# DEVELOPMENT OF A COUNTERPART VERTICAL FIN OF PAPREG FOR THE AT-6 AIRPLANE

December 1945



This Report is One of a Series
Issued In Cooperation with the
ARMY-NAVY-CIVIL COMMITTEE
on
AIRCRAFT DESIGN CRITERIA
Under the Supervision of the
AERONAUTICAL BOARD

No. 1594

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison, Wisconsin
In Cooperation with the University of Wisconsin

# DEVELOPMENT OF A COUNTERPART VERTICAL FIN

# OF PAPREG FOR THE AT-6 AIRPLANE[1]

By E. C. JUNGMANN, Engineer

------

## Summary

To explore the possibilities of making primary aircraft structures of papreg, a vertical fin for the AT-6A airplane was designed and fabricated from papreg, and was tested under static loads representing gust and steady dive condition. The metal fin for the same airplane is of conventional two-spar construction with ribs. In the development of the papreg fin, trials of complete fins and of several rear spar designs led to the adoption of a semimonocoque design as most suitable because of the properties of the materials used. The papreg fin, equipped with an I-beam rear spar of papreg, supported 200 percent of the design load in static gust-load tests. Stress data obtained indicate that, while the papreg fin did not exceed the aluminum fin in weight, its weight can be reduced.

## Introduction

Development by the Forest Products Laboratory of papreg,[2] a laminated paper plastic of high tensile strength, during World War II led to the decision to investigate the utility of this material in a primary structural assembly in cooperation with the Army-Navy-Civil Committee on Aircraft Design Criteria. The vertical fin of the AT-6A basic training aircraft was selected as a suitable structure, as in it papreg could be employed for spars, stiffeners, and skin, both alone and in combination with veneer and plywood in sandwich-type materials. The metal AT-6A fin, which is of conventional two-spar construction with ribs, was duplicated in papreg, but exploratory tests (appendix) indicated that, for the papreg and sandwich materials to be used, a semimonocoque design would be most suitable.

---

[1]This report 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]"Strength and related properties of Forest Products Laboratory Laminated paper plastic (papreg) at normal temperature," FPL Rept.No.1319, rev. 1945.

In this report are presented the results obtained from tests of a fin with papreg-faced, sandwich-construction skin and solid papreg spars, stiffeners, and formers. The types of loading used, gust and steady dive-condition static loads, were believed to represent the most critical loads to which the structure would be subjected in service. The objective of the tests was twofold: (1) to determine the suitability for aircraft structures of the materials used, and (2) to ascertain the most suitable design for a spar and complete fin built of these materials.

## Method of Test

Gust-condition loads were applied to the fins so as to impose critical bending stresses. Steady dive-condition loads were applied so as to impose torque, which is primarily critical for the skin.

For steady dive-condition tests, the fin was mounted as for the gust-load tests (fig. 1). The simulated air load was applied to the fin surface in accordance with a specified pattern (table 1) and the rudder load was applied in the opposite direction, upward, through a pulley system which permitted use of the trays to carry the loads. During loading, jackscrews were used as in the gust-load tests.

In the gust-load tests, the fin was mounted horizontally on two wood stanchions (fig. 1). The rear spar root fitting was fastened to one stanchion and the front spar fitting to the other. Simulated air load was then applied by means of sand bags and other weights distributed on the surface of the fin in a specified pattern and hung by means of trays from the rudder-hinge fittings. The fin surfaces and rudder-hinge fittings were loaded simultaneously (table 2). Loads on fin surfaces and fittings were in the same direction. While the weights were put in place as shown in the diagram accompanying table 2, the fin was supported by jackscrews, which were removed to apply the load.

The preliminary tests of spars were made with the same apparatus as was used to test the fins. Each rear spar was fitted to a simulated internal structure of the fin consisting of a front spar and three internal ribs formed from 16-gage galvanized iron (fig. 2). The high rigidity of this frame permitted concentration of stress in the rear spar. A flat wood platform the shape of the fin in plan view was placed loosely on this metal frame to support the simulated air load. Jackscrews were used for support as in the fin tests. Four deflection readings were taken along the length of each spar tested as the load was applied.

Deflections produced in the fins and spars by application of the loads were read by means of a cathetometer (fig. 1,B) equipped with a vernier measuring device. Two deflection readings were taken along the spar and two on the leading edge of the fin. Strains produced by the stresses applied were read by means of type SR-4 electric strain gages. Where the direction of strain was known, simple gages were attached to the skin and spar; where the direction was not apparent, rosette-type gages were attached. The strains were read on an automatic strain recorder.

## Preliminary Investigation and Design

Preliminary experiments with a fin made by duplicating in papreg and papreg-plywood sandwich materials the various parts of an aluminum AT-6A fin showed that these materials were not adapted to the conventional design of the aluminum structure (appendix) because the stresses could not be properly distributed. These results led to the decision to adopt a semimonocoque construction, for which special attention was given to the design of a rear spar that would support the bending loads without assistance from the shell structure.

A series of spars was therefore investigated to determine the efficiency of various types of cross sections, including C-, I-, and box-sections. Materials from which these spars were made included papreg, staypak,[3] and such combinations as papreg and staypak, papreg and wood, and a papreg-basswood veneer sandwich (figs. 3-9). Results of steady dive-condition and gust-condition loading tests on these spars (appendix) indicated that a papreg rear spar of I-section (fig. 6) would be entirely satisfactory through 200 percent of the design ultimate load.

In the semimonocoque papreg design, much of the internal structure was eliminated. A front stub spar 10 inches long replaced the front spar to transfer the drag load to the fin. Angles and formers replaced the ribs and acted only as skin stiffeners. The formers and stiffeners thus acted as auxiliaries that enabled the skin to transfer air loads directly to the rear spar. Since stresses beyong the proportional limit are likely to cause creep in the plastic, the test fins were designed to stresses below the proportional limit. This design limitation also made it possible to ignore the amount of additional shear which could be taken by a buckled spar web or section of skin. By ignoring the shear loads taken by the diagonal tension field, a conservative structure was produced. The margin of safety calculated for the spar web at its buckling stress in shear was 7.18. Reduction of this extreme margin of safety was not attempted, because the primary goal was to design a plastic fin that would equal or exceed the aluminum fin in performance without exceeding it in weight. Consequently, the fin design did not represent the best attainable strength-weight ratio.

A preliminary fin of this design (fig 10) was given a single test in gust-condition loading. Results essentially substantiated the theoretical assumption that the semimonocoque design was more suitable for the materials used than for a conventional two-spar design, although several modifications in the materials used were indicated (appendix). These modifications were incorporated in the construction of the final papreg fin.

---

[3] "Heat-stabilized compressed wood (staypak)," by R. M. Seborg, M. A. Millett, and A. J. Stamm. FPL Rept. No. 1580, rev. 1944.

## Description of Materials and Fabrication of Parts

The semimonocoque design selected for the AT-6A fin called for the following parts: a leading edge, side skin panels, a rear spar, a front stub spar, skin stiffeners, and formers. Materials used in these parts and their method of fabrication were as follows:

### Leading Edge

The leading edge part consisted of inner and outer papreg facings on a plywood core and constituted the skin of the fin to a chord point 10-1/2 inches back from the leading edge. The papreg facings were 0.028 inch thick, with the fiber direction of adjacent sheets of the phenolic-resin impregnated paper parallel to each other and to the leading edge. They were partially cured flat in a press at 200 pounds of pressure per square inch and 284° F. for 8 minutes, then drawn without cooling and preformed to approximate final shape on a wood mold (fig. 11) by means of a piece of cotton duck fastened to a wood bar at either side for convenience in pulling it down over the papreg during the forming operation. The papreg was partially cooled on the mold, then removed. It was held in clamps to retain its approximate curved shape pending the final assembly operation.

The core consisted of yellow-poplar plywood. It was made of two-ply sheets 1/80 inch thick which were 90° cross banded and glued together with a dry film phenolic-resin glue. The grain direction of the veneer was 45° with respect to that of the leading edge. The two-ply sheets were trimmed while flat so that they were 2 inches shorter than the papreg facings. This was done so that only the facings would be scarfed to the side panels when assembling the fin. Each two-ply sheet was preformed on the mold after being wetted down the center on both sides to soften it, then stored at 80° F. and 65 percent relative humidity until the final assembly of the leading edge, being held in shape during storage by means of clamps.

Assembly of the leading edge was done by placing the inner preformed facing on the mold, laying two sheets of resin-impregnated paper on it, next placing the three preformed two-ply sheets alternately with two sheets of impregnated paper, and finally laying the outer preformed facing in place over two sheets of impregnated paper.[4] Over the whole was laid a sheet of moistureproof cellophane, about which 2-inch-wide webbing was tightly

---

[4] It was found by trial that the phenolic-resin impregnated sheets of paper provided a better bond between the components of the sandwich than either liquid phenolic glue or dry-film glue. This was probably due to the fact that the moisture content was not so critical for the paper, that flow in molding was not so severe as in the liquid glues, and that the paper had higher strength during bonding than did the dry-film glue and consequently stayed in place better. Because the laminations pulled down better than with other bonding agents, the impregnated paper appeared to have better slip qualities.

wrapped in order to pull the material firmly against the mold. No caul was used, because the outer papreg face was stiff enough to resist indentation by the webbing.

This assembly was bag molded for 30 minutes in an autoclave at 75 pounds of steam pressure per square inch and a temperature of 320° F., using a neoprene bag, and was withdrawn while hot from the autoclave.

## Side Panels

The side panels were of papreg 0.060 inch thick made up of sheets of resin-impregnated paper laid so that the fiber direction was at right angles in adjacent sheets. The panels were molded in a flat press at 200 pounds of pressure per square inch and 320° F. for 15 minutes. The grain direction of the panels was 45° with respect to the spar center line.

## Rear Spar

An I-section papreg spar of a design that had previously withstood gust-load tests up to 200 percent of the design load (fig. 8) was used. This spar consisted of a cross-laminated papreg web 0.104 inch thick and flanges and papreg angles 0.120 inch thick. The outstanding legs of the angles were tapered in width from 1-1/2 inches at the root to 3/4 inch at the tip. The angles were glued to the web with a room-temperature-setting, urea-resin glue.

## Skin Stiffeners

The skin stiffeners, consisting of 0.120-inch cross-laminated 3/4- by 3/4-inch papreg angles, were die molded at 200 pounds of pressure per square inch (fig. 12).

