it is fairly simple to cut down the resistance until it approximates that of glass.

# APPENDIX

TO

## REPORT No. 6, PART 1.

[Containing details, data, and plates.]

### LINEN FABRICS.

Linen is the most widely used material for aeroplane wings, on account of its great strength and toughness. The grades now on the market have weights and strengths as shown:

| | Weight (ounces per square yard). | Strength. | |
|---|---|---|---|
| | | Warp. | Filler. |
| I | 3. 67 | 65. 0 | 54. 4 |
| II | 3. 78 | 69. 5 | 49. 2 |
| III | 3. 87 | 80. 7 | 79. 0 |
| IV | 4. 04 | 86. 9 | 74. 0 |
| V | 4. 09 | 90. 2 | 82. 7 |
| VI | 4. 48 | 82. 9 | 100. 1 |
| VII | 4. 60 | 95. 0 | 60. 0 |
| VIII | 4. 86 | 90. 4 | 102. 5 |

In Great Britain there has recently been adopted the method of testing the sample wet, after soaking some time. This is to avoid error due to humidity changes. While this method may seem somewhat arbitrary, it is convenient and nearer the conditions of use than a test on absolutely dry material. They figure that this test corresponds to what could be expected at a theoretical humidity of 111 per cent.

*Tests on transparent cellulose acetate sheets.*

| No. | (1) Thickness. | (2) Weight (ounces per square yard). | (3) Tensile strength (pounds per inch). | | (4) Maximum difference in tests (in per cent of average value). | |
|---|---|---|---|---|---|---|
| 1 | 10/1000 | 9. 33 | 55. 3 | 57 | 10. 8 | 10. 5 |
| 2 | 16/1000 | 15. 49 | 106. 3 | 85. 8 | 14. 1 | 8. 1 |
| 3 | 24/1000 | 22. 96 | 127. 1 | 130 | 30. 6 | 25. 2 |
| 4 | 32/1000 | 30. 35 | 178. 6 | 187. 7 | 21. 2 | 2. 6 |
| 5 | 64/1000 | 59. 02 | 326 | 345. 8 | 10. 7 | . 8 |

Tests made on Riehle machine, 1-inch strips, 1-inch jaw, 3 inches between jaws; speed, 18 inches per minute.

The strength was measured both ways on each sheet, since it was thought that the material might show a grain, such as often occurs in materials in sheet form which have been made by a calendering process. Except in the case of No. 2, there is no perceptible difference in strength. The material runs fairly uniform in strength except for the one sheet No. 3. Column 4 shows the difference between the highest and lowest tests, compared to the average.

The material is quite flexible, in thin sheets, and can be bent double several times in one place without cracking. On the other hand, it tears very easily when once cut. It is noninflammable.

## STRETCHING TESTS.

Figures 1–4 show the relation between load and per cent stretch. The numerical values for the tests are given on page 155 and need little comment.

The tests were made on a Riehle fabric-testing machine, and measurements were made on an initial distance of 20 inches, so the results are probably quite accurate. The jaws moved apart at a rate of 6 inches per minute.

It is interesting to note that the rate of stretch is usually low in doped fabrics up to 10 to 20 pounds load, after which it rises more rapidly. On the other hand, the uncoated fabrics tend to be just the opposite of this—that is, there is a considerable stretch at first under light load, up to say 20 pounds, then the "slack" having been removed from the fibers, the stretch is much slower. It will be noticed that this holds true even for samples when the total stretch of the coated fabric greatly exceeds that of the uncoated, as in figure 2, Curves VIII, IX, X, XI, when the fabric was not stretched on a frame without coating. The stretch of the coated fabric only becomes equal to that of the uncoated at loads of 12 to 20 pounds.

The application of this seems to lie in the fact that ordinarily even at high speeds the loading due to wind pressure is very light. According to Austerweil[1] even at highest speeds the load would not amount to more than 145.5 kilograms per meter, or about 8 pounds per inch. Ordinarily it would be much less. It would seem therefore that from the standpoint of keeping the fabric taut against stretching just as good results could be obtained by putting it on loosely enough to allow shrinkage, and get the benefit of increased tensile strength and efficiency shown by the fabrics in Curves VIII–X, inclusive.

---

[1] Die Angewandte Chemie in der Luftfahrt, 179.

*Stretch of aeroplane fabric.*

| Fabric. | Curve. | Stretch under load of (pounds per inch)— | | | | | | | | | | | Efficiency—in (1-inch by 12-inch strip) foot-pounds. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | |
| **Linen No. 1:** | | | | | | | | | | | | | |
| Untreated warp........ | I | 3.65 | 7.10 | 8.30 | 9.35 | 10.10 | 10.65 | 11.15 | 11.55 | 12.05 | (96) 12.35 | ......... | 8.67 |
| Untreated Filler........ | | 1.62 | 2.37 | 2.90 | 3.37 | 3.75 | 4.16 | ...... | ...... | ...... | ...... | ......... | ......... |
| Varnish 1875— | | | | | | | | | | | | | |
| W........ | II | 1.25 | 3.75 | 6.66 | 9.25 | 10.58 | 11.83 | 12.92 | 13.75 | 14.75 | ...... | ......... | 7.77 |
| F........ | | .80 | 1.68 | 1.86 | 2.12 | 2.66 | 3.19 | 3.73 | 4.36 | ...... | ...... | ......... | ......... |
| Varnish 1876— | | | | | | | | | | | | | |
| W........ | III | 1.17 | 3.58 | 7.50 | 9.92 | 11.50 | 12.58 | 13.50 | 14.12 | 14.50 | 15.00 | ......... | 9.62 |
| F........ | | .75 | 1.58 | 2.58 | 3.42 | 4.11 | 4.42 | 5.25 | 5.62 | 6.00 | ...... | ......... | ......... |
| Varnish 1877— | | | | | | | | | | | | | |
| W........ | IV | 1.75 | 4.7 | 7.42 | 9.35 | 11.25 | 12.00 | 12.83 | 13.33 | 14.12 | 14.50 | 14.75 | 10.93 |
| F........ | | .75 | 1.75 | 3.00 | 3.50 | 4.00 | 4.75 | 5.25 | 6.00 | (86) 6.75 | ...... | ......... | ......... |
| Varnish 1875 and Spar— | | | | | | | | | | | | | |
| W........ | V | 1.17 | 3.42 | 5.92 | 8.00 | 9.33 | 10.62 | 11.50 | 12.08 | 13.00 | (95) 14.00 | ......... | 7.54 |
| F........ | | 1.00 | 1.75 | 2.75 | 3.33 | 4.25 | 4.62 | 5.33 | 6.00 | (86) 6.50 | ...... | ......... | ......... |
| Varnish 1876 and Spar— | | | | | | | | | | | | | |
| W........ | VI | 1.10 | 3.5 | 6.42 | 8.80 | 10.30 | 11.25 | 12.16 | 13.00 | 13.53 | 14.00 | ......... | 8.75 |
| F........ | | .83 | 1.75 | 2.75 | 3.75 | 4.33 | 4.92 | 5.33 | 5.92 | 6.37 | (96) 7.00 | ......... | ......... |
| Varnish 1877 and Spar— | | | | | | | | | | | | | |
| W........ | VII | 1.75 | 4.00 | 6.50 | 8.75 | 10.50 | 11.75 | 12.12 | 12.50 | 13.00 | (96) 14.2 | ......... | 7.32 |
| F........ | | 1.04 | 1.99 | 2.85 | 3.55 | 3.81 | 4.08 | 4.60 | 4.86 | ...... | ...... | ......... | ......... |
| **Linen No. 1, coated, without prestretching, coated with—** | | | | | | | | | | | | | |
| Varnish 1875— | | | | | | | | | | | | | |
| W........ | VIII | 5.00 | 6.89 | 11.44 | 15.33 | 17.55 | 18.89 | 20.00 | 21.17 | 21.75 | 22.67 | 120–23.67<br>23.33 | 19.41 |
| F........ | | 2.20 | 3.33 | 4.33 | 5.07 | 5.76 | 6.33 | 7.00 | 7.37 | (88) 8.13 | ...... | ......... | ......... |
| Varnish 1876— | | | | | | | | | | | | | |
| W........ | IX | 3.16 | 7.83 | 12.00 | 15.08 | 17.08 | 18.08 | 19.66 | 20.42 | 21.17 | 22.00 | 120–23.83<br>22.50 | 19.11 |
| F........ | | 2.00 | 3.80 | 4.77 | 5.25 | 6.00 | 6.37 | 6.50 | 7.00 | ...... | ...... | ......... | ......... |
| Varnish 1877— | | | | | | | | | | | | | |
| W........ | ....... | 2.81 | 10.43 | 15.00 | 17.50 | 18.75 | 19.75 | 20.43 | 21.06 | 21.56 | 22.12 | 22.83 | 18.19 |
| F........ | ....... | 1.83 | 3.08 | 4.16 | 4.58 | 5.16 | 5.66 | 6.16 | 6.37 | ...... | ...... | ......... | ......... |
| **Linen No. 1:** | | | | | | | | | | | | | |
| Rubberized— | | | | | | | | | | | | | |
| W........ | IR | 7.42 | 11.25 | 12.44 | 13.44 | 14.06 | 14.56 | 15.06 | 15.56 | 15.92 | 16.50 | ......... | 12.89 |
| F........ | | 2.25 | 3.50 | 4.00 | 5.25 | 5.8 | 6.25 | ...... | ...... | ...... | ...... | ......... | ......... |
| Rubberized— | | | | | | | | | | | | | |
| Varnish 1875— | | | | | | | | | | | | | |
| W........ | ....... | 1.92 | 5.58 | 8.58 | 10.92 | 11.66 | 13.08 | 13.92 | 14.42 | 14.92 | 15.33 | 16.25 | 11.77 |
| F........ | ....... | 1.92 | 2.81 | 4.00 | 5.12 | 5.62 | 6.37 | 6.50 | 7.00 | ...... | ...... | ......... | ......... |
| Varnish 1876— | | | | | | | | | | | | | |
| W........ | ....... | 2.56 | 7.25 | 10.37 | 12.12 | 13.19 | 14.00 | 14.6 | 15.19 | 15.6 | 16.19 | 120–17.25<br>16.75 | 15.16 |
| F........ | ....... | 1.37 | 3.00 | 4.00 | 5.12 | 5.5 | 6.00 | 6.57 | 6.81 | ...... | ...... | ......... | ......... |
| Varnish 1877— | | | | | | | | | | | | | |
| W........ | ....... | 2.75 | 7.08 | 10.5 | 12.25 | 13.33 | 14.17 | 14.92 | 15.5 | 15.92 | 16.37 | 16.70 | 13.46 |
| F........ | ....... | 1.62 | 3.19 | 4.19 | 5.08 | 5.66 | 6.17 | 6.50 | 6.92 | 7.25 | ...... | ......... | ......... |
| Varnish 1875— | | | | | | | | | | | | | |
| Spar— | | | | | | | | | | | | | |
| W........ | ....... | 1.75 | 6.75 | 9.25 | 11.50 | 12.66 | 13.21 | 14.06 | 14.69 | 15.44 | 15.5 | ......... | 12.25 |
| F........ | ....... | 1.33 | 2.42 | 3.50 | 4.50 | 5.16 | 5.58 | 6.00 | 6.16 | ...... | ...... | ......... | ......... |
| Varnish 1876— | | | | | | | | | | | | | |
| Spar— | | | | | | | | | | | | | |
| W........ | ....... | 2.50 | 7.94 | 11.06 | 12.81 | 13.77 | 14.69 | 15.37 | 16.00 | 16.37 | 16.62 | 17.00 | 13.64 |
| F........ | ....... | 1.37 | 3.06 | 4.44 | 4.62 | 5.19 | 5.56 | 6.19 | 6.31 | ...... | ...... | ......... | ......... |
| Varnish 1877— | | | | | | | | | | | | | |
| Spar— | | | | | | | | | | | | | |
| W........ | ....... | 2.66 | 6.66 | 9.83 | 11.5 | 12.92 | 13.83 | 14.58 | 15.08 | 15.58 | 16.06 | 16.5 | 12.66 |
| F........ | ....... | 1.33 | 2.42 | 3.58 | 4.42 | 4.92 | 5.33 | 5.50 | 5.87 | ...... | ...... | ......... | ......... |

*Stretch of aeroplane fabric*—Continued.

| Fabric. | Curve. | Stretch under load (pounds per inch). | | | | | | | | | | Efficiency in (piece 1 by 12 inches) foot-pounds. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | |
| Medium-grade linen No. 2: | | | | | | | | | | | | |
| W | IM | 5.08 | 7.42 | 8.42 | 9.16 | 9.50 | 10.12 | | | | | 4.51 |
| F | | 3.75 | 5.00 | 5.75 | 6.12 | | | | | | | |
| Linen No. 2: | | | | | | | | | | | | |
| Varnish 1875— | | | | | | | | | | | | |
| W | IIM | 1.58 | 4.16 | 6.42 | 8.67 | 9.92 | 10.62 | 11.50 | | | | 4.77 |
| F | | .67 | 1.42 | 2.33 | 3.16 | 3.83 | 4.42 | 5.00 | 5.12 | 5.50 | | |
| Varnish 1876— | | | | | | | | | | | | |
| W | IIIM | 1.33 | 3.08 | 5.08 | 6.58 | 7.50 | 8.33 | 8.75 | 9.50 | | | 4.56 |
| F | | 1.17 | 2.50 | 3.83 | 4.92 | 5.83 | 6.50 | 7.12 | | | | |
| Varnish 1877— | | | | | | | | | | | | |
| W | IVM | 1.66 | 3.92 | 5.92 | 7.58 | 8.50 | 9.42 | 10.12 | | | | 4.18 |
| F | | 1.42 | 3.00 | 4.25 | 5.67 | 6.25 | 6.87 | 7.50 | | | | |
| Varnish 1875 and spar— | | | | | | | | | | | | |
| W | VM | 1.17 | 2.75 | 4.83 | 6.33 | 7.33 | 8.75 | 8.83 | 9.58 | 10.00 | | 5.50 |
| F | | 1.19 | 2.50 | 3.58 | 5.00 | 5.75 | 6.42 | 6.83 | 7.17 | 7.75 | | |
| Varnish 1876 and spar— | | | | | | | | | | | | |
| W | VIM | 1.50 | 3.50 | 5.50 | 6.92 | 7.75 | 8.58 | 9.25 | 10.00<br>(75) | | | 4.82 |
| F | | 1.00 | 2.16 | 3.17 | 4.08 | 4.75 | 5.25 | 5.83 | 6.00 | | | |
| Varnish 1877 and spar— | | | | | | | | | | | | |
| W | VIIM | 1.33 | 3.33 | 5.00 | 6.58 | 7.75 | 8.50 | 9.16 | 9.75<br>(75) | 10.25 | | 5.68 |
| F | | 1.58 | 2.66 | 3.50 | 4.83 | 5.42 | 6.08 | 6.58 | 6.75 | | | |

## TEARING TESTS.

In these tests wooden jaws were used, fitted to a Riehle fabric testing machine. The jaws moved apart at a speed of approximately 6 inches per minute.

