A STUDY OF TEMPERATURES ATTAINED IN A DUMMY AIRCRAFT WING DURING THE SUMMER AT MADISON, WISCONSIN

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A STUDY OF TEMPERATURES ATTAINED IN A DUMMY AIRCRAFT WING DURING THE SUMMER AT MADISON, WISCONSIN[1]

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This report presents the detailed results of a study of temperatures attained in a dummy wing. A summary of these results is given in Forest Products Laboratory Mimeograph No. 1343A.

Introduction

The wings of aircraft enclose air spaces that are vented to the outside atmosphere only through a limited number of very small holes that provide little or no circulation of air through the spaces when the craft is at rest on the ground. For that reason, higher temperatures are attained within the wings and within the plywood wing coverings than those prevailing in the surrounding atmosphere. The use of camouflage paints of dark colors contributes to the absorption of heat from sunlight and the attainment of still higher temperatures. The experiments herein described were made to supply data on the magnitude of the temperatures so attained. Information was also sought about the relative temperatures attained when the wing surfaces are finished with paints of different colors and different reflective power for infrared radiation. No attempt was made to determine temperature conditions that might prevail in an aircraft wing during flight and, in view of that limitation of objective, the dummy wing used resembled an aircraft wing only to the extent of being a skin of aircraft plywood glued around a light framework of wood, not to the extent of following aircraft proportioning and contouring.

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[1]This mimeograph is one of a series of progress reports issued by the Forest Products Laboratory to further the Nation's war effort. Results here reported are preliminary and may be revised as additional data becomes available.

Details of Construction of Dummy Wing

The dummy wing (fig. 1) was made with parallel sides in such a manner that both edges simulated leading edges having a 2-inch radius of curvature. This type of construction was adopted for two reasons: first, it was simple and convenient; second, it permitted testing a maximum number of treatments of the leading edges, in which the plywood is sharply bent or glued to shape. The over-all size of the test structure was 4 by 28 by 96 inches. The framework was constructed of 3/4- by 4-inch solid spruce stock which was used for the spars and all of the ribs. All ribs other than the end ribs were bored with four 2-inch lightening holes.

The skin was 3/32-inch aircraft plywood of 3-ply construction, applied to the framework with the face grain parallel to the spars. Three species of wood -- birch, yellowpoplar, and mahogany -- were used in the face plies. Some of the details of construction, together with the arrangement of the test sections and the numbers assigned to them, are shown on the sketch in figure 2.

The sketch shows the division of the dummy wing into six test sections numbered 1 to 6, starting at the left. Each section consists of a central portion B, covered with panels of flat plywood, and two leading edges, A and C, covered with curved plywood. Panels on the tops of the central portions are designated B_1 panels and those on the bottoms B_2 panels. The plywood skin on sections 1 and 2 was of yellowpoplar, that on 3 and 4 of mahogany, and that on 5 and 6 of birch.

Holes 1/8 inch in diameter were drilled in the four corners of each of the bottom (B_2) test panels to simulate the vents in an actual airplane wing. Holes were likewise drilled at 8-inch intervals in the flat bottom faces of the leading edges.

Two glues, Butacite 4644, a thermoplastic polyvinyl butyrate resin glue (a liquid glue); and Tego, a high-temperature thermosetting, phenol-formaldehyde resin glue (film form) were used in the plywood construction. The leading edges were made by four different methods:

1. Flat plywood bent dry and nailed in place.
2. Flat plywood bent after soaking in cold water and dried on a form before being attached to the framework.
3. Flat plywood bent after soaking in hot water and dried on a form before being attached to the framework.
4. Plywood bag molded before being attached.

Some of the pieces of flat plywood for the top and bottom surfaces of the wing were nail glued in place, leaving the nails in place, whereas the others were nail-strip glued, thereby leaving only nail holes. Details of the plywood construction, including the type of glue, the method of gluing, and the method of attachment to the frame, are recorded in table 1.

Eight copper-constantan thermocouples of No. 30 gage were installed in the dummy wing. In each case the thermocouples were placed at the center of the 16-inch square center sections. No thermocouples were installed in sections 1 and 6. All thermocouples were checked before installation and found to read 211° F. in boiling water, which is about right for the boiling point of water at the elevation of Madison. The location of the thermocouples in section 2, 3, 4, and 5 was as follows:

In section 2:

One in the upper glue line of panel $2B_1$.

One in the air space between panels $2B_1$ and $2B_2$.

One in the bottom glue line of panel $2B_2$.

In section 3:

One in the air space between panels $3B_1$ and $3B_2$.

In section 4:

One in the air space between panels $4B_1$ and $4B_2$.

In section 5:

One in the upper glue line of panel $5B_1$.

One in the air space between panels $5B_1$ and $5B_2$.

One in the bottom glue line of panel $5B_2$.

Two more thermocouples were installed after the dummy wing was assembled; one (dipped in camouflage paint) was taped to the top surface of panel $3B_1$ and the other was suspended by string about 6 inches below panel $3B_2$, in the shade. The thermocouples installed in the air spaces within the wing were placed about 1/2 inch from the top (B_1) panels. Their positions are more clearly shown in the end view of the diagram given in figure 2.

A central constantan lead was strung from section 5 to the outside opening in section 1 and constantan leads were extended from it to the thermocouples. Individual copper wires were led from each thermocouple to the opening in section 1. At this point, 20-foot extensions of copper and constantan wires were soldered to the respective leads and all of the wires were taped into a cable leading to the potentiometer.

Finishes Applied to the Dummy Wing

After the wiring was completed, the interior of the dummy wing was finished. The Tuf-On finishing system designed by the Wipe-On Corporation was used in finishing the interior and exterior of the dummy wing. Among the interior surfaces, only those of sections 2B, 3B, 4B, and 5B were finished. All finishes were applied by brush because the Laboratory is not equipped to spray an object of this size. Sections 2B and 3B were given a coat of clear sealer (Tuf-On No. 74 clear sealer), which was followed 1 hour later by a coat of aluminized sealer (1-1/2 pounds aluminum paste to 1 gallon of No. 74 clear sealer). Sections 4B and 5B received 2 coats of the Tuf-On No. 74 clear sealer. Heavy cardboard separators were stapled to both sides of the center rib (fig. 1) for the purpose of dividing the interior of the test structure into two separate compartments. The bottom test panels were then nailed into place on the frame with 1/2-inch wire brads.

The exterior finishing systems were next applied, as follows:

For yellowpoplar and birch, 1 coat Tuf-On No. 74 clear sealer, 1 coat Tuf-On No. P-40 primer surfacer, and 2 coats Tuf-On No. 261 dark olive drab camouflage enamel.

For mahogany, 1 coat Tuf-On No. 74 filler, 1 coat Tuf-On No. P-40 primer surfacer, and 2 coats Tuf-On No. 261 dark olive drab camouflage.

Most of these were fast-drying finishes designed for rapid production work; it was hence necessary to reduce them with kerosene in order to apply them with a brush.

Exposure of the Dummy Wing

The dummy wing was then ready for exposure. Accordingly, on July 1, 1942, it was mounted on a hinged supporting rack on the south promenade outside the main Forest Products Laboratory building, with the north end about 2 feet from the building. The dummy wing was mounted so that the spars were in a north-south line and the section sloped to the south at an angle of about 7° from the horizontal. This angle was selected because it was thought to be representative of the maximum dihedral for a modern plane wing. Naturally, since this angle was constant, the maximum angle of elevation of the sun decreased from day to day. Starting July 10, temperature readings were taken at intervals varying between one-half and 1 hour from 8 or 8:30 a.m. to 4:30 or 5 p.m., except on rainy days, when fewer readings were taken. Attention was also given to the recording of the weather, relative humidity, and wind velocity. Daily readings were taken until August 24.

