EFFECTS OF VARIATIONS IN DESIGN ON THE STRENGTH OF SOME TYPICAL GLUED FASTENINGS IN WOOD AIRCRAFT

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EFFECTS OF VARIATIONS IN DESIGN ON THE STRENGTH OF SOME TYPICAL GLUED FASTENINGS IN WOOD AIRCRAFT[1]

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Summary

This report presents the results of approximately 1,700 tests performed to determine the effects of variations in design on the strength of four types of typical glued fastenings commonly employed in wood aircraft construction. Appropriate methods were devised to test full-scale glue joint assemblies of each type. A cold-setting urea-formaldehyde glue commonly used for such fastenings was used throughout the experiments. This glue developed sufficient shearing strength to cause wood failures in practically all of the joints tested.

The major portion of this study was devoted to gussets joining Sitka spruce members that were perpendicular to each other at rib-to-spar and web member-to-rib cap junctions. For each of these types of fastenings, separate series of specimens were made for the testing of each of the three elements of gusseted joints which might be critical. The dimensions of the critical elements were varied in each series. Yellow-poplar and mahogany plywoods of 0.070-, 0.100-, and 0.125-inch thickness were used to include the effects of varying the species and thickness. Face grain directions of the gussets of 0°, 45°, and 90° to the direction of load were also included in the program.

Several types of corner attachments between ribs and spars of Sitka spruce were tested for shearing strength. Square and triangular corner blocks of various sizes and plywood angles of various species and thicknesses were used for the corner pieces.

Saddle gussets of three sizes were tested for bearing strength when glued to framing members of Sitka spruce or Douglas-fir. Yellow birch and

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

mahogany plywoods of 3/48- to 3/16-inch thickness were used in these tests to include the effects of varying the species and thickness. In the gussets the grain directions were 0°, 45°, and 90°.

The results showed that concentrations of stress occurring in the joints of glued fastenings prevented the development of the full strengths over the entire areas of the critical joints. The extent to which the strengths of such fastenings were affected by these stress concentrations varied with the relative size, shape, and elastic properties of the joined members.

The ultimate tensile strength of gussets in rib-to-spar and web member-to-rib cap fastenings varied approximately as the thickness and as the two-thirds power of the width of the gusset. Concentrations of stress induced shear failures in the joints of web member-to-rib cap fastenings before the tensile strength of the web member could be developed. The proportion of the tensile strength of the web member that could be attained varied with the ratio of its width to its depth between gussets.

In gussets of medium density and of the thicknesses studied, delamination of the plywood (separation along planes approximately parallel to its faces) did not generally occur, and the shearing strength of Sitka spruce either parallel or perpendicular to the grain was developed regardless of the direction of the face grain of the plywood.

Certain strength-area relationships were found for the various elements of glued joints. These relationships can be used to obtain efficient designs in glued fastenings employing joints of sizes within the scope of this investigation. The results of these tests may also be of value in the design of fastenings of other sizes and types, subject to confirmation by actual tests.

Purpose

In an effort to achieve more efficient design of assembly glued joints, this investigation was made to determine the general principles that govern the strengths of certain typical fastenings now commonly employed in wood aircraft. A knowledge of the facts applicable to the various elements of specific joints is essential in designing new fastenings of similar types.

Types of Test Specimens

Four types of glued fastenings commonly employed in aircraft were selected for this investigation. From exploratory tests, specimens incorporating full scale glue joint assemblies of each type were designed, and appropriate methods of test were developed.

Type I. Web Member-to-rib Cap Fastening

In test specimens of web member-to-rib cap fastenings, tensile stresses in a single web member, usually 3/8 inch thick, are transferred to a rib cap by means of plywood gussets (fig. 1). Series of specimens were made for each of three conditions, as determined by the manner in which failure could take place, as follows:

1. Tensile failure of the plywood gussets.
2. Shearing failure in the joint between the gusset and rib cap.
3. Shearing failure in the joint between the gusset and web member.

Within each series, the critical dimensions were varied as shown in figure 1. Other dimensions were varied as required to induce failure in the desired manner. Plywood gussets were varied as to species, thickness, grain direction, and size.

Type II. Rib-to-spar Gusset Fastening

In test specimens representing rib-to-spar gusset fastenings, the bending moment in a solid wood rib 3/8 inch thick was transferred to a spar by means of plywood gussets (fig. 2). Triangular 1/2-inch corner blocks 6 inches long were used in all specimens to resist vertical shear. Series of specimens of various critical dimensions were used to investigate the strength of rib-to-spar gusset fastenings under each of the following three conditions:

1. Tensile failure of the plywood gussets.
2. Shearing failure in the joint between the gusset and spar.
3. Shearing failure in the joint between the gusset and rib.

Plywood gussets were varied as to species, thickness, grain direction, and size.

Type III. Rib-to-spar Corner Attachment

Symmetrical specimens with rib members thickened to resist compression were used to determine the shearing strengths of various kinds of rib-to-spar corner attachments (fig. 3). Square and triangular corner blocks and plywood angles of various species and thickness were used for the corner pieces.

Type IV. Saddle Gusset Fastenings

In the saddle gusset fastenings, plywood saddle gussets glued to solid wood framing members support an intercostal 3/8 inch thick. Figure 4 illustrates this type of specimen and shows the sizes of gussets used. Plywood gussets were varied as to species, thickness, grain direction, and size.

Materials

Kiln-dried Sitka spruce of approximately 0.40 specific gravity, based on volume and weight when oven dry, was selected for the solid wood parts of specimens of types I, II, and III. Exception was made for one series of web member-to-rib cap specimens in which the solid wood members were of yellow birch. Framing members of the saddle gusset specimens of type IV were of Sitka spruce and Douglas-fir of average specific gravities of 0.38 and 0.48, respectively, based on weight when oven dry and volume at test. After they were cut to size, only clear, straight-grained pieces were selected for use.

Types I and II

Plywoods for the gussets of specimens of types I and II were of aircraft grade fabricated in accordance with AN-NN-P-511b specifications by commercial producers of these materials. Yellow-poplar was selected as a low-density wood and mahogany as one of medium density. The yellow-poplar, however, was of exceptionally high specific gravity, approximately the same as that of the mahogany. Laboratory-made yellow-poplar plywood of aircraft grade was used to augment one series of rib-to-spar specimens.

The average thickness and the specific gravity, based on volume and weight when oven dry, of 15 random specimens of each plywood were as follows:

Specimen	Specific gravity
0.077-inch yellow-poplar (commercial)	0.56
.063-inch yellow-poplar (Laboratory-made)	.48
.110-inch yellow-poplar	.55
.140-inch yellow-poplar	.55
.074-inch mahogany	.58
.106-inch mahogany	.52
.133-inch mahogany	.53

Type III

Plywood angles were purchased from the stock of a commercial producer. The plywoods in these angles were constructed similar to the aircraft plywoods of Specification AN-NN-P-511b, and the grain of the plies was at an angle of 45° to the long axes. The inside radius of the bend was approximately 3/16 inch, and the plane surface of each leg was approximately 3/4 inch wide. The species, nominal thickness, and specific gravity, based on volume and weight when oven dry, of the plywood angles investigated were as follows:

Specimen	Specific Gravity
0.070-inch yellow-poplar	0.59
.070-inch yellow birch	.76
.070-inch sweetgum	.73
.125-inch sweetgum	.64
.100-inch mahogany with yellow-poplar core	.61

Type IV

Plywood specimens for the saddle gussets of type IV specimens were of three plies of aircraft grade veneers of uniform thickness. The yellow birch plywood was commercially made, while the mahogany plywood was made in the Laboratory. The average thickness and the specific gravity, based on volume and weight when oven dry, of random samples were as follows:

Specimen	Specific gravity
0.063-inch (3/48-inch) mahogany	0.48
.097-inch (3/32-inch) mahogany	.53
.204-inch (3/16-inch) mahogany	.49
.064-inch (3/48-inch) yellow birch	.63
.146-inch (3/20-inch) yellow birch	.64
.170-inch (3/16-inch) yellow birch	.66

Matching and Preparation of Specimens

Web Member-to-rib Cap and Rib-to-spar Specimens

For each of the web member-to-rib cap and rib-to-spar fastenings and for each condition, the specimens with plywood gussets of one species and thickness were designated as a series. When more than one depth (between gussets) of web member was employed for type I specimens, the specimens for each depth were designated as a separate series. One series with mahogany and one with yellow-poplar gussets included the entire range of design variables employed for each condition and each type of fastening, while for the remaining series, a more limited number of designs were selected to provide a comparison.

Sets of five specimens were made for each design included in a given series. One series for each species, condition, and type of fastening included additional sets in which the face grain of the gussets was at angles of 45° and 90° to the direction of loading.

All gussets for a given series of specimens were cut from a single sheet of plywood. The gussets for each specimen were cut in pairs with a common side, and pairs for each design were cut in line along the face grain of the plywood insofar as possible. For those series employing gussets of three face-grain directions, each three consecutive pairs included one pair for each grain direction.

With the exception of the spars, solid wood parts of each kind used in a given series were generally cut from a single solid piece. Parts for each specimen were selected at random for assembly.

Preparation of Corner-attachment Specimens

A set of five specimens was made for each of the corner-attachment designs shown in figure 3. For the specimens of size 1, the rib and spar parts of each were radially matched, and for each set of five these parts were end-matched consecutively. A single plank furnished rib and spar parts for specimens with corner blocks 6 inches long, and a second plank supplied those parts for specimens with corner blocks shorter than 6 inches and those with plywood angles.

For specimens of size 2, two planks furnished all of the spar and one-half of the rib parts. Parts from one plank were used for specimens with corner blocks and from the other for specimens with plywood angles. The balance of the rib parts in both groups was taken from a third plank. Consecutive end-matched spar parts and consecutive pairs of end-matched rib parts were used in each set of specimens.

Preparation of Saddle Gusset Specimens

Specimens of saddle gussets were made in sets of eight. The framing members of each species were cut consecutively from a single piece, and four consecutive pieces were used in each set. Gussets for each set were cut in line along the face grain of the plywood. Two saddle gussets were glued to each framing member as shown in figure 4.

Plywood Tensile Specimens

Tensile tests of the commercially produced, aircraft grade, plywoods employed specimens of the size shown in figure 5. Representative pieces from the sheets of plywood of each species and thickness were included in sets of five or six tensile specimens for each of 0°, 45°, and 90° grain directions.

Conditioning and Assembly

The parts for all glued-joint specimens were cut to size and conditioned to constant weight at 70° F. and 64 percent relative humidity prior to assembly. This conditioning was calculated to produce a moisture content of 12 percent in the wood. Care was taken to avoid excessive moisture changes during fabrication of the specimens. All completed specimens were reconditioned to constant weight at 70° F. and 64 percent relative humidity prior to testing.

Assembly Gluing

The glue used in this investigation for the assembly of typical aircraft joints was a cold-setting, urea-formaldehyde glue commonly used for such joints. This glue was mixed in the proportion of 65 grams of water to 100 grams of dry glue and applied when not less than 15 minutes nor more than 4 hours old. Maximum assembly time was 15 minutes.

All of the specimens were assembled in the carpenter shop, where glue was applied with a brush. For the web member-to-rib cap, rib-to-spar, and corner-attachment specimens, jigs were used to hold the parts in position while they were glued. Pressure was applied by means of 3/16- by 3/8-inch nailing strips with 5/8-inch No. 20 wire nails spaced approximately 3/4 inch apart. The nails and nailing strips were removed from specimens prior to testing. For saddle gusset specimens, pressure was applied to the glued joints by means of hand clamps.

Matched sets of five web member-to-rib cap specimens with 0.100-inch yellow-poplar gussets of design "T" (fig. 1) were made to compare the results obtained by three methods of applying gluing pressures. These methods included the use of removable nailing strips, the application of pressure with hand clamps, and nail-gluing with the nails left in place.

Methods of Test

The following methods were devised for testing the strengths of specimens of each of the four types of fastenings investigated.

Web member-to-rib cap specimens were tested as shown in figure 6 by applying a tensile load to the web member with the rib cap supported by self-adjusting knife edges placed 6 inches apart. Metal bearing blocks were placed on the knife edges to prevent crushing of the rib cap. Load was applied at the rate of head movement of 0.05 inch per minute by means of a spherically seated tensile grip. Small pieces of spruce were glued to either side of the web members of the larger specimens to avoid excessive crushing in the grip.

Rib-to-spar specimens were tested as cantilevers, as shown in figure 7, with the spar fixed and the load applied to the top of the rib at a point 9 inches from the face of the spar. To prevent crushing, the load was applied through a 2-inch steel block, and to prevent buckling, oak stiffeners were bolted to the loaded end of the rib. The rate of head movement was 0.015 inch per minute.

Measurements to determine the distribution of strains were made on the 0.070-inch yellow-poplar tension gusset of one rib-to-spar specimen of design SM (fig. 2). Five resistance-type electrical strain gages 3/4 inch long were bonded to the outer surface of the gusset in line with the junction between the rib and the spar, as shown in the sketch on figure 8. Gages equidistant from the center of the rib were wired in series and simultaneous readings of all gages were taken at each load increment by means of three Wheatstone bridges.

Tests of corner attachments were made by shearing the corner pieces from the spar or rib members under compressive loading, as illustrated in figure 9. The load was applied through a spherical head to the top of the spar piece while the specimen was supported by the bottom edges of the ribs. An adjustable hardwood frame, not shown in this figure, prevented the ribs from spreading, thus minimizing bending moments at the joints.

The saddle gusset specimens were tested in pairs held 3 inches apart by pieces screwed to the ends of the framing members, as shown in figure 4. Load was applied, by means of a 2-1/2 inch diameter spherical head, to the center of a 3-inch intercostal resting in the gussets, while the frame was supported on the table of the testing machine. Tests of these specimens using intercostals of Sitka spruce resulted in failure of the intercostals in bearing at the gussets. A steel bar was substituted for the spruce intercostal to determine the strengths of the saddle gusset.

Plywood tensile specimens, held by means of self-aligning, wedge-type grips, were loaded at a rate of head movement of 0.05 inch per minute. The elongation between gage points 2 inches apart was read at equal increments of load by means of a dial-gage extensometer.

Moisture and Specific Gravity Determinations

For all specimens, except saddle gussets, moisture and specific gravity determinations were made from pieces cut from each specimen immediately after testing. For the web member-to-rib cap and the rib-to-spar specimens, determinations were made for the plywood gussets and for the solid wood member of the critical joint. For corner-attachment specimens, samples were cut from the rib or spar pieces in which failure was predominant. For the parts of saddle gusset specimens, specific gravity and moisture determinations were made from end-matched samples conditioned with the test specimens.

Explanation of Tables and Charts

The relationship of strains at various points across the width of the tensile gusset of a rib-to-spar specimen to the cantilever load applied to the specimen are shown in figure 8. A sketch showing the positions of the strain gages on the specimen is included in this figure.

