MOISTURE CONTENT OF WOOD IN AIRPLANE STRUCTURES

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MOISTURE CONTENT OF WOOD IN AIRPLANE STRUCTURES[1]

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The criteria[2] that have been used for many years in the design of wood aircraft structures are based on the assumption of a moisture content of 15 percent in wood parts. This report presents information on the moisture content of wood airplane parts and other data pertinent to a re-examination of the design criteria.

Presentation of Data

I. Early Studies of Moisture Content of Aircraft Parts

Two studies were made in 1923-24 to determine the moisture content of wood in aircraft parts under actual service conditions at various Navy and Army air stations, Army air intermediate depots, and factories having contracts to supply wood parts to these departments. The study for the Navy was conducted by the Forest Products Laboratory and that for the Army by the Engineering Division, McCook Field, Dayton, Ohio.

At each station included in the studies, representative parts were selected that had been in service or storage at each location a length of time presumed to be sufficient for equilibrium with the existing atmosphere to be reached. Care was taken to select samples from materials which presumably had not been exposed to unusual conditions.

One or more moisture sections 1 inch in length along the grain were cut from the parts selected, except that for plywood a sample several square inches in area was taken. Specimens were weighed immediately and were later oven-dried to obtain moisture content values. Average values are presented in tables 1 and 2.

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[1]This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available.

[2]Table 2-3 of ANC-18 "Design of Wood Aircraft Structures."

Spruce (presumably Sitka spruce), ash, poplar (presumably yellow-poplar), and Douglas-fir are represented by a large number of determinations, whereas other species are represented by comparatively few specimens. The combined weighted averages for four of the species, including data from all sources, are as follows: spruce 12.5 percent, ash 12.3 percent, Douglas-fir 10.8 percent, and poplar 11.2 percent. The investigators concluded that the species had no marked effect on the equilibrium moisture content.

Extreme conditions in this study were represented by an average moisture content of 9.85 percent for San Antonio, Texas, and 15.3 percent for Seattle, Washington. It should be noted that these are probably not the extremes that would be obtained in a more comprehensive series of tests covering all seasons of the year or including the particularly severe conditions that might prevail at some points or during certain seasons.

II. Matched Specimen Study in the United States

To obtain data on seasonal changes and on the effect of location and of protective coatings, a series of tests on matched specimens was conducted by the Forest Products Laboratory at 10 locations in the United States over a period of 27 months (April 1925 to July 1927).

Two species, Sitka spruce and ash, were used. All specimens were prepared at Madison where they were conditioned to constant weight at 80° F and 60 percent relative humidity, both before and after the application of coating to some of the specimens. The panels (5/8 inch thick by 4 inches wide by 8 inches long) were wrapped in waxed paper for shipment. Nine panels of each species were exposed at each location. They were suspended under cover where they were protected from rain or snow, but were subject to all changes of temperature and relative humidity.

Three specimens in each location were left uncoated; three were finished with a filler and three coats of spar varnish, and three were covered with an aluminum leaf coating.

Each specimen was weighed monthly. Table 3 lists for both species and for the three coating conditions, the maximum and minimum values found for an individual specimen during the period of the observations, together with averages over the period. Figures 1 (Sitka spruce) and 2 (ash) show the variations of average values over the period at each of the 10 locations.

This investigation led to the conclusions that the fluctuations of ash and spruce were not materially different; that of the locations covered by the study, the Northwestern portion of the United States showed the widest fluctuations of moisture content during the test period; and that the type of coating used materially affected the range of moisture content experienced, with aluminum leaf coating showing a superior protective value as compared to filler with three coats of spar varnish.

III. Aircraft Wing Study

A study of temperature and moisture content in wood aircraft wings was undertaken in 1943 through the cooperation of laboratories in different parts of North America. The study includes data for determination of moisture content of solid Sitka spruce and of birch veneer specimens placed at representative positions within two wooden Anson bomber wings located in fixed positions on the ground. Tests were made at Tucson, Arizona, and Madison, Wisconsin, in the United States, and at Ottawa, Ontario, and Prince Albert, Saskatchewan, in Canada.

Reports have been issued covering the full test period of approximately 1 year for Canadian[3] stations, and for the first 4 months of the test period for the stations in the United States.[4] The data for the balance of the year at Madison were available from original records.

For these tests one group of Sitka spruce specimens, consisting of four sticks 1-1/2 by 1-1/2 inches in cross-section by 11 inches long, was placed at each of four locations in each wing, and one group of birch veneer specimens, consisting of three pieces of 1/48-inch veneer 1-1/2 inches wide by 5-1/2 inches long was placed at each of seven locations in each wing.

All of the veneer specimens, including reserves for possible replacements, needed for the two stations in the United States and for the stations in Canada, were rotary-cut at Madison from a single birch log. Similarly, all spruce specimens for the United States and Canada were cut at Madison from adjacent parts of a single log that had been air-seasoned for several years. The birch was dried in a regulation veneer drier at 175° F. for approximately 4 minutes, with a resulting moisture content estimated at from 8 to 12 percent. All specimens of both types were brought to constant weight in 65 percent relative humidity at 80° F., and the weight when oven dry was calculated from the weight of each specimen and its moisture content as determined by oven-drying suitable cuttings.

The specimens were shipped from Madison wrapped in aluminum foil (foil, paper, paper, foil) sealed with cellulose tape.

The relatively large Sitka spruce specimens were intended to reveal chiefly the seasonal changes in average moisture content, therefore specimens were used in groups of four. One specimen of the group was weighed each week, choosing specimens from the group in rotation so that any one specimen was weighed only once in 4 weeks. The thin birch specimens were

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[3]Canada - Forest Products Laboratories. Study of temperatures and moisture contents attained in wooden aircraft wings in different climates, Progress reports 1-6, project 239.

[4]United States - Forest Products Laboratory. Study of temperature and moisture content in wood aircraft wings in different climates; first progress report, June to October 1943, Report No. 1597, February, 1944.

used to follow the rapid daily fluctuations. Three weighing schedules were used for the veneer specimens, depending on weather conditions, but, in general, at least one specimen was weighed daily (except Sunday) from each of six locations.

The data at Tucson, Arizona, are not considered in this report; as moisture conditions at that location, as would be expected, were considerably lower than at Madison or the Canadian stations.

The annual variation of moisture content for Sitka spruce specimens at Madison is shown in figure 3. The four lower curves show the variation of the average moisture content for the eight specimens (located in different parts of the wings) in each set (S1 to S4). As previously noted, these weights were obtained at 4-week intervals, a different set being weighed each week. The upper curve shows the same data plotted in sequence week by week. The trend of this composite curve is in substantial agreement with the individual curves below it. Although the four sets were of matching material, the composite (top) curve may reflect minor variations in moisture equilibrium characteristics, as well as trends in equilibrium conditions resulting from changes in the angle of incidence of the sun on fixed wings.

Figure 4 presents a comparison of the average moisture content for Sitka spruce specimens at Madison, Ottawa, and Prince Albert from June 1943 to August 1944. These curves are of the composite type shown at the top of figure 3. The seasonal variations at the three locations were similar for the period covered by these tests.

Figure 5 shows the maximum, minimum, and average moisture content values for Sitka spruce specimens at Madison, Ottawa, and Prince Albert. These curves are also of the composite type similar to the upper curve of figure 3.

Figure 6 is a graph showing the seasonal variation of moisture content for the average of three birch veneer specimens at Madison. A fourth specimen for which similar readings were taken was not included in this group because of soaked conditions resulting from a leak in the wing covering. The three specimens E1V1, E3V4, and W3V4 were, in most cases, weighed daily except Sunday for 1 year from July 24, 1943, except for an interval from April 15 to May 12, 1944. The fluctuations in the curve, therefore, represent actual variations in the average moisture content of the three specimens.

