BOLT-BEARING STRENGTH OF WOOD AND MODIFIED WOOD

BEARING STRENGTH OF COMMERCIAL AIRCRAFT PLYWOOD UNDER AIRCRAFT BOLTS

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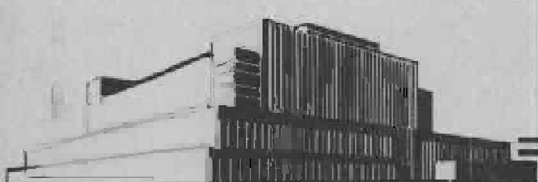

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

BOLT-BEARING STRENGTH OF WOOD AND MODIFIED WOOD

Bearing Strength of Commercial Aircraft Plywood Under Aircraft Bolts[1,2]

By

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Summary

This report presents results of test performed at the Forest Products Laboratory, to determine the bolt-bearing strength and the necessary spacing of the bolt from the end and edge of members constructed of 3 species of commercially-made plywood of aircraft grade (Specification AN-NN-P-511b). The species tested were yellow birch (group I), Douglas-fir (group II), and yellow-poplar (group III). Three thicknesses of plywood of each species, 0.125 inch--three-ply (0.155 inch in the case of Douglas-fir), 0.315 inch--five-ply, and 0.590 inch--nine-ply, were tested with 3 diameters of aircraft bolt, namely, 1/4, 1/2, and 3/4 inch. Both tensile and compressive loadings were employed. Results were based upon tests of approximately 3,000 bolt-bearing specimens and 1,500 compression specimens.

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[1] This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft. Results here reported are preliminary and may be revised as additional data become available. Original Report No. 1523-C was issued Nov. 1946.

[2] This report is one of a series of reports dealing with bolt-bearing strength of wood and modified wood. Other reports are: No. 1523, "Effects of Different Methods of Drilling Bolt Holes in Wood and Plywood;" No. 1523-A, "Bolt-Bearing Strength of Laboratory Made Crossbanded Yellow Birch Compreg Under Aircraft Bolts;" and "Bearing Strength of Commercial Crossbanded Compreg Under Aircraft Bolts." Other reports will be issued as data become available.

[3] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

The necessary end margin, measured from the center of the bolt to the end of the member, did not exceed 2.5 diameters for any grain direction or under either type of loading. Edge clearance of 1.5 diameters was adequate when the loading was parallel to the face grain and of 2 diameters when the loading was at angles of 45° or 90° to the face grain.

The bolt-bearing stresses at both proportional limit and ultimate were found to decrease with an increase in diameter of bolt and to increase with an increase in thickness of plywood within the ranges studied in this investigation. An analysis of the causes of these variations is presented in Appendix A.

The bolt-bearing stresses at proportional limit were found to bear a systematic relationship to the ultimate compressive strength, which was applicable to all three of the species tested. A suggested procedure is presented for determining bolt-bearing design stresses at proportional limit by applying this relationship to established values for ultimate compressive strength, such as are presented in ANC Bulletin 18. Design ultimate bearing stresses can safely be assumed to equal 150 percent of proportional limit stresses thus determined.

The deformations in bearing varied approximately as the thickness of plywood, but bore no consistent relationship to the diameter of bolt. The maximum deformations for the three species tested were on the order of 0.01 inch at proportional limit and 0.10 inch at ultimate.

Introduction

The efficient use of plywood reinforcing plates for bolted joints in wood aircraft structural members necessitates more accurate information than has been available concerning the bearing strength of plywood under aircraft bolts.

This study, to determine the bearing strength and the critical end margins and edge clearances for commercial aircraft plywood of different species, thicknesses, and grain orientations under single aircraft bolts of various diameters, was carried out at the Forest Products Laboratory with the guidance of the ANC Technical Subcommittee on Wood Aircraft Structures.

End margin is defined here as the dimension from the center of the bolt hole to the free end of the member and edge clearance as the dimension from the center of the bolt hole to the edge of the member measured perpendicular to the direction of the applied load.

It is believed that the data obtained will apply to other bolt sizes and plywood thicknesses within and above the range covered, except for L/D ratios at which bending of the bolt becomes a factor.

Description of Material

The plywood was of aircraft grade, manufactured commercially according to Army-Navy Aeronautical Specification AN-NN-P-511b for plywood and veneer. One species was selected from each of the three density classifications of this specification, and three thicknesses of plywood of each species were used as follows:

Group I, rotary-cut yellow birch of 0.125-, 0.315-, and 0.590-inch nominal thickness, average specific gravity of 0.697.

Group II, quarter-sliced Douglas-fir of 0.155-, 0.315-, and 0.590-inch nominal thickness, average specific gravity of 0.484.

Group III, rotary-cut yellow-poplar of 0.125-, 0.315-, and 0.590-inch nominal thickness, average specific gravity of 0.475.

The Douglas-fir and yellow-poplar plywoods were each supplied by a single manufacturer, while the yellow birch was supplied by two manufacturers.

All the plywood conformed to Specification AN-NN-P-511b for quality, and all conformed in thickness except the 0.315-inch yellow birch, which was slightly undersize.

A minimum of 64 square feet of any species and thickness was available for test.

The bolts used in these tests were standard hexagon-head, steel aircraft bolts manufactured according to Army-Navy Aeronautical specification An-B-3a. The strength requirements for this class of bolts include a yield strength of 96,000 pounds per square inch in tension and an ultimate of 125,000 pounds per square inch. Sizes employed were 1/4, 1/2, and 3/4-inch nominal diameter. Specified sizes and tolerances were as follows:

1/4 inch, 0.249 (+0.0000;-0.0030) inch;

1/2 inch, 0.499 (+0.0000;-0.0035) inch;

3/4 inch, 0.749 (+0.0000;-0.0045) inch;

Matching

The variables involved in this study were: (1) Species; (2) thickness; (3) grain orientation; (4) type of loading; (5) diameter of bolt; and (6) edge clearance or end margin.

One combination of the first five variables defined a group of test specimens. Three groups, one for each of the three bolt diameters used, formed a series. Groups were composed of five sets of five specimens, each set having a different end margin or edge clearance. In order to determine definitely the critical distance and the bolt-bearing strength with this number of specimens, it was necessary to straddle the estimated critical dimension with the group so that at least two sets would have safe dimensions, and the loads obtained for the five sets together would indicate the point at which the increasing edge or end distance became adequate to develop the full bearing strength. From existing information, the critical dimension was estimated, and a trial group consisting of one specimen of each of five sizes straddling this dimension was tested before the complete group was cut. All specimens for one series (three groups) were cut together from a single sheet of plywood, except those of 0.315-inch thick yellow birch, the panel size of which was too small for some series. Matching between the groups of a series was achieved by cutting them consecutively from the same panel.

The cutting diagram (fig. 1) shows the matching within a group. The five trail bolt-bearing specimens were cut first. Following this, the five sizes selected on the basis of results obtained with the trial specimens were cut consecutively. This pattern was repeated five times to make the group of 25 bolt-bearing specimens. The variations of end margin or edge clearance used in three different groups are illustrated in figure 2.

Compression specimens with the face grain parallel or perpendicular to the direction of loading were cut with the corresponding bolt-bearing specimens. For the bolt-bearing specimens having the face grain at 45°, however, compression specimens with both 0° and 90° grain orientation were used. Under this condition, it was not possible to alternate compression specimens with bolt-bearing specimens in the manner shown in figure 1-A for 0° and 90° specimens without being wasteful of material. The compression specimens were, therefore, cut around the edges of the panels and in groups in the interior of the panels as shown in figure 1-B.

Preparation of Specimens

The cutting and drilling of the specimens were done with considerable care to obtain true, smooth surfaces. Hollow ground saws were used because ordinary saws roughened or splintered the edges, particularly those of the Douglas-fir. With these saws, careful handling of the birch was necessary to avoid burning. The speed of rotation of the saws was 3,500 revolutions per minute, and the saw diameter was 12 inches. It was possible to cut most of the specimens to within 0.01 inch of the desired dimension.

Twist drills[4] were used for drilling the bolt holes because with proper handling of this type of drill, holes of such accurate dimension and surface smoothness could be produced that quality of hole was eliminated as a variable factor that might otherwise interfere with the evaluation of the variables under study. The drills were machine-sharpened and hand-honed and were centered accurately in the chuck. They were operated at rotational speeds of 475 revolutions per minute for the 1/4- and 1/2-inch drills and 280 revolutions per minute for the 3/4-inch drills, resulting in peripheral speeds of 311, 622, and 550 feet per minute, respectively. The rate of feed was about 1 inch per minute. The specimen was held securely in place with a hand lever during the drilling operation. The resulting holes were straight and of accurate dimension, and their surfaces had a distinct shine.

Conditioning

Material, cut in strips whose width was equal to the length of the specimen, was conditioned at 65 percent relative humidity and 70° F. for at least 1 week before it was cut into specimens and drilled. Specimens were then further conditioned several days before testing. All handling of specimens outside the conditioning room was done in closed containers. Testing was generally done in the conditioning room. Those specimens that were tested outside the conditioning room were removed one at a time, protected from moisture loss, and sampled for moisture content after test.

Method of Tests

Methods used in testing the bearing strength of plywood under bolts are classified according to the manner of application of load to the specimen as follows:

(1) Tensile
(2) Compressive
(3) Modified compressive

Diagrams of the specimens and a chart indicating the extent of the testing with each method are shown in figure 3.

The same jig, adaptable to the three types of loading, was used for all tests. The main features of the jig, shown in figures 4, 5, and 6 are (1) two mild steel plates bolted to a base (one plate is removed in fig. 4), (2) spacers for adjusting the distance between the plates to accomodate the various thicknesses of plywood, (3) hardened steel bushings for adapting the jig to various sizes of bolts, and (4) a centrally-located dial gage reading in increments of 1/10,000 inch to measure displacement of the bolt.

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[4] "Bolt-Bearing Strength of Wood and Modified Wood: Effects of different methods of drilling bolt holes in wood and plywood" Forest Products Laboratory Report No. 1523 (December 1944).

The two plates were spaced about 1/8-inch farther apart than the thickness of the specimen to provide room for extrusion of the wood fibers as the specimen was deformed under load. Bolts were used without nuts, and the heads were kept clear of the bushings. These precautions were taken to preclude the possibility of binding and of introducing friction or lateral restraint as a factor in the measured load.

Fit of the bolts in the holes in the specimens was such that they could be pushed through by hand. A projecting lug on the inner face of each bushing provided support for the bolt in the gap between the plates and the specimen without interfering with extrusion of the wood fibers. Bushings were keyed in place to insure accurate positioning and were reversible to provide support for the bolt under either tensile or compressive loading.

After placing the specimen in the jig and applying a small load to stabilize the apparatus, the dial was centered on the end of the specimen, and then positioned longitudinally to a zero reading. These two adjustments were fixed by thumb screws and could be made quickly. In the early part of the testing, contact between the plunger of the dial and the specimen was made through a flat-headed tack pressed into the specimen, but difficulties were encountered with this method, such as splitting of the thin specimens and the tack creeping out of the wood during the test. It was found that the specimen surfaces produced with the hollow ground saws used were sufficiently smooth that direct contact of the gage with the specimen produced more reliable data than could be obtained with the metal contact.

Deformation taking place in the jig, under load, between the bolt and the point at which the gage support is fixed to the jig, adds to the reading of the bolt displacement. The amount, however, as computed from the dimensions of the jig parts was inconsiderable for deformations at the proportional limit and was in all instances less than 1 percent of the deformation at maximum load

In applying load, the rate of head movement was 0.01 inch per minute as determined by a metronome and an auxiliary dial gage. A minimum of 15 readings of load and displacement were taken up to the proportional limit, and readings were continued to failure. In general, very careful attention to detail was necessary at all times to produce consistent data.

Tensile loading.--Tensile loads were applied to bolt-bearing specimens as shown in figure 5. The jig with the detachable base removed was bolted to the movable head of the testing machine. Tensile loads were applied to the specimen by means of a self-aligning Templin grip, the jaws of which covered the full width of the specimen and about 2 inches of the length, leaving a minimum of 3 inches between the grip and the center of the bolt hole.

Compressive loading.--For compressive loading of bolt-bearing specimens, the jig was attached to the removable base and set on the bed of the testing machine as shown in figure 6. Loads were applied to the specimen with a fixed loading head. Difficulties encountered in applying bolt-bearing loads to thin materials with a self-adjusting head were discussed in an earlier report.[5] Lateral stability of the movable head of the testing machine also was of considerable importance in the testing of thin material. Slight shifts of the head caused uneven stress distribution at the bolt and produced erratic results. Further difficulty was experienced when the weight of the movable head was equal to or slightly less than the proportional limit load. After transfer of the weight of the head to the specimens, loading stopped until the screws of the testing machine began to take load in tension. During this interval, deformation continued. If this occurred at or near the proportional limit load, resulting irregularities in the curve tended to obscure the proportional limit.

Modified compressive loading.--In earlier tests under tensile loading, difficulty was experienced in gripping the specimen. For this reason and also because of greater speed of the compressive method, a modification of the tensile specimen was devised by which the necessary end margin for tensile loading could be determined approximately under compressive loading (fig. 3). It was intended to test similar materials by both methods and then to proceed with the modified compressive method if the results obtained were comparable. The modified method was dropped, however, because adequate improvement was made in the tensile loading technique.

Testing technique other than the method of load application was the same as described for tensile and compressive loadings. It was necessary that the specimen be of sufficient width so that failure would not be affected by the proximity of the two loading blocks to the bolt hole.

Compression Test of Plywood

The compressive strength of the plywood was determined by the methods and with the type of lateral supporting device described in ASTM tentative specification D805-44T, paragraphs 5-9, inclusive, and figures 1 and 2.

Specimens were 1 inch wide by 4 inches long by the thickness of the material. They were supported laterally to prevent bending under load. Deformations in a 2-inch gage length were measured with a Marten's mirror compressometer reading to 1/100,000 inch. The compressometer was removed after the proportional limit was passed, and the specimen was then loaded to failure.

Loads were applied by means of a hydraulic press, the head speed of which was controlled to 0.012 inch per minute by means of a dial gage reading to 1/10,000 inch and a metronome.

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[5] "Bolt-Bearing Strength of Wood and Modified Wood: Bolt-Bearing Strength of Laboratory-made, crossbanded, yellow birch compreg under aircraft bolts." Forest Products Laboratory Report No. 1523-A (March 1945)

Tables and Charts

Typical load-deformation curves for specimens having adequate dimensions to produce failure in bearing under the bolt are shown in figure 7. From these curves, the proportional limits could be determined fairly accurately. In general, the loads reached definite ultimate values as shown in curve A. Those curves that did not show definite ultimates, regardless of the displacement of the bolt, either leveled off momentarily, as in curve B, or assumed a very small and uniform slope, as in curve C, at points which agreed well in both load and deformation with more definite values obtained from curves of type A. Since loads at excessive deformations would be of little significance, values thus selected were assumed to represent reliable ultimate loads.

Figure 8 shows a plot of a typical relationship between the end margin (or edge clearance) and bearing stresses at the proportional limit and at ultimate. Each plotted point is the average of five tests. No value is shown for the proportional limit of the first set of five specimens because failure occurred through the inadequate margin and at a bearing stress less than the proportional limit.

Figure 9 shows the influence of diameter of bolt on the ratio of bearing to compressive stresses for the several species and thicknesses of plywood.

Tables 1 through 5 present the summarized results of tests on those bolt-bearing specimens that had adequate dimensions to produce bearing failures and on all the compression specimens. In each table, columns 1 through 9 summarize the bolt-bearing tests and columns 10 through 17 the compression tests. Each value shown is the average for the number of specimens listed and is without adjustment. The maximum and minimum values indicate the variability. The specific gravities of the compression specimens (column 16) are based on volume at test and weight when ovendry. The specific gravities and moisture contents of the compression specimens are assumed to represent the bolt-bearing specimens also, since corresponding specimens were cut from the same panel (fig. 1) and processed and tested under the same conditions. Bearing stresses at proportional limit and ultimate are further summarized in table 6.

Variations in moisture content were so small that no adjustment of the strength values to a common moisture content was necessary. While there were variations in specific gravity within each species the same values of specific gravity were essentially common to bolt-bearing and compression specimens because of the method of taking specimen from the original panels. It is convenient, therefore, to relate the bolt-bearing strengths to the corresponding compressive strengths. These relationships are summarized as ratios in table 7.

Tables 8 and 9 consist of summaries of critical dimensions and of deformations, respectively, for various diameters of bolt and species, thicknesses, and grain orientations of plywood.

Analysis of Results

Edge Clearance and End Margin

In general, the plywoods studied required relatively small edge clearance or end margins to develop the ultimate bearing strength. An edge clearance (measured from axis of bolt) of 1.5 diameters was adequate for the three thicknesses of each of the species under either tensile or compressive loading parallel to the grain of the face plies. Douglas-fir plywood of 0.315-inch thickness, which was tested also at 45° and 90° to the direction of the face grain, did not require edge clearances in excess of two diameters for these grain orientations.

It should be kept in mind that these tests were made on plywood specimens employing only single bolts. The edge clearances thus determined are not applicable without modification to joints employing two or more bolts in line nor to plywood used as bearing plates for wood structural members.

Critical values of end margin for loading parallel to the face grain did not exceed 2.5 diameters for the three species tested. This value was also the maximum required for 0.315-inch Douglas-fir plywood loaded at 45° and 90°

There was a tendency for the required edge clearances and end margins, expressed as multiples of bolt diameter, to increase with plywood thickness and to decrease with an increase in bolt diameter. The trend, however, was not sufficiently well defined nor of sufficient magnitude to warrant consideration of other than the blanket values presented. The proportional limit load is developed at dimensions much smaller than those required for developing the ultimate bearing strength, (fig.8).

Bolt-Bearing Strength

The average bolt-bearing stresses at both proportional limit and ultimate for grain orientation of 0°, summarized in table 6, varied with the diameter of bolt and with the thickness of plywood.[6] In general, the values decreased with increase in diameter and increased with increase in thickness, within the ranges studied in this investigation. The results of earlier tests to determine the bearing strength of wood under bolts[7,8] have shown that bearing stress at proportional limit drops off rapidly as the ratio of the bearing length to diameter of bolt (L/D ratio) increases above a certain critical value. This is the L/D ratio at which bending of the bolt becomes a factor. At ratios less than the critical value no change in proportional limit stress is considered to take place. For the ultimate bearing stress, the critical

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[6] Analysis of the cases of these variations is presented in Appendix A of this report.

[7] NACA Technical Note No. 296.

[8] USDA Technical Bulletin No. 332.

ratio is larger, and the percentage reduction, for ratios exceeding this value, is less. In these tests the upward trends, with increase in L/D ratio indicated in both proportional limit and ultimate bearing stresses for plywood suggest that the maximum ratio employed (2.4) is less than the critical value.

With the exception of modified compressive loading, the manner of loading did not significantly influence the bearing values. The values obtained under modified compressive loading, were generally higher than those obtained by the other methods. Since this method was employed for only 1/2- and 3/4-inch bolts in 0.315- and 0.590-inch plywoods inclusion of the results with those for the other loadings, causes the trends in the average results to be somewhat irregular. Further irregularity was introduced by the difference in specific gravity between the 0.315-inch and the 0.125- and 0.590-inch yellow birch plywood. Adjustment for this difference in specific gravity, on the basis of the relationship developed for compressive strength, reduced the irregularity but did not eliminate it. Adjustment on the basis of average compressive strength likewise failed to produce a uniform relationship between bearing stress and thickness of plywood, but the improvement was greater than was obtained by adjusting on the basis of specific gravity. This suggested using the ratio of bearing stress to compressive stress as the means of presenting these results.