The Plates I–VI were made by setting up the machine in a dark room, putting the sample under tension, and holding a dry plate against the sample. An electric bulb on the other side of the sample furnishes light for the exposure. In the case of cotton fabrics the small size of the yarn and its transparency gave poor definition; this difficulty was removed by first coloring the sample with a yellow naphtha soluble dye. The photographs are therefore actual size, and show up the conditions of the threads quite clearly.

The factor obtained by dividing the breaking load for a 1-inch cut by that for the uncut fabric gives some idea as to the relative tearing resistance of various materials. This, with the actual tensile, should furnish a good basis for comparing fabrics as to suitability.

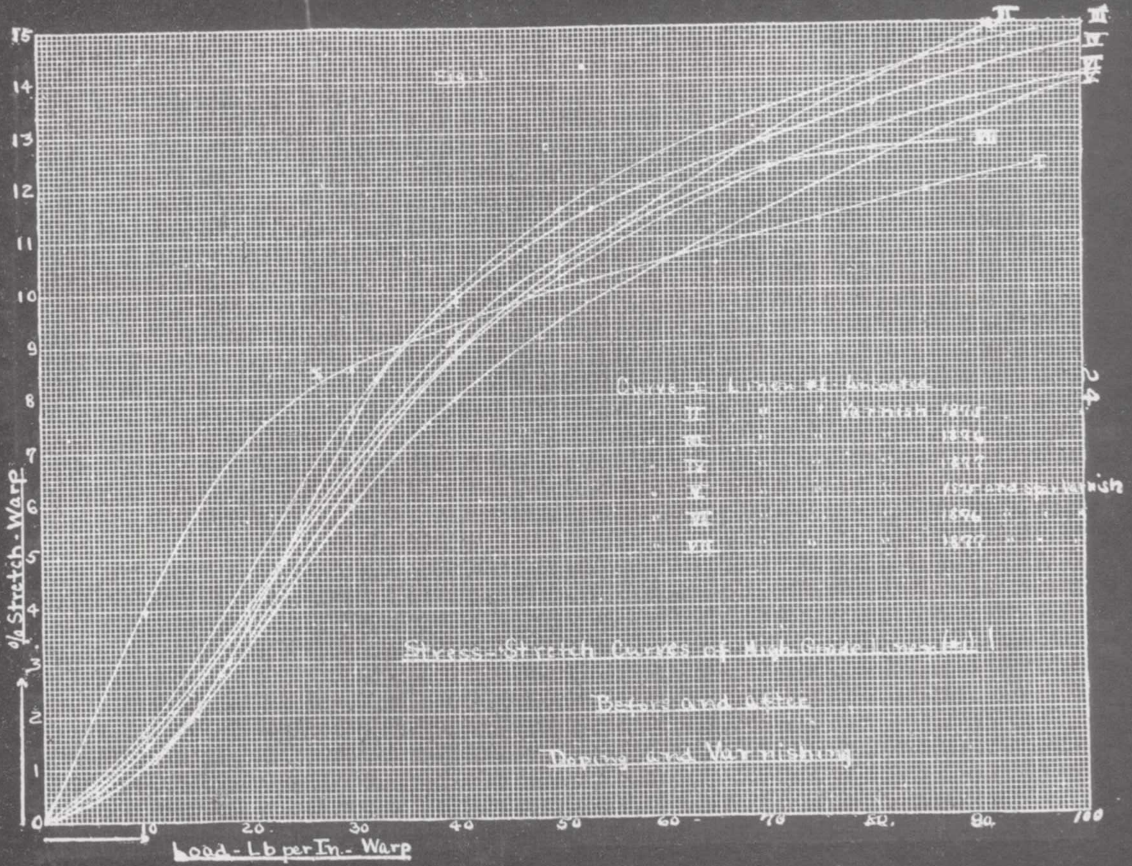

Stress-Stretch Curves of High Grade Linen
Before and After
Doping and Varnishing
24
Curve I Linen
II Varnish 1875
III 1876
IV 1877
V 1875 and Spar Varnish
VI 1876
VII 1877
% Stretch - Warp
Load - Lb per In. - Warp
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
10
20
30
40
50
60
70
80
90
100
I
II
III
IV
V
VI
VII

Fig. 2

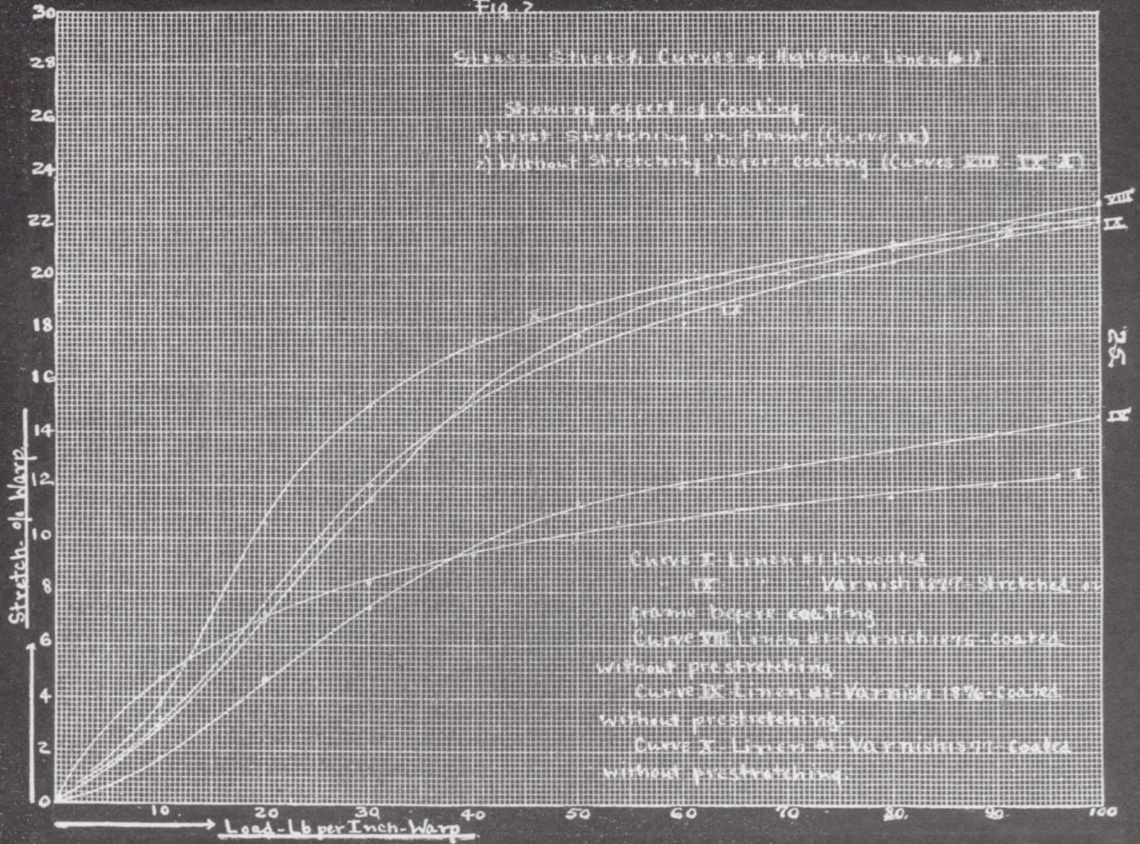

Stress Stretch Curves of Highgrade Linen #1
Showing effect of Coating
1) First Stretching on frame (Curve IX)
2) Without Stretching before coating (Curves VIII IX X)
Curve I Linen #1 Uncoated
IX " " Varnish 1877 Stretched on frame before coating
Curve VIII Linen #1 - Varnish 1875 - coated without prestretching
Curve IX Linen #1 - Varnish 1876 - coated without prestretching
Curve X Linen #1 - Varnish 1877 - coated without prestretching
VIII
IX
25
II
I
Stretch - % Warp
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Load - Lb per Inch - Warp
10
20
30
40
50
60
70
80
90
100

Fig 3

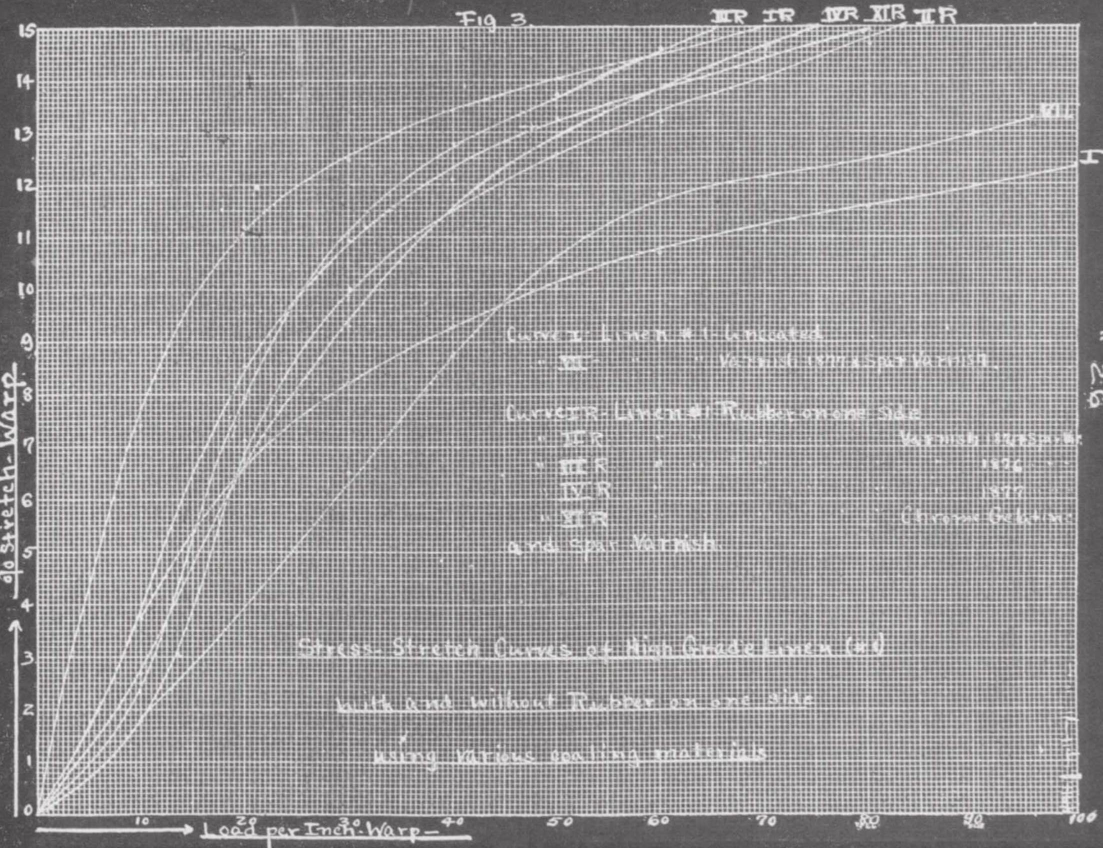
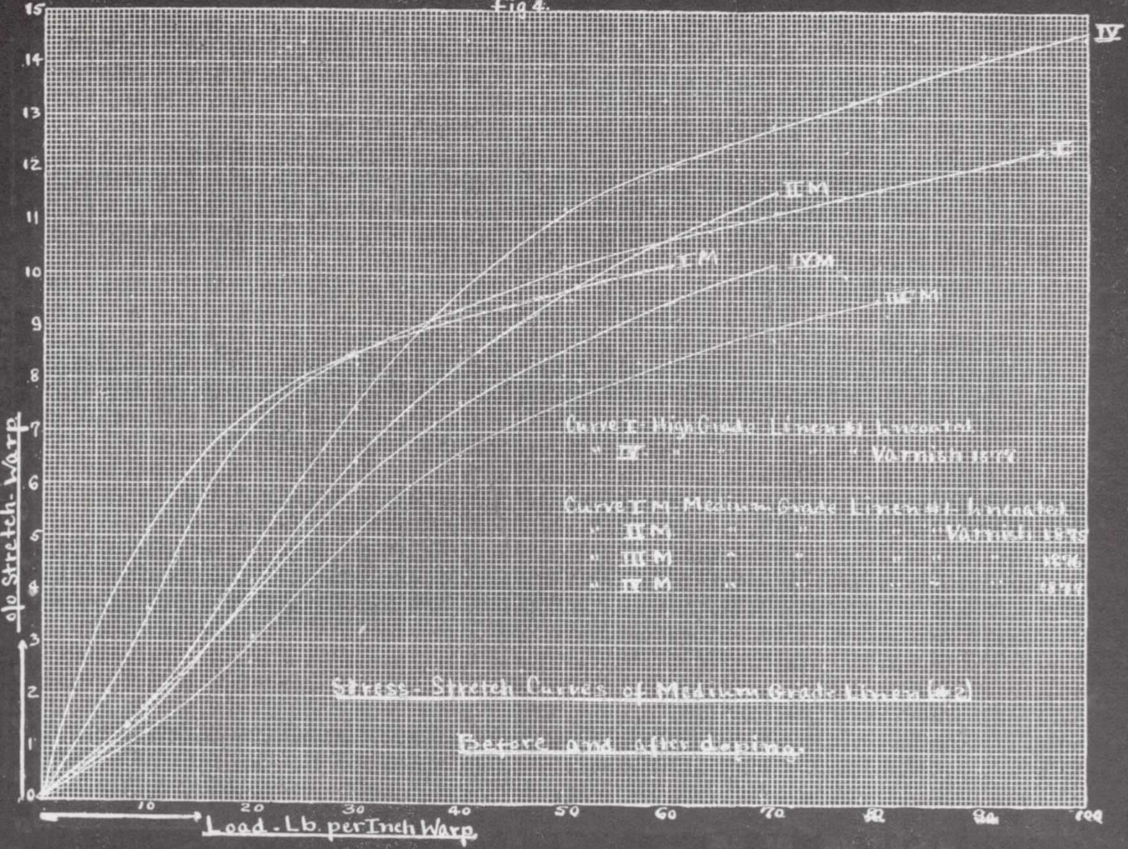

III R
I R
IV R
V R
II R
VI
I
2.6
Curve I Linen #1 Uncoated
" VI " " Varnish 1877 & Spar Varnish
Curve I R Linen #1 Rubber on one side
" II R " " Varnish 1925 & Spar
" III R " " 1876 "
" IV R " " 1877 "
" V R " " Chrome Gelatine
and Spar Varnish
Stress-Stretch Curves of High Grade Linen (#1)
with and without Rubber on one side
using various coating materials
% Stretch-Warp
Load per Inch-Warp
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
10
20
30
40
50
60
70
80
90
100

Fig 4.