Figure 7 shows the daily variation in moisture content for the average of two birch veneer specimens E5V4 and W5V4. These specimens were located directly above holes (about 1 inch in diameter) in the lower skins of the wings, and as a consequence were probably affected by the entrance of moist air or possibly direct moisture in the form of wind-driven rain or snow. This curve shows a large variation from day to day as compared to the corresponding curve for fully enclosed specimens (fig. 6).

The moisture content values reported for veneer specimens included in this study were based largely on weights obtained at 8 a.m. In some instances, weights were not taken at that hour. In such instances, the weights obtained at another hour were used, although it is recognized this has the effect of making the data somewhat more variable.

Figure 8 presents cumulative frequency distribution curves for all moisture content values obtained on Sitka spruce specimens at Madison from July 24, 1943 to July 24, 1944; at Ottawa from August 9, 1943 to July 31, 1944; and at Prince Albert from August 16, 1943 to August 7, 1944. Each of the curves thus includes data from approximately 13 readings on each of 32 specimens.

Figure 9 shows, for each of the three stations, the cumulative frequency distribution of the highest of the eight individual moisture content values observed each week for 1 year on Sitka spruce specimens.

Figure 10 shows the cumulative frequency distribution of moisture content values for the two groups of yellow birch veneer specimens used in the aircraft wing studies at Madison for the period from July 24, 1943 to April 14, 1944 and from May 13 to July 24, 1944. Curves A and C include all observations (nominal daily) on the specimens in each group. Curves B and D include only the maximum observed value (nominal daily) for each group. Specimens included in curves A and B were located in enclosed positions; those included in curves C and D were located above the 1-inch holes previously mentioned.

Table 4 summarizes average moisture content values and other data for all Sitka spruce specimens and for two groups of birch veneer specimens included in the aircraft wing study. Included are numbers of specimens and various percentage values obtained from the data and the appropriate frequency curves (figs. 8 to 10).

IV. Flight Conditions

An attempt to obtain data comparing ground with flight conditions was made in Australia[5] in connection with the study of aircraft wings in service.

Two flight tests were made to determine the rates at which temperature and moisture content change in various positions in aircraft wings. Moisture content measurements were made by means of electrical resistance readings ("Techtron" moisture meter) between pairs of electrodes placed in the wood at selected positions. The actual measurements were carried out

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[5] Australia - Council for Scientific and Industrial Research, Division of Forest Products, Temperatures and Moisture Contents of Wooden Aircraft Wings in Service; Project TP13; Progress Report 1, No. 1, first report on experiment TP13-X-2, Flight Tests Conducted at Laverton during February, 1944.

on a test cell representing a typical section of the wing from top to bottom skins, including a box spar section. This cell was carefully built into and made an integral part of the starboard wing of the plane.

The attempts made to measure the moisture content of the cell were not entirely successful. While at rest on the ground satisfactory readings were obtained with the moisture meter, but as the aircraft cooled down in flight many of the readings fell below the range of the meter.

The report concludes, "It would appear that moisture content changes occur only slowly and values attained on the ground must be taken as persisting during flight."

Discussion of Data

It is difficult to determine upon a moisture content value for use in aircraft design that correctly weighs all possible factors. These include species, types of materials, protective coatings, volume and exposed surface area of wood members, effect of glue lines, geographical location, weather conditions, seasonal variations, exposure to the elements, relations for ground and flight conditions, relative proportion of use under different conditions, and the like. Furthermore, since most strength properties of wood decrease with increase in moisture, it is necessary to give consideration to extreme conditions that may be encountered. On the other hand, it would not appear to be reasonable to penalize a large percentage of aircraft by requiring that the most extreme possible condition be applied to all design.

Flight Conditions

The determination of moisture content in wood aircraft under flight conditions is extremely difficult. As noted in item IV under "Presentation of Data" such information as is available on the effect of flight conditions on moisture content points to the conclusion that for purposes of studying moisture content conditions in aircraft, ground conditions may be accepted as persisting in flight.

Ground Conditions

The data available in items I, II, and III under "Presentation of Data" are obviously not representative of all conceivable ground conditions in the United States and Canada, nor do they include any information as to relative use.

Tables 1 and 2 show that the average moisture content for samples taken from representative aircraft or aircraft parts throughout the United States (item I) was in the vicinity of 12 percent, with a maximum value of

15.3 percent for specimens selected at Seattle, Washington, in November, 1923.

The combined weighted average for Army and Navy material from the data in item I was 12.5 percent for spruce and 12.3 percent for ash. Other studies also indicated little difference in the equilibrium value for varìour species commonly used in aircraft.

Table 3, presenting data for ash and spruce panels at 10 different locations in the United States (item II) shows an average of 12.6 percent for uncoated material of both species. The time and locations of exposure, type of material, type of specimens, and manner of exposure were quite different for this study than for the Army-Navy studies (item I), but it is notable that the species averages are approximately the same and that the highest average and maximum values were also obtained in the Pacific northwest (Priest River, Idaho).

Table 3 shows that average and maximum values were greatly reduced for finished specimens as compared to uncoated specimens. Both coatings used are much superior to those in current use in aircraft, and in general, the effectiveness of most currently used protective coatings is subject to question. Studies at the Forest Products Laboratory, including the work reported in Report No. 1597, indicate that it is doubtful whether two coats of aircraft sealer now commonly specified in the United States exert any appreciable effect on the moisture content or the daily changes in moisture content.

Table 3 further shows that the average values for Madison, Wisconsin, are nearly as high as for Priest River, Idaho, for uncoated specimens, and are among the higher values for maximum moisture content attained. It would, therefore, appear that the values obtained in the aircraft wing studies (item III) at Madison are representative of the more severe conditions likely to be encountered in the United States.

Wing studies at the three locations selected for consideration (Madison, Prince Albert, and Ottawa) are not entirely representative of aircraft materials for several reasons:

(1) All specimens were uncoated.

(2) It is not known how well the moisture conditions during the period covered by the test represent either average or extreme conditions, both as regards the period as a whole and the seasonal variations.

(3) The specimen types and sizes do not fully represent all materials used in aircraft, and the moisture content attained by the specimens is considerably affected by their location.

(4) The wings used in these studies were mounted in fixed positions close to the ground. Had the wings been oriented differently, temperatures within the wings would presumably have been affected, with consequent change in moisture content values as well.

Figure 3 shows that at Madison, seasonal variation of moisture content for the four groups of Sitka spruce specimens considered as a whole follows the trend exhibited by each of the individual groups. Figure 4 indicates that the variation of average values at Prince Albert and Ottawa is essentially similar to that at Madison.

Conditions at the two Canadian stations appear to be somewhat more severe than at Madison, although the differences in average and maximum values for Sitka spruce specimens as shown in figure 5 and in columns 7 and 8 in table 4 are not large. In the case of maximum values, it should be noted that during the period from January 28 to May 13, 1944, specimens in location W1 at Madison were water soaked as a result of leakage through a break in the surface material of the west wing. The measured values were, therefore, replaced by values computed from the average of the other seven specimens, based on the ratio of moisture content values for location W1 to the average of the remaining seven locations for the balance of the year.

Figures 1 to 5 show that isolated determinations of moisture content as obtained in the Army-Navy study (item I) cannot be relied upon to yield data for either average or maximum conditions.

Veneer specimens were included in the aircraft wing studies largely to indicate the most extreme conditions that could be expected to prevail in the wings. These specimens were sufficiently small to reach equilibrium with surrounding conditions in a few hours. Figure 6, showing almost daily moisture content values for the average of three specimens over an extended period, presents evidence that the variation of equilibrium conditions from day to day is large. The trend of this curve is similar to those representing the larger Sitka spruce specimens (figs. 3 to 5). It may also be noted that the average value, 13.0 percent, is relatively little higher than the Sitka spruce average, 12.4 percent, for Madison, although the average would probably be somewhat higher if data were included for the period from April 15 to May 12, 1944.

