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A STUDY OF THE TIGHTNESS AND FLUSHNESS OF MACHINE-COUNTERSUNK RIVETS FOR AIRCRAFT

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A STUDY OF THE TIGHTNESS AND FLUSHNESS OF MACHINE-COUNTERSUNK RIVETS FOR AIRCRAFT

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SUMMARY

The results of an investigation undertaken to determine possible improvements in the tightness and the flushness of machine-countersunk rivets are presented. Specimens used in this study were simple lap joints made by different riveting methods.

The results revealed the necessity of having the height of the rivet heads greater than the depth of the countersunk holes if tight riveted joints were to be obtained. Machine-countersunk rivets thus installed protruded above the skin surface after the rivets were driven. The protruding portions of the rivet heads had to be removed in order to obtain flush rivets. If ordinary round-head rivets were inserted from the opposite side of the joint and the countersunk heads formed in the driving of the rivets filled the countersunk holes completely, still tighter riveted joints were obtained.

The qualities of tightness of the joint and flushness of the rivet required separate operations in the procedure of riveting if the joint was to have a high quality in both these respects.

INTRODUCTION

Flush rivets in the skin of airplanes are not always tight and perfectly faired with the wing or fuselage surface. (See fig. 1.) When the rivets are not tight, excessive permanent displacement of the attached parts may render the joints unfit for the service required after a small percentage of the maximum load has been applied. When the rivets are not perfectly faired, a smooth surface from the aerodynamic standpoint is not achieved.

An investigation was therefore undertaken to determine what improvements were possible in the tightness and flushness of machine-countersunk rivets. The results of tests made to study the shear strength, the tightness, and the flushness of rivets in simple lap joints made by different methods of flush riveting, as well as the general conclusions that have resulted from this investigation, are the subject of this paper.

METHODS OF FLUSH RIVETING INVESTIGATED

The type of rivet used and its dimensions, the angle of the countersunk hole, and the side from which the rivet is inserted are shown in figure 2 for riveting methods A, B, C, and D and in figure 3 for riveting method E.

The distinguishing features of the riveting methods used in this investigation are (see fig. 4):

A - The manufactured head of the countersunk rivet is bucked on a flat plate while the shank end is driven by hand with a hammer.

B - The manufactured head of the countersunk rivet is bucked on a flat plate while the shank end is driven with a vibrating gun.

C - The manufactured head of the countersunk rivet is driven with a vibrating gun while the shank end is bucked with a bar.

D - The countersunk rivet is driven with a pneumatic squeeze.

E - The manufactured roundhead of the rivet is driven with a vibrating gun while the shank end is bucked with a bar. After the rivet is driven, the portion of the formed head that protrudes above the skin surface is milled off and finished smooth with the sheet.

SPECIMENS, APPARATUS, AND METHOD OF TESTING

The three types of riveted joint investigated are shown in figure 5. The specimens consisted of two lapped sheets of 24S-T aluminum-alloy material riveted together with 1/8-inch-diameter A 17S-T aluminum-alloy rivets. The sheet thicknesses were 0.040 inch with the exception of those specimens prepared by riveting method E where the thicknesses varied from 0.040 to 0.102 inch.

In the specimens made by riveting methods A, B, C, and D, the height of the center of the rivet head above or below the surface of the sheet was measured. This height is designated h_b when measured before the rivet is driven and h_a when measured after the rivet is driven. (See fig. 6.) The measurements of h_b and h_a were made with the apparatus shown in figure 7. The spindle of the dial gage was placed on the center of the rivet and then placed on the sheet adjacent to the rivet. The difference in dial readings is h_b or h_a depending on which quantity is being measured.

The test set-up is shown in figure 8. Loads were applied to the specimen with a hydraulic testing machine, which is accurate to better than one-half of 1 percent. This testing machine was equipped with Templin grips. Two 18-power microscopes with filar micrometers were used to observe and measure the movement, or the displacement, of one sheet with respect to the other. The displacements were measured on the edges of the sheet opposite the center of the riveted joint. Both the displacement under load and the permanent displacement remaining after the removal of load were measured for successively increasing loads until failure occurred.

TESTS AND RESULTS

Throughout this report, the tightness of a rivet is measured by the yield load, which is defined as the shear load per rivet for which the sheets are permanently displaced an amount equal to 4 percent of the rivet diameter. This definition of yield load is arbitrary and corresponds, in a measure, to the arbitrary definition of yield point commonly specified for aircraft material.

Riveting methods A, B, C, and D. - Riveting methods A, B, C, and D employed the same type of rivet in 0.040-inch thick sheet. The test results for these methods of riveting are presented as a group. The first specimens tested were made with three rivet rows by riveting method A. A more comprehensive group of specimens was made later with 1, 2, and 3 rivet rows by riveting methods B, C, and D, which more closely approximate present aircraft practice than method A. The tests of the specimens riveted by methods B, C, and D revealed that, for a given value of h_b, the number of rivet rows may have a small but an inconsistent effect on the yield load and the maximum load. (See fig. 9.) For this reason, no distinction is made between various numbers of rivet rows in subsequent figures.

The effect of h_b on the load-displacement curves is shown in figure 10. For the same value of h_b, the load-displacement curves for joints made by riveting methods A, B, C, and D tend to be alike. For the specimens with negative valves of h_b, permanent displacement occurs at loads near zero but, for the specimens with positive h_b, permanent displacement does not begin until a fairly large proportion of the maximum load is applied.

The effect of h_b on maximum load, yield load, ratio of yield load to maximum load, and h_a is shown in figures 11, 12, 13, and 14, respectively. In each of these figures, the band of scatter for the data obtained from tests of specimens made by riveting method A is superimposed as dotted lines on the plots of data for specimens made by riveting methods B, C, and D. A careful study of figures 11 to 14 reveals the following facts:

1. For riveting methods A, B, C, and D, the maximum load is higher when h_b is negative than when h_b is positive. (See fig. 11.)

2. For riveting methods A, B, C, and D, the yield load increases from low values for large negative values of h_b to high values for large positive values of h_b. (See fig. 12.)

3. For a given value of h_b, riveting method D gives slightly lower yield loads than methods A, B, and C. (See fig. 12.)

4. The ratio of yield load to maximum load increases from values near zero for large negative values of h_b to values near unity for large positive values of h_b. (See fig. 13.)

5. When h_b is negative, the value of h_a tends to be nearly zero regardless of the magnitude of h_b; whereas, when h_b is positive, h_a is approximately equal to h_b. (See fig. 14.)

It may be that the pressure used in the squeeze method of riveting, method D, was not sufficiently great to give the same yield load as obtained for rivets driven by a hand hammer or vibrating gun, methods A, B, and C. On the other hand, it may be that the squeeze method of riveting always gives lower yield loads. This point needs to be cleared up by further tests.

On the basis of maximum load as the sole criterion of quality of a riveted joint, h_b should always be negative. When h_b is negative, however, permanent displacement of the attached parts after a small percentage of the maximum load has been applied may render the joint unfit for the service required, especially if the loads are repeated. In addition, the excessive distortion of the joint before maximum load is reached when h_b is negative and the relatively small distortion prior to failure when h_b is positive renders a comparison of quality on the basis of maximum load unjustified.

For the rivets on the exterior surfaces of aircraft, it appears that flushness and yield load as a measure of tightness should be the criterion of quality.

If h_b is positive, the rivets will be relatively tight but will protrude above the skin surface after driving and, if h_b is negative, the rivets will be approximately flush after driving but will not be tight. If it is desired to achieve tightness and flushness in a single operation by holding h_b equal to zero, very small tolerances must be used in the dimensions of both the rivet head and the countersunk hole. In this investigation a perfectly flush rivet was not obtained even when h_b was essentially zero; a small annular depression was always present around the rivet head.

The practical method of obtaining rivets that are tight and perfectly flush may be to use a definitely positive value of h_b and then to remove the portion of the rivet head that protrudes above the skin surface after driving. The removal of the protruding portion of the rivet head reduces only slightly the yield load and the maximum load. (See fig. 15.)

<u>Riveting method E.</u> - Riveting method E differed from methods A, B, C, and D in that a roundhead rivet was used instead of a countersunk-head rivet and the rivet was inserted from the side opposite the countersunk hole.

The included angle of the countersunk hole was varied from 30° to 82° and the sheet thicknesses varied from 0.040 to 0.102 inch. Rivets were driven by method E, where the included angle of the countersunk hole was 100°, but the increased shank length required made it difficult to produce consistently satisfactory filling of the countersunk hole. Because of this fact, the test program was limited to head angles of not more than 82°.

The tests of specimens made by riveting method E reveal that, within the range of angles tested, the rivet-head angle θ has no effect on the yield load and the maximum load. (See fig. 16.)

For the range of sheet thicknesses used ($t = 0.040$ to 0.102 in.), the yield load and the maximum load tend to be higher when the riveted joints are made with thin sheets than when made with thick sheets. (See fig. 17.)

Comparison of results for riveting methods C and E. - Riveting methods C and E are similar except for the type of rivet and the side of the joint from which the rivet is inserted. Riveting method C gave yield loads and maximum loads as high as or higher than methods A, B, and D; therefore, the highest values obtained by riveting methods A, B, C, and D are compared with the corresponding values obtained by method E.

For riveting method C, the results for the ideal value of $h_b = 0.000$ inch and the arbitrary value of $h_b = 0.020$ inch are selected for comparison with the results of riveting method E, $\theta = 82°$. For the rivets of method C with $h_b = 0.020$ inch, the protruding portion of the rivet head was removed in order to make the rivets flush. Thus, all comparisons are made for rivets that are flush and have essentially the same head angle.

In figure 18 are presented, for comparison, load-displacement curves for the joints made by riveting methods C and E with the foregoing values of h_b and θ. Method C with $h_b = 0.000$ inch shows a progressively more favorable load-displacement relationship as the sheet thicknesses increase. Method C with $h_b = 0.020$ inch gives more favorable load-displacement curves than when $h_b = 0.000$ inch. Method E gives load-displacement curves somewhat more favorable than method C with $h_b =$ 0.020 inch.

Figure 19 has been prepared to show the difference between the yield loads and the maximum loads for riveting methods C and E. The points plotted were obtained from the load-displacement curves of figure 18. Figure 19 shows that for the range of sheet thicknesses tested (0.040 to 0.102 in.):

Method E gives the highest yield loads and maximum loads.

Method C with h_b = 0.020 inch and the protruding portion of the rivet head removed gave higher yield loads but gave about the same maximum load as method C with h_b = 0.000 inch.

CONCLUDING REMARKS

From the results of these tests, it is concluded that a comparison of the quality of machine-countersunk riveted joints on the basis of maximum load alone is not justified. For the rivets on the exterior surfaces of aircraft, it appears that flushness and yield load as a measure of tightness should be the criterior of quality.