The average ultimate tensile strengths of gussets in rib-to-spar and web member-to-rib cap specimens (condition 1) are recorded in table 1. The relationship between tensile strength and width of gusset in these types of fastenings are shown graphically in figure 10 for each species, thickness, and grain direction of plywood tested. Each plotted point represents the average ultimate tensile strength per gusset of five test specimens. In plotting the tensile strengths of gussets in rib-to-spar specimens, 140 pounds were deducted from each value in table 1 to allow for moment resisted by the corner block joints (see page 11). The plotted tensile strengths of gussets of Laboratory-made plywood were adjusted in accordance with ANC Bulletin No. 18 to the average specific gravity of the commercial plywood and increased by the average difference in thickness.

The results of tensile tests of commercially produced plywoods of aircraft grade are recorded in table 2.

The average ultimate shearing strengths of the joints between gussets and spars in rib-to-spar specimens and of the joints between gussets and rib caps in web member-to-rib cap specimens (condition 2) are recorded in table 3. The relationships between shearing strength and area of joint are shown on separate graphs in figure 11 for each type of specimen. Each plotted point represents the average ultimate shearing strength per gusset of five test specimens. In plotting the shearing strengths of gusset-spar joints in rib-to-spar specimens, 140 pounds were deducted from each value in table 1 to allow for moment resisted by the corner block joints. A solid line on each graph shows one-third the ultimate shearing strength of spruce parallel to grain as given in ANC Bulletin No. 18 adjusted to the average moisture content of the specimens.

The average ultimate shearing strengths of the joints between the gussets and web members (condition 3) in web member-to-rib cap specimens are recorded in table 4. The relationships between shearing strength and area of joint are shown graphically in figure 12. Each plotted point represents the average ultimate shearing strength per gusset of five specimens.

The average ultimate shearing strengths of the joints between gussets and ribs (condition 3) in rib-to-spar specimens are recorded in table 5. The relationship between shearing strength and area of joint is shown graphically on figure 13. Each plotted point represents the average ultimate shearing strength of five specimens with no deduction for moment resisted by the corner blocks.

The results of tests of shearing strength of corner attachments of ribs to spars are recorded in table 6. Because of differences in moisture content and specific gravity of the Sitka spruce in the series of specimens, the values were adjusted in accordance with ANC Bulletin No. 18 to 12 percent moisture content and 0.40 specific gravity (based on volume and weight when oven dry). The exponent of the specific gravity ratio used to adjust shearing strength perpendicular to the grain was 1.58 (1.33 between species + 0.25 within species). The relationship of shearing strength to area of joint of solid wood corner blocks is shown graphically in figure 14.

Each plotted point represents the average ultimate shearing strength of five specimens. The average shearing strength of all specimens of each size employing plywood angles is included in the graph for comparison. A solid line shows one-third the shearing strength value of spruce parallel to grain as given in ANC Bulletin No. 18 adjusted to the moisture content of the specimens.

The results of tests of plywood saddle gussets glued to solid wood framing members are recorded in table 7.

Analysis of Results

In all of the specimens included in this analysis, the glued joints, where critical, developed the full strength of the wood in shear. Matched specimens of design "T" (fig. 1) in which nails that were left in place or clamps were used for gluing pressure were of essentially the same strength as those in which removable nailing strips were used.

Exploratory tests disclosed that the ultimate strength or the manner of failure could not be predicted from established unit strength values applied to the areas involved. The various gusset designs were therefore determined from exploratory tests and from experience gained as the work progressed.

Tensile Tests of Commercial Plywood

In commercial plywood, differences in density, slope of grain, and thickness of individual plies within allowable tolerances may result in a wide range of tensile strengths within a single sheet. The tensile strengths of individual specimens in these tests varied as much as 25 percent above or below the average values listed in table 1. The tensile strength of plywood with grain at an angle of 45° to the direction of load is not developed by this type of specimen, as failures are largely due to shear.

The tensile strength of the yellow-poplar plywood, because of its unusually high density, was somewhat higher than that of the mahogany. The yellow-poplar used in this investigation should therefore be considered as of the medium-density group.

A comparison of the unit tensile strengths obtained by tests with similar values given in ANC Bulletin 18 was made by comparing the sums of the parallel and perpendicular values. For this purpose the values in ANC Bulletin 18 were divided by the variability and rate-of-loading factors and adjusted in accordance with that handbook to the average specific gravity and moisture content of each plywood at time of test. These corrections were large, aggregating more than 200 percent in some cases. The results obtained by tensile tests of plywoods expressed as percentages of the adjusted handbook values were as follows:

Type of plywood	Tensile strength, percent of handbook value
0.070-inch yellow-poplar	95
.100-inch yellow-poplar	99
.125-inch yellow-poplar	94
.070-inch mahogany	110
.100-inch mahogany	118
.125-inch mahogany	103

Comparison of Rib-to-spar with Web Member-to-rib Cap Specimens

The strengths of gusset fastenings in rib-to-spar specimens were computed by assuming that all of the moment applied by the cantilever loading was resisted by the gussets (tables 1, 3, and 5). Under condition 1 (tensile failures of gussets) and condition 2 (shearing failures of gusset-spar joints), the average strength values thus obtained were found to be consistently higher by about 140 pounds than those obtained by tests of web member-to-rib cap fastenings with gussets of essentially the same dimensions. This difference was apparently contributed by the corner blocks. For the graphs of figures 10 and 11, the average computed strengths were reduced by 140 pounds to allow for moment resisted by the corner block joints.

The corner blocks of rib-to-spar fastenings under condition 3 (shearing failures of gusset-rib cap joints) probably also contribute to the ultimate strengh, but their influence cannot be evaluated by comparison with web member-to-rib cap specimens.

A few types of corner attachments in cantilever type rib-to-spar specimens were tested without gussets. The average ultimate loads, 9 inches from the joints, of such specimens at 12 percent moisture content were as follows:

Corner attachment	Average ultimate load of five specimens
	Pounds
1/2- by 1/2-inch triangular Sitka spruce	163
3/4- by 3/4-inch triangular Sitka spruce	182
1/16-inch yellow-poplar plywood angles	57
1/16-inch yellow birch plywood angles	60
1/8-inch sweetgum plywood angles	108

Triangular corner blocks 1/2 by 1/2 inch, the kind and size used exclusively with rib-to-spar gusset fastenings, are thus shown to have an ultimate resistance equivalent to a tension of 244 pounds (163 x 9/6) in the gusset of a gusset-type fastening. That their contribution to the strength of fastenings of this type was only about 140 pounds is attributed to failure of the corner blocks to reach their ultimate strength when failure by tension of the gusset or shear of the gusset from the spar occurred.

Tensile Strengths of Gussets in Typical Fastenings
(Condition 1, Fig. 10)

The test data show that the rate of increase in the ultimate tensile strength of a gusset (P) decreases as the width of gusset (W) is increased. For 0.07- and 0.10-inch yellow-poplar and 0.07- and 0.125-inch mahogany plywoods with face grain parallel (0°) to the direction of loading, the series of tests were more extensive than for other orientations of face grain and included both types of specimens. In figure 10, the plotted data from the two types of specimens define similar curves for each of these plywoods. The empirical curves are closely approximated by the equation:

$$P = KFtW^{0.7}$$

where

K = a constant

t = thickness of plywood in inches

F = tensile strength of plywood in pounds per square inch

The data for 0.125-inch yellow-poplar and 0.10-inch mahogany cover a lesser range of width of gusset but are nevertheless in conformity to equations of the same type.

The implication of these equations, since they contain width to a power less than unity, is that tensile strength of a gusset does not increase in proportion when the width is increased. That this should be true is apparent from the fact that tension is applied through a member of lesser width than that of the gusset and is supported by the further fact of nonuniformity of strain as indicated by figure 8. A rational basis for taking the value of K as 0.75 for a width of tension member of 3/8 inch is that if it is assumed that, in a gusset of this same width, stress is uniformly distributed, a value of $K = 0.75$ is necessary to give that result, namely $P = 3/8$ Ft. If the power of W were taken as two-thirds, the necessary value of K would then be 0.72.

The following tabulation shows values of K obtained by dividing the empirical coefficients of $W^{0.7}$ by the thickness and by the tensile-strength values for the corresponding plywoods as found from test and recorded in table 2:

Plywood	K
0.075-inch yellow-poplar	0.69
.102-inch yellow-poplar	.76
.138-inch yellow-poplar	.61
.073-inch mahogany	.81
.104-inch mahogany	.76
.134-inch mahogany	.68
Average of all	.72

The fact that these values average 0.72 and that this is the value of K that corresponds to two-thirds as the exponent of W suggest that these values of coefficient and exponent would be as valid as 0.75 and 0.7. Hence, the general equation may be written:

$$P = 0.72\ FtW^{2/3}$$

Values of $W^{2/3}$ are somewhat easier to compute, and the difference between the resulting curves is not significant.

In these tests, the width of the member (rib in rib-to-spar specimens or web member in web member-to-rib cap specimens) through which load was applied to the gusset was kept constant at 3/8 inch. Hence, the equations given previously are strictly applicable only to that width. It may be noted, however, that 0.72, the coefficient in the equation derived from tests made with tension members 3/8 inch wide, is equal to $(3/8)^{1/3}$. It is suggested, therefore, that for other values of w within reasonable limits (such as from 1/4 to 1 inch) an estimate of the tensile strength of the gusset may be obtained from the following formula:

$$P = Ftw^{1/3}W^{2/3} = Ft\sqrt[3]{w\ W^2}$$

where

W = the width of the gusset (inches)

and

w = the width of the tension member to which the gusset is glued (inches)

The quantity, $\sqrt[3]{wW^2}$, may be considered the effective width, that is, the width by which the tensile strength of the plywood in pounds per inch of width is to be multiplied to get the strength of the gusset.

The data for gussets with face grain at 45° or 90° are more variable than for those at 0°, and the strength-width relationship is not always well defined in these more limited series. Conservative values that are generally applicable to the data can be determined by using 67 percent of the strengths at 0° for gussets at 45°, and 90 percent of the strength at 0° for those at 90°.

Distribution of Stresses in Gussets

Measurements of strains in a tensile gusset 4 inches wide in a rib-to-spar joint taken in line with the junction between the rib and the spar (fig. 8) show that stress concentrations exist at the center of the gusset that cause failures to occur when the plywood beyond 3/4 inch from the center has developed about half its tensile strength. Stresses are more uniformly distributed at lower loads. The change in stress distribution with load causes the stress-strain graph of the central portion of the gusset to be curved throughout its length.

Shearing Strength of Joints Between Plywood Gussets and Sitka Spruce with Grain Perpendicular to the Direction of Loading (Condition 2, Fig. 11)

In designing specimens for testing the shearing strength of joints between gussets and solid members perpendicular to the load (condition 2) the shearing areas had to be kept small to prevent failure in other elements. In exploratory tests, specimens were used in which the rib caps were 1/2 inch thick and of sufficient depth to prevent failure in bending. When gussets wide enough to resist the tensile load were placed entirely across the rib cap, failure occurred in the gusset-web member joints. With gussets across only a portion of their depth, rib caps 1/2 inch thick split at the ends of the gussets, after which only the material covered by the gusset was effective in resisting bending. To avoid splitting and to induce the desired manner of failure, the solid members were therefore made disproportionately thick. Rib caps of greater depth than the gussets (fig. 1) were used only for expediency.

Failures of all joints of condition 2 were due to shearing of Sitka spruce perpendicular to the grain. The average shearing strength of these joints was approximately one-third the shearing strength of spruce parallel to the grain[2] (values of ANC Bulletin No. 18 adjusted to moisture content of the specimens) when the joints were about 3 square inches in area (fig. 11). The shearing strengths of smaller areas were somewhat greater.

The shearing strength of joints between gussets and spruce members under forces perpendicular to the direction of grain in the members was essentially the same for all species and thicknesses of plywood investigated for use in gussets and for all face grain directions.

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[2] In block shear tests of glued joints at various angles to the grain, the shearing strength perpendicular to the grain of softwoods was shown to be one-third of the shearing strength parallel to the grain, Forest Products Laboratory Report No. 1522.

Shearing Strengths of Gusset-web Member Joints of Web Member-to-rib Cap Fastenings (Condition 3, Fig. 12)

The plotted test data of condition 3 show that the shearing strengths of the joints between gussets and web members 3/8 inch thick increased at a diminishing rate as the length was increased. The maximum shearing strength that can be developed in such fastenings depends on the species and dimensions of the web member. The length of joint required to obtain this maximum strength was twice the length required to develop about 80 percent of that value. The range in length of joints employed for 3/4- by 1-inch web members did not permit developing the maximum possible shearing load for a member of that size.

The curves of figure 12 show that the greatest tensile load that can be sustained by web member-to-rib cap fastenings employing Sitka spruce web members 3/8 inch thick is about 1,400 pounds (700 pounds per gusset) when the depth between gussets is 1/2 inch and about 2,000 pounds when the depth is 1 inch. These loads are 77 and 55 percent, respectively, of the tensile strengths of the web members as determined from modulus of rupture values given in ANC Bulletin 18 (adjusted to moisture content of specimens but without the variability and rate of loading factors). The efficiency of such fastenings varies, therefore, with the ratio of the width of web member at the joint to its depth between gussets. The ultimate tensile strengths of the web members could not be developed by web member-to-rib cap fastenings of the construction used in this study.

The shearing strengths of joints between Sitka spruce web members and plywood gussets were essentially the same for all species, thicknesses, and grain directions of plywood. Failures were preponderantly in the Sitka spruce. Plywoods with face grain parallel to the loading were not generally delaminated, although partial delamination occurred in some instances. The ultimate loads of specimens with partial plywood failures were equal to those failing entirely in Sitka spruce.

It is notable that failure occurred in the spruce member and parallel to the grain regardless of the grain orientation in the gusset. This may be partially accounted for by the lower moisture contents (about 9 percent) attained by the aircraft plywoods when conditioned in a relative humidity producing 12 percent moisture content in the Sitka spruce members. This difference in moisture content between aircraft plywoods and Sitka spruce was found consistently throughout the tests.

The use of yellow birch members, in a limited number of specimens, resulted in shearing strengths proportionately higher than for Sitka spruce. Most of the failures were in the yellow birch; the yellow-poplar plywood with face grain parallel to the direction of loading was not delaminated.

Shearing Strength of Gusset-rib Joints in Rib-to-spar Fastenings (Condition 3, Fig. 13)

The rate of increase in the shearing strength of glued joints between gussets and ribs in rib-to-spar specimens diminished as the length of joint was increased. Maximum attainable shearing strengths, however, were not reached within the range of lengths employed in these series. Although nearly all failures were due to shearing of the Sitka spruce rib, the decrease in unit strength with increase in length of joint was much less in specimens with gussets 0.125 inch thick than in those with gussets 0.100 inch thick. The ultimate strengths of specimens with 0.125-inch gussets were about 40 percent higher than those with 0.100-inch gussets when the joints were 5 inches long. Lower values resulted, however, when very narrow gussets of 0.125-inch plywood were used (designs ST, SU1, and SV, table 5).

Shearing Strengths of Corner Attachments (Fig. 14)

Specimens with Sitka spruce corner blocks were originally planned only in size 1 shown in figure 3. Since their ultimate strengths with corner blocks of the larger sizes apparently exceeded the compressive strength of the ribs and spars, a similar series of specimens with larger members (size 2) was prepared and tested. Specimens with solid corner blocks developed higher shearing strengths in the larger specimens than in the smaller specimens. The shearing strengths of specimens with plywood angles, however, were about the same for both sizes of specimen.