The location of the veneer specimens within the wings has a considerable effect on the moisture content attained. Moisture content values for specimens E5V4 and W5V4, which were located above 1-inch holes, were obtained at the same intervals as for the three specimens included in figure 6; but, as indicated in figure 7, it is evident that the range of moisture content for these specimens is much greater than for those located in less exposed positions, and the average value, 15.2 percent, is also considerably higher.

Table 4 (column 9) shows that the average of the maximum moisture content values obtained at each observation date was approximately 15 percent for spruce specimens. This average is some 2 percentage points higher than the average of all observations (column 7). For veneer specimens the corresponding average was 1 percentage point higher than the annual average, and again the average maximum value was in the vicinity of 15 percent.

A study of the distribution of observed moisture content values for 1 year brings out the various relations somewhat more clearly. Columns 11 to 14 in table 4 summarize pertinent data obtained from cumulative frequency curves, figures 8 to 10.

Figures 8 and 10 and columns 11 and 12 in table 4 show the distribution of all moisture content values measured on each specimen type during the 1-year period. There is no means of determining from these data the manner in which specimens having a moisture content higher than some particular value are distributed. That is, the high values might all occur within a short period, or might represent a very few specimens. If only the maximum value obtained at each observation date is considered, however, irrespective of the specimen on which it occurs, (as in figure 9 and columns 13 and 14 in table 4) the percentage of the year during which such maximum values occurred may be approximated. Thus, from these data it would appear entirely possible for solid uncoated Sitka spruce material within aircraft wings to exceed 15 percent moisture content more than one-half the time (column 14) under conditions that would appear to be fairly common in the United States and Canada. Similarly, from these data (column 13), it appears that some portion of the material could be expected to exceed the annual average moisture content approximately three-fourths of the time.

Surprisingly, for thin veneer specimens other than those located near drain holes, the probability of exceeding 15 percent moisture content appears to be considerably less than for the larger spruce specimens, and even for those veneer specimens located near holes, the percentage of time in which at least one specimen exceeded 15 percent was approximately the same as for spruce.

This may possibly be explained by the tendency of larger specimens (or aircraft parts) to lose moisture slowly. If conditions that would produce a high moisture content persist long enough for the material to reach a high value, a temporary reduction in equilibrium conditions, which might bring about a substantial decrease in the moisture content of thin specimens or parts, may have little effect on larger parts.

Summary

The data summarized in this report indicate that the present value of 15 percent moisture content used in wood aircraft design is not high enough to include all conditions of service. This is apparent from the results of tests on actual aircraft parts (tables 1 and 2) in which values exceeding 15 percent were measured.

Studies on matched specimens at various locations (table 3) show that on uncoated material maximum values considerably in excess of 15 percent were found in many parts of the United States, and that the 15 percent level was exceeded even in the case of varnished material. On the other

hand, the conditions of exposure for these specimens were quite different from those encountered in aircraft structures.

The aircraft wing study showed that, during the period of 1 year covered by the observations, moisture content values in excess of 15 percent occurred in one or more uncoated specimens on more than one-half of the dates on which measurements were made. The use of finishing materials on aircraft parts might tend to reduce the probability of high moisture content to some extent as compared to the unfinished wood, but it is questionable whether the two coats of aircraft sealer now commonly specified can be relied upon to exert any substantial effect. Flight conditions, or differences in exposure on the ground, might likewise be expected to influence the moisture content, but it would not seem justified to rely upon any considerable reduction when dispersal of planes on the ground in stationery positions is a distinct possibility.

The determination of a proper design moisture content would appear to depend largely upon a decision as to whether such a design value is to be fixed at a level high enough to include: (1) all, (2) a substantial percentage, or (3) some lesser percentage of moisture content values that might be encountered under severe conditions.

(1) To include all specimens under severe conditions would require a design value of at least 24 percent.

(2) To include a substantial percentage of moisture content values that might be encountered; and to insure that the design value would be exceeded only a small proportion of the time under severe conditions, would require an increase in the design level to some 17 or 18 percent.

(3) In the recorded data, the present 15 percent design value is exceeded somewhat more than half the time, but, for the United States and Canada as a whole, the percentage of time in which the 15 percent level is exceeded might be quite different if data were available on the proportion of use under varying conditions.

Table 1.--Average moisture content of wood aircraft parts selected at Naval Air Stations or factories

Species	Cleveland, Ohio		New York, New York		Philadelphia, Pennsylvania		Quantico, Virginia		Anacostia, D. C.		Hampton Roads, Virginia		Pensacola, Florida		Seattle, Washington		San Diego, California		Santa Monica, California		Species averages for all stations	
	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content
		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent
Wood																						
Spruce	4	13.3	15	13.0	30	11.6	15	12.5	17	14.2	20	13.9	65	12.9	11	15.3	69	12.5	4	9.8	290	12.9
Ash	4	10.5	10	12.9	18	11.9	5	11.5	21	14.3	23	14.7	22	12.4			12	12.4	2	10.9	117	12.4
Poplar					6	12.5	6	12.4									9	11.1			21	12.0
Oak					6	10.6					6	12.5					1	14.6			13	12.6
Walnut	2	8.8			2	9.0															4	8.9
Hickory													3	14.0							3	14.0
Maple									1	13.5											1	13.5
Port Orford cedar			2	13.2																	2	13.2
Douglas-fir							2	10.8													2	10.8
Spanish cedar	2	12.2																			2	12.2
Average		11.2		13.0		11.1		11.8		14.0		13.7		13.1		15.3		12.6		10.4		12.4
Plywood																						
Mahogany and birch	2	15.4															5	13.1			7	14.2
Mahogany and poplar	2	10.8					1	13.1			2	14.2					2	11.3			7	12.4
Birch and poplar	6	9.8			5	13.1															11	11.5
Birch and cottonwood	2	9.1																			2	9.1
Birch	2	13.6					2	11.8	2	17.6	2	17.8									8	15.2
Laminated wood																						
Poplar and spruce					1	11.6															1	11.6
Ash and spruce											1	14.4	2	11.7							3	13.0
Time of selection	October 9-10, 1923		October 12, 1923		October 15-16, 1923		October 18, 1923		October 22-23, 1923		October 26, 1923		October 29, 1923		November 26, 1923		December 4-6, 1923		December 12, 1923			

Table 2.--Average moisture content of wood aircraft parts selected at Army flying fields and air intermediate depots

Species	San Francisco, California		Garden City, New York		Aberdeen, Maryland		Hampton, Virginia		Washington, D. C.		San Diego, California		San Antonio, Texas		Sacramento, California		Little Rock, Arkansas		Fairfield, Ohio		Dayton, Ohio		Species averages for all stations	
	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content	Number of specimens	Average moisture content
		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent		Percent
Spruce	16	13.14	24	11.96	12	12.74	13	12.51	23	12.70	56	13.01	18	10.70	6	11.03	6	10.84	23	10.48			197	11.91
Ash	6	13.63	7	13.13	2	12.53			3	13.96	16	12.22			2	10.62	1	9.66	13	11.12			50	12.11
Douglas-fir	5	13.07	18	11.42	1	10.35	6	10.91	13	11.18	10	11.46	4	9.31	6	10.53	4	9.72	21	9.73			66	10.77
Poplar	3	12.07	12	11.23	2	9.30	8	11.67	2	11.01	1	10.96	5	9.55	2	10.37			1	9.70			36	10.65
Average		12.96		11.94		11.23		11.70		12.21		11.91		9.85		10.62		10.07		10.26				11.34
All plywood	5	14.31	2	16.78	4	15.01	6	15.08	8	11.96	2	11.66									12	12.21	39	13.9
All propellers	4	10.79	13	10.89	9	10.09	13	10.68	16	11.28	6	11.34	3	10.46	6	8.71			6	8.41			75	10.3
Time of selection	July 24, 1923		August 18-28, 1923		August 30-31, 1923		September 7, 1923		September 17-18, 1923		June 23 to August 4, 1923		May 26 to June 2, 1923		July 12-16, 1923		May 12-14, 1923		March 17 to May 16, 1923		February 1, 1924			