The fact that higher yield loads were obtained by riveting methods A, B, C, and D when h_b was positive than when h_b was negative indicates that the driving of the rivet material into the hole to fill it is the most important factor in obtaining tight rivets. Because riveting method E gave higher yield loads than methods A, B, C, and D, it is probable that, of the riveting methods investigated, this method of riveting fills the hole most completely. In the process of driving the rivets of method E, the shank swells along its entire length, filling the countersunk-rivet hole progressively from bottom to top.

In addition to producing tight rivets, any method of riveting that completely fills the machine countersunk holes and removes the protruding portions of the rivet heads after driving also provides a method of obtaining a uniform surface finish that is particularly useful where extreme smoothness is required. Use of either of the milling tools shown in figures 20 and 21 to remove the protruding portions of the rivet heads will give a surface sufficiently smooth that, when the surface is painted and rubbed down, the rivets cannot be detected. If paint is not applied, a final rubbing down or finishing operation on the metal surface is required to accomplish the same result. Rivets installed by method E could not be detected by inspection of the unpainted surface when the final finish was made with either of the tools shown in figures 22 and 23.

It appears that separate operations are necessary in the procedure of riveting if the joint is to be of high quality with respect to both tightness of the joint and flushness of the rivet.

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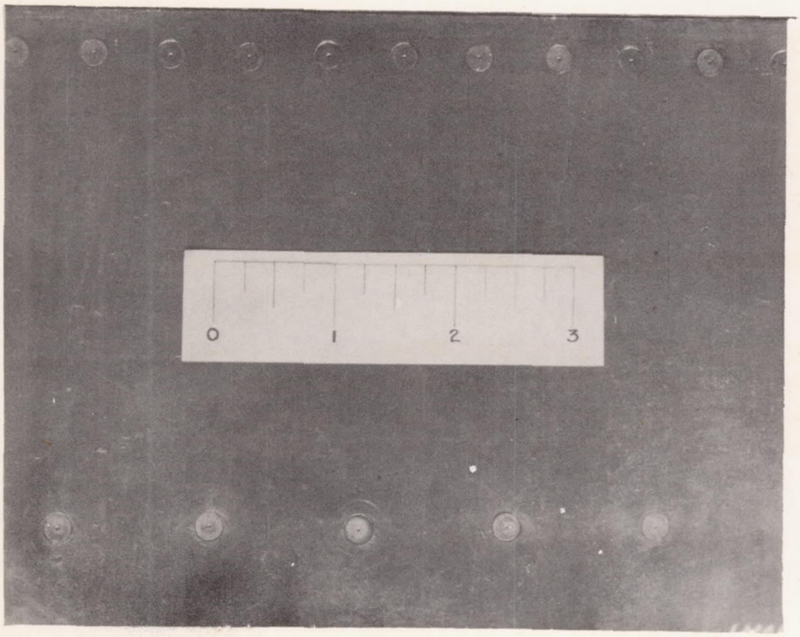

Figure 1.- Rivets on a wing surface that do not completely fill the countersunk hole and are not perfectly flush.

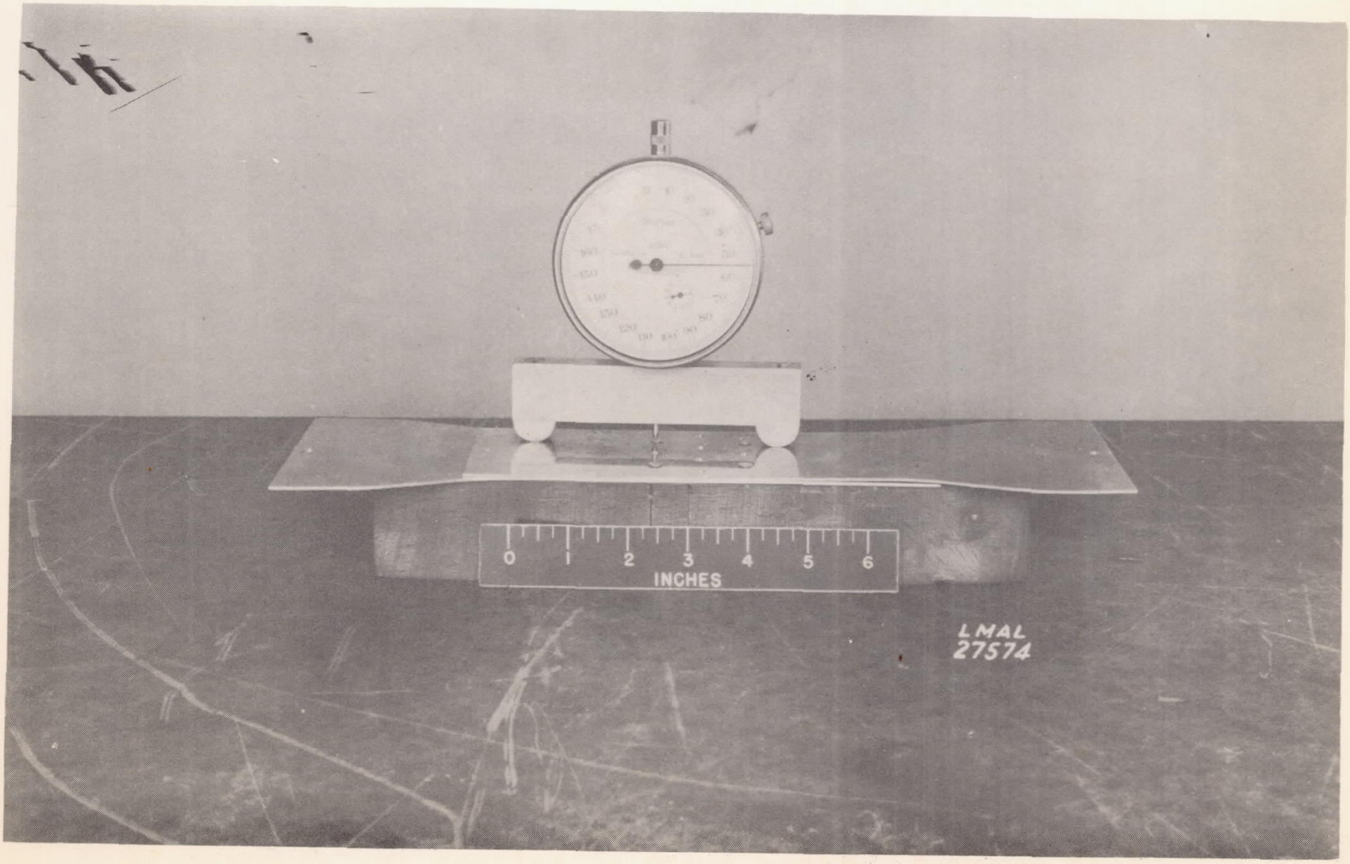

Figure 7.- Apparatus used to measure h_b and h_a with a dial gage graduated to 1/10,000 inch.

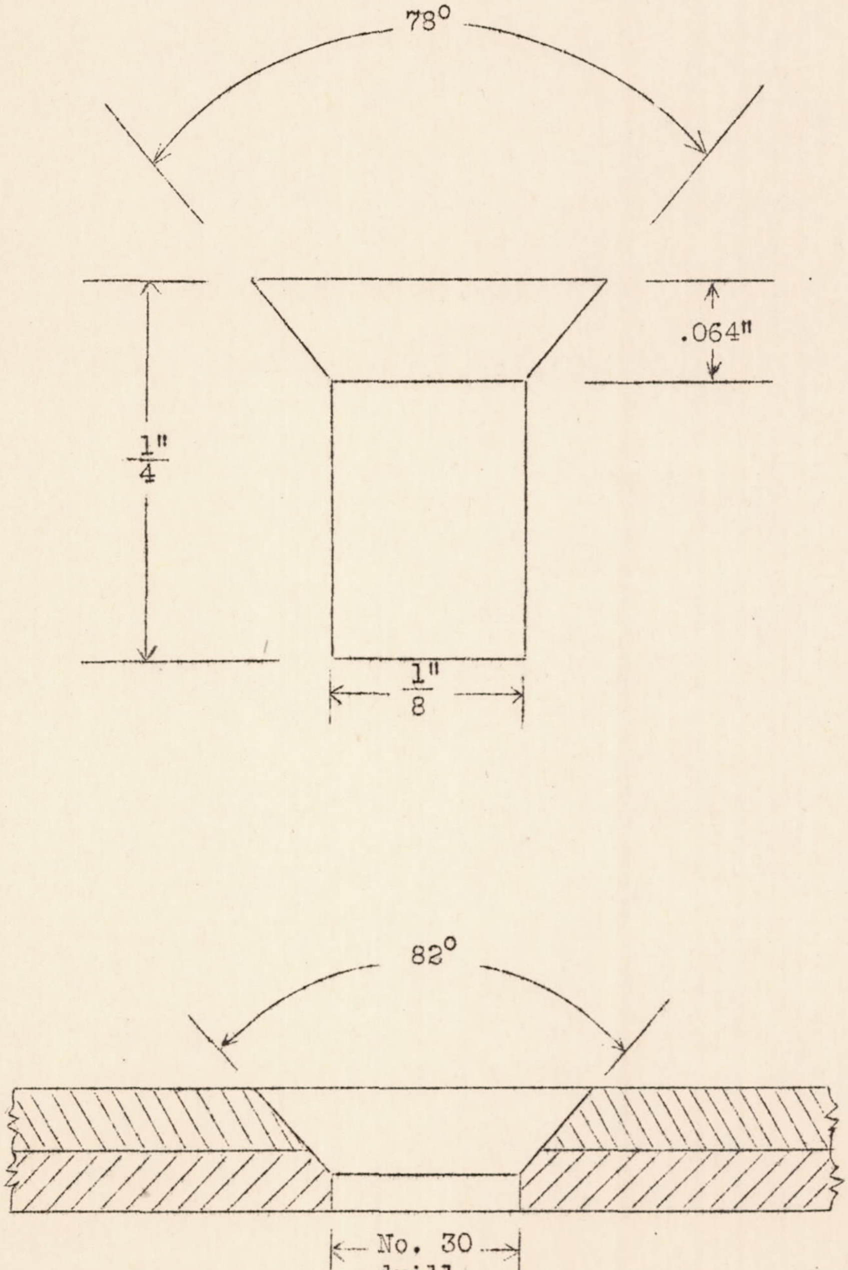

Figure 2.- Dimensions of machine-countersunk rivet and angle of countersink used in riveting methods A, B, C, and D.