The plotted data for solid wood corner blocks in figure 14 show that for total areas of joints of 12 square inches, (3 square inches per joint) or less, at least one-third of the shearing strength of spruce parallel to the grain was developed. For specimens of both sizes, the amount of increase in ultimate strength with increase in area became small when the area of the joints exceeded 12 square inches.

The shearing strengths of specimens with square corner blocks were essentially the same as for specimens with triangular blocks having the same glue areas.

In specimens with either solid wood corner blocks or plywood angles, nearly all failures were in the perpendicularly grained Sitka spruce of the ribs or spars, that is, in parts subjected to so-called "rolling shear." The strengths of specimens with plywood angles increased somewhat with the thickness of plywood.

The relative efficiencies of the various types of corner attachments of 6-inch length in specimens of size 2 are shown by the following tabulation:

Triangular corner blocks	Shearing strength Pounds per gram of weight
1/4- by 1/4-inch Sitka spruce	570
3/8- by 3/8-inch Sitka spruce	306
1/2- by 1/2-inch Sitka spruce	224
5/8- by 5/8-inch Sitka spruce	152
3/4- by 3/4-inch Sitka spruce	107
Plywood angles	
0.07-inch sweetgum	161
.07-inch yellow-poplar	156
.10-inch mahogany-yellow-poplar-mahogany	131
.07-inch yellow birch	111
.125-inch sweetgum	103

Saddle Gussets

Tests of saddle gussets were confined to an exploratory series, since further investigation was deemed unnecessary. The results of these tests, presented in table 7, show that the strengths of saddle gussets in sizes normally used greatly exceeded the bearing strength of wood intercostals. In all but the largest sizes, the saddle gussets failed either in bearing or by shearing out the bottom of the gusset, when tested with a steel bar substituted for the intercostal. The larger gussets were sheared from the framing member at loads exceeding one-third of the shearing strength parallel to the grain of the Douglas-fir or Sitka spruce used for the framing members.

Conclusions

The cold-setting urea-formaldehyde glue used throughout these tests developed sufficient shearing strength to cause wood failures in all specimens. It is therefore presumed that similar results would have been obtained with any efficient glue.

Properties of Gusset Fastenings

The strengths of glued fastenings in which perpendicular members are joined by plywood gussets could not be predicted by applying established unit strength values to the areas involved. Strain measurements taken across the width of a gusset showed that concentrations of stress caused failures to occur before the tensile strength of the entire area of plywood could be developed. The results of shear tests of the glued joints indicated that stress concentrations also prevented the development of the shearing strength of the entire area of the joint. The extent to which the strengths of such fastenings were affected by stress concentrations varied with the relative size, shape, and elastic properties of the joined members.

Gussets of medium density and 0.07 inch or more in thickness developed the full shearing strength of either parallel or perpendicular Sitka spruce members regardless of the direction of the face grain of the plywood. Delamination of the plywood did not generally occur, and the strengths of joints showing partial plywood failures were equal to those failing entirely in the spruce.

Condition 1: Tensile Strengths of Gussets in Glued Fastenings

The ultimate tensile strengths of gussets in the typical fastenings tested increased approximately as the two-thirds power of the width. An empirical formula, applicable to the test data, for the determination of the ultimate tensile strengths (P) of gussets when the face grain is parallel (0°) to the direction of loading is:

$$P = Ft \sqrt[3]{wW^2}$$

where

F = tensile strength of the plywood -- pounds per square inch

t = thickness of plywood -- inches

W = width of gusset -- inches

w = width of the tension member to which the gusset is glued -- inches

Conservative values generally applicable to the test data are obtained when 67 percent of the 0° value is used for gussets at 45°, and 90 percent for those at 90°. It is preferable, however, to orient the face grain in the direction of the stress or parallel to the tension member when other members are involved.

A high tensile strength can be attained with narrow gussets by using thick plywoods of high density. Wider and thinner gussets of medium density, however, are usually more efficient and provide a larger joint area and better distribution of stress on the perpendicular member.

Condition 2: Shearing Strengths of Joints Between Gussets and Members with Grain Perpendicular to the Direction of Loading

Gussets should be extended entirely across the width of a perpendicular member to avoid the possibility of its cracking or splitting under tensile loads. Since the width of a gusset is determined by the tensile (or compressive) strength, the area of joint thus provided is generally more than sufficient to induce failure in other elements. The unit shearing strengths of joints of the limited areas that could be tested by using specimens of unbalanced design equalled or exceeded one-third of the shearing strength of spruce parallel to grain as given in ANC Bulletin 18.

Condition 3: Shearing Strengths of Joints Between Gussets and Narrow Members with Grain Parallel to the Direction of Loading

In the joints between gussets and web members of web member-to-rib cap specimens, a maximum shearing strength was reached (depending upon the species and dimensions of the web member) that apparently could not be exceeded by further increases in the length of joint. The tensile strength of the web member was not developed by this type of fastening, since it exceeded the maximum shearing strength. The proportion of the tensile strength that could be attained varied with the ratio of the width of the web member to its depth between gussets.

The unit shearing strengths of joints long enough to attain the maximum value were equal to or greater than one-third the shearing strength of spruce parallel to the grain as given in ANC Bulletin 18. The length of joint required to obtain the maximum shearing strength, however, was twice the length required to develop about 80 percent of that value.

In rib-to-spar specimens, the maximum attainable shearing strength was not indicated within the range of lengths of gusset-to-rib joints employed. The distribution of stresses was apparently improved when the plywood thickness was increased. The unit shearing strengths of all rib-to-spar specimens tested under this condition exceeded one-half the shearing strength of spruce parallel to the grain as given in ANC Bulletin 18.

Shearing Strengths of Corner Attachments

The unit shearing strengths of all corner attachments tested exceeded one-third the shearing strength of spruce parallel to the grain as given in ANC Bulletin 18 when the total area of joints was not greater than 12 square inches (3 square inches per joint). The increase in ultimate strength with increase in area became small, however, when the area per joint exceeded 3 square inches.

Specimens with triangular corner blocks were equal in strength to those constructed with rectangular ones having the same glue areas.

Of the plywood angles investigated, those of medium density and 0.07-inch thickness were most efficient. Such plywood angles with gluing surfaces 3/4 inch wide were more efficient on a strength-weight basis than triangular spruce corner blocks in sizes larger than 1/2 by 1/2 inch.

Bearing Strength of Saddle Gussets

The saddle gusset specimens were higher in bearing strength than the wood intercostals they were designed to support. The shearing strengths of those in which the gusset was sheared from the framing member exceeded one-third of the shearing strength parallel to the grain of the species of the framing member.

Applications of Results of Tests

The strength-area relationships of the various elements of glued joints presented herein should aid in obtaining efficient designs in glued fastenings employing joints of sizes within the scope of this investigation. In the gusset fastenings studied, the widths of the members with grain parallel to the direction of loading were largely confined to 3/8 inch. The relationships shown, however, are believed generally applicable to any fastening involving narrow longitudinal members of like proportions. The results of these tests should be of value in the design of fastenings of other sizes or types, subject to confirmation by actual tests.

Table 1.--Results of tests of glued fastenings with plywood gussets
Condition 1.--Tensile strengths of plywood gussets

Type of fastening	Description of gussets: Nominal thickness	Description of gussets: Angle of face grain to load	Description of gussets: Width of gussets at joint	With yellow-poplar gussets: Design	Yellow-poplar gussets: Area of cross section	Yellow-poplar gussets: Moisture content	Yellow-poplar gussets: Specific gravity[1]	Sitka spruce: Moisture content	Sitka spruce: Specific gravity[1]	Average maximum tensile strength of five specimens[2]	With mahogany gussets: Design	Mahogany gussets: Area of cross section	Mahogany gussets: Moisture content	Mahogany gussets: Specific gravity[1]	Sitka spruce: Moisture content	Sitka spruce: Specific gravity[1]	Average maximum tensile strength of five specimens[2]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
	Inch	Degrees	Inches		Square inch	Percent		Percent		Pounds		Square inch	Percent		Percent		Pounds
Web member to rib cap (Two gussets in tension)	0.070	0	0.625	A4	0.0958	8.6	0.592	10.9	0.413	933	....	....	....	....	....	....	....
			.625	A2	.0967	8.6	.592	11.5	.414	826	A1	0.0937	8.6	0.620	11.8	0.408	699
			.750	B2	.1181	8.6	.592	10.9	.414	910	B1	.1112	11.0	.561	11.6	.419	756
			.875	C2	.1377	8.6	.592	10.9	.398	1,160	C1	.1340	8.9	.563	13.3	.428	866
			1.000	D2	.1550	8.6	.592	11.1	.409	1,121	D1	.1501	9.0	.602	12.2	.411	879
			1.500	E2	.2379	8.4	.636	11.1	.407	1,395	E1	.2196	9.2	.567	11.5	.397	1,134
			2.000	F2	.3031	8.0	.592	11.4	.391	1,677	F1	.2830	8.0	.586	11.1	.398	1,386
	.100	0	.625	A3	.1281	8.3	.548	12.0	.416	928	A1	.1342	8.3	.544	12.0	.403	894
			.750	B3	.1556	7.2	.624	12.1	.409	1,133	B1	.1551	7.5	.559	11.6	.395	1,002
			.875	C3	.1748	7.7	.643	11.9	.412	1,258	C1	.1808	7.5	.597	12.7	.419	1,071
			1.000	D3	.1983	7.7	.661	12.4	.409	1,382	D1	.2088	8.3	.551	12.2	.399	1,234
		45	.625	A3	.1293	8.3	.548	12.6	.431	670	A1	.1314	8.3	.544	11.3	.382	556
			.750	B3	.1526	7.2	.624	12.1	.423	688	B1	.1541	7.5	.559	12.3	.392	672
			.875	C3	.1755	7.7	.643	12.5	.418	850	C1	.1810	7.5	.597	12.4	.412	713
			1.000	D3	.1991	7.7	.661	12.5	.418	847	D1	.2036	8.3	.551	12.5	.404	835
		90	.625	A3	.1287	8.3	.548	12.2	.413	961	A1	.1316	8.3	.544	11.7	.398	740
			.750	B3	.1516	7.2	.624	12.2	.420	900	B1	.1571	7.5	.559	12.6	.400	961
			.875	C3	.1799	7.7	.643	12.3	.422	1,342	C1	.1766	7.5	.597	12.8	.395	996
			1.000	D3	.1980	7.7	.661	12.4	.420	1,224	D1	.2075	8.3	.551	12.3	.405	1,144
	.125	0	.625	A3	.1711	8.1	.522	12.8	.407	926	A1	.1721	8.0	.545	11.4	.409	712
			.750	B3	.2103	8.1	.522	13.1	.415	1,144	B1	.2018	8.0	.505	11.3	.422	914
			.875	C3	.2440	8.1	.522	12.2	.379	1,286	C1	.2371	7.8	.495	11.3	.401	1,007
			1.000	D3	.2720	8.1	.522	11.6	.383	1,337	D1	.2676	8.0	.520	11.4	.423	1,236
			1.500	....	....	....	....	....	....	....	E1	.4074	8.3	.550	11.5	.396	1,520
			2.000	....	....	....	....	....	....	....	F1	.5291	7.7	.535	11.6	.397	1,917
			2.500	....	....	....	....	....	....	....	H3	.6584	8.2	.530	13.1	.441	2,151
Rib to spar (One gusset in tension)	.070	0	.625	SA2	.0472	8.6	.596	12.7	.405	516	SA1	.0453	8.9	.588	11.2	.389	447
			1.000	SC1	.0774	9.0	.593	12.7	.387	691	SC1	.0720	8.2	.590	12.8	.385	696
			1.500	SE1	.1118	8.4	.544	11.6	.410	896	SE1	.1093	10.0	.570	12.4	.385	747
			1.750	SF1	.1300	6.9	.608	11.8	.389	993	SF1	.1257	8.4	.590	12.2	.387	782
			2.000	SG1	.1483	7.5	.619	12.1	.398	996	SG1	.1439	9.0	.584	11.9	.384	876
			2.000	[3]SG2	.1260	8.8	.475	11.9	.389	584	....	....	....	....	....	....	....
			2.250	SH1	.1676	7.6	.566	11.9	.397	1,191	SH1	.1613	8.9	.574	11.9	.381	970
			2.500	SJ1[3]	.1575	9.0	.474	11.7	.370	714	....	....	....	....	....	....	....
			3.000	SK1[3]	.1890	9.1	.493	11.7	.359	811	....	....	....	....	....	....	....
			3.500	SL1[3]	.2205	9.1	.481	11.9	.364	882	....	....	....	....	....	....	....
			4.000	SM1[3]	.2520	9.0	.499	11.5	.361	945	....	....	....	....	....	....	....
		45	.750	SB1	.0574	7.9	.595	11.0	.380	411	....	....	....	....	....	....	....
			1.000	SC1	.0744	7.9	.570	11.8	.384	541	SC1	.0684	8.2	.583	11.3	.408	457
			1.250	SD2	.0955	7.9	.584	10.5	.383	513	....	....	....	....	....	....	....
			1.500	SE1	.1137	8.2	.542	12.5	.405	672	SE1	.1102	9.4	.591	13.0	.397	542
			1.750	SF1	.1346	8.3	.541	12.7	.405	721	SF1	.1302	7.8	.600	12.3	.406	730
			2.000	SG1	.1531	8.1	.616	12.7	.397	828	SG1	.1452	6.9	.613	12.8	.411	758
			2.250	SH1	.1702	8.3	.615	12.7	.405	1,009	SH1	.1597	7.7	.602	12.3	.413	775
		90	1.000	SC1	.0754	8.7	.582	11.4	.391	607	SC1	.0691	9.1	.578	11.5	.394	558
			1.500	SE1	.1135	8.2	.542	12.8	.413	762	SE1	.1099	9.7	.587	12.4	.414	783
			1.750	SF1	.1331	8.0	.596	13.0	.407	783	SF1	.1292	8.5	.572	12.6	.397	831
			2.000	SG1	.1496	8.1	.614	12.7	.399	980	SG1	.1435	7.0	.614	12.5	.434	836
			2.250	SH1	.1723	8.4	.603	12.4	.417	1,203	SH1	.1634	7.2	.610	12.0	.409	942
	.100	0	.750	SB	.0817	8.5	.589	12.2	.401	676	....	....	....	....	....	....	....
			1.250	SD	.1172	8.8	.650	12.7	.397	917	....	....	....	....	....	....	....
			1.750	SF2	.1727	8.9	.611	13.5	.396	1,147	....	....	....	....	....	....	....
			2.250	SH2	.2213	8.1	.590	12.3	.393	1,262	....	....	....	....	....	....	....
	.125	0	1.000	....	....	....	....	....	....	....	SC2	.1349	8.5	.536	12.4	.440	720
			1.500	....	....	....	....	....	....	....	SE2	.1956	8.2	.540	12.2	.389	898
			1.750	....	....	....	....	....	....	....	SF3	.2232	8.1	.554	11.9	.398	990
			2.000	....	....	....	....	....	....	....	SG2	.2619	8.4	.542	12.3	.387	1,080
			2.250	....	....	....	....	....	....	....	SH2	.2912	8.3	.562	12.9	.390	1,065

[1]Based on volume and weight when oven dry.