The readings for several of the more representative days are recorded in table 2.

In this location, the maximum angle of elevation of the sun was about 76°, at 1 p.m., C.W.T., on July 10. The glass architectural panels of the Laboratory building directly above the dummy wing reflected some light on it between 11 a.m. and 3 p.m. This condition undoubtedly added somewhat to the total radiation. The temperature readings recorded on July 10 in this location are given in table 2. It should be added that the reflections from the aforementioned glass panels were somewhat spotty and the inconsistent temperature readings for this day are attributed to this circumstance.

From table 2 it is seen that the maximum temperature of 184° F. was recorded for thermocouple No. 1, which is located in the top glue line of panel $5B_1$. This reading was taken at 2 p.m., at which time there was no appreciable wind, and the sky was clear.

It was felt that more accurate and consistent readings could be obtained if the dummy wing were erected further away from the side of the building at a point where reflection from the glass panels could not fall on it. Accordingly, the test structure was moved 15 feet farther from the building to its present location. (Fig. 3).

A comparison of the temperatures recorded on July 11 and July 17 is very enlightening. Both of these days were very clear; however, the 11th was extremely quiet, whereas the 17th was definitely windy. The maximum glue-line temperature recorded on July 11 was 175° F. at 12:45 p.m. on thermocouple 8, which is in the top glue line of section 2B. At this time the sun was very nearly at its highest elevation, and the air temperature in the shade was 86° F. The maximum glue-line temperature on July 17 was only 155° F. (at 12 noon on the same thermocouple) although the air temperature in the shade at this time was 94° F. This would seem to indicate that the surface temperature is affected greatly by the velocity of air movement over the surface.

A study of the readings taken on July 11 results in the further conclusion that the interior finish has an effect on both the top and bottom skin temperatures, as well as a slight effect on the air temperature within the enclosed space. The temperatures for the top glue line in the section painted on the inside with aluminum were slightly, but consistently, higher than the corresponding temperatures over the clear finish. As would be expected, since aluminum is a good reflector, the bottom skin temperatures were consistently lower in the aluminized sections than they were in the clear sections. The air temperatures in the aluminized sections varied from 0 to 3° F. lower than those in the clear sections.

The above observations are supported by the data recorded for other days. Included in table 2 are the temperature readings recorded on August 11, 13, and 17. A comparison of these shows the effect of wind and cloudiness on the relative temperatures.

The test shows that, under the weather conditions prevailing at Madison, Wis., for those days, other than July 10, designated in table 2, it was possible to attain a temperature of 175° F. in the top glue line of a dummy wing finished with the conventional dark olive drab camouflage paint with a maximum sun angle to the wing surface of only 75° and an outside air temperature of 86° F.

Cracking and Delamination

On July 11, the second day of exposure, a crack in both the finish and the face ply of veneer between sections $6B_1$ and 6C was observed. These two sections were of birch plywood, glued with Butacite 4644, the thermoplastic glue (table 1). Apparently, exposure to a temperature above 150° F. for several hours softened the glue and allowed the top ply of veneer to shrink slightly. The crack is shown in figure 4.

Although cracks developed in the plywood skin glued with both Tego thermosetting glue and Butacite 4644, they were far more general and more severe where Butacite was used.

Far better results were obtained with nail-strip gluing than with plain nail gluing. In the case of the latter, the nails soon worked out sufficiently to crack the paint coating and permit the ingress of moisture, which ultimately led to cracking around the nails. On the other hand, the slight depressions left by the withdrawal of the nails on the nail-strip glued panels did not prove a source of cracking. Figures 4, 5, and 6 show different types of breakdown of the skin and finish.

Moisture Content of Wood Within the Dummy Wing

The variations in temperature in the air space within the dummy wing caused corresponding changes in the relative humidity within the enclosed space which tended to set up fluctuations in the moisture content of the wood. Protective finish on the wood surfaces should reduce the extent of variations in moisture content taking place within short intervals of time; but no finish would be expected to prevent changes in moisture content under successive widely differing conditions which persist for a considerable length of time.

To obtain preliminary data on the subject, arrangements were made to insert two small pieces of spruce, one finished and one unfinished, in the air space of section 6 of the dummy wing in such a way that they could be removed, weighed, and reinserted periodically. The specimens were taken from braces in a rib from a Fairchild trainer plane. They bore a generous coating of clear sealer which is understood to consist of two applications of Tuf-On No. 74 sealer. The coated surfaces exhibited a full, uniform varnish gloss with numerous "runs" and "beads" where the coating was exceedingly thick. From one specimen the finish was completely removed by planing off approximately 1/64 inch from each face. The specimens were then cut to such length that each contained 0.38 cubic inch of wood. The dimensions then were, for the specimen protected with finish, 1/4 by 5/16 by 4-7/8 inches and, for the unfinished specimen, 7/32 by 9/32 by 6-1/8 inches. The cut ends of the finished specimen were given three coats of Tuf-On No. 74 sealer so that all surfaces would be protected.

The specimens were dried to constant weight at 105° C. and weighed. One end-grain end of each specimen was then fastened by means of a small nail, the weight of which was recorded, to the center of a rubber stopper, which in turn was inserted in a hole drilled in the end of section 6 of the dummy wing. (Fig. 3). The specimens therefore hung freely in the air space of section 6B.

The oven-dry weight of the unfinished specimen was 2.701 grams, that of the finished specimen 3.047 grams. After the portion of the work described in this report had been completed, the specimens were brought to constant weight in a room at 65 percent relative humidity and 80° F. The unfinished specimen then weighed 3.064 grams, representing a moisture content of 9.8 percent. The finished specimen weighed 3.305 grams from which, assuming that it likewise contained 9.8 percent moisture, the weight of dry wood was computed to be 2.635 grams and the weight of the finish 0.412 grams. In view of the obviously thick coating applied and the many thick runs and beads of finish left on the surfaces of the specimen, this weight of coating seems quite reasonable. For purposes of calculating moisture content from the changes in weight observed during these experiments, it was therefore assumed that the dry wood in the finished specimen weighed 2.635 grams and that the coating of finish remained constant in weight under all conditions.

Starting at the oven-dry condition when placed in the dummy wing at 11:30 a.m. on July 18, both the finished and unfinished specimens promptly began to absorb moisture. By 8 a.m. on July 20, the unfinished specimen reached a moisture content of 5.5 percent and the finished specimen one of 2.4 percent. The air temperature outside was then 68° F. and the temperature within the dummy wing 88° F. During the day the outside temperature reached a maximum of 87° F. and the enclosed air space 140° F. As a result, the moisture content of the unfinished specimen fell to 5.1 percent but that of the finished specimen continued to rise throughout the day, reaching 2.9 percent by 5 p.m.