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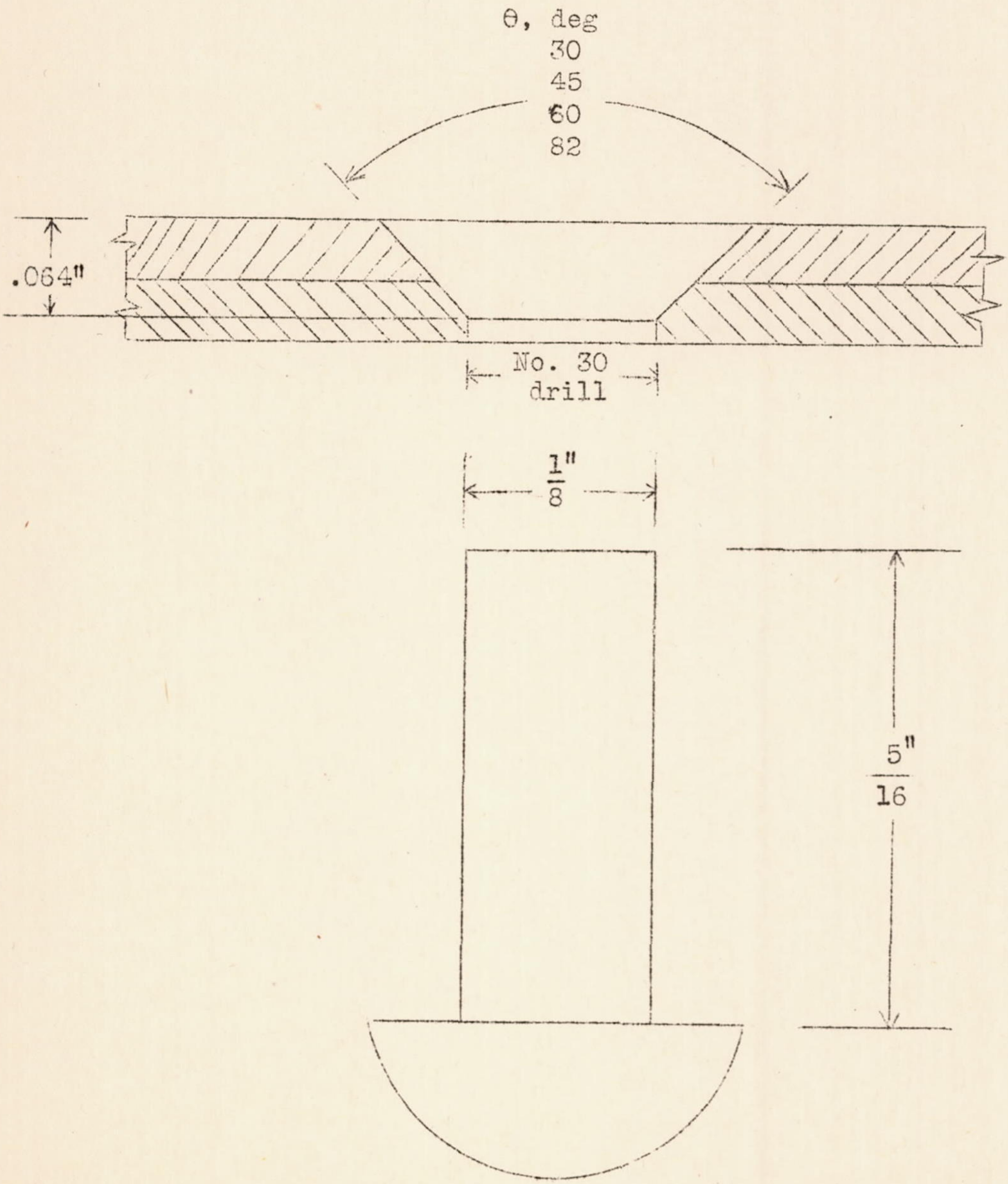

Figure 3.- Dimensions of roundhead rivet and angle of countersink used in riveting method E.

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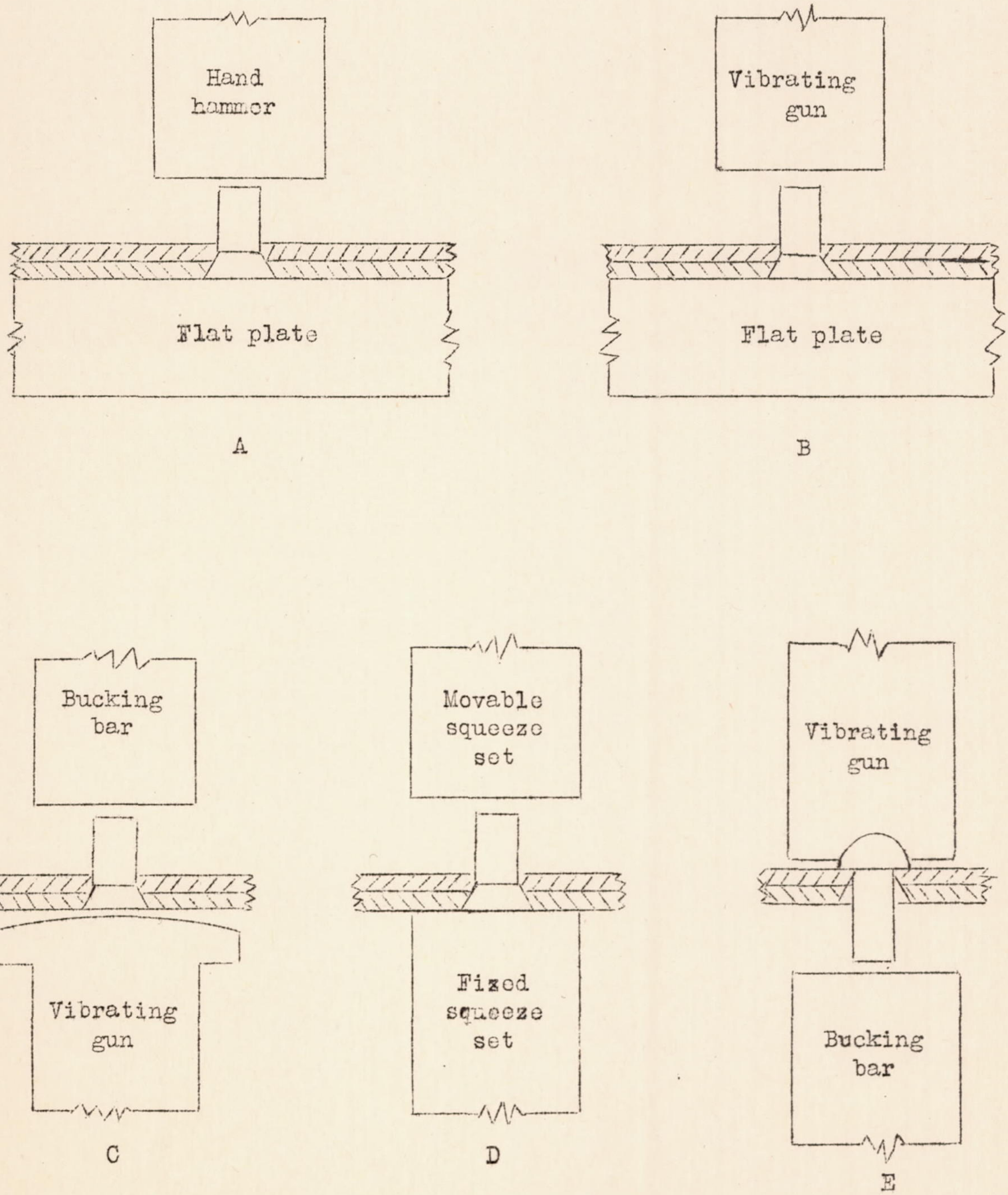
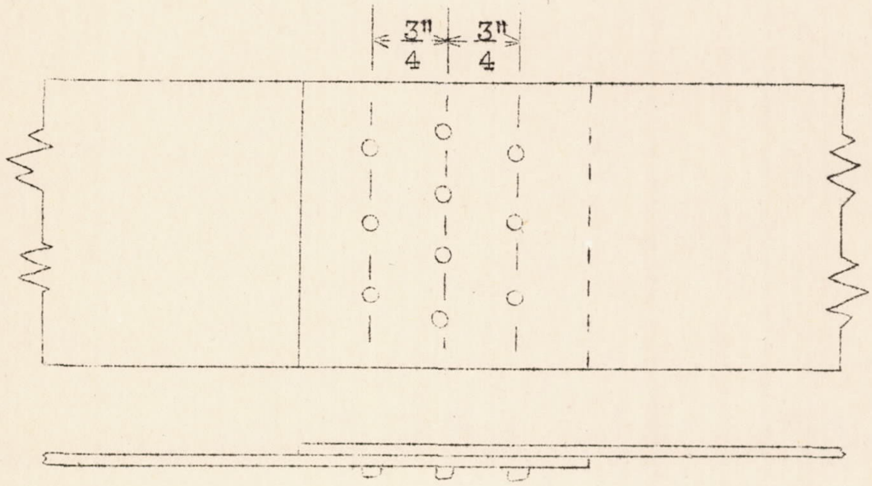
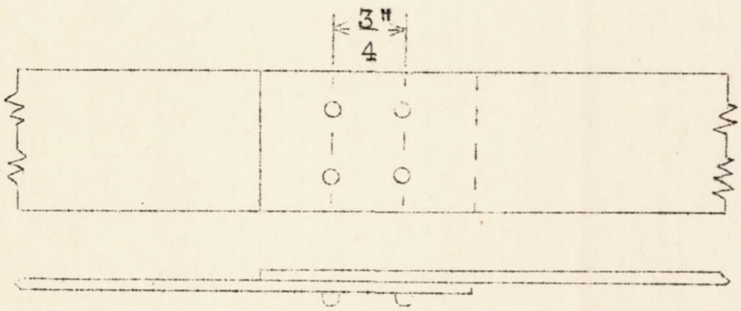


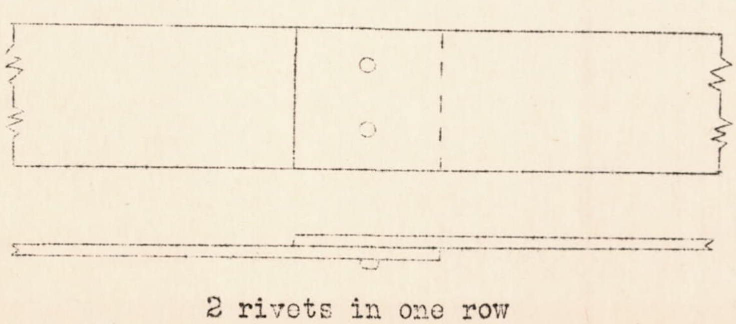
Figure 4.- Methods of riveting used in this investigation.



10 rivets in three rows



4 rivets in two rows



2 rivets in one row

Figure 5.- Riveted joints drawn to scale.