% Stretch - Warp
Load - Lb. per Inch Warp
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
10
20
30
40
50
60
70
80
90
100
IV
I
II M
I M
IV M
III M
Curve I High Grade Linen #1 Uncoated
" IV " " " " Varnish 1878
Curve I M Medium Grade Linen #1 Uncoated
" II M " " " " Varnish 1875
" III M " " " " " 1876
" IV M " " " " " 1877
Stress - Stretch Curves of Medium Grade Linen (#2)
Before and after doping.

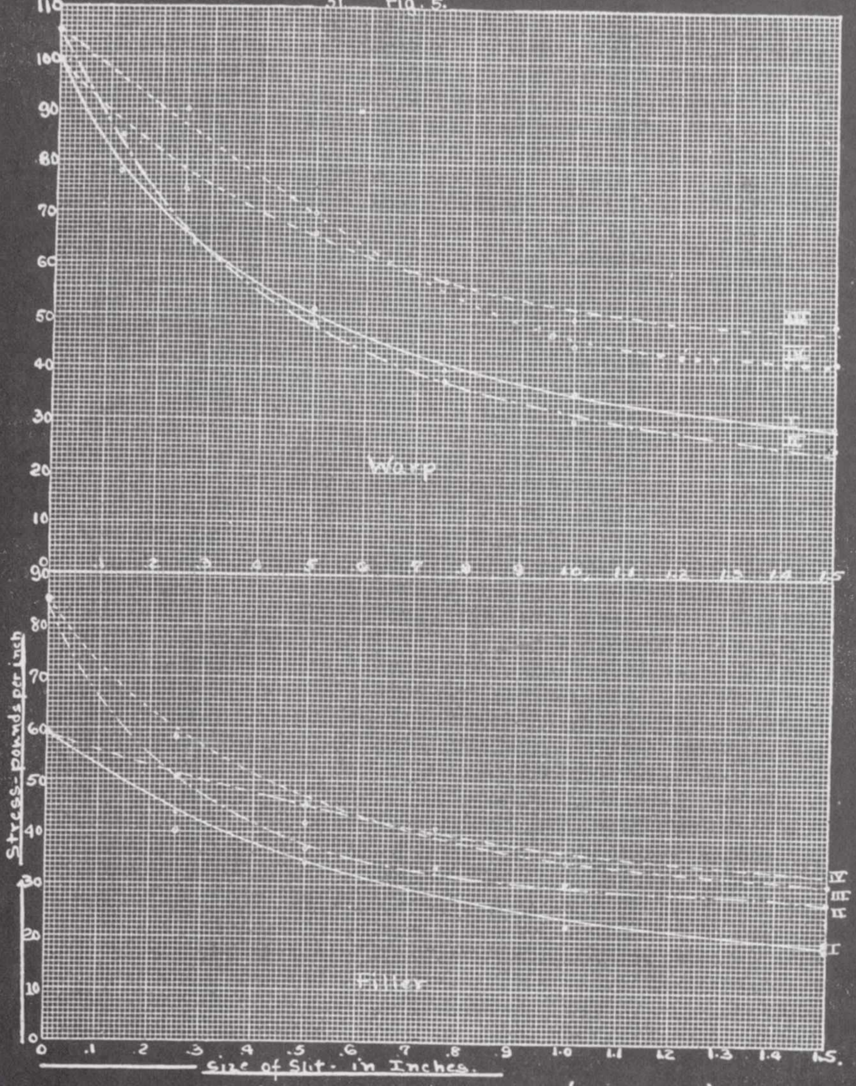
| | Tensile strength (pounds per inch). | | Tearing factor. | |
|---|---|---|---|---|
| | Warp. | Filler. | Warp. | Filler. |
| Linen No. 1, high grade: | | | | |
| Uncoated | 100 | 59 | 0.50 | 0.52 |
| Doped | 106 | 86 | .29 | .44 |
| Linen No. 2, medium grade: | | | | |
| Uncoated | 65 | 45 | .67 | .57 |
| Doped | 85 | 75 | .58 | .58 |
| Cotton, light weight: | | | | |
| Uncoated | 37 | 49½ | .48 | .36 |
| Doped | 45 | 45 | .38 | .37 |
| Balloon fabric: | | | | |
| Double parallel | 85 | 70 | .36 | .33 |
| Double bias | 65 | ....... | .66 | ....... |

From the above figures it will be seen that the lower grade of linen is relatively more difficult to tear than the high grade. This is probably because the higher grade fabrics, both linen and cotton, owe their greater strength for a given weight to the greater number of yarns per inch. These are of necessity smaller, and since tearing depends to a considerable extent on the strength of the individual threads, we find that strong, closely woven fabrics tear more easily in proportion than weaker ones. A good example of this is the filler of the cotton fabric, compared with filler of No. 2 linen. The actual tensile strength of the cotton is higher, but the effect of a cut much greater, giving the factors as shown: 0.36 for the cotton and 0.57 for the linen.

*Tearing tests on aeroplane and balloon fabrics—Load required to start tear, and to break, for slits of various sizes.*

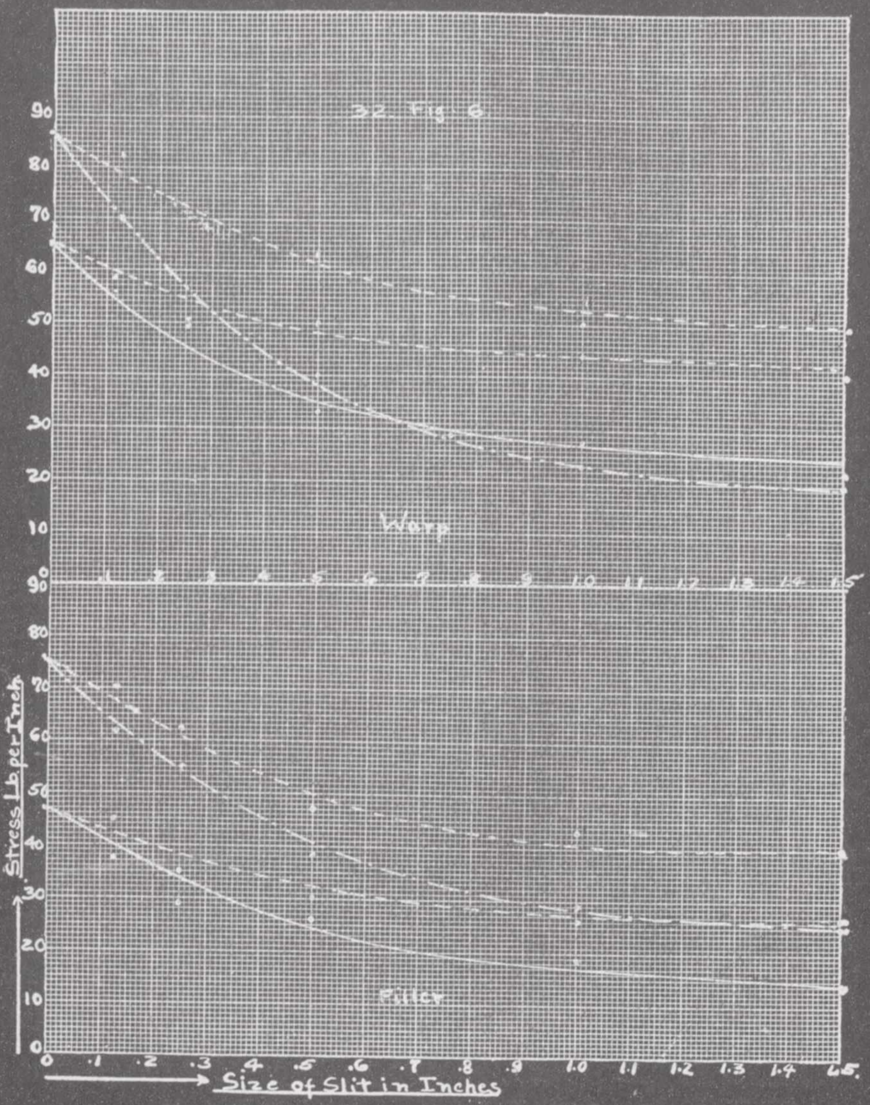
| Fabric. | Size slit. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 inch. | | ¼-inch. | | ½-inch. | | 1-inch. | | 1½-inch. | |
| | Load per inch. | | | | | | | | | |
| | Tear. | Break. | Tear. | Break. | Tear. | Break. | Tear. | Break. | Tear. | Break. |
| Linen, No. 1, high grade, uncoated: | | | | | | | | | | |
| Warp | 100 | 100 | 66½ | 74 | 48½ | 66 | 36 | 50 | 27 | 49 |
| Filler | 59 | 59 | 40 | 44 | 34 | 42 | 23½ | 31 | 18 | 29 |
| Linen, No. 1, high grade, coated, 1875 var.: | | | | | | | | | | |
| Warp | 106 | 106 | 74 | 90 | 49 | 70 | 31 | 45 | 26 | 43 |
| Filler | 86 | 86 | 51 | 68½ | 37½ | 45½ | 30 | 38 | 27 | 31 |
| Linen, No. 2, medium grade, uncoated: | | | | | | | | | | |
| Warp | 65 | 65 | 49½ | 51 | 32 | 50 | 28 | 44 | 21 | 42 |
| Filler | 45 | 45 | 29½ | 35 | 26 | 30 | 20 | 26 | 17 | 25 |
| Linen, No. 2, medium grade, coated, 1875 var.: | | | | | | | | | | |
| Warp | 85 | 85 | 57 | 74 | 41 | 64 | 23 | 50 | 21 | 49 |
| Filler | 75 | 75 | 55 | 62 | 38 | 46 | 29 | 43½ | 25 | 36 |
| Cotton, light weight, uncoated: | | | | | | | | | | |
| Warp | 37 | 37 | 16 | 18 | 10½ | 18 | 10 | 18 | 9 | 18 |
| Filler | 49½ | 49½ | 18 | 20 | 14 | 18 | 10 | 18 | (8) | (15) |
| Cotton, light weight, coated, 1875 var.: | | | | | | | | | | |
| Warp | 45 | 45 | 23 | 26 | 18½ | 22 | 15½ | 17½ | 14 | 18 |
| Filler | 45 | 45 | 20½ | 22 | 15 | 16½ | 11½ | (17) | 11 | 14½ |
| Balloon fabric, double, parallel: | | | | | | | | | | |
| Warp | 85 | 85 | 41 | 46 | 30 | 37 | 23 | 31 | 20 | 25 |
| Filler | 70 | 70 | 34 | 36 | 23 | 29½ | 17½ | 23½ | 14 | 20 |
| Balloon fabric, double bias | 65 | 65 | 53 | 57 | 47 | 52 | 30 | 43 | 20 | 34 |

31 Fig. 5.



Tearing Tests on Linen - #1 (High Grade)

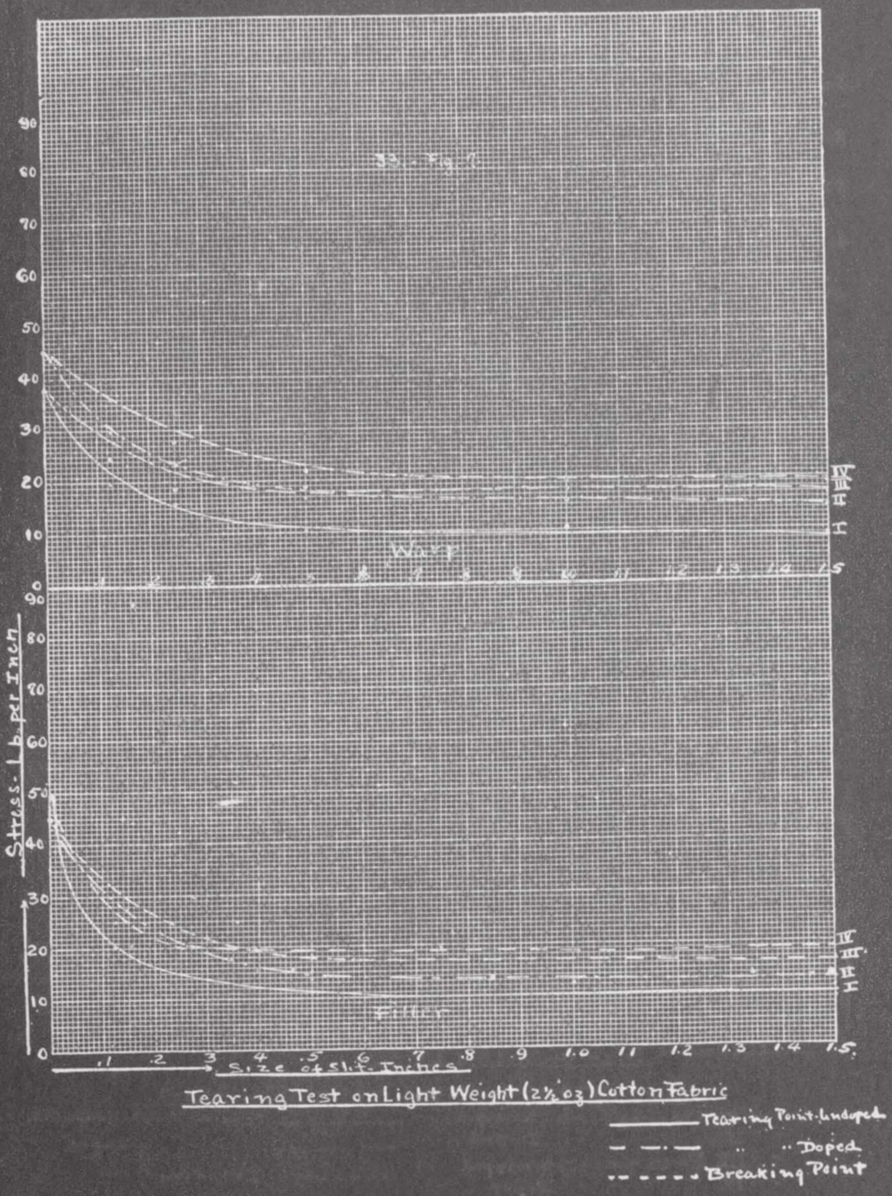
| | | | | |
|---|---|---|---|---|
| Curve I | Tearing Point | Undoped | ———— | Tearing Point, - Undoped |
| " II | " | " Doped | — — · — | " " Doped |
| " III | Breaking | " Undoped | ········ | Breaking Point |
| " IV | " | " Doped | | |