Bolt-bearing tests with grain orientations of 45° and 90° made only on the 0.315-inch Douglas-fir plywood, indicated that for plywood of balanced construction, the bearing stresses at both proportional limit and ultimate are essentially the same for these grain orientations as for 0°. The conclusions drawn in this report with reference to bolt-bearing strength at 0° can therefore be presumed to apply equally well at 45° and 90°.

Compressive Strength

Average compressive stresses at both proportional limit and ultimate were essentially the same for all thicknesses of plywood of a given species. In yellow birch the effect of the higher specific gravity of the 0.315-inch plywood was apparent only in the ultimate strength. No compression tests were made on any of the species at 45°, the average of compressive strengths at 0° and 90° being used for correlation with the bolt-bearing strength of 0.315 Douglas-fir plywood at 45°. The average compressive strength for this species and thickness at 90° was essentially the same as at 0°.

Relationship Between Bearing Strength and Compressive Strength

Average ratios of bearing stress to compressive stress at proportional limit for grain orientations of 0° are shown in A of table 7, and corresponding ratios at ultimate in B of table 7. Within each species, these ratios naturally follow the same general trends as the bearing stresses themselves, decreasing with increase in diameter of bolt and increasing with increase in thickness of plywood. The magnitudes of the ratios, however, differ considerably among the three species and are somewhat higher for ultimate than for proportional limit stresses. The relationship of these two ratios to diameter of bolt for the three species are shown in figures 9A and 9B.

While all curves display a downward trend with increase in diameter, they are widely separated and are not all mutually parallel.

Average ratios of proportional limit stress in bearing to ultimate stress in compression are shown in C of table 7. These ratios display the same general trends with variations in diameter and thickness, but they are much more uniform among the three species than those in figures 9A and 9B. This is demonstrated by the close proximity of the curves of figure 9C and suggest that the relationship between proportional limit stress in bearing and ultimate in compression provides the most satisfactory basis for design. Average ratios of proportional limit stress in bearing to ultimate stress in compression for the three species studied are plotted in figure 9D. All average ratios for the individual species are within +13 percent -10 percent of the corresponding combined average.

Relationship Between Proportional Limit and Ultimate in Bearing

Average ratios of proportional limit in bearing to ultimate in bearing are shown in D of table 7. In general, these ratios vary only slightly with variations in diameter and thickness and are reasonably uniform among the three species tested. If it is desired to derive values of ultimate bearing stress from empirical values of proportional limit stress, the higher ratios are the more conservative. The use of a ratio of 2/3 (approximately the average found for Douglas-fir plywood) would correspond to the ultimate factor of safety of 1.5, currently used in design of wood aircraft structures and would provide design ultimate bearing stresses that would be adequately conservative.

Determination of Bolt-Bearing Design Stresses

The results of this investigation indicate that bolt-bearing design stresses for plywood should be based on proportional limit stresses rather than ultimate stresses. At least until the results of repeated loading tests (currently under way) become available, design "limit stresses" should not exceed proportional limit stresses. It is possible that the repeated-loading tests may indicate a "yield stress" somewhat higher and more closely related to the ultimate bearing stress than the proportional limit stress determined in this investigation.

Bolt-bearing proportional limit stresses for design purposes can be determined by applying ratios presented in figure 9D of this report to ultimate compressive strength values currently available in table 2-9 of ANC Bulletin 18. If it is desired to specify design ultimate stresses, the values should not exceed 150 percent of the proportional limit stresses thus determined.

Deformation

Deformation of the plywood in bearing under the bolt ranged in individual tests up to 0.01 inch at the proportional limit and up to 0.10 inch at ultimate.

Average values were about one-half of these maximums. There was a definite increase in deformation at ultimate and a less significant increase in deformation at proportional limit with increase in thickness of plywood. There was, however, no consistent trend of deformation in relation to diameter of bolt. In general, deformations were greater in yellow birch and yellow-poplar than in Douglas-fir.

Conclusions

(1) Edge clearances equal to 1-1/2 diameters (measured from axis of bolt) are adequate for single-bolted connections in aircraft grade plywood under either tensile or compressive loading parallel to the grain of the face plies. For loading at 45° or 90°, edge clearances of 2 diameters are adequate. End margins of 2-1/2 diameters are adequate for tensile loading at any grain orientation.

(2) The bolt-bearing stresses at both proportional limit and ultimate tend to decrease with increase in diameter of bolt and to increase with increase in thickness of plywood.

(3) The bolt-bearing stresses at both proportional limit and ultimate bear systematic relationships to the corresponding compressive stresses. These relationships differ markedly, however, among species.

(4) The bolt-bearing stress at proportional limit bears a systematic relationship to ultimate compressive strength, and this relationship is reasonably uniform for the three species tested.

(5) Bolt-bearing stresses at proportional limit provide the most satisfactory basis for determining design stresses. Bearing stresses at proportional limit can be determined by applying relationships developed in this investigation to established values for ultimate compressive strength such as are presented in ANC Bulletin 18.

(6) Design ultimate bearing stresses should not exceed 150 percent of the proportional limit stresses thus determined.

(7) The deformations under bolts in aircraft plywood vary approximately as the thickness of plywood but bear no consistent relationship to diameter of bolt. The maximum deformations for the three species tested were on the order of 0.01 inch at proportional limit and 0.10 inch at ultimate.

APPENDIX A

Analysis of the Causes of Variations in Bearing Strength with Variations in Diameter of Bolt and Thickness of Plywood

In the foregoing report, it was shown that bolt-bearing stresses at both proportional limit and ultimate tended to decrease with increase in diameter of bolt and to increase with increase in thickness of plywood. It follows, therefore, that corresponding bearing loads do not vary in direct proportion to the projected bearing area. This is demonstrated in figures 8 and 9, wherein it is evident that the load carried by a bolt of a given diameter at the proportional limit or at the ultimate is not directly proportional to the thickness of the material. A straight line relationship does exist for each bolt diameter, however, within the range of thicknesses used. If extended, these lines intersect the horizontal or thickness scale. It is evident that the material near the face of the member carries less than the average stress. It can be assumed that the intercept represents the thickness carrying no stress and that the balance of the thickness carries uniform stress.

For each species, straight lines drawn to fit the points plotted for each of the three bolt diameters intersect the thickness scale at virtually the same point. If thicknesses are reduced by the average value of this intercept, uniform values of computed stress are obtained for all thicknesses used with a given bolt diameter. These stress values differ, however, with the diameter, increasing as the diameter decreases.

In figures 10 and 11, it may be seen that the load carried by a bolt at the proportional limit or at the ultimate is not directly proportional to the diameter. A straight line relationship does not exist for each thickness, however, within the range of diameters used. If extended, these lines intersect the vertical or load scale indicating a supporting effect in addition to direct bearing. A supporting effect[6] at the edges of bolts or plates has been described as the support provided by adjacent material through fibers that continue beyond the bearing area.

Considering each species separately, straight lines were drawn to fit the points for each of the three plywood thicknesses. Dividing the intercepts on the load scale by the length of edge (twice the effective thickness) produces fairly uniform values, which indicates that the supporting effect is dependent on the length of bearing only and independent of bolt diameter.

Basic bearing stress values (table 10, columns 4 and 8) were obtained by subtracting from the load the amount of the supporting effect of the edges and dividing the remaining load by the reduced area (diameter multiplied by reduced thickness).

The three factors involved in obtaining the bearing strength of plywood under bolts are, therefore: (1) the basic bearing stress; (2) the reduction in thickness which must be made to obtain the effective area on which to apply the basic stress, and (3) the support at the edges, which must be added to the load computed by the use of factors 1 and 2.

The load in pounds which will be supported by bolts in 50-50 plywood of the species used for any combination of bolt diameter and thickness within the range of sizes covered is therefore:

$$P = (T - t) \quad (DS + 2C)$$

where
T = total thickness (inch)
t = ineffective thickness (inch)
S = basic unit bolt-bearing stress (pounds per square inch)
C = support at edges (pounds per inch)
D = diameter of bolt (inch)

Loads computed by this formula (table 10, columns 5 and 9) using the values of S, C, and t determined in these tests (table 11) are in good agreement with the test values of columns 3 and 7. From columns 6 and 10 it may be seen that 94 percent of the computed ultimate load values are within $\pm$ 9 percent of the test values. Agreement is not quite so good for the proportional limit loads. This is to be expected, since these values cannot be determined with the same accuracy as ultimate values.

The loads obtained with 0.315-inch thick Douglas-fir plywood with the face grain at 45° and 90° to the direction of loading were found in these tests to be about the same as the bearing strength parallel to grain. The supporting effect of continuous fibers (edge support) produces load-scale intercepts of similar magnitude for the three directions of loading. Differences are within the range of accuracy of determination. Since only one thickness of plywood was used for grain angles of 45° and 90°, no value of ineffective thickness could be determined. No appreciable error will result, however, from assuming the value of t for Douglas-fir to be the same for the three grain angles. An increase or decrease in t of 50 percent will not produce an error in load of more than 3 percent. This cannot be assumed to be true for other species, however, on the basis of these tests.

It is recognized that, in order to apply these refinements to design, values of S, t, and C would have to be developed for each species of plywood and that the increase in efficiency thus obtained might not justify the added steps involved. It is felt, however, that the possibility of future application of the results of this supplemental analysis justifies its inclusion in this report.

Table 1.--Summary of bolt-bearing and compression tests of yellow birch, aircraft grade plywood with the face grain parallel to the direction of loading

Nominal bolt diameter	Nominal plywood thickness	Bolt bearing: Number of specimens	Value	Bolt bearing: Proportional limit: Stress	Bolt bearing: Proportional limit: Deformation	Bolt bearing: Ultimate: Stress	Bolt bearing: Ultimate: Deformation	Bolt bearing: Proportional limit / Ultimate	Compression: Number of specimens	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Proportional limit / Ultimate	Compression: Modulus of elasticity	Compression: Specific gravity[1]	Compression: Moisture content	Bolt bearing / Compressive: Proportional limit stress	Bolt bearing / Compressive: Ultimate stress	Critical dimension
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Inch	Inch			P.s.i.	Inch	P.s.i.	Inch			P.s.i.	Inch per inch	P.s.i.		P.s.i. x10^-3		Percent			Diameters
								Tensile loading - Edge clearance (TC)											
1/4	0.125	15	Av.	3,927	0.00277	6,799	0.0158	0.57	8	3,755	0.00603	6.148	0.61	1,247	0.675	7.5	1.05	1.10	1.25
			Max.	4,485	.00550	7,292	.0200	.65		4,715	.00685	6.927	.68	1,480	.698	8.3			
			Min.	3,376	.00197	6,158	.0120	.50		3,044	.00550	5.356	.53	1,072	.638	7.1			
1/4	.315	15	Av.	4,777	.00385	9,905	.0512	.48	14	3,468	.00537	6.135	.56	1,308	.782	8.6	1.38	1.61	1.25
			Max.	6,000	.00550	11,038	.0860	.57		4,018	.00780	7,346	.63	1,546	.805	8.9			
			Min.	4,076	.00330	8,655	.0300	.43		3,161	.00438	5,439	.49	996	.740	7.4			
1/4	.590	15	Av.	3,834	.00549	8,296	.0543	.46	13	3,177	.00535	5,460	.58	1,186	.657	8.8	1.21	1.52	1.50
			Max.	4,371	.00663	8,924	.0650	.50		3,607	.00620	5,903	.67	1,279	.682	9.3			
			Min.	3,369	.00460	7,530	.0360	.41		2,409	.00450	4,935	.49	1,027	.634	8.0			
1/2	.125	15	Av.	4,003	.00473	5,982	.0155	.67	8	3,846	.00620	6,240	.61	1,258	.678	7.7	1.04	.96	1.00
			Max.	4,675	.00640	6,602	.0170	.75		4,564	.00840	7,112	.73	1,434	.698	8.3			
			Min.	3,542	.00260	5,628	.0140	.58		3,446	.00533	5,675	.57	1,053	.661	6.9			
1/2	.315	20	Av.	4,289	.00369	7,482	.0309	.57	14	3,264	.00502	6,008	.52	1,307	.738	8.9	1.31	1.24	1.25
			Max.	5,040	.00485	8,582	.0540	.64		4,254	.00570	6,554	.67	1,518	.764	9.6			
			Min.	3,348	.00250	6,781	.0210	.49		2,044	.00310	5,480	.31	1,074	.686	8.3			
1/2	.590	20	Av.	3,722	.00416	7,216	.0692	.50	14	3,058	.00517	5,465	.56	1,185	.667	8.6	1.22	1.32	1.00
			Max.	4,264	.00530	7,787	.0880	.59		3,652	.00630	5,812	.65	1,350	.690	9.1			
			Min.	3,039	.00320	6,740	.0480	.43		2,430	.00420	5.117	.47	1,118	.649	8.1			
								Compressive loading - Edge clearance (C)											
1/4	.125	15	Av.	3,481	.00238	6,399	.0230	.54	8	3,104	.00531	5.108	.58	1.169	.657	8.7	1.12	1.25	1.00
			Max.	4,232	.00282	7,437	.0400	.61		3,631	.00645	5.579	.71	1,328	.682	9.1			
			Min.	2,804	.00200	5,643	.0130	.47		1,914	.00385	4.713	.41	994	.627	7.8			
1/4	.315	20	Av.	4,595	.00389	8,907	.0511	.51	14	3,470	.00568	5,698	.60	1,219	.748	9.0	1.32	1.56	1.25
			Max.	5,328	.00580	9,814	.0820	.60		4,605	.00835	6,296	.73	1,462	.781	9.5			
			Min.	4,046	.00272	8,046	.0330	.46		2,890	.00525	5,242	.48	763	.726	8.3			
1/4	.590	20	Av.	4,167	.00693	9,107	.0770	.46	12	3,129	.00563	5,252	.59	1,114	.665	9.1	1.33	1.73	1.25
			Max.	4,897	.00900	9,725	.1140	.56		3,612	.00665	5,519	.67	1,214	.681	9.5			
			Min.	3,586	.00550	8,347	.0560	.40		2,601	.00470	4,693	.47	1.000	.659	8.8			
1/2	.125	15	Av.	3,794	.00484	5,931	.0184	.64	8	3,242	.00544	5.569	.57	1,199	.656	8.2	1.17	1.06	1.00
			Max.	4,437	.00970	6,494	.0220	.74		3,762	.00670	6,332	.68	1,434	.670	8.6			
			Min.	3,459	.00320	5.550	.0145	.58		2,392	.00430	5.007	.48	1,040	.637	6.9			
1/2	.315	20	Av.	4,219	.00313	7,392	.0271	.57	14	3,225	.00481	6,324	.50	1,356	.757	8.9	1.31	1.17	1.00
			Max.	5,468	.00440	8,029	.0660	.68		4,817	.00722	7.110	.68	1,538	.788	9.1			
			Min.	3,221	.00216	6,769	.0160	.46		2,608	.00350	5,754	.43	1.162	.722	8.6			
1/2	.590	15	Av.	3,481	.00361	7,693	.0638	.45	14	3,107	.00536	5.283	.58	1.161	.673	9.2	1.12	1.46	1.25
			Max.	3,836	.00413	8,159	.0850	.51		3,802	.00625	5.785	.66	1.273	.698	10.4			
			Min.	3,190	.00302	7,265	.0500	.40		2,632	.00455	4,972	.48	966	.659	8.8			
3/4	.125	15	Av.	3,258	.00394	5,347	.0146	.61	12	3,323	.00535	5.700	.57	1,250	.657	7.9	.98	.94	1.00
			Max.	4,046	.00535	5,718	.0180	.71		4,043	.00635	6,356	.73	1,524	.675	8.5			
			Min.	2,738	.00315	4,645	.0110	.53		2,604	.00410	5,181	.48	936	.634	7.0			
3/4	.315	20	Av.	4,044	.00398	7,145	.0291	.56	15	3,455	.00523	6,242	.54	1,333	.760	8.9	1.17	1.14	1.00
			Max.	4,585	.00470	7,790	.0560	.62		5,243	.00940	7.327	.74	1,657	.795	9.7			
			Min.	3,343	.00314	6,698	.0220	.47		2,853	.00384	5,396	.43	1,116	.723	8.0			
3/4	.590	20	Av.	3,713	.00461	7,059	.0609	.52	14	2,860	.00496	5.217	.54	1.166	.674	9.0	1.30	1.35	1.00
			Max.	4,234	.00585	7,502	.0830	.58		3,479	.00625	5.782	.60	1,261	.700	9.8			
			Min.	3,123	.00315	6,712	.0460	.45		2,175	.00345	4.769	.41	923	.657	8.4			

Sheet 1 of 2

Z M 68625 F

Table 1.—Summary of bolt-bearing and compression tests of yellow birch, aircraft grade plywood with the face grain parallel to the direction of loading (Continued)