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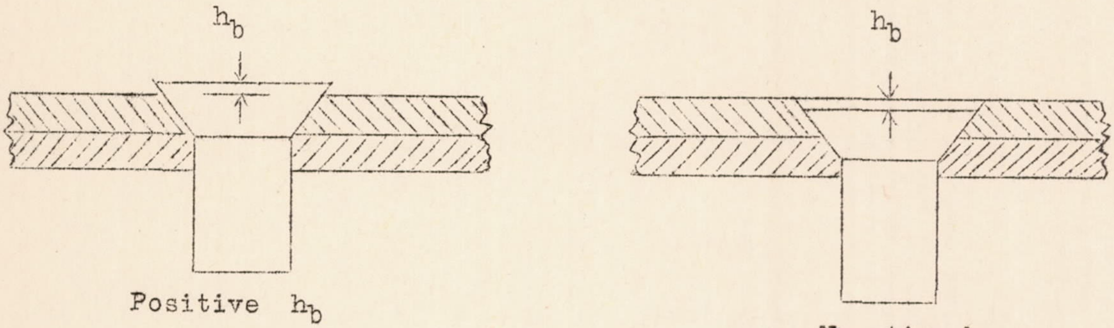
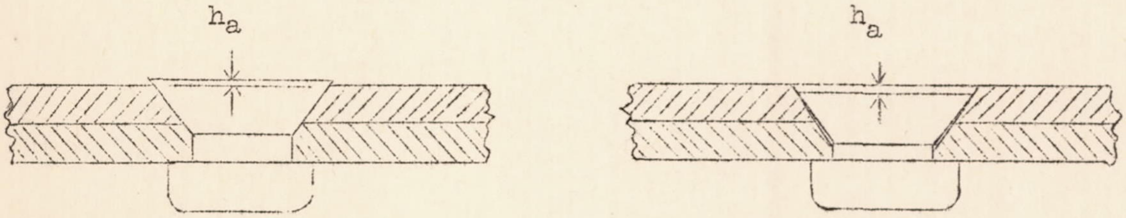


Positive h_b Negative h_b

Before driving



Positive h_a Negative h_a

After driving

Figure 6.- Illustration of h_b and h_a for machine-countersunk rivets.

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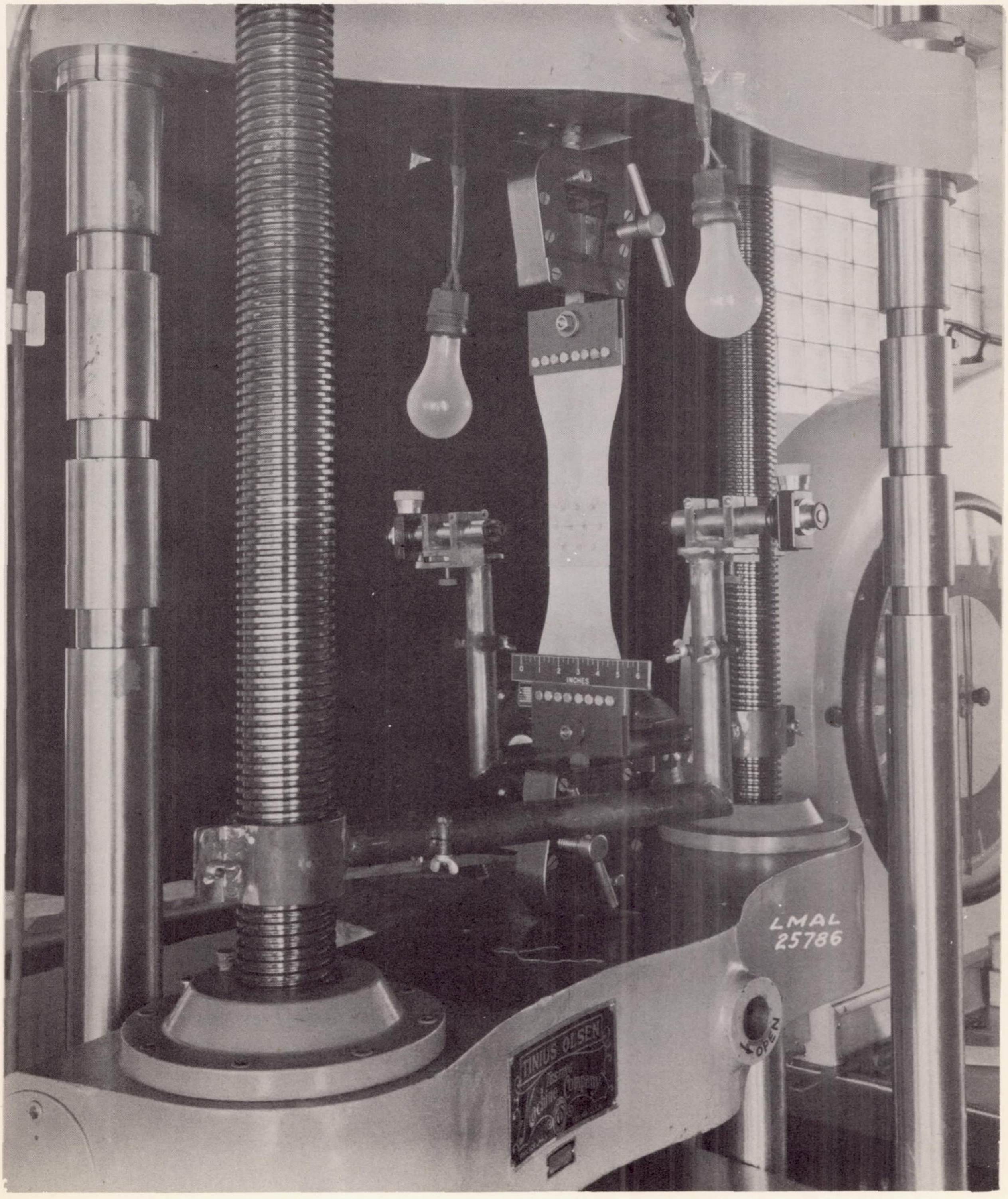

Figure 8.- Test apparatus and specimen with 10 rivets in three rows.

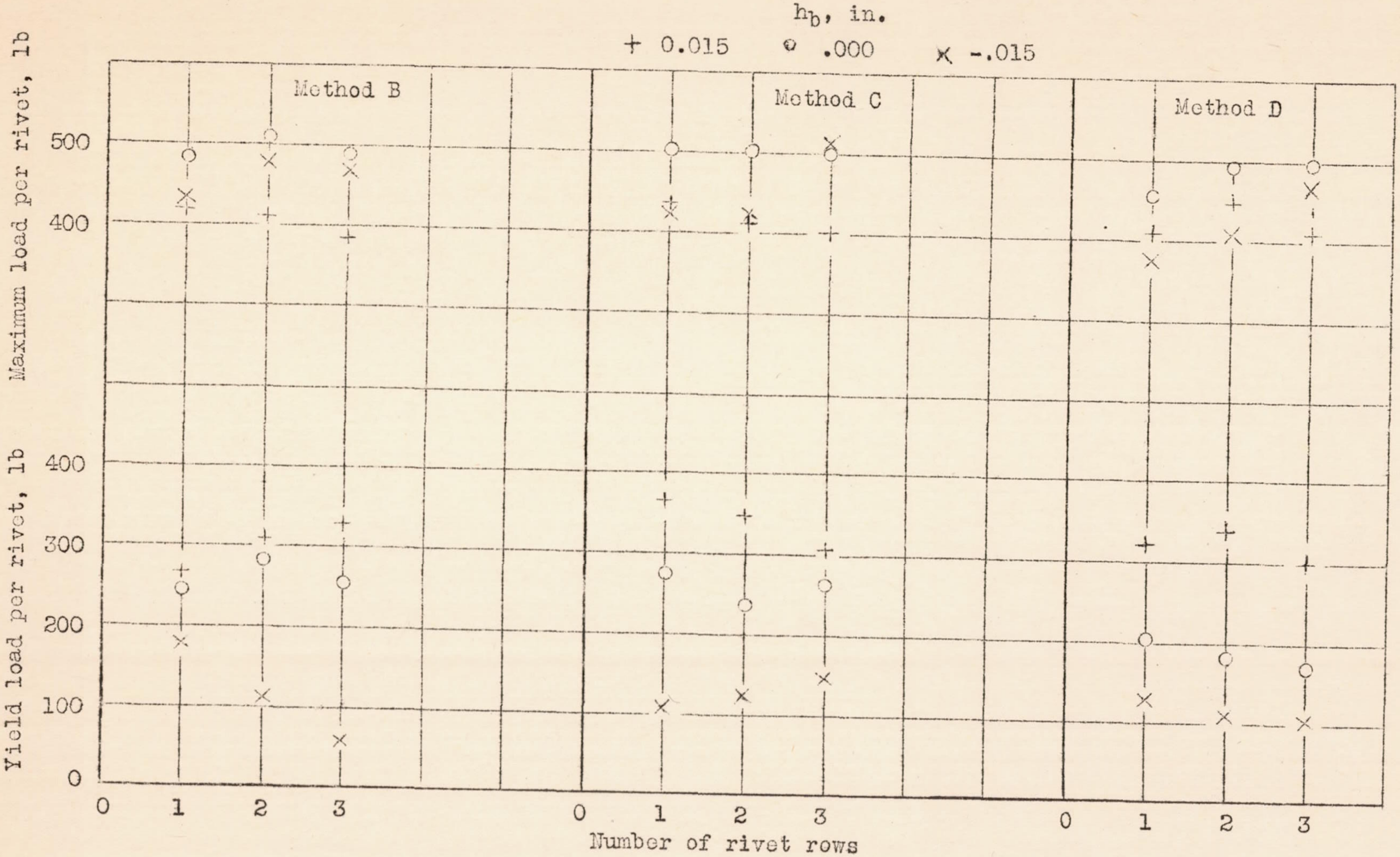

Figure 9.- Variation of yield load and maximum load with number of rivet rows.