During the next 7 days of much the same weather conditions (warm days with clear sky), the moisture content of the unfinished specimen alternately increased during the night and dropped to a minimum during the day as the temperature within the air space soared. The maximum moisture content observed during this period was 6.3 percent and the minimum 4.6 percent. The unfinished specimen was clearly in fairly close moisture equilibrium with its environment, and fluctuated as much as 1.1 percent in moisture content between morning and evening conditions. Apparently the unfinished specimen came to rough equilibrium within 2 days after it was placed in the dummy wing. The finished specimen, however, required 6 days to approach closely enough to rough equilibrium with the environment to exhibit a slight drop in moisture content between morning and afternoon. Up to that time the moisture content continued to increase during the daylight hours when that of the unfinished specimen fell off. On July 22, for example, when the moisture content of the unfinished specimen at 8 a.m., 4 p.m., and 6:30 p.m. was 6.3, 5.2, and 5.4 percent respectively, that of the finished specimen was 3.7, 4.0, and 4.1 percent, respectively. By July 25, however, the finished specimen reached 4.55[2] percent moisture content at 8 a.m. and dropped slightly to 4.51[2] percent by 12 m. The moisture content of the unfinished specimen at this time was about 5.1 percent. By 4 p.m. on July 27, the moisture contents of finished and unfinished specimens approached within 0.3 percent of each other, namely 4.6 percent for the unfinished and 4.3 percent for the finished specimen. If the weather had remained unchanged for another day, they probably would have come to the same moisture content.

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[2]Moisture content was not determined accurately enough to justify expressing it to the second decimal place but the actual weighings of the specimens were reliable enough to show that on July 25 there was a slight loss of moisture between 8 a.m. and 12 m. The second decimal place in moisture contents is reported here only to show the direction in which such slight changes took place.

The next 3 days, July 28 to July 30, marked a change in the weather from clear to overcast skies, with much lower maximum temperatures within the dummy wing in the middle of the day and less change in relative humidity during the day. Both specimens responded to the change in weather by gaining in moisture content, but the unfinished specimen reacted sooner and more markedly. By 8 a.m. on July 31, the unfinished specimen reached 6.5 percent and the finished specimen 5.42 percent moisture content. July 31 was a clear day with a maximum temperature within the dummy wing of 146° F. at 3 p.m. and a sharp drop in relative humidity during the day. As a result, by 4 p.m. the moisture content of the unfinished specimen fell off sharply to 5.7 percent and that of the finished specimen to only 5.39 percent.

August 1 and 2 were again overcast with the unfinished specimen gaining moisture more rapidly than the finished specimen, but August 3 to August 5 marked a resumption of clear days with soaring temperatures within the dummy wing and low minimum relative humidities. At 8 a.m. on August 3 the unfinished specimen contained 7.5 percent and the finished specimen 6.75 percent moisture, but both specimens lost moisture during the day, the unfinished one more rapidly, until at 5 p.m. they both reached 6.56 percent, agreeing in moisture content for the first time since their insertion in the dummy wing. In 9 hours the unfinished specimen lost 1.0 percent while the finished specimen lost only 0.2 percent of moisture. On August 4, a still warmer day with relative humidity between 32 and 42 percent, the unfinished specimen dropped 1.3 percent and the finished specimen 0.6 percent in moisture content in a space of 6 hours. From 11 a.m. on August 4 to the early morning of August 6, the finished specimen contained more moisture than the unfinished one. August 6 was cool and overcast and the finished specimen contained less moisture than the unfinished specimen throughout the day; but on August 7, a bright, warm day, the two specimens again agreed in moisture content at 11 a.m., containing 6.3 percent. This is a trifle below the moisture content of 6.56 percent at which they agreed the first time. For the rest of August, overcast days brought the moisture content of the finished specimen below that of the unfinished specimen, whereas sunny days caused the finished specimen to retain more moisture than did the unfinished specimen.

During August the unfinished specimen fluctuated between 7.6 and 5.4 percent moisture content, a variation of 2.2 percent, whereas the finished specimen fluctuated between 6.8 and 5.7 percent, a variation of 1.1 percent. In both cases, the fluctuations for the period centered close to an over-all average of approximately 6.5 percent moisture content, that is, the finish failed to alter significantly the average moisture content of the wood but it cut the extent of fluctuation above and below the average about in half and greatly slowed the rate of change from one level to another.[3] The observations in the dummy wing were continued through the fall and early winter. As the intensity of sunlight and the length of day decreased, the specimens steadily gained in moisture content until by the middle of December they reached moisture contents of approximately 15 percent.

[3] The 6.5 percent average moisture content about which the specimens fluctuated is much below the moisture contents reported for airplane woodwork in table 2-4 on page 22 of the "Wood Aircraft Fabrication Manual." The data in the Manual, however, are for woodwork in equilibrium with outdoor conditions uncomplicated by enclosure in spaces raised to the high temperatures that prevailed within the dummy wing during the midday hours of clear days.

It is further true that the drying of the specimens at 105° C. before inserting them in the dummy wing reduced somewhat the moisture content at which they would subsequently come to equilibrium in an atmosphere of given relative humidity and temperature. When equilibrated at 65 percent humidity and 80° F. at the end of December, they attained only 9.8 percent moisture content, whereas the equilibrium moisture content for normal wood under this condition is considered to be approximately 11.5 percent. Other studies have been started in which the specimens were not reduced to the oven-dry condition before being inserted in a dummy wing.

Effect of Reflective Power of the Finish on Temperatures Attained in the Dummy Wing

Another objective of this study involves a determination of the relation between the temperatures attained within the dummy wing and the color and infrared reflective power of the exterior finish. A second dummy wing was designed for use as a test frame in which the center panels could be replaced at will. This arrangement was designed to permit the testing of several finishing systems simultaneously.

The construction is very similar to that of the first dummy wing; they differ only in length. Its over-all size is 4 by 28 by 108 inches. Details of the framework are shown in figure 7. The ribs and spars were again made of 3/4- by 4-inch solid spruce. The "skin" (except on the center panels) is 3/32-inch mahogany plywood of aircraft grade, made with hot-pressed phenolic-resin glue. Mahogany plywood was used to cover the entire frame except the center panels, which are replaceable and are made of 3/32-inch birch plywood bonded with Tego glue. The leading edges were made by soaking the mahogany plywood in hot water for one hour and permitting it to cool in the water overnight; the pieces were nail-glued in place next morning.

Thermocouples were placed in the center of the inside surface of each birch test panel, under a spruce rib-cap 1/2 by 3/8 by 15 inches in dimension, which was glued perpendicular to the face grain of the test panel. In addition, thermocouples were suspended on string in the center of each space between the top and bottom test panels. Two thermocouples were also placed between the upper and lower glue lines of the top panel in test section 1. The locations of the thermocouples, and their post numbers, are given in table 3. The relative position of each thermocouple is illustrated in figure 7.

The interiors of the test sections and the inside surfaces of the test panels were given 2 brush coats of Tuf-On No. 74 clear sealer. Heavy cardboard separators, which also received 2 coats of the clear sealer, were stapled to both sides of the ribs.

The 12 test panels (6 top and 6 bottom) were then finished before being attached to the test frame. Thus 6 different finishing systems were used, since the top and bottom panels of each section received the same finish. The finishing systems for the respective test sections are as follows:

Section 1, 1 coat Tuf-On No. 74 clear sealer and 2 coats Pyroxcote #14-109 camouflage olive drab (10 percent infrared reflectance).

Section 2, 1 coat Tuf-On No. 74 clear sealer and 2 coats Pyroxcote #14-109 camouflage olive drab (50 percent infrared reflectance).

Section 3, 1 coat aluminized Tuf-On No. 74 sealer and 2 coats Pyroxcote #14-109 camouflage olive drab (50 percent infrared reflectance).

Section 4, 1 coat aluminized Tuf-On No. 74 sealer and 2 coats Pyroxcote #14-109 camouflage olive drab (10 percent infrared reflectance).

