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MOISTURE RELATIONS OF AIRCRAFT FABRICS

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ABSTRACT

The amount of moisture held at various relative humidities and the rate of absorption of this moisture have been determined for airplane and balloon cloths, airplane fabric doped with cellulose nitrate, outer-cover fabric doped with cellulose acetate, dope films, and gas-cell fabrics. The fabrics coated with cellulose nitrate dope show a maximum gain in weight in a saturated atmosphere of approximately 12 percent of their weight when in equilibrium with air at 21° C and 65 percent relative humidity. The fabrics coated with cellulose acetate dope behave similarly to the cellulose nitrate products at relative humidities as high as 97 percent; in a saturated atmosphere they are considerably more hygroscopic. Gas-cell fabric, which consisted of balloon cloth coated with a mixture of gelatin and rubber latex, containing polyglycerol as a plasticizer, is the most hygroscopic of the materials studied. On exposure to a saturated atmosphere lightweight gas-cell fabric takes up in 7 days water equivalent to approximately 50 percent of its weight, and in 4 weeks it approximately doubles its weight. Paraffin, which is always applied to the gas-cell fabric in service, retards considerably the rate of absorption; thus 14 percent by weight decreases the absorption of moisture to approximately 30 percent in 1 week and 60 percent in 4 weeks at 100 percent relative humidity. The deterioration of the gas-cell fabric by mold attack at high humidities has been found to take place very rapidly; it is recommended that a small amount of a fungicide be incorporated with the "gelatin-latex" coating to prevent this action.

CONTENTS

I. INTRODUCTION

Very few data are available in the literature relative to the amount of water held by airplane and airship fabrics at various relative humidities. W. G. Bird[1] presents the results of a few experiments with gas-cell fabric made with goldbeaters skin and doped (type unstated) outer cover cloth at 90 to 95 percent relative humidity and various temperatures. It was the purpose of this investigation to

[1] *The influence of atmospheric humidity and other factors upon the static lift of airships.* J. Roy. Aeron. Soc. **35,** 973 (1931).

obtain data on the sensitivity of aircraft fabrics to humidity in order to ascertain the amount of water which the aircraft will be required to support under varying atmospheric conditions.

II. EXPERIMENTAL PROCEDURE

It was first attempted to determine the amount of moisture absorbed by balloon cloth at various humidities by the desiccator method described by McKee.[2] The method was found to be unsatisfactory because equilibrium conditions were disturbed when the lid of the desiccator was taken off to remove a sample for weighing. Frequently equilibrium was not restored in 24 hours. Furthermore considerable condensation of moisture on the samples and on the sides and tops of the desiccators took place at relative humidities above 90 percent, making accurate measurements of absorption of vapor impossible.

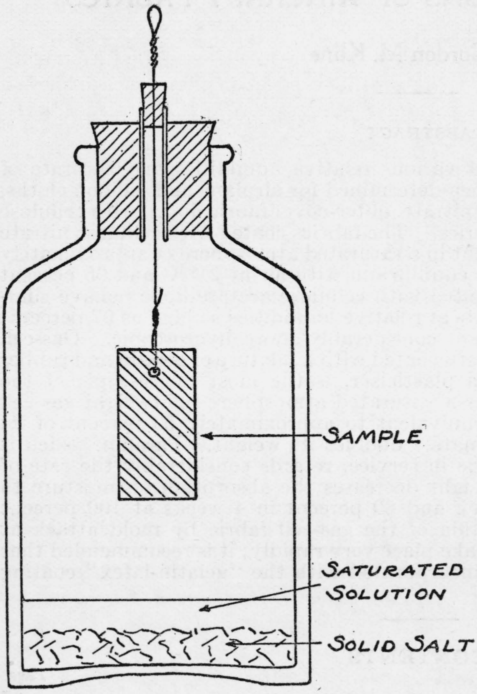

FIGURE 1.—*Diagram of apparatus used in measurement of absorption of moisture.*

The method described by Evans and Critchfield,[3] in which the sample is suspended on a wire through narrow glass tubing in the stopper of a 6-ounce bottle (fig. 1), was found to be satisfactory. The glass tube is closed between weighings by a paraffined cork through which the wire passes. The sample is weighed without removal from the bottle by supporting the bottle on a bridge over the balance pan and suspending the wire from the balance hook. Equilibrium conditions in the bottle are not noticeably disturbed during this weighing procedure. Condensation of moisture on the inner surfaces of the containers took place only at 100 percent relative humidity. No trouble was experienced even at this humidity with water dripping on the samples from above, as occurred when the desiccators were used. The reagents listed in table 1 were placed in the bottoms of the bottles to obtain the various humidities.[4] The solutions were agitated after each weighing to promote equilibrium conditions. These saturated salt solutions are much more satisfactory for obtaining various relative humidities than sulphuric-acid

[2] Paper Trade J. 97, No. 6, 33 (Aug. 10, 1933).
[3] BS J. Research 11, 147 (1933).
[4] International Critical Tables, first edition, McGraw-Hill Book Co., New York, 1, 67 (1926).

solutions, since at constant temperature there is no change in concentration in the solution during the experiment and hence no change in the relative humidity above the solution as occurs when sulphuric acid is used. The bottles were placed in a constant temperature room which is kept at 21° C ± 1. All samples were conditioned at 65 percent relative humidity and 21° C ± 1 before being placed in the containers. The weights of the test pieces varied from 1 to 2.5 g (8 to 24 in.^{2}) depending upon the weight per unit area. The rate of change in weight at the various humidities was ascertained by weighing at suitable intervals until equilibrium was attained. The samples were weighed with a chemical balance and calibrated weights to the nearest tenth of a mg. The cork and wire, from which the sample was suspended, were weighed at the start and finish of each experiment and correction made on the equilibrium value only for any change in weight. The data given in the tables are the percentage changes in weight from the initial weight in the standard conditioning environment. For relative humidities below 65 percent the values are, therefore, negative.

TABLE 1.—*Reagents used to obtain various relative humidities*

Relative humidity	Reagent
Percent:	
0	Phosphorus pentoxide.
6	Saturated sodium hydroxide solution.
20	Saturated potassium acetate solution.
33	Saturated magnesium chloride solution.
55	Saturated calcium nitrate solution.
76	Saturated sodium chloride solution.
86	Saturated potassium chloride solution.
90	Saturated zinc sulphate solution.
94	Saturated potassium nitrate solution.
97	Saturated potassium sulphate solution.
100	Water.