Nominal bolt diameter	Nominal plywood thickness	Bolt bearing: Number of specimens	Value	Bolt bearing: Proportional limit: Stress	Bolt bearing: Proportional limit: Deformation	Bolt bearing: Ultimate: Stress	Bolt bearing: Ultimate: Deformation	Bolt bearing: Proportional limit / Ultimate	Compression: Number of specimens	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Proportional limit / Ultimate	Compression: Modulus of elasticity	Compression: Specific gravity[1]	Compression: Moisture content	Bolt bearing / Compressive: Proportional limit stress	Bolt bearing / Compressive: Ultimate stress	Critical dimension
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Inch	Inch			P.s.i.	Inch	P.s.i.	Inch			P.s.i.	Inch per inch	P.s.i.		P.s.i. x10^-3		Percent			Diameters
Tensile loading - End margin (TM)																			
1/4	0.125	25	Av.	3,528	0.00239	6,227	0.0170	0.56	21	3,782	0.00498	5,960	0.63	1,201	0.653	8.1	0.93	1.04	2.50
			Max.	4,130	.00433	7,300	.0380	.68		4,941	.00855	6,574	.78	1,530	.681	8.9			
			Min.	2,810	.00142	5,478	.0100	.42		3,292	.00250	4,736	.55	868	.619	7.5			
1/4	.315	20	Av.	4,453	.00391	8,676	.0488	.51	17	3,248	.00367	6,117	.53	1,288	.735	8.7	1.37	1.42	2.50
			Max.	5,463	.00520	9,670	.0900	.60		3,764	.00650	6,819	.63	1,489	.785	9.6			
			Min.	3,619	.00320	7,748	.0201	.44		2,894	.00218	5,618	.46	1,128	.692	8.1			
1/4	.590	15	Av.	4,281	.00543	8,713	.0702	.50	14	3,278	.00536	5,542	.59	1,230	.656	9.0	1.31	1.57	2.50
			Max.	4,558	.00620	9,089	.0880	.55		3,795	.00720	5,817	.67	1,352	.674	9.4			
			Min.	3,867	.00480	8,230	.0520	.43		2,816	.00450	5,246	.52	1,054	.635	8.6			
1/2	.125	20	Av.	3,546	.00301	5,669	.0155	.62	22	3,574	.00500	5,833	.61	1,083	.657	8.7	.99	.97	2.00
			Max.	4,190	.00503	6,210	.0278	.71		4,150	.00770	6,429	.74	1,356	.687	9.3			
			Min.	3,000	.00110	5,208	.0110	.56		2,557	.00290	4,957	.52	753	.623	8.0			
1/2	.315	15	Av.	4,691	.00306	8,222	.0387	.57	16	3,491	.00372	6,564	.53	1,414	.735	8.5	1.34	1.25	2.00
			Max.	5,478	.00480	9,459	.0570	.64		4,417	.00865	6,940	.64	1,696	.774	9.5			
			Min.	4,081	.00230	7,456	.0213	.51		2,900	.00197	5,772	.44	858	.701	7.7			
1/2	.590	10	Av.	3,860	.00316	7,303	.0632	.53	13	3,188	.00525	5,469	.58	1,219	.653	8.9	1.21	1.34	2.00
			Max.	4,108	.00370	7,891	.0780	.57		3,507	.00660	5,894	.65	1,336	.668	9.4			
			Min.	3,515	.00270	7,000	.0560	.45		2,827	.00454	5,201	.52	1,034	.636	8.6			
3/4	.125	23	Av.	3,679	.00327	5,953	.0141	.61	22	3,691	.00527	6,165	.60	1,105	.670	8.4	1.00	.97	1.50
			Max.	4,610	.00665	6,490	.0209	.72		4,633	.00928	7,076	.68	1,547	.713	9.0			
			Min.	3,014	.00172	5,249	.0100	.52		2,800	.00299	5,210	.53	520	.632	7.8			
3/4	.315	14	Av.	4,182	.00309	7,441	.0214	.56	19	3,314	.00367	6,276	.53	1,397	.754	8.3	1.26	1.18	2.00
			Max.	4,958	.00380	8,205	.0262	.60		4,148	.00600	7,467	.64	2,017	.806	9.4			
			Min.	3,652	.00265	6,522	.0168	.50		2,961	.00150	5,023	.47	1,117	.702	7.4			
3/4	.590	10	Av.	3,453	.00314	6,569	.0666	.53	14	3,270	.00537	5,440	.60	1,230	.658	9.1	1.06	1.21	1.75
			Max.	3,699	.00363	6,714	.0740	.56		3,679	.00755	5,903	.68	1,333	.694	9.4			
			Min.	3,123	.00270	6,451	.0480	.48		2,840	.00442	5,133	.54	922	.636	8.7			
Modified compressive loading - End margin (MC)																			
1/4	.315	10	Av.	5,475	.00639	9,580	.0464	.57	10	3,740	.00267	6,639	.56	1,404	.747	8.4	1.46	1.44	....
			Max.	6,024	.00780	10,154	.0580	.62		4,045	.00302	7,020	.62	1,576	.785	8.7			
			Min.	5,058	.00545	8,709	.0320	.52		3,520	.00240	6,118	.52	1,310	.727	8.3			
1/4	.590	10	Av.	5,447	.00923	9,727	.0896	.56	10	4,322	.00311	6,432	.67	1,397	.676	8.1	1.26	1.51	....
			Max.	5,900	.01055	10,560	.1140	.52		4,840	.00352	6,930	.70	1,569	.715	8.0			
			Min.	5,090	.00815	8,920	.0540	.61		3,780	.00255	5,810	.64	1,230	.637	7.8			
1/2	.315	10	Av.	4,856	.00564	7,726	.0277	.63	10	3,505	.00490	6,686	.50	1,411	.758	8.2	1.38	1.16	....
			Max.	5,335	.00710	8,456	.0530	.69		3,888	.00603	7,502	.56	1,872	.791	8.6			
			Min.	4,415	.00500	7,271	.0160	.58		2,582	.00370	5,610	.46	1,137	.740	7.6			
1/2	.590	10	Av.	5,394	.00655	8,291	.0534	.65	10	4,134	.00629	6,369	.64	1,320	.691	7.7	1.30	1.30	....
			Max.	5,560	.00930	8,830	.0660	.68		4,830	.00715	6,780	.73	1,518	.721	7.9			
			Min.	5,040	.00570	7,700	.0460	.63		3,510	.00565	5,790	.54	1,088	.663	7.6			
3/4	.315	10	Av.	4,875	.00612	7,591	.0249	.64	10	3,550	.00484	6,709	.53	1,466	.744	8.5	1.37	1.13	....
			Max.	5,544	.00700	8,520	.0280	.69		3,923	.00522	7,320	.57	1,592	.780	9.6			
			Min.	4,356	.00520	6,864	.0220	.60		2,675	.00395	5,990	.43	1,338	.699	7.1			
3/4	.590	10	Av.	4,640	.00683	7,461	.0486	.62	10	4,024	.00611	6,515	.61	1,343	.669	7.6	1.15	1.14	....
			Max.	5,130	.00790	7,810	.0680	.66		4,640	.00880	7,020	.66	1,614	.693	8.2			
			Min.	4,280	.00570	7,000	.0360	.59		3,480	.00525	6,070	.56	911	.648	7.3			

[1]Oven dry, based on volume at test.

Z M 68626 F

Table 2.--Summary of bolt-bearing and compression tests of Douglas-fir, aircraft grade plywood with the face grain parallel to the direction of loading

Nominal bolt diameter	Nominal plywood thickness	Bolt bearing: Number of specimens	Value	Bolt bearing: Proportional limit: Stress	Bolt bearing: Proportional limit: Deformation	Bolt bearing: Ultimate: Stress	Bolt bearing: Ultimate: Deformation	Bolt bearing: Proportional limit / Ultimate	Compression: Number of specimens	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Proportional limit / Ultimate	Compression: Modulus of elasticity	Compression: Specific gravity[1]	Compression: Moisture content	Bolt bearing / Compressive: Proportional limit stress	Bolt bearing / Compressive: Ultimate stress	Critical dimension
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Inch	Inch			P.s.i.	Inch	P.s.i.	Inch			P.s.i.	Inch per inch	P.s.i.		P.s.i. $x10^{-3}$		Percent			Diameters
								Tensile loading - Edge clearance (TC)											
1/4	0.155	15	Av.	2,801	0.00320	4,341	0.0113	0.64	13	3,346	0.00508	4,518	0.74	1,247	0.492	8.7	0.84	0.96	1.25
			Max.	3,467	.00505	4,667	.0160	.81		3,600	.00597	4,805	.81	1,372	.512	9.0			
			Min.	2,413	.00225	3,920	.0070	.57		3,026	.00480	4,066	.65	1,085	.471	8.5			
1/4	.315	20	Av.	2,790	.00399	4,303	.0212	.65	14	3,207	.00587	4,585	.69	1,102	.478	7.9	.87	.94	1.25
			Max.	3,185	.00520	4,697	.0310	.74		3,671	.00796	4,949	.77	1,321	.500	8.4			
			Min.	2,308	.00303	3,884	.0130	.56		2,397	.00460	4,164	.57	856	.453	7.6			
1/4	.590	15	Av.	2,702	.00556	4,692	.0573	.57	14	3,346	.00640	4,442	.76	1,073	.469	7.5	.80	1.06	1.25
			Max.	3,135	.00810	5,010	.0960	.63		3,723	.00840	4,691	.84	1,262	.479	7.8			
			Min.	2,410	.00425	4,219	.0200	.50		2,727	.00517	4,139	.62	789	.457	7.2			
1/2	.155	20	Av.	2,315	.00266	3,683	.0117	.62	13	3,455	.00538	4,649	.74	1,294	.502	8.7	.67	.79	1.00
			Max.	2,989	.00427	4,130	.0210	.75		3,867	.00618	5,162	.83	1,396	.521	9.0			
			Min.	1,600	.00200	3,216	.0070	.48		3,067	.00400	4,000	.61	1,057	.476	8.5			
1/2	.315	25	Av.	2,433	.00268	3,799	.0115	.64	13	2,942	.00566	4,237	.69	1,048	.486	7.9	.83	.90	1.00
			Max.	2,820	.00475	4,250	.0160	.70		3,344	.00637	4,767	.76	1,249	.504	8.2			
			Min.	2,032	.00105	3,401	.0090	.55		2,716	.00435	3,938	.61	893	.462	7.5			
1/2	.590	15	Av.	2,711	.00350	4,186	.0165	.65	14	3,183	.00590	4,610	.68	1,098	.469	7.8	.85	.91	1.00
			Max.	3,003	.00445	4,361	.0290	.71		3,620	.00744	4,908	.77	1,222	.483	8.4			
			Min.	2,427	.00280	4,047	.0110	.56		2,475	.00386	4,249	.55	839	.456	7.3			
								Compressive loading - Edge clearance (C)											
1/4	.155	15	Av.	3,201	.00503	4,511	.0127	.71	12	3,190	.00534	4,037	.77	1,206	.501	7.4	1.00	1.12	1.25
			Max.	3,062	.00775	5,020	.0180	.82		3,790	.00687	5,163	.96	1,311	.526	8.9			
			Min.	2,749	.00318	3,760	.0085	.65		2,308	.00352	2,968	.66	1,007	.483	6.6			
1/4	.315	15	Av.	2,777	.00406	4,100	.0121	.68	13	2,867	.00537	4,351	.66	1,075	.471	8.3	.97	.94	1.00
			Max.	3,007	.00560	4,394	.0170	.76		3,340	.00650	4,980	.76	1,220	.487	10.8			
			Min.	2,517	.00278	3,788	.0100	.59		2,460	.00408	3,720	.58	951	.456	7.8			
1/4	.590	15	Av.	3,521	.00674	4,844	.0242	.72	12	3,434	.00669	4,719	.71	1,034	.462	7.8	1.03	1.03	1.00
			Max.	3,774	.00800	5,229	.0420	.80		3,922	.00800	4,975	.83	1,161	.472	8.2			
			Min.	3,093	.00530	4,536	.0130	.64		3,043	.00565	4,216	.61	826	.451	7.6			
1/2	.155	15	Av.	2,700	.00263	3,948	.0090	.68	14	3,618	.00620	4,728	.76	1,171	.496	8.5	.75	.84	1.00
			Max.	3,115	.00360	4,206	.0110	.77		4,160	.00710	5,065	.85	1,293	.516	9.1			
			Min.	2,240	.00144	3,551	.0070	.60		3,228	.00505	4,445	.69	976	.460	8.0			
1/2	.315	25	Av.	2,621	.00350	3,748	.0094	.70	13	3,063	.00574	4,370	.68	1,066	.475	7.7	.86	.86	1.00
			Max.	2,997	.00440	4,676	.0120	.81		4,100	.00740	4,890	.99	1,142	.492	8.6			
			Min.	2,201	.00228	3,455	.0070	.58		2,080	.00440	3,840	.51	945	.446	5.7			
1/2	.590	20	Av.	2,772	.00432	4,395	.0178	.63	14	3,508	.00731	4,716	.74	977	.468	7.7	.79	.93	1.00
			Max.	3,464	.00645	4,670	.0310	.74		3,987	.00950	4,950	.84	1,225	.480	8.0			
			Min.	2,328	.00380	4,084	.0130	.55		3,053	.00640	4,366	.68	729	.454	7.5			
3/4	.155	20	Av.	2,457	.00423	3,728	.0123	.66	15	3,342	.00583	4,648	.71	1,157	.504	8.7	.74	.80	1.00
			Max.	3,032	.00780	4,090	.0190	.77		3,730	.00670	5,105	.79	1,329	.535	8.9			
			Min.	2,170	.00280	3,317	.0080	.58		2,710	.00472	4,175	.61	946	.471	8.4			
3/4	.315	15	Av.	2,360	.00436	3,541	.0130	.67	13	2,931	.00583	4,249	.68	1,017	.477	7.9	.81	.83	1.00
			Max.	2,439	.00590	3,755	.0160	.71		3,450	.00725	4,590	.84	1,100	.492	8.5			
			Min.	2,095	.00350	3,368	.0110	.60		2,330	.00446	3,680	.60	952	.442	7.7			
3/4	.590	20	Av.	2,595	.00497	4,169	.0233	.62	15	3,487	.00657	4,728	.74	1,067	.463	7.8	.75	.88	1.00
			Max.	2,870	.00680	4,368	.0350	.68		3,740	.00770	4,967	.78	1,216	.477	8.2			
			Min.	2,418	.00442	3,938	.0160	.56		3,212	.00584	4,538	.67	928	.454	7.6			

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Table 2.--Summary of bolt-bearing and compression tests of Douglas-fir, aircraft grade plywood with the face grain parallel to the direction of loading (Continued)

Nominal bolt diameter	Nominal plywood thickness	Bolt bearing: Number of specimens	Value	Bolt bearing: Proportional limit: Stress	Bolt bearing: Proportional limit: Deformation	Bolt bearing: Ultimate: Stress	Bolt bearing: Ultimate: Deformation	Bolt bearing: Proportional limit / Ultimate	Compression: Number of specimens	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Proportional limit / Ultimate	Compression: Modulus of elasticity	Compression: Specific gravity[1]	Compression: Moisture content	Bolt bearing / Compressive: Proportional limit stress	Bolt bearing / Compressive: Ultimate stress	Critical dimension
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Inch	Inch			P.s.i.	Inch	P.s.i.	Inch			P.s.i.	Inch per inch	P.s.i.		P.s.i. x10^-3		Percent			Diameters
								Tensile loading - End margin (TM)											
1/4	0.155	20	Av.	2,520	0.00274	4,055	0.0118	0.62	20	3,109	0.00404	4,308	0.71	1,177	0.486	7.7	0.81	0.94	2.00
			Max.	3,133	.00446	4,427	.0251	.71		3,770	.00735	4,990	.85	1,461	.527	8.7			
			Min.	2,133	.00130	3,640	.0074	.53		2,420	.00208	3,660	.60	927	.446	6.6			
1/4	.315	15	Av.	2,829	.00539	4,318	.0142	.65	19	3,045	.00418	4,673	.65	1,098	.471	7.4	.93	.92	2.50
			Max.	3,230	.00922	4,760	.0191	.74		3,510	.00700	5,110	.77	1,280	.508	7.9			
			Min.	2,660	.00250	3,970	.0090	.52		2,618	.00240	4,010	.56	544	.432	6.4			
1/4	.590	20	Av.	2,805	.00520	4,430	.0360	.63	7	3,179	.00611	4,322	.73	1,041	.464	8.1	.88	1.03	2.50
			Max.	3,313	.00770	4,950	.0650	.76		3,424	.00650	4,601	.79	1,134	.477	8.2			
			Min.	2,522	.00364	4,173	.0160	.56		2,726	.00520	4,100	.63	982	.436	8.0			
1/2	.155	15	Av.	2,815	.00288	4,055	.0098	.69	20	3,187	.00353	4,498	.70	1,289	.502	8.0	.88	.90	1.50
			Max.	3,397	.00370	4,650	.0126	.81		3,569	.00526	5,090	.79	1,641	.535	8.7			
			Min.	2,300	.00220	3,620	.0080	.63		2,455	.00164	3,730	.56	1,041	.463	7.3			
1/2	.315	20	Av.	2,791	.00381	4,059	.0111	.68	17	3,066	.00380	4,702	.65	1,147	.484	7.5	.89	.86	2.00
			Max.	3,655	.00660	4,960	.0140	.81		3,480	.00562	5,120	.72	1,359	.526	7.9			
			Min.	2,132	.00172	3,425	.0085	.55		2,830	.00214	4,374	.61	730	.449	7.3			
1/2	.590	14	Av.	2,535	.00283	3,999	.0224	.63	13	3,141	.00614	4,410	.70	1,023	.468	7.9	.81	.91	1.50
			Max.	2,810	.00462	4,268	.0520	.70		3,631	.00675	4,700	.79	1,117	.479	8.5			
			Min.	2,149	.00217	3,744	.0100	.57		2,436	.00465	4,152	.56	974	.453	6.8			
3/4	.155	20	Av.	2,396	.00355	3,656	.0119	.65	19	3,238	.00373	4,400	.74	1,300	.498	8.2	.74	.83	2.00
			Max.	3,189	.00645	4,371	.0164	.76		3,870	.00617	5,435	.83	1,629	.542	8.9			
			Min.	1,771	.00083	3,140	.0050	.48		2,394	.00213	3,849	.60	1,100	.450	6.7			
3/4	.315	19	Av.	2,457	.00419	3,868	.0130	.63	17	3,204	.00366	4,705	.67	1,264	.487	7.4	.77	.82	2.00
			Max.	2,818	.00710	4,155	.0192	.70		3,480	.00623	5,195	.76	1,481	.518	7.7			
			Min.	2,090	.00212	3,410	.0080	.55		2,620	.00190	4,020	.60	1,044	.455	5.7			
3/4	.612	12	Av.	2,409	.00223	3,905	.0084	.61									[2] .76	[2] .89	2.00
			Max.	2,646	.00289	4,386	.0100	.71											
			Min.	2,080	.00158	3,642	.0042	.55											
								Modified compressive loading - End margin (ME)											
1/4	.315	18	Av.	3,020	.00550	4,606	.0180	.65	21	3,108	.00275	4,497	.69	1,135	.477	8.0	.97	1.02	2.50
			Max.	3,342	.00734	5,310	.0325	.75		3,567	.00325	4,960	.76	1,345	.507	8.7			
			Min.	2,790	.00380	4,222	.0105	.55		2,556	.00230	4,038	.59	980	.443	7.7			
1/4	.590	25	Av.	3,580	.00866	4,877	.0304	.73	22	3,490	.00330	4,814	.72	1,065	.474	7.9	1.02	1.01	2.00
			Max.	3,960	.01190	5,255	.0680	.83		3,943	.00400	5,210	.80	1,263	.483	8.4			
			Min.	3,260	.00665	4,431	.0150	.67		2,980	.00236	4,094	.63	959	.440	7.3			
1/2	.315	20	Av.	2,451	.00563	3,932	.0184	.62	21	3,041	.00553	4,295	.69	1,189	.489	7.8	.81	.92	1.50
			Max.	2,717	.00640	4,300	.0250	.68		3,960	.00699	4,760	.83	2,051	.507	8.2			
			Min.	2,057	.00480	3,496	.0130	.56		2,338	.00228	3,752	.50	834	.457	7.3			
1/2	.590	20	Av.	3,274	.00674	4,426	.0186	.74	22	3,532	.00672	4,849	.69	1,059	.480	7.8	.93	.91	2.00
			Max.	3,824	.00810	4,872	.0310	.81		4,334	.00950	5,193	.83	1,204	.496	8.3			
			Min.	3,003	.00580	4,076	.0100	.68		3,013	.00582	4,635	.53	690	.465	7.2			
3/4	.315	20	Av.	2,705	.00616	4,068	.0170	.66	20	3,069	.00559	4,465	.66	1,115	.480	7.9	[illegible]	.91	2.00
			Max.	3,103	.00880	4,360	.0270	.80		3,790	.00750	5,058	.87	1,354	.500	8.4			
			Min.	2,050	.00490	3,680	.0120	.54		2,410	.00430	4,196	.57	823	.454	7.5			
3/4	.590	20	Av.	3,284	.00719	4,374	.0169	.75	19	3,366	.00636	4,814	.69	1,065	.482	7.7	.98	.91	2.00
			Max.	3,750	.00840	4,795	.0280	.83		3,845	.00780	5,044	.81	1,185	.508	8.7			
			Min.	2,839	.00620	4,011	.0140	.71		2,880	.00520	4,564	.63	872	.470	7.1			

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

[2] Based on compressive strength of material used with 1/4-inch and 1/2-inch bolts of this same group.