Section 5, 1 coat Tuf-On No. 74 clear sealer and 2 coats Pyroxcote M-485 blue-gray lacquer (5 percent infrared reflectance).

Section 6, 1 coat Tuf-On No. 74 clear sealer and 2 coats Tuf-On orange-yellow enamel No. 173 (said to have about 80 percent infrared reflectance).

With the exception of the finish coats, which were sprayed, the finishes were applied by brush.

Copper wire (24 gage) and constantan wire (30 gage) extensions were soldered to the thermocouple wires and strung from test section 6 through small holes in the cardboard separators to an outlet in the opposite end of the test structure. The edges of the ribs and spars were then coated with a commercial latex manufactured by the General Latex and Chemical Corporation for the purpose of making water-tight joints without using glue. The test panels were laid in their respective positions and nailed in place with 1/2-inch, cement-coated nails.

This second dummy wing was set up August 24 on the south promenade of the Laboratory on a hinged supporting rack in such a manner that the spars were in an east-west line and the surface sloped to the south at an angle of about 15°. (Fig. 8). From August 25 until September 5, temperature readings were taken at approximately 1 hour intervals (on some days readings were taken every half-hour). The temperature readings are not so consistent as might be desired; they were found to be very sensitive to changes in the weather. It took some time to determine and record all of the temperatures, and the mere passage of a cloud before the sun had a pronounced effect on the temperature in the test panel.

Typical temperatures for two different days are recorded in table 3. The thermocouple numbers 1 to 6 give the temperatures at the center of the interior surface of each top panel; numbers 7 to 12 give the air space temperatures, and numbers 13 to 18 represent the temperatures at the interior surface of each bottom panel. Numbers 19 and 20 represent the temperatures in the glue lines of the top panel on section 1; through an error, however, it is not known which glue line is represented by 19 and which by 20. This can be determined when the panels are removed from the test frame, but it is of no consequence because the same temperatures, within the limit of error of the measurements, were observed in both glue lines. Moreover the close agreement of thermocouples 1, 19, and 20 indicates that essentially the same temperature was attained in the secondary glue line between plywood and rib cap and in the primary glue lines of the plywood covering.

Several interesting observations can be made from table 3: Considering first the readings for August 26, it is apparent that at 8 a.m. and 5 p.m., times at which the angle of the sun was so low that it was not an important factor, the temperatures throughout the dummy wing structure were very nearly the same. This was especially true when the outside temperature was low (about 70° F.).

By comparing the temperature readings of thermocouples 1, 7, and 13, of 2, 8, and 14, or of any similar series, the relation between the temperatures at the top, in the air space, and at the bottom, respectively, (all interior surfaces) of a panel is obtained. Comparison of the temperature readings of thermocouples 1, 7, and 13 at 1 p.m. on August 26 shows that the temperature at the bottom panel was 12° F. lower than that at the top panel, and the temperature in the air space was 5° lower than that at the top panel. Readings of the same thermocouples at 1 p.m. on August 28 show a difference of 35° F. between the top and bottom panels. As the dummy wing cooled off, this difference gradually decreased until the temperatures were practically the same throughout the structure.

A comparison of the values in table 3 for August 26 and 28 shows definitely that the olive drab finish having 50 percent infrared reflectance produced lower temperatures than the finish having only 10 percent infrared reflectance. Again, this difference was most marked when the sun was at its highest elevation.

No great difference in temperature resulted from the use of the aluminized sealer under the conditions encountered in this study. Closely agreeing temperatures were recorded by thermocouples 1 and 4 for the 10-percent reflective paint over clear sealer and aluminized sealer respectively. Similarly, closely agreeing temperatures were recorded by thermocouples 2 and 3 for the 50-percent reflective paint over clear sealer and aluminized sealer respectively.

Thermocouple 5 recorded the temperature at the inside surface of the top panel finished with the 5-percent reflective blue-gray lacquer. When these temperatures were compared with the readings of thermocouple 1, it was found that the blue-gray lacquer produced slightly higher temperatures than were obtained with the 10 percent infrared reflectant olive drab paint. The same relation existed between the air space temperatures (compare thermocouples 11 and 7) and between the temperatures at the surface of the bottom panel (compare thermocouples 17 and 13).

As would be expected, the orange-yellow enamel produced the lowest temperatures at the top and bottom panels, as well as in the air space. This can be attributed to its high (80 percent) infrared reflectance value.

Table 1.--Details of plywood gluing, forming, attachment, and interior finish for various wing sections

Section number	Plywood construction and species	Glue	Method of gluing and forming	Method of attaching	Interior finish
1A	3-ply yellowpoplar 1/40-inch face and back 1/20-inch core	Tego	Press, bent dry (20 percent moisture content)	Nail glued	None
1B	(Forest Products Laboratory manufacture)	Tego	Press	Nail glued	None
1C		Tego	Press, hot water bent	Nail glued	None
2A		Tego	Press, cold water bent	Nail-strip glued	None
2B		Butacite 4644	Press	Nail-strip glued	Aluminum
2C		Butacite 4644	Bag molded	Nail-strip glued	None
3A	3-ply mahogany 1/40-inch face and back 1/20-inch poplar core	Tego	Press, cold water bent	Nail glued	None
3B		Tego	Press	Nail glued	Aluminum
3C		Tego	Press, hot water bent	Nail glued	None
4A	(Commercial manufacture)	Tego	Press, cold water bent	Nail glued	None
4B		Tego	Press	Nail-strip glued	Clear
4C		Tego	Press, bent dry (20 percent moisture content)	Nail glued	None
5A	3-ply birch 1/50-inch face and back 1/20-inch core	Tego	Press, bent dry (20 percent moisture content)	Nail glued	None
5B	(Forest Products Laboratory manufacture)	Tego	Press	Nail glued	Clear
5C		Tego	Press, hot water bent	Nail glued	None
6A		Tego	Press, cold water bent	Nail glued	None
6B		Butacite 4644	Press	Nail-strip glued	None
6C		Butacite 4644	Bag molded	Nail glued	None

Table 2. Temperature readings in dummy wing on days selected to represent different typical weather condition.