An experimental method for determining the absorption of moisture was also used in which air at various relative humidities circulated about the sample. McKee [5] has described an apparatus for this purpose which is connected directly to a balance. It was found more convenient, however, to use the apparatus described below which permits the concurrent study of several samples. Air was passed through a series of 8 wide-mouthed bottles (one 22 ounces, four 12 ounces, one 6 ounces, two 12 ounces) fitted with 2-holed rubber stoppers and glass tubing; the bottles were interconnected by means of small pieces of rubber tubing over the ends of the glass tubing. The first bottle served as a trap. The next 3 contained the solution through which the air was bubbled to give the desired relative humidity. The temperature of the solution in the third bottle was found to be the same as the room temperature. Glass wool was added to the solutions to break up the bubbles and thereby promote the attainment of equilibrium conditions between vapor and solution. The fifth bottle contained only glass wool to trap any liquid particles carried with the air. The air at the desired relative humidity was then passed through the 6-ounce bottle con-

[5] Paper Trade J. 97, no. 6, 33 (Aug. 10, 1933).

taining the sample of aircraft fabric suspended from a wire passing through a third hole in the stopper. The seventh bottle served as a trap and the eighth bottle contained a small amount of the same solution that was present in the second, third, and fourth bottles. The speed with which the air passed through the system was readily estimated by the rate of formation of bubbles in the last bottle and was adjusted by means of stopcocks in the air line. The rate of passage of air was maintained at about 15 liters/hr. It was found advantageous to insert a 22-ounce bottle containing water and glass wool in the air line in order to approximately saturate the air before it reached the salt solutions. The excess moisture was removed by the salt solutions without difficulty, whereas less saturated air took up moisture from the solutions, causing the salt to crystallize in the glass tubing and stopping the flow of air. In order to weigh the sample it was only necessary to disconnect the bottle at the rubber tubing joints, stopper the glass tubing, place the bottle on the balance bridge, and hang the wire holding the sample on the balance hook.

Data are presented later in this paper which show that the moisture absorption is practically the same by both methods, moving air and static air. This indicates that the rate of diffusion of the water molecules to the neighborhood of the samples merely suspended over the salt solutions or water exceeded or was at least equal to the rate of absorption of the water vapor. The simplicity, reliability, and compactness of the static method make it the one to be preferred for most purposes. The data recorded in the tables were obtained by the static air method unless otherwise noted.

III. MOISTURE RELATIONS OF AIRCRAFT CLOTHS, DOPED FABRICS, AND DOPE FILMS AT VARIOUS RELATIVE HUMIDITIES

The equilibrium values for the moisture content of various aircraft cloths, fabrics coated with cellulose nitrate and cellulose acetate dopes, and dope films are presented in table 2. The change in weight of these materials up to and including 94 percent relative humidity is less than 10 percent of their weight in the conditioning atmosphere. The doped fabrics increase in weight by less than 10 percent at 97 percent relative humidity. At 100 percent relative humidity the cellulose acetate samples absorb more moisture than either the cellulose nitrate or cloth samples. This moisture, however, is taken up very slowly over long periods of time. Although the results obtained at 100 percent relative humidity are not as reliable as those at lower humidities, because of collection of moisture on the samples, the good agreement found for the 3 classes of materials, namely, cloth, cellulose acetate products, and cellulose nitrate products, indicates that the values are fairly reproducible. This has also been demonstrated with the gas-cell fabrics.

TABLE 2.—*Percentage change in weight of aircraft fabrics and dope films which have been conditioned in air at 21° C and 65 percent relative humidity when they are exposed at other relative humidities until equilibirium is reached*

Materials	Weight	Percentage change in weight at various relative humidities										
		At 0%	At 6%	At 20%	At 33%	At 55%	At 76%	At 86%	At 90%	At 94%	At 97%	At 100%
	oz/sq yd	%	%	%	%	%	%	%	%	%	%	%
Balloon cloth, unmercerized	2. 11	−6. 5	−4. 7	−3. 0	−2. 3	−0. 8	1. 4	3. 5	5. 3	7. 1	11. 6	18. 9
Airplane cloth, mercerized	4. 13	−7. 3	−5. 1	−3. 2	−2. 2	−0. 5	2. 4	4. 9	6. 5	9. 7	15. 3	20. 6
Airship outer cover, new cellulose acetate doped	5. 90	−5. 5	−4. 5	−3. 4	−2. 9	−1. 4	0. 8	2. 2	3. 1	4. 5	7. 3	55. 3
Airship outer cover, old cellulose acetate doped	6. 12	−3. 8	−2. 8	------	−1. 4	−0. 5	0. 8	1. 9	2. 6	4. 0	9. 4	39. 5
Dope film, cellulose acetate	5. 12	−2. 6	−2. 2	−1. 8	−1. 4	−0. 7	0. 7	1. 6	2. 3	2. 9	4. 0	30. 5
Airplane fabric, new cellulose nitrate doped	5. 88	−5. 9	−4. 1	−2. 7	−2. 0	−0. 6	1. 1	2. 8	3. 9	5. 5	8. 6	11. 2
Airplane fabric, old cellulose nitrate doped	8. 89	−4. 6	−3. 3	−2. 1	−1. 5	−0. 5	0. 7	1. 7	2. 5	3. 7	5. 7	11. 8
Dope film, cellulose nitrate	5. 52	−1. 0	−0. 8	−0. 6	−0. 5	−0. 2	0. 2	0. 5	0. 6	0. 7	1. 0	7. 7

The results obtained with the mercerized airplane cloth and the unmercerized balloon cloth are similar to the moisture relations found by Urquhart [6] and his colleagues for mercerized yarn and raw cotton (fig. 2). It should be pointed out, however, that the latter investigators started with products which had been dried over phosphorus pentoxide at room temperature in obtaining their data. Our data were calculated to the dry basis for comparison in figure 2 with Urquhart's results. It will be noted that the moisture contents of the mercerized materials are slightly greater than those of the unmercerized materials.

The results of the tests on outer cover fabric doped with cellulose acetate are shown in figure 3. The "old-doped" sample was taken from the U. S. Navy dirigible *Los Angeles;* the "freshly-doped" sample was obtained from the Goodyear-Zeppelin Corporation, Akron, Ohio. Very little difference in the moisture relations of the 2 samples was observed. The data obtained for airplane fabrics coated with cellulose nitrate are also plotted in figure 3. The curves are very similar to those of the cellulose acetate products except that there is no sharp rise at 100 percent relative humidity. It will be noted that the cellulose acetate film unsupported by cloth holds considerably more moisture at all humidities than the cellulose nitrate film. However, both films hold less moisture than the cotton cloth up to and including 97 percent relative humidity. At 100 percent relative humidity the cellulose acetate film takes up more water than the cotton cloth. This water is not all absorbed by the sample, however, as it can be seen collecting on the surface. Sheppard and Newsome [7] have observed that esterification of the hydroxyl groups of the cellulose molecule decreases the amount of water taken up. The fact that the moisture content of the cellulose acetate film exceeds that of the cotton cloth may be attributed to a difference in the wettability of the surfaces or to other materials present in the dope. Since we are interested in the behavior of these materials under atmospheric conditions in which the dewpoint is often reached, the amount of moisture

[6] J. Text. Inst. **15**, T138 (1924); **23**, T135 (1932).
[7] J. Phys. Chem. **33**, 1817 (1929).