Table 3.--Summary of bolt-bearing and compression tests of five-ply, 0.315 inch thick Douglas-fir, aircraft grade plywood with the face grain of the bolt-bearing specimens at 45° to the direction of loading

Bolt bearing

Nominal bolt diameter (1)	Nominal plywood thickness (2)	Number of specimens (3)	Value (4)	Proportional limit: Stress (5)	Proportional limit: Deformation (6)	Ultimate: Stress (7)	Ultimate: Deformation (8)	Proportional limit / Ultimate (9)
Inch	Inch			P.s.i.	Inch	P.s.i.	Inch	
1/4	0.315	15	Av.	2,739	0.00409	4,564	0.0270	0.60
			Max.	3,213	.00550	5,090	.0490	.71
			Min.	2,270	.00245	4,281	.0140	.52
1/2	.315	15	Av.	2,272	.00418	3,536	.0221	.64
			Max.	2,625	.00517	3,809	.0420	.74
			Min.	2,062	.00350	3,297	.0130	.58
1/4	.315	10	Av.	2,923	.00432	4,371	.0193	.67
			Max.	3,383	.00605	4,987	.0330	.75
			Min.	2,395	.00265	4,128	.0100	.61
1/2	.315	15	Av.	2,461	.00381	3,771	.0168	.65
			Max.	2,848	.00430	4,190	.0220	.70
			Min.	2,187	.00315	3,454	.0130	.57
3/4	.315	15	Av.	2,192	.00498	3,629	.0224	.60
			Max.	2,431	.00590	4,042	.0300	.65
			Min.	1,885	.00387	3,232	.0180	.51
1/4	.315	20	Av.	3,032	.00665	4,879	.0295	.62
			Max.	3,545	.00830	5,300	.0440	.72
			Min.	2,530	.00495	4,620	.0187	.53
1/2	.315	20	Av.	2,914	.00555	4,316	.0221	.67
			Max.	3,410	.00870	4,943	.0360	.75
			Min.	2,380	.00405	3,710	.0130	.60
3/4	.315	25	Av.	3,047	.00708	4,418	.0245	.68
			Max.	3,851	.00920	5,020	.0370	.81
			Min.	2,359	.00475	4,120	.0150	.55

Compression

Nominal bolt diameter (1)	Value (4)	Parallel-to-grain: Number of specimens (10)	Proportional limit: Stress (11)	Proportional limit: Deformation (12)	Ultimate stress (13)	Proportional limit / Ultimate (14)	Modulus of elasticity (15)	Perpendicular-to-grain: Number of specimens (16)	Proportional limit: Stress (17)	Proportional limit: Deformation (18)	Ultimate stress (19)	Proportional limit / Ultimate (20)	Modulus of elasticity (21)	Specific gravity[1,2] (22)	Moisture content[1] (23)	Bolt bearing / Compression: Proportional limit stress (24)	Bolt bearing / Compression: Ultimate stress (25)	Critical dimension (26)
Inch			P.s.i.	Inch per inch	P.s.i.		P.s.i. x10^-3		P.s.i.	Inch per inch	P.s.i.		P.s.i. x10^-3		Percent			Diameters
Tensile loading - Edge clearance (TC)																		
1/4	Av.	11	2,875	0.00576	4,054	0.70	1,005	10	2,756	0.00565	4,042	0.68	948	0.472	7.9	0.97	1.13	2.00
	Max.		3,350	.00730	4,400	.86	1,190		3,145	.00710	4,438	.81	1,116	.508	8.3			
	Min.		2,350	.00395	3,840	.57	906		2,118	.00440	3,634	.51	840	.448	7.7			
1/2	Av.	9	3,102	.00459	4,539	.68	1,109	10	2,918	.00566	4,214	.68	994	.483	7.9	.76	.81	1.50
	Max.		3,556	.00610	5,086	.76	1,254		3,530	.00690	4,860	.80	1,068	.512	8.1			
	Min.		2,484	.00465	3,854	.64	953		2,380	.00528	3,690	.61	850	.453	7.6			
Compressive loading - Edge clearance (C)																		
1/4	Av.	10	2,931	.00529	4,160	.67	1,112	6	3,037	.00586	4,447	.68	1,037	.485	7.9	.98	1.01	2.00
	Max.		3,646	.00665	4,890	.79	1,370		3,291	.00626	4,652	.70	1,081	.502	8.6			
	Min.		2,125	.00402	3,450	.61	896		2,811	.00520	4,267	.64	985	.490	7.6			
1/2	Av.	6	3,095	.00541	4,424	.70	1,150	8	2,811	.00606	4,169	.68	943	.481	7.3	.84	.88	1.50
	Max.		3,364	.00590	4,890	.78	1,370		3,135	.00775	4,827	.72	1,126	.502	8.5			
	Min.		2,822	.00525	3,871	.64	1,023		2,397	.00498	3,476	.63	651	.449	6.9			
3/4	Av.	13	2,956	.00526	4,415	.67	1,130	14	2,736	.00602	3,980	.68	919	.476	8.0	.77	.87	1.50
	Max.		3,354	.00593	4,931	.78	1,370		3,077	.00775	4,483	.76	1,126	.502	8.5			
	Min.		2,360	.00446	3,871	.55	932		2,368	.00498	3,476	.59	651	.449	6.9			
Modified compressive loading - End margin (MC)																		
1/4	Av.	11	3,122	.00498	4,805	.65	1,260	14	2,991	.00564	4,255	.70	1,066	.496	7.4	.99	1.08	2.50
	Max.		3,480	.00540	5,340	.76	1,450		3,300	.00634	4,650	.77	1,225	.523	7.9			
	Min.		2,720	.00430	4,420	.61	1,141		2,500	.00490	3,620	.64	931	.475	6.9			
1/2	Av.	9	3,212	.00523	4,823	.67	1,229	8	2,968	.00571	4,241	.69	1,043	.492	7.1	.94	.96	2.00
	Max.		3,690	.00570	5,580	.74	1,378		3,350	.00650	4,500	.77	1,218	.514	7.5			
	Min.		2,870	.00474	4,420	.60	874		2,580	.00500	3,770	.65	874	.467	6.9			
3/4	Av.	11	3,185	.00520	4,947	.64	1,242	12	3,020	.00564	4,356	.68	1,074	.500	7.3	.99	.95	1.50
	Max.		3,600	.00637	5,600	.72	1,600		3,350	.00612	4,740	.75	1,218	.516	7.6			
	Min.		2,480	.00310	4,520	.44	1,089		2,620	.00520	4,070	.58	936	.430	6.9			

[1]Values of specific gravity and moisture content are average for the 0° and 90° compression specimens.

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

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Table 4.--Summary of bolt-bearing and compressive tests of five ply, 0.315 inch thick Douglas-fir, aircraft grade plywood with the face grain direction perpendicular to the direction of loading

Nominal bolt diameter	Nominal plywood thickness	Bolt bearing: Number of specimens	Value	Bolt bearing: Proportional limit: Stress	Bolt bearing: Proportional limit: Deformation	Bolt bearing: Ultimate: Stress	Bolt bearing: Ultimate: Deformation	Bolt bearing: Proportional limit / Ultimate	Compression: Number of specimens	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Proportional limit / Ultimate	Compression: Modulus of elasticity	Compression: Specific gravity[1]	Compression: Moisture content	Bolt bearing / Compressive: Proportional limit stress	Bolt bearing / Compressive: Ultimate stress	Critical dimension
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Inch	Inch			P.s.i.	Inch	P.s.i.	Inch			P.s.i.	Inch	P.s.i.		P.s.i. x10^-3		Percent			Diameters
								Tensile loading - Edge clearance (TC)											
1/4	0.315	10	Av.	2,599	0.00409	4,551	0.0370	0.56	14	2,872	0.00643	4,084	0.69	901	0.477	7.9	0.90	1.11	2.00
			Max.	3,077	.00495	4,860	.0760	.67		3,555	.00900	4,660	.79	1,074	.512	8.2			
			Min.	1,988	.00320	3,969	.0130	.47		2,112	.00504	3,550	.55	742	.446	7.8			
1/2	.315	15	Av.	2,330	.00322	3,607	.0202	.65	15	2,773	.00629	4,173	.66	895	.472	7.7	.84	.86	1.25
			Max.	2,630	.00450	4,130	.0370	.73		3,155	.00865	4,632	.78	1,090	.497	7.9			
			Min.	2,005	.00248	3,290	.0110	.56		2,500	.00496	3,898	.57	730	.437	7.5			
								Compressive loading - Edge clearance (C)											
1/4	.315	20	Av.	2,841	.00386	4,302	.0155	.65	14	2,829	.00615	4,109	.69	957	.478	7.9	.98	1.05	1.50
			Max.	3,562	.00482	4,974	.0250	.75		3,396	.00680	4,450	.79	1,061	.494	9.0			
			Min.	2,273	.00278	3,961	.0090	.53		2,032	.00400	3,205	.45	804	.463	7.0			
1/2	.315	15	Av.	2,649	.00341	3,820	.0102	.69	15	3,052	.00643	4,230	.72	951	.479	7.9	.87	.90	1.00
			Max.	3,025	.00730	4,088	.0160	.83		3,344	.00735	4,709	.78	1,045	.497	8.1			
			Min.	2,235	.00201	3,494	.0062	.60		2,617	.00582	3,981	.64	818	.457	7.8			
3/4	.315	15	Av.	2,517	.00411	3,829	.0142	.65	13	3,065	.00627	4,259	.72	978	.488	7.9	.82	.90	1.00
			Max.	2,975	.00500	4,049	.0210	.74		3,567	.00730	4,787	.79	1,127	.502	8.1			
			Min.	1,918	.00310	3,601	.0120	.52		2,722	.00573	3,780	.66	878	.476	7.6			
								Modified compressive loading - End margin (MC)											
1/4	.315	20	Av.	3,057	.00628	4,880	.0379	.62	22	3,030	.00290	4,338	.66	1,050	.479	7.8	1.01	1.12	2.50
			Max.	3,549	.00800	5,668	.0800	.72		3,625	.00408	4,669	.81	1,363	.524	8.2			
			Min.	2,168	.00400	4,488	.0170	.44		2,152	.00210	3,811	.49	880	.444	7.4			
1/2	.315	18	Av.	3,088	.00614	4,256	.0202	.72	20	3,124	.00634	4,438	.70	1,018	.504	7.7	.99	.96	1.50
			Max.	3,614	.00800	4,647	.0280	.85		3,364	.01125	4,896	.79	1,196	.535	8.0			
			Min.	2,692	.00500	3,862	.0100	.63		2,650	.00530	3,968	.64	561	.489	7.2			
3/4	.315	24	Av.	2,781	.00621	4,100	.0166	.68	18	2,901	.00585	4,319	.67	1,001	.489	7.7	.96	.95	1.50
			Max.	3,426	.00920	4,575	.0280	.78		3,205	.00750	4,903	.73	1,202	.512	8.2			
			Min.	2,241	.00435	3,562	.0120	.60		2,397	.00476	3,526	.57	768	.439	7.4			

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

Z M 68630 F

Table 5.--Summary of bolt bearing and compression tests of yellow-poplar, aircraft grade plywood with the face grain parallel to the direction of loading

Nominal bolt diameter	Nominal plywood thickness	Bolt bearing: Number of specimens	Value	Bolt bearing: Proportional limit: Stress	Bolt bearing: Proportional limit: Deformation	Bolt bearing: Ultimate: Stress	Bolt bearing: Ultimate: Deformation	Bolt bearing: Proportional limit / Ultimate	Compression: Number of specimens	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Proportional limit / Ultimate	Compression: Modulus of elasticity	Compression: Specific gravity[1]	Compression: Moisture content	Bolt bearing / Compressive: Proportional limit stress	Bolt bearing / Compressive: Ultimate stress	Critical dimension
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Inch	Inch			P.s.i.	Inch	P.s.i.	Inch			P.s.i.	Inch per inch	P.s.i.		P.s.i. x10^-3		Percent			Diameters
								Tensile loading - Edge clearance (E)											
1/4	0.125	20	Av.	2,550	0.00247	4,116	0.0163	0.62	13	2,525	0.00577	4,026	0.63	878	0.499	7.8	1.01	1.02	1.25
			Max.	2,769	.00347	4,668	.0320	.73		2,862	.00670	4,637	.68	999	.531	8.6			
			Min.	2,229	.00185	3,398	.0080	.55		1,923	.00506	3,054	.56	723	.444	7.3			
1/4	.315	20	Av.	2,207	.00341	4,316	.0530	.51	13	2,200	.00639	3,335	.66	702	.478	8.1	1.00	1.29	1.25
			Max.	2,516	.00395	5,406	.0950	.63		2,539	.00845	3,756	.75	883	.501	8.7			
			Min.	1,911	.00300	3,532	.0250	.45		1,881	.00490	2,952	.56	488	.446	7.7			
1/4	.590	20	Av.	2,581	.00576	4,588	.0408	.56	13	2,296	.00524	3,560	.64	882	.498	8.8	1.12	1.29	1.25
			Max.	3,116	.00770	5,160	.0690	.66		2,728	.00688	4,060	.74	1,021	.535	9.1			
			Min.	2,171	.00410	4,050	.0300	.47		1,843	.00385	3,025	.48	702	.473	8.3			
1/2	.125	20	Av.	2,201	.00216	3,627	.0109	.60	11	2,358	.00547	3,802	.62	864	.494	8.2	.93	0.95	1.00
			Max.	3,173	.00282	4,025	.0210	.81		2,637	.00610	4,377	.70	989	.514	9.5			
			Min.	1,743	.00123	3,138	.0058	.52		1,923	.00486	3,100	.55	684	.449	7.7			
1/2	.315	20	Av.	2,127	.00294	3,765	.0532	.56	14	2,364	.00588	3,467	.68	804	.456	8.0	.90	1.09	1.00
			Max.	2,397	.00372	4,123	.0700	.63		2,784	.00665	3,823	.78	886	.478	8.6			
			Min.	1,824	.00233	3,367	.0420	.48		1,904	.00482	3,135	.53	731	.438	7.6			
1/2	.590	15	Av.	2,066	.00305	4,182	.0650	.49	13	2,340	.00561	3,605	.64	848	.495	8.9	.88	1.16	1.00
			Max.	2,402	.00400	4,626	.0900	.58		2,964	.00830	4,249	.70	979	.533	9.3			
			Min.	1,743	.00220	3,708	.0445	.42		1,566	.00320	3,067	.48	661	.464	8.2			
								Compressive loading - Edge clearance (D)											
1/4	.125	10	Av.	2,166	.00227	3,680	.0171	.59	13	2,094	.00564	3,363	.68	830	.467	9.0	1.03	1.09	1.25
			Max.	2,392	.00275	3,988	.0240	.65		2,814	.00677	3,787	.80	1,005	.508	9.7			
			Min.	1,839	.00202	3,440	.0110	.55		1,858	.00420	2,763	.57	549	.416	8.6			
1/4	.315	15	Av.	2,332	.00389	3,643	.0262	.65	8	2,190	.00581	3,221	.68	757	.437	8.6	1.06	1.13	1.25
			Max.	3,006	.00465	4,305	.0390	.73		2,535	.00665	3,582	.79	894	.461	9.3			
			Min.	1,607	.00273	2,924	.0180	.55		1,898	.00500	2,870	.59	662	.417	7.7			
1/4	.590	20	Av.	2,561	.00580	4,384	.0408	.58	6	2,414	.00515	3,893	.61	935	.496	8.5	1.06	1.13	1.25
			Max.	2,888	.00790	5,073	.0600	.68		2,802	.00594	4,188	.72	1,010	.526	8.7			
			Min.	2,135	.00440	3,726	.0260	.53		1,896	.00417	3,602	.47	846	.472	8.1			
1/2	.125	20	Av.	2,254	.00277	3,306	.0136	.67	13	2,406	.00593	3,538	.67	823	.426	8.5	.94	.93	1.00
			Max.	2,955	.00332	3,637	.0370	.84		2,943	.00935	4,232	.78	1,025	.461	9.4			
			Min.	1,808	.00193	3,011	.0060	.56		1,715	.00507	3,016	.49	630	.385	7.4			
1/2	.315	15	Av.	2,262	.00405	3,701	.0342	.61	13	2,231	.00635	3,440	.64	716	.455	8.2	1.02	1.08	1.00
			Max.	2,682	.00550	4,355	.0520	.70		2,503	.00885	3,943	.74	905	.472	8.8			
			Min.	1,858	.00260	3,205	.0240	.52		1,879	.00495	3,132	.57	559	.436	6.8			
1/2	.590	15	Av.	2,151	.00420	3,884	.0361	.56	9	2,630	.00662	3,993	.65	825	.495	8.7	.82	.97	1.00
			Max.	2,332	.00540	4,398	.0600	.64		3,230	.00900	4,492	.75	1,012	.525	9.7			
			Min.	1,859	.00320	3,496	.0220	.50		2,212	.00448	3,544	.51	573	.460	8.1			
3/4	.129	20	Av.	2,290	.00421	3,444	.0148	.66	14	2,366	.00571	3,692	.64	836	.465	7.7	.97	.93	1.00
			Max.	2,881	.00540	4,599	.0210	.82		2,900	.00700	4,099	.79	1,035	.537	8.2			
			Min.	1,556	.00320	2,362	.0080	.51		1,612	.00400	3,300	.49	693	.402	7.1			
3/4	.315	15	Av.	2,058	.00400	3,385	.0303	.61	14	2,042	.00565	3,282	.62	733	.446	8.1	1.01	1.03	1.00
			Max.	2,442	.00550	4,067	.0360	.68		2,361	.00740	3,585	.72	867	.474	8.6			
			Min.	1,893	.00313	2,944	.0240	.53		1,686	.00448	2,773	.52	456	.425	7.5			
3/4	.590	15	Av.	2,305	.00441	3,850	.0475	.61	13	2,559	.00610	3,796	.67	850	.495	8.6	.90	1.00	1.00
			Max.	2,621	.00495	4,336	.0600	.67		3,224	.00790	4,318	.79	1,035	.523	9.0			
			Min.	2,115	.00405	3,463	.0160	.53		1,314	.00535	3,167	.57	621	.463	8.3			

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Table 5.--Summary of bolt-bearing and compression tests of yellow-poplar, aircraft grade plywood with the face grain parallel to the direction of loading (Continued)