Hour	Weather	$5B_1$ top glue line	$5B_2$ bottom glue line	$5B_3$ air space	$4B_3$ air space	$3B_3$ air space	$2B_3$ air space	$2B_2$ bottom glue line	$2B_1$ top glue line	Air temp. shade	Paint surface temp.	Relative humidity
		Temperature (Fahrenheit)										Percent
July 10, 1942												
8:00	Cloudy	75	72	74	74	74	74	71	76	67	77	
10:00	Clear-no wind	141	112	132	131	129	129	103	144	73	141	
10:30	" " "	149	113	140	139	138	138	106	155	74	150	
11:00	" " "	157	121	148	146	145	148	115	167	80	161	
11:30	" " "	175	125	160	155	152	157	119	182	85	170	
12:00	" " "	165	124	157	155	158	158	118	177	85	182	
12:30	" " "	172	130	165	160	160	165	121	180	86	174	51
1:00	" " "	182	131	167	162	162	166	121	180	89	182	
1:30	" " "	170	127	161	160	160	167	122	179	87	179	
2:00	" " "	184	135	171	161	160	164	125	181	91	178	
2:30	" " "	173	136	162	161	161	165	128	180	96	174	
3:00	Partly cloudy	158	123	147	147	143	145	120	170	92	166	
3:30	" "	156	123	143	142	142	143	121	166	94	164	
4:00	Clear	150	120	142	142	142	144	118	155	92	154	
July 11, 1942												
8:30	Clear & still	108	75	103	103	101	100	92	108	72	108	
9:30	" "	127	107	122	120	120	122	105	132	79	129	
10:00	" "	142	120	136	139	134	134	115	149	84	144	
10:30	" "	146	121	140	138	138	140	117	155	88	152	
11:00	" "	155	126	148	145	145	145	119	158	84	155	
11:30	" "	160	127	152	148	148	150	121	169	85	165	
12:00	Slight haze	158	123	149	147	147	148	118	166	86	163	
12:45	" "	172	133	156	153	153	153	120	175	86	171	36
2:00	" "	165	128	156	155	155	155	122	167	87	165	
2:30	" "	162	131	154	152	152	153	125	166	89	165	
3:00	" "	160	131	152	151	151	152	126	165	90	161	
4:00	" "	149	129	146	146	146	146	124	153	92	151	
5:00	" "	129	115	129	129	130	130	115	135	94	137	
7:15	" "	93	95	95	95	95	95	93	90	88	90	
July 17, 1942												
8:00	Clear - wind	102	94	98	96	96	95	90	102	82	98	76
8:30	" "	109	99	107	105	105	104	93	111	82	101	
9:05	" "	117	104	116	112	112	111	98	118	86	107	
9:35	" "	132	112	124	121	123	123	101	131	90	123	
10:00	" "	133	112	127	125	123	123	104	135	88	118	
10:30	" "	144	116	137	133	132	131	111	142	96	122	
11:00	" "	147	118	138	138	134	134	110	146	88	135	49
11:30	" "	147	109	138	138	138	140	112	150	93	140	
12:00	" "	155	118	145	140	138	138	118	155	94	150	
12:40	" "	153	118	143	140	136	136	109	152	93	148	
1:00	" "	147	114	141	137	130	134	105	147	91	139	
1:30	" "	150	119	142	142	137	137	111	151	92	142	
2:00	" "	149	116	141	140	133	135	118	150	92	139	52
2:30	" "	155	124	148	145	141	139	117	152	98	145	
3:00	" "	151	123	144	142	139	139	114	153	99	140	
3:30	" "	143	121	138	138	132	136	113	142	100	140	
4:00	" "	145	125	140	137	135	135	117	146	99	136	
4:30	" "	141	121	137	134	133	133	116	140	96	135	49
August 11, 1942												
8:00	Clear-no wind	87	81	81	81	81	79	79	78	66	80	51
9:00	" " "	106	90	102	101	99	99	85	111	64	89	
10:00	" " "	125	97	116	114	110	114	93	127	66	97	
11:00	" " "	143	110	140	132	131	131	103	148	71	102	47
12:00	" " "	148	114	138	138	138	138	101	154	68	113	
1:00	" " "	157	114	143	140	135	141	102	161	77	112	41
2:45	" " "	148	118	141	140	137	140	113	156	78	120	
4:00	" " "	123	113	122	120	121	122	103	127	81	100	
5:00	" " "	102	88	96	96	96	96	91	104	74	87	38
August 13, 1942												
8:30	Clear & windy	86	77	83	82	83	83	77	85	67	67	
10:00	" "	118	100	108	110	110	110	93	125	74	72	
11:00	" "	125	102	116	113	113	113	88	121	71	78	52
12:00	" "	129	103	123	119	119	119	93	130	72	78	
1:00	" "	135	104	125	124	121	121	94	141	76	76	44
2:00	" "	130	109	125	121	122	118	93	130	74	81	
5:00	" "	95	95	97	100	102	99	90	93	81		46
August 17, 1942												
8:00	Cloudy, slight wind	67	67	67	67	67	68	67	72	64		67
9:30		96	82	95	95	95	94	83	97	72		59
10:40	" " "	112	90	105	104	105	106	87	115	77		
11:45	" " "	129	98	124	122	118	118	97	129	79		54
12:50	" " "	125	101	115	117	115	117	94	126	78		
2:00	" " "	129	108	124	124	121	121	97	128	79		
4:50	" " "	102	95	97	98	100	100	91	102	80		55

Z M 45176 F

Table 3.--Temperatures in dummy wing under exterior paints of different colors and infra-red reflection

Weather data			Olive drab 10 percent infra-red reflectance over clear sealer	Olive drab 50 percent infra-red reflectance over clear sealer	Olive drab 50 percent infra-red reflectance over aluminized sealer	Olive drab 10 percent infra-red reflectance over aluminized sealer	Blue-gray lacquer 5 percent infra-red reflectance over clear sealer	Orange-yellow enamel 80 per cent infra-red reflectance over clear sealer	Olive drab 10 percent infra-red reflectance over clear sealer	Olive drab 50 percent infra-red reflectance over clear sealer	Olive drab 50 percent infra-red reflectance over aluminized sealer	Olive drab 10 percent infra-red reflectance over aluminized sealer	Blue-gray lacquer 5 percent infra-red reflectance over clear sealer	Orange-yellow enamel 80 per cent infra-red reflectance over clear sealer	Olive drab 10 percent infra-red reflectance over clear sealer	Olive drab 50 percent infra-red reflectance over clear sealer	Olive drab 50 percent infra-red reflectance over aluminized sealer	Olive drab 10 percent infra-red reflectance over aluminized sealer	Blue-gray lacquer 5 percent infra-red reflectance over clear sealer	Orange-yellow enamel 80 per cent infra-red reflectance over clear sealer		
			Thermocouple inside surface of top panel[1]						Thermocouple suspended in the air space						Thermocouple inside surface of bottom panel[1]						Thermocouple at glue lines[2]	
			Sec. No. 1	Sec. No. 2	Sec. No. 3	Sec. No. 4	Sec. No. 5	Sec. No. 6	Sec. No. 1	Sec. No. 2	Sec. No. 3	Sec. No. 4	Sec. No. 5	Sec. No. 6	Sec. No. 1	Sec. No. 2	Sec. No. 3	Sec. No. 4	Sec. No. 5	Sec. No. 6	Sec. No. 1	Sec. No. 1
Hour	Weather	Air temp.	Thermo. No. 1	Thermo. No. 2	Thermo. No. 3	Thermo. No. 4	Thermo. No. 5	Thermo No. 6	Thermo. No. 7	Thermo. No. 8	Thermo. No. 9	Thermo. No. 10	Thermo No. 11	Thermo No. 12	Thermo. No. 13	Thermo. No. 14	Thermo. No. 15	Thermo. No. 16	Thermo. No. 17	Thermo. No. 18	Thermo. No. 19	Thermo. No. 20
August 26, 1942																						
8:00	Clear - wind	61	67	65	66	66	66	64	65	64	64	64	64	62	63	63	63	63	63	63	69	69
10:00	Clear - wind	72	122	110	111	120	120	100	104	97	97	103	106	93	95	90	89	93	95	86	120	122
11:00	Hazy - wind	74	100	100	103	110	110	95	99	95	96	101	102	93	89	87	87	90	91	85	110	110
12:00	Hazy - wind	76	115	107	108	117	116	101	99	95	97	101	104	93	91	88	87	91	91	85	119	120
1:00	Cloudy - wind	75	95	91	91	95	96	88	90	87	88	90	91	86	83	83	82	83	84	85	94	93
2:00	Cloudy	75	92	88	90	92	93	86	87	86	86	89	89	85	83	82	82	83	84	81	91	90
3:00	Few drops of rain	73	82	80	81	81	81	80	82	82	82	82	82	80	78	78	78	78	78	78	80	80
4:00	Cloudy - wind	72	76	76	76	76	76	76	76	76	76	76	76	76	73	73	73	73	73	73	76	76
5:00	Cloudy - wind	70	72	72	72	72	72	72	72	72	72	72	72	72	71	71	71	71	71	71	72	72
August 28, 1942																						
8:00	Clear-breezy	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71	71
11:00	Clear-breezy	--	99	94	94	100	100	88	90	88	88	89	91	84	84	84	83	85	85	80	99	100
1:00	Clear-breezy	85	155	143	144	158	158	135	135	129	131	139	142	126	120	118	118	126	127	114	154	154
1:30	Clear-breezy	90	156	145	145	157	159	136	138	133	133	141	146	129	123	120	121	127	128	116	156	157
2:00	Clear-breezy	92	155	144	143	157	157	135	139	131	132	140	143	127	124	120	122	127	128	116	154	154
2:30	Clear-breezy	93	154	142	141	154	155	133	135	130	131	139	140	126	124	119	121	125	125	115	155	156
3:00	Clear-breezy	91	139	132	132	141	143	127	131	127	126	133	136	123	121	117	118	123	123	114	130	130
4:00	Clear-breezy	86	113	108	108	112	114	105	110	107	106	111	111	102	103	100	100	101	102	97	111	110
5:00	Hot & humid	88	114	109	109	114	114	104	108	106	106	108	109	100	103	101	99	103	103	98	113	114