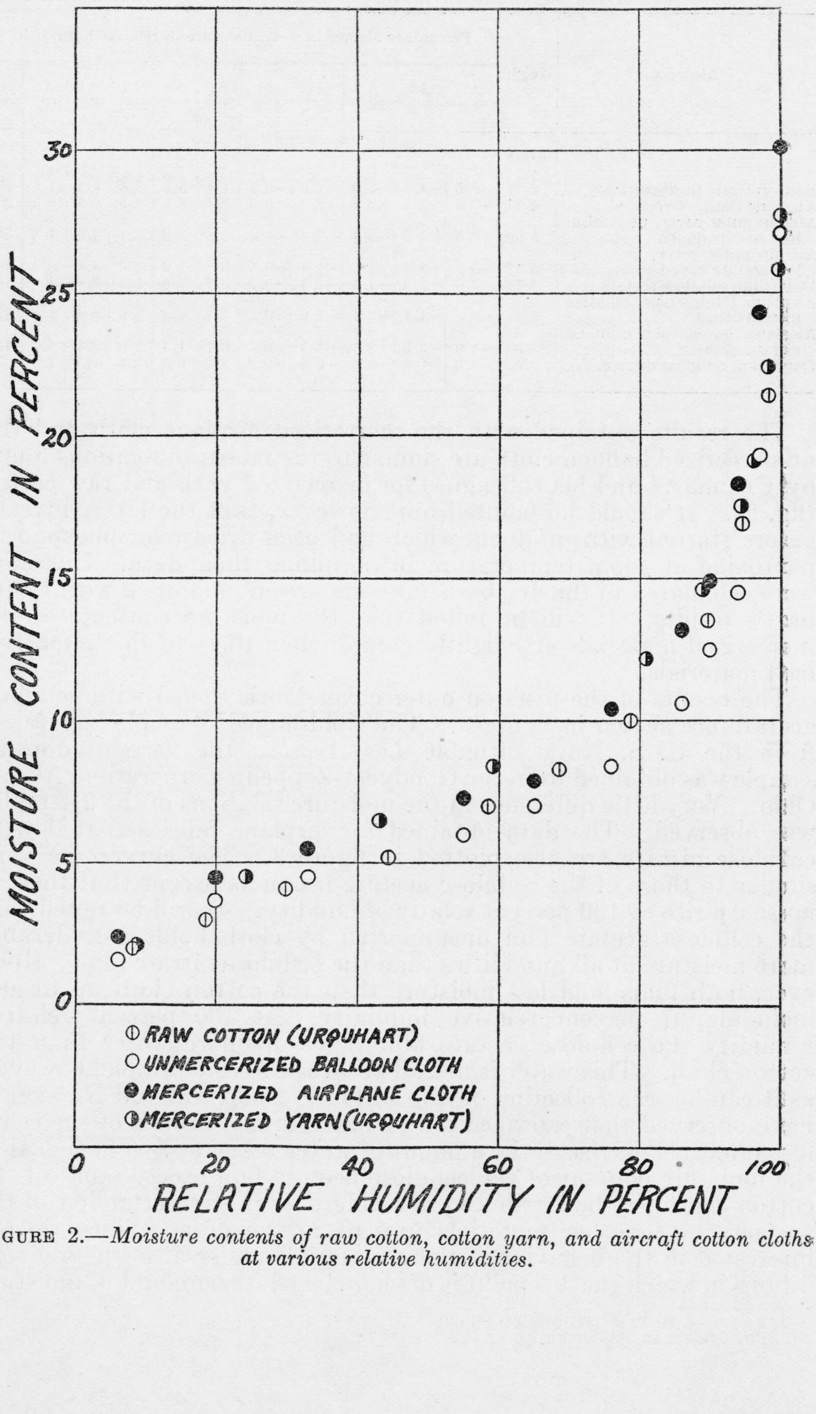

FIGURE 2.—*Moisture contents of raw cotton, cotton yarn, and aircraft cotton cloths at various relative humidities.*

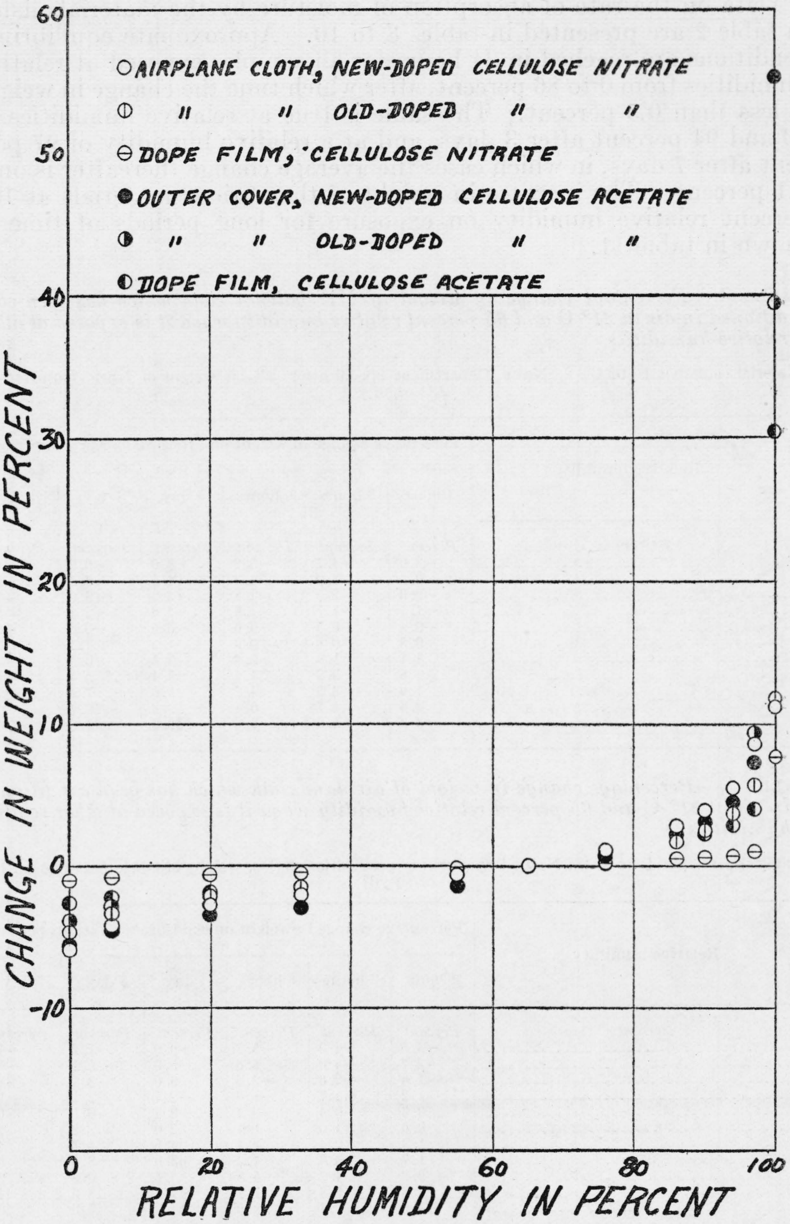

FIGURE 3.—*Changes in weight of fabrics coated with cellulose nitrate and cellulose acetate dopes and of dope films unsupported by cloth, which have been conditioned in air at 21° C and 65 percent relative humidity, when they are exposed at other relative humidities.*

which would be taken up by the material either by absorption or as a surface collection is of importance.

Data on the rate of absorption of moisture by the materials listed in table 2 are presented in tables 3 to 10. Approximate equilibrium conditions are reached in 24 hours for all samples exposed at relative humidities from 0 to 86 percent, after which time the change in weight is less than 0.5 percent. The same is true at relative humidities of 90 and 94 percent after 3 days, and at a relative humidity of 97 percent after 7 days, in which cases the average change thereafter is only 0.1 percent. The increase in weight of the various materials at 100 percent relative humidity on exposure for long periods of time is shown in table 11.