Nominal bolt diameter	Nominal plywood thickness	Bolt bearing: Number of specimens	Value	Bolt bearing: Proportional limit: Stress	Bolt bearing: Proportional limit: Deformation	Bolt bearing: Ultimate: Stress	Bolt bearing: Ultimate: Deformation	Bolt bearing: Proportional limit / Ultimate	Compression: Number of specimens	Compression: Proportional limit: Stress	Compression: Proportional limit: Deformation	Compression: Ultimate stress	Compression: Proportional limit / Ultimate	Compression: Modulus of elasticity	Compression: Specific gravity[1]	Compression: Moisture content	Bolt bearing / Compressive: Proportional limit stress	Bolt bearing / Compressive: Ultimate stress	Critical dimension
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
Inch	Inch			P.s.i.	Inch	P.s.i.	Inch			P.s.i.	Inch per inch	P.s.i.		P.s.i. x10^-3		Percent			Diameters
									Tensile loading - End margin (TM)										
1/4	0.125	25	Av.	2,065	0.00207	3,387	0.0196	0.61	16	2,244	0.00361	3,432	0.65	868	0.478	7.8	0.92	0.99	2.00
			Max.	2,590	.00435	4,140	.0327	.69		2,652	.00705	3,880	.79	1,019	.501	9.2			
			Min.	1,491	.00126	2,733	.0070	.53		2,031	.00208	2,923	.55	589	.422	6.9			
1/4	.315	20	Av.	2,163	.00380	3,897	.0458	.55	15	2,374	.00360	3,611	.65	883	.465	8.0	.91	1.08	2.00
			Max.	2,600	.00580	4,574	.0961	.62		2,935	.00685	4,235	.73	1,023	.493	8.7			
			Min.	1,646	.00218	3,155	.0257	.46		1,831	.00230	2,978	.52	562	.437	7.5			
1/4	.590	15	Av.	2,405	.00415	4,588	.0481	.52	12	2,398	.00491	3,849	.62	985	.501	8.8	1.00	1.19	2.50
			Max.	2,760	.00525	5,099	.0615	.61		2,726	.00590	4,274	.68	1,250	.532	9.4			
			Min.	1,982	.00305	3,811	.0190	.46		2,161	.00422	3,470	.55	808	.483	8.4			
1/2	.125	25	Av.	1,827	.00290	3,017	.0123	.61	22	2,130	.00365	3,361	.63	928	.448	8.6	.86	.90	1.50
			Max.	2,308	.00430	3,504	.0180	.69		2,750	.00540	4,270	.71	1,234	.488	9.8			
			Min.	1,522	.00173	2,380	.0079	.55		1,890	.00183	2,792	.54	754	.410	7.1			
1/2	.315	14	Av.	2,345	.00475	3,794	.0520	.62	21	2,259	.00395	3,555	.63	881	.471	7.9	1.04	1.07	2.00
			Max.	2,854	.00805	4,310	.0925	.70		3,145	.00650	4,300	.74	1,106	.522	8.4			
			Min.	2,036	.00350	3,257	.0290	.56		1,602	.00193	3,005	.53	623	.439	7.3			
1/2	.590	15	Av.	2,309	.00329	4,639	.0658	.50	11	2,322	.00537	3,852	.60	883	.512	9.0	.99	1.20	2.00
			Max.	2,726	.00455	5,045	.0840	.54		2,784	.00686	4,130	.74	1,107	.548	9.4			
			Min.	1,924	.00225	4,170	.0480	.45		1,933	.00480	3,512	.49	633	.486	8.8			
3/4	.125	25	Av.	2,217	.00359	3,479	.0133	.63	22	2,335	.00393	3,647	.63	926	.490	8.1	.95	.95	1.50
			Max.	2,960	.00510	4,008	.0210	.77		3,111	.00615	4,480	.81	1,467	.538	9.0			
			Min.	1,779	.00240	3,018	.0060	.55		1,603	.00205	3,023	.50	601	.445	7.0			
3/4	.315	20	Av.	1,927	.00334	3,261	.0301	.59	22	2,352	.00417	3,561	.65	851	.463	8.1	.82	.92	2.00
			Max.	2,205	.00460	3,550	.0568	.64		3,225	.00645	4,245	.76	1,030	.497	9.2			
			Min.	1,793	.00235	2,930	.0110	.52		1,809	.00263	2,998	.56	680	.433	7.5			
3/4	.590	10	Av.	2,015	.00322	3,996	.0564	.50	14	2,514	.00549	3,595	.64	914	.511	8.7	.80	1.03	2.00
			Max.	2,354	.00425	4,736	.0700	.60		3,125	.00638	4,750	.72	1,107	.562	9.6			
			Min.	1,698	.00242	3,381	.0360	.42		1,778	.00420	3,324	.47	758	.478	8.1			
									Modified compressive loading - End margin (MC)										
1/4	.315	10	Av.	2,519	.00549	4,314	.0441	.58	10	2,248	.00286	3,426	.65	791	.473	8.0	1.12	1.26	....
			Max.	2,805	.00676	5,520	.0820	.68		2,525	.00360	4,025	.74	879	.516	8.6			
			Min.	2,160	.00445	3,750	.0180	.49		1,875	.00228	3,040	.60	667	.446	7.6			
1/4	.590	10	Av.	3,039	.00747	5,186	.0682	.58	9	2,628	.00306	3,881	.68	866	.491	8.0	1.16	1.34	....
			Max.	3,550	.00102	5,690	.0940	.68		2,980	.00364	4,260	.76	1,030	.512	8.5			
			Min.	2,530	.00555	4,640	.0520	.50		2,360	.00258	3,500	.64	744	.462	7.5			
1/2	.315	10	Av.	2,300	.00479	3,387	.0295	.68	9	2,198	.00595	3,477	.63	744	.436	7.6	1.05	.97	....
			Max.	2,885	.00520	3,660	.0510	.82		2,550	.00660	3,810	.69	882	.476	8.1			
			Min.	2,065	.00428	3,120	.0130	.61		1,910	.00510	3,235	.58	658	.399	7.4			
1/2	.590	10	Av.	2,692	.00663	4,411	.0486	.61	10	2,554	.00618	3,880	.65	831	.492	8.0	1.05	1.14	....
			Max.	3,030	.00710	4,980	.0860	.65		3,115	.00745	4,370	.71	1,038	.506	8.4			
			Min.	2,440	.00600	3,910	.0280	.58		1,870	.00502	3,190	.56	671	.465	7.5			
3/4	.315	10	Av.	2,554	.00594	3,772	.0357	.68	10	2,103	.00552	3,517	.60	765	.461	8.0	1.21	1.07	....
			Max.	2,975	.00645	4,235	.0450	.74		2,385	.00600	3,980	.66	909	.509	8.9			
			Min.	2,280	.00540	3,490	.0190	.61		1,660	.00450	3,130	.50	678	.424	7.5			
3/4	.590	10	Av.	2,494	.00656	4,165	.0623	.60	10	2,798	.00636	4,141	.66	891	.484	8.3	.89	1.01	....
			Max.	2,815	.00805	4,810	.0740	.67		3,180	.00720	4,590	.75	1,087	.521	8.9			
			Min.	2,260	.00570	3,700	.0500	.57		2,520	.00495	3,830	.61	750	.451	8.0			

[1] Based on weight when oven dr~ and volume at test.

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Table 6.--Summary of bolt-bearing stresses

Nominal thickness of plywood	Diameter of bolt	At proportional limit: Yellow birch 0°[1]	At proportional limit: Douglas-fir 0°	At proportional limit: Douglas-fir 45°	At proportional limit: Douglas-fir 90°	At proportional limit: Yellow-poplar 0°	At ultimate: Yellow birch 0°	At ultimate: Douglas-fir 0°	At ultimate: Douglas-fir 45°	At ultimate: Douglas-fir 90°	At ultimate: Yellow-poplar 0°
Inch	Inch	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
[2]0.125	1/4	3,640	2,840	...	...	2,260	6,480	4,300	...	...	3,730
.125	1/2	3,780	2,610	...	...	2,090	5,860	3,900	...	...	3,320
.125	1	3,470	2,430	...	...	2,250	5,650	3,690	...	...	3,460
.315	1/4	4,830	2,850	2,780	2,830	2,310	9,270	4,330	4,600	4,580	4,040
.315	1/2	4,510	2,570	2,550	2,690	2,260	7,710	3,880	3,870	3,390	3,660
.315	1	4,370	2,510	2,620	2,650	2,180	7,390	3,830	4,020	3,960	3,470
.590	1/4	4,430	3,150	...	...	2,650	8,960	4,710	...	...	4,690
.590	1/2	4,110	2,820	...	...	2,300	7,630	4,250	...	...	4,280
.590	1	3,940	2,760	...	...	2,270	7,030	4,150	...	...	3,990

[1]Angle between direction of load and face grain of specimen.

[2]Includes values for 0.155-inch Douglas-fir plywood.

Table 7.--Average ratios of bearing and compressive stresses at 0°

Ratio	Diameter of bolt	Yellow birch 0.125	Yellow birch 0.315	Yellow birch 0.590	Douglas-fir 0.155	Douglas-fir 0.315	Douglas-fir 0.590	Yellow-poplar 0.125	Yellow-poplar 0.315	Yellow-poplar 0.590	Average for three species [1]0.125	Average for three species 0.315	Average for three species 0.590
	Inch												
A		Ratio -- Proportional limit stress in bearing to proportional limit stress in compression											
	1/4	1.03	1.38	1.28	0.88	0.94	0.93	0.99	1.02	1.08	0.97	1.11	1.10
	1/2	1.07	1.34	1.21	.77	.85	.84	.91	1.00	.94	.92	1.06	1.00
	3/4	.99	1.27	1.17	.74	.82	.83	.96	1.01	.86	.90	1.03	.95
B		Ratio -- Ultimate stress in bearing to ultimate stress in compression											
	1/4	1.13	1.51	1.58	1.01	.96	1.03	1.03	1.19	1.24	1.06	1.22	1.28
	1/2	1.00	1.20	1.36	.84	.88	.92	.93	1.05	1.12	.92	1.04	1.13
	3/4	.96	1.15	1.23	.82	.85	.89	.94	1.01	1.01	.91	1.00	1.04
C		Ratio -- Proportional limit stress in bearing to ultimate stress in compression											
	1/4	.64	.78	.78	.66	.63	.69	.62	.68	.70	.64	.70	.72
	1/2	.64	.70	.72	.57	.58	.61	.59	.65	.60	.60	.64	.64
	3/4	.58	.68	.68	.54	.56	.59	.62	.63	.58	.58	.62	.62
D		Ratio -- Proportional limit stress in bearing to ultimate stress in bearing											
	1/4	.54	.51	.50	.67	.66	.65	.62	.58	.57	.61	.58	.57
	1/2	.60	.57	.56	.67	.66	.65	.62	.59	.58	.63	.61	.60
	3/4	.63	.60	.59	.67	.66	.65	.63	.60	.59	.64	.62	.61

[1]Includes values for 0.155-inch Douglas-fir plywood.

Table 8.--Critical edge clearances and end margins expressed in diameters

Plywood thickness	Bolt diameter	Yellow birch 0°[1]	Douglas-fir 0°	Douglas-fir 45°	Douglas-fir 90°	Yellow-poplar 0°	Yellow birch 0°	Douglas-fir 0°	Douglas-fir 45°	Douglas-fir 90°	Yellow-poplar 0°	Yellow birch 0°	Douglas-fir 0°	Douglas-fir 45°	Douglas-fir 90°	Yellow-poplar 0°
		End margin -- Tensile					Edge clearance -- Tensile					Edge clearance -- Compression				
[2]0.125	1/4	2.50	2.00			2.00	1.25	1.25			1.25	1.00	1.25			1.25
	1/2	2.00	1.50			1.50	1.00	1.00			1.00	1.00	1.00			1.00
	3/4	1.50	2.00			1.50						1.00	1.00			1.00
.315	1/4	2.50	2.50	2.50	2.50	2.00	1.25	1.25	2.00	2.00	1.25	1.25	1.00	2.00	1.50	1.25
	1/2	2.00	2.00	2.00	1.50	2.00	1.25	1.00	1.50	1.25	1.00	1.00	1.00	1.50	1.00	1.00
	3/4	1.50	2.00	1.50	1.50	1.50						1.00	1.00	1.50	1.00	1.00
.590	1/4	2.50	2.50			2.50	1.50	1.25			1.25	1.25	1.00			1.25
	1/2	2.00	2.00			2.00	1.00	1.00			1.00	1.25	1.00			1.00
	3/4	1.75	2.00			2.00						1.00	1.00			1.00

[1]Angle between direction of load and face grain of specimens.

[2]Includes 0.155-inch Douglas-fir plywood.

Table 9.--Summary of bolt-bearing deformations

Nominal thickness of plywood	Diameter of bolt	At proportional limit: Yellow birch 0°[1]	At proportional limit: Douglas-fir 0°	At proportional limit: Douglas-fir 45°	At proportional limit: Douglas-fir 90°	At proportional limit: Yellow-poplar 0°	At ultimate: Yellow birch 0°	At ultimate: Douglas-fir 0°	At ultimate: Douglas-fir 45°	At ultimate: Douglas-fir 90°	At ultimate: Yellow-poplar 0°
Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch	Inch
[1]0.125	1/4	0.0025	0.0036			0.0023	0.0189	0.0119			0.0177
	1/2	.0042	.0027			.0026	.0165	.0102			.0123
	3/4	.0036	.0039			.0039	.0144	.0141			.0140
	Av.	.0034	.0034			.0029	.0166	.0121			.0147
.315	1/4	.0045	.0048	0.0050	0.0038	.0042	.0494	.0164	0.0253	0.0301	.0423
	1/2	.0039	.0039	.0045	.0042	.0041	.0311	.0126	.0203	.0169	.0422
	3/4	.0044	.0049	.0060	.0052	.0044	.0251	.0143	.0234	.0154	.0320
	Av.	.0043	.0045	.0052	.0044	.0042	.0352	.0144	.0230	.0208	.0388
.590	1/4	.0068	.0066			.0058	.0728	.0370			.0495
	1/2	.0044	.0043			.0043	.0624	.0188			.0539
	3/4	.0048	.0048			.0051	.0587	.0162			.0554
	Av.	.0053	.0052			.0051	.0646	.0240			.0529

[1]Angle between direction of load and face grain of specimen.

Z M 68634 F

Table 10.--Basic stresses and comparison of loads computed by the formula P=(T-t)(DS+2C) with the loads obtained by test

Type of test[1]	Average thickness of specimens	Proportional limit				Ultimate			
		Load[2]	Basic stress[3]	Computed load[4]	Deviation of computed load from Col. 3	Load[2]	Basic stress[3]	Computed load[4]	Deviation of computed load from Col. 7
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Inch	Pounds	P.s.i.	Pounds	Percent	Pounds	P.s.i.	Pounds	Percent
				GROUP I PLYWOOD (YELLOW BIRCH)					
				Nominal bolt diameter=1/4 inch					
				θ = 0°					
TC	0.125	111	4,057	117	+ 5	201	6,083	216	+ 7
C	.131	125	4,357	125	0	199	5,381	230	+16
TM	.131	104	3,507	125	+20	239	7,128	230	- 4
TC	.274	321	4,667	301	- 6	641	7,724	585	- 9
C	.291	327	4,407	322	- 2	573	6,639	580	+ 1
TM	.290	338	4,597	321	- 5	602	6,401	625	+ 4
MC	.272	338	4,997	299	-12	664	7,366	627	- 6
TC	.602	617	3,697	706	+14	1,338	6,338	1,398	+ 4
C	.606	686	4,157	711	+ 4	1,320	6,270	1,388	+ 5
TM	.603	669	4,067	707	+ 6	1,384	6,648	1,401	+ 1
MC	.598	640	3,897	701	+10	1,533	7,665	1,408	- 8
				Nominal bolt diameter=1/2 inch					
				θ = 0°					
TC	.125	223	4,411	220	- 1	354	6,553	363	+ 3
C	.127	255	4,961	225	-12	372	6,517	384	+ 3
TM	.130	220	4,101	232	+ 5	397	7,361	371	- 7
TC	.278	626	4,751	575	- 8	1,016	6,897	1,001	- 1
C	.287	644	4,711	596	- 7	944	6,359	993	+ 5
TM	.279	642	4,861	577	-10	1,028	6,961	1,005	- 2
MC	.276	654	5,021	570	-13	990	6,375	1,039	+ 5
TC	.602	1,255	4,081	1,326	+ 6	2,343	6,736	2,353	0
C	.603	1,157	3,731	1,328	+15	2,296	6,612	2,340	+ 2
TM	.602	1,249	4,061	1,326	+ 6	2,378	6,861	2,353	- 1
MC	.599	1,338	4,401	1,319	- 1	2,596	7,624	2,357	- 9
				Nominal bolt diameter=3/4 inch					
				θ = 0°					
C	.130	329	4,185	340	+ 3	555	7,083	534	- 4
TM	.129	331	4,265	337	+ 2	542	6,810	539	- 1
C	.281	847	4,295	854	+ 1	1,373	6,710	1,384	+ 1
TM	.278	905	4,665	844	- 7	1,455	7,037	1,407	- 3
MC	.274	969	5,095	830	-14	1,421	6,747	1,425	0
C	.602	2,013	4,495	1,946	- 3	3,033	6,144	3,296	+ 9
TM	.600	1,632	3,615	1,940	+19	3,220	6,590	3,296	+ 2
MC	.600	1,782	3,965	1,940	+ 9	3,604	7,476	3,307	- 8

Table 10.--Basic stresses and comparison of loads computed by the formula $P = (T-t)(DS+2C)$ with the loads obtained by test (Continued)

Type of test[1]	Average thickness of specimens	Proportional limit: Load[2]	Proportional limit: Basic stress[3]	Proportional limit: Computed load[4]	Proportional limit: Deviation of computed load from Col. 3	Ultimate: Load[2]	Ultimate: Basic stress[3]	Ultimate: Computed load[4]	Ultimate: Deviation of computed load from Col. 7
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Inch	Pounds	P.s.i.	Pounds	Percent	Pounds	P.s.i.	Pounds	Percent
				GROUP II PLYWOOD (DOUGLAS-FIR)					
				Nominal bolt diameter=1/4 inch					
				θ = 0°					
TC	0.151	100	2,199	108	+ 8	161	3,714	161	0
C	.154	123	2,792	110	-11	192	4,508	165	-14
TM	.153	99	2,127	109	+10	161	3,643	163	- 1
TC	.318	220	2,219	235	+ 7	334	3,377	359	+ 7
C	.322	248	2,547	238	- 4	339	3,384	363	+ 7
TM	.323	238	2,407	239	0	334	3,300	365	+ 9
MC	.316	244	2,557	234	- 4	360	3,759	356	- 1
TC	.605	384	1,940	454	+18	717	3,835	699	- 3
C	.604	492	2,687	454	+ 8	695	3,690	697	0
TM	.612	429	2,217	460	+ 7	701	3,666	707	+ 1
MC	.596	486	2,687	448	- 8	673	3,604	688	+ 2
				θ = 45°					
TC	.320	228	...	...	...	388	...	...	...
C	.317	228	...	...	...	343	...	...	...
MC	.321	234	...	...	...	372	...	...	...
				θ = 90°					
TC	.320	211	...	...	...	372	...	...	...
C	.316	226	...	...	...	347	...	...	...
MC	.319	235	...	...	...	374	...	...	...
				Nominal bolt diameter=1/2 inch					
				θ = 0°					
TC	.151	162	1,975	193	+19	269	3,443	287	+ 7
C	.154	184	2,238	197	+ 7	292	3,690	393	0
TM	.148	209	2,711	189	-10	301	4,013	281	- 7
TC	.320	424	2,421	424	0	649	3,742	644	- 1
C	.319	436	2,501	423	- 3	618	3,550	641	+ 4
TM	.322	469	2,691	427	- 9	624	3,549	648	+ 4
MC	.314	405	2,351	416	+ 3	651	3,842	631	- 3
TC	.604	824	2,456	813	- 1	1,239	3,694	1,243	0
C	.603	763	2,256	812	+ 6	1,264	3,787	1,241	- 2
TM	.608	786	2,311	819	+ 4	1,247	3,692	1,251	0
MC	.590	876	2,706	794	- 9	1,210	3,695	1,213	0
				θ = 45°					
TC	.321	358	...	...	...	563	...	...	...
C	.319	393	...	...	...	606	...	...	...
MC	.317	442	...	...	...	658	...	...	...
				θ = 90°					
TC	.321	397	...	...	...	583	...	...	...
C	.315	402	...	...	...	599	...	...	...
MC	.318	462	...	...	...	645	...	...	...
				Nominal bolt diameter=3/4 inch					
				θ = 0°					
C	.151	268	2,325	278	+ 4	409	3,669	413	+ 1
TM	.149	266	2,343	274	+ 3	419	3,825	407	- 3
C	.319	619	2,460	610	- 1	898	3,594	923	+ 3
TM	.319	589	2,330	610	+ 4	887	3,546	923	+ 4
MC	.312	663	2,718	596	-10	962	3,976	902	- 6
C	.606	1,086	2,215	1,177	+ 8	1,808	3,736	1,795	- 1
TM	.612	1,124	2,301	1,189	+ 6	1,846	3,779	1,813	- 2
MC	.589	1,385	2,982	1,143	-17	1,817	3,878	1,743	- 4
				θ = 45°					
C	.318	545	...	...	...	899	...	...	...
MC	.319	696	...	...	...	985	...	...	...
				θ = 90°					
C	.314	570	...	...	...	898	...	...	...
MC	.314	665	...	...	...	947	...	...	...