[1]Representative of a secondary glue line between plywood covering and a rib cap.

[2]Primary glue lines in the upper plywood covering of the section painted with 10 percent reflective olive drab paint.

Z M 45177 F

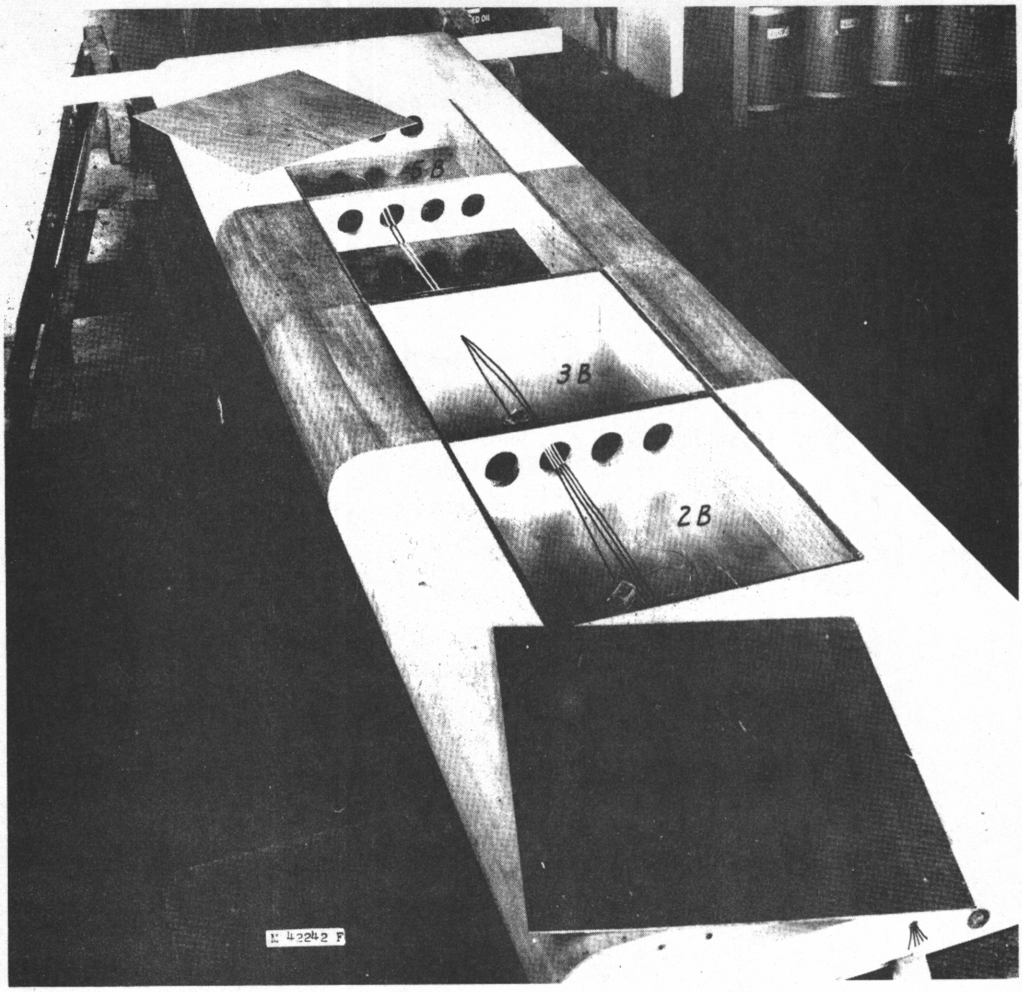

Figure 1.--The dummy wing partly assembled, showing some of the wiring for the thermocouples.