[2]Corner blocks of rib-to-spar fastenings assumed to carry no tensile load.

[3]Plywood made in the Laboratory.

Table 2.--Results of tensile tests of commercially produced aircraft plywoods

Plywood			Properties of specimens[2]				
Species	Nominal thickness	Angle of face grain to load	Moisture content	Specific gravity[2]	Stress at proportional limit	Ultimate strength in tension	Modulus of elasticity
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Inch	Degrees	Percent		Psi	Psi	1,000 psi
Yellow-poplar	0.070	0	8.2	0.592	8,510	10,480	1,018
		45	7.9	.640	2,510	4,400	177
		90	8.7	.560	3,430	5,880	714
	.100	0	8.3	.569	6,840	8,570	1,014
		45	8.1	.616	2,120	4,020	186
		90	8.2	.557	4,880	7,940	883
	.125	0	7.8	.564	7,480	9,300	970
		45	8.2	.579	1,420	2,770	145
		90	8.1	.576	4,600	6,860	765
Mahogany	.070	0	9.2	.593	5,090	7,400	1,030
		45	9.3	.553	2,190	3,330	142
		90	10.6	.584	5,180	8,060	804
	.100	0	8.6	.538	5,340	7,660	1,158
		45	7.2	.561	2,140	3,470	185
		90	10.8	.549	3,640	7,060	784
	.125	0	8.7	.531	3,770	6,130	975
		45	7.5	.536	2,130	3,760	187
		90	10.1	.552	3,670	6,620	688

[1]Average values of 5 or 6 specimens.

[2]Based on volume and weight when oven-dry.

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Table 3.--Results of tests of glued[1] fastenings with plywood gussets
Condition 2.--Shearing strengths of joints between gussets and members with grain perpendicular to the direction of loading.

Type of fastening	Description of fastenings: Gusset-to-rib-cap joints: Area	Gusset-to-rib-cap joints: Width of gussets	Gusset-to-rib-cap joints: Depth on rib cap	Plywood gussets: Design	Plywood gussets: Angle of face grain to load	Plywood gussets: Nominal thickness	Properties of fastenings: With yellow-poplar gussets: Sitka spruce rib caps: Moisture content	Sitka spruce rib caps: Specific gravity[2]	Yellow-poplar gussets: Moisture content	Yellow-poplar gussets: Specific gravity[2]	Average maximum shearing strength of five specimens[3]	With mahogany gussets: Sitka spruce rib caps: Moisture content	Sitka spruce rib caps: Specific gravity[2]	Mahogany gussets: Moisture content	Mahogany gussets: Specific gravity[2]	Average maximum shearing strength of five specimens[3]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
	Square Inches	Inches	Inches		Degrees	Inch	Percent		Percent		Pounds	Percent		Percent		Pounds
Web member to rib cap	0.7500	1.000	0.375	S	0	0.070	12.8	0.390	8.4	0.556	324	12.2	0.412	9.9	0.597	328
					0	.100	13.6	.410	7.4	.591	319	12.5	.402	7.7	.552	317
					45	.100	12.6	.401	7.4	.591	302					
					90	.100	13.2	.415	7.4	.591	329					
					0	.125	12.4	.379	8.2	.552	353	13.2	.400	8.6	.550	269
					45	.125						12.7	.402	8.6	.550	272
					90	.125						12.6	.397	8.6	.550	252
	1.3750	1.375	.500	T	0	.070	12.9	.382	8.4	.556	575	12.4	.397	8.0	.602	618
					[illegible]	.100	12.8	.407	6.9	.645	548					
					[illegible]	.100	12.5	.388	6.9	.630	507					
					0	.100	12.4	.396	8.2	.585	564	12.4	.398	7.6	.553	629
					45	.100	12.0	.404	8.2	.585	570					
					90	.100	12.2	.406	8.2	.585	496					
					0	.125	12.5	.380	8.2	.552	506	11.8	.399	7.7	.546	470
	2.1875	1.750	.625	U	0	.070	13.2	.393	8.4	.556	857	12.3	.398	7.8	.592	721
					0	.100	12.9	.403	7.6	.610	788	12.3	.401	7.7	.510	705
					45	.100	13.1	.389	7.6	.610	728					
					90	.100	12.9	.400	7.6	.610	763					
					0	.125	13.4	.384	8.2	.552	840	12.2	.391	8.4	.549	652
					45	.125						12.5	.403	8.4	.549	700
					90	.125						12.6	.407	8.4	.549	731
	3.1875	2.125	.750	V	0	.070	13.4	.394	8.4	.556	1,085	12.4	.403	8.4	.562	945
					0	.100	13.3	.410	7.6	.577	986	12.3	.407	8.2	.530	918
					45	.100	13.0	.416	7.6	.577	961					
					90	.100	12.6	.402	7.6	.577	999					
					0	.125	13.4	.395	8.2	.552	1,152	11.7	.400	7.8	.548	931
	1.8750	.625	1.500	W	0	.125	12.3	.407	7.5	.561	785					
	2.2500	.750	1.500	X	0	.125	11.5	.407	8.1	.556	1,158					
	2.6250	.875	1.500	Y	0	.125	11.7	.422	8.1	.556	1,231					
					90	.125	11.7	.411	8.0	.544	1,151					
	3.0000	1.000	1.500	Z	0	.125	11.5	.406	8.1	.556	1,366					
Rib to spar	.5625	.750	.750	SZ1	0	.070	11.0	.395	8.2	.631	428	11.1	.374	8.0	.614	420
					90	.070	11.0	.381	8.1	.578	419	11.6	.386	8.5	.524	410
	.7500	.750	1.000	ST1	0	.100						11.8	.403	7.7	.556	480
	.9375	1.250	.750	SZ2	0	.070	10.2	.405	7.8	.587	549	11.1	.382	8.2	.595	552
					90	.070	11.1	.385	8.0	.582	528	11.1	.396	8.5	.524	571
	1.0000	1.000	1.000	ST2	0	.100	10.6	.414	8.3	.551	687					
					0	.125	11.4	.430	8.1	.522	705					
	1.0200	.750	1.360	SZ1	0	.125						12.2	.405	8.8	.553	630
	1.2500	1.250	1.000	ST3	0	.100						11.7	.390	8.2	.542	545
	1.3125	1.750	.750	SZ3	0	.070	11.3	.383	8.6	.612	585	11.9	.407	8.5	.561	639
	1.6310	1.250	1.305	SZ2	0	.125						12.5	.399	8.9	.532	740
	1.7500	1.750	1.000	ST4	0	.100						11.5	.386	7.8	.560	723
	2.2500	2.250	1.000	ST5	0	.100						10.4	.401	8.2	.542	852
	2.2940	1.750	1.311	SZ3	0	.125						12.1	.405	9.2	.549	867

[1] Urea-formaldehyde cold-setting glue. Pressure applied by removable nailing strips except where noted.

[2] Based on volume and weight when oven dry.

[3] Corner block joints of rib-to-spar specimens assumed to carry no tensile load.

[4] Gluing pressure applied with clamps.

[5] Gluing pressure applied with nails that were left in place.

Z M 60338 F

Table 4.--Results of tests of glued[1] fastenings of web members to rib caps
Condition 3.--Shearing strengths of the joints between gussets and web members

Species	Description of fastenings: Web member: Depth between gussets	Web member: Length on web member	Web member: Area of joints	Plywood gussets: Nominal thickness	Plywood gussets: Angle of face grain to load	Properties of fastenings: With yellow-poplar gussets: Design	Web members: Moisture content	Web members: Specific gravity[2]	Yellow-poplar gussets: Moisture content	Yellow-poplar gussets: Specific gravity[2]	Average maximum shearing strength of five specimens	With mahogany gussets: Design	Sitka spruce web members: Moisture content	Sitka spruce web members: Specific gravity[2]	Mahogany gussets: Moisture content	Mahogany gussets: Specific gravity[2]	Average maximum shearing strength of five specimens
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
	Inch	Inches	Inches	Inch	Degrees		Percent		Percent		Pounds		Percent		Percent		Pounds
Sitka spruce	0.5	0.75	0.5625	0.070	0	G2	11.2	0.412	8.4	0.556	503	G1	12.8	0.377	8.4	0.577	534
		1.00	.7500	.100	0	H2	11.8	.395	8.3	.551	590	H1	12.3	.392	8.5	.524	599
				.100	0		12.0	.415	7.2	.631	637		12.9	.416	7.2	.544	668
				.100	45		12.6	.430	7.2	.631	661		13.1	.398	7.2	.544	638
				.100	90		12.7	.432	7.2	.631	673		14.1	.395	7.2	.544	574
				.125	0		10.7	.393	8.2	.552	608		11.5	.383	8.2	.530	626
		1.50	1.1250	.070	0	J2	11.4	.385	8.4	.556	791	J1	12.6	.382	8.4	.577	881
		2.00	1.5000	.100	0	K2	11.4	.382	8.3	.551	1,010	K2	12.4	.404	8.5	.524	1,104
				.100	0		12.2	.415	7.7	.627	1,060	K2	14.3	.391	7.9	.538	1,072
				.100	45		12.0	.417	7.7	.627	1,064	K2	14.1	.406	7.9	.538	1,063
				.100	90		11.2	.411	7.7	.627	1,020	K2	14.3	.409	7.9	.538	1,143
				.125	0		10.6	.390	8.2	.552	989	K1	11.0	.386	8.2	.530	1,013
		2.25	1.6875	.070	0	L2	10.5	.372	8.4	.556	1,046	L1	12.6	.400	8.4	.577	1,138
				.070	0	....	....	....	....	....	....	L3	11.8	.386	8.4	.577	1,086
		3.00	2.2500	.070	0	M4	10.2	.390	8.4	.556	1,231	M4	11.7	.386	8.4	.577	1,251
				.070	0	....	....	....	....	....	....	M6[3]	12.4	.378	8.4	.577	1,171
				.100	0	M2	10.5	.396	8.3	.551	1,170	M3	12.4	.443	8.5	.524	1,315
				.100	0	M2	11.9	.429	8.1	.605	1,239	M3	13.9	.400	7.7	.540	1,104
				.100	45	M2	12.6	.418	8.1	.605	1,390	M3	13.3	.402	7.7	.540	1,220
				.100	90	M2	11.8	.424	8.1	.605	1,296	M3	13.7	.417	7.7	.540	1,133
				.125	0	M2	10.2	.399	8.2	.552	1,228	M1	11.2	.372	8.2	.530	1,163
		4.00	3.0000	.100	0	N2	9.4	.391	8.3	.551	1,340	N4	11.5	.404	8.5	.524	1,310
				.100	0		13.1	.435	7.2	.553	1,357	N4	13.1	.422	7.6	.541	1,363
				.100	45		12.7	.409	7.2	.553	1,300	N4	13.8	.415	7.6	.541	1,390
				.100	90		12.9	.418	7.2	.553	1,361	N4	12.9	.419	7.6	.541	1,341
				.125	0		10.5	.399	8.2	.552	1,362	N1	12.6	.383	8.2	.530	1,360
				.125	0	....	....	....	....	....	....	N3	12.7	.383	8.2	.530	1,189
		5.00	3.7500	.100	0	P1	12.1	.405	....	....	1,355	....	....	....	....	....	....
Sitka spruce	1.0	2.00	1.5000	.100	0	K3	11.4	.431	7.6	.552	1,129	....	....	....	....	....	....
		3.00	2.2500	.070	0	M7	13.3	.447	8.4	.556	1,828	....	....	....	....	....	....
				.100	0	M8	10.9	.437	7.5	.539	1,514	....	....	....	....	....	....
				.100	0	M5	12.1	.429	7.6	.528	1,633	....	....	....	....	....	....
		4.00	3.0000	.100	0	N6	13.3	.427	....	....	1,919	....	....	....	....	....	....
				.125	0	....	....	....	....	....	....	N5	11.7	.433	8.2	.530	1,731
		4.50	3.3750	.125	0	O	11.3	.414	8.2	.566	1,761	....	....	....	....	....	....
		5.00	3.7500	.100	0	P2	12.7	.385	7.9	.585	2,032	....	....	....	....	....	....
		5.50	4.1250	.125	0	Q	11.6	.408	8.4	.550	1,915	....	....	....	....	....	....
Sitka spruce	1.0	2.00	3.0000	.125	0	KK	11.3	.390	7.6	.549	1,928	....	....	....	....	....	....
		3.00	4.5000	.125	0	MM	11.6	.392	7.5	.528	2,715	....	....	....	....	....	....
Yellow birch	.5	1.50	1.1250	.070	0	J2	9.6	.644	8.1	.569	1,158	....	....	....	....	....	....
		2.25	1.6870	.070	0	L2	9.6	.642	9.5	.566	1,494	....	....	....	....	....	....
		4.00	3.0000	.100	0	N6	9.9	.659	8.3	.551	1,878	....	....	....	....	....	....

[1] Urea-formaldehyde cold-setting glue. Pressure applied by removable nailing strips.

[2] Based on volume and weight when oven dry.

[3] Average of three specimens.

Z M 60339 F

Table 5.--Results of tests of glued[1] fastenings of ribs to spars
Condition 3.--Shearing strengths of the joints between gussets and ribs

Description of fastenings				Properties of fastenings											
Gusset-to-rib joints		Plywood gussets		With yellow-poplar gussets						With mahogany gussets					
Length on rib	Area	Nominal thickness	Angle of face grain to load	Design	Sitka spruce ribs		Yellow-poplar gussets		Average maximum shearing strength of five specimens[3]	Design	Sitka spruce ribs		Mahogany gussets		Average maximum shearing strength of five specimens[3]
					Moisture content	Specific gravity[2]	Moisture content	Specific gravity[2]			Moisture content	Specific gravity[2]	Moisture content	Specific gravity[2]	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Inches	Square inches	Inch	Degrees		Percent		Percent		Pounds		Percent		Percent		Pounds
1.0	0.3750	0.070	0							SW2	12.9	0.405	9.2	0.592	528
		.125	0	SW1	13.2	0.404	8.3	0.487	543						
		.125	45	SW1	13.0	.395	9.0	.504	546						
		.125	90	SW1	12.6	.404	8.8	.454	525						
1.5	.5625	.070	0	SP1	12.6	.398	7.5	.600	690	SP2	13.0	.407	9.2	.587	692
		.100	0							SP2	12.0	.383	8.2	.533	636
2.0	.7500	.070	0	SQ3	11.4	.379	8.3	.571	780	SQ2	12.6	.429	9.5	.592	774
		.100	0	SQ1	12.0	.442	8.2	.612	711	SQ1	12.2	.436	8.4	.540	670
		.100	0	SQ2	12.2	.399	8.0	.630	795						
		.125	0	SQ2	12.5	.407	8.6	.491	844	SQ2	12.9	.407	8.1	.554	843
		.125	0	SQ2	12.6	.403	8.2	.488	840	SQ2	12.4	.413	8.6	.552	788
		.125	45	SQ2	12.9	.401	8.4	.505	843						
		.125	90	SQ2	12.5	.396	8.2	.497	842						
2.5	.9375	.070	0	SR	11.6	.379	8.1	.607	885	SR	12.8	.412	8.7	.598	787
		.100	0							SR	11.9	.383	9.2	.573	797
3.0	1.1250	.100	0	SS1	11.6	.431	8.6	.581	844	SS1	11.8	.434	8.1	.547	825
		.100	0	SS2	12.4	.395	7.6	.646	885						
		.125	0	SS3	13.1	.402	8.2	.504	1,257	SS3	12.0	.416	8.5	.528	1,008
3.5	1.3125	.125	0	ST	12.1	.408	8.4	.556	652						
4.0	1.5000	.100	0	SU2	12.5	.394	7.6	.633	944						
		.125	0	SU1	12.0	.414	8.2	.523	866						
		.125	0	SU3	12.6	.415	8.2	.475	1,266	SU3	12.6	.413	8.2	.534	1,055
4.5	1.6875	.125	0	SV	12.9	.402	8.0	.512	1,106						
5.0	1.8750	.100	0	SW1	12.5	.390	7.9	.641	1,094	SW1	12.2	.427	8.1	.558	966
		.125	0	SW2	12.9	.407	8.2	.496	1,590	SW2	12.5	.415	8.3	.530	1,274

[1] Urea-formaldehyde cold-setting glue. Pressure applied by removable nailing strips.