Table 10.--Basic stresses and comparison of loads computed by the formula P=(T-t)(DS+2C) with the loads obtained by test (Continued)

Type of test[1]	Average thickness of specimens	Proportional limit				Ultimate			
		Load[2]	Basic stress[3]	Computed load[4]	Deviation of computed load from Col. 3	Load[2]	Basic stress[3]	Computed load[4]	Deviation of computed load from Col. 7
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Inch	Pounds	P.s.i.	Pounds	Percent	Pounds	P.s.i.	Pounds	Percent
					GROUP III PLYWOOD (YELLOW-POPLAR)				
					Nominal bolt diameter=1/4 inch				
					θ = 0°				
TC	0.128	74	2,272	72	- 3	116	3,701	117	+ 1
C	.129	77	2,360	73	- 5	125	4,015	118	- 6
TM	.129	69	2,074	73	+ 6	114	3,589	118	+ 4
TC	.320	185	2,076	194	+ 5	367	4,212	334	- 9
C	.316	194	2,231	192	- 1	318	3,599	329	+ 3
TM	.315	166	1,859	191	+15	303	3,403	328	+ 8
MC	.320	207	2,370	194	- 6	359	4,102	334	- 7
TC	.598	388	2,316	371	- 4	686	4,029	647	- 6
C	.604	370	2,163	375	+ 1	607	3,425	654	+ 8
TM	.604	350	2,025	375	+ 7	640	3,656	654	+ 2
MC	.602	402	2,394	374	- 7	718	4,220	651	- 9
					Nominal bolt diameter=1/2 inch				
					θ = 0°				
TC	.129	140	2,283	135	- 4	220	3,812	217	- 1
C	.128	140	2,306	134	- 4	214	3,736	215	0
TM	.128	128	2,092	134	+ 5	207	3,601	215	+ 4
TC	.315	330	2,024	356	+ 8	616	3,858	601	- 2
C	.320	381	2,324	362	- 5	620	3,812	611	- 1
TM	.315	381	2,366	356	- 7	605	3,782	601	- 1
MC	.312	380	2,386	352	- 7	543	3,391	595	+10
TC	.603	620	1,932	698	+12	1,255	3,958	1,196	- 5
C	.603	574	1,774	690	+22	1,049	3,241	1,196	+14
TM	.601	696	2,200	695	0	1,294	4,110	1,192	- 8
MC	.596	732	2,347	689	- 6	1,219	3,885	1,181	- 3
					Nominal bolt diameter=3/4 inch				
					θ = 0°				
C	.129	219	2,441	198	-10	324	3,864	315	- 3
TM	.130	216	2,388	200	- 7	333	3,937	318	- 5
C	.321	567	2,355	531	- 6	892	3,752	891	0
TM	.312	447	1,888	516	-15	774	3,330	864	-11
MC	.315	670	2,865	521	-22	909	3,914	873	- 4
C	.603	952	2,042	1,021	+ 7	1,627	3,494	1,736	+ 7
TM	.594	834	1,802	1,005	+20	1,651	3,609	1,709	+ 4
MC	.596	931	2,019	1,009	+ 8	1,624	3,532	1,715	+ 6

Sheet 3 of 3

[1]Designation of type of test.
- TC = tensile loading - edge clearance.
- C = compressive loading - edge clearance.
- TM = tensile loading - end margin.
- MC = modified compressive loading - end margin.

[2]Load values adjusted to average strength of control specimens.

[3]Stress computed on effective thickness after subtracting edge support from load.

[4]Load computed by formula P=(T-t)(DS+2C) using average value of basic stress.

[5] = angle between grain of face plies and direction of applied load.

Table 11.--Values of the basic bolt-bearing stress (S), the edge support (C), and the effective thickness (T) and of the relation of the basic bearing stress to the compressive stress

Species	Grain angle	Basic bearing stress						Average compressive stress		Basic bearing stress / Compressive stress	
		Proportional limit			Ultimate						
		S	C	T	S	C	T	Proportional limit	Ultimate	Proportional limit	Ultimate
	Degrees	P.s.i.	Pounds per inch	Inch	P.s.i.	Pounds per inch	Inch	P.s.i.	P.s.i.		
Yellow birch	0	4,336	84	0.030	6,770	407	0.038	3,453	5,945	1.26	1.14
Douglas-fir	0	2,422	84	.010	3,706	136	.015	3,230	4,544	.75	.82
	[1]45	....	81	......	....	132	......	2,982	4,358	.79	.85
	[1]90	....	81	......	....	132	......	2,963	4,260	.81	.86
Yellow-poplar	0	2,199	48	.015	3,752	102	.024	2,349	3,617	.94	1.04

[1]Values based on assumption that "T" for 45° and 90° is the same as for 0°.

Z M 68638 F

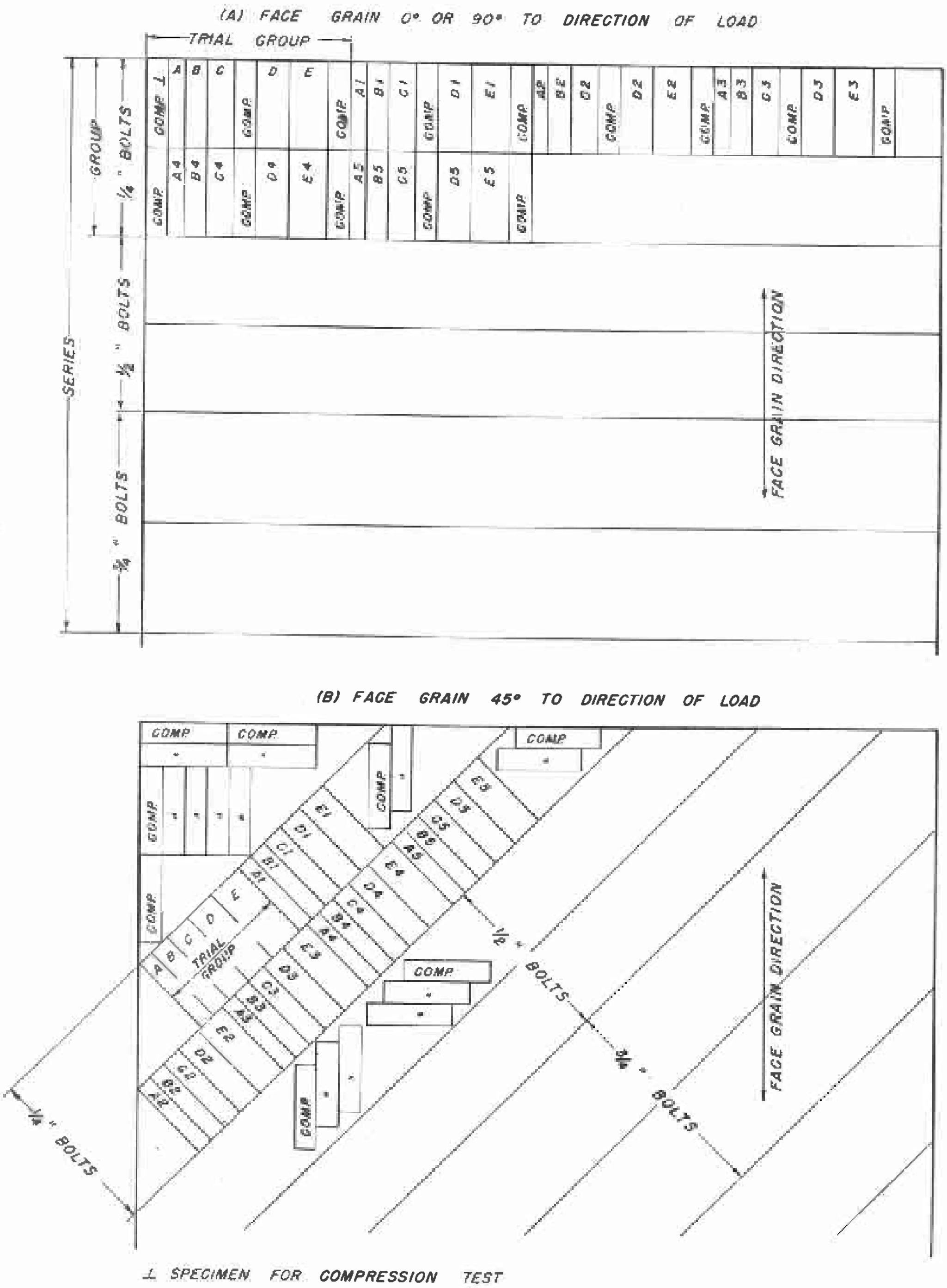


Figure 1.--Cutting diagram showing manner of cutting trial groups, final groups, and series for the three grain angles used.

Z M 69369 F

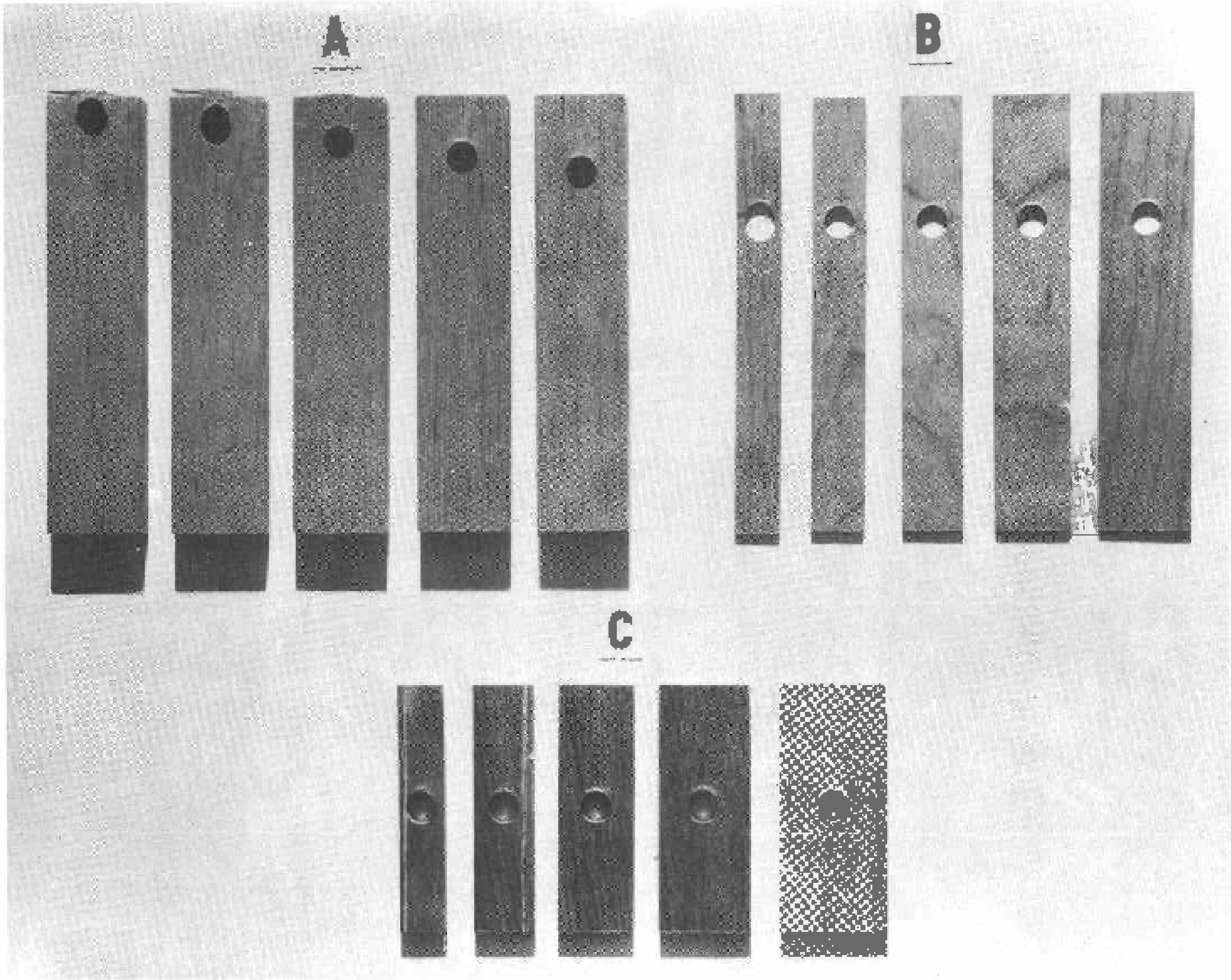


Figure 2.--Specimens after test showing the five variations of end margin or edge clearance used in three different groups: (A) end margin determination by tensile loading; (B) edge clearance determination by tensile loading; and (C) edge clearance determination by compressive loading.

Z M 69871 F

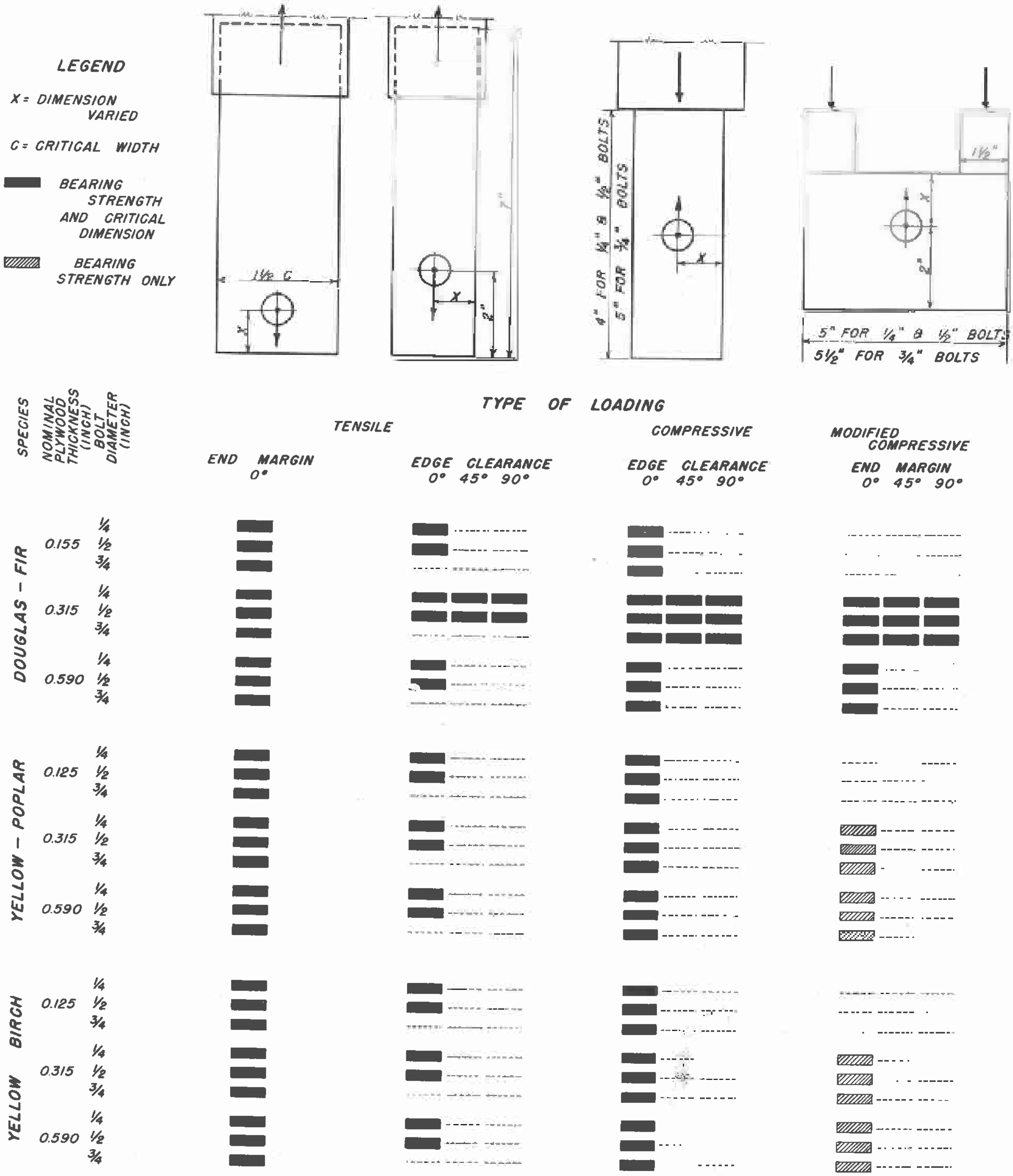


Figure 3.--Diagram of the four types of specimens showing manner of load application and the extent of the testing with each.

Z M 69370 F

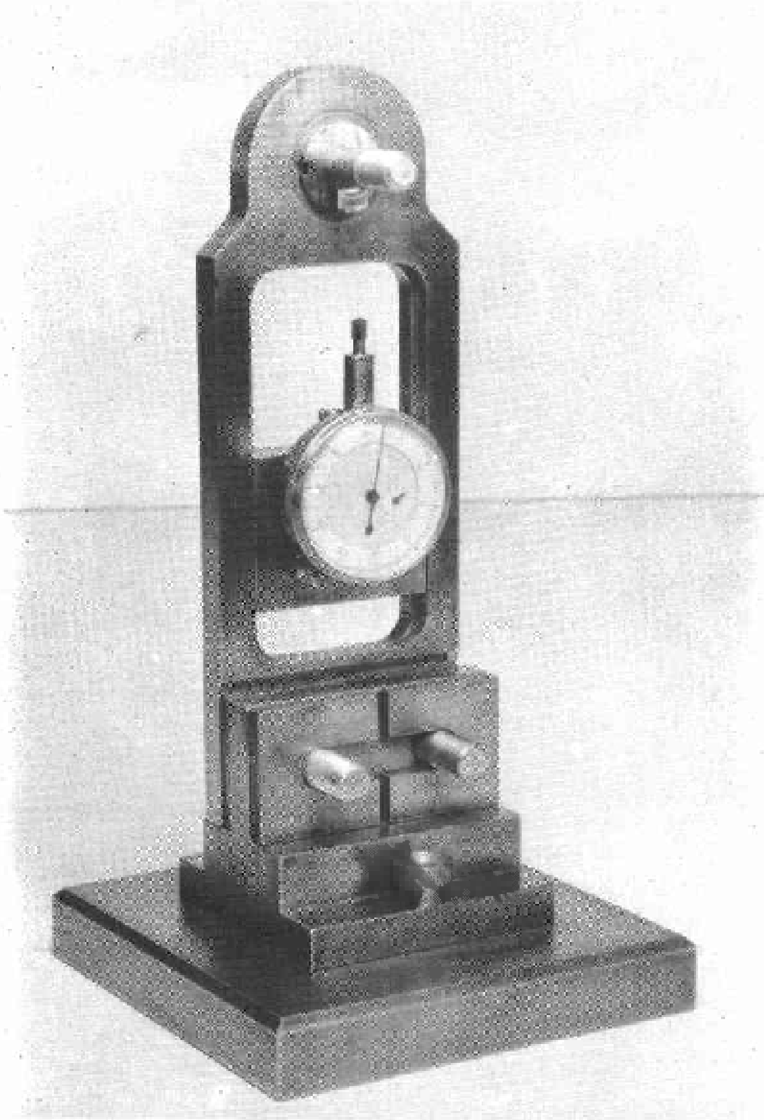


Figure 4.--Jig for bolt-bearing tests with test bolt in place but one plate and bushing removed. Note spacers, dial support and bushing with projecting lug.