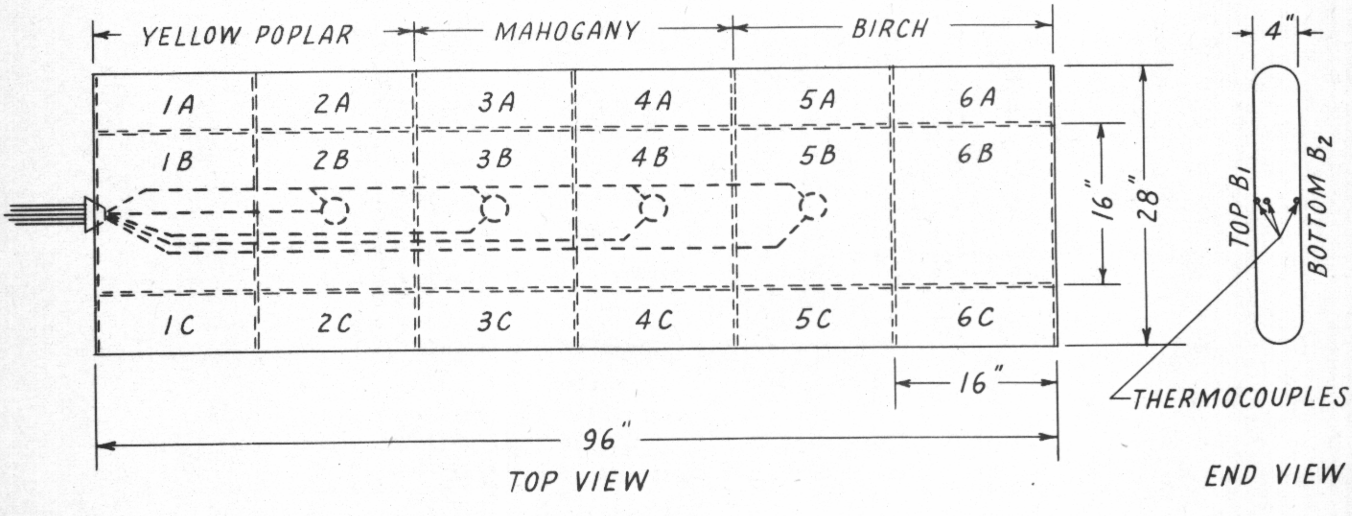

FIG. 2—FIRST DUMMY WING SHOWING DISTRIBUTION OF THE THERMOCOUPLES AND SYSTEM OF IDENTIFICATION NUMBERS

Z M 45172 F

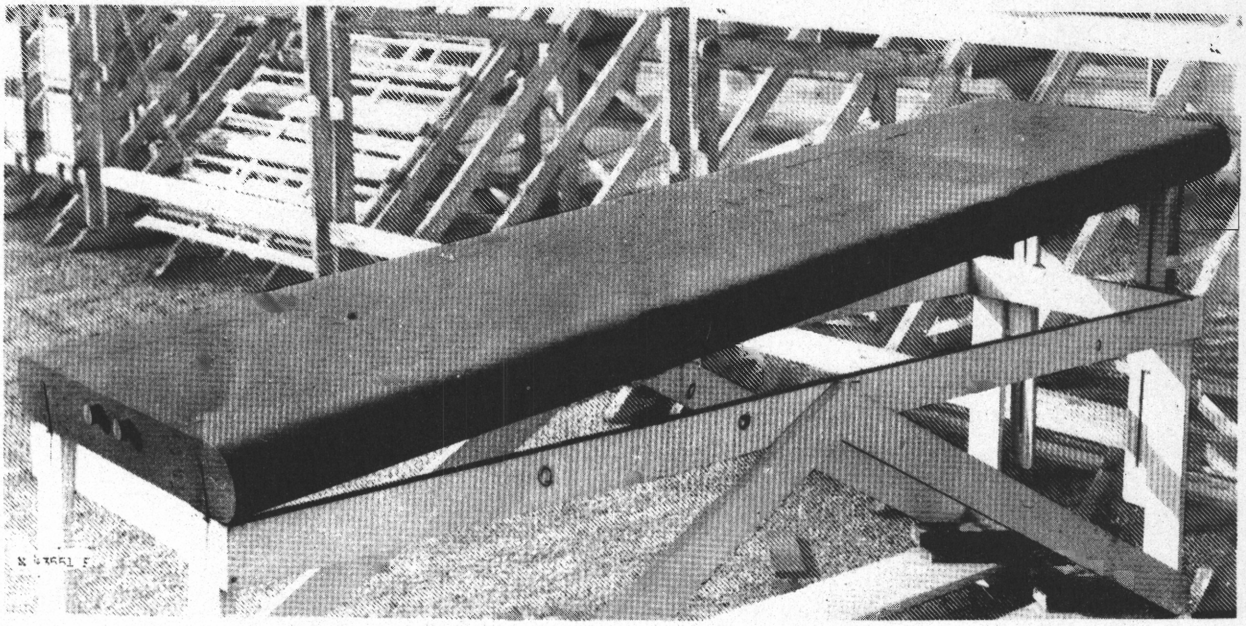

Figure 3.--The dummy wing in position on the Laboratory's south promenade.

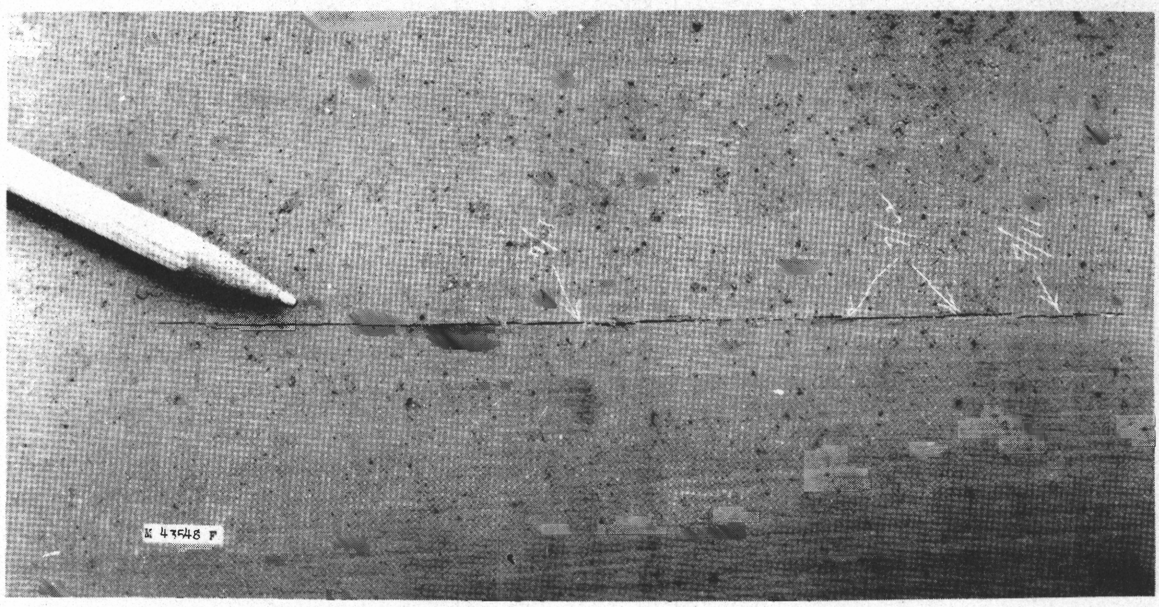

Figure 4.--Leading edge 6C, showing crack that opened after 2 days' exposure. This crack is at the beginning of the bend in the leading edge.

Z M 45173 F

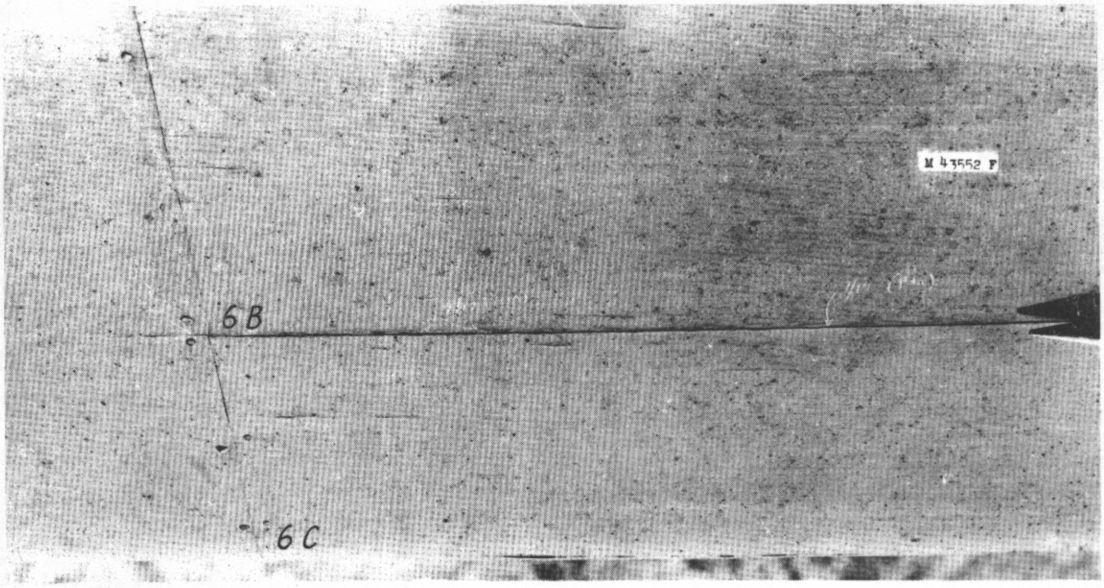

Figure 5.--Cracks that appeared after 8 days of exposure. Both section 6B and 6C were made with Butacite 4644; 6B was pressed, whereas 6C is a bag molded leading edge.