## Formers

The skin formers for the top and bottom ends of the fin consisted of facings of 0.038-inch, parallel-laminated papreg on a 3/8-inch core of parallel-laminated, 1/8-inch, basswood veneer. The formers were cut with the grain of the core lengthwise from panels that were press molded in a single operation at 100 pounds per square inch and 320° F. for 20 minutes.

## Front Stub Spar

The front stub spar (fig. 13) was made of the same papreg-basswood veneer combination as were the formers. This material was chosen because it could be easily worked, would provide sufficient glue area for the transfer of the drag load to the fin, and was of the correct stiffness for the air loads applied.

## Assembly of Fin

With one exception, all assembly gluing was done with a low-temperature-setting, urea-resin glue. The single exception was the gluing of the leading edge to the side panels, this scarf joint being glued under about 15 pounds of air pressure per square inch on a steam-heated strip heater, using a high-temperature-setting, phenolic-resin glue.

The leading-edge section was scarfed so that it overlapped the side panels on the outer surfaces of the fin. Since the trailing edges of the leading-edge section had been fabricated so that they consisted only of papreg, the total thickness of each was only 0.060 inch, the same thickness as the side panel to which it was scarfed. The plywood core of the leading-edge section had been sanded during fabrication of the section so that its thickness receded gradually to the point where the papreg facings were joined. The effects upon the smoothness of the skin surface produced by the greater thickness of the sandwich construction in the leading edge were thereby minimized.

After the leading edge had been glued to the side panels, the panels were glued to the rear spar, pressure being applied with woodworking clamps. The stub spar, stiffeners, and formers were then glued in place also with clamps; in the case of the stiffeners, a metal bar was used to distribute the clamp pressure.

In volume production of such fins, of course, jigs could be designed to facilitate the assembly gluing operation. Gluing could be speeded by the use of thermosetting glue and strip heaters.

This papreg fin, which possessed a smooth surface unimpaired by rivets or other external fastenings (fig. 14), weighed 13.2 pounds. The actual weight of the original aluminum fin, complete with electric fixtures and all fittings, was 13.75 pounds. Subtracting the estimated weight of these fittings, for comparison purposes, the aluminum fin was calculated to weigh 13.25 pounds. For practical purposes, the two fins were therefore of the same weight.

## Discussion of Test Results

Static load tests applied according to tables 1 and 2 were successfully carried by the papreg fin.

In steady dive-condition loading, a deflection of 0.82 inch was read with the cathetometer at both the spar tip (station C on diagram accompanying table 3) and the leading edge (station D, table 3) at 100 percent of the design ultimate load, which was the maximum applied in this test. This loading applied torque to the fin, since rudder loads are opposed to air loads. Under gust-condition loading, at 100 percent of the design ultimate load the spar tip (station C on diagram accompanying table 4) was deflected 1.02 inches and the leading edge (station D, table 4) 0.72 inch. At 200 percent of the design ultimate load in gust-condition loading, the spar tip was deflected 1.97 inches and the leading edge 1.47 inches (table 4). These results indicated that the structure was rigid enough to maintain its shape and was not critically displaced from position through any practical range of loading. Tables 3 and 4 present data on set observed immediately after test. The preliminary tests on the spar had indicated that, even at 200 percent of the design load, the spar was essentially straight, thus assuring that no binding would take place in the rudder hinges (appendix).

Strain data obtained from gages installed at various stations on the upper surface of the fin (figs. 15 and 16) indicated that the most highly stressed area in the skin under either loading condition was in the upper corner near the spar (table 5). In gust-condition loading, stresses approached the proportional limit for the material. The spar flanges between the bottom rudder fitting and the fin showed a high concentration of stress at 200 percent of the design ultimate load in gust-condition loading. The direction of highest stress in the spar web indicated that an incomplete diagonal tension field was developed in the spar between the stiffeners. The tension stresses were considerably under the proportional limit.

The evidence of set produced by the deflection readings indicates that strain gages were not placed in some critically stressed area of the fin. The fact that strain gages Nos. 22 and 4 produced evidence of unusually high stress at two points indicates that the proportional limit may have been exceeded in the vicinity of either of these gages. Further tests would, however, be necessary to locate these points of set exactly. The set data given in table 3 are well within the margin of error permitted in reading deflections. Since the proportional limit for the material was used as the basis for 100 percent of the design load, the set at 200 percent (table 4) is not regarded as critical.

## Conclusions

The results of the steady dive-condition and gust-load tests indicated that, with proper design to develop the properties of the material, papreg is a promising material for use in fabricating primary aircraft structures. While the tests made did not include all conditions to which such a structure would be subjected to establish definitely its practicality, they did represent the most critical loadings. The papreg fin under load was not deflected sufficiently to interfere with the proper operation of the rudder, and it proved to be rigid enough to maintain its aerodynamic shape throughout all loadings applied, so that flight characteristics would not be impaired.

Aerodynamic smoothness of the skin was attained. The skin was, moreover, rigid enough to permit adoption of semimonocoque design, with its advantage of a virtually unobstructed interior. Such design, while not important in the fin, offers definite advantages for wings, affording greater space for such parts as retractable landing gear, gasoline tanks, and armament, with which an elaborate internal rib structure is likely to interfere.

The parts of the papreg fin are simple to make. Only one shape of molding die is necessary. The die-molded pieces can be turned out in a single operation of a hot-plate hydraulic press. All necessary fabrication and assembly of parts can be done with ordinary woodworking tools. Neither high-pressure hot presses nor autoclaves of high-pressure capacity are needed.

While no attempt was made to produce a fin of less weight than the one tested, the fact that the fin tested carried 200 percent of the design ultimate load in gust loading without failure indicates that a fin of adequate strength can be made with reduction in weight considerably below that of the aluminum AT-6A fin.

## APPENDIX

The design, fabrication, and test of the papreg AT-6A fin were preceded by preliminary investigations intended to establish the most promising of various designs and combinations of wood, papreg, and sandwich materials for use in the construction of the final fin.

These investigations were begun by planning and fabricating, with wood and papreg, equivalent parts of the aluminum fin used in the AT-6A aircraft. In this preliminary fin, all structural parts were made of papreg, while the skin consisted of a sandwich of papreg facings and a yellow-poplar core. The fin was assembled with a thermosetting glue cured by means of electric strip heaters (fig. 17). Skin stiffeners were eliminated because the sandwich material was calculated to be 5.6 times as stiff in bending as was the aluminum in the leading edge and 4.6 times as stiff as the aluminum in the side panels.

This preliminary fin carried the design ultimate load in steady dive-condition loading, but failed in gust-condition loading at 60 percent of the design ultimate load because the rear spar lacked the necessary lateral stability. The outstanding leg of the spar (fig. 18) buckled on the compression side. When the leg was stiffened (fig. 19) a tension failure at the root fitting resulted. Stiffening of the flanges of the spar and increase of the tension area by addition of compreg plates at the root (fig. 20) strengthened the spar somewhat, but two successive gust-condition loadings to 120 percent of the design ultimate load caused a lateral failure in the spar above the intermediate rudder fitting (fig. 21).

From these results it became clear that the most important factor in achieving a suitable fin with papreg was a modified design that would permit proper distribution of stresses. For this reason, the two-spar-and rib design of the original aluminum fin was abandoned and a semimonocoque structure adopted. Special attention was given to the design of a rear spar that would support all bending loads regardless of the shell structure.

## Spar Design Tests

The tests of spar designs were undertaken first. A series of spars with five types of cross sections, including C, I, and box, was made of various materials, including papreg, solid staypak, and combinations of papreg, staypak, papreg and wood, and a papreg-basswood sandwich material. Equipped with new fittings, these spars were made as follows:

(1) A spar of papreg-basswood sandwich construction (fig. 3) was made of parallel-laminated papreg faces 0.038 inch thick pressed and bonded to a three-ply, parallel-laminated, 1/8-inch basswood veneer core in a single compression and assembly operation. The spar was reinforced with extra papreg plates 0.050 inch thick at all points of attachment except at the main attachment point at the root of the spar, which was reinforced with four tapering lower-hinge fastenings of compreg made from yellow birch veneer. The aluminum lower-hinge fitting was replaced by a steel block to adapt the fitting to the construction.

(2) A solid staypak spar (fig. 4) approximately 1/2 inch thick was made from 17 plies of 1/16-inch parallel-laminated yellow birch. Lightening holes were cut to reduce the weight. A set of flat steel plates was designed to hold this spar at the root for the fuselage attachment, such plates being considered more efficient than the standard aluminum attachment.

(3) A box-beam spar (fig. 5) was made with staypak flanges and papreg webs. The staypak was made from 1/16-inch parallel-laminated yellow birch veneer and cut into tapered sticks 3/4 inch square in cross section at the root end and 1/2 inch square at the tip, with widened zones at points of attachment. The 0.052-inch cross-laminated papreg webs were glued to the flanges with a room-temperature-setting, urea-resin glue.

(4) A spar of I-section was made with a cross-laminated papreg web 0.104 inch thick and papreg flanges 0.120 inch thick (fig. 6). The papreg angle-type flanges were tapered from 1-1/2 inches on the outstanding leg at the root to 3/4 inch at the tip. These angles were glued in pairs to the web with a room-temperature-setting, urea-resin glue to constitute the flanges.

(5) An I-section spar was made of papreg and Sitka spruce with a 0.104-inch, cross-laminated, papreg web and spruce flanges (fig. 7). The flanges were tapered from 1 inch square in cross section at the root to 1/2 inch square at the tip. The flanges and several spruce stiffeners located at various points along the spar were glued to the web with a room-temperature-setting, urea-resin glue.

## Spar Test Results

The spars were tested in gust-condition loading with the apparatus shown in figures 1 and 2.

The papreg-basswood spar failed first at 140 percent of the design ultimate load in the compreg because of a lack of sufficient tension area. After correction of this failure, the spar buckled above the juncture with the lower rib at 160 percent of the design ultimate load.

The solid staypak spar failed in the staypak on the tension side at the bottom lightening hole in shear at 120 percent of the design ultimate load.

The box-beam spar with papreg webs and staypak flanges developed a tension field in the web, which sheared from the staypak at 180 percent of the design ultimate load.

The I-beam spar with papreg web and flanges was entirely satisfactory through 200 percent of the design ultimate load. (This spar was essentially the same as the one used in the tests of the final fin described in the main body of this report.)