[2] Based on volume and weight when oven dry.

[3] Corner blocks assumed to carry no tensile load.

Z M 60340 F

Table 6.--Shearing strengths of corner attachments of ribs to spars

Description of specimens							Properties of specimens	
Thickness of members		Corner blocks					Area of joints on spars	Average maximum shearing strength of five[1]
Spars	Ribs	Type	Species	Mark	Gluing faces: Width	Gluing faces: Length		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Inches					Inches		Sq. in.	Pounds
1.5	0.5	Triangular	Sitka spruce	A	0.250	6.0	6	2,710
				B	.375	6.0	9	3,210
				C3	.500	3.0	6	2,190
				C4	.500	4.0	8	2,539
				C4½	.500	4.5	9	2,827
				C	.500	6.0	12	3,660
				D	.625	6.0	15	3,905
				E	.750	6.0	18	4,290
		Square	Sitka spruce	J	.375	6.0	9	3,220
				K	.625	6.0	15	4,020
		Plywood angles	1/16-inch yellow-poplar	Y	.750	6.0	18	4,020
			1/16-inch yellow birch	X	.750	6.0	18	4,470
2.0	1.0	Triangular	Sitka spruce	2A	.250	6.0	6	2,815
				2B	.375	6.0	9	3,390
				2C	.500	6.0	12	4,410
				2D	.625	6.0	15	4,665
				2E	.750	6.0	18	4,755
		Plywood angles	1/16-inch yellow-poplar	2Y	.750	6.0	18	4,325
			1/16-inch yellow birch	2X	.750	6.0	18	4,305
			1/16-inch sweetgum	2G	.750	6.0	18	5,450
			3/32-inch mahogany	2M	.750	6.0	18	5,800
			1/8-inch sweetgum	2G2	.750	6.0	18	6,040

[1] For Sitka spruce of 0.40 specific gravity (based on weight and volume when oven-dry) and 12 percent moisture content.

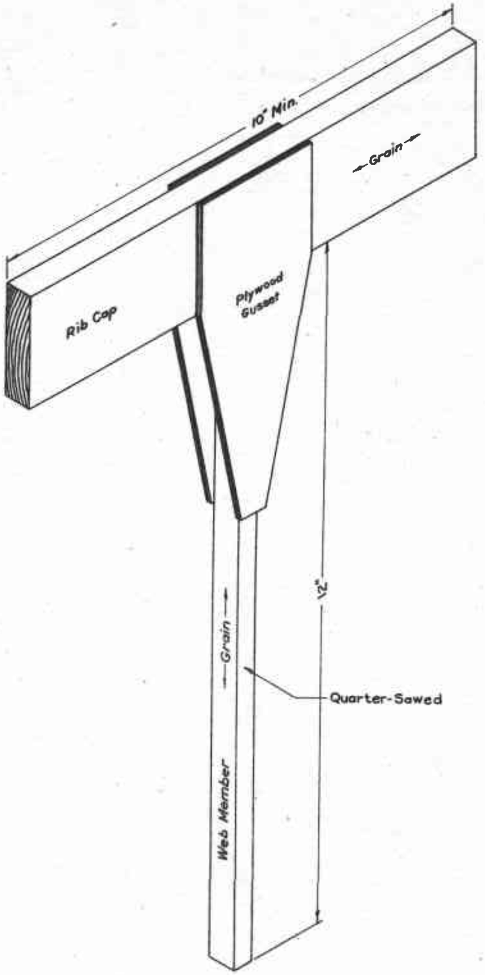
Z M 60341 F

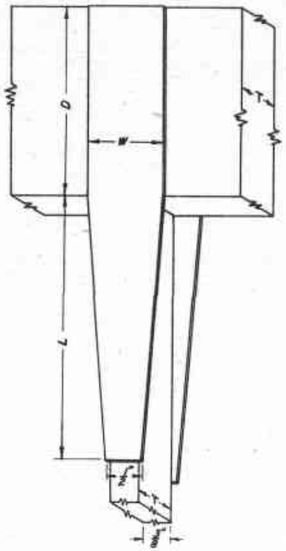
Table 7.--Strengths of saddle gussets glued to solid wood framing members

Description of gussets				Properties of gussets		
Species of plywood	Thick-ness	Glue area	Angle of face grain	Average ultimate strength per gusset of four specimens		Manner of failure
				When glued to Sitka spruce[1]	When glued to Douglas-fir[1]	
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Inch	Sq. in.	Degrees	Pounds	Pounds	
Yellow birch	0.063	0.74	0	192	....	Plywood failed in bearing
	.063	1.08	0	188	187	
	.063	1.08	45	165	173	
	.063	1.08	90	165	179	
Mahogany	.066	.74	0	123	....	
	.066	1.08	0	134	....	
	.095	1.08	0	217	....	
Yellow birch	.146	1.08	0	382	408	Bottom of gusset sheared out
	.170	1.08	0	416	493	
Mahogany	.066	.44	0	149	150	
	.095	.44	0	197	193	
	.095	.74	0	195	....	
	.202	.74	0	348	....	
	.202	1.08	0	408	....	
Yellow birch	.146	.74	0	335	....	Gussets sheared from framing members
	.170	.74	0	340	....	
Mahogany	.202	.44	0	243	....	
	.202	1.08	0	485	....	
	.202	1.08	45	495	....	
	.202	1.08	90	465	....	

[1]Conditioned to approximately 12 percent moisture content.

ZM 60342 F

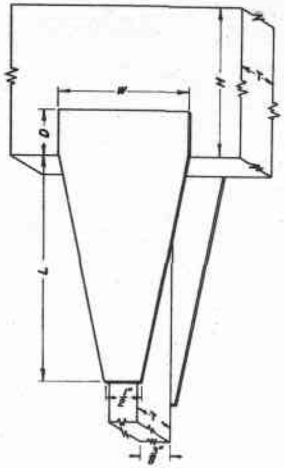




CONDITION 1.

SPECIMENS FOR DETERMINING TENSILE STRENGTHS OF GUSSETS

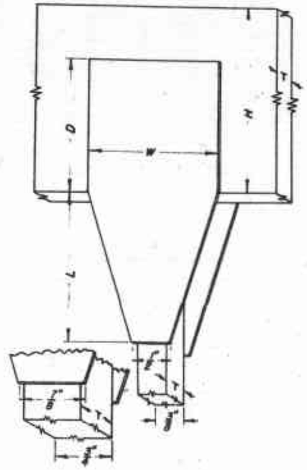
W	DESIGN	D	L	T
IN.		IN.	IN.	IN.
0.625	A4	2.5	2.0	0.5
	A1	2.5	2.0	1.0
	A2	3.0	2.0	1.0
	A3	3.0	3.5	1.0
.75	B1	2.5	2.5	1.0
	B2	3.0	2.5	1.0
	B3	3.0	4.0	1.0
.875	C1	2.5	3.0	1.0
	C2	3.0	3.0	1.0
	C3	3.0	4.5	1.0
1.0	D1	2.5	3.5	1.0
	D2	3.0	3.5	1.0
	D3	3.0	5.0	1.0
1.5	E1	2.5	4.5	1.0
	E2	3.0	4.5	1.0
2.0	F1	2.5	5.5	1.0
	F2	3.0	5.5	1.0
2.5	N3	2.5	4.0	1.0



CONDITION 2

SPECIMENS FOR DETERMINING SHEARING STRENGTHS OF JOINTS BETWEEN GUSSETS AND RIB CAPS

DESIGN	W	D	L	T	H
	IN.	IN.	IN.	IN.	IN.
S	1.0	0.375	1	1.5	2.0
T	1.375	.50	2	1.5	2.0
U	1.75	.625	3	2.0	2.0
V	2.125	.75	4	2.0	2.0
W	.675	1.50	4	1.5	1.5
X	.75	1.50	4	1.5	1.5
Y	.875	1.50	4	1.5	1.5
Z	1.0	1.50	4	1.5	1.5



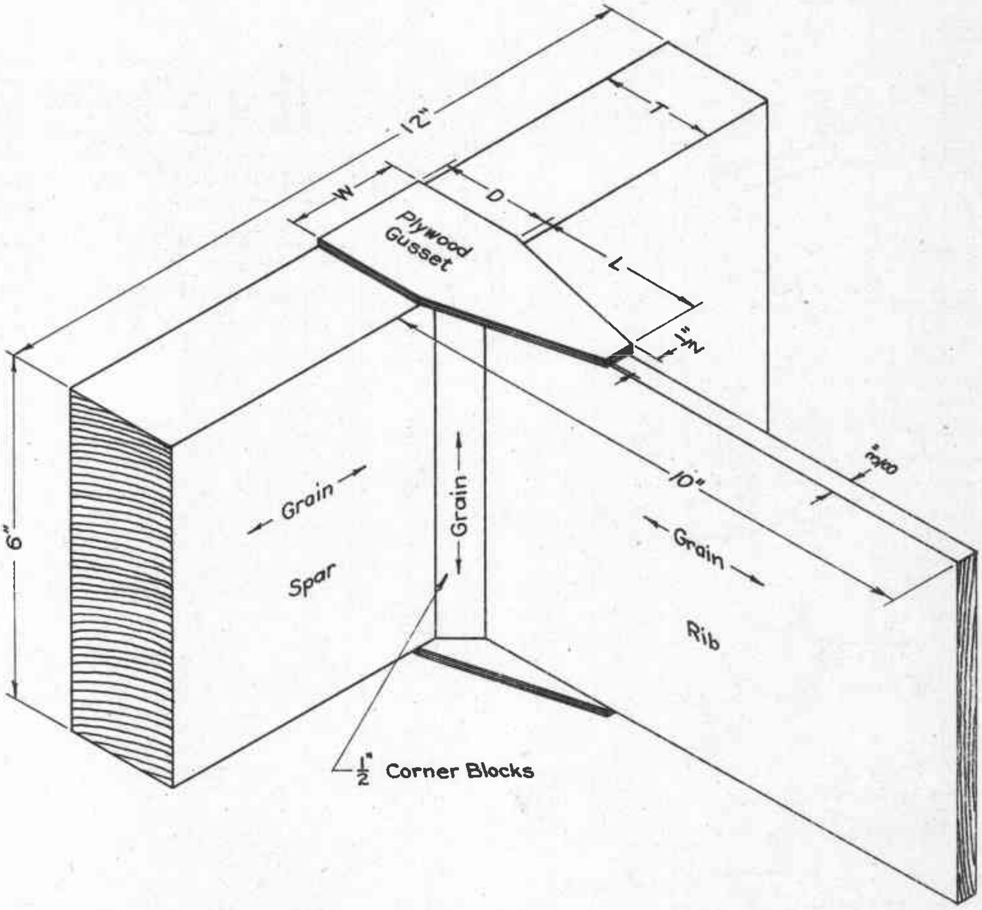
CONDITION 3.

SPECIMENS FOR DETERMINING SHEARING STRENGTHS OF JOINTS BETWEEN GUSSETS AND WEB MEMBERS

L	DESIGN	W	D	T	H
5/8" WEB MEMBER					
IN.		IN.	IN.	IN.	IN.
0.75	G1	1.125	1.5	0.5	2.5
	G2	1.5	1.5	.5	2.5
1.00	H1	1.0	1.5	.5	2.5
	H2	1.25	1.5	.5	2.5
1.50	J1	1.75	1.75	.5	2.5
	J2	2.25	1.75	.5	2.5
2.00	K1	1.25	1.75	.5	2.5
	K2	1.75	1.75	.5	2.5
	K3	3.0	1.75	1.0	2.5
2.25	L1	2.375	2.0	.5	2.5
	L2	2.75	2.0	.5	2.5
	L3	3.0	2.0	.5	2.5
3.00	M1	1.5	2.0	.5	2.5
	M2	2.0	2.0	.5	2.5
	M8	2.0	2.0	1.0	2.5
	M3	2.5	2.0	.5	2.5
	M4	3.0	2.25	.5	2.5
	M5	3.5	2.0	1.0	2.5
	M6	4.0	2.25	.5	2.5
	M7	4.5	2.0	1.0	2.5
4.00	N1	1.75	2.25	.5	2.5
	N2	2.25	2.25	.5	2.5
	N3	2.5	2.5	.5	2.5
	N4	3.0	2.25	.5	2.5
	N5	3.5	2.5	1.0	2.5
	N6	4.0	2.0	1.0	2.5
4.50	O	1.5	3.0	1.0	3.0
5.00	P1	2.75	2.5	.5	2.5
	P2	4.0	2.0	1.0	2.5
5.50	Q	2.0	3.0	1.0	3.0
3/4" WEB MEMBER					
2.00	KK	3.0	2.0	1.0	2.5
3.00	MM	3.5	2.0	1.0	2.5

Figure 1.--Specimens used for the determination of strength of typical web member-to-rib cap fastenings (Type I).