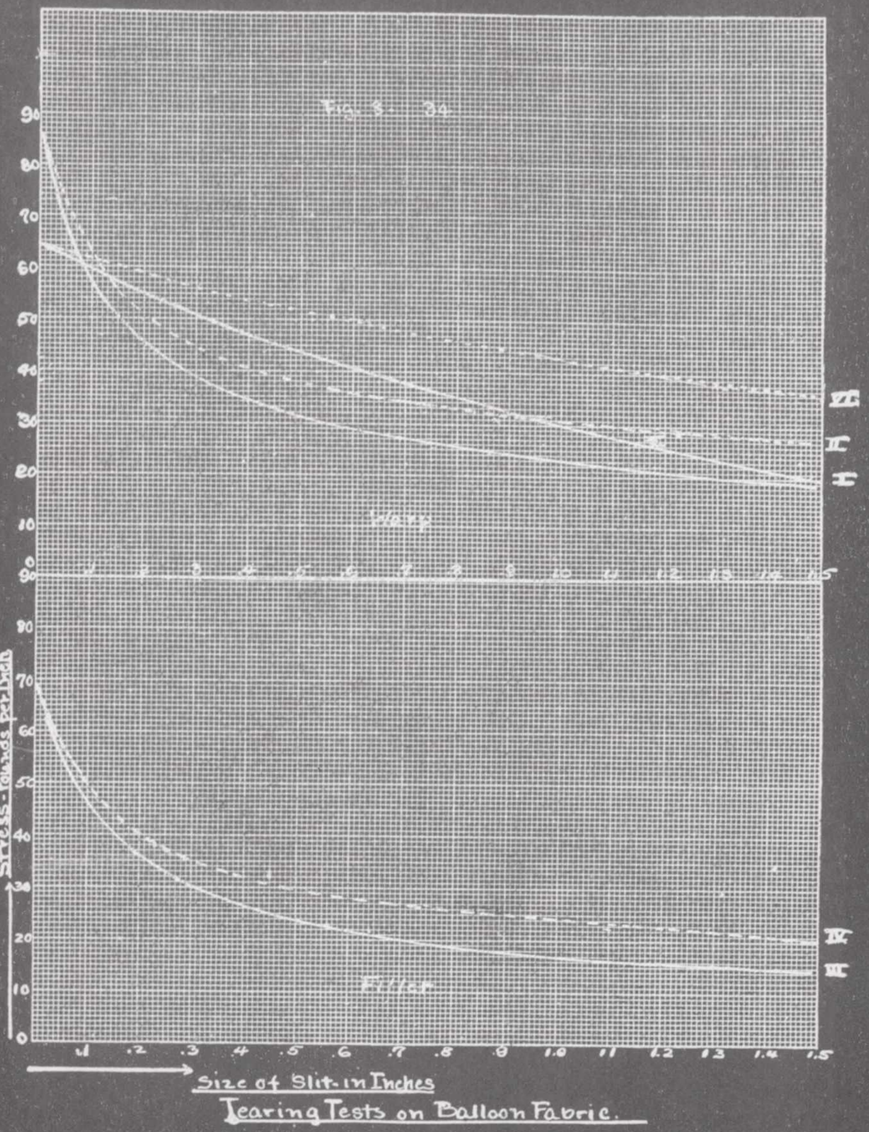
Tearing Tests on Linen #2 (Medium Grade)

Curve I - Tearing Point - Undoped
" II - " " Doped
" III Breaking - Undoped
" IV " " Doped

———— Tearing Point - Undoped
—·—·— " " Doped
------ Breaking Point.



Tearing Test on Light Weight (2½ oz) Cotton Fabric



Tearing Tests on Balloon Fabric.

Curves I & III - Tearing points Double parallel balloon fabric. Warp & Filler resp.
" II & IV - Breaking " " " " " " " "
" V & VI Tearing and Breaking Points " " Double bias.

## COTTON FABRICS.

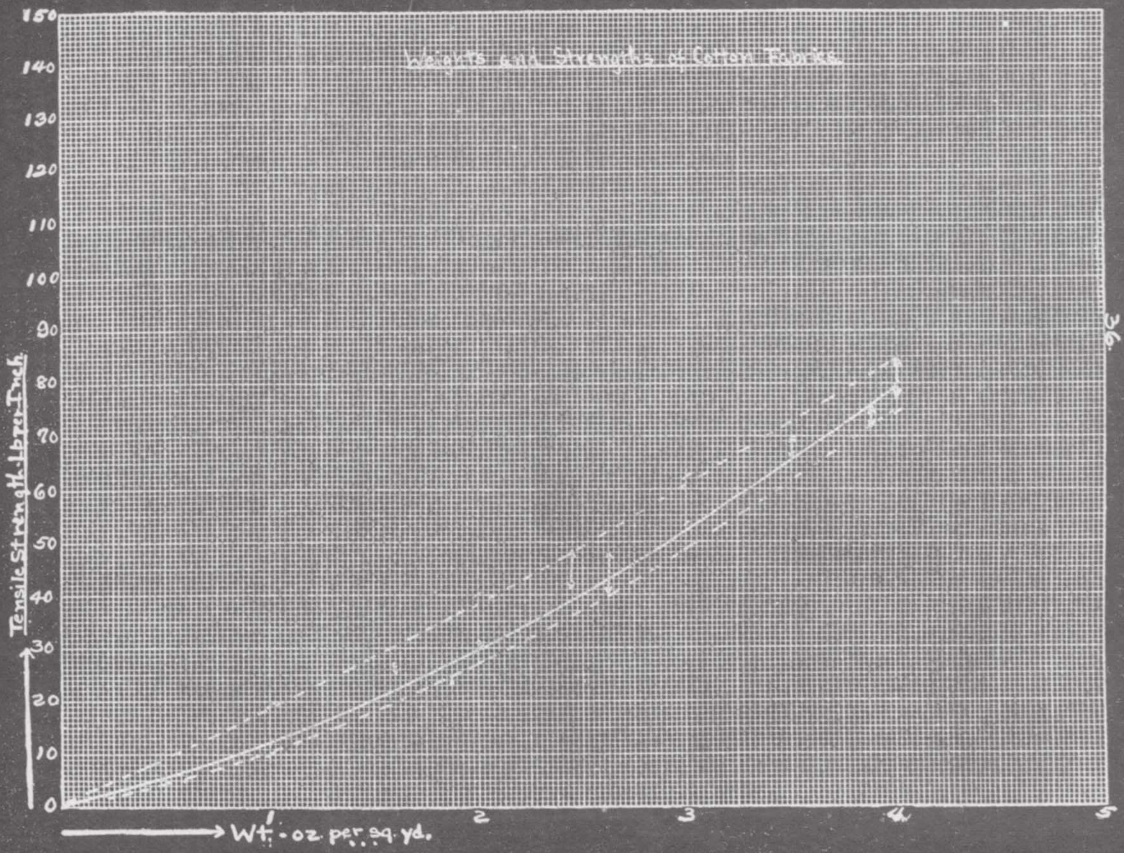
Sea island or Egyptian cotton, preferably the former, should be used for fabrics intended for use in making balloon fabric. In general the fabrics should be as nearly as possible of the same strength in both directions. Ordinary fabrics intended for clothing are, of course, usually much stronger in the direction of the warp than in the direction of the filling, because the strain comes mostly on the warp, and such fabrics are softer. Another item is, of course, the expense, since the fillers represent a greater manufacturing outlay.

It is difficult to establish any very definite relation between weight and maximum strength attainable, since the methods of manufacture play a very important rôle. A heavy tightly woven fabric may actually test much lower than one apparently not so strong, probably on account of a shearing or grinding action.

The fabrics examined are in general of single-ply yarns, the number of threads varying between 120 and 144 per inch, depending on the weight and strength. The data given represent samples made and tested in this country, and also test published abroad.

| | Weight (ounces per square yard). | Strength (pounds per inch). | |
|---|---|---|---|
| | | Warp. | Filler. |
| I | 1.60 | 27.0 | 26.0 |
| II | 1.85 | 24.3 | 24.5 |
| III | 1.98 | 31.0 | 31.0 |
| IV | 2.44 | 41.5 | 49.0 |
| V | 2.67 | 40.9 | 49.2 |
| VI | 3.51 | 70.0 | 67.0 |
| VII | 3.86 | 72.0 | 75.0 |
| VIII | 4.05 | 84.0 | 78.0 |

The curve shows that considerable variation is to be expected, probably to a large extent owing to the great variation in methods of testing. Accordingly, two curves are drawn as limits, with a mean or average value. Any fabric whose tests would place it within the area included by these curves would probably be about as good as could be expected in that grade. This does not mean, of course, that fabrics falling below this area would be unsatisfactory. It simply gives a rough idea of the possibilities under best conditions.


Weights and Strengths of Cotton Fabrics
Tensile Strength-Lbs per Inch
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
Wt.-oz. per sq. yd.
1
2
3
4
5
36

*Summary of various tests on aeroplane fabrics.*

| Fabric. | Weight (ounces per square yard). | Tensile strength (pounds per inch). | | | | Effect of exposure (per cent strength of original.) | | Fire test. | | Water absorption. | | Loss in weight from soaking. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Original. | | After 3 weeks' exposure. | | | | Seconds to burn 3½ feet. | Distance burned. | In saturated atmosphere. | Soaking. | |
| | | Warp. | Filler. | Warp. | Filler. | Warp. | Filler. | | | | | |
| | | | | | | | | | Inch. | Per cent. | Per cent. | Per cent. |
| 1. Linen No. 1 (high grade), varnish, 1875 | 5.18 | 95 | 92 | 62 | 66.7 | 65.0 | 72.5 | 35.0 | ..... | 12.94 | 44.2 | 3.96 |
| Linen No. 1 varnish: | | | | | | | | | | | | |
| 2. 1875, and spar varnish | 5.88 | 101 | 90 | 75 | 72 | 74.2 | 80.0 | 33.6 | ..... | 12.90 | 43.6 | 3.33 |
| 3. 1876 | 5.49 | 100 | 88 | 68 | 57 | 68.0 | 65.0 | 23 | ..... | 10.01 | 43.6 | 5.47 |
| 4. 1876, and spar varnish | 6.18 | 98 | 92 | 71 | 70 | 72.8 | 76.5 | 22.6 | ..... | 11.49 | 38.2 | 3.27 |
| 5. 1877 | 5.24 | 106 | 91 | 90 | 75 | 84.8 | 82.5 | 38.3 | ..... | 13.74 | 51.9 | 3.94 |
| 6. 1877 and spar varnish | 6.42 | 113 | 83 | 81 | 59 | 71.7 | 71.2 | 39.6 | ..... | 12.14 | 60.9 | 4.03 |
| 7. Cotton (light weight) varnish, 1875 | 3.45 | 58 | 68 | 28 | 40 | 48.4 | 59.3 | 23.0 | ..... | 8.7 | 32.4 | .84 |
| Cotton varnish: | | | | | | | | | | | | |
| 8. 1875, and spar varnish | 4.62 | 51 | 59 | 38 | 40 | 74.0 | 68.0 | 20.6 | ..... | 6.27 | 45.0 | .75 |
| 9. 1876 | 3.43 | 50 | 62 | 24 | 23 | 48.5 | 36.6 | 9.6 | ..... | 6.42 | 37.9 | .31 |
| 10. 1876, and spar varnish | 4.07 | 55 | 63 | 29 | 40 | 49.8 | 63.2 | 10.0 | ..... | 5.66 | 34.3 | .79 |
| 11. 1877 | 3.24 | 51 | 59 | 44 | 44 | 87.2 | 74.2 | 22.0 | ..... | 8.03 | 40.0 | .96 |
| 12. 1877, and spar varnish | 4.18 | 51 | 53 | 43 | 43 | 85.2 | 82.0 | 18.3 | ..... | 7.41 | 42.1 | .71 |
| Linen No. 1, Am. chloride varnish: | | | | | | | | | | | | |
| 13. 1875, and spar | 7.16 | 97 | 95½ | 52 | 58.4 | 53.5 | 61.0 | ..... | 1.6 | ..... | ..... | ..... |
| 14. 1876, and spar | 6.90 | 117 | 100 | 79 | 60.2 | 67.5 | 60.2 | ..... | 1.3 | ..... | ..... | ..... |
| 15. 1877, and spar | 7.57 | 107 | 96 | 58 | 54 | 54.2 | 56.3 | ..... | 1.4 | ..... | ..... | ..... |
| Linen No. 2 (medium grade) varnish: | | | | | | | | | | | | |
| 16. 1875 | 4.17 | 88.8 | 74.9 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 17. 1875, and spar | 5.50 | 100 | 86 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 18. 1876 | 4.15 | 92 | 79 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 19. 1876, and spar | 5.50 | 91 | 77 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 20. 1877 | 4.23 | 78 | 78 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 21. 1877, and spar | 5.39 | 91 | 82 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| Linen No. 1 (rubberized) varnish: | | | | | | | | | | | | |
| 22. 1875 | 7.37 | 121 | 104 | ..... | ..... | 79.2 | 75.0 | ..... | ..... | 7.73 | 63.5 | 4.34 |
| 23. 1875, and spar | 8.44 | 116 | 99 | ..... | ..... | 89.0 | 86.0 | ..... | ..... | 8.18 | 39.4 | 3.27 |
| 24. 1876 | 7.63 | 120 | 94 | 96 | 78 | 87.5 | 78.7 | ..... | ..... | 8.53 | 44.3 | 3.38 |
| 25. 1876, and spar | 8.89 | 119 | 96 | 103 | 85 | 94.5 | 100.0 | ..... | ..... | 10.69 | 38.9 | 2.82 |
| 26. 1877 | 7.57 | 119 | 91 | 105 | 74 | 93.2 | 95.5 | ..... | ..... | 8.32 | 55.3 | 5.92 |
| 27. 1877, and spar | 8.94 | 119 | 97 | 113 | 96 | 96.5 | 86.7 | ..... | ..... | 6.04 | 39.0 | 5.23 |
| Linen No. 1 varnish: | | | | | | | | | | | | |
| 28. 1875 | 5.18 | 95 | 92 | 111 | 87 | 89.5 | 92.3 | ..... | ..... | ..... | ..... | ..... |
| 29. 1875, and spar | 5.88 | 101 | 90 | 115 | 84 | 90.0 | 91.0 | ..... | ..... | ..... | ..... | ..... |

NOTE.—Samples Nos. 22 and 29 were exposed 2 weeks to weather; all others, 3 weeks. Varnish, 1876—cellulose nitrate; varnishes, 1875 and 1877—cellulose acetate.