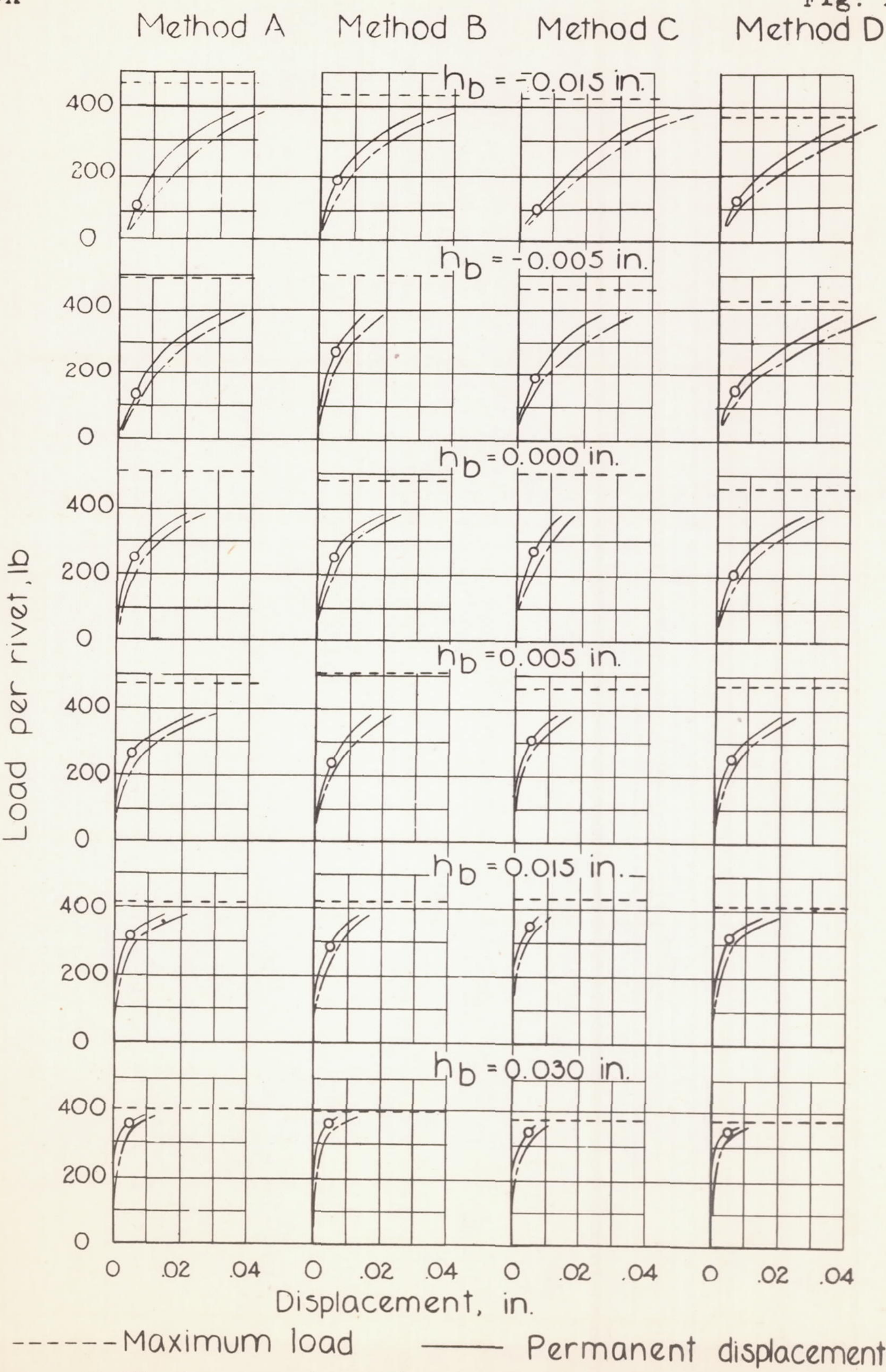

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Figure 10. - Load-displacement curves for riveting methods A, B, C, and D.

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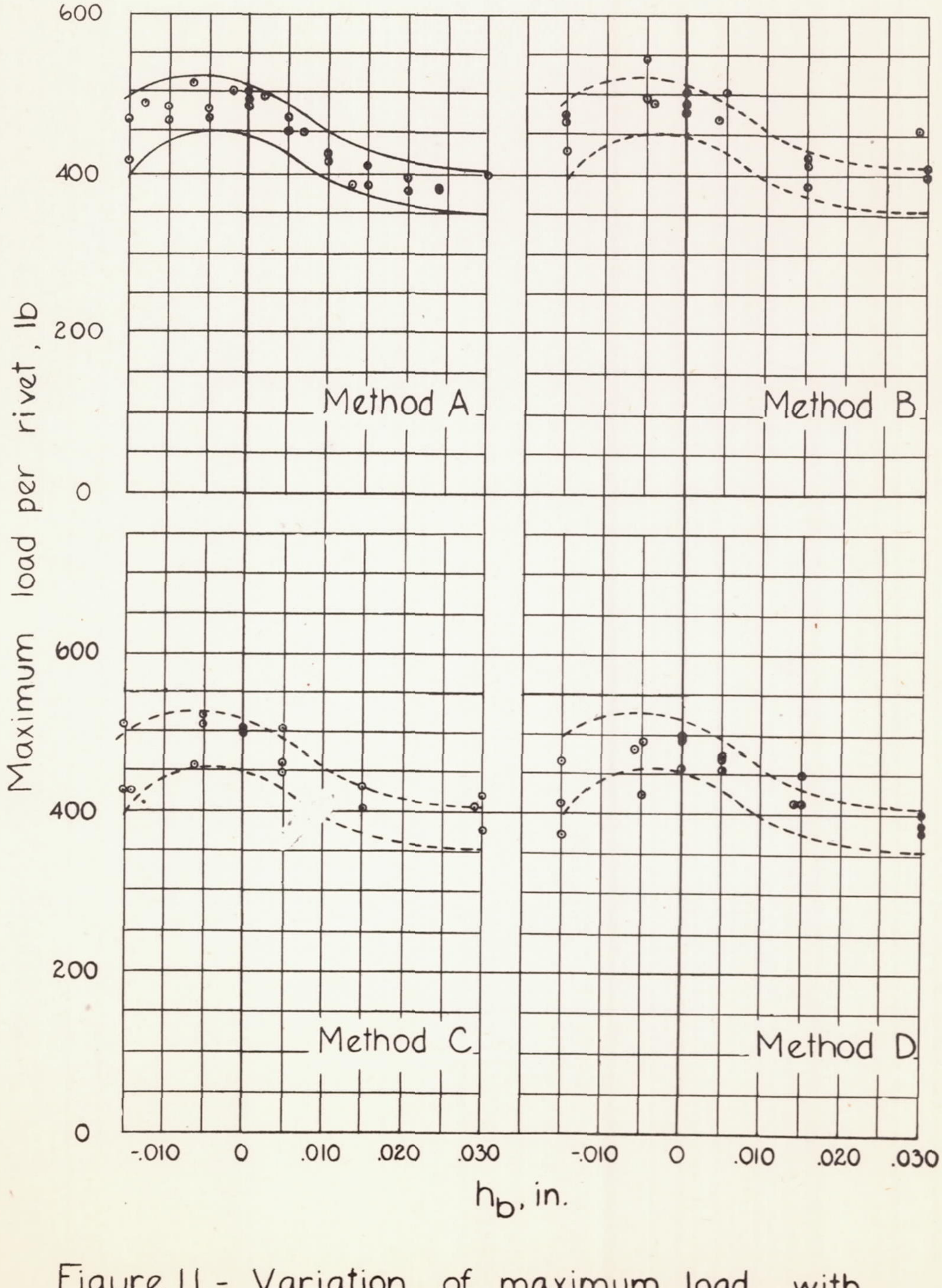

Figure 11.- Variation of maximum load with h_b for riveting methods A, B, C, and D.

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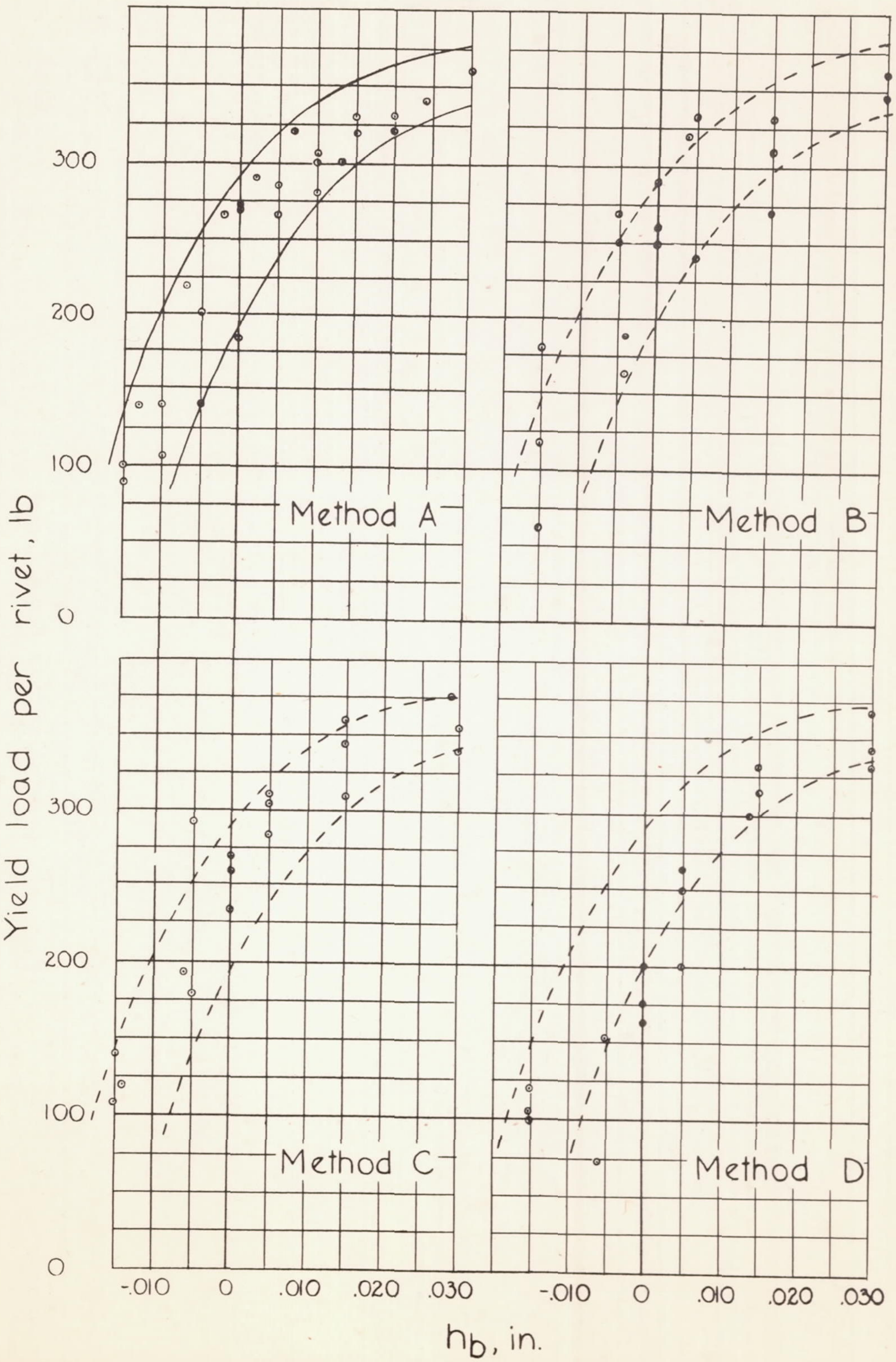

Figure 12.- Variation of yield load with h_b for riveting methods A, B, C, and D.