The I-beam spar with papreg web and spruce flanges failed at 120 percent of the design ultimate load in bearing at the root fitting.

The tests of these spars indicated that the I-beam papreg spar and the papreg-staypak box spar, each of which showed a maximum bowing of 0.020 inch at 200 percent of the design ultimate load in gust condition, might with modifications be suitable for incorporation in fins of semimonocoque design for further tests. The web of the I-beam spar was strengthened (fig. 8) by angle stiffeners glued to it with a low-temperature-setting, urea-resin glue and the flanges at the root with additional angle plates also glued in place with the same glue. The box spar, when stiffened in the webs by papreg angles glued in place as for the I-beam spar (fig. 9), also carried 200 percent of the design ultimate load.

## Development of Semimonocoque Fin

Theoretical considerations upon which the semimonocoque design of the fin was based are discussed in the main body of this report. To test these considerations, a trial fin (fig. 10) was fabricated. This fin corresponded to the final fin described in the main body of this report in all details of construction except the side panels. These were of sandwich construction instead of the solid papreg used in the final papreg fin. The faces consisted of 0.020-inch, parallel-laminated papreg. The core consisted of three-ply, 1/60-inch, yellow-poplar plywood glued with a high-temperature-setting, phenolic-resin film glue and cross banded at 90°, with the grain at 45° to the fiber direction of the papreg facings. The grain of the facings was parallel to the leading edge. These panels were press molded in one operation at 200 pounds of pressure per square inch and 320° F. for 15 minutes. After being trimmed to shape they were scarfed to a slope of 1 in 12 for bonding to the leading edge. The strengthened I-beam papreg rear spar (fig. 8) was incorporated in this fin. All parts of the fin were bonded together with a low-temperature-setting, urea-resin glue after being sanded thoroughly with No. 0 sandpaper.

A single test in gust-condition loading was made. At 160 percent of the design ultimate load, the plywood core in the side panels delaminated; inspection revealed 80 to 90 percent glue failure in the glue lines of the plywood. Delamination is believed to have been due to poor gluing. The increase in stress imposed upon the papreg by failure of the plywood, on the other hand, caused failure that was entirely in the plastic rather than in the glue between the laminations.

Although the fin did not sustain the high loading sought, this test indicated that the semimonocoque design developed the inherent strength properties of the material satisfactorily. It was therefore decided to fabricate a final test fin in which papreg side panels would replace the sandwich construction used in the preliminary fin. The test results with the fin so modified are presented in the main body of this report.

## Tests of Papreg-staypak Box Spar Fin

Tests of the various types of spars had indicated that, in addition to the I-beam papreg spar, the box-beam spar fabricated with papreg webs and staypak flanges (fig. 5), which failed in test at 180 percent of its design ultimate load, also held promise of meeting load requirements in a semimonocoque design. Accordingly, this spar was modified with the addition of papreg angles to stiffen its webs (fig. 9) and incorporated in a fin similar in other respects, except that bag-molded papreg hat-section skin stiffeners replaced the angle stiffeners, to the final fin discussed in the main body of this report.

The box-spar fin carried steady dive-condition loading successfully through 100 percent of the design ultimate load. The spar tip was deflected 0.72 inch and the leading edge 0.88 inch (table 6). This structure showed more eivdence of torque than did the fin incorporating the papreg I-beam spar. At 100 percent of the design ultimate load in gust-condition loading (table 7) the spar tip was deflected 0.72 inch and the leading edge 0.70 inch. The fin failed at 180 percent of the design ultimate load (figs. 22 and 23). At 160 percent of the design load, the spar tip was deflected 1.51 inches and the leading edge 1.10 inches. Gust-condition loading did not deflect the box-spar fin at 100 percent of the design ultimate load so far as it did the papreg fin, the spar in the papreg fin having been deflected 1.02 inches. The leading-edge deflection of the papreg fin was practically the same as that of the box-spar fin.

Strain gages were installed on the box-spar fin in the same locations as on the papreg fin. Stress calculated from strain-gage data indicated that higher stresses were developed in the spar root (table 8) than in the papreg spar. The skin at the upper corner near the spar was not stressed nearly so much in either loading condition as that in the papreg fin. Relatively speaking, the box spar did not work so effectively as did the I-section spar. At 100 percent of the design ultimate load in gust-condition loading, the spar was again the weak part of the structure. In the papreg fin, the most highly stressed areas had approached the same stress values, indicating equal strength. This condition in the papreg fin persisted throughout the tests. The box-spar fin failed at the top corner of the skin, even though the stresses did not indicate that ultimate strength had been reached.

TABLE 1:- LOADING SCHEDULE USED TO TEST FINS IN STEADY DIVE-CONDITION LOADING. LOADING METHOD IS INDICATED ON DIAGRAM. LOADS AT STATIONS $R_1$, $R_2$, AND $R_3$ BEAR IN DIRECTION OPPOSITE TO LOADS AT AREAS A, B, C, AND D. SCHEDULE IS FROM DRAWING X44A888, MATERIEL DIVISION, U.S. ARMY AIR FORCES.

| DESIGN LOAD INCREMENT | LOAD INCREASES | | | | | | |
|---|---|---|---|---|---|---|---|
| | ON AREAS | | | | AT STATIONS | | |
| | A | B | C | D | $R_1$ | $R_2$ | $R_3$ |
| PERCENT | LB. | LB. | LB. | LB. | LB. | LB. | LB. |
| 20 | 28 | 55 | 25 | 3 | 11 | 9 | 12 |
| 40 | 27 | 55 | 25 | 2 | 11 | 8 | 12 |
| 60 | 27 | 55 | 25 | 4 | 11 | 10 | 12 |
| 80 | 30 | 55 | 25 | 2 | 10 | 10 | 12 |
| 100 | 26 | 57 | 24 | 2 | 10 | 8 | 10 |

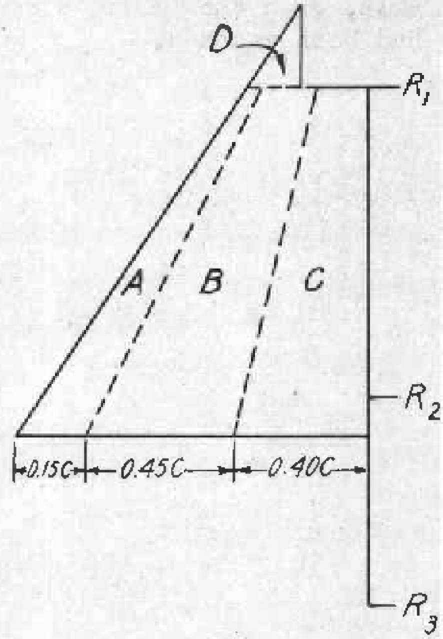
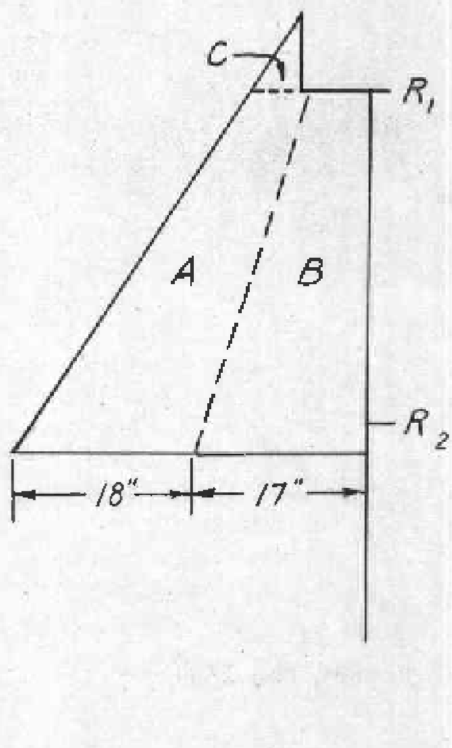



TABLE 2:- LOADING SCHEDULE USED TO TEST FINS AND SPARS IN GUST-CONDITION LOADING. LOADING METHOD IS INDICATED ON DIAGRAM. ALL LOADS WERE APPLIED IN THE SAME DIRECTION. SCHEDULE THROUGH 100 PERCENT DESIGN LOAD IS FROM DRAWING X44A888, MATERIEL DIVISION, U.S. ARMY AIR FORCES.

| DESIGN LOAD INCREMENT | LOAD INCREASES | | | | |
|---|---|---|---|---|---|
| | ON AREAS | | | AT STATIONS | |
| | A | B | C | $R_1$ | $R_2$ |
| PERCENT | LB. | LB. | LB. | LB. | LB. |
| 20 | 50 | 35 | 7 | 35 | 15 |
| 40 | 50 | 35 | 8 | 35 | 15 |
| 60 | 50 | 35 | 8 | 35 | 15 |
| 80 | 50 | 35 | 8 | 35 | 15 |
| 100 | 50 | 34 | 8 | 35 | 14 |
| 120 | 50 | 35 | 7 | 35 | 15 |
| 140 | 50 | 35 | 8 | 35 | 15 |
| 160 | 50 | 35 | 8 | 35 | 15 |
| 180 | 50 | 35 | 8 | 35 | 15 |
| 200 | 50 | 34 | 8 | 35 | 14 |




Z M 64002 F

TABLE 3.- CORRECTED NET DEFLECTION OF PAPREG FIN IN STEADY DIVE-CONDITION LOADING. DIAGRAM INDICATES STATIONS AT WHICH DEFLECTION WAS MEASURED IN CENTIMETERS WITH A CATHETOMETER. DEFLECTION IN INCHES CALCULATED.

| DESIGN LOAD INCREMENT | DEFLECTION AT STATION | | | |
|---|---|---|---|---|
| | A | B | C | D |
| PERCENT | INCH | INCH | INCH | INCH |
| 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | .03 | .01 | .08 | .05 |
| 20 | .06 | .00 | .14 | .16 |
| 30 | .09 | .00 | .19 | .20 |
| 40 | .11 | .02 | .26 | .31 |
| 60 | .19 | .02 | .49 | .49 |
| 80 | .24 | .11 | .68 | .69 |
| 100 | .34 | .12 | .82 | .82 |
| SET | .00 | .00 | .01 | .01 |