## PERMEABILITY TESTS.

As already stated in the main body of the report, the method used was similar to that of the National Physical Laboratory of Great Britain, in which the hydrogen diffusing through the fabric is burned to water and weighed.

Owing to the limited time at our disposal, the tests were each two hours in length. Several tests were made on each sample at each temperature, and ordinarily agreed within a few per cent, when the slight temperature differences were allowed for. (To save time the thermostat was not run always at the same temperature, but simply kept constant at one temperature for each run. As the room temperature varied greatly from day to day during the period in which the tests were made, this made the operation of the thermostat more simple, and in addition gave in many cases a further check on the temperature effect.)

The diameter of the cell was 220 millimeters.

The hydrogen was run through one side of the cell at a rapid rate for several hours at the start of an experiment, to insure the expulsion of air. The proper rate for the passage of the air was found by experiment; it was noted that above a certain point, even with increased absorption apparatus, the total weight of water absorbed did not increase, indicating that the hydrogen was swept out practically as soon as it entered the cell. In the interval between tests on the same fabric, the air side was continually swept out, to prevent the accumulation of hydrogen on the air side. For this purpose a three-way stop-cock was introduced, and connections with trap-bottles made so that the furnace and cell could be swept out separately with air. It was found that in some cases the furnace contained small amounts of moisture that had not been all removed during the experiment, so at the expiration of the time by turning the cock the cell was swept out in preparation for the next run, while dry air was drawn from without through the furnace and absorption tubes for 10 to 15 minutes.

Specimen tests are shown.

*Permeability tests on various fabrics.*

| Fabric. | Temperature (° C.). | Permeability (liters per square meter per 24 hours, at 760/0°). |
|---|---|---|
| No. 1 balloon fabric, 2-ply parallel (9.25 ounces per square yard):<br>1.65 ounces per square yard rubber between plies<br>1 ounce per square yard rubber on inside face | 21.2 | 54.99 |
| | 22.07 | 56.37 |
| | 29.68 | 63.4 |
| | 30.01 | 65.3 |
| | 40.08 | 79.1 |
| | 40.09 | 79.4 |
| No. 2 balloon fabric, 2-ply parallel (10.81 ounces per square yard):<br>3.11 ounces per square yard rubber between plies<br>1 ounce per square yard rubber on inside face | 20.45 | 11.64 |
| | 21.65 | 11.29 |
| | 29.87 | 16.8 |
| | 30.71 | 17.32 |
| | 32.27 | 18.79 |
| | 38.58 | 24.35 |
| | 39.19 | 25.34 |
| No. 3 balloon fabric, 2-ply parallel (93.2 ounces per square yard):<br>5.51 ounces per square yard rubber between plies<br>1 ounce per square yard rubber on inside face | 20.04 | 11.2 |
| | 20.23 | 11.7 |
| | 39.48 | 25.25 |
| | 39.63 | 25.55 |
| | 40.14 | 26.37 |
| Balloon cloth No. 3, 4 coats varnish No. 1876 on cloth (about 2 ounces per square yard) | 21.42 | 10.86 |
| | 21.91 | 11.8 |
| | 22.00 | 11.34 |
| | 29.99 | 15.44 |
| | 31.68 | 17.11 |
| | 40.51 | 24.73 |
| | 40.75 | 25.25 |
| Balloon cloth No. 3, 4 coats varnish No. 1877 on cloth (about 2 ounces per square yard) | 20.81 | 11.18 |
| | 20.85 | 11.34 |
| | 21.28 | 11.5 |
| | 30.51 | 16.90 |
| | 30.57 | 17.15 |
| | 39.09 | 24.13 |
| | 39.74 | 24.22 |
| Balloon cloth No. 3, gelatin compound on rubber (2 ounces per square yard) | 20.2 | 1.4 |
| | 20.01 | .8 |
| | 21.29 | 1.4 |
| | 38.91 | 5.6 |
| | 38.95 | 6.6 |
| Balloon fabric No. 3, varnish No. 1876 (2 ounces per square yard), on rubber | 20.02 | 4.5 |
| | 20.22 | 5.0 |
| | 20.46 | 5.6 |
| | 38.96 | 10.2 |
| | 39.24 | 11.2 |

*Permeability tests on various fabrics*—Continued.

| Fabric. | Temperature (° C.). | Permeability (liters per square meter per 24 hours, at 760/0°). |
|---|---|---|
| Balloon cloth No. 3, varnish No. 1877 (2 ounces per square yard), on rubber | 19.91 | 4.55 |
| | 20.25 | 4.15 |
| | 37.45 | 10.85 |
| | 38.90 | 11.35 |
| | 38.96 | 12.7 |
| Balloon cloth No. 19 (12 ounces per square yard) | 20.3 | 11.2 |
| | 21.1 | 11.37 |

(1) It will be noted that gelatin compound gives very low permeability. The use of gelatin on fabric for balloons was suggested by Julhe.[1] Austerweil tried this and found[2] that at first there was practically no loss in volume, even a slight gain due to gases dissolved in the water. After 35 hours the membrane was apparently saturated and lost gas at practically the same rate as the comparison rubber membrane. On the other hand, although each of our tests was only two hours long, the total time in which the cell was filled with hydrogen, and the gelatin-rubber fabric in place, was 48 hours, yet at the end of that time, when the tests were made at 40° C., the permeability was only one-fourth that of the rubberized fabric alone. It is possible that in contact with dry rubber and dry gases, as in our apparatus, the membrane might act differently.

(2) Another point of interest is the test on fabrics 2 and 3 compared with fabric 19. The first two were experimental samples, and for convenience made parallel. The fabric 19 was bias, yet showed practically no difference in permeability. There has been some indication in tests made at the National Physical Laboratory that parallel fabrics were much more permeable. They state that probably the method of manufacture has a considerable effect. This has not been noticed in our tests, and the reason for any such difference is not apparent.

(3) *Temperature coefficient.*—This varies with the temperature and degree of permeability of the material. From our experiments we found the following values:

| | Rate of increase at— | | |
|---|---|---|---|
| | 10-20° C. | 20-30° C. | 30-40° C. |
| | *Per cent.* | *Per cent.* | *Per cent.* |
| Rubber fabric, permeability at 15° C. | 4.4 | 4.6 | 4 |
| Rubber fabric coated with 2-ounce gelatin on rubber | | 1.3 | 3.4 |

(4) *Effect of Weathering.*—On account of the limited time at our disposal for making this investigation, long weathering tests on these samples were not made. Aging by continuous exposure for one month caused no increase in permeability; in fact, one of our samples seemed improved. The rubber layers were apparently unaffected, so this improvement was not due to resinification which has been noted in England, but was more likely due to a slight variation in samples.

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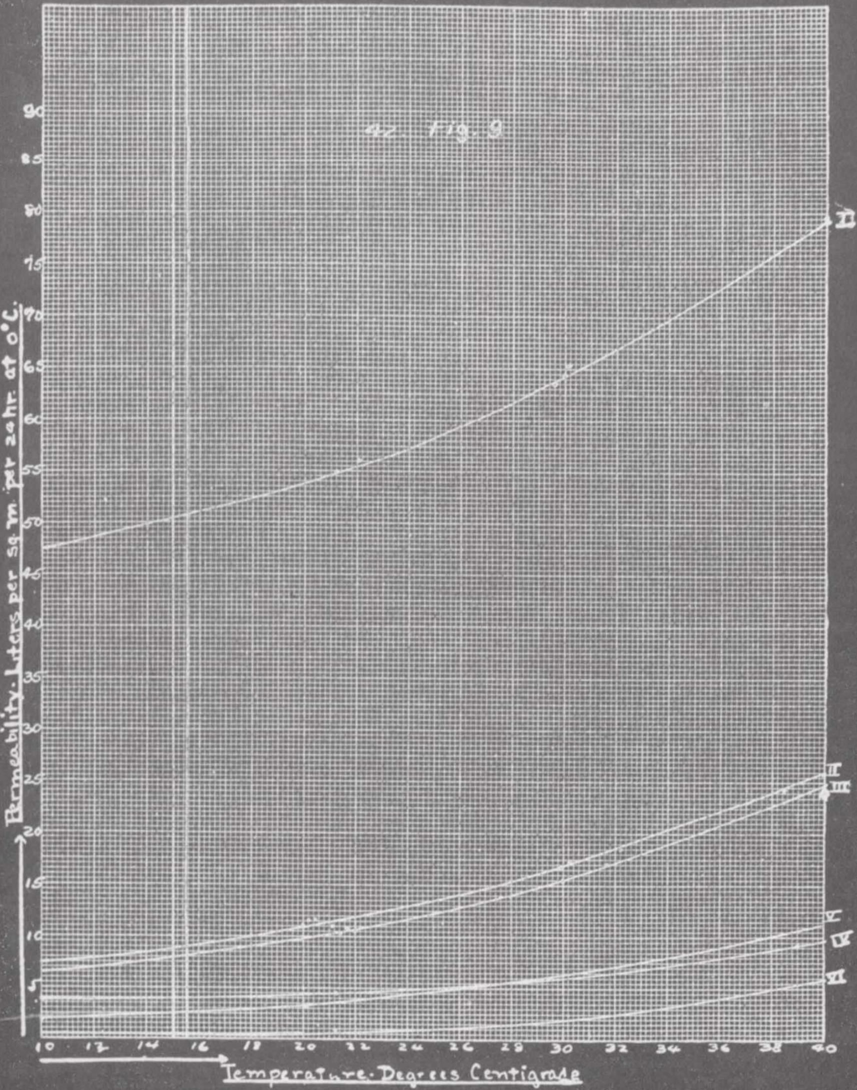
[1] C. R. Acad. Sc., 1912, Feb. 12.

[2] Die Angewandte Chemie in der Luftfahrt, p. 90.



42 Fig. 9

Effect of Temperature on Permeability.

I. Balloon Fabric. 1.65 oz. Rubber between plies
II " " (s) 3.11 & 5,51 oz " " "
III " " 5 51 oz rubber. Coated on cloth - with Aerovarnish 2 oz
IV-V " " " " " " " rubber " " 1876 & 1877 resp 2 oz
VI. " " " " " " " " gelatine compound 2 oz

*Surface friction of aeronautic fabrics at different wind velocities.*

| Condition and area (square feet). | | Experiment No. 1. | | | | | Experiment No. 2. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Plate glass. | | | | | Linen No. 1, 1 coat varnish, 1876 (area, 50.35). | | | | |
| Miles per hour. | Net correction, pound. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. |
| 30 | 0.020 | 0.384 | 0.404 | 0.0079 | 0 | 0 | 0.408 | 0.428 | 0.0085 | 0.0006 | 1.081 |
| 40 | .031 | .637 | .668 | .0131 | | | .679 | .710 | .0141 | .0010 | 1.080 |
| 50 | .046 | .969 | 1.015 | .0199 | | | 1.046 | 1.092 | .0218 | .0019 | 1.098 |
| 60 | .071 | 1.342 | 1.413 | .0276 | | | 1.480 | 1.551 | .0309 | .0023 | 1.118 |
| 70 | .094 | 1.768 | 1.862 | .0364 | | | 2.040 | 2.134 | .0424 | .0060 | 1.162 |

| Condition and area (square feet). | | Experiment No. 3. | | | | | Experiment No. 4. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Linen No. 1, 3 coats varnish, 1876 (area, 50.35). | | | | | Linen No. 1, 3 coats varnish, 1876; 1 coat spar varnish (area, 50.35). | | | | |
| Miles per hour. | Net correction, pound. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. |
| 30 | 0.020 | 0.394 | 0.414 | 0.00822 | 0.0003 | 1.042 | 0.389 | 0.409 | 0.0081 | 0.0002 | 1.031 |
| 40 | .031 | .665 | .696 | .0138 | .0007 | 1.060 | .649 | .680 | .0135 | .0004 | 1.034 |
| 50 | .046 | .938 | 1.044 | .0208 | .0009 | 1.048 | .981 | 1.027 | .0204 | .0005 | 1.028 |
| 60 | .071 | 1.410 | 1.481 | .0295 | .0019 | 1.067 | 1.376 | 1.447 | .0287 | .0011 | 1.038 |
| 70 | .094 | 1.919 | 2.013 | .0403 | .0039 | 1.108 | 1.854 | 1.948 | .0387 | .0023 | 1.061 |

| Condition and area, (square feet). | | Experiment No. 5. | | | | | Experiment No. 6. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Linen No. 1, uncoated (area, 50.18). | | | | | Linen No. 1, 3 coats varnish, 1877 (area, 50.18). | | | | |
| Miles per hour. | Net correction, pound. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. |
| 30 | 0.020 | 0.457 | 0.477 | 0.0095 | 0.0016 | 1.205 | 0.390 | 0.410 | 0.0082 | 0.0003 | 1.034 |
| 40 | .031 | .778 | .810 | .0161 | .0030 | 1.234 | .652 | .683 | .0136 | .0005 | 1.040 |
| 50 | .046 | 1.204 | 1.250 | .0249 | .0050 | 1.254 | .988 | 1.034 | .0206 | .0007 | 1.039 |
| 60 | .071 | 1.738 | 1.809 | .0361 | .0085 | 1.305 | 1.392 | 1.463 | .0292 | .0016 | 1.056 |
| 70 | .094 | 2.395 | 2.489 | .0496 | .0132 | 1.362 | 1.880 | 1.984 | .0395 | .0031 | 1.085 |

| Condition and area (square feet). | | Experiment No. 7. | | | | | Experiment No. 8. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Linen No. 1, 3 coats varnish, 1877; 1 coat spar varnish (area, 50.18). | | | | | Linen No. 1, 3 coats varnish, 1877; 2 coats spar varnish (area, 50.18). | | | | |
| Miles per hour. | Net correction, pound. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. |
| 30 | 0.020 | 0.393 | 0.413 | 0.0082 | 0.0003 | 1.044 | 0.393 | 0.413 | 0.0082 | 0.0003 | 1.044 |
| 40 | .031 | .655 | .686 | .0137 | .0006 | 1.049 | .644 | .675 | .0134 | .0003 | 1.026 |
| 50 | .046 | .977 | 1.023 | .0204 | .0005 | 1.028 | .978 | 1.024 | .0204 | .0005 | 1.028 |
| 60 | .071 | 1.384 | 1.455 | .0288 | .0012 | 1.041 | 1.367 | 1.438 | .0286 | .0010 | 1.033 |
| 70 | .094 | 1.884 | 1.978 | .0394 | .0030 | 1.081 | 1.874 | 1.968 | .0392 | .0028 | 1.078 |