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Table 3.--Moisture content of ash and spruce panels at several locations in the United States during the period from April 1925 to July 1927

Location	Number of times inspected	Moisture content -- percent of weight when oven-dry																	
		Ash									Spruce								
		Uncoated			Standard varnish finish			Aluminum leaf coating			Uncoated			Standard varnish finish			Aluminum leaf coating		
		Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum	Average
Colorado Springs, Colorado	28	7.4	13.2	9.8	8.0	11.3	9.9	8.7	11.2	10.0	7.4	13.6	10.0	7.8	11.0	9.7	8.9	11.0	10.1
Priest River, Idaho	26	6.7	26.3	14.2	7.5	16.2	12.0	9.8	11.5	10.5	7.0	22.9	14.0	8.0	16.6	12.3	9.9	11.1	10.5
Amherst, Massachusetts[1]	26	7.0	17.3	13.0	10.2	15.0	12.4	9.6	12.7	11.6	9.0	18.4	12.7	9.7	13.6	11.6	9.2	12.5	11.2
Dayton, Ohio	27	7.6	16.4	12.5	9.0	13.9	11.5	10.5	11.4	10.9	7.9	15.9	12.5	9.0	13.6	11.5	10.2	11.8	10.9
Flagstaff, Arizona[2]	25	5.2	13.9	9.6	6.5	10.6	8.4	9.1	11.0	10.2	5.3	14.3	10.1	6.2	10.5	8.4	8.4	10.8	9.7
Carson, Washington	28	8.1	20.0	13.4	8.5	15.8	12.0	9.7	11.5	10.6	8.4	20.8	13.4	8.6	15.3	11.8	8.8	12.9	10.7
St. Paul, Minnesota[3]	24	7.6	17.1	12.9	9.1	13.3	11.8	10.2	11.3	10.7	7.9	16.5	12.7	9.1	14.0	11.7	10.4	11.4	10.8
San Francisco, California	28	10.2	15.2	13.0	10.7	14.1	12.6	10.9	12.5	12.0	10.4	15.1	13.1	10.8	14.1	12.6	11.1	13.0	12.2
Valparaiso, Florida	21	11.2	17.2	13.9	11.1	18.1	13.7	11.4	13.7	12.4	11.0	17.9	13.9	11.1	17.1	13.4	11.3	13.4	12.3
Madison, Wisconsin[4]	25	10.0	17.0	13.7	10.9	14.2	12.7	11.0	14.5	11.9	10.0	18.1	13.8	10.6	14.0	12.6	11.1	13.1	12.0
Average..................	....	....	....	12.6	....	....	11.7	....	....	11.1	....	....	12.6	....	....	11.6	....	....	11.0

[1]One ash panel and two of spruce with the aluminum leaf coating were lost or destroyed in storms and most of the figures therefore represent the results on only one or two specimens with this finish.

[2]Only 24 inspections of spruce panels.

[3]Records of these specimens were not furnished each month and the results are therefore not strictly comparable with those from other stations where complete records were taken. (Figs. 1 and 2.)

[4]Results are for two complete sets of specimens, twice as many as at other stations.

Z M 64860 F

Table 4.--Average moisture content and other data for Sitka spruce and yellow birch specimens included in aircraft wing studies at Madison, Wisconsin, at Prince Albert, Saskatchewan, and at Ottawa, Ontario

Location	Total number of specimens	Number of specimens included in each observation	Schedule of observations	Number of observation dates	Total number of observations of moisture content	Average moisture content for all observations	Maximum observed moisture content	Average moisture content of the maximum value obtained at each observation date	Ratio of the average of maximum values to the average of all observations, column 9 / column 7	Percentage of individual observations exceeding the annual average moisture content	Percentage of individual observations exceeding 15 percent moisture content	Percentage of observation dates (column 5) on which at least one specimen exceeded the annual average for all observations (column 7)	Percentage of observation dates (column 5) on which at least one specimen exceeded 15 percent moisture content
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
						Percent	Percent	Percent		Percent	Percent	Percent	Percent
							Sitka spruce specimens						
Madison	32	[1]8	Weekly[1]	[1]51	408	12.4	[2]17.4	14.8	1.18	55	14	84	58
Prince Albert	32	[1]8	Weekly[1]	[1]52	416	12.8	[3]24.0	14.8	1.16	50	26	74	50
Ottowa	32	[1]8	Weekly[1]	[1]52	416	12.8	19.9	15.0	1.17	57	31	74	64
						Birch veneer specimens--normal locations[4]							
Madison	3	3	Daily[5]	274	813	13.0	20.0	14.0	1.08	58	19	72	33
						Birch veneer specimens--near drain holes[4]							
Madison	2	2	Daily[5]	274	542	15.2	27.5	16.4	1.08	51	54	61	63

[1] Four specimens were placed at each of eight locations in the wings. One specimen in each group of four (a total of eight specimens) was weighed each week. Specimens were chosen from the group at each location in rotation, so that any one specimen was weighed only once in four weeks.

[2] Higher values were obtained for specimens in location W1, but are not included because they were soaked as the result of a leak.

[3] This is an isolated value and may have been on a wet specimen. The next higher value was 17.9 percent.

[4] All moisture content values for birch veneer specimens are based on estimated weight when oven dry.

[5] Observations were scheduled daily (except Sunday) for every specimen, for 1 year from July 24, 1943 to July 24, 1944, with the exception that no data were obtained from April 15 to May 12, 1944. Three groups of specimens having less frequent observations or questionable data are not included in this summary.