TABLE 3.—*Percentage change in weight of* HH *balloon cloth which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material corresponds to U. S. Navy Department specification 27C13; weight of fabric found to be 2.11 oz/sq yd]

Relative humidity	Percentage change in weight on exposure for various periods					
	1 hour	3 hours	6 hours	1 day	3 days	7 days
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	−3.9	−4.7	−5.2	−6.0	−6.2	−6.3
6	−2.6	−3.9	−4.3	−4.5	−4.6	−4.6
20	−2.0	−2.6	−2.8	−2.9	−3.0	−3.0
33	−1.1	−1.7	−1.9	−2.0	−2.1	−2.1
55	−0.4	−0.5	−0.6	−0.6	−0.6	−0.7
76	0.5	0.8	0.9	1.2	1.4	1.5
86	1.1	1.9	2.6	3.3	3.5	3.6
90	1.8	3.2	4.1	5.4	5.4	5.3
94	1.9	3.5	4.7	6.6	7.1	7.3
97	2.8	4.7	6.1	9.2	10.7	11.3
100	3.3	5.3	7.0	10.9	14.0	15.8

TABLE 4.—*Percentage change in weight of airplane cloth which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material corresponds to U. S. Navy Department specification 27C12; weight of fabric found to be 4.13 oz/sq yd]

Relative humidity	Percentage change in weight on exposure for various periods					
	1 hour	3 hours	6 hours	1 day	3 days	7 days
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	−3.5	−4.9	−5.7	−6.9	−7.2	−7.3
6	−2.7	−4.0	−4.6	−5.0	−5.1	−5.1
20	−1.8	−2.6	−2.9	−3.0	−3.1	−3.1
33	−1.2	−1.7	−1.9	−2.1	−2.1	−2.2
55	−0.3	−0.4	−0.4	−0.4	−0.5	−0.5
76	0.6	1.0	1.4	2.0	2.2	2.3
86	1.3	2.5	3.4	4.5	4.7	4.8
90	1.7	3.3	4.3	5.9	6.2	6.3
94	2.2	4.2	5.8	8.5	9.2	9.5
97	2.9	5.3	7.2	11.4	13.9	14.9
100	5.0	7.1	8.5	12.9	17.0	19.8

TABLE 5.—*Percentage change in weight of "freshly-doped" outer cover (cellulose acetate) which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material corresponds to Goodyear-Zeppelin specification K-7204-A; weight of doped fabric found to be 5.90 oz/sq yd. Cloth corresponds to U. S. Navy Department specification 27C13a for BB type, weight 2.90 oz/sq yd]

Relative humidity	Percentage change in weight on exposure for various periods					
	1 hour	3 hours	6 hours	1 day	3 days	7 days
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	−3.1	−4.2	−4.7	−5.2	−5.4	−5.5
6	−2.4	−3.5	−4.0	−4.3	−4.4	−4.4
20	−1.9	−2.7	−3.0	−3.2	−3.3	−3.3
33	−1.3	−2.0	−2.3	−2.5	−2.6	−2.7
55	−0.5	−0.7	−0.9	−0.9	−1.1	−1.2
76	0.3	0.6	0.6	0.8	0.7	0.5
86	0.8	1.4	1.8	2.2	2.0	1.8
90	1.1	1.9	2.5	3.1	3.0	2.8
94	1.4	2.5	3.4	4.5	4.4	4.3
97	1.4	3.0	4.2	6.4	7.1	7.3
100	3.2	4.7	6.0	8.7	12.1	15.7

TABLE 6.—*Percentage change in weight of "old-doped" outer cover (cellulose acetate) which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material taken from the *Los Angeles;* specification unknown; weight of doped fabric found to be 6.12 oz/sq yd]

Relative humidity	Percentage change in weight on exposure for various periods					
	1 hour	3 hours	6 hours	1 day	3 days	7 days
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	−2.4	−3.1	−3.4	−3.7	−3.8	−3.8
6	−2.0	−2.5	−2.6	−2.7	−2.7	−2.7
33	−0.9	−1.2	−1.2	−1.3	−1.3	−1.3
55	−0.3	−0.4	−0.4	−0.4	−0.5	−0.5
76	0.3	0.5	0.6	0.7	0.7	0.8
86	0.8	1.3	1.5	1.7	1.8	1.9
90	1.0	1.5	1.9	2.3	2.4	2.5
94	1.5	2.2	2.7	3.6	3.8	4.0
97	1.9	3.0	3.9	6.2	8.5	9.5
100	2.4	3.7	4.9	9.2	15.5	23.4

TABLE 7.—*Percentage change in weight of cellulose acetate dope film which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material corresponds to U. S. Navy Department specification D-14 and thinner T-33; weight of film found to be 5.12 oz/sq yd]

Relative humidity	Percentage change in weight on exposure for various periods				
	1 hour	3 hours	6 hours	1 day	3 days
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	−1.7	−2.2	−2.3	−2.4	−2.6
6	−1.6	−2.0	−2.1	−2.1	−2.2
20	−1.1	−1.5	−1.6	−1.7	−1.8
33	−0.8	−1.2	−1.2	−1.3	−1.4
55	−0.3	−0.5	−0.5	−0.6	−0.7
76	0.4	0.6	0.7	0.7	0.5
86	0.8	1.3	1.5	1.6	1.6
90	0.8	1.4	1.8	2.2	2.3
94	1.1	1.9	2.4	2.9	2.9
97	1.5	2.6	3.2	3.9	4.0
100	1.7	2.8	3.5	5.0	6.5

TABLE 8.—*Percentage change in weight of "freshly-doped" airplane fabric (cellulose nitrate) which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material corresponds to U. S. Navy Department Specifications 27C12a for cloth, D-12 for dope and T-25 for thinner; 4 coats of clear dope only; weight of doped fabric found to be 5.88 oz/sq yd]

Relative humidity	Percentage change in weight on exposure for various periods					
	1 hour	3 hours	6 hours	1 day	3 days	7 days
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	−3.3	−4.4	−4.9	−5.6	−5.8	−5.9
6	−2.5	−3.5	−3.9	−4.1	−4.2	−4.2
20	−1.5	−2.3	−2.5	−2.7	−2.8	−2.8
33	−1.1	−1.6	−1.7	−1.8	−1.9	−2.0
55	−.4	−.5	−.5	−.6	−.6	−.6
76	.3	.5	.6	.8	1.0	1.0
86	.9	1.5	2.0	2.6	2.7	2.8
90	1.1	2.0	2.6	3.5	3.7	3.8
94	1.4	2.6	3.5	4.8	5.2	5.4
97	2.3	3.6	4.5	6.7	7.8	8.4
100	2.7	3.9	4.9	7.6	9.5	10.7

TABLE 9.—*Percentage change in weight of "old-doped" airplane fabric (cellulose nitrate) which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material corresponds to U. S. Navy Department Specifications 27C12 for cloth and 52-D2 for dope; aluminum pigment in top coats; weight of doped fabric found to be 8.89 oz/sq yd]

Relative humidity	Percentage change in weight on exposure for various periods					
	1 hour	3 hours	6 hours	1 day	3 days	7 days
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	−2.3	−3.2	−3.7	−4.3	−4.5	−4.6
6	−2.0	−2.7	−3.0	−3.2	−3.3	−3.3
20	−1.2	−1.7	−1.9	−2.1	−2.1	−2.1
33	−.8	−1.2	−1.3	−1.4	−1.5	−1.5
55	−.3	−.4	−.4	−.4	−.4	−.5
76	.3	.5	.5	.6	.7	.7
86	.6	1.0	1.3	1.6	----------	----------
90	.7	1.3	1.6	2.1	2.3	2.4
94	1.0	1.7	2.3	3.2	3.5	3.6
97	1.2	2.3	3.0	4.6	5.4	5.8
100	1.9	2.9	3.8	5.9	8.1	10.8