Z M 69874 F

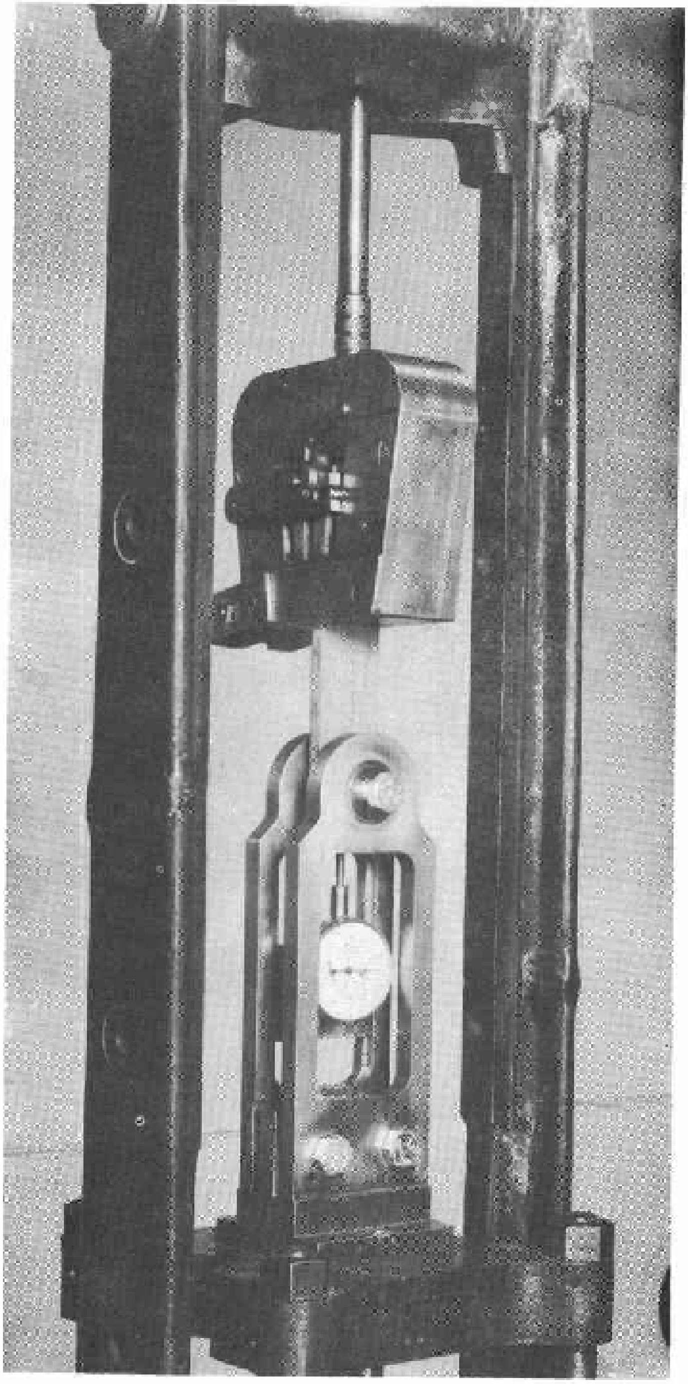


Figure 5.--Setup for tensile loading of bolt-bearing specimens. Note spacing between plates and specimen and also between bolt head and bushing.
Z M 69875 F

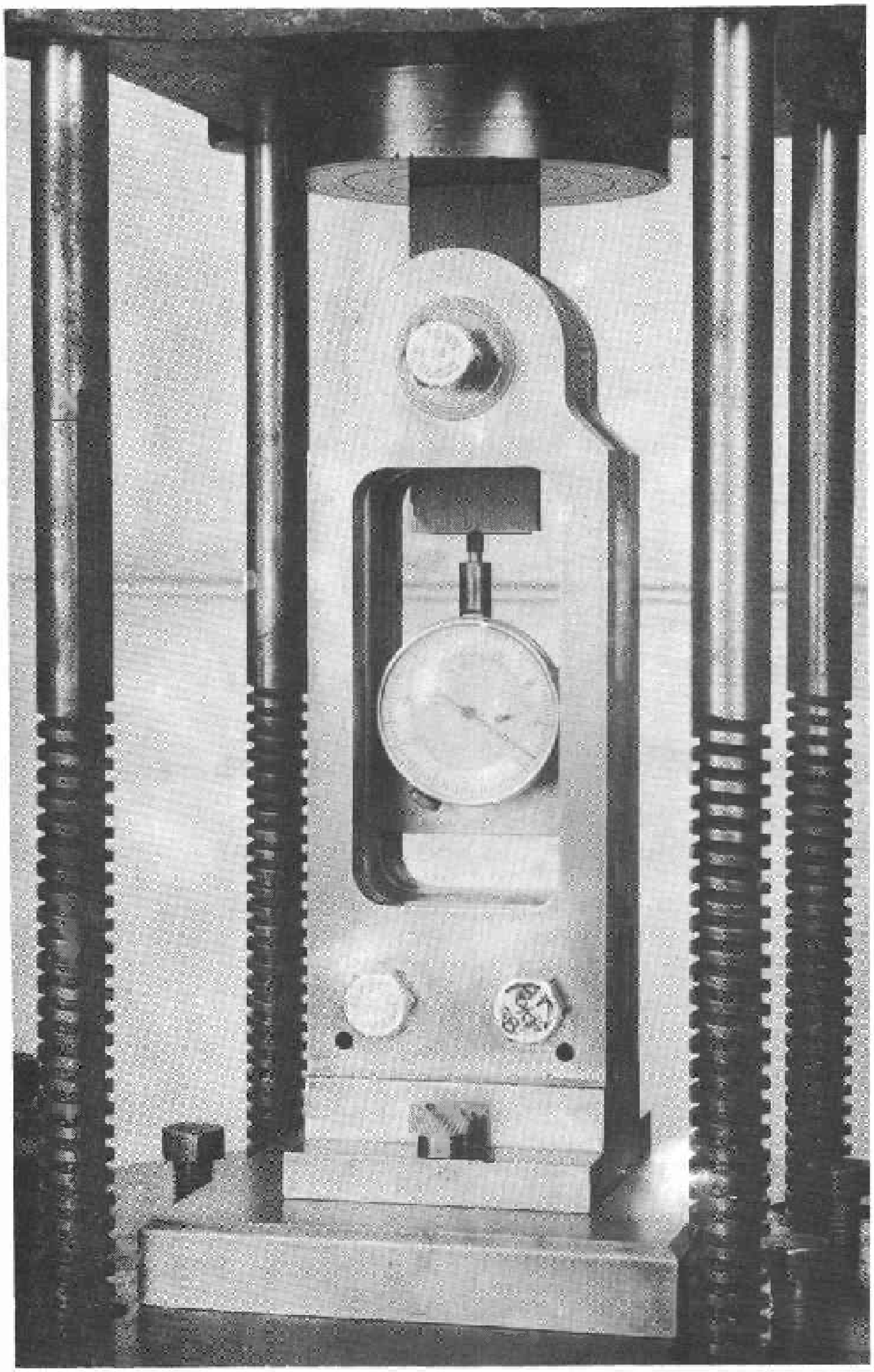


Figure 6.--Setup for compressive loading of bolt-bearing specimens.

Z M 69876 F

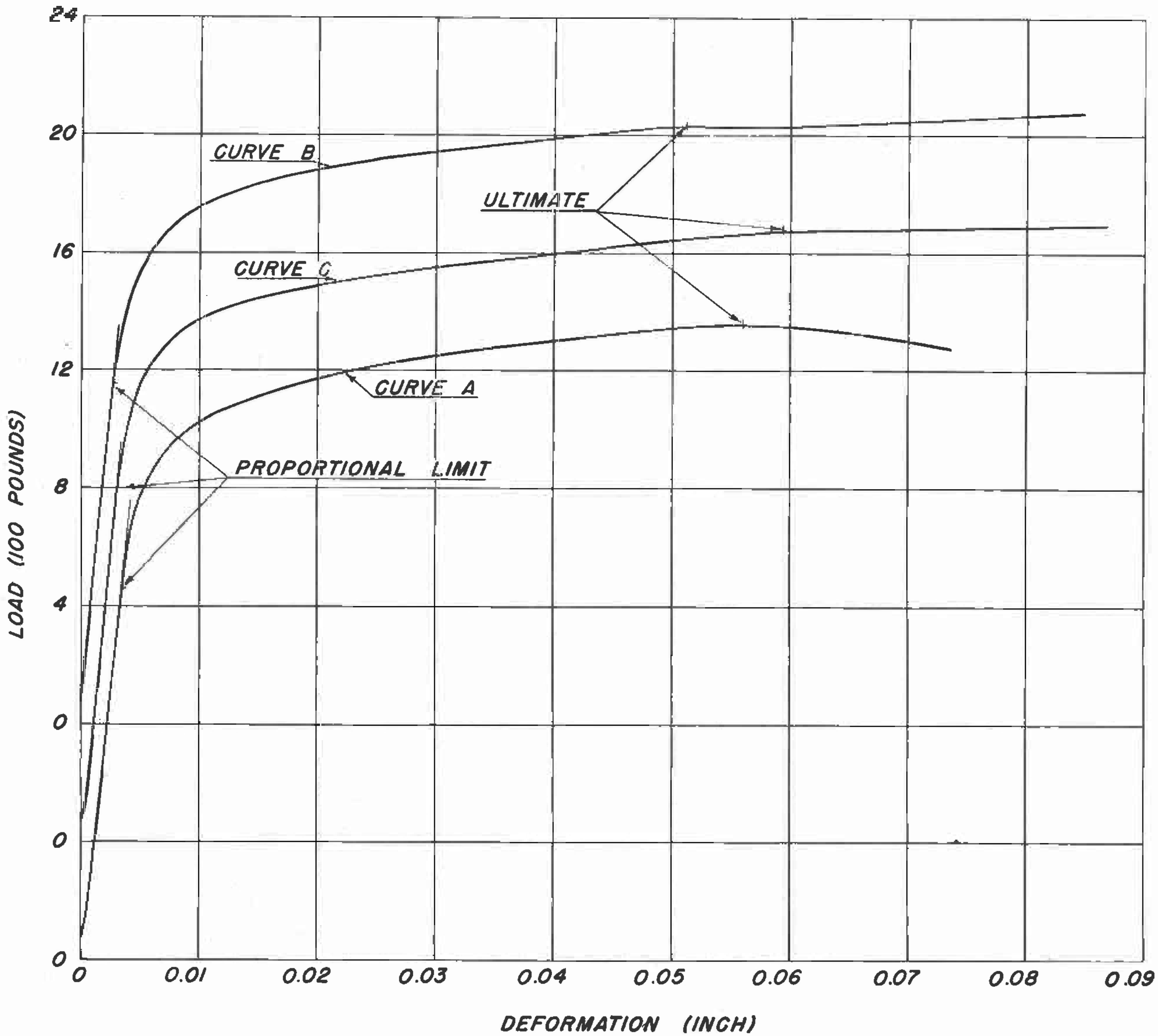


Figure 7.--Typical load deformation curves of three types showing selection of ultimate load for each.

Z M 69371 F

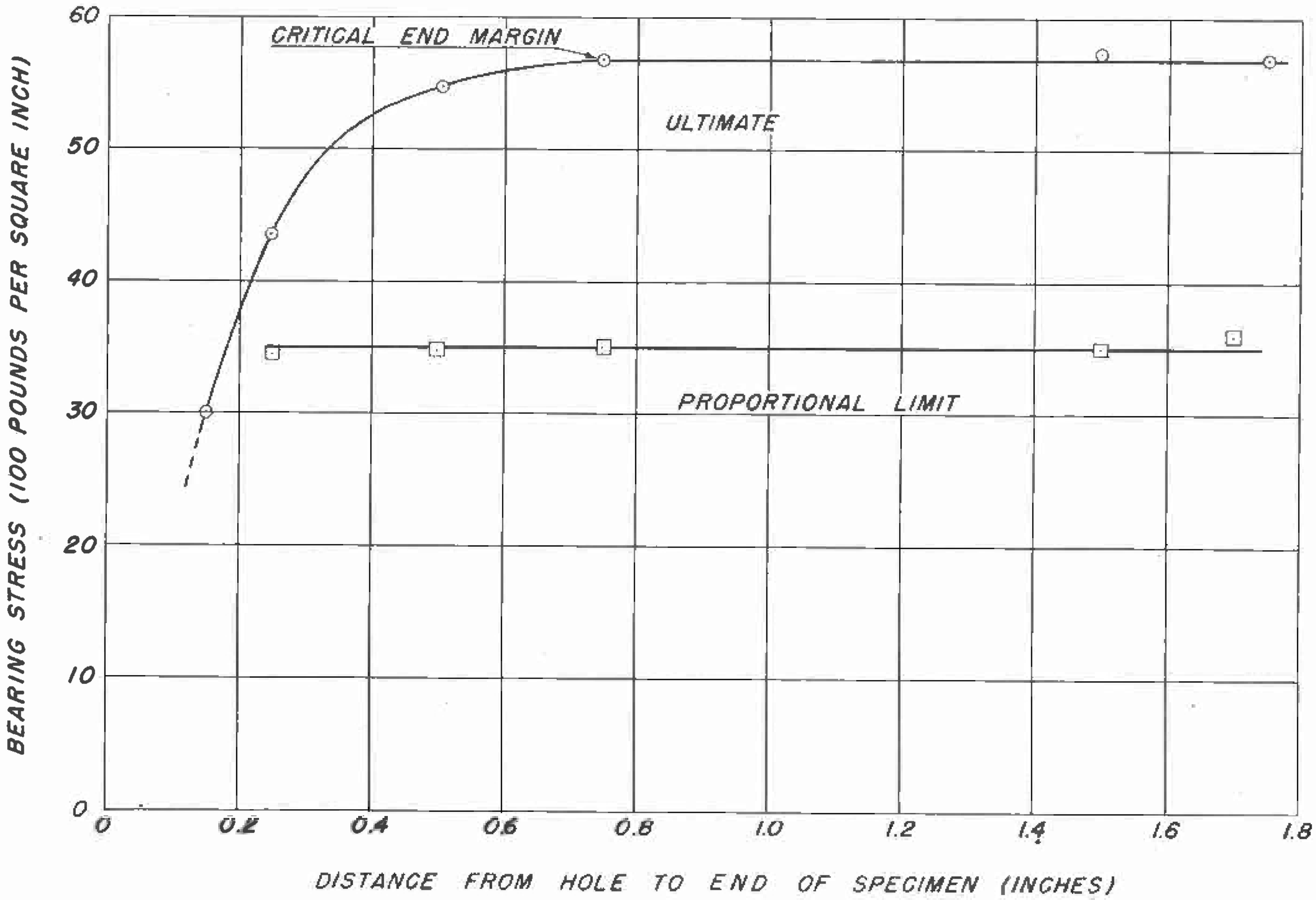
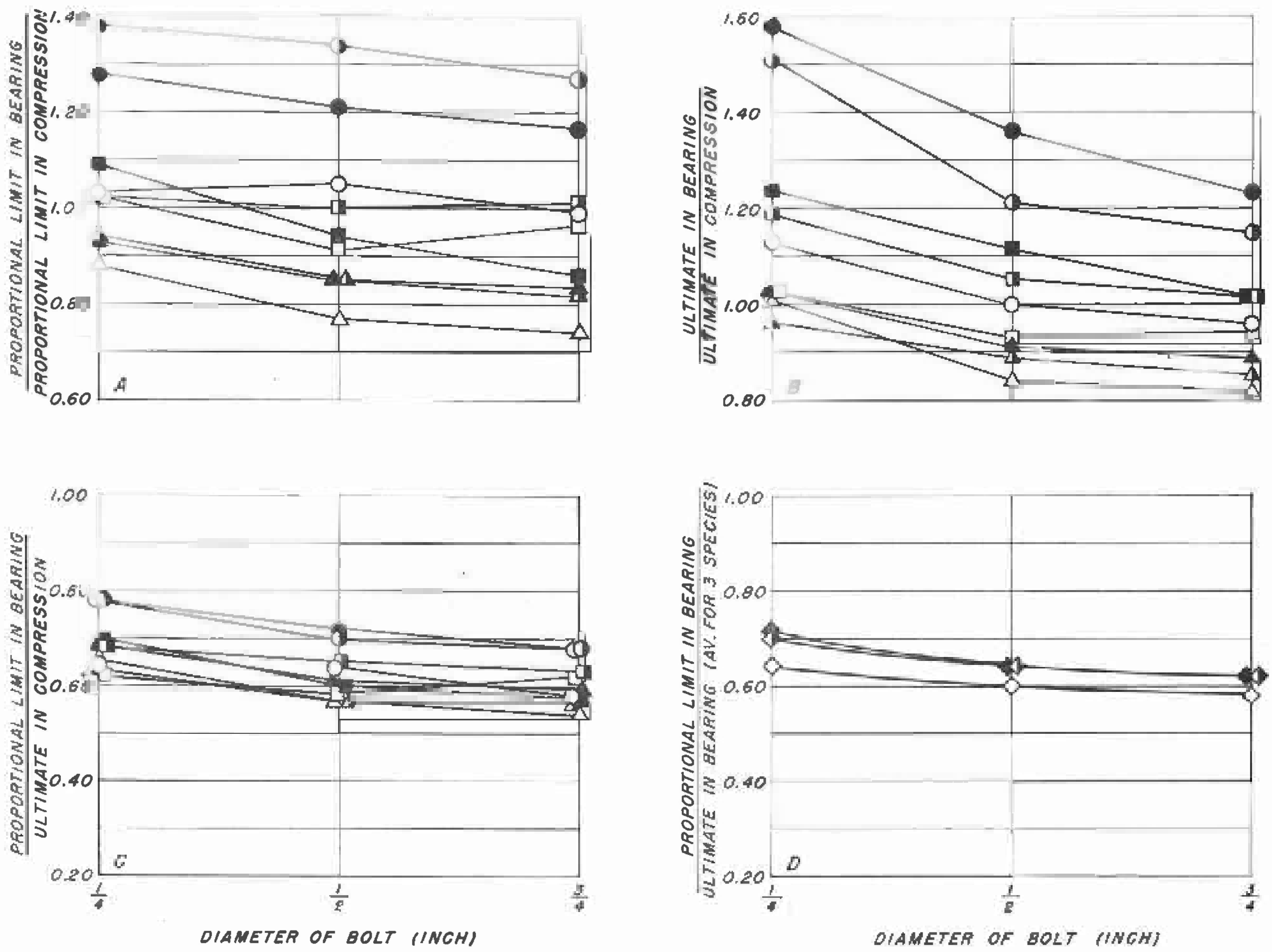


Figure 8.--Typical relationship between the distance from the hole to the end of the specimen and the bearing stress at the proportional limit and ultimate.

Z M 69372 F



LEGEND												
SPECIES	YELLOW BIRCH			DOUGLAS-FIR			YELLOW-POPLAR			AVERAGE FOR 3 SPECIES		
SYMBOL	○	◐	●	△	◭	▲	□	◨	■	◇	◈	◆
THICKNESS (INCH)	.125	.315	.590	.155	.315	.590	.125	.315	.590	.125 .155	.315	.590

Z M 69373 F

Figure 9.--Relation of bearing stress to diameter of bolt for the three species and thicknesses of plywood.