Z M 64861 F

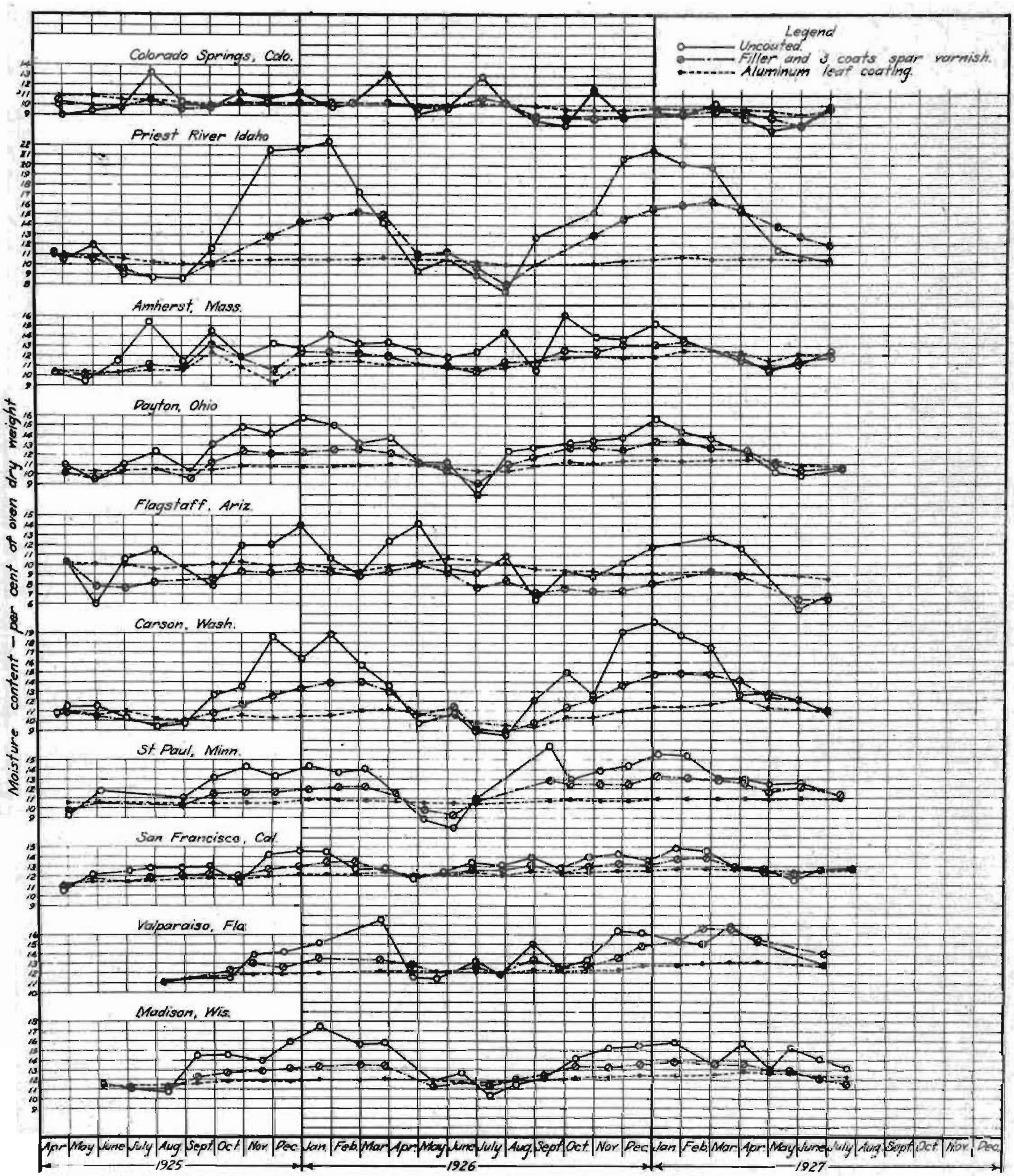

Figure 1.--Fluctuations in moisture content of spruce panels at several locations in the United States, from a matched specimen study conducted from 1925 to 1927.

Z M 64857 F

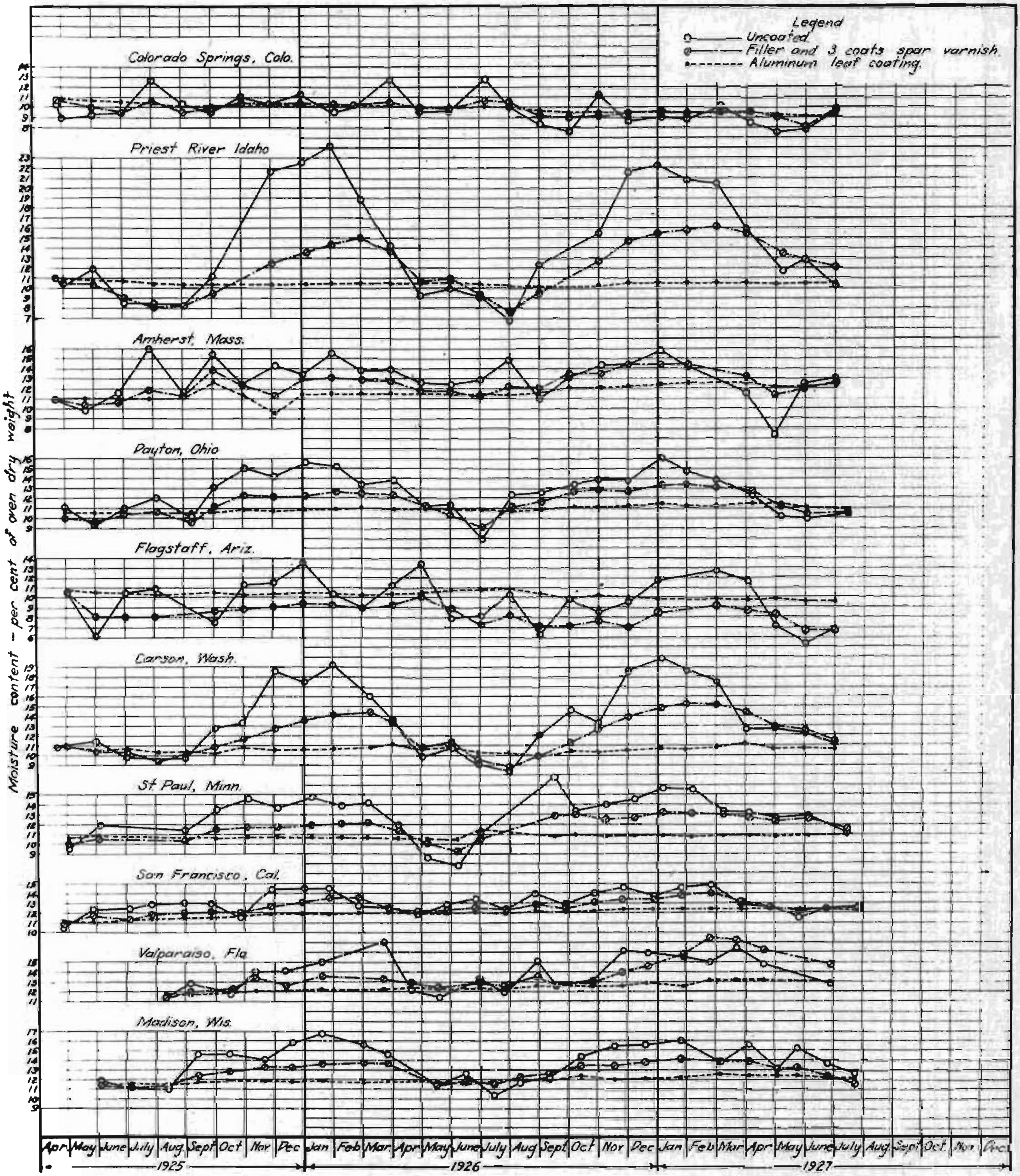

Figure 2.--Fluctuations in moisture content of ash panels at several locations in the United States, from a matched specimen study conducted from 1925 to 1927.