TABLE 10.—*Percentage change in weight of cellulose nitrate dope film which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material corresponds to U. S. Navy Department Specifications D-12 for dope and T-25 for thinner; weight of dope film found to be 5.52 oz/sq yd]

Relative humidity	Percentage change in weight on exposure for various periods				
	1 hour	3 hours	6 hours	1 day	2 days
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
0	−0.69	−0.90	−0.95	−0.92	−0.90
6	−.59	−.77	−.81	−.77	−.74
20	−.45	−.60	−.61	−.58	−.54
33	−.34	−.46	−.47	−.45	−.44
55	−.13	−.16	−.16	−.12	−.09
76	.16	.23	.24	.24	.22
86	.28	.43	.48	.52	.53
90	.33	.48	.55	.59	.55
94	.44	.58	.65	.69	.66
97	.50	.75	.87	.99	1.00
100	.64	.96	1.10	1.44	1.64

TABLE 11.—*Percentage gain in weight at 100 percent relative humidity of various aircraft fabrics and dope films which have been conditioned in air at 21° C and 65 percent relative humidity*

Materials	Percentage change in weight on exposure for various periods											
	1 week	2 weeks	3 weeks	4 weeks	5 weeks	6 weeks	9 weeks	10 weeks	16 weeks	18 weeks	24 weeks	25 weeks
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Balloon cloth, unmercerized	15.8	18.3	18.6	19.2	19.3	19.2	-----	-----	-----	-----	-----	-----
Airplane cloth, mercerized	19.8	20.7	20.8	20.8	20.7	-----	-----	-----	-----	-----	-----	-----
Outer cover, freshly-doped cellulose acetate	15.7	20.8	24.2	-----	31.4	33.4	40.7	-----	-----	48.6	55.6	53.6
Outer cover, old-doped cellulose acetate	23.4	29.4	33.9	33.5	-----	35.9	39.8	38.3	-----	-----	-----	-----
Cellulose acetate dope film	10.6	13.8	16.5	18.7	21.6	24.8	26.6	-----	30.5	25.1	-----	17.2
Airplane fabric, freshly-doped cellulose nitrate	10.7	-----	11.3	11.5	11.4	11.4	-----	-----	-----	-----	-----	-----
Airplane fabric, old-doped cellulose nitrate	10.8	11.7	-----	11.5	11.9	11.8	-----	-----	-----	-----	-----	-----
Cellulose nitrate dope film	2.8	4.1	5.0	6.3	6.8	7.0	7.7	-----	-----	3.4	-----	-----

IV. MOISTURE RELATIONS OF GAS-CELL FABRICS AT VARIOUS RELATIVE HUMIDITIES

The gas-cell fabrics studied were unmercerized balloon cloth coated with plasticized gelatin-latex. The base cloth of the lightweight fabric weighs 2.80 oz/sq yd and the gelatin-latex coating 2.13 oz/sq yd, according to Goodyear-Zeppelin Corporation specification K–13328. The base cloth of the heavyweight material weighs 4.20 oz/sq yd and the gelatin-latex coating 2.13 oz/sq yd, according to Goodyear-Zeppelin Corporation specification K–13329. It is the practice to coat both surfaces of the gas cell with paraffin after assembly. The results of tests with unparaffined and paraffined gas-cell fabrics are presented in table 12 and figure 4. All increases in weight are based on the weight of gelatin-latex fabric without paraffin in order to make the data comparable. The values given are the maximum observed rather than equilibrium points, since at relative humidities of 94 percent and higher mold grew on all samples, which caused them to lose weight after 3 to 4 weeks. The mold becomes visible to the eye after approximately 10 days. In regard to the prevention of this mold attack on gas-cell fabric, the studies on mildew prevention on painted surfaces conducted by Gardner, Hart, and Sward [8] are particularly pertinent. Mercuric chloride, mercurophen, and phenyl mercury acetate proved most effective. If it is desired to avoid toxic mercury compounds because of the danger to workmen in mixing, spraying and other operations, some of the chemicals which are suggested for use are thymol, methylisopropylphenol, mercaptobenzothiazole, sodium orthophenylphenate, and guaiacol. It is hoped that a mold-proof gas-cell fabric will be available at a later date in order to better establish the equilibrium points at 97 and 100 percent relative humidities. The concordance of the results on the various samples at the other humidities is very good.

[8] Scientific Section Circulars, National Paint, Varnish, and Lacquer Association, Inc., Washington, D.C. nos. 442, 448, and 464.