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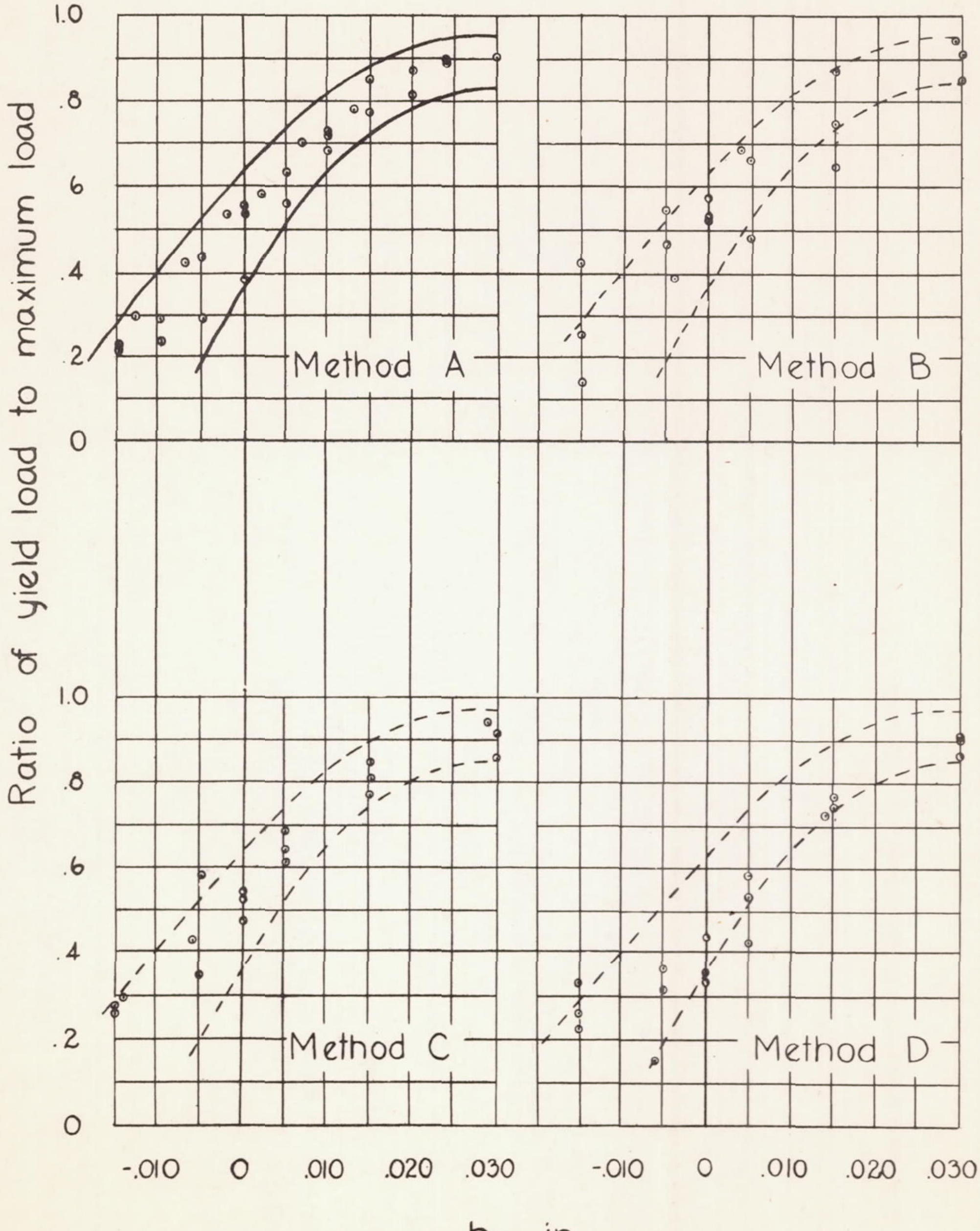

Figure 13.- Variation of ratio of yield load to maximum load with h_b for riveting methods A, B, C, and D.

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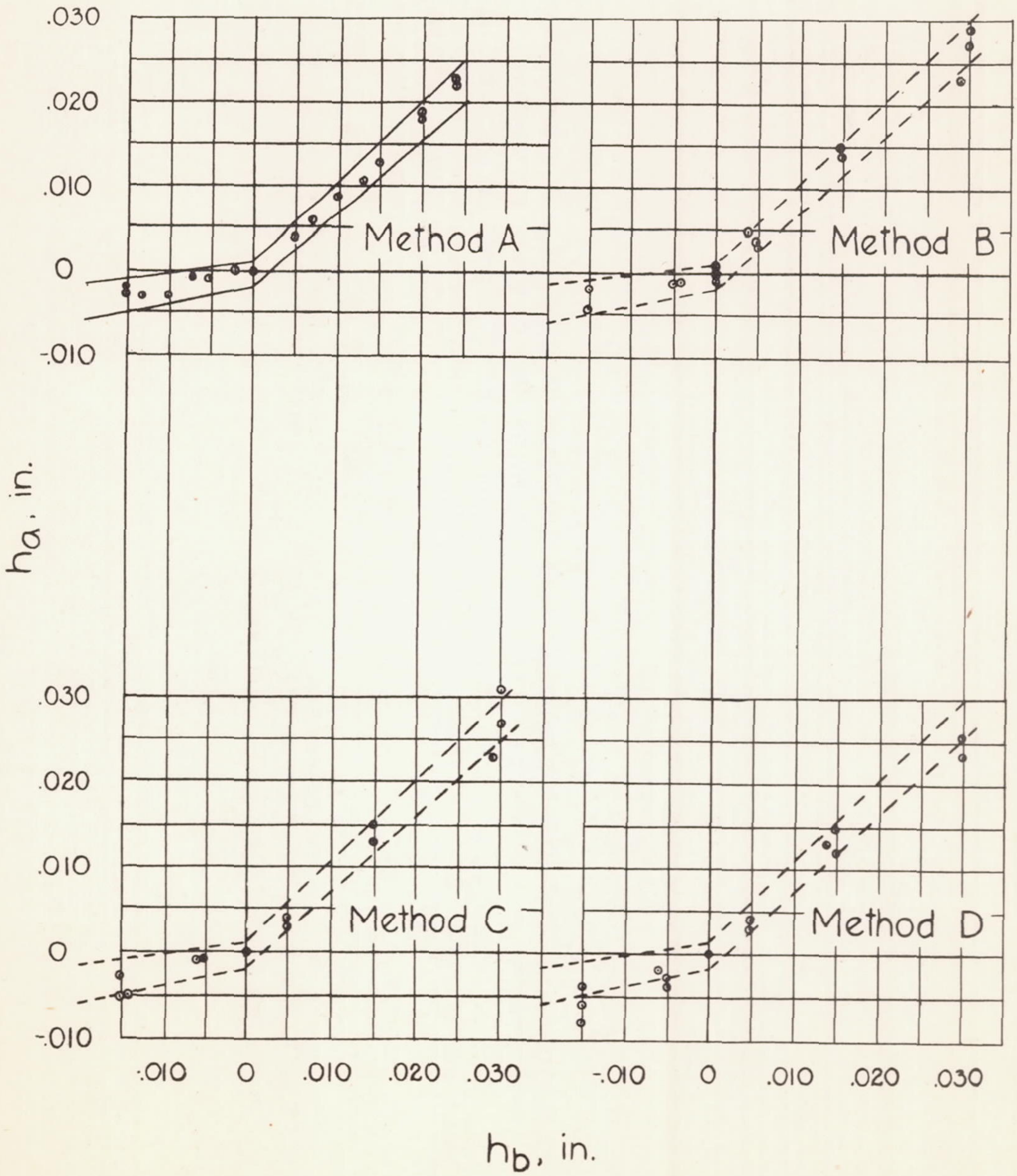

Figure 14.- Variation of h_a with h_b for riveting methods A, B, C, and D.

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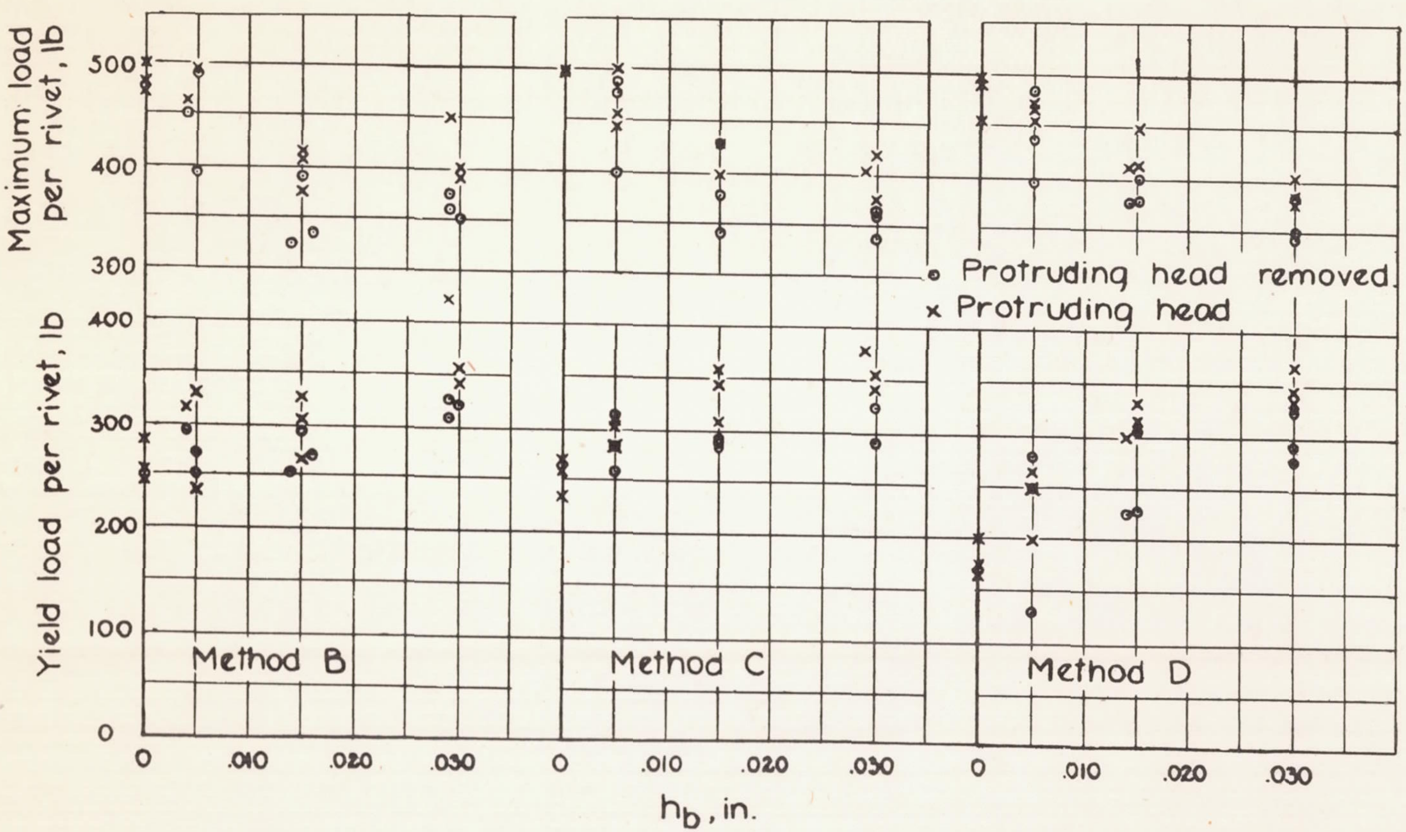

Figure 15. - Comparison of yield load and maximum load for rivets before and after removal of the protruding portion of the rivet head.