*Surface friction of aeronautic fabrics at different wind velocities*—Continued.

| Condition and area (square feet). | | Experiment No. 9. | | | | | Experiment No. 10. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Balloon fabric No. 3, double par. cloth outside (area, 49.6). | | | | | Balloon fabric No. 3 (same as 9), freshly singed (area, 49.6). | | | | |
| Miles per hour. | Net correction, pound. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. |
| 30 | 0.020 | 0.672 | 0.692 | 0.0139 | 0.0060 | 1.766 | 0.493 | 0.513 | 0.0103 | 0.0024 | 1.311 |
| 40 | .031 | 1.149 | 1.180 | .0238 | .0107 | 1.822 | .883 | .914 | .0184 | .0053 | 1.408 |
| 50 | .046 | 1.764 | 1.810 | .0365 | .0166 | 1.838 | 1.403 | 1.449 | .0292 | .0093 | 1.470 |
| 60 | .071 | 2.501 | 2.573 | .0518 | .0242 | 1.873 | 2.041 | 2.112 | .0426 | .0150 | 1.539 |
| 70 | .094 | 3.452 | 3.546 | .0715 | .0351 | 1.965 | 2.898 | 2.992 | .0603 | .0239 | 1.654 |

| Condition and area (square feet). | | Experiment No. 11. | | | | | Experiment No. 12. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Balloon fabric No. 3 (same as 10); 1 coat varnish, 1876 (area, 49.6). | | | | | Balloon fabric No. 3 (same as 10); 3 coats varnish, 1876 (area, 49.6). | | | | |
| Miles per hour. | Net correction, pound. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. | Gross force, pounds. | Net force, pounds. | Net force, pound, square foot. | Net excess. | Resistance factor. |
| 30 | 0.020 | 0.446 | 0.466 | 0.0094 | 0.0015 | 1.180 | 0.394 | 0.414 | 0.0083 | 0.0004 | 1.056 |
| 40 | .031 | .783 | .814 | .0164 | .0033 | 1.253 | .661 | .692 | .0139 | .0008 | 1.063 |
| 50 | .046 | 1.199 | 1.245 | .0251 | .0052 | 1.264 | 1.009 | 1.055 | .0213 | .0014 | 1.072 |
| 60 | .071 | 1.722 | 1.793 | .0362 | .0086 | 1.309 | 1.419 | 1.490 | .0300 | .0024 | 1.082 |
| 70 | .094 | 2.332 | 2.426 | .0490 | .0126 | 1.345 | 1.904 | 1.998 | .0403 | .0039 | 1.107 |

| Condition and area (square feet). | | Experiment No. 13. | | | | | Experiment No. 14. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Balloon fabric No. 3, bias (area, 48.88). | | | | | Balloon fabric No. 3, bias, freshly singed (area, 48.88). | | | | |
| Miles per hour. | Net correction, pound. | Gross force, pounds. | Net force, pounds. | Net force, pound/ square foot. | Net excess. | Resistance factor. | Gross force, pounds. | Net force, pounds. | Net force, pound/ square foot. | Net excess. | Resistance factor. |
| 30 | 0.020 | 0.631 | 0.651 | 0.0133 | 0.0054 | 1.691 | 0.483 | 0.503 | 0.0103 | 0.0024 | 1.308 |
| 40 | .031 | 1.078 | 1.109 | .0227 | .0096 | 1.739 | .864 | .895 | .0183 | .0052 | 1.402 |
| 50 | .046 | 1.632 | 1.678 | .0343 | .0144 | 1.728 | 1.461 | 1.507 | .0309 | .0110 | 1.555 |
| 60 | .071 | 2.343 | 2.414 | .0494 | .0218 | 1.782 | 2.157 | 2.228 | .0457 | .0181 | 1.651 |
| 70 | .094 | 3.294 | 3.388 | .0694 | .0330 | 1.902 | 3.043 | 3.137 | .0642 | .0278 | 1.762 |

| Condition and area (square feet). | | Experiment No. 15. | | | | | Experiment No. 16. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Balloon fabric No. 6, double bias, special fabric (area, 49.34). | | | | | Balloon fabric No. 6, double bias, special fabric, freshly singed (area, 49.34). | | | | |
| Miles per hour. | Net correction, pound. | Gross force, pounds. | Net force, pounds. | Net force, pound/ square foot. | Net excess. | Resistance factor. | Gross force, pounds. | Net force, pounds. | Net force, pound/ square foot. | Net excess. | Resistence factor. |
| 30 | 0.020 | 0.468 | 0.488 | 0.0099 | 0.0020 | 1.252 | 0.423 | 0.443 | 0.0099 | 0.0020 | 1.139 |
| 40 | .031 | .858 | .889 | .0180 | .0049 | 1.378 | .744 | .775 | .0157 | .0026 | 1.202 |
| 50 | .046 | 1.343 | 1.389 | .0281 | .0082 | 1.414 | 1.170 | 1.216 | .0247 | .0048 | 1.243 |
| 60 | .071 | 1.959 | 2.030 | .0412 | .0136 | 1.490 | 1.744 | 1.815 | .0368 | .0092 | 1.331 |
| 70 | .094 | 2.648 | 2.742 | .0556 | .0292 | 1.528 | 2.378 | 2.472 | .0500 | .0136 | 1.372 |

*Surface friction of aeronautic fabrics at different wind velocities*—Continued.

| Condition and area (square feet). | | Experiment No. 21. | | | | | Experiment No. 22. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Aeroplane fabric, rubberized, No. 23 (area, 48.8). | | | | | Aeroplane fabric, aluminum coated, No. 24 (area, 48.6). | | | | |
| Miles per hour. | Net correction, pound. | Gross force, pounds. | Net force, pounds. | Net force, pound/square foot. | Net excess. | Resistance factor. | Gross force, pounds. | Net force, pounds. | Net force, pound/square foot. | Net excess. | Resistence factor. |
| 30 | 0.020 | 0.382 | 0.412 | 0.0084 | 0.0005 | 1.070 | 0.394 | 0.414 | 0.0085 | 0.0006 | 1.078 |
| 40 | .031 | .653 | .690 | .0142 | .0011 | 1.082 | .657 | .688 | .0142 | .0011 | 1.083 |
| 50 | .046 | 1.004 | 1.050 | .0215 | .0016 | 1.083 | .988 | 1.034 | .0213 | .0014 | 1.073 |
| 60 | .081 | 1.379 | 1.460 | .0299 | .0023 | 1.081 | 1.375 | 1.456 | .0299 | .0023 | 1.081 |
| 70 | .094 | 1.824 | 1.918 | .0393 | .0029 | 1.079 | 1.856 | 1.950 | .0401 | .0037 | 1.101 |

## SURFACE FRICTION TESTS.

In the next to the last column of each experiment, pages 43–4, are given under the heading "Net excess" the numerical difference between the resistance in pounds per square foot of the material, and the resistance of plate glass. In the last column are given factors obtained by dividing the resistance of the material by that of glass at the same velocity.

In general the resistance of an object to the wind increases with the square of the velocity. The general form is, for unit area:

$$P = K V^2.$$

When $P$ = pressure.
$V$ = velocity.
$K$ = a constant.

It has been found by Froude and others that surface friction varies with about the 1.87 power of the velocity.

Plotting the logarithms of the velocity against the pressure, we obtained from our results, in practically all cases, a straight line. The values at 70 miles per hour were a little off in most cases, indicating the pressure of another factor, possibly due to temperature.

The logarithms were plotted and from the values of the faired curves, the approximate exponents and coefficients were obtained algebraically for some of the most interesting cases.

General equation $P = K V^n$.

When $P$ = pressure in pounds per square foot.
$V$ = velocity in miles per hour.
$n$ and $K$ = constants.

| | $K$ | $N$ |
|---|---|---|
| Experiment 1. Plate glass | 0.0000178 | 1.84 |
| Experiment 2. Linen No. 1, varnish No. 1876 | .0000156 | 1.85 |
| Experiment 5. Linen No. 1, uncoated | .0000137 | 1.92 |
| Experiment 9. Balloon fabric No. 3 | .0000192 | 1.93 |

It will be noted that in general the rougher materials have higher exponents, approaching 2 in the case of balloon fabric.

*Absorption tests, balloon and aeroplane fabrics.*

| Fabric. | Atmospheric weight. | Dry weight. | Moist weight. | Normal moisture. | | Moisture after suspension in saturated atmosphere. | | Atmospheric weight. | Dry weight. | Wet weight. | Dry weight after soaking. | Normal moisture. | | Water held in fabric after soaking. | | Weight of material removed by soaking. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ounces. | Per cent. | Ounces. | Per cent. | | | | | Ounces. | Per cent. | Ounces. | Per cent. | Ounces. | Per cent. |
| High-grade linen No. 1, untreated, weight 4.6 ounces: | | | | | | | | | | | | | | | | | |
| Varnish 1875 (cell. acetate) | 5.52 | 5.18 | 5.85 | 0.34 | 6.56 | 0.67 | 12.94 | 5.65 | 5.30 | 7.34 | 5.09 | 0.35 | 6.61 | 2.25 | 44.2 | 0.21 | 3.96 |
| Varnish 1875 and spar varnish | 6.26 | 5.88 | 6.57 | .38 | 6.46 | .69 | 12.90 | 6.09 | 5.71 | 7.93 | 5.52 | .38 | 6.65 | 2.41 | 43.6 | .19 | 3.33 |
| Varnish 1876 (cell. nitrate) | 5.71 | 5.49 | 6.04 | .22 | 4.02 | .55 | 10.01 | 5.71 | 5.49 | 7.45 | 5.19 | .22 | 4.02 | 2.26 | 43.6 | .30 | 5.47 |
| Varnish 1876 and spar varnish | 6.54 | 6.18 | 6.89 | .36 | 5.83 | .71 | 11.49 | 6.46 | 6.11 | 8.17 | 5.91 | .35 | 5.44 | 2.26 | 38.2 | .20 | 3.27 |
| Varnish 1877 (cell. acetate) | 5.61 | 5.24 | 5.96 | .37 | 7.07 | .72 | 13.74 | 5.72 | 5.34 | 7.79 | 5.13 | .38 | 7.13 | 2.66 | 51.9 | .21 | 3.94 |
| Varnish 1877 and spar varnish | 6.87 | 6.42 | 7.20 | .45 | 7.01 | .78 | 12.14 | 6.64 | 6.20 | 9.57 | 5.95 | .44 | 7.10 | 3.62 | 60.9 | .25 | 4.03 |
| Rubberized (one side) | 6.49 | 6.27 | 7.08 | .22 | 3.51 | .59 | 9.41 | 6.63 | 6.41 | 9.88 | 6.16 | .22 | 3.43 | 3.72 | 60.4 | .25 | 3.90 |
| Rubberized, varnish 1875 | 7.63 | 7.37 | 8.20 | .26 | 3.53 | .57 | 7.73 | 7.62 | 7.36 | 11.51 | 7.04 | .26 | 3.53 | 4.47 | 63.5 | .32 | 4.34 |
| Rubberized, varnish 1875 and spar varnish | 8.80 | 8.44 | 9.49 | .36 | 4.27 | .69 | 8.18 | 8.82 | 8.56 | 11.54 | 8.28 | .26 | 3.03 | 3.26 | 39.4 | .28 | 3.27 |
| Rubberized, varnish 1876 | 7.85 | 7.63 | 8.50 | .22 | 2.89 | .65 | 8.53 | 7.89 | 7.69 | 10.72 | 7.43 | .20 | 2.61 | 3.29 | 44.3 | .26 | 3.38 |
| Rubberized, varnish 1876 and spar varnish | 9.13 | 8.89 | 10.08 | .24 | 2.70 | .95 | 10.69 | 8.82 | 8.51 | 11.49 | 8.27 | .31 | 3.64 | 3.22 | 38.9 | .24 | 2.82 |
| Rubberized, varnish 1877 | 7.83 | 7.57 | 8.46 | .26 | 3.43 | .63 | 8.32 | 7.81 | 7.60 | 11.10 | 7.15 | .21 | 2.76 | 3.95 | 55.3 | .45 | 5.92 |
| Rubberized, varnish 1877 and spar varnish | 9.23 | 8.94 | 9.77 | .29 | 3.25 | .54 | 6.04 | 9.19 | 8.85 | 11.69 | 8.14 | .34 | 3.84 | 3.28 | 39.0 | .44 | 5.23 |
| Cotton (light weight): | | | | | | | | | | | | | | | | | |
| Varnish 1875 | 3.74 | 3.45 | 3.75 | .29 | 8.40 | .30 | 8.70 | 3.89 | 3.58 | 4.70 | 3.55 | .31 | 8.67 | 1.15 | 32.4 | .03 | .84 |
| Varnish 1875 and spar varnish | 4.86 | 4.62 | 4.91 | .24 | 5.19 | .29 | 6.27 | 4.20 | 3.99 | 5.74 | 3.96 | .21 | 5.27 | 1.78 | 45.0 | .03 | .75 |
| Varnish 1876 | 3.60 | 3.43 | 3.65 | .17 | 4.96 | .22 | 6.42 | 3.36 | 3.20 | 4.40 | 3.19 | .16 | 5.00 | 1.21 | 37.9 | .01 | .31 |
| Varnish 1876 and spar varnish | 4.28 | 4.07 | 4.30 | .21 | 5.16 | .23 | 5.66 | 3.98 | 3.79 | 5.05 | 3.76 | .19 | 5.02 | 1.29 | 34.3 | .03 | .79 |
| Varnish 1877 | 3.46 | 3.24 | 3.50 | .22 | 6.80 | .26 | 8.03 | 3.35 | 3.13 | 4.34 | 3.10 | .22 | 7.03 | 1.24 | 40.0 | .03 | .96 |
| Varnish 1877 and spar varnish | 4.47 | 4.18 | 4.49 | .29 | 6.94 | .31 | 7.41 | 4.59 | 4.29 | 6.01 | 4.23 | .30 | 7.00 | 1.78 | 42.1 | .03 | .71 |
| Balloon fabric, cloth outside (1½-ounce double bias), No. 3 | 11.35 | 10.98 | 11.62 | .37 | 3.37 | .64 | 5.83 | 11.35 | 10.68 | 14.52 | ........ | .37 | 3.37 | 3.54 | 32.3 | ........ | ........ |
| Balloon fabric No. 3 and balloon fabric No. 3 spot proof | 11.60 | 11.30 | 11.76 | .30 | 2.68 | .46 | 4.07 | 11.38 | 11.05 | 13.92 | ........ | .33 | 3.00 | 2.87 | 24.8 | ........ | ........ |
| Balloon fabric No. 3, proof No. 123 | 12.37 | 11.95 | 13.20 | .42 | 3.52 | 1.25 | 10.50 | 12.28 | 11.89 | 15.20 | ........ | .39 | 3.28 | 3.31 | 27.8 | ........ | ........ |