Z M 60343 F



CONDITION 1

SPECIMENS FOR DETERMINING TENSILE STRENGTHS OF GUSSETS

W	DESIGN	D=T	L
IN.		IN.	IN.
0.625	SA1	1.5	1.5
	SA2	1.5	2.0
0.75	SB	2.0	3.5
1.0	SC1	1.5	2.0
	SC2	2.0	5.0
1.25	SD	2.0	4.0
1.5	SE1	1.5	2.5
	SE2	2.0	5.0
1.75	SF1	1.5	3.5
	SF2	2.0	4.5
	SF3	2.0	5.0
2.0	SG1	1.5	4.5
	SG2	2.0	5.0
2.25	SH1	1.5	5.5
	SH2	2.0	5.0
2.5	SJ	2.0	5.0
3.0	SK	2.0	5.0
3.5	SL	2.0	5.0
4.0	SM	*	5.0

*D = 1.5, T = 2.0

CONDITION 2

SPECIMENS FOR DETERMINING SHEARING STRENGTHS OF JOINTS BETWEEN GUSSETS AND SPARS

D	DESIGN	W	L	T
IN.		IN.	IN.	IN.
0.75	SX1	0.75	2.0	1.5
	SX2	1.25	3.0	1.5
	SX3	1.75	4.0	1.5
1.0	SY1	.75	2.5	1.0
	SY2	1.0	3.0	1.5
	SY3	1.25	3.0	1.5
	SY4	1.75	4.0	1.5
	SY5	2.25	5.0	1.5
1.3	SZ1	.75	2.5	1.3
	SZ2	1.25	3.5	1.3
	SZ3	1.75	4.5	1.3

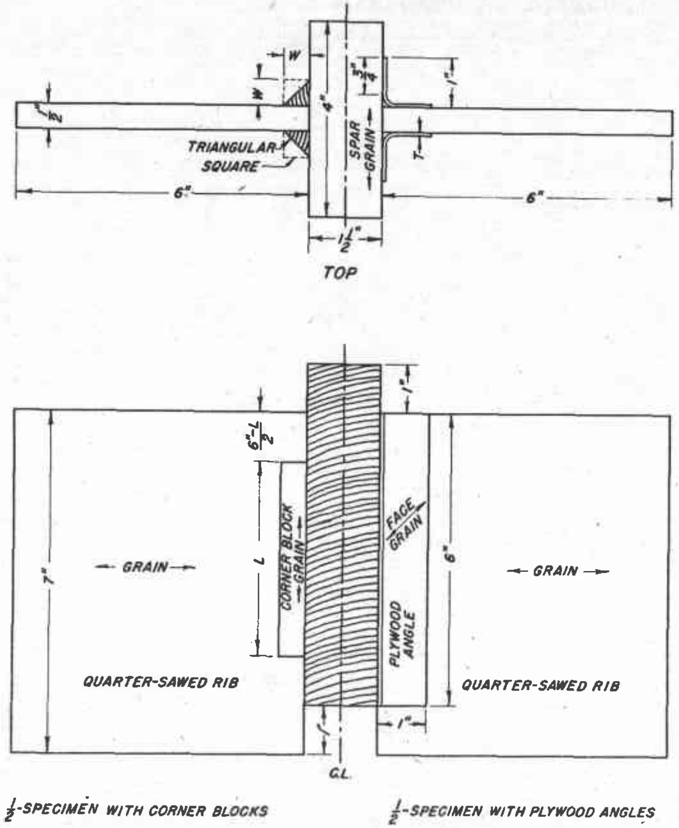
CONDITION 3

SPECIMENS FOR DETERMINING SHEARING STRENGTHS OF JOINTS BETWEEN GUSSETS AND RIBS

L	DESIGN	W	D=T
IN.		IN.	IN.
1.0	SN1	1.0	2
	SN2	1.25	2
1.5	SP1	1.5	2
	SP2	1.75	2
2.0	SQ1	1.0	2
	SQ2	1.5	2
	SQ3	2.25	2
2.5	SR	2.75	2
3.0	SS1	1.5	2
	SS2	1.75	2
	SS3	2.0	2
3.5	ST	.75	2
4.0	SU1	1.25	2
	SU2	2.0	2
	SU3	2.5	2
4.5	SV	1.75	2
5.0	SW1	2.25	2
	SW2	3.0	2

Figure 2.--Cantilever-type specimens used for the determination of strength of typical rib-to-spar fastenings (Type II).

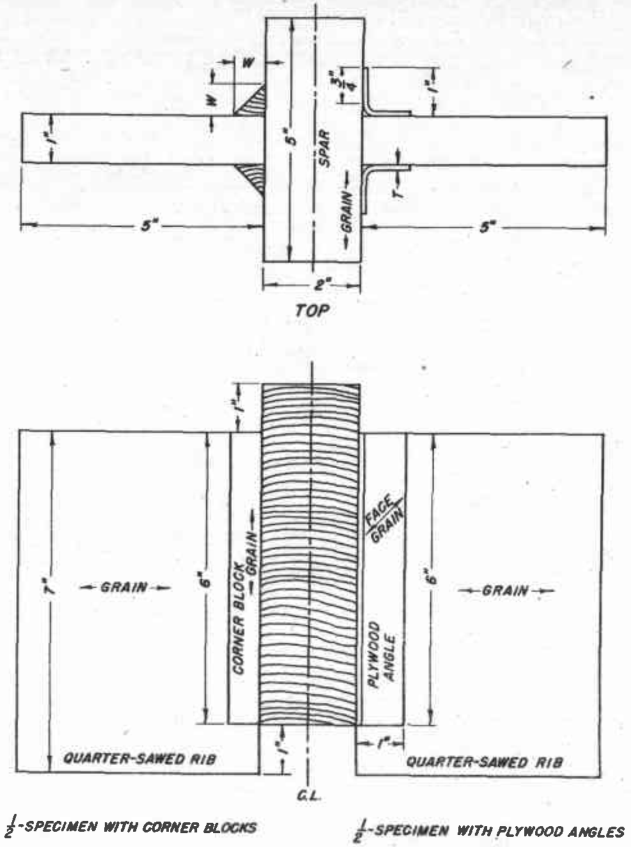
Z M 60344 F



SPECIMEN SIZE 1

CORNER BLOCKS			
TYPE	MARK	L	W
		IN.	IN.
TRIAN-GULAR	A	6	0.25
	B	6	.375
	C	6	.50
	C3	3	.50
	C4	4	.50
	C4.5	4.5	.50
	D	6	.625
	E	6	.75
SQUARE	J	6	.375
	K	6	.625

PLYWOOD ANGLES		
MARK	SPECIES	T
		IN.
Y	YELLOW-POPLAR	0.070
X	YELLOW BIRCH	.070



SPECIMEN SIZE 2

CORNER BLOCKS		
TYPE	MARK	W
		IN.
TRIAN-GULAR	2A	0.25
	2B	.375
	2C	.50
	2D	.625
	2E	.75

PLYWOOD ANGLES		
MARK	SPECIES	T
		IN.
2Y	YELLOW-POPLAR	0.070
2X	YELLOW BIRCH	.070
2G	SWEETGUM	.070
2G2	SWEETGUM	.125
2M	MAHOGANY	.100

Figure 3.--Specimens used for the determination of shearing strength of the corner attachments of rib-to-spar fastenings (Type III).

Z M 60345 F

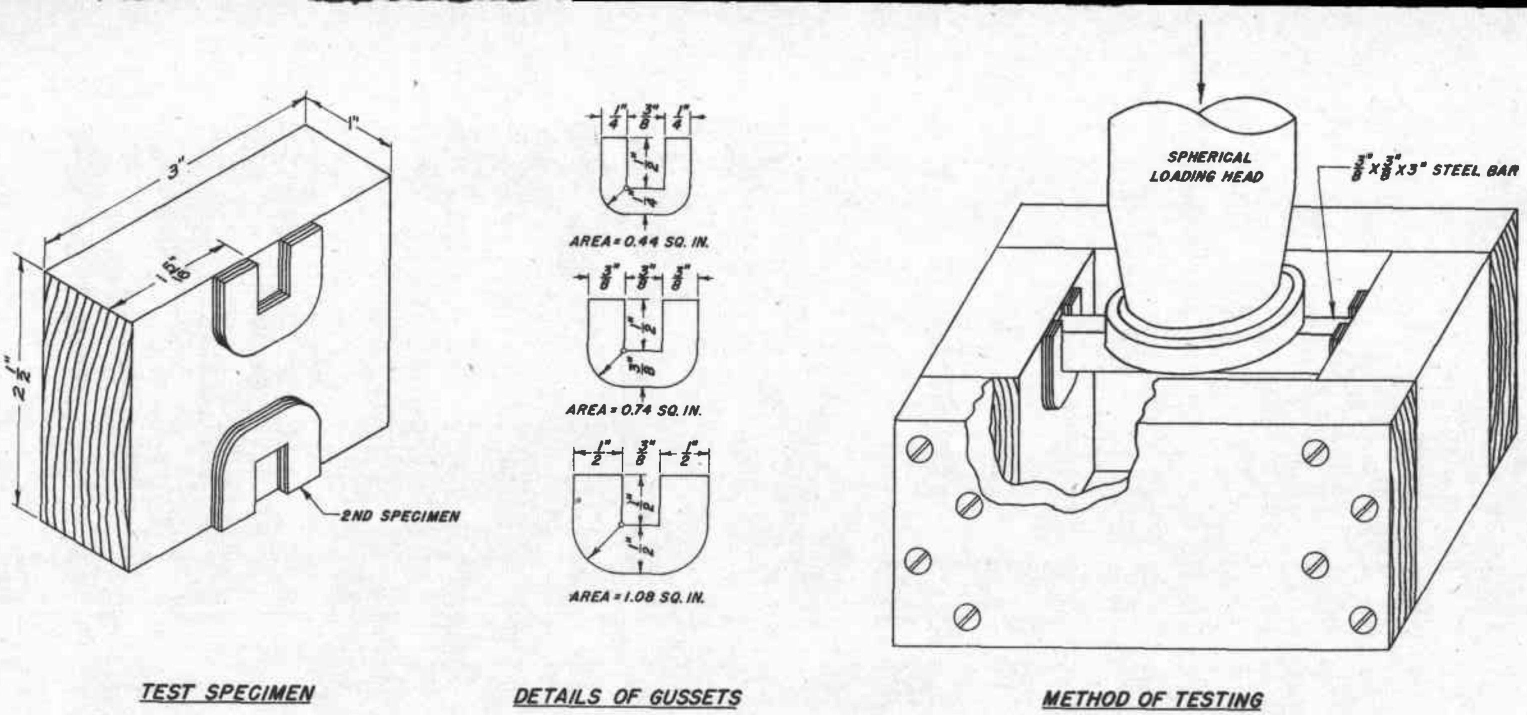


Figure 4.--Specimens and method of testing used for the determination of bearing strength of saddle gussets when glued to framing members (Type IV).

M 60346 F

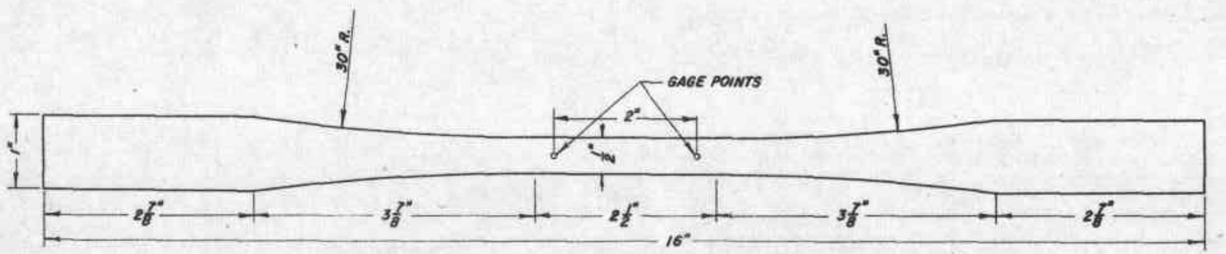


Figure 5.--Specimen used for the determination of tensile strength of plywood.

Z M 60347 F

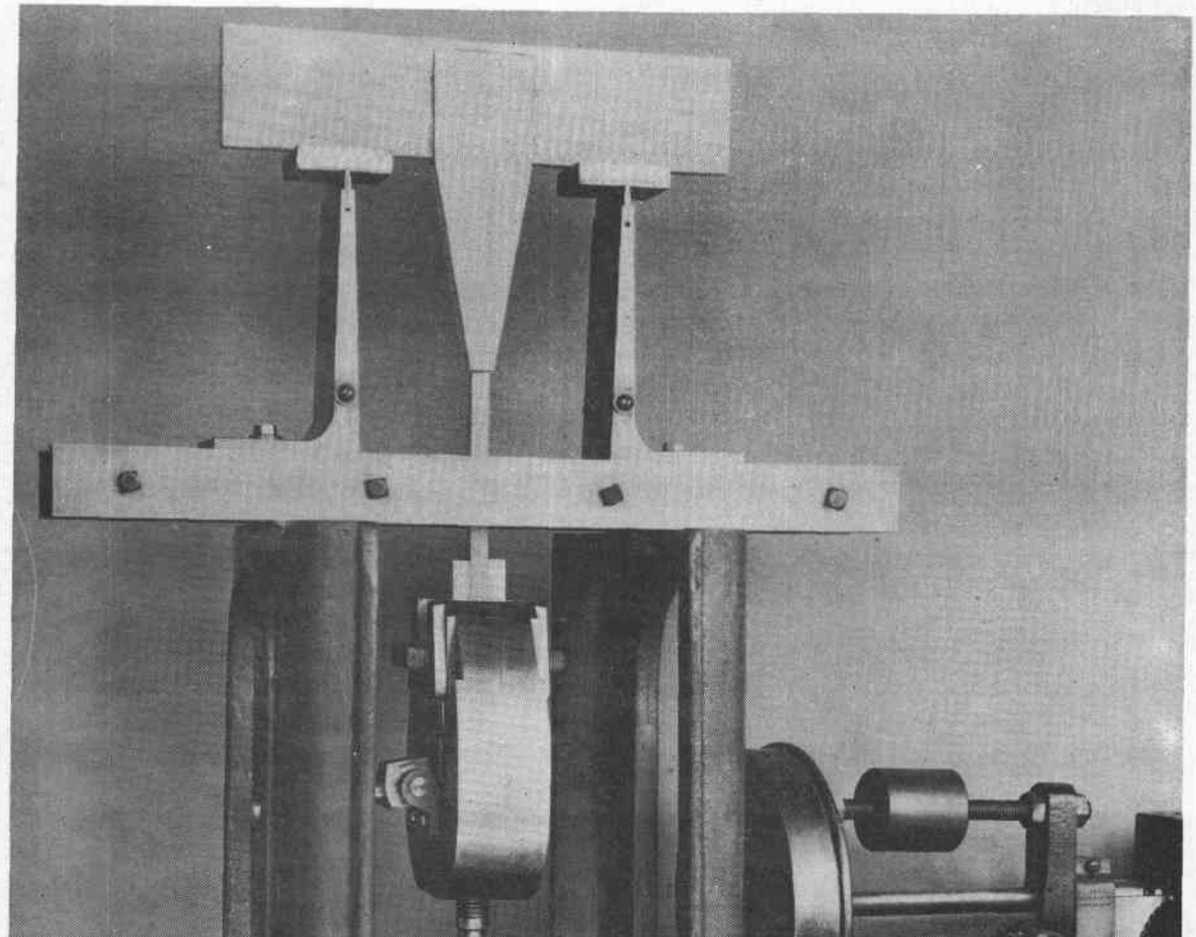


Figure 6.--Apparatus used for the testing of web member-to-rib cap fastenings showing specimen in place.
M 60348 F