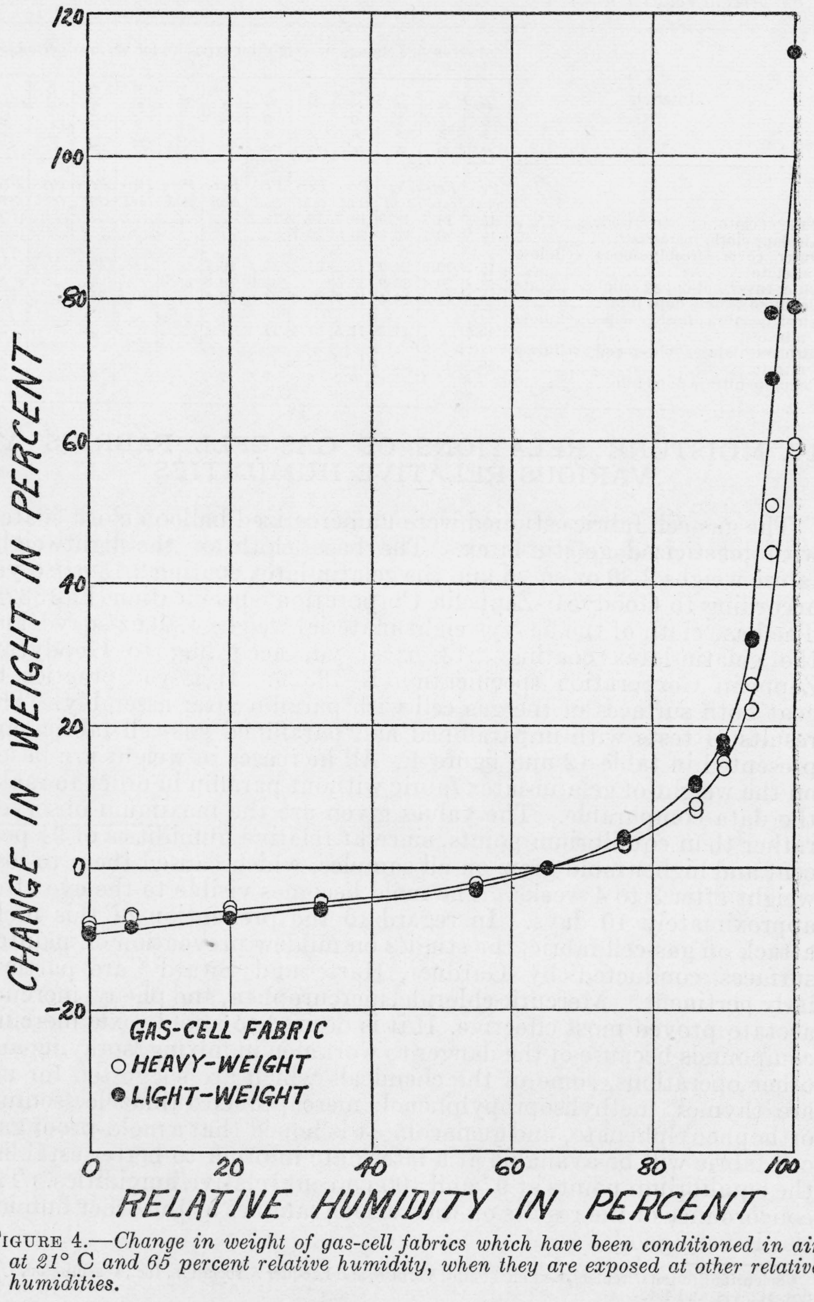

FIGURE 4.—*Change in weight of gas-cell fabrics which have been conditioned in air at 21° C and 65 percent relative humidity, when they are exposed at other relative humidities.*

TABLE 12.—*Change in weight of unparaffined and paraffined gas-cell fabrics which have been conditioned in air at 21° C and 65 percent relative humidity when they are exposed at other relative humidities*

[Materials correspond to Goodyear-Zeppelin Corporation specifications K-13328 (lightweight fabric) and K-13329 (heavyweight fabric)]

LIGHTWEIGHT FABRIC

Weight of paraffin	Total weight	Percentage change in weight at various relative humidities										
		At 0%	At 6%	At 20%	At 33%	At 55%	At 76 %	At 86%	At 90%	At 94%	At 97%	At 100%
oz/sq yd	oz/sq yd	%	%	%	%	%	%	%	%	%	%	%
0.0	5.24	−9.1	−8.3	−7.0	−6.0	−3.0	4.2	11.5	17.8	32.2	68.9	79.0
0.0	4.93	−8.3	------	------	------	------	------	11.4	------	30.4	65.2	87.0
0.2	5.21	−9.4	−8.5	−7.0	−5.8	−2.9	4.4	11.6	16.7	32.0	78.2	114.6
0.7	5.63	−7.2	------	------	------	------	------	11.6	------	27.4	50.1	61.6
1.0	5.94	−8.5	------	------	------	------	------	12.1	------	29.7	56.6	79.9

HEAVYWEIGHT FABRIC

Weight of paraffin	Total weight	At 0%	At 6%	At 20%	At 33%	At 55%	At 76 %	At 86%	At 90%	At 94%	At 97%	At 100%
0.0	6.35	−6.9	------	------	------	------	------	9.1	------	24.5	51.9	60.3
0.6	6.95	−7.8	−6.9	−5.6	−4.7	−2.2	3.4	9.4	14.0	25.8	51.0	58.9
0.8	7.03	−8.5	−6.6	−5.8	−4.9	−2.3	3.1	8.0	14.9	22.4	44.4	59.6

The increase in the moisture content of the samples at the high humidities is much greater for these gas-cell fabrics than for the other aircraft fabrics, listed in table 2. This is, of course, due to the gelatin and polyglycerol which are very hygroscopic. Bird[9] found that gas-cell fabric made with goldbeaters skin also takes up large amounts of water at high humidities. At 65° F and 90 to 95 percent relative humidity his sample increased in weight about 20 percent (dry basis) after 33 days, and when the conditions were changed to 75° F and 100 percent relative humidity it increased in weight about 60 percent and showed no sign of having reached a limit.

The rate of absorption of moisture by the lightweight and heavyweight gas-cell fabrics is shown in tables 13 and 14 for 86, 94, 97, and 100 percent relative humidities. The edges of the 2- by 8-inch pieces used for these tests were sealed with paraffin. The data in table 15 show that this treatment retards the moisture absorption quite appreciably at the high relative humidities for the paraffin-covered fabrics although the effect is rather slight on the unparaffined samples. It is evident from the data in tables 13 and 14 that the paraffin coating slows down the rate of absorption of moisture. However, several days are required even at these high humidities before the increase in weight due to the paraffin, namely, 14 and 20 percent, respectively, for the 2 lightweight paraffined fabrics and 9.5 percent for the heavyweight paraffined fabric, is counterbalanced by the lowered moisture absorption. It is also noteworthy that both paraffined and unparaffined samples reach the same equilibrium points at relative humidities up to and including 94 percent. At 97 and 100 percent relative humidities the retardation in rate of absorption of moisture because of the paraffin coating is not balanced by a similar inhibition of the attack by mold and an apparently lower total absorption of moisture is, therefore, obtained for these samples. In connection with this discussion of the effect of paraffin on the rate of absorption of

[9] J. Roy. Aero. Soc. **35**, 973 (1931).

moisture, it should be noted that Dunlap [10] has found that waxes are among the least efficient moisture-proofing materials when applied to wood. It is recognized that the paraffin also serves to overcome the inherent tackiness of the gelatin-latex gas-cell fabric and prevent it from adhering to itself. However, it is believed that a thorough study of moisture-proofing and tackiness-proofing coatings for gas-cell fabrics would lead to a more efficient material than paraffin for this purpose and might thereby effect a considerable saving in weight.

TABLE 13.—*Percentage change in weight of unparaffined and paraffined lightweight gelatin-latex fabric which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material corresponds to Goodyear-Zeppelin specification K-13328; weight of unparaffined finished fabric found to be 4.93 oz/sq yd (fabric=2.80, gelatin-latex=2.13)]

Time (days)	Percentage change in weight at various relative humidities														
	At 0 percent, par. in oz/sq yd			At 86 percent, par. in oz/sq yd			At 94 percent, par. in oz/sq yd			At 97 percent, par. in oz/sq yd			At 100 percent, par. in oz/sq yd		
	0	0.7	1.0	0	0.7	1.0	0	0.7	1.0	0	0.7	1.0	0	0.7	1.0
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1/24	−1.6	−0.4	−0.3	0.7	0.2	0.2	1.0	0.3	0.3	1.2	0.5	0.4	1.8	0.5	0.5
1/8	−3.7	−.9	−.8	1.7	.5	.4	2.6	.7	.7	2.9	1.1	.9	4.3	1.3	1.1
1/4	−5.3	−1.7	−1.4	3.1	1.0	.8	4.5	1.4	1.3	5.0	2.1	1.6	7.1	2.3	2.0
1	−7.1	−4.2	−4.1	6.9	3.3	2.6	10.9	4.6	4.2	12.5	6.6	5.0	17.1	7.3	6.5
2	−7.4	−5.6	−6.0	9.2	5.2	4.5	15.6	7.5	7.3	18.9	10.8	8.7	24.6	12.4	11.2
3	−7.5	−6.2	−7.1	10.3	6.6	6.0	18.5	9.8	10.0	23.5	14.2	11.9	30.3	16.5	15.5
5	−7.6	−6.6	−7.9	11.1	8.4	7.8	22.2	13.4	13.5	30.5	20.1	16.5	40.0	23.5	21.6
7	−7.6	−6.8	−8.2	11.5	9.4	9.0	24.7	15.8	16.2	36.2	24.5	20.7	48.8	29.2	27.7
14	−7.7	−6.9	−8.5	11.5	10.9	11.2	28.1	21.4	22.2	48.5	36.1	32.2	71.1	45.0	46.4
21	−7.7	−7.0	−8.6	11.8	11.1	11.8	30.2	24.2	25.4	57.8	44.8	41.4	87.6	58.8	61.4
28	−7.7	−7.0	−8.6	11.7	11.3	11.9	29.9	25.9	27.2	62.9	49.9	49.1	95.7	62.3	74.0
35	−7.8	−7.0	−8.6	11.7	11.3	12.1	28.8	26.8	28.5	67.3	43.2	54.6	98.5	51.9	81.6
42	−7.8	−7.0	−8.7	11.6	11.3	12.2	28.2	26.6	28.8	69.9	47.4	53.6	91.2	53.4	64.2
70	−7.8	−7.0	−8.7	11.9	11.5	12.4	26.2	25.9	25.0	67.4	48.1	27.8	54.4	76.8	54.3