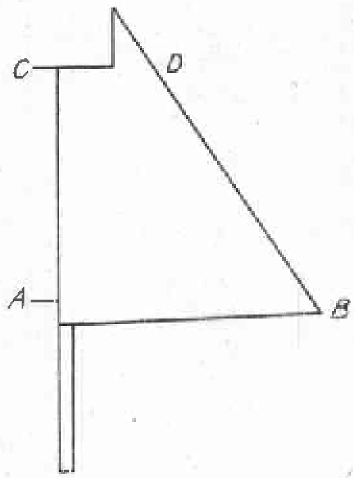
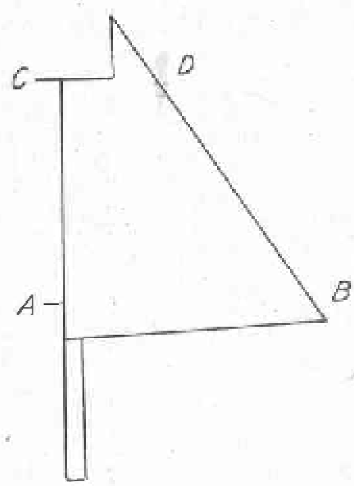



TABLE 4.- CORRECTED NET DEFLECTION OF PAPREG FIN IN GUST-CONDITION LOADING. DIAGRAM INDICATES STATIONS AT WHICH DEFLECTION WAS MEASURED IN CENTIMETERS WITH A CATHETOMETER. DEFLECTION IN INCHES CALCULATED.

| DESIGN LOAD INCREMENT | DEFLECTION AT STATION | | | |
|---|---|---|---|---|
| | A | B | C | D |
| PERCENT | INCH | INCH | INCH | INCH |
| 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | .02 | .01 | .13 | .11 |
| 20 | .10 | .02 | .26 | .20 |
| 30 | .13 | .05 | .38 | .30 |
| 40 | .11 | .03 | .35 | .26 |
| 60 | .23 | .02 | .79 | .44 |
| 80 | .36 | .08 | .79 | .58 |
| 100 | .42 | .11 | 1.02 | .72 |
| 120 | .60 | .12 | 1.24 | .87 |
| 140 | .57 | .11 | 1.36 | .99 |
| 160 | .63 | .14 | 1.52 | 1.08 |
| 180 | .74 | .11 | 1.76 | 1.28 |
| 200 | .82 | .17 | 1.97 | 1.47 |
| SET | .00 | .00 | .04 | .03 |



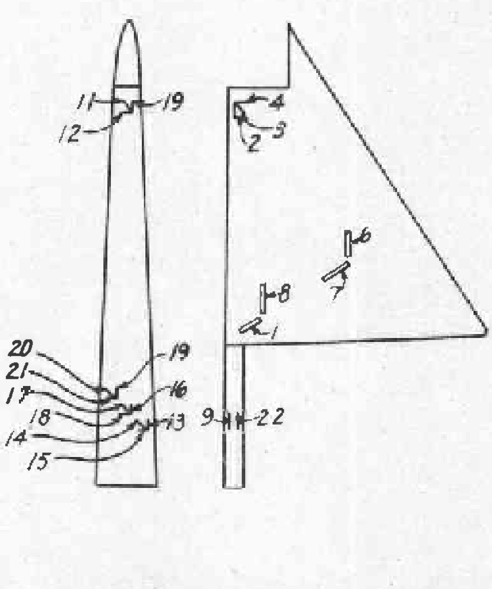

Z M 64003 F

TABLE 5.- STRESSES AND STRAINS IN PAPREG FIN IN STATIC LOADING. LOCATION OF STRAIN GAGES SHOWN ON ACCOMPANYING DIAGRAM[1]

| STRAIN GAGE | | 100 PERCENT STEADY-DIVE LOADING | | 100 PERCENT GUST LOADING | | 200 PERCENT GUST LOADING | |
|---|---|---|---|---|---|---|---|
| NO. | LOCATION | STRESS | STRAIN[2] | STRESS | STRAIN[2] | STRESS | STRAIN[2] |
| | | P.S.I. | INCH PER INCH | P.S.I. | INCH PER INCH | P.S.I. | INCH PER INCH |
| 22 | FLANGE | 1,742 | T0.000728 | 3,024 | T0.001260 | 5,470 | T 0.002279 |
| 9 | FLANGE | 595 | T .000248 | 1,632 | T .000680 | 3,880 | T .001616 |
| 13 | WEB | 835 | T .000348 | 1,488 | T .000620 | 2,976 | T .001240 |
| 14 | WEB | 657 | T----- | 1,507 | T----- | 2,929 | T .001220 |
| 15 | WEB | 96 | T.000040 | 288 | C .000120 | 336 | C .000140 |
| 16 | WEB | 96 | T .000040 | 192 | T .000080 | 240 | T .000100 |
| 17 | WEB | 240 | T ---- | 893 | T ----- | 1,729 | T .000720 |
| 18 | WEB | 156 | T.000065 | --- | T --- | --- | T ---- |
| 19 | WEB | 336 | C .000140 | 1,027 | C .000428 | 2,371 | C .000988 |
| 20 | WEB | 66 | T---- | 480 | T---- | 989 | T .000412 |
| 21 | WEB | 192 | T .000080 | 192 | T .000080 | 310 | T .000128 |
| 10 | WEB | 288 | T .000120 | 58 | T .000024 | 115 | T .000048 |
| 11 | WEB | 288 | T---- | 1,229 | T---- | 2,592 | T .001080 |
| 12 | WEB | 312 | T .000130 | 355 | T .000148 | 816 | T .000340 |
| 4 | SKIN | 4,368 | T .001820 | 3,884 | T .001618 | 6,190 | T .002580 |
| 3 | SKIN | 2,756 | T .001148 | 2,593 | T .001080 | 2,929 | T .001220 |
| 2 | SKIN | 792 | T .000330 | 1,056 | T .000440 | 1,986 | T .000828 |
| 1 | SKIN | 451 | T .000188 | 125 | C .000052 | 883 | T .000368 |
| 8 | SKIN | 72 | C .000030 | 144 | C .000060 | 1,315 | C .000548 |
| 7 | SKIN | 122 | C .000510 | 989 | C .000412 | 1,411 | C .000588 |
| 6 | SKIN | 50 | C .000210 | 1,267 | C .000528 | 1,027 | C .000428 |

[1] ON DIAGRAM, ▯ REPRESENTS A SINGLE STRAIN GAGE AND ↗ A ROSETTE TYPE

[2] T REFERS TO TENSION STRAIN, C TO COMPRESSION STRAIN.




Z M 64004 F

TABLE 6.- CORRECTED NET DEFLECTION OF BOX-SPAR FIN IN STEADY DIVE-CONDITION LOADING. DIAGRAM INDICATES STATIONS AT WHICH DEFLECTION WAS MEASURED IN CENTIMETERS WITH A CATHETOMETER. DEFLECTION IN INCHES CALCULATED.

| DESIGN LOAD INCREMENT | DEFLECTION AT STATION | | | |
|---|---|---|---|---|
| | A | B | C | D |
| PERCENT | INCH | INCH | INCH | INCH |
| 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | .04 | .02 | .03 | .08 |
| 20 | .04 | .01 | .05 | .09 |
| 30 | .10 | .05 | .14 | .21 |
| 40 | .13 | .08 | .21 | .27 |
| 60 | .17 | .10 | .36 | .49 |
| 80 | .23 | .51 | .51 | .65 |
| 100 | .32 | .72 | .72 | .88 |
| SET | .00 | .00 | .01 | .01 |

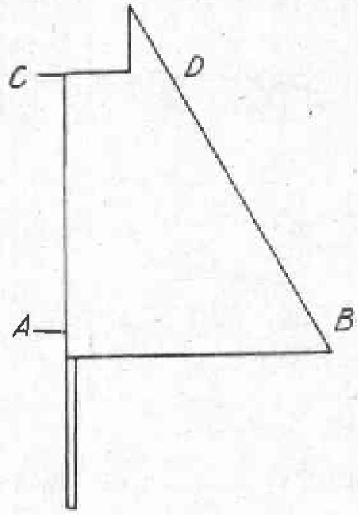
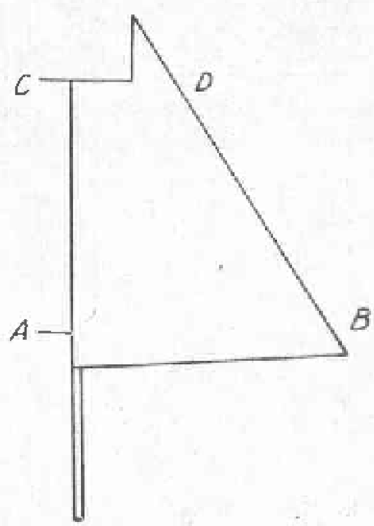



TABLE 7.- CORRECTED NET DEFLECTION OF BOX-SPAR FIN IN GUST-CONDITION LOADING. DIAGRAM INDICATES STATIONS AT WHICH DEFLECTION WAS MEASURED IN CENTIMETERS WITH A CATHETOMETER. DEFLECTION IN INCHES CALCULATED.

| DESIGN LOAD INCREMENT | DEFLECTION AT STATION | | | |
|---|---|---|---|---|
| | A | B | C | D |
| PERCENT | INCH | INCH | INCH | INCH |
| 0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 10 | .03 | .008 | .08 | .09 |
| 20 | .05 | .008 | .08 | .15 |
| 30 | .05 | .01 | .18 | .18 |
| 40 | .05 | .03 | .19 | .20 |
| 60 | .13 | .004 | .37 | .36 |
| 80 | .14 | .008 | .49 | .49 |
| 100 | .24 | .03 | .72 | .70 |
| 120 | .30 | .03 | .88 | .86 |
| 140 | .38 | .04 | 1.11 | 1.06 |
| 160 | .38 | .03 | 1.51 | 1.10 |