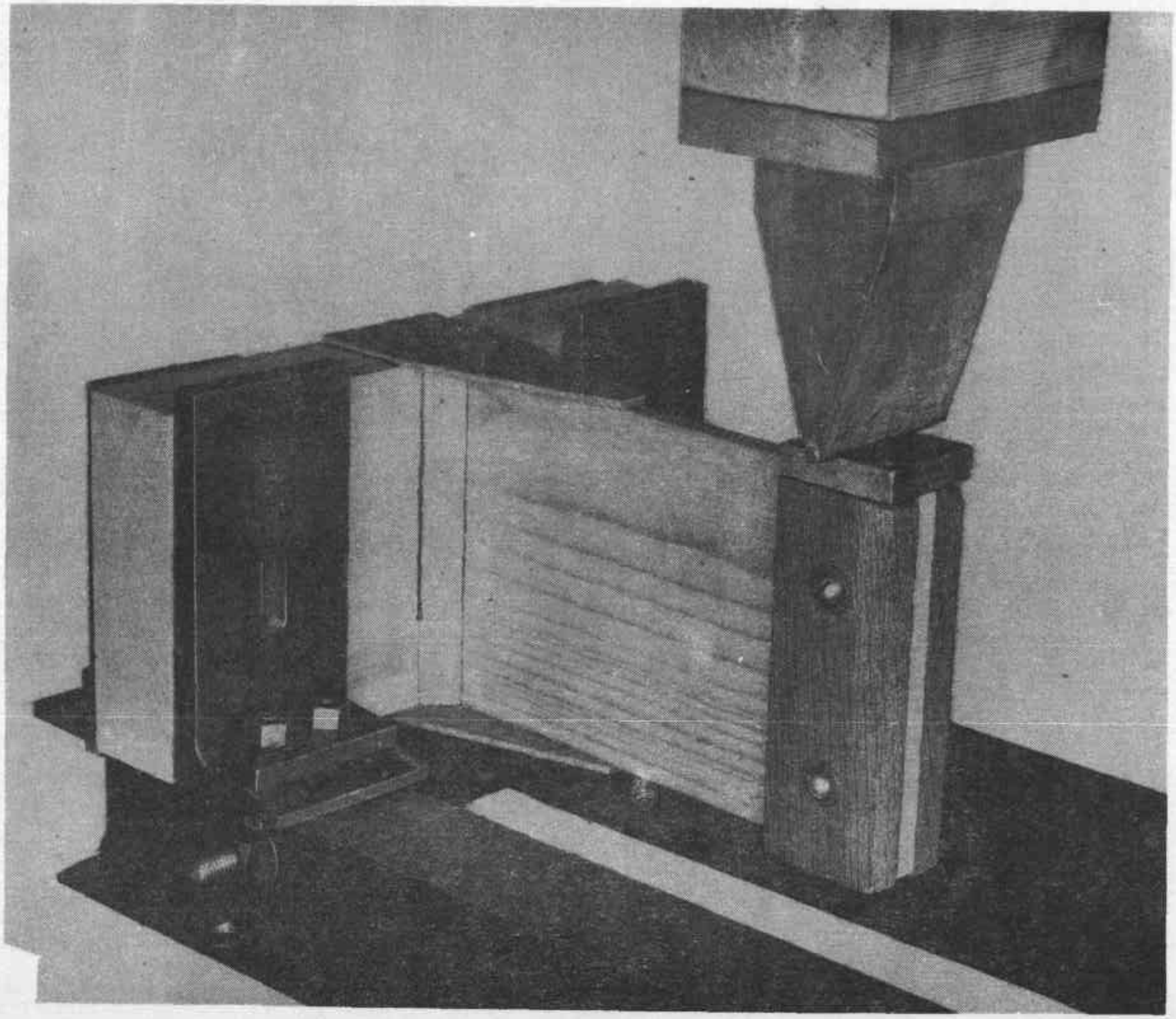


Figure 7.--Apparatus used for the testing of cantilever-type rib-to-spar fastenings showing specimen in place.

M 60349 F

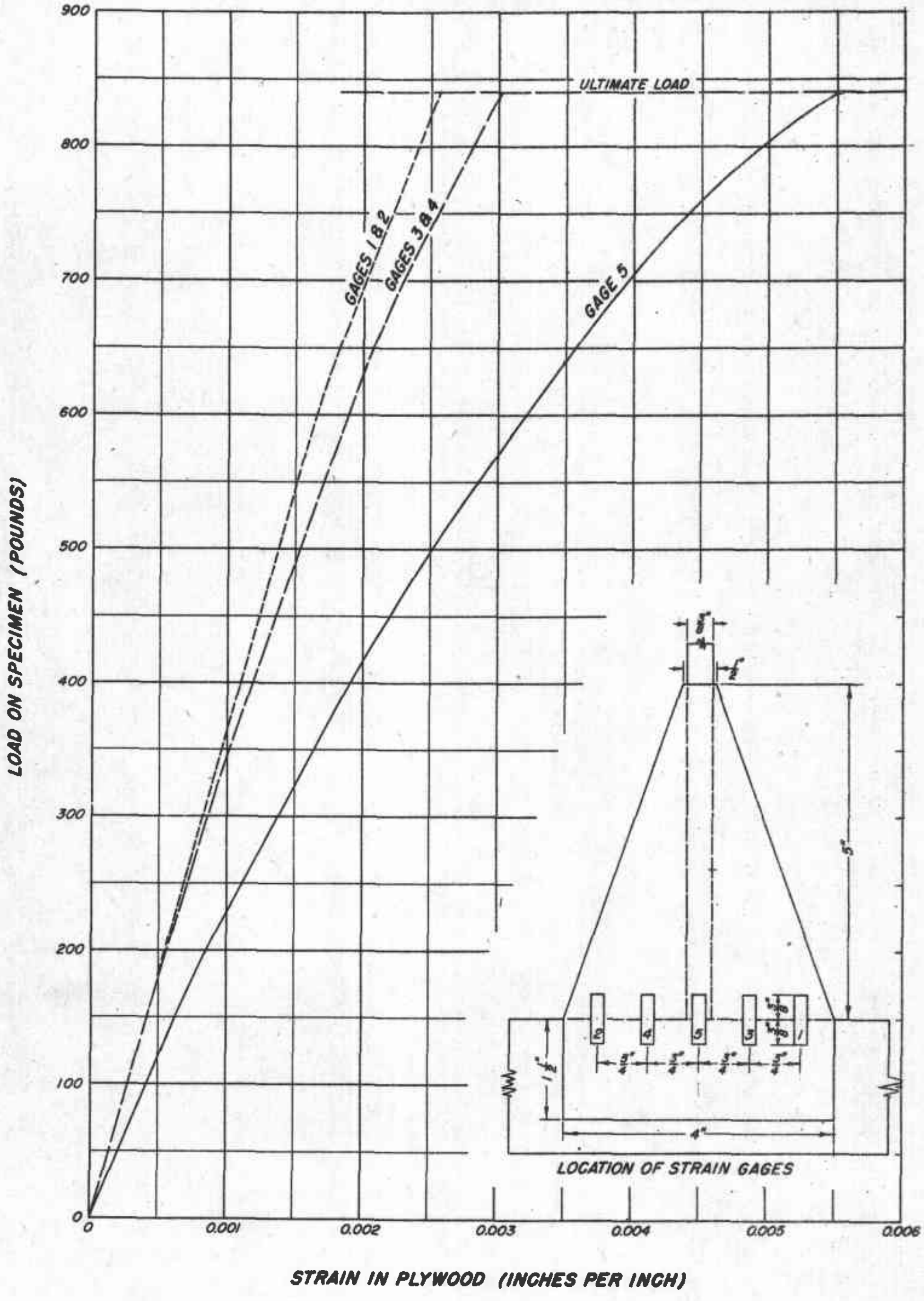


Figure 8.--Relationship of strains at various points in the width of the tensile gusset of a rib-to-spar fastening to the load applied to the specimen.

Z M 60350 F

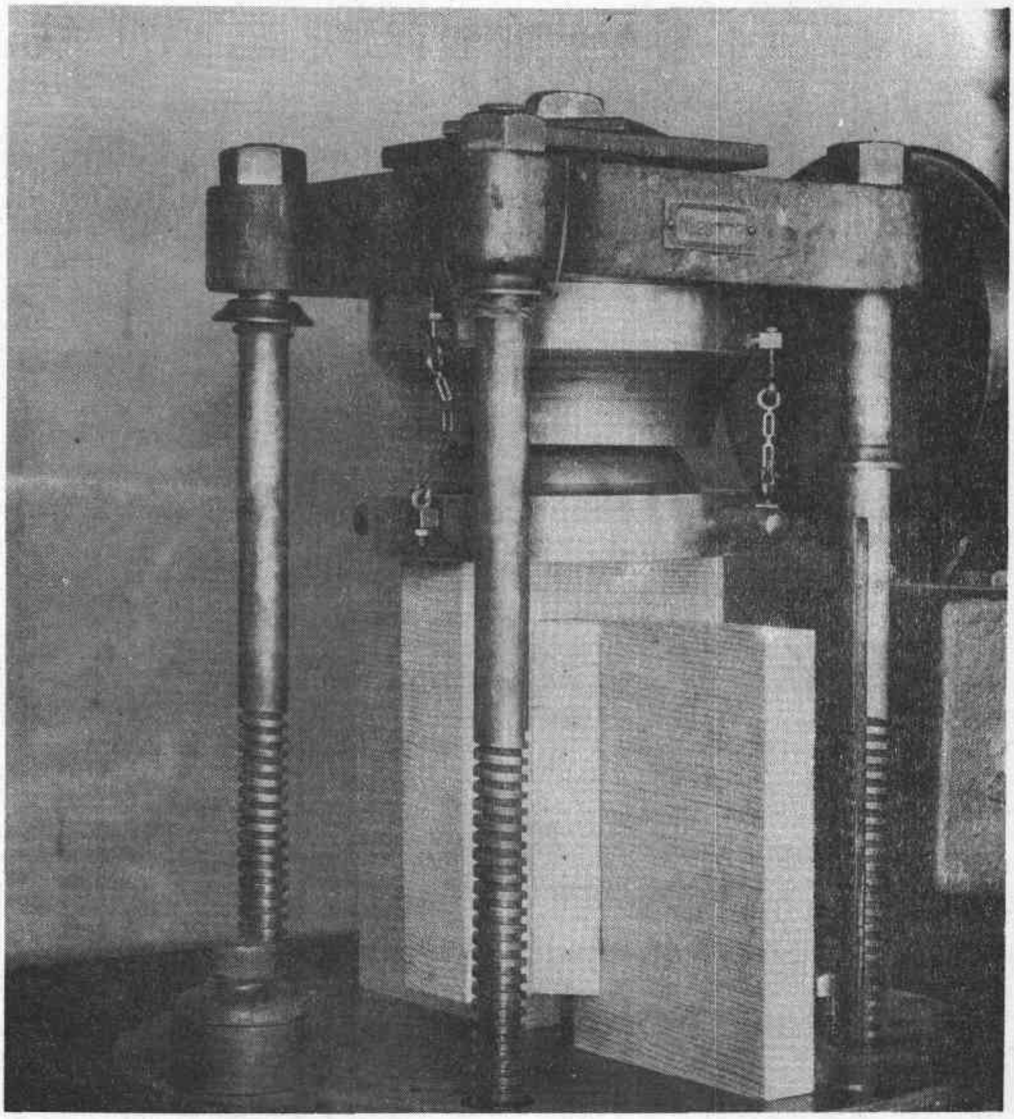


Figure 9.--Method of testing corner attachments under compressive loading. A hardwood frame used to prevent the ribs from spreading is not shown.
M 60351 F

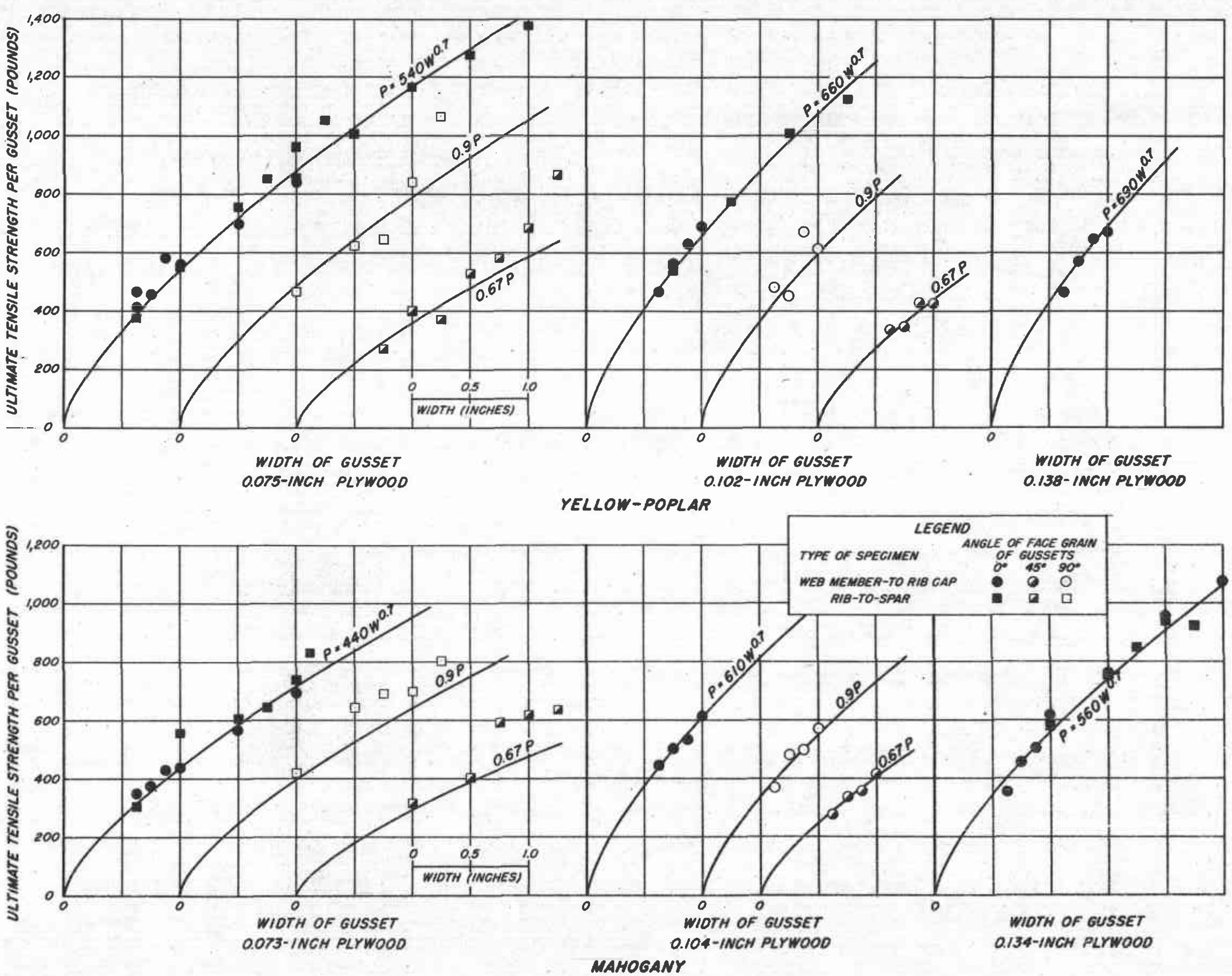


Figure 10.--Relationship between ultimate tensile strength and width of gusset in typical rib-to-spar and web member-to-rib cap fastenings.