TABLE 14.—*Percentage change in weight of unparaffined and paraffined heavyweight gelatin-latex fabric which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material corresponds to Goodyear-Zeppelin Corporation specification K-13329; weight of unparaffined finished fabric found to be 6.35 oz/sq yd (fabric=4.20, gelatin-latex=2.15); paraffined fabric contained 0.6 oz/sq yd paraffin]

Time (days)	Percentage change in weight at various relative humidities									
	At 0 percent		At 86 percent		At 94 percent		At 97 percent		At 100 percent	
	Unpar.	Par.	Unpar.	Par.	Unpar.	Par.	Unpar.	Par.	Unpar.	Par.
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1/24	−1.2	−0.4	0.5	0.2	0.7	0.2	1.0	0.3	1.2	0.4
1/8	−2.8	−1.2	1.4	.5	1.8	.6	2.3	.8	2.9	1.0
1/4	−4.3	−1.9	2.3	1.0	3.1	1.2	3.8	1.5	4.7	1.7
1	−6.2	−4.7	5.5	3.0	8.1	3.9	9.7	4.7	11.0	4.9
2	−6.5	−5.9	7.3	4.7	11.9	6.4	14.5	7.8	16.4	8.3
3	−6.6	−6.4	8.1	5.7	14.1	8.2	17.9	10.2	20.4	11.0
5	−6.7	−6.7	9.0	7.0	17.1	10.8	23.3	14.2	27.3	15.8
7	−6.7	−6.8	9.3	7.8	19.1	12.9	27.3	17.3	33.0	19.6
14	−6.7	−6.9	9.6	8.9	22.4	17.2	35.8	25.7	44.9	31.1
21	−6.7	−7.0	9.7	9.1	24.0	19.8	41.0	33.0	50.8	40.2
28	−6.7	−7.0	9.9	9.3	24.7	21.7	45.3	40.0	63.4	45.0
35	−6.7	−7.0	9.7	9.3	23.6	23.0	44.6	44.6	70.9	52.2
42	−6.8	−7.0	9.7	9.2	22.0	23.4	43.2	46.9	66.4	58.8
70	−6.8	−7.0	9.7	9.2	18.8	24.1	34.6	45.2	94.8	80.8

[10] Ind. Eng. Chem. **18**, 1230 (1926).

TABLE 15.—*Effect of edge sealing on the rate of absorption of moisture by unparaffined and paraffined lightweight gelatin-latex fabric which has been conditioned in air at 21° C and 65 percent relative humidity when it is exposed at other relative humidities*

[Material corresponds to Goodyear-Zeppelin Corporation specification K–13328; weight of unparaffined finished fabric found to be 4.93 oz/sq yd (fabric=2.80, gelatin-latex=2.13); paraffined fabric contained 1.0 oz/sq yd paraffin]

UNPARAFFINED FABRIC

Time	Percentage change in weight at various relative humidities									
	At 0 percent		At 86 percent		At 94 percent		At 97 percent		At 100 percent	
	Sealed	Open	Sealed	Open	Sealed	Open	Sealed	Open	Sealed	Open
Days	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	−7.1	−7.7	6.9	7.1	10.9	11.6	12.5	14.4	17.1	17.7
3	−7.5	−7.9	10.3	10.3	18.5	19.1	23.5	26.2	30.3	32.0
7	−7.6	−7.9	11.5	11.6	24.7	25.2	36.2	40.0	48.8	51.5
14	−7.7	−7.9	11.5	11.6	28.1	28.1	48.5	53.2	71.1	73.7
21	−7.7	−7.9	11.8	11.9	30.2	30.0	57.8	63.0	87.6	85.6
28	−7.7	−7.9	11.7	11.7	29.9	29.7	62.9	66.4	95.7	93.4
35	−7.8	−8.0	11.7	11.7	28.8	29.1	67.3	67.7	98.5	80.2

PARAFFINED FABRIC

Time	At 0 percent Sealed	At 0 percent Open	At 86 percent Sealed	At 86 percent Open	At 94 percent Sealed	At 94 percent Open	At 97 percent Sealed	At 97 percent Open	At 100 percent Sealed	At 100 percent Open
1	−4.1	−4.7	2.6	3.1	4.2	5.4	5.0	7.3	6.5	10.1
3	−7.1	−7.6	6.0	6.5	10.0	11.8	11.9	16.3	15.5	21.4
7	−8.2	−8.4	9.0	9.5	16.2	18.1	20.7	27.2	27.7	36.9
14	−8.5	−8.6	11.2	11.4	22.2	24.1	32.2	40.4	46.4	55.3
21	−8.6	−8.6	11.8	11.9	25.4	26.9	41.1	45.4	61.4	57.8
28	−8.6	−8.6	11.9	12.0	27.2	28.1	49.1	46.4	74.0	59.1
35	−8.6	−8.6	12.1	12.1	28.5	28.2	54.6	45.1	81.6	58.3

The rate of loss of moisture taken up at the high humidities has also been investigated. After 7 days' exposure at the high humidities the edge-sealed samples were removed from the bottles and placed in the atmosphere of the room, kept at 65 percent relative humidity. The results in table 16 show that the moisture absorbed in 7 days by the unparaffined heavyweight fabrics is practically all lost at 65-percent relative humidity in 2 days, whereas the paraffined samples require about the same time for the desorption as for the absorption of the moisture. Similar results were obtained with lightweight gas-cell fabric.

A comparison of the use of static and flowing air of various relative humidities on the absorption of moisture by heavyweight gas-cell fabric is presented in table 17. It will be noted that there is practically no difference in the rate of absorption. The edges of the pieces used in this experiment were not sealed; thus there resulted a faster absorption of moisture than indicated for this material in tables 14 and 16. This would have served to emphasize any difference in rate due to the two methods of supplying moisture. Similar results were obtained with unparaffined lightweight gas-cell fabric.