Z M 64858 F

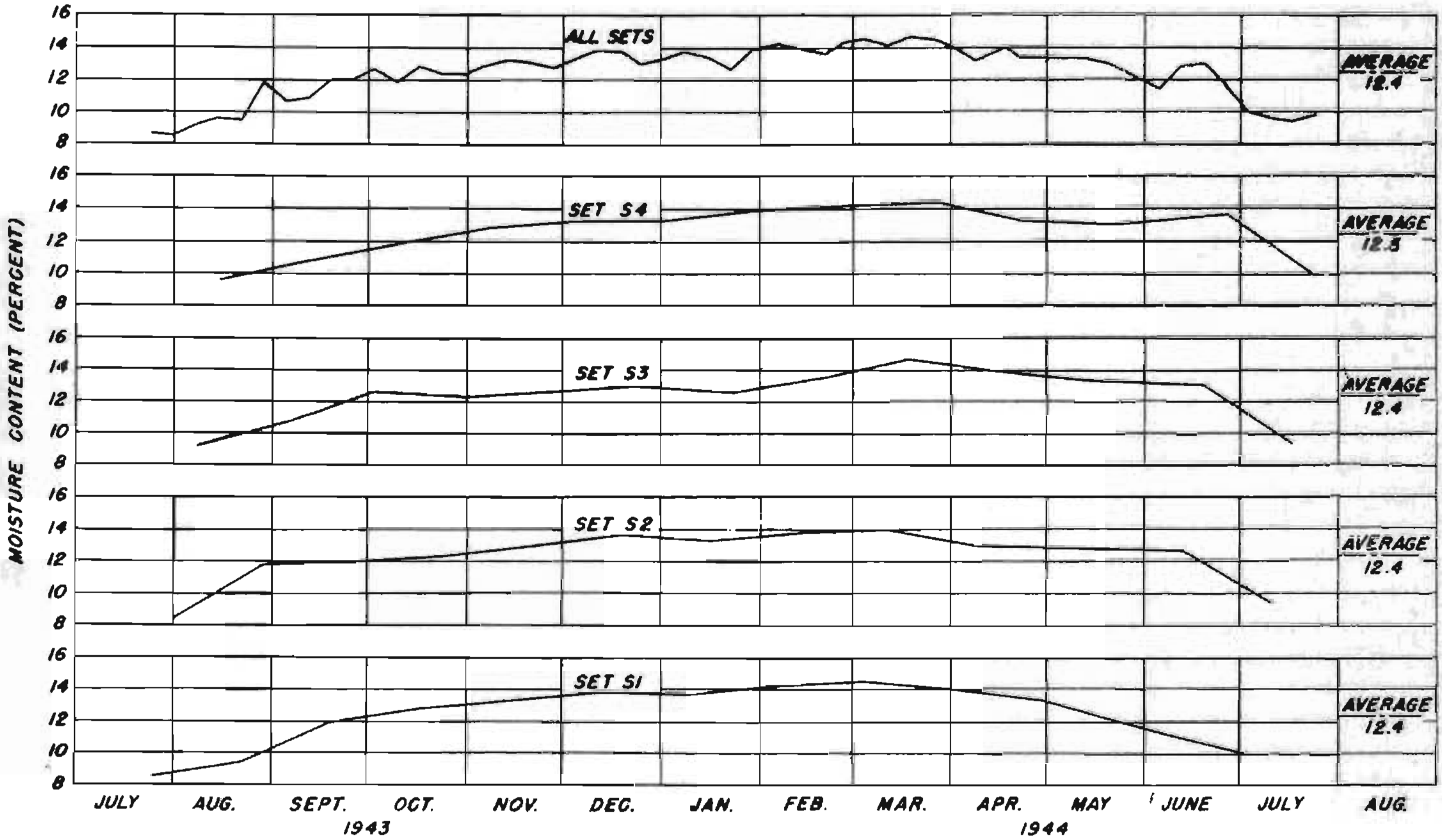

Figure 3.--Fluctuation of the average moisture content from aircraft wing studies at Madison, Wisconsin, for four sets of eight specimens each of Sitka spruce, and a combination of the four sets.

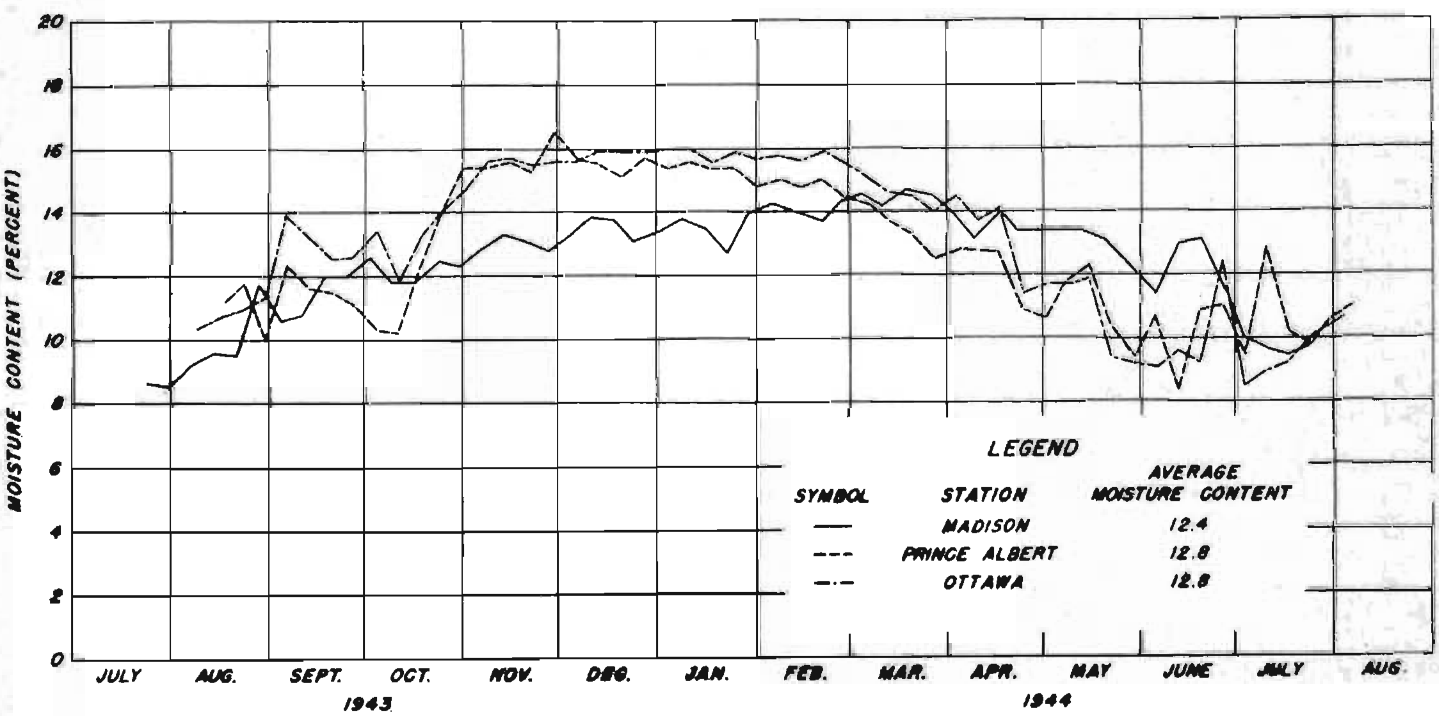

Figure 4.--Comparison of the average moisture content values from weekly observations of Sitka spruce specimens included in aircraft wing studies at three locations.