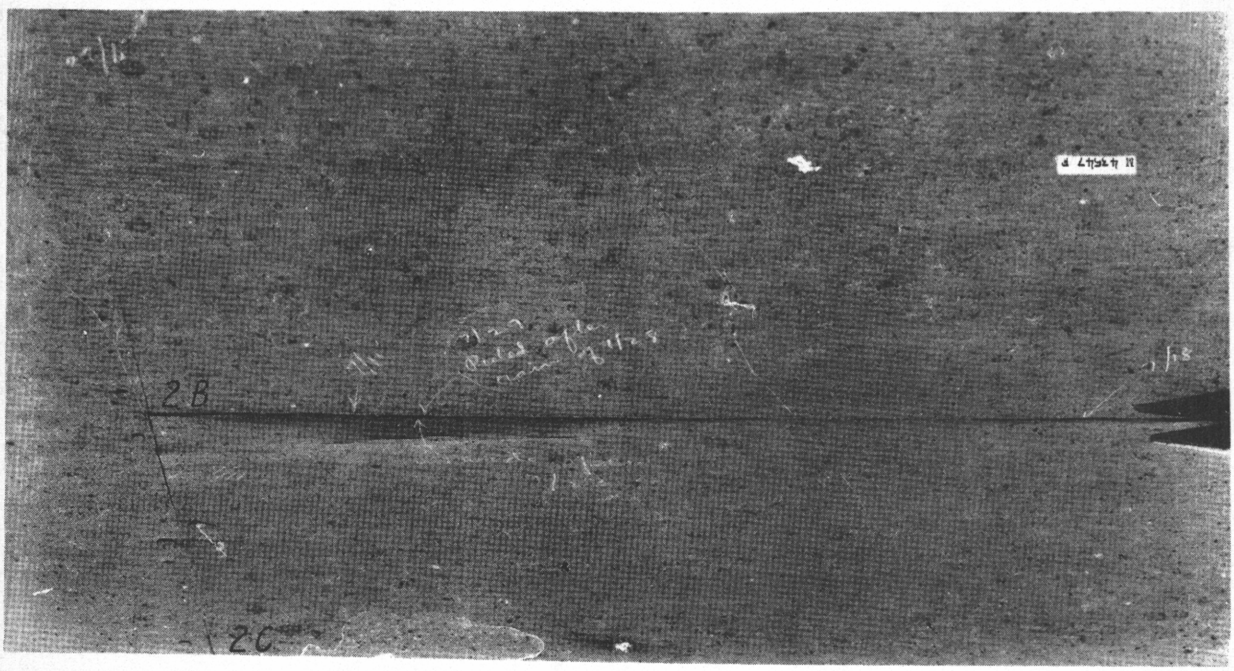

Figure 6.--Sections 2B and 2C after 3 months' exposure. Section 2C pulled away from 2B after 2 days' exposure. This section was bag molded, using Butacite 4644 thermoplastic glue.

Z M 45174 F

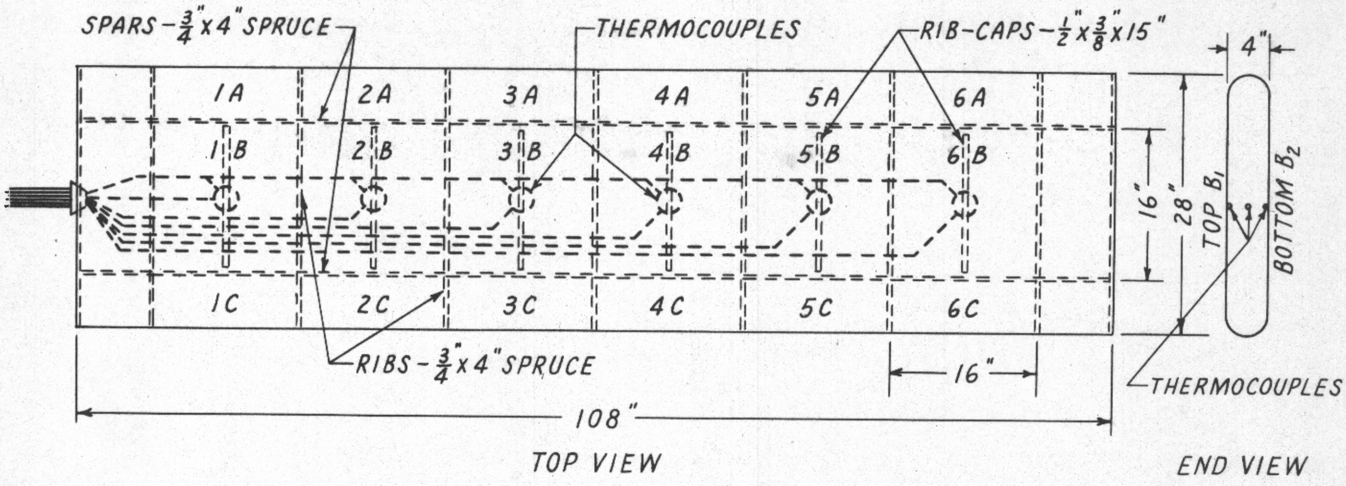

FIG. 7—SECOND DUMMY WING SHOWING DISTRIBUTION OF THERMOCOUPLES AND SYSTEM OF IDENTIFICATION NUMBERS

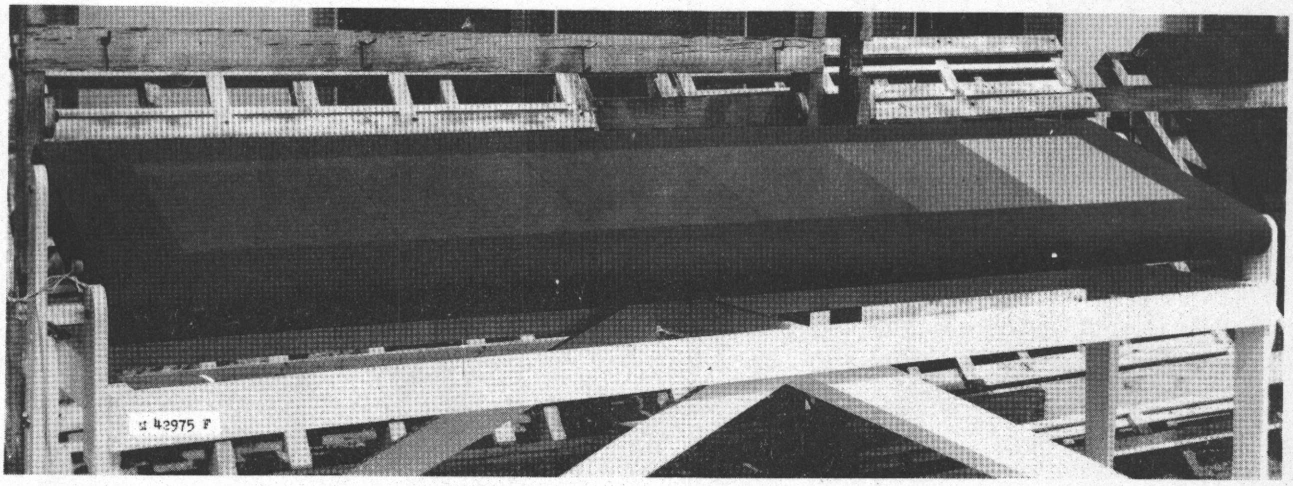

Figure 8.--Second dummy wing in position on the Laboratory south promenade.

Z M 45175 F