# REPORT No. 6.

## PART 2.

# SKIN FRICTION OF VARIOUS SURFACES IN AIR.

By Willis A. Gibbons.

## INTRODUCTION.

The relation of skin friction or surface friction, to the relative velocity of a surface and the surrounding medium, and the variation of this relation with the nature of the surface is of growing importance to the science of aeronautics. Owing to the greater speeds now developed in air craft of all kinds, it was decided to investigate these relations with particular reference to the sort of surfaces which would be used in aeronautic work.

W. Froude[1] measured the resistance for various surfaces of various lengths in a water channel, and the results of his experiments lead to the following conclusions:

1. The force tangential to the plane due to skin friction, ordinarily varies according to the 1.85–2 power of the velocity for smooth surfaces. For rougher surfaces, it varies practically as the square of the velocity.
2. The length of the plane has a decided effect on the average resistance per unit area, the resistance decreasing as the length increases.
3. Smooth surfaces do not necessarily increase according to a lower power of the velocity than *rougher* surfaces, although the numerical value of the resistance per unit area is less.
4. The index decreases as the length increases for smooth surfaces.

Zahm[2] measured the resistance due to surface friction of planes in a current of air, and found that all smooth surfaces showed an increase in resistance according to the 1.85 power of the velocity. Buckram with 16 threads per inch gave a high resistance and an index of 2.05, practically 2.

He measured the resistance of planes of various lengths and obtained the following equation connecting the length of a plane with its velocity and surface friction:

$$P \propto L^{-.07} V^{1.85} \qquad (1)$$

When $V$ = Velocity in feet per second.
$L$ = Length of planes.
$p$ = Tangential force per square foot.

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[1] British Assoc. Report, 1872, 118; 1874, 249.

[2] Phil. Mag., VIII, 58-66 (1904).

Lanchester[1] shows that to express the resistance of a plane bringing into account the linear size and kinematic viscosity, we have the relation—

$$R \propto v^q L^1 V^r \tag{2}$$

When $q+r=2$
$v$ = Kinematic viscosity.
$L$ = Linear size.
$V$ = Velocity.

The kinematic viscosity[2] $v=\frac{\mu}{\rho}$

When $\mu$ = Coefficient of viscosity.
$\rho$ = Density.

The kinematic resistance, $R=\frac{F}{\rho}$, i. e., it is the resistance per unit density.

Lanchester points out that in terms of $R$, Zahm's equation (1) becomes

$$R \propto L^{1.93} V^{1.85} \tag{3}$$

whereas according to (2) $L$ and $V$ should have the same index. He adopts the following for a smooth surface.

$$R \propto v^{.1} L^{1.9} V^{1.9} \tag{4}$$

Assuming, what we have found to be the case, that the exponent varies with the nature of the surface, we may put this in the form

$$R \propto v^{2-n} L^n V^n \tag{5}$$

whence

$$F = \kappa \rho v^{2-n} L^n V^n \tag{6}$$

For any one surface it is convenient to neglect the length, and embody this and the $\rho$ and $v$ values in one constant, so we have.

$$F = KV^n \tag{7}$$

The value of $K$ depends of course on the units.—throughout this paper $F$ will be in lbs. per square feet, and $V$ in miles per hour. The value of .1 for air is 1.3 times that for water, so this and the relative densities give a means of calculating from one medium to the other.

The values of $n$ and $K$ vary with the surface even for so-called smooth surfaces, and as will be shown, seem in such cases to bear a more or less definite relation to each other.

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[1] Tech. Rept. Adv. Com. for Aeronautics, 1909–10, p. 34.

[2] Lanchester's Aerodynamics, p. 36.

## EXPERIMENTAL.

Through the kindness of the Bureau of Construction and Repair of the Navy Department the excellent facilities afforded by the wind-tunnel of the Washington Navy Yard became available for experiments on the frictional resistance of various surfaces. These experiments were made for the purpose of looking into the matter of surface friction with particular reference to surfaces of the sort which would be of most interest from the standpoint of aeronautics.

A glass plate about 9½ feet long and 34 inches wide was suspended vertically, with its surface tangent to the direction of the wind, by two wires fastened to the upper edge of the plate. The ends of the plate were enclosed in slots in faired struts, which were fixed rigid to the floor and ceiling of the tunnel, and stayed to prevent vibration. Smooth steel rollers attached to each side of the slots, at the upper and lower ends, prevented side movement of the plate. They did not ordinarily touch the latter, being set to allow a clearance of 0.01 inch. Thus the plate was free to move within limits only in the line of the air current.

The trailing edge of the plate was connected by a steel rod to the balance, allowing the horizontal force to be measured.

## CORRECTIONS.

It was found by experiment that the ends of the plate, although protected by the struts, were affected by the air current. Tubes were set in the slots and connected with a hook gauge manometer. From the pressure at each end, the force on the plate was measured for different velocities, and by a faired curve, a set of corrections at different velocities was obtained. Both of these corrections are to be added since the air rushing past the slot in which the leading edge fits causes a diminution in pressure, and in the other slot, an increased pressure. Both of these changes in pressure would give a thrust against the wind.

The correction for the wires was found by adding 4 more supporting wires, making 6 in all and measuring the force on the plate with these additional supports, then removing the original wires and measuring the resistance of the plate at different velocities with four wires. Subtraction gave the effect of the two wires, which were used as supports in all regular tests. This correction is of course to be deducted from the observed force. To avoid masking, small wedges were used to hold the added wires away from the glass, the added wire passing around under the lower edge of the plate in each case.

## SURFACES.

Plate glass was used as a standard, or ideal surface, since it is probably as smooth as any surface, and can be easily duplicated. The various fabrics were attached to this by a nitrocellulose varnish, by which, with a little practice, we were able to obtain a surface practically smooth, so far as unevennesses from wrinkles, etc., were concerned. The amount of varnish needed was so small and its colloidal nature such that it was possible to attach an uncoated linen to the glass without affecting the outer surface of the fabric appreciably. The linen surface could then be tested, and treated further as desired.

When more than two coats of varnish were applied, the surface was sand-papered between each coat.

Where fabrics were singed between tests, the singeing was done with a blow-torch.

The surfaces tested may be grouped as follows:

1. Plate glass.
2. Fabric surfaces with nap.
3. Fabric surfaces without nap (linen and cotton).
4. Varnished fabrics (cotton and linen).
5. Rubber coated linen (plain and aluminum surface).

The experiments were made at velocities of 30, 40, 50, 60, and 70 miles per hour. Owing to the large size of the plate (area about 50 square feet) the forces were large enough to enable considerable accuracy to be obtained. For example in the case of plate glass, the gross uncorrected force is about 0.27 pound at 30 miles per hour. On this account and also on account of the greater range of velocities we were able to detect variations in apparently smooth surfaces which were not noticeable in earlier experiments at low velocities.

The values of *F* (pound per square feet) the relative value of *F* compared with that for glass called for want of a better term, the resistance factor (*R. F.*) and the values of *n* and *K* are given in Table I.

TABLE I.—*Results of experiments on surface friction, in air, of various surfaces.*

[Tests were made in wind-tunnel, Washington, D. C.]

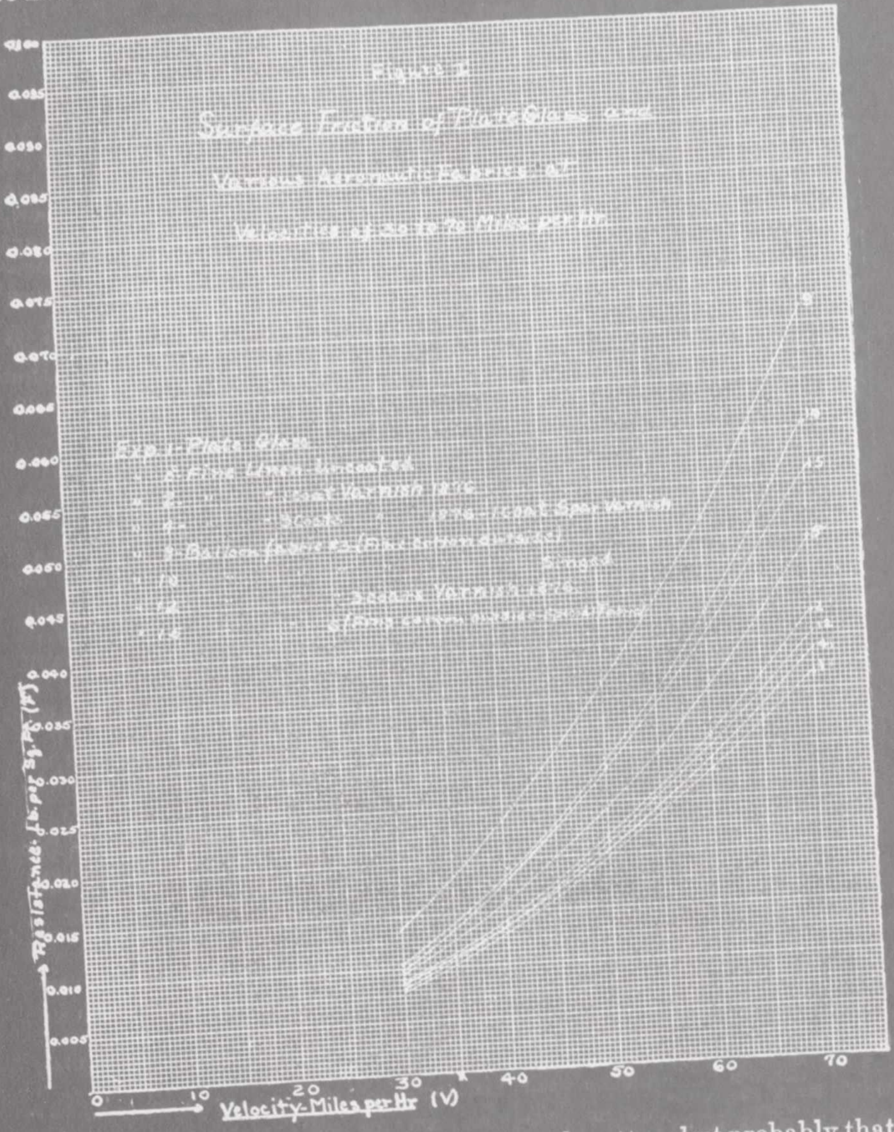
NOTE.—$n$, $k$, and $F$ are values in equation $F=KV^n$. $F$=lb./sq. ft.
$V$=miles per hour.
*R. F.*=Resistance factor=$F$ observed/$F$ glass.