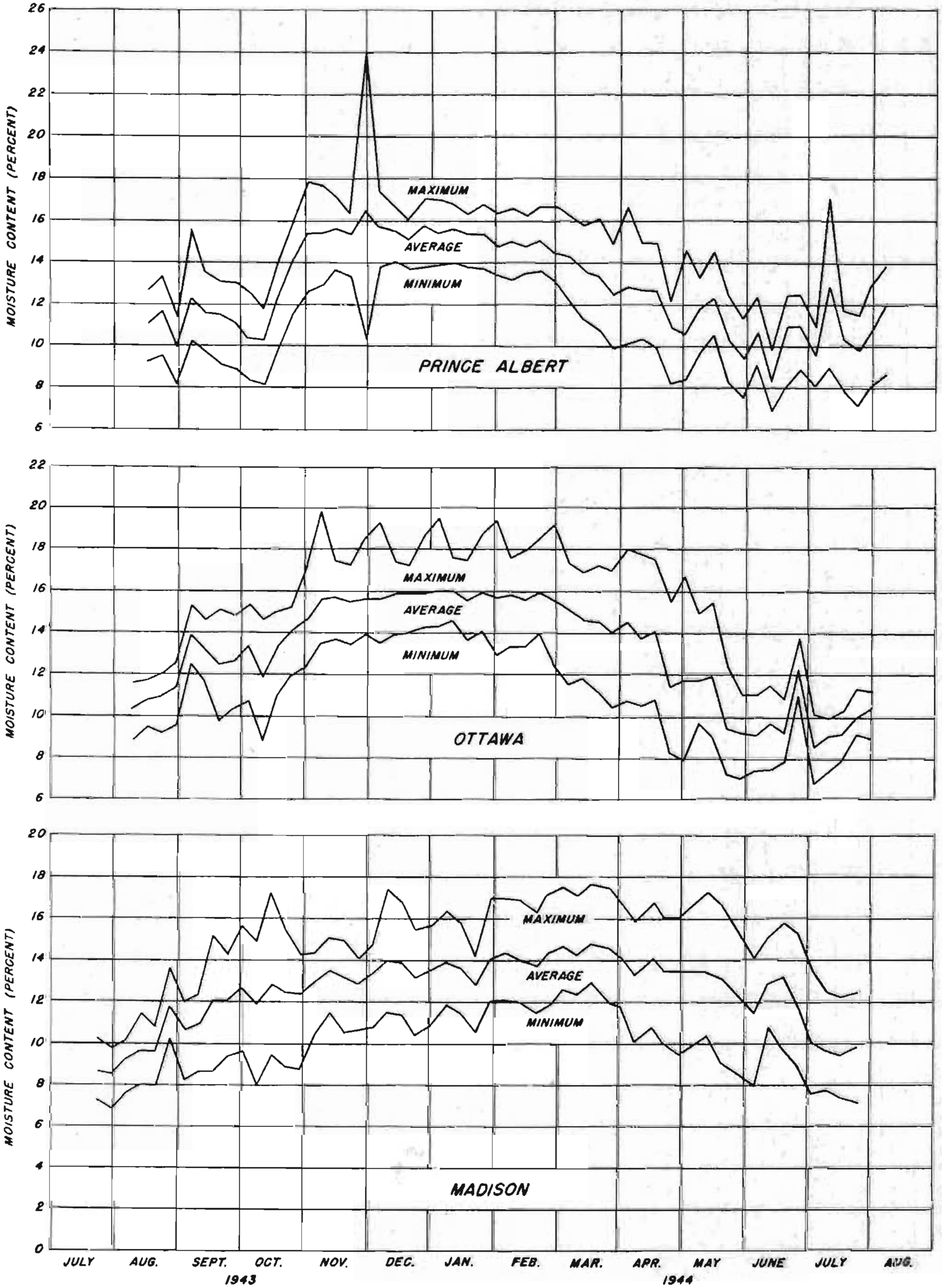

Figure 5.--Weekly variation of maximum, minimum and average moisture content values for Sitka spruce specimens included in aircraft wing studies at three locations.

ZM 61304 F

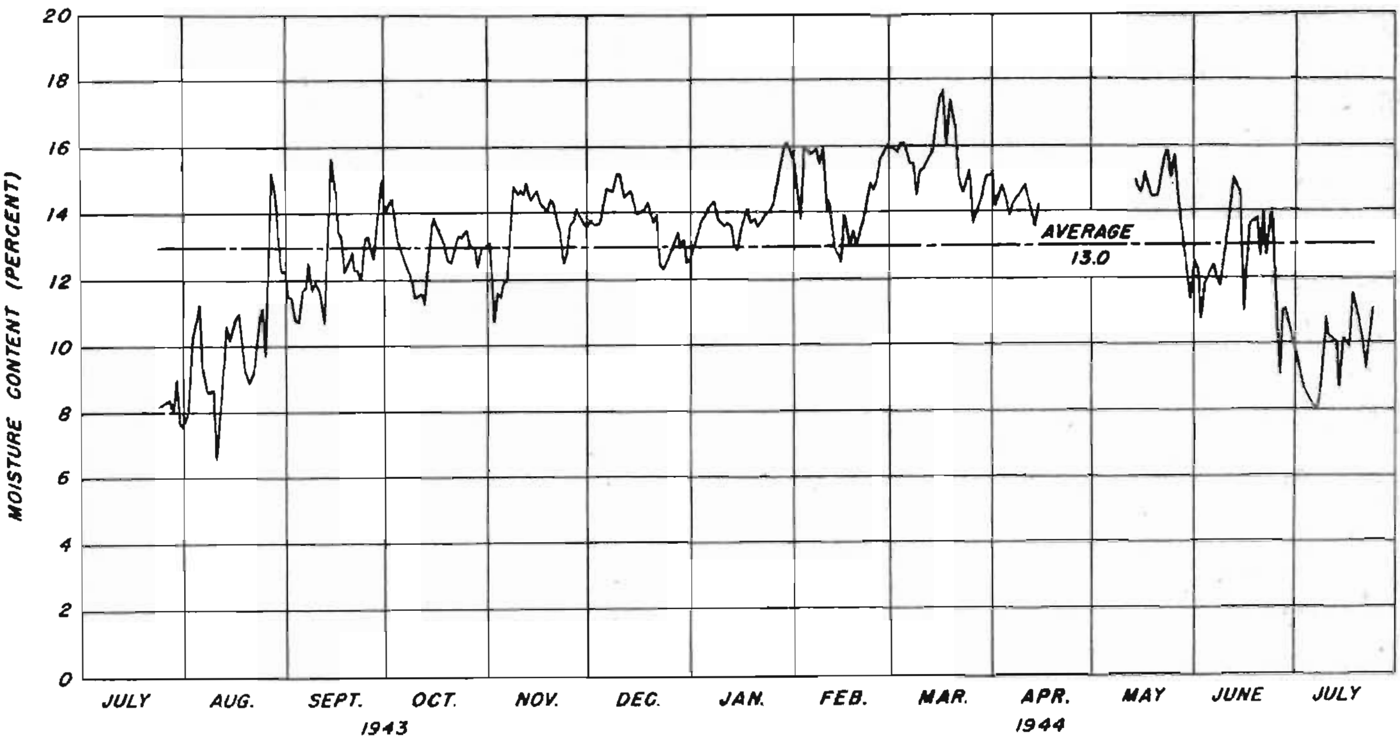

Figure 6.--Variation of moisture content for the average of three yellow birch veneer specimens located in enclosed positions, from aircraft wing studies at Madison, Wisconsin.

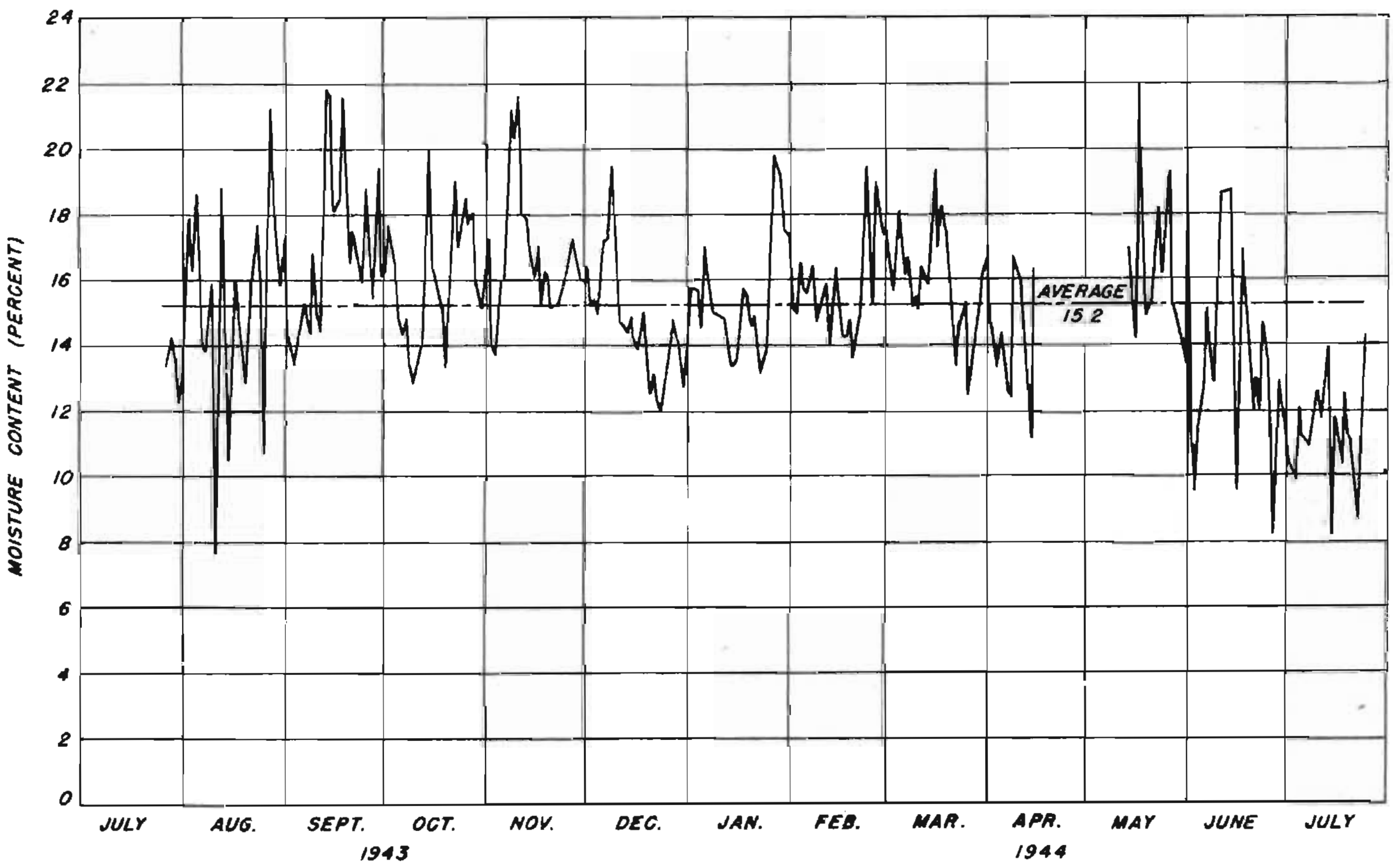

Figure 7.--Variation of moisture content for the average of two yellow birch veneer specimens located near drain holes, from aircraft wing studies at Madison, Wisconsin.