TABLE 16.—*Absorption and desorption of moisture by unparaffined and paraffined heavyweight gelatin-latex fabric which has been conditioned in air at 21° C and 65 percent relative humidity*

[Material corresponds to Goodyear-Zeppelin Corporation specification K-13329; weight of unparaffined finished fabric found to be 6.35 oz/sq yd (fabric=4.20, gelatin-latex=2.15); paraffined fabric contained 0.6 oz/sq yd paraffin]

Time	Percentage change in weight at various relative humidities									
	At 0 percent		At 86 percent		At 94 percent		At 97 percent		At 100 percent	
	Unpar.	Par.	Unpar.	Par.	Unpar.	Par.	Unpar.	Par.	Unpar.	Par.
Days	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1/24	−1.4	−0.4	0.6	0.2	0.7	0.2	0.9	0.4	1.3	0.4
1/8	−3.0	−1.0	1.4	0.5	1.9	0.6	2.3	0.9	3.0	1.1
1/4	−4.4	−1.8	2.3	0.9	3.3	1.1	3.8	1.7	4.9	1.9
1	−6.2	−4.5	5.4	2.9	8.5	3.4	9.5	5.0	11.0	5.4
2	−6.5	−5.8	7.4	4.6	12.5	5.8	14.9	8.5	17.4	8.9
3	−6.6	−6.3	8.2	5.6	14.9	7.5	18.6	11.0	22.0	11.7
5	−6.7	−6.6	8.9	7.0	17.9	10.2	24.4	15.3	29.9	16.7
7	−6.7	−6.7	9.1	7.8	19.8	12.3	28.6	18.4	35.0	20.7
SAMPLES REEXPOSED TO 65 PERCENT RELATIVE HUMIDITY										
1/24	1.6	0.3	−1.0	−0.3	−1.5	−0.3	−2.2	−0.6	−4.6	−1.0
1/8	3.3	0.9	−2.5	−0.7	−3.9	−0.7	−5.0	−1.4	−8.1	−2.0
1/4	4.7	1.5	−4.2	−1.2	−7.0	−1.3	−8.5	−2.5	−12.2	−3.1
1	6.4	3.9	−7.9	−3.7	−16.1	−4.4	−21.6	−7.6	−27.6	−8.3
2	6.7	5.3	−8.7	−5.6	−18.9	−7.3	−27.3	−12.3	−34.5	−13.1
3	6.7	5.9	−8.7	−6.4	−19.3	−8.9	−28.1	−14.8	−35.4	−15.9
5	6.7	6.5	−8.8	−7.1	−19.4	−10.7	−28.4	−17.0	−35.6	−18.8
7	6.7	6.6	−8.9	−7.4	−19.5	−11.5	−28.5	−17.8	−35.7	−20.0

TABLE 17.—*Comparison of the effects of static and flowing air of various relative humidities on the change in weight of heavyweight gelatin-latex fabric which has been conditioned in air at 21° C and 65 percent relative humidity*

[Material corresponds to Goodyear-Zeppelin Corporation specification K-13329; weight of finished fabric found to be 6.95 oz/sq yd (fabric=4.20, gelatin-latex=2.15, paraffin=0.60)]

Time	Percentage gain in weight at various relative humidities							
	At 86 percent		At 94 percent		At 97 percent		At 100 percent	
	Static	Flowing	Static	Flowing	Static	Flowing	Static	Flowing
Days	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1/24	0.4	0.5	0.7	0.6	1.1	1.0	1.7	0.8
1/8	1.0	1.0	1.7	1.5	2.5	2.4	3.7	2.2
1/4	1.7	1.7	2.7	2.6	4.1	4.2	5.8	3.9
1	4.2	4.6	7.3	7.1	10.7	12.0	12.8	12.3
3	7.4	7.7	14.4	13.9	21.3	23.9	24.4	26.0
7	8.9	9.0	19.4	19.7	33.1	37.2	40.0	42.5
14	9.4	8.9	23.6	21.6	45.1	44.8	57.7	57.0

With the foregoing data as a basis of calculation of the moisture absorption of the coated fabrics that are used on an airship of the GZ–1 type such as the *Macon*, the values for gain in weight after 1 day, 1 week, and 4 weeks have been obtained and are presented in table 18. The outer cover data are calculated from the results given in tables 2, 5, and 11, those for the lightweight and heavyweight, gas cell fabrics from tables 13 and 14, respectively. The data for the lightweight fabric are on the basis of the sample containing 0.7 oz/sq yd paraffin or 14 percent by weight; those for the heavyweight fabric are on the basis of the sample containing 0.6 oz/sq yd paraffin or 9.5 percent by weight. It will be observed that the gain in weight in 1 day at the high humidities is approximately 1 ton; after 1 week it varies from 1.5 to 3.25 tons and after 4 weeks from 2.5 to 6.75 tons. A comparison of the figures in table 18 with those that Bird [11] calculated for the British dirigible "*R.100*" is interesting. He calculated that the scheduled weight of the gas bags on the "*R.100*", namely, 7.3 tons, might increase 70 percent in weight or 5.1 tons, according to his experimental data; he likewise noted that the scheduled weight of the outer cover, namely, 4.35 tons, might be increased by not more than 1 ton. This makes a net increase of 6.1 tons. The higher value noted in table 18 is due to the larger size of the airship and to the greater hygroscopicity of the fabrics.

TABLE 18.—*Gain in weight (pounds) of the fabrics used on an airship (GZ-1 type) at various humidities*

Materials	Weight at 65 percent relative humidity and 21° C	Gain in weight at various relative humidities								
		At 94 percent relative humidity			At 97 percent relative humidity			At 100 percent relative humidity		
		1 day	1 week	4 weeks	1 day	1 week	4 weeks	1 day	1 week	4 weeks
	lb	lb	lb	lb	lb	lb	lb	lb	lb	lb
Outer cover	11,680	526	526	526	748	853	853	1,016	1,834	3,247
Gas-cell fabric, lightweight	11,163	513	1,764	2,891	737	2,735	5,570	815	3,260	6,955
Gas-cell fabric, heavyweight	7,171	280	925	1,556	337	1,241	2,868	351	1,406	3,227
Total	30,014	1,319	3,215	4,973	1,822	4,829	9,291	2,182	6,500	13,429

V. SUMMARY AND CONCLUSIONS

1. Aircraft fabric doped with cellulose nitrate absorbs only small amounts of water at high humidities; the gain in weight noted in a saturated atmosphere was less than 12 percent of its weight in the standard conditioning environment, 21° C and 65 percent relative humidity.

2. Aircraft fabric doped with cellulose acetate behaves similarly to fabrics coated with cellulose nitrate dope at relative humidities as high as 97 percent. At 100 percent relative humidity the cellulose acetate product is more hygroscopic and absorbs about 20 percent of moisture in 1 week and 40 to 55 percent of moisture over a period of weeks.

3. Gas-cell fabric, that is balloon cloth coated with gelatin-latex plasticized with polyglycerol, is exceedingly hygroscopic and is capable of approximately doubling its weight at 100 percent relative humidity in 4 weeks. The rate of absorption is retarded considerably by paraffin which is always applied to the surfaces of the gas-cell fabric in service.

4. Unparaffined gas-cell fabric loses absorbed moisture comparatively rapidly when the relative humidity of the atmosphere is

[11] J. Roy. Aero. Soc. **35**, 973 (1931).

decreased, whereas the paraffined material requires approximately the same period for the desorption as for the absorption of moisture.

5. The gas-cell fabrics have been found to be susceptible to attack by mold at 21° C and relative humidities from 94 to 100 percent, inclusive. It is desirable that a fungicide be added to fabrics with the gelatin-latex coating in order to prevent the deterioration of the finished product by mold action.

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