| No. | Nature of surface exposed. | $n$. | $K10^7$. | 30 miles/hr. | | 40 miles/hr. | | 50 miles/hr. | | 60 miles/hr. | | 70 miles/hr. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *F.* | *R. F.* | *F.* | *R. F.* | *F.* | *R. F.* | *F.* | *R. F.* | *F.* | *R. F.* |
| 1 | Plate glass | 1.81 | 166 | .0079 | 1.000 | 0.0133 | 1.000 | 0.0199 | 1.000 | 0.0276 | 1.000 | 0.0364 | 1.000 |
| 2 | Fine linen:<br>1 coat aero varnish, 1876 | 1.84 | 163 | .0085 | 1.081 | .0141 | 1.080 | .0218 | 1.098 | .0309 | 1.118 | .0424 | 1.162 |
| 3 | 3 coats aero varnish, 1876 | 1.89 | 129 | .00822 | 1.042 | .0138 | 1.060 | .0208 | 1.048 | .0295 | 1.067 | .0403 | 1.108 |
| 4 | 3 coats aero varnish, 1876, 1 coat spar varnish | 1.84 | 153 | .0081 | 1.031 | .0135 | 1.034 | .0204 | 1.028 | .0287 | 1.038 | .0387 | 1.061 |
| 5 | Uncoated | 1.94 | 128 | .0095 | 1.205 | .0161 | 1.234 | .0249 | 1.254 | .0361 | 1.305 | .0496 | 1.362 |
| 6 | 1 coat varnish, 1877 | 1.85 | 149 | .0082 | 1.034 | .0136 | 1.040 | .0206 | 1.039 | .0292 | 1.056 | .0395 | 1.085 |
| 7 | 3 coats varnish, 1877 | 1.85 | 149 | .0082 | 1.044 | .0137 | 1.040 | .0204 | 1.028 | .0288 | 1.041 | .0394 | 1.081 |
| 8 | 3 coats varnish, 1877, 2 coats spar varnish | 1.84 | 157 | .0082 | 1.044 | .0134 | 1.026 | .0204 | 1.028 | .0286 | 1.033 | .0392 | 1.078 |
| 9 | Balloon fabric:<br>No. 3, double parallel, cotton surface | 1.90 | 219 | .0139 | 1.766 | .0238 | 1.822 | .0365 | 1.838 | .0518 | 1.873 | .0715 | 1.965 |
| 10 | No. 3, double parallel, singed | 2.05 | 96.5 | .0103 | 1.311 | .0184 | 1.408 | .0292 | 1.470 | .0426 | 1.539 | .0603 | 1.654 |
| 11 | No. 3, double parallel, 1 coat varnish, 1876 | 1.95 | 123 | .0094 | 1.190 | .0164 | 1.253 | .0251 | 1.264 | .0362 | 1.309 | .0490 | 1.345 |
| 12 | No. 3, double parallel, 3 coats varnish, 1876 | 1.85 | 153 | .0083 | 1.056 | .0139 | 1.063 | .0213 | 1.072 | .0300 | 1.082 | .0403 | 1.107 |
| 13 | No. 3, bias, cotton surface | 1.95 | 207 | .0133 | 1.691 | .0227 | 1.739 | .0343 | 1.728 | .0494 | 1.782 | .0694 | 1.902 |
| 15 | No. 6, bias, special, cotton surface | 2.03 | 99.7 | .0099 | 1.252 | .0180 | 1.378 | .0281 | 1.414 | .0412 | 1.490 | .0556 | 1.528 |
| 16 | No. 6 bias, special, cotton, singed | 2.05 | 82.5 | .0088 | 1.127 | .0157 | 1.202 | .0247 | 1.243 | .0368 | 1.331 | .0500 | 1.372 |
| 21 | Aeroplane fabric:<br>Rubber surface | 1.83 | 165 | .0084 | 1.070 | .0142 | 1.082 | .0215 | 1.083 | .0299 | 1.081 | .0393 | 1.079 |
| 22 | Rubber aluminum surface | 1.83 | 166 | .0085 | 1.078 | .0142 | 1.083 | .0213 | 1.073 | .0299 | 1.081 | .0401 | 1 101 |

## RESULTS.

### QUALITATIVE.

The great resistance offered by fabrics with nap on the surface will be noted. The effect of the weave is shown by comparison of experiments 9 and 15. Both fabrics are high-grade cotton, but probably that used in experiment 15 is closer woven and made of longer staple. Biasing seems to increase the index, but the effect would probably not be noted except at very high speeds.



Cotton shows a higher resistance than linen, although the cotton surfaces were finer weave than the linen. The linen yarn, while of more varying thickness, is smoother than cotton yarn, due to the nature of the ultimate fiber and its greater length. The linen yarn is more like a wire.

The effect of varnishing is very apparent, although no conclusion can be drawn as to the relative merits of various aeronautic varnishes. Probably it is more a matter of workmanship in applying and finishing the coat than any particular merit in the varnish itself. The use of a finishing coat of spar varnish gives some improvement.

The use of a varnish seems particularly advantageous in the case of cotton fabrics. This explains the good results obtained in Europe by varnishing the gas bags of dirigibles with cellulose acetate varnish, which both improves the gas-holding properties of the bag and decreases the frictional resistance. In a well-designed balloon most of the resistance offered by the air to the motion of the balloon is due to friction.

### QUANTITATIVE.

If we plot the logarithms of the velocity ($V$) and frictional resistance in pounds per square foot ($F$) we obtain practically straight lines. From their slope we find the index $n$. Figure II shows the logarithmic plots for the most interesting cases. It will be noted that in many cases the value for 70 miles per hour seems to lie above the line, possibly indicating an increase in the index as velocity increases, due to greater turbulence. This has been predicted.

Using the slope obtained by logarithmic plots and $F$ = pounds per square foot, $V$ = miles per hour, we may obtain the constant $K$, as given in Table I.

From these results it will be noted that the smooth surfaces do not necessarily have lower indices. When this was first noted it seemed so anomalous that it was thought at first that there might be some experimental error. However, we note that Froude found a similar result (Table III) in the case of tin foil, varnish, and paraffin.

The high resistance of fabrics having nap on the surface is noteworthy.

Froude's results obtained with an 8-foot plane in a water channel were reduced to the same units, and to air conditions. The values are given in Table II. Considering the differences in conditions the agreement for smooth surfaces is close. The resistance of calico was somewhat higher than the cloth resistance found in our tests. from the photograph accompanying Froude's paper[1] the fabric used by him probably had about 80 threads per inch. Those used by us had about 120 threads per inch, and on this account presumably a smoother surface.

### VALUES OF K AND N.

As already noted, smooth surfaces may show a higher index than rougher ones, while the coefficients $K$ vary in the opposite direction. To obtain an idea as to the relative values of these two quantities, we plotted the values of $K$ and $N$ as shown in Figure III. It will be

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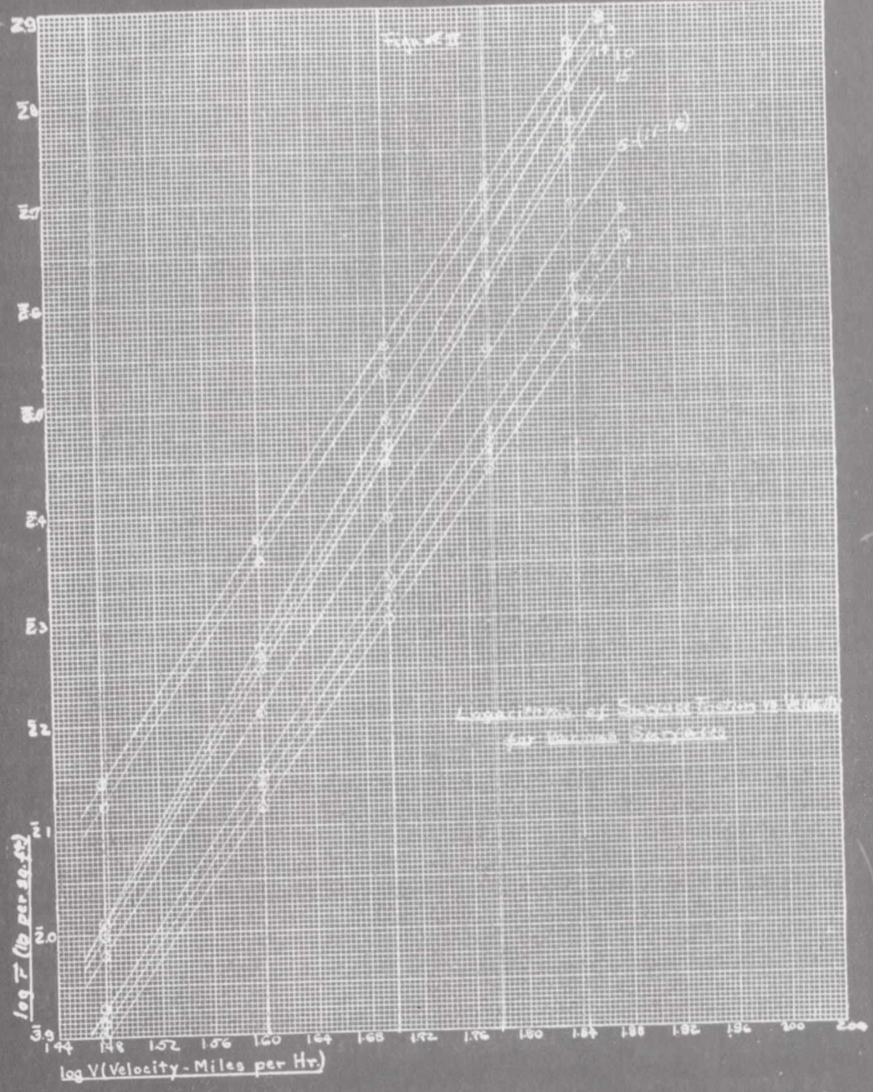
[1] Brit. Assoc. Report, 1874, p. 249.

noted that the results of our experiments seem to show two distinct types of surface:

1. Those having nap on the surface have high indices and high exponents. They act somewhat similarly to calico and sand-coated surfaces investigated by Froude, and may be classed as rough,



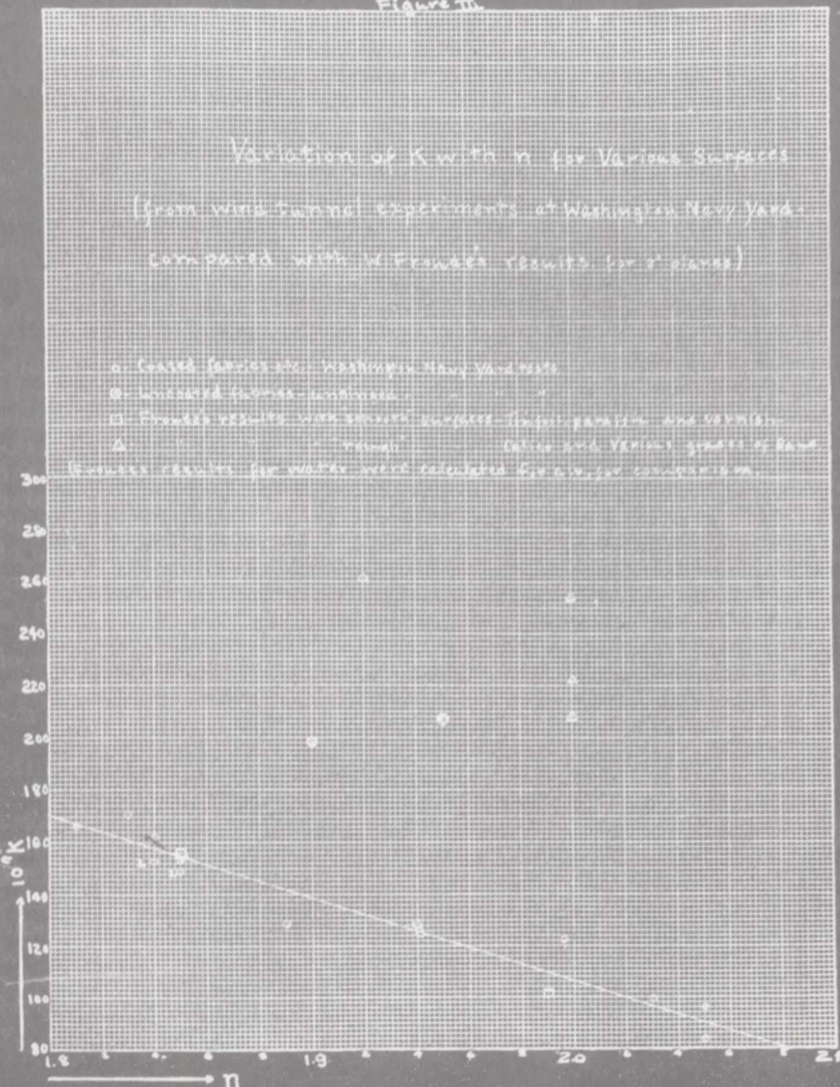
relatively. The index is 1.9 to 2, usually nearer 2, and the coefficient $K$, 0.00002 or more. ($V$ in miles per hour.)

2. Surfaces which are free from nap, and more or less continuous and even. Fabric surfaces of fine threads closely woven and free from nap (due to singeing or natural great length of fiber, as linen)

are the roughest of this class. At the other extreme we have coated and varnished fabrics, which may approach glass in smoothness under good conditions.

Considering the nature of the quantities *n* and *K*, the points for smooth surfaces lie remarkably close to a straight line, the deviation amounting to not more than 6 to 8 per cent, except in two cases, and these fall on opposite sides of the line (Fig. III).

Figure III



The values found by Froude for varnishes, tin foil and paraffin for an 8-foot plane in water are also shown (Table II), and fall close to the line. On the other hand, "rough" surfaces, calico and roughened sand, do not come near the line.

**TABLE II.**—*Results of Froude's experiments, calculated to air.*

[8-foot plane (600 feet per minute) $K$ in terms of miles per hour.

| Surface. | $n$. | $K.10^7$. |
|---|---|---|
| Varnish | 1.85 | 156 |
| Paraffin | 1.94 | 126 |
| Tin foil | 1.99 | 101 |
| Calico | 1.92 | 261 |
| Fine sand | 2.00 | 209 |
| Medium sand | 2.00 | 223 |
| Coarse sand | 2.00 | 255 |

From these figures we may express the relation of $n$ and $K$ for "smooth" surfaces by the empirical equation—

$$K = .0000746 - .000032n \tag{8}$$

whence

$$F = (.0000746 - .000032n)\,V^n \tag{9}$$

$F$ being in pounds per square foot and $V$ in miles per hour. While this expression is purely empirical, in view of our results it would seem as if it might be possible, within limits, to evaluate the complete equation for a smooth plane of fixed size, from the results of one experiment. To apply this rigidly would of course mean that the curves for smooth surfaces must not cross, i. e., that one given value of $F$ and $V$ applies to one curve only. While our results do not adhere strictly to this the deviations occur generally in the case of curves which are so close together as to almost overlap, and are probably due to experimental error. The value of $K$ depends on $L$, but this can be figured as already shown.

On the other hand, Froude's results indicate that in the case of water, there is a fall in the index as the length of the plane increases. This change seems to be in the opposite sense to what would be expected. The equation

$$R \propto v^9\,L^r\,V^r \tag{2}$$

shows that $L$ and $V$ vary according to the same power in every case. We should expect from this the same change in $r$, whether due to change in $L$ or $V$. It is known, and our own experiments indicate that increase in $V$ tends to increase $r$; in other words, at high speeds, the resistance would vary according to a higher power of length and velocity. It seems logical to assume that this interchangeability of $V$ and $L$ would give a similar result as $L$ increases, namely, that $r$ would also increase, for both $L$ and $V$. These changes in index would probably be so small for ordinary experimental differences as to be negligible.