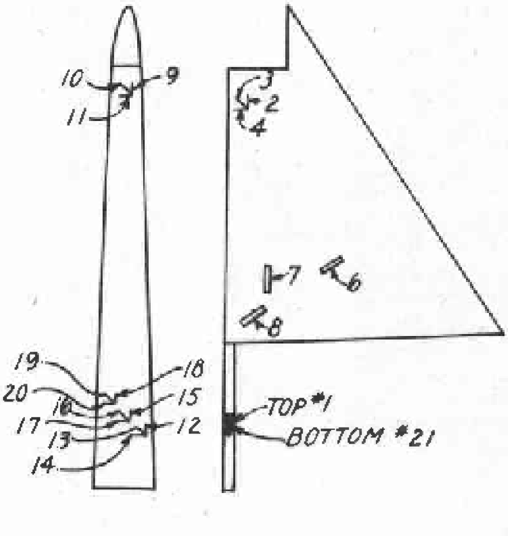



Z M 64005 F

TABLE 8.- STRESSES AND STRAINS IN BOX-SPAR FIN IN STATIC LOADING. LOCATION OF STRAIN GAGES SHOWN ON ACCOMPANYING DIAGRAM.[1]

| STRAIN GAGE | | 100 PERCENT STEADY DIVE LOADING | | 100 PERCENT GUST LOADING | | 160 PERCENT GUST LOADING | |
|---|---|---|---|---|---|---|---|
| NO. | LOCATION | STRESS | STRAIN[2] | STRESS | STRAIN[2] | STRESS | STRAIN[2] |
| | | P.S.I. | INCH PER INCH | P.S.I. | INCH PER INCH | P.S.I. | INCH PER INCH |
| 1 | TOP FLANGE | 3,134 | T0.000670 | 6765 | T0.001468 | 10,270 | T0.002228 |
| 21 | BOTTOM FLANGE | 2,840 | C .000620 | 6,410 | C.001400 | 9,980 | C.002179 |
| | | | | | | | |
| 12 | WEB | 1,129 | T.000470 | 2,063 | T.000860 | 2,851 | T.001188 |
| 13 | WEB | 817 | T.000340 | 2,209 | T.000920 | 3,120 | T.001300 |
| 14 | WEB | 144 | C.000060 | 413 | C.000172 | 556 | C.000232 |
| | | | | | | | |
| 15 | WEB | 240 | T.000100 | 355 | C.000148 | 1,133 | C.000472 |
| 16 | WEB | 240 | T.000100 | 1,151 | T.000480 | 1,536 | T.000640 |
| 17 | WEB | 48 | T.000020 | 288 | C.000288 | 509 | C.000212 |
| | | | | | | | |
| 18 | WEB | 912 | C.000380 | 2737 | C.001140 | 5,152 | C.002147 |
| 19 | WEB | 24 | C.000010 | 787 | T.000328 | 893 | T.000372 |
| 20 | WEB | 168 | T.000070 | 192 | T.000080 | --- | T --- |
| | | | | | | | |
| 9 | WEB | 24 | C.000010 | 144 | C.000060 | 125 | T.000052 |
| 10 | WEB | 192 | T.000080 | 1,008 | T.000420 | 1,488 | T.000620 |
| 11 | WEB | 192 | T.000080 | 269 | T.000112 | 336 | T.000140 |
| | | | | | | | |
| 4 | SKIN | 360 | T.000150 | 1,008 | T.000420 | 1,324 | C.000552 |
| 3 | SKIN | 600 | T.000250 | 1,488 | T.000620 | 1,795 | T.000748 |
| 2 | SKIN | 1,305 | T.000542 | 1,363 | T.000568 | 1,699 | T.000708 |
| | | | | | | | |
| 8 | SKIN | --- | T- --- | 19 | C.000008 | 547 | T.000228 |
| 7 | SKIN | 384 | T.000160 | 48 | C.000020 | 115 | C.000048 |
| 6 | SKIN | 384 | C.000160 | 38 | C.000016 | 652 | C.000272 |

1ON DIAGRAM, ▯ REPRESENTS A SINGLE STRAIN GAGE AND ↗ A ROSETTE TYPE.
2T REFERS TO TENSION STRAIN, C TO COMPRESSION STRAIN




Z M 64006 F

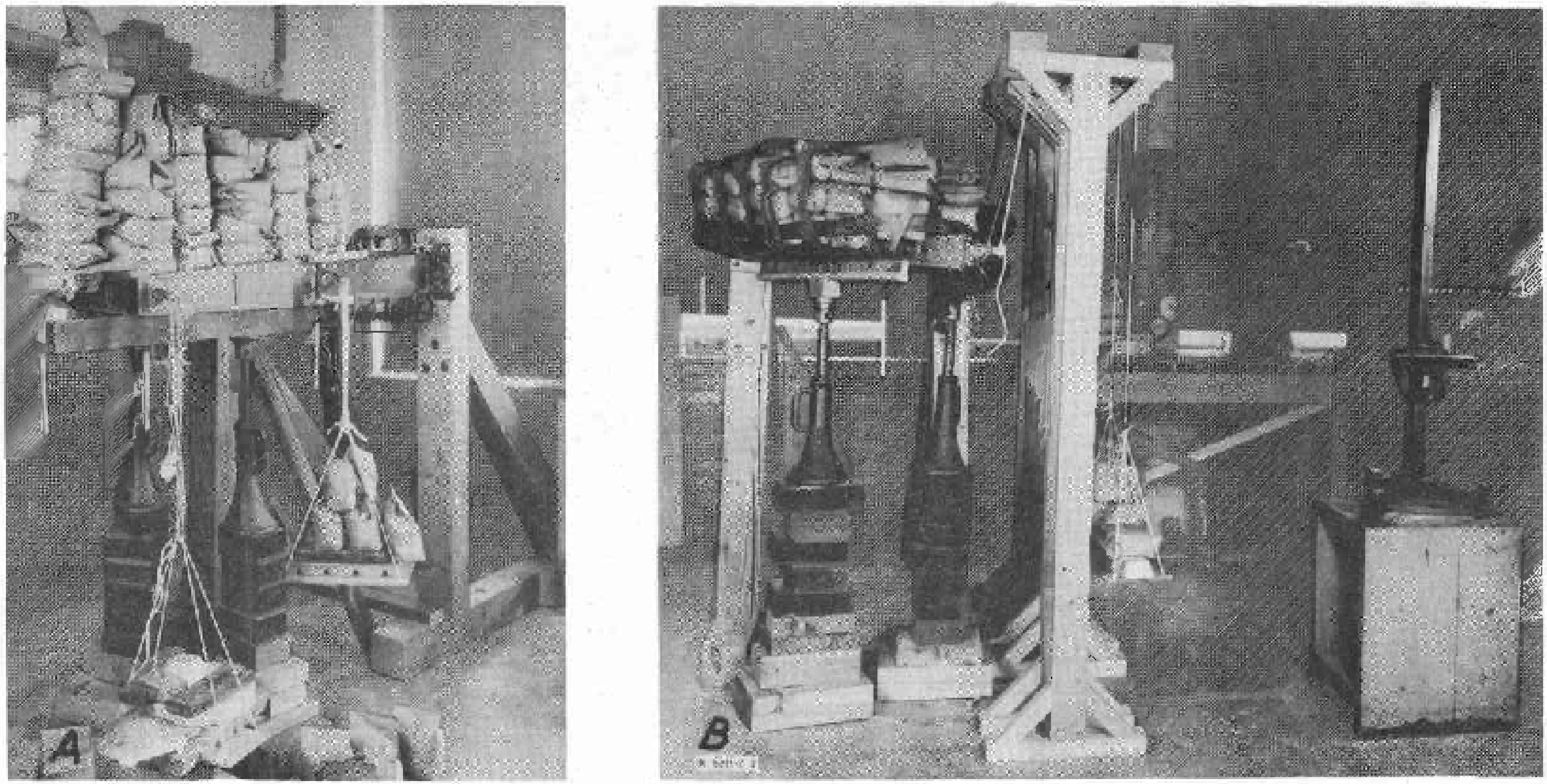



Figure 1.--Test setups for static load tests of vertical fins. A, loads applied for gust-condition test. B, loads applied for steady dive-condition test; cathetometer used to measure deflections is shown at right.

Z M 63993 F

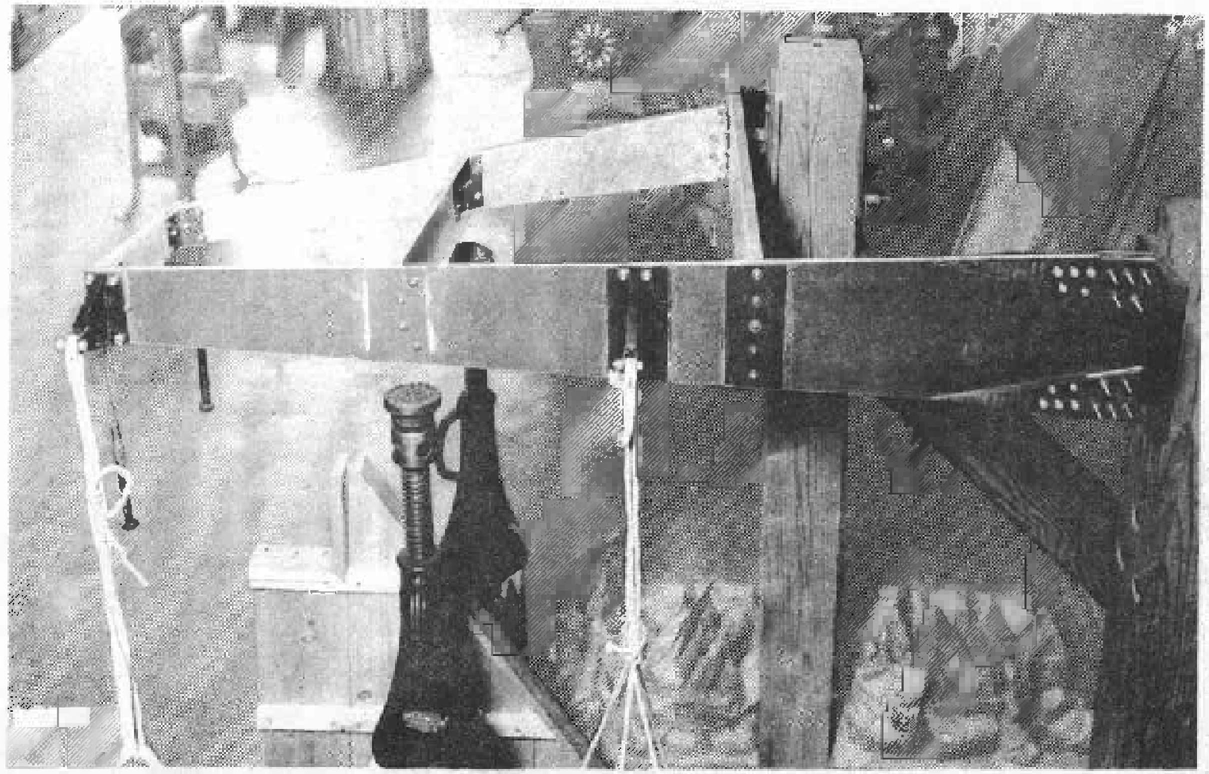


Figure 2.--Rear spar test setup for gust-condition loading. The spar shown is of papreg-basswood sandwich construction. The air-load platform, not yet in place, can be seen between the jacks.