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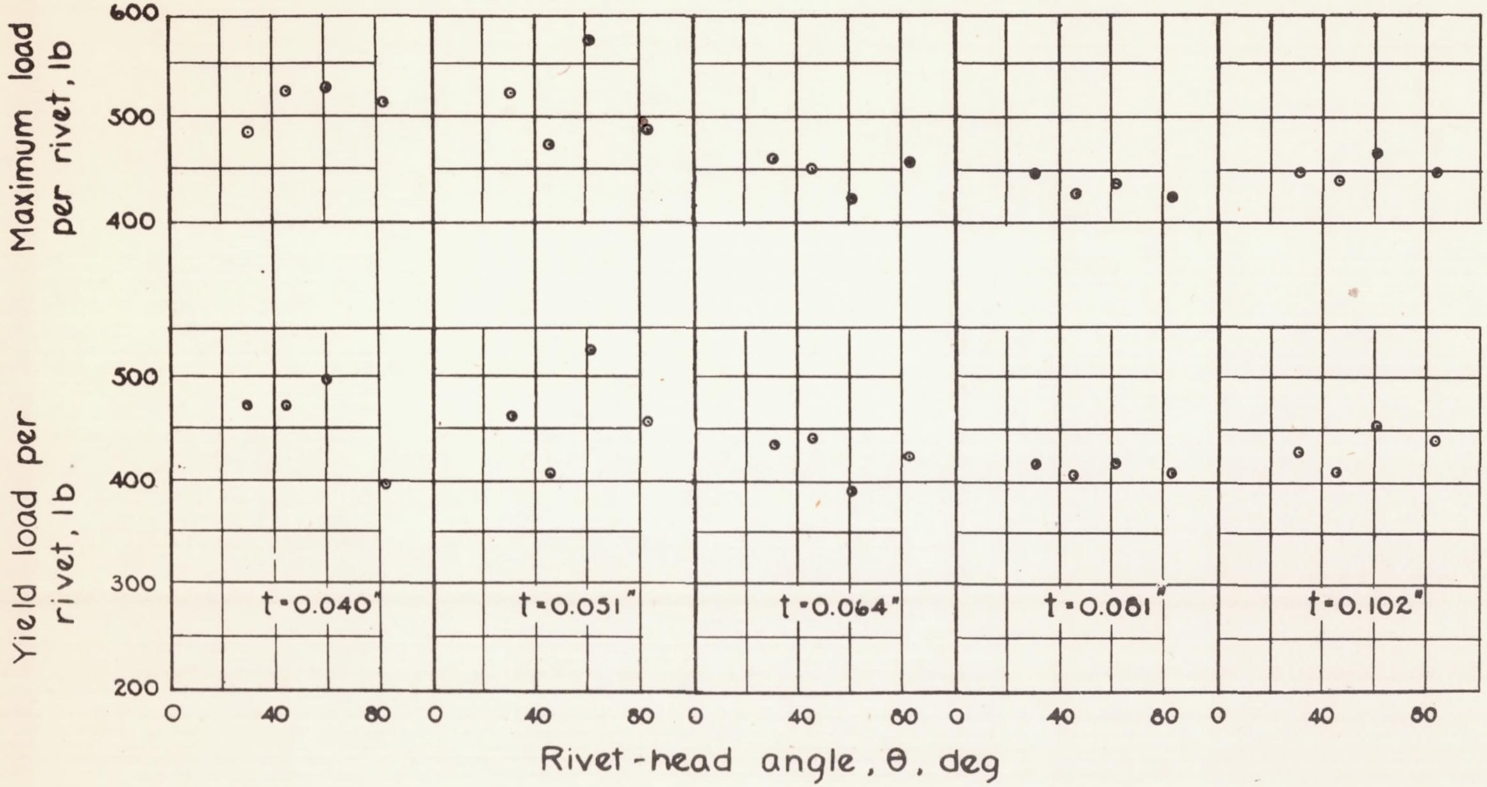

Figure 16.- Variation of yield load and maximum load with rivet-head angle for different thicknesses t for riveting method E.

Fig. 16

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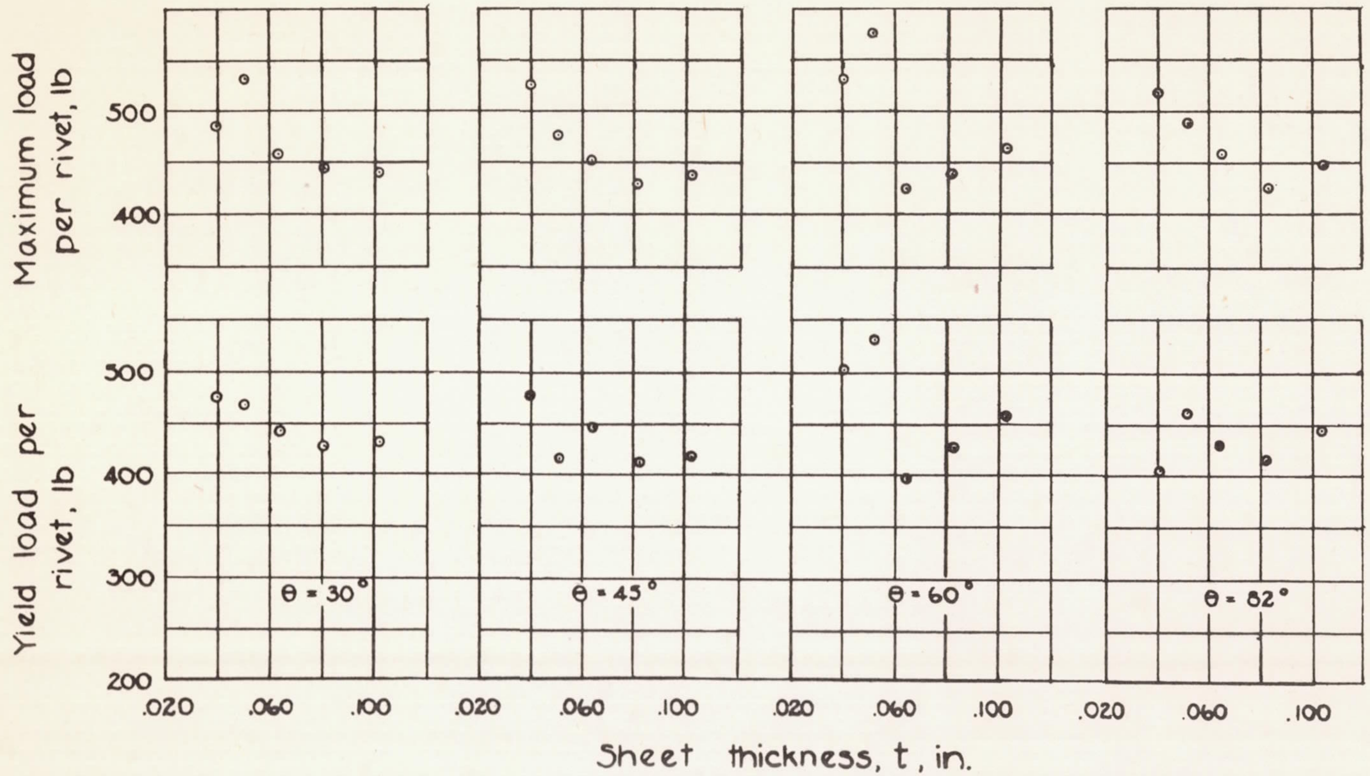

Figure 17.- Variation of yield load and maximum load with sheet thickness for different rivet-head angles θ for riveting method E.

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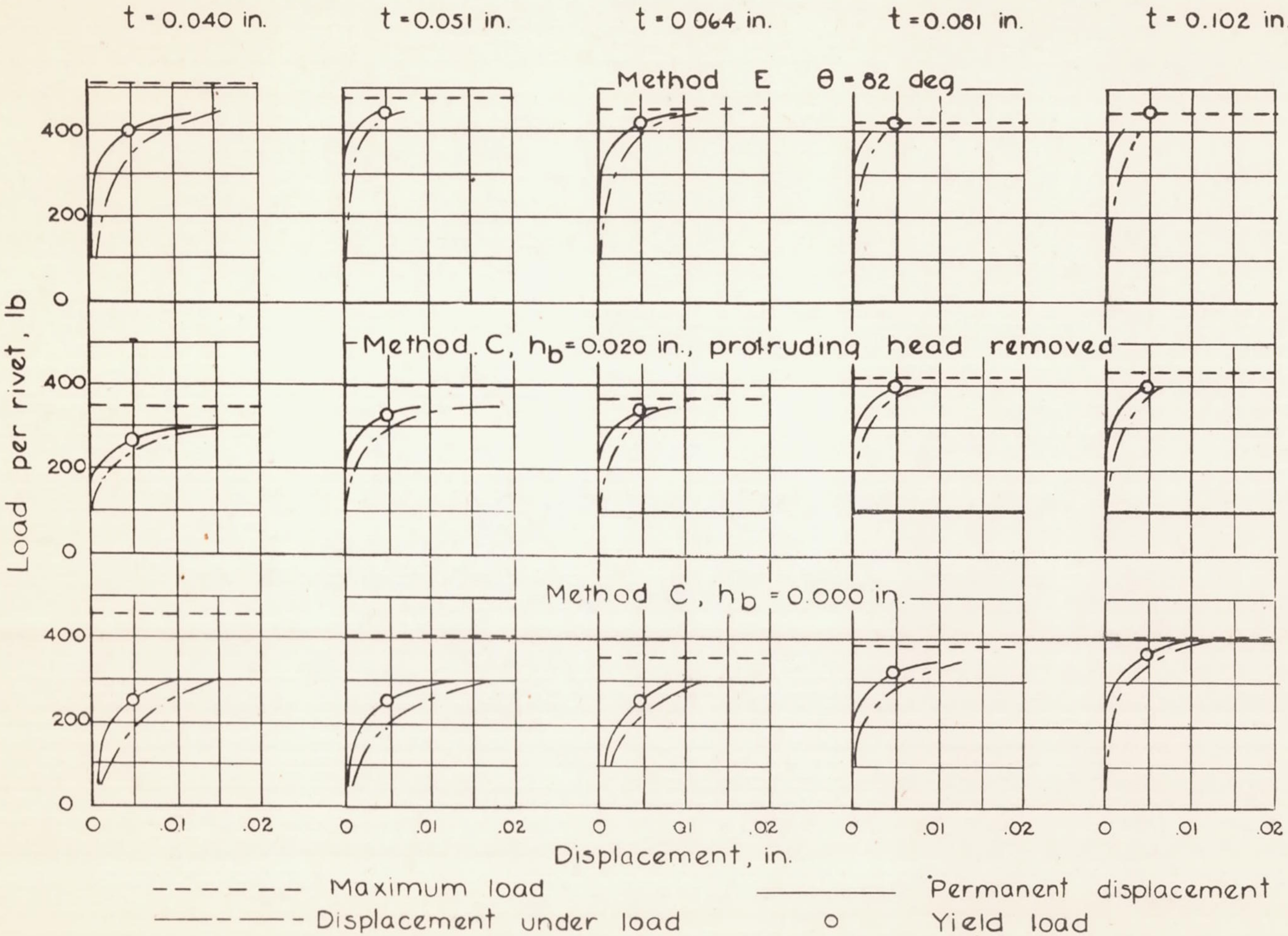

Figure 18.- Load-displacement curves for riveting methods C and E.