Z M 61305 F

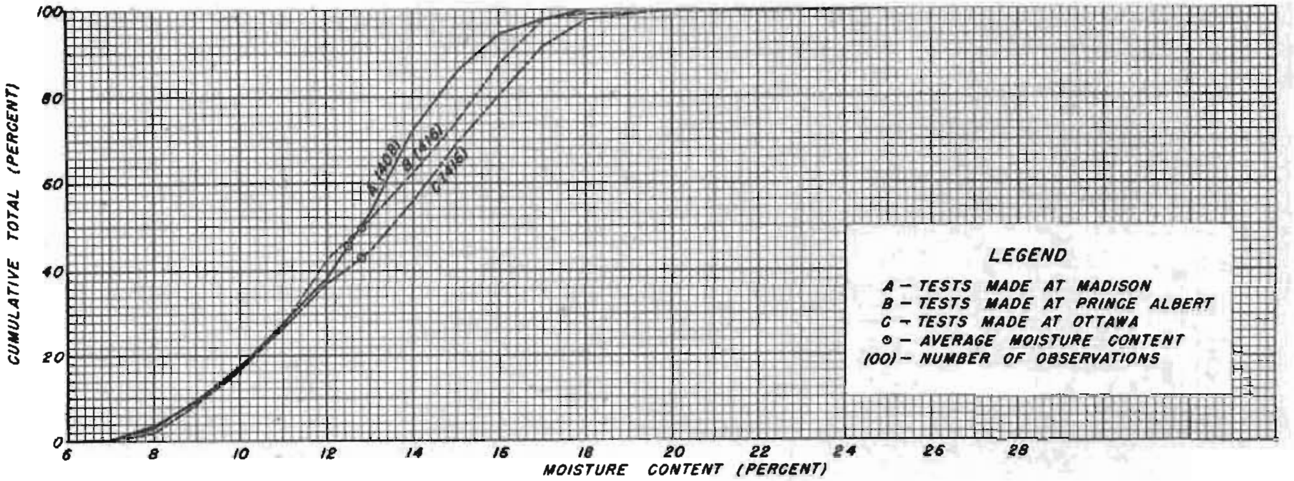

Figure 8.--Cumulative frequency distribution of all moisture content values obtained on Sitka spruce specimens used in aircraft wing studies at three locations, for a period of 1 year.

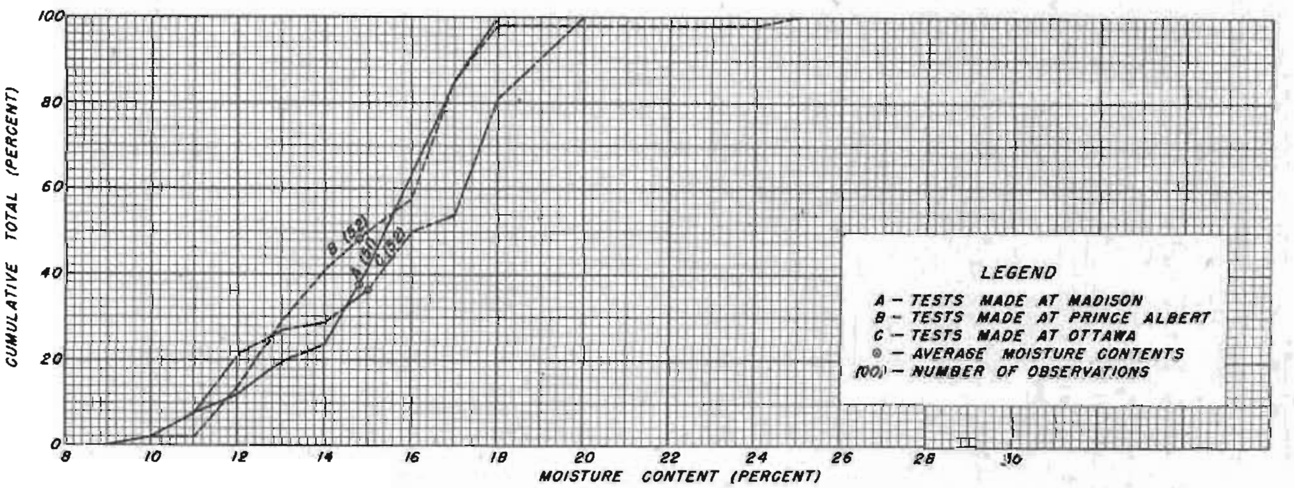

Figure 9.--Cumulative frequency distribution of the maximum moisture content values obtained each week for a period of one year, from observations on Sitka spruce specimens used in aircraft wing studies at three locations.

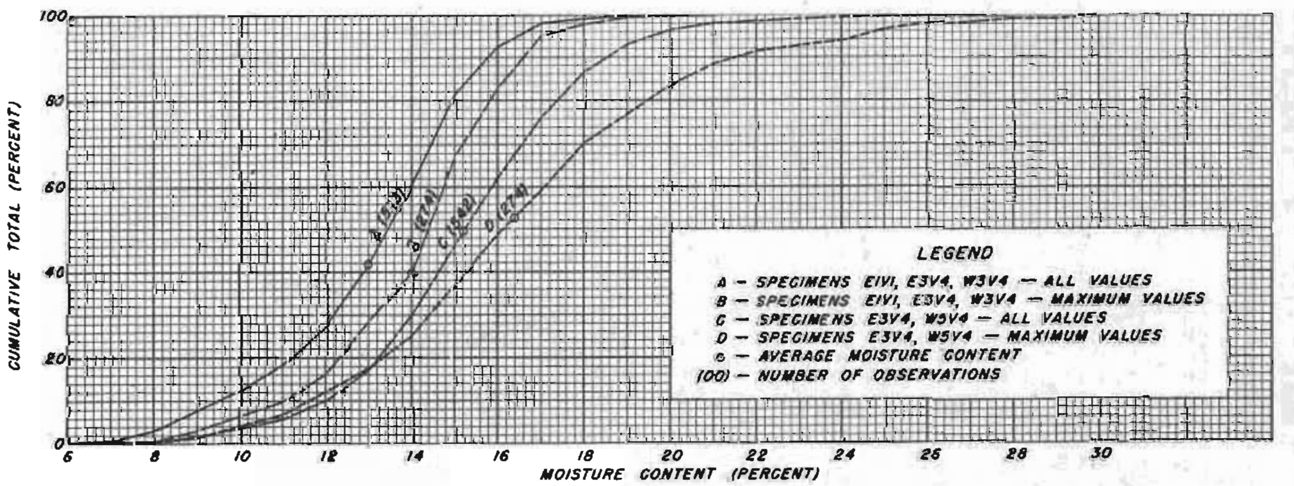

Figure 10.--Cumulative frequency distribution of moisture content values for two groups of yellow birch veneer specimens used in aircraft wing studies at Madison, Wisconsin, from July 24, 1943 to July 24, 1944.

Z M 61306 F