Z M 64841 F

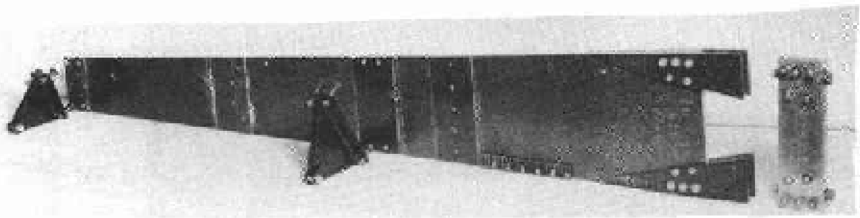


Figure 3.--Papreg-basswood sandwich-construction rear spar is shown with its test fittings.

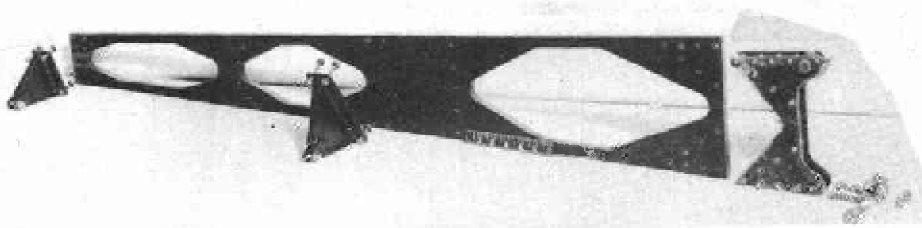


Figure 4.--Staypak rear spar. Note the root fitting for fuselage attachment.

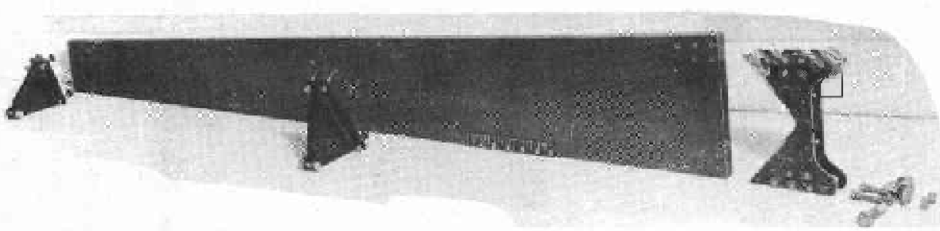


Figure 5.--Papreg-staypak box-type rear spar with fittings.

Figure 6.--Papreg I-section rear spar with fittings.

Z M 63997 F

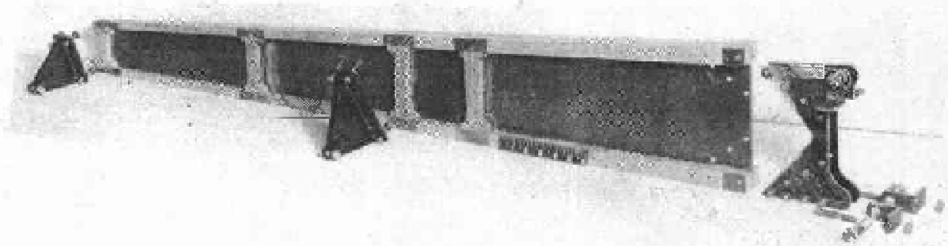


Figure 7.--Papreg-Sitka spruce I-section rear spar with fittings.

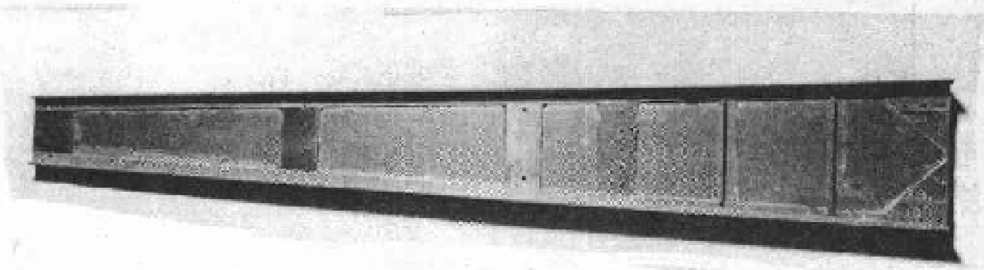


Figure 8.--The papreg I-section rear spar used in the final design of the fin.

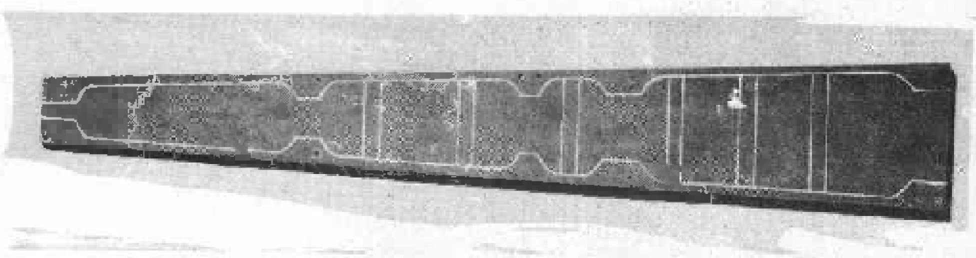


Figure 9.--The papreg-staypak box-type rear spar which had been redesigned to include papreg angle web stiffeners. The position of the spar flanges and web stiffeners is outlined for clarity in this picture.

Z M 63998 F

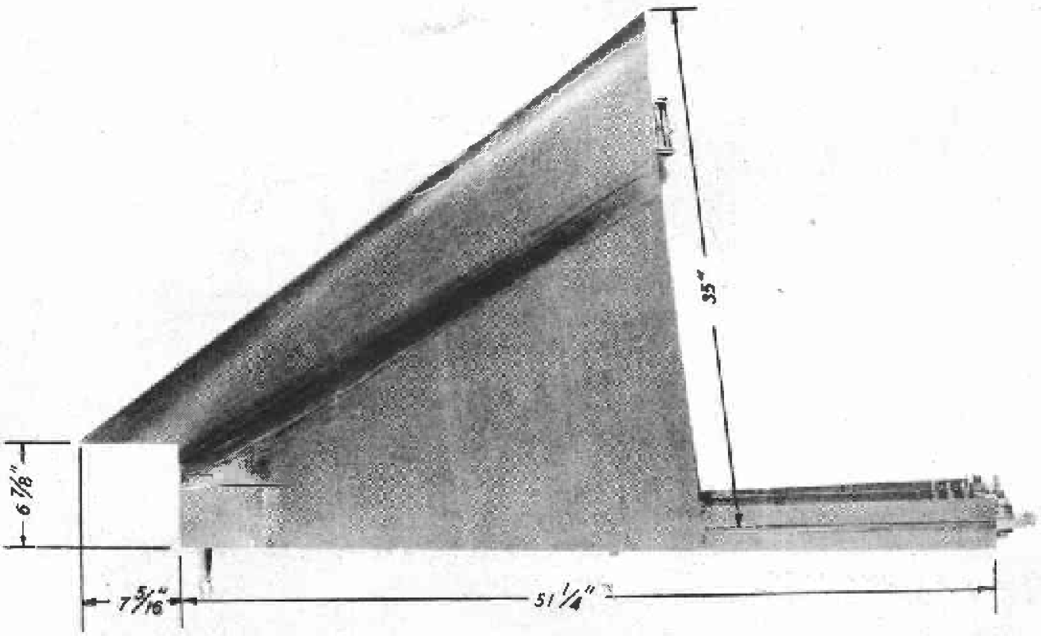



Figure 10.--Vertical fin assembled for preliminary trial of semimonocoque design.

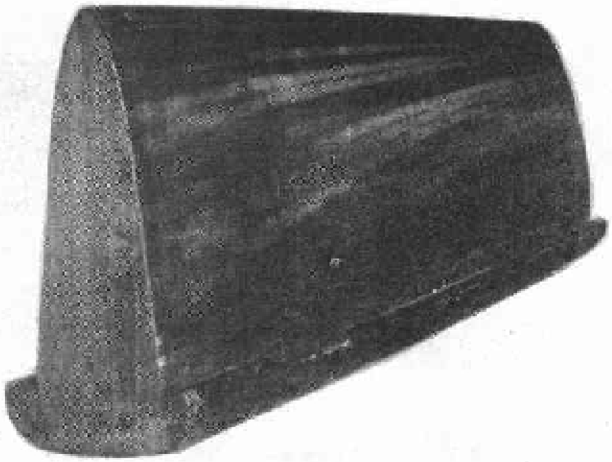


Figure 11.--Laminated wood mold for molding leading-edge section. The inner radius of the leading-edge section at the tip, shown in the foreground, is 3/32 inch. At the bottom it enlarges to 1/2 inch.

Z M 63999 F

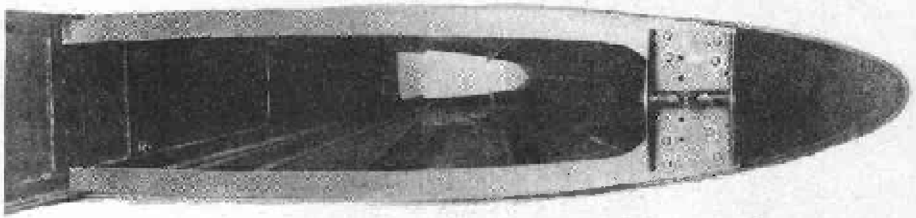


Figure 12.--Skin stiffeners glued in place to skin interior. The bottom formers appear in the foreground and the top formers in the background interior.