Z M 60352 F

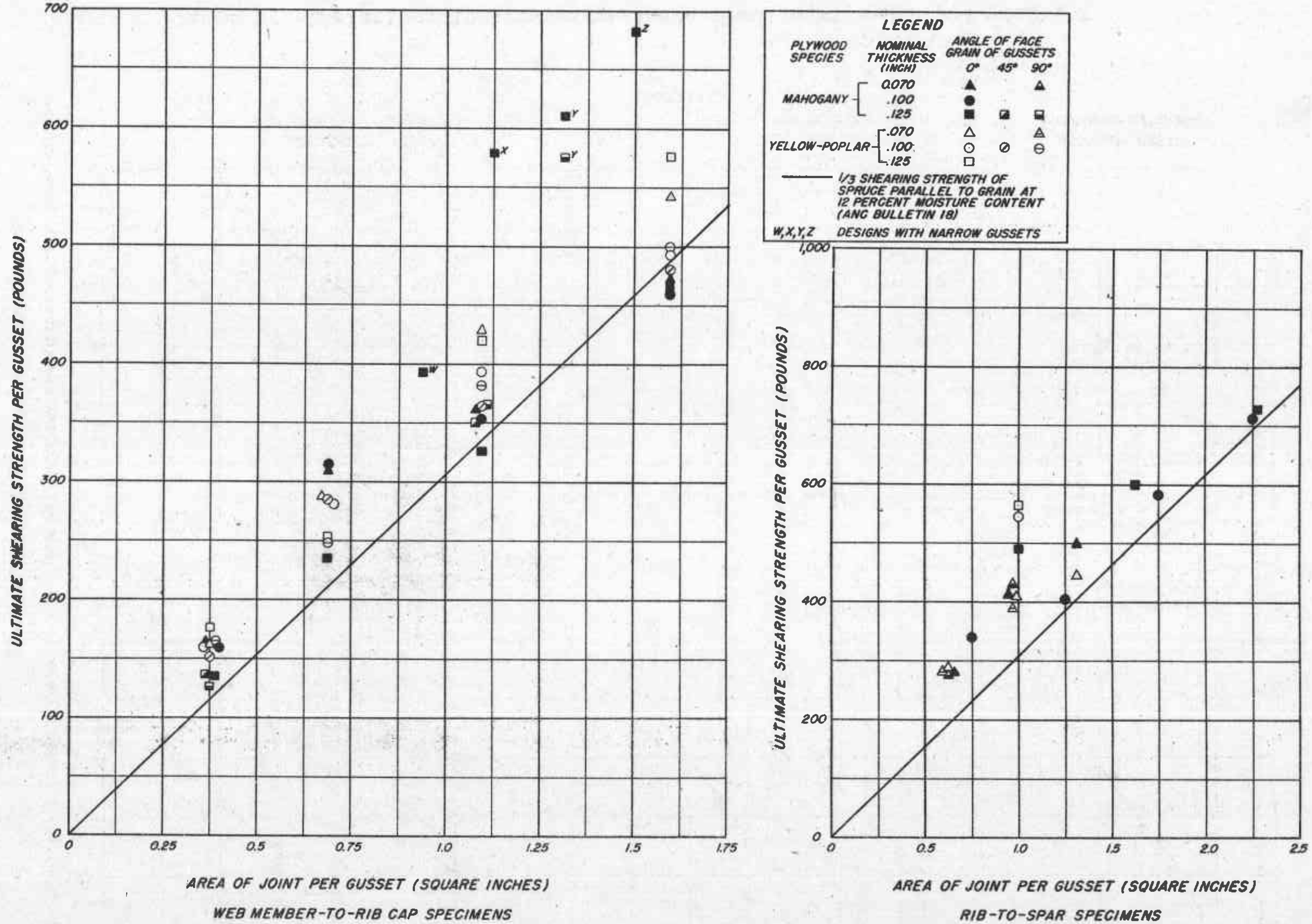


Figure 11.--Relationship between ultimate shearing strength and area of glued joints between gussets and spars in rib-to-spar fastenings and between gussets and rib caps in web member-to-rib cap fastenings.

Z M 60353 F

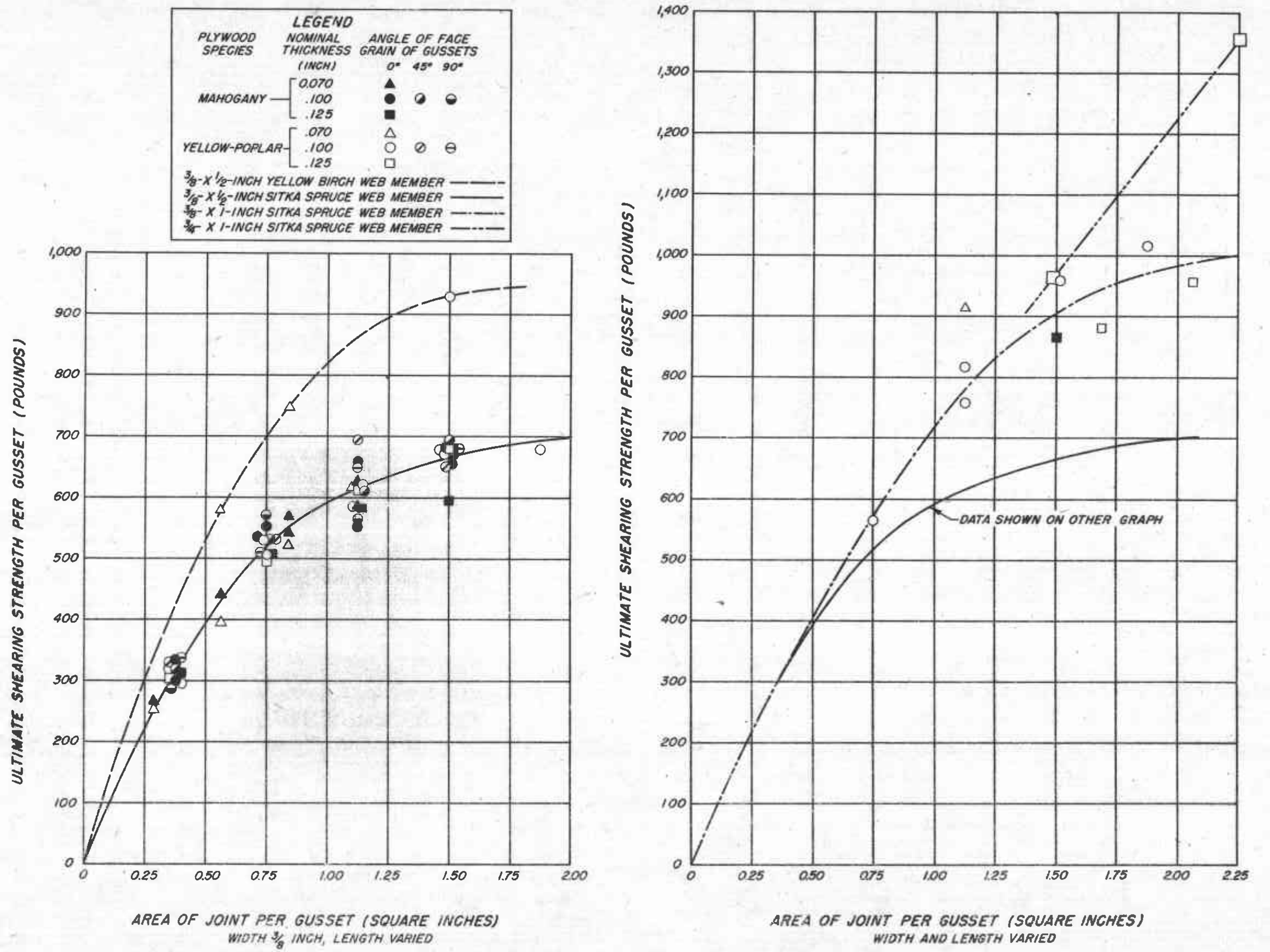


Figure 12.--Relationship between ultimate shearing strength and area of glued joints between gussets and web members in web member-to-rib cap fastenings.

Z M 60354 F

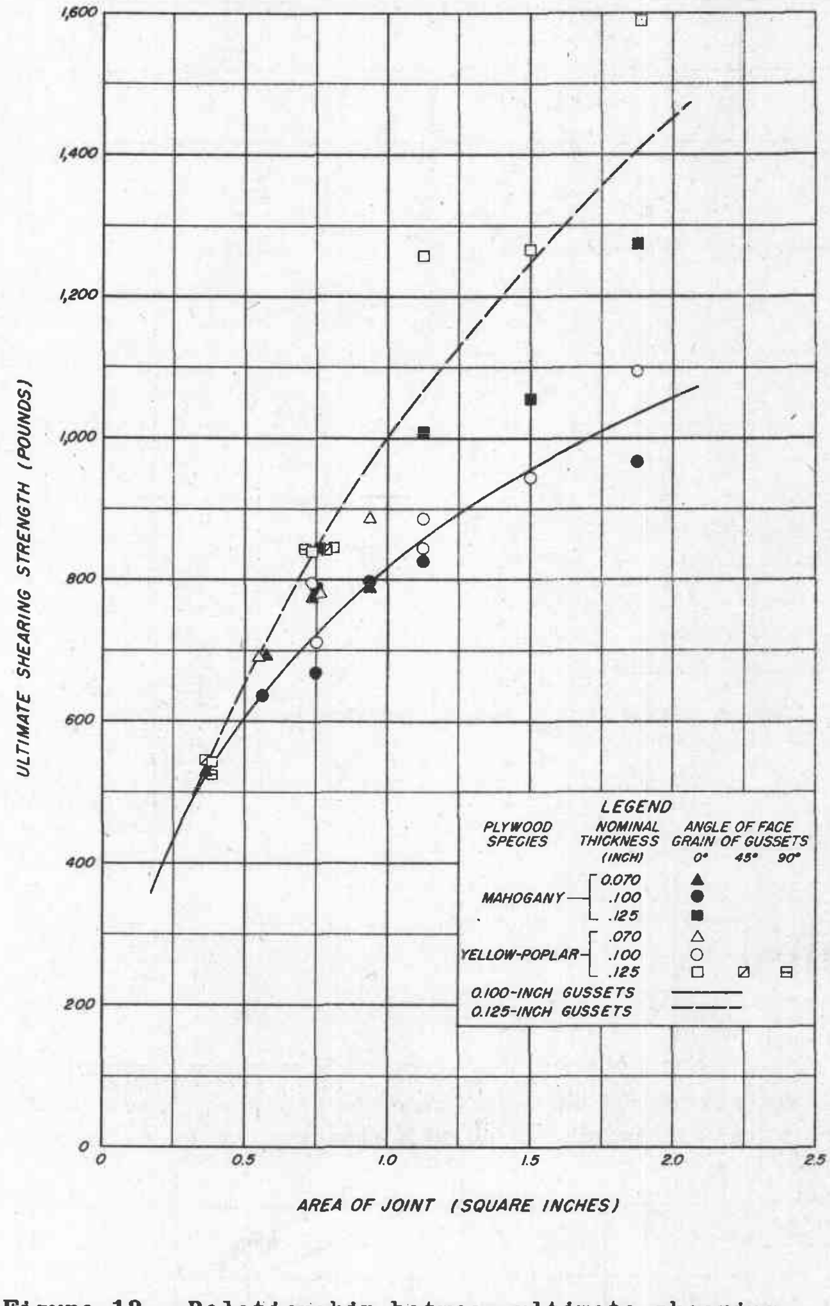


Figure 13.--Relationship between ultimate shearing strength and area of glued joints between gussets and ribs in rib-to-spar fastenings.

ZM 60355 F

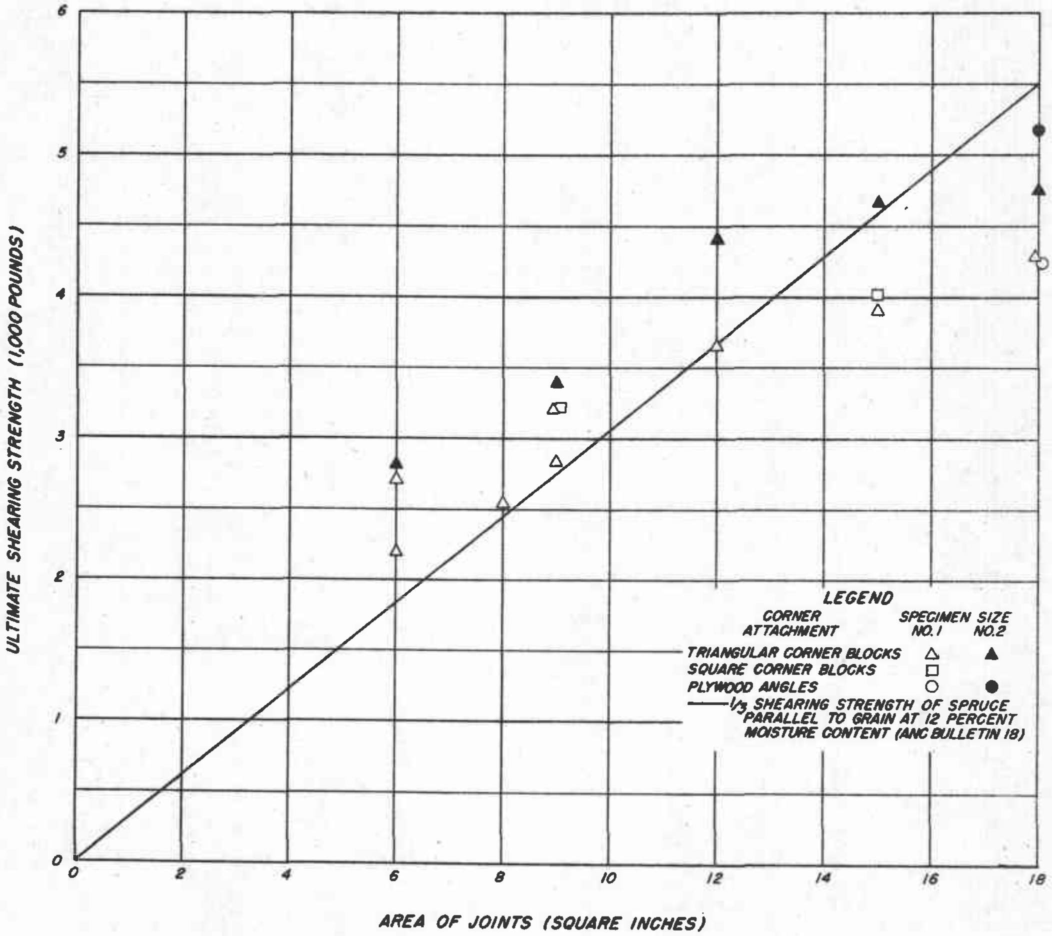


Figure 14.--Relationship between ultimate shearing strength and area of glued joints in corner attachments of ribs to spars.

Z M 60356 F