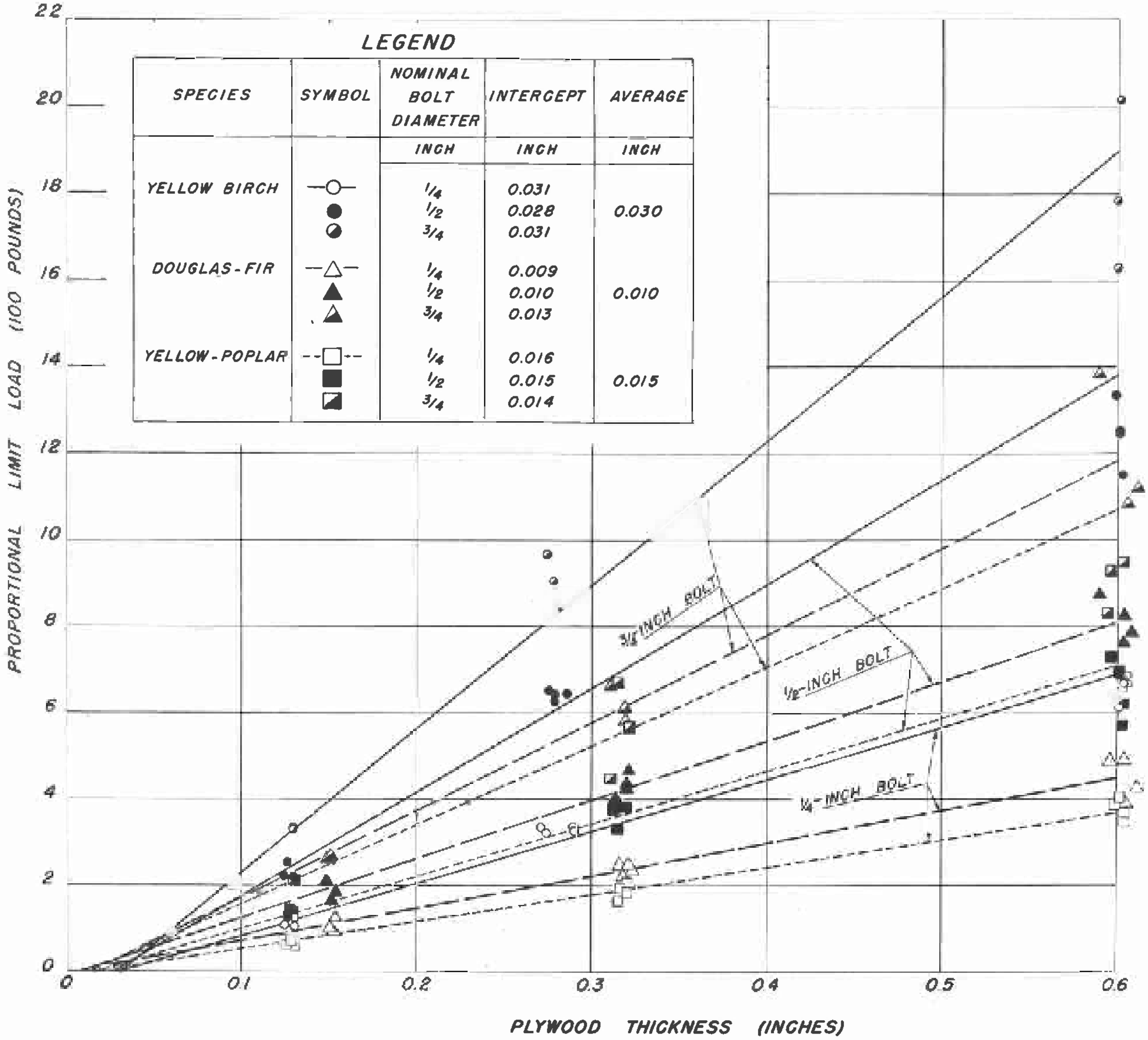


Figure 10.--Relationship between proportional limit load and thickness of plywood for each species and bolt diameter.

Z M 69374 F

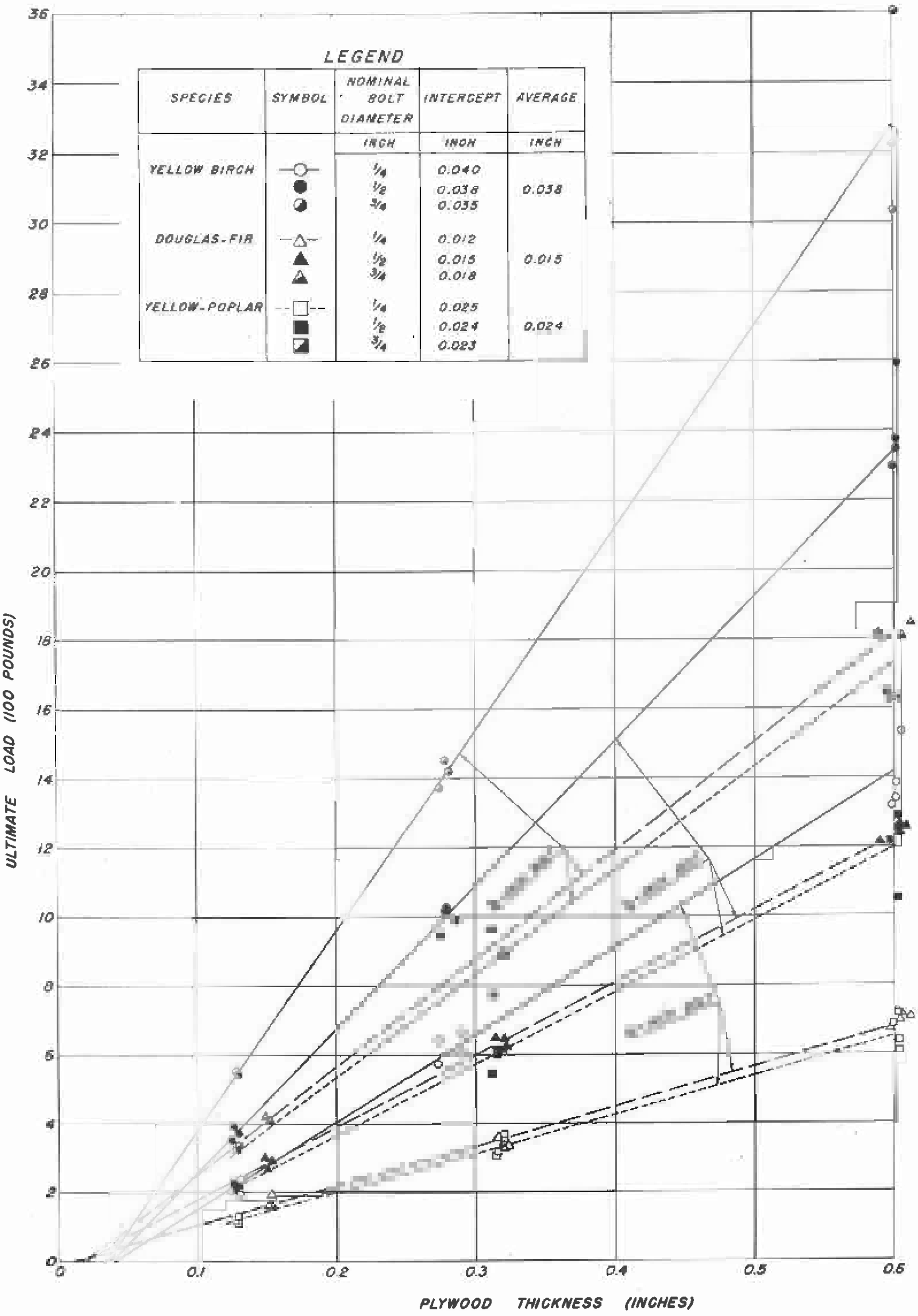


Figure 11.--Relationship between ultimate load and thickness of plywood for each species and bolt diameter.

Z M 69375 F

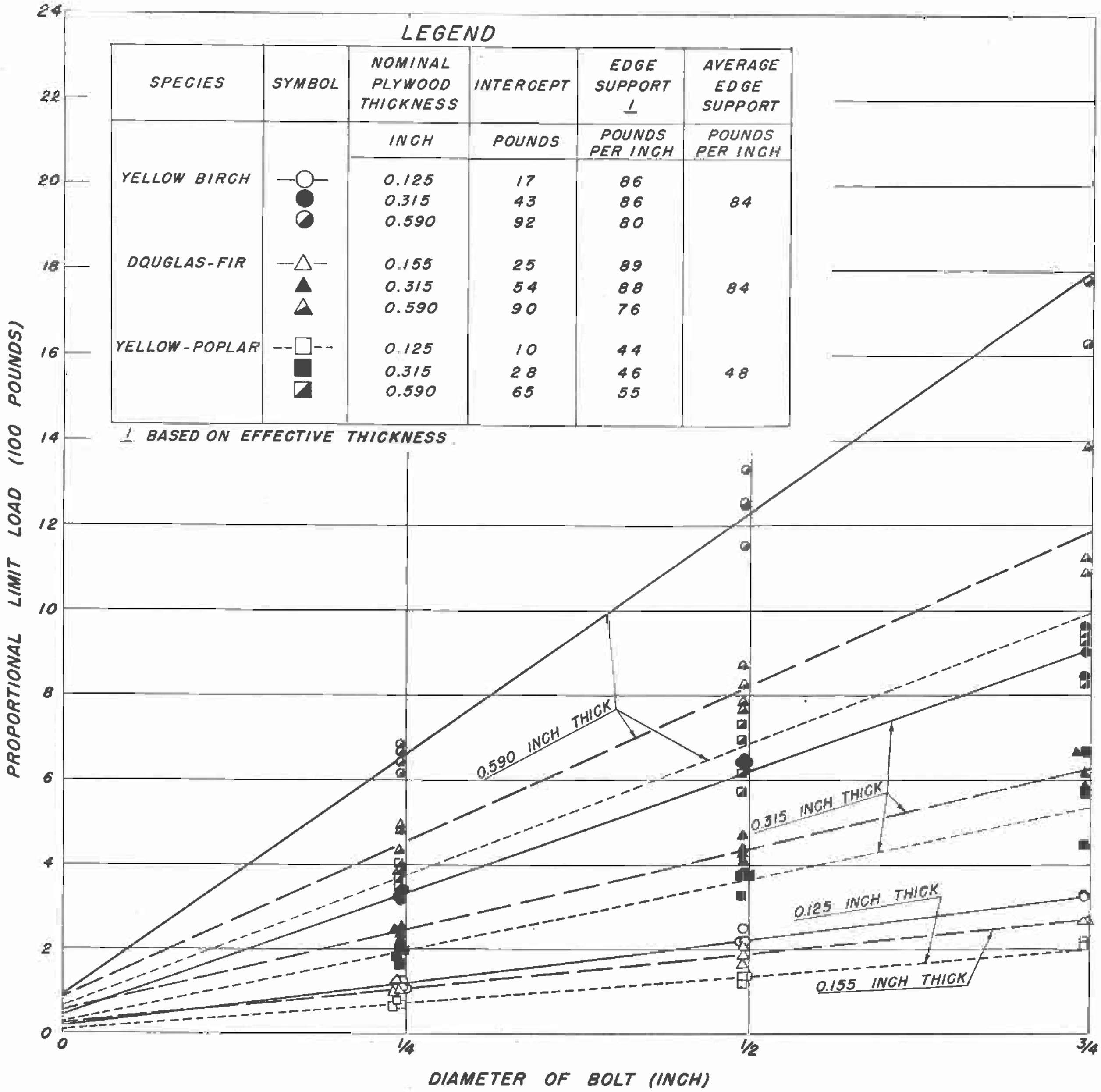


Figure 12.--Relationship between proportional limit load and diameter of bolt for each species and plywood thickness.

Z M 69376 F

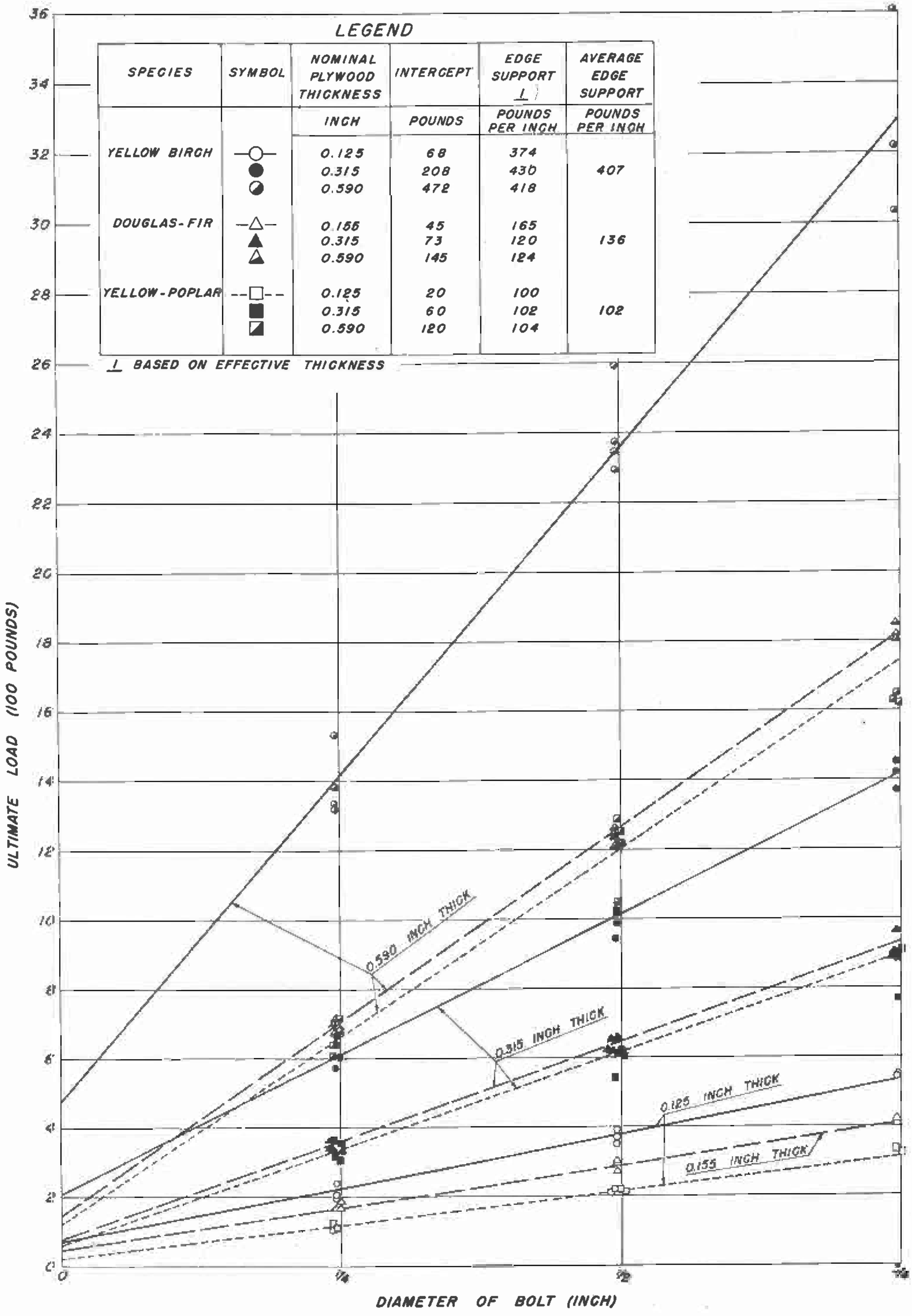


Figure 13.--Relationship between ultimate load and diameter of bolt for each species and plywood thickness.

Z M 69377 F

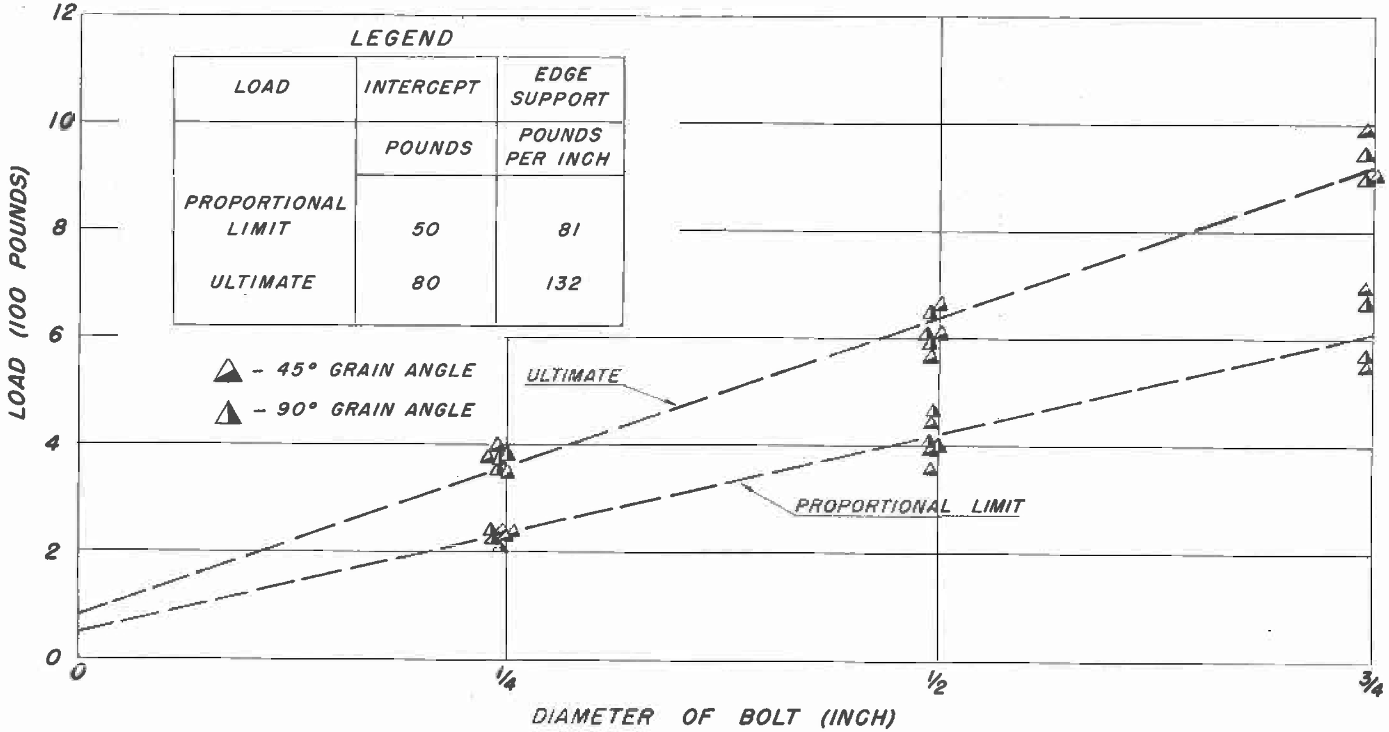


Figure 14.--Relation of the loads at the proportional limit and at the ultimate to the diameter of the bolt for 0.315-inch thick Douglas-fir plywood when the angle of the face grain is 45° and 90° to the direction of loading. Intercept at proportional limit is 50 pounds and at ultimate is 80 pounds per inch. Edge support at proportional limit is 81 pounds and at ultimate is 132 pounds per inch.

Z M 69378 F