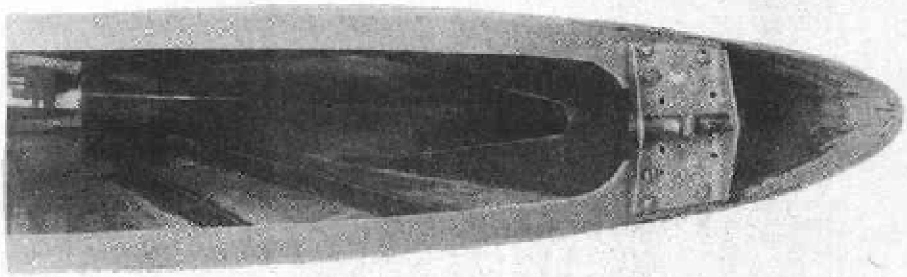


Figure 13.--Front stub spar in position in the fin. The drag-load fitting is in place. Bolts through the fitting go through the former and through a molded papreg angle glued to the root of the stub spar.

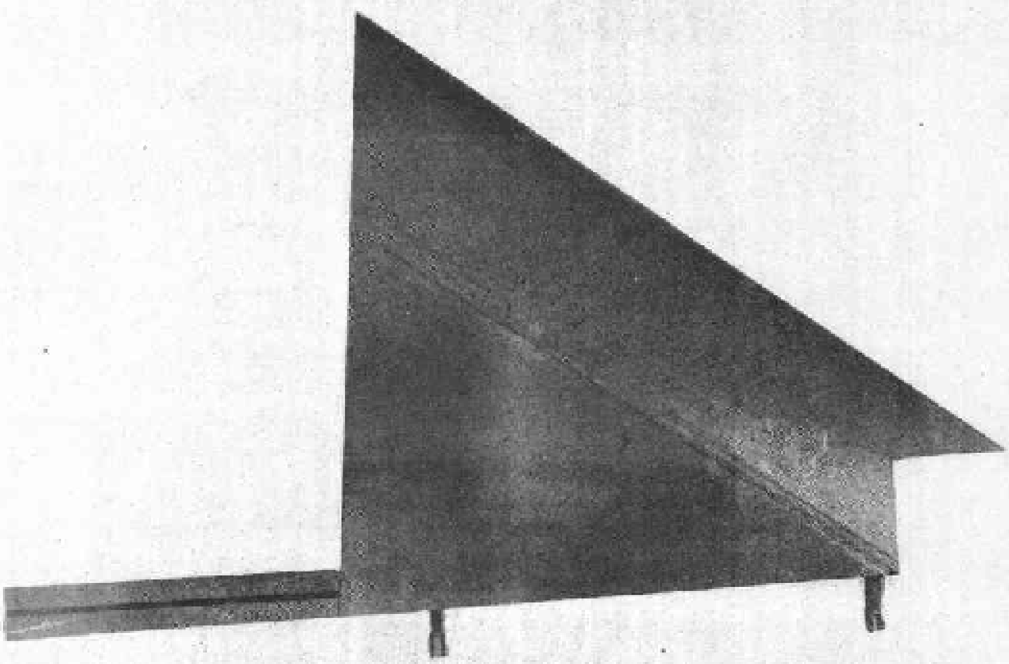


Figure 14.--Side elevation of papreg fin. Note the smooth surface unimpaired by external fastenings, such as rivets.

Z M 64000 F

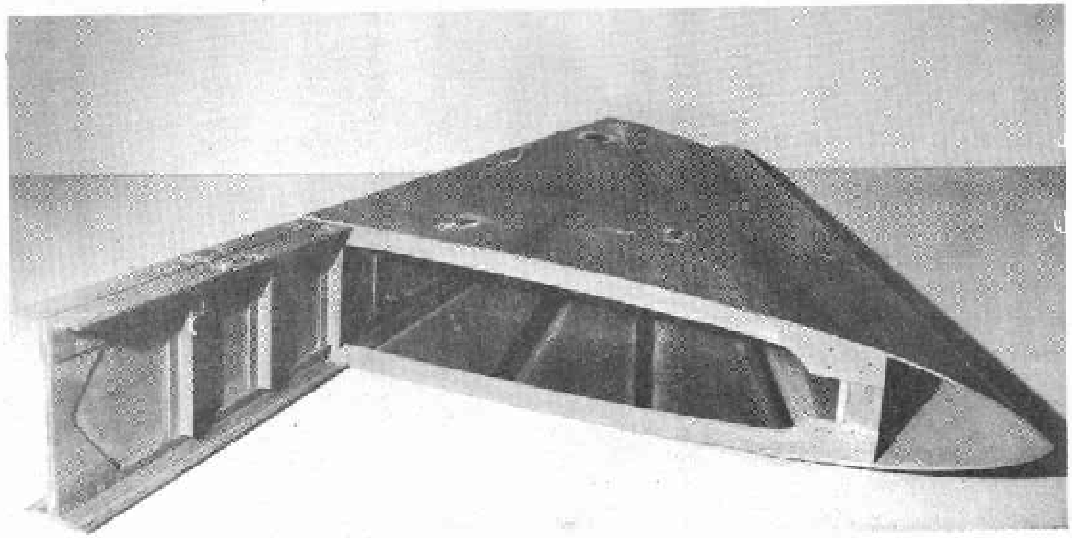


Figure 15.--Strain gages used in static tests on the upper surface of the skin.

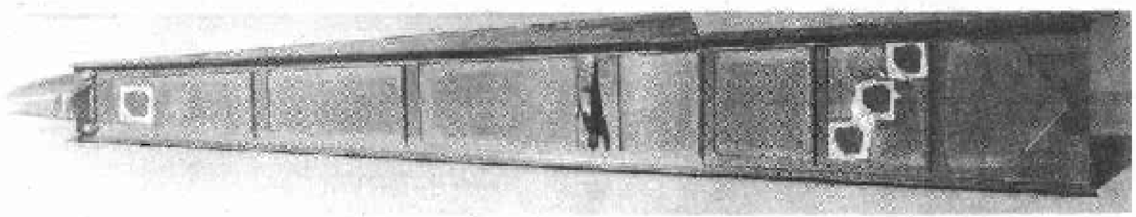


Figure 16.--Strain gages on spar web. Note method of web stiffening with small papreg angles.

Z M 64842 F

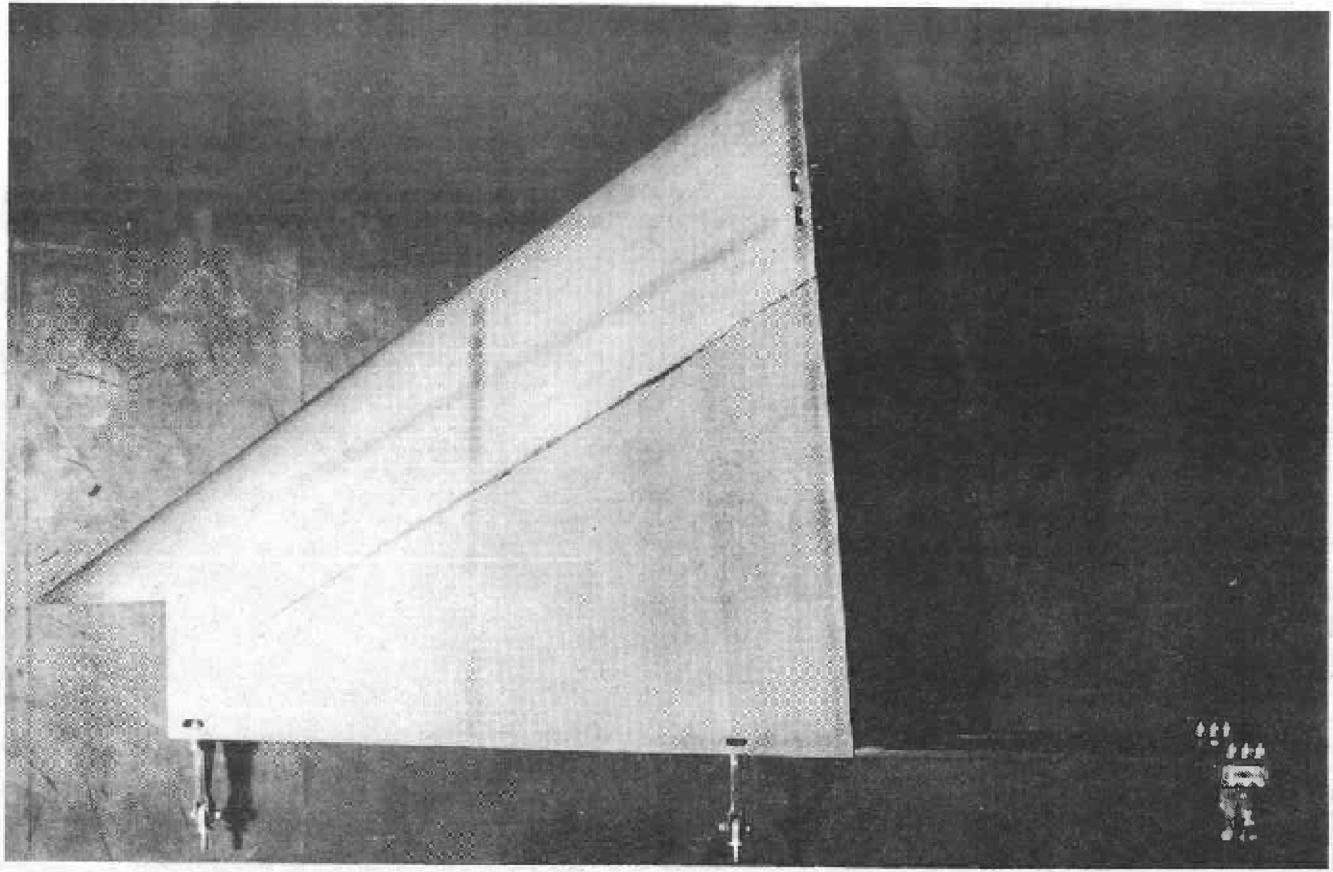


Figure 17.--Fin of papreg and sandwich construction designed for AT-6A airplane. The original rudder fittings of the metal fin were used. The dark stripes are the areas over the ribs and spars and were caused by heating the skin with strip heaters to set the glue joints.