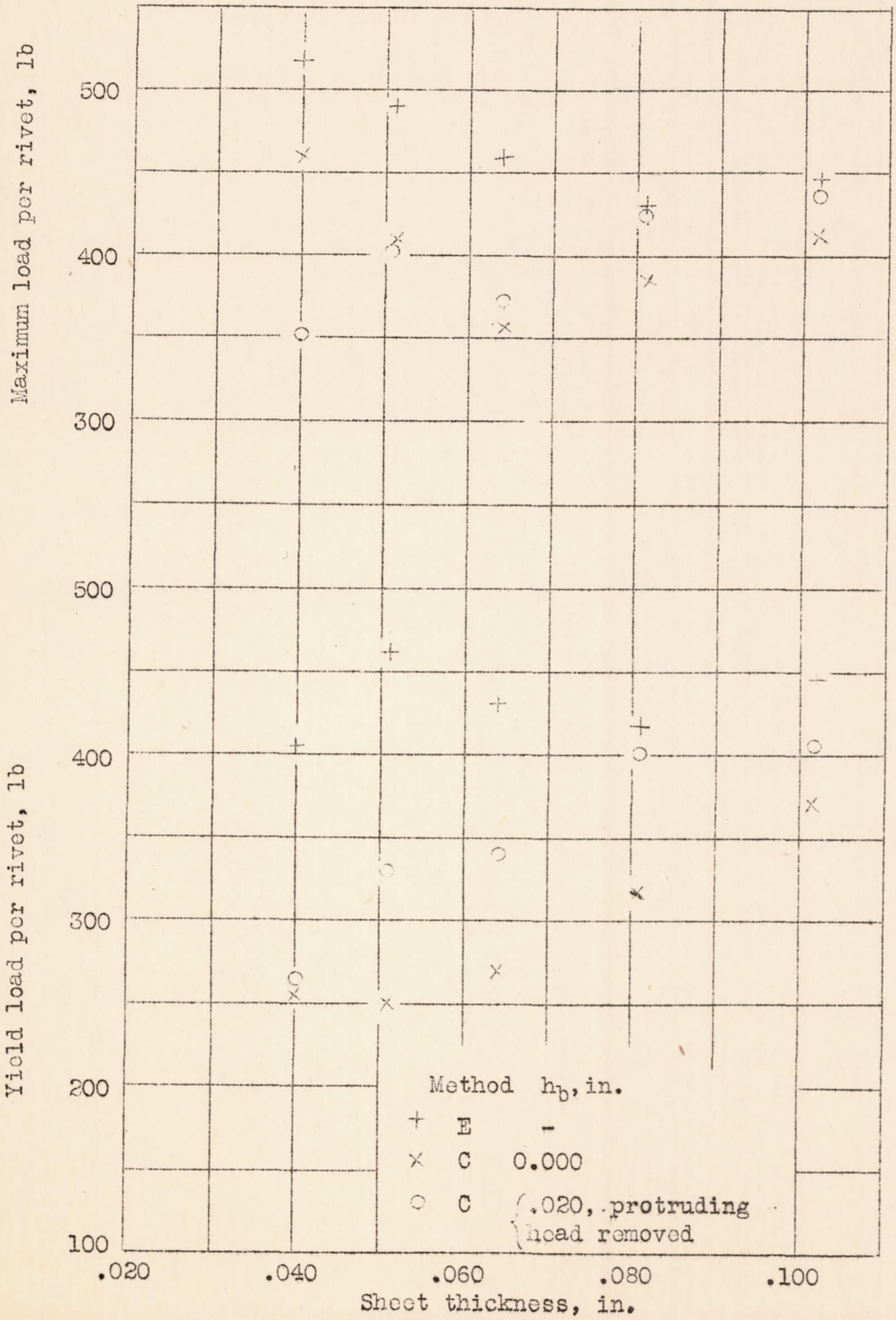

Figure 19.- Comparison of yield load and maximum load for riveting methods C and E.

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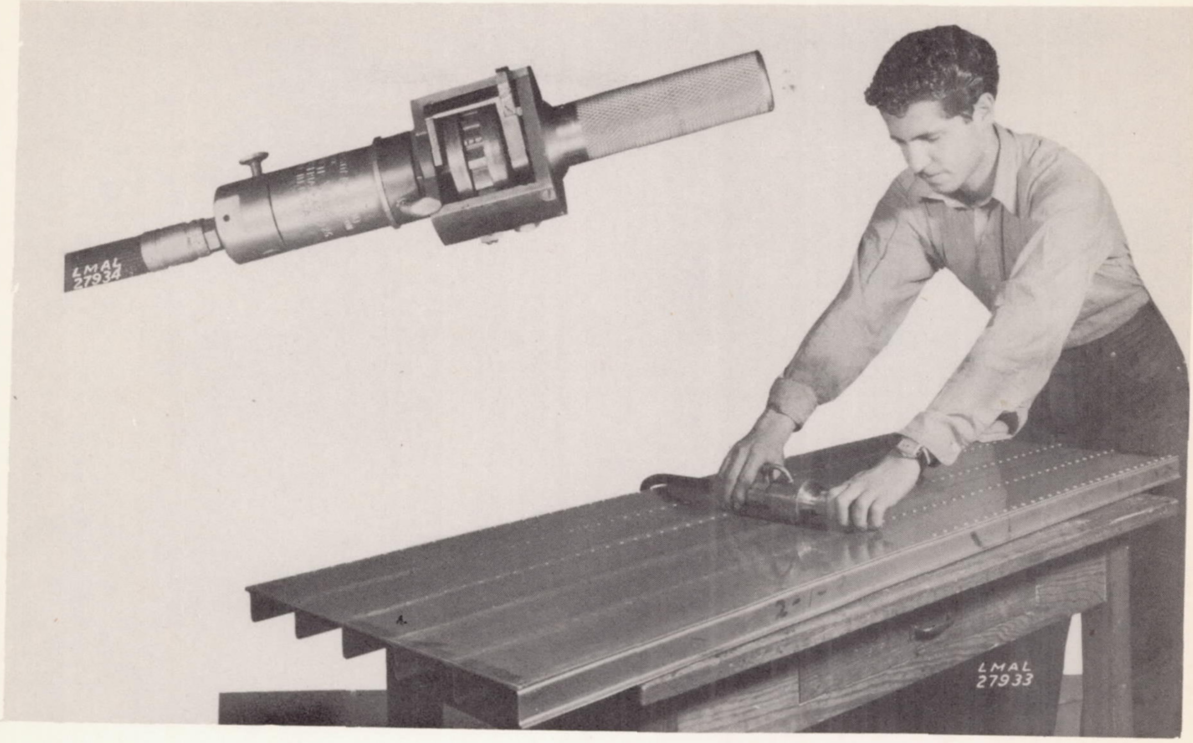

Figure 20.- Rotary-milling tool for removing the protruding portion of the rivet head.

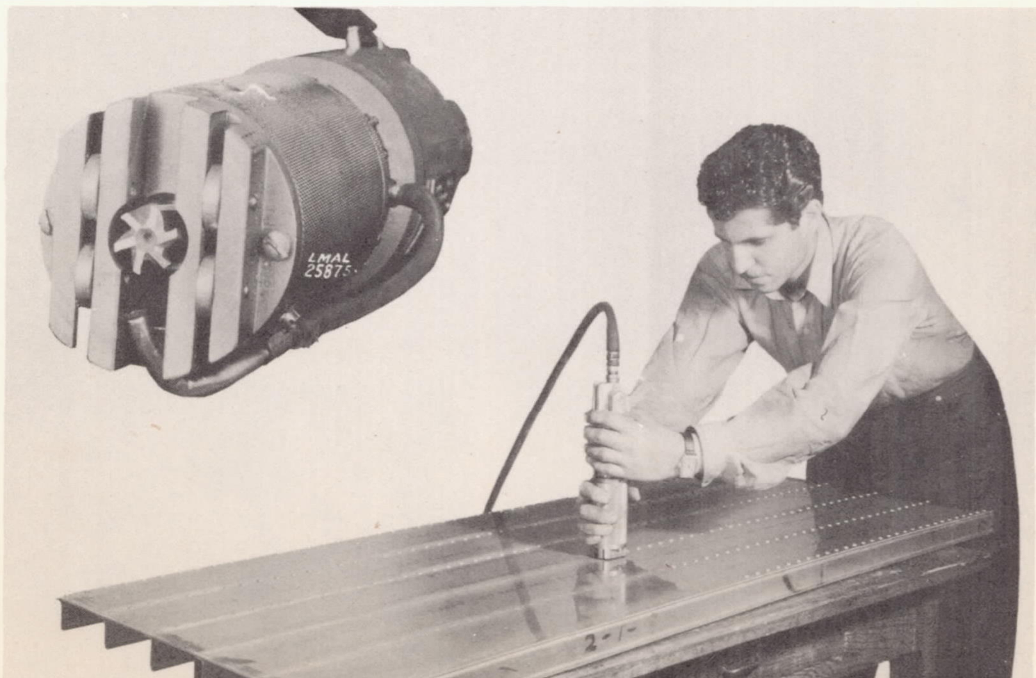

Figure 21.- End-milling tool for removing the protruding portion of the rivet head.

Figure 22.- Disk-surfacing tool used to finish the rivet heads after the protruding portion has been removed.