Z M 64843 F

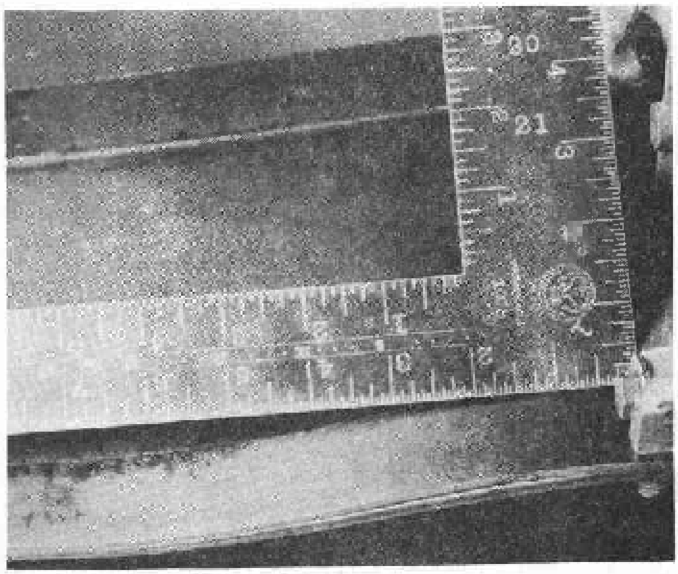


Figure 18.--View looking forward at base of rear spar of first vertical fin tested. Shear failure occurred between flange and web at proof load in gust condition.

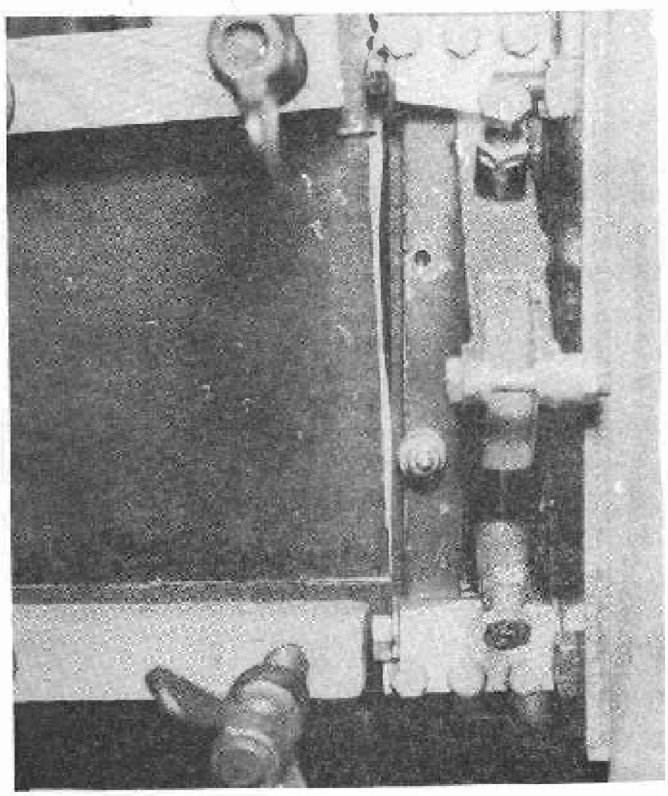


Figure 19.--View looking forward at rear spar of first vertical fin tested. Fracture developed at 80 percent of the design ultimate load. The spar had been stiffened by clamping 1 inch by 1 inch oak strips to it from fitting to bottom rib.

Z M 63995 F

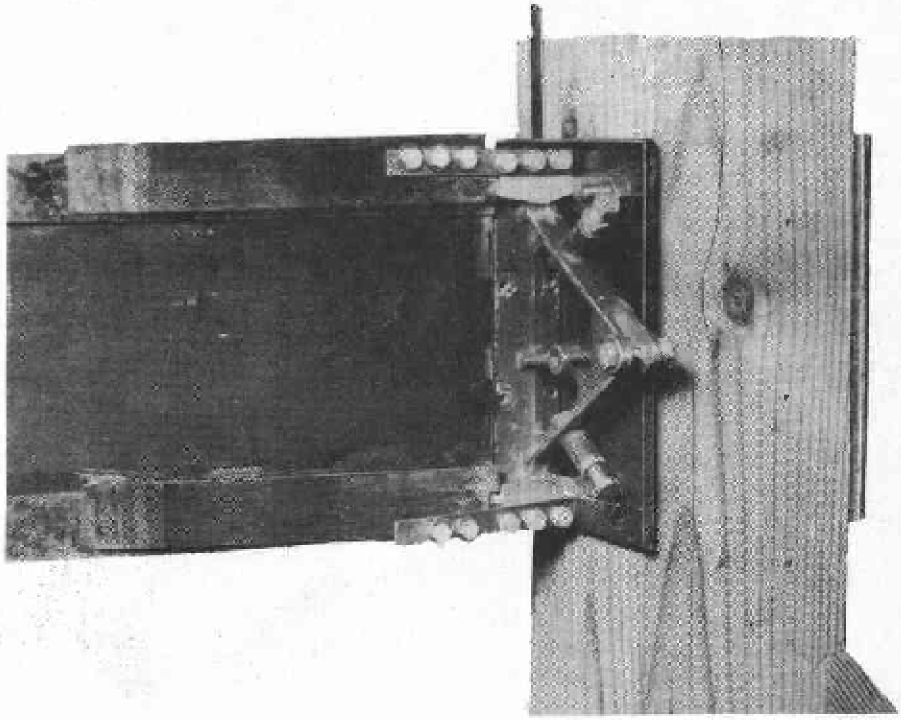


Figure 20.--Vertical fin with compreg spar-root stiffeners.

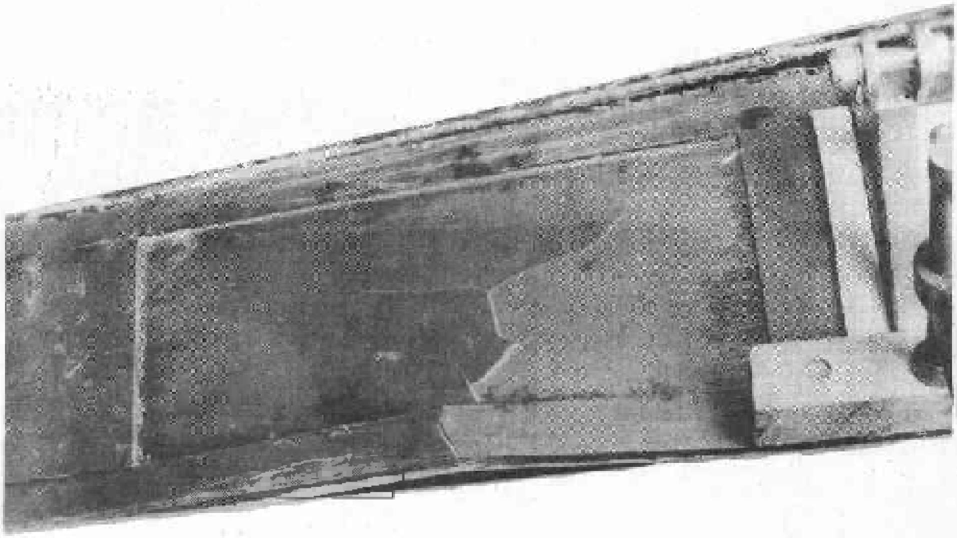


Figure 21.--Lateral failure above the intermediate rudder fitting of the rear spar in the first fin tested.

Z M 63996 F

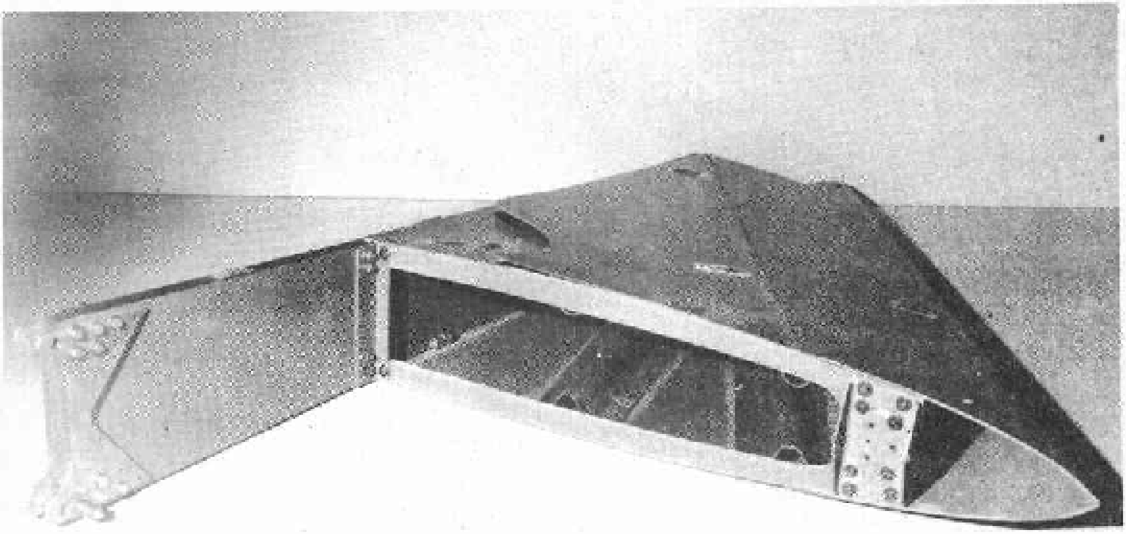


Figure 22.--Fin in which was incorporated the papreg-staypak box spar. Locations of the strain gages on the skin surface are shown. Note the hat-section stiffeners on the skin interior.

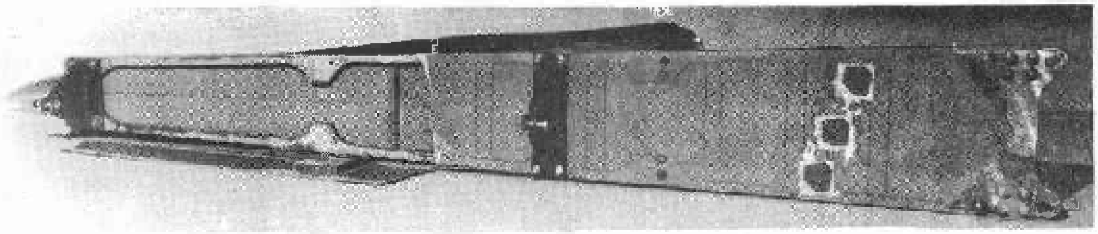


Figure 23.--Position of strain gages on spar web. The spar web is shown sheared away from the spar flanges. The web stiffeners are illustrated in the broken section.

Z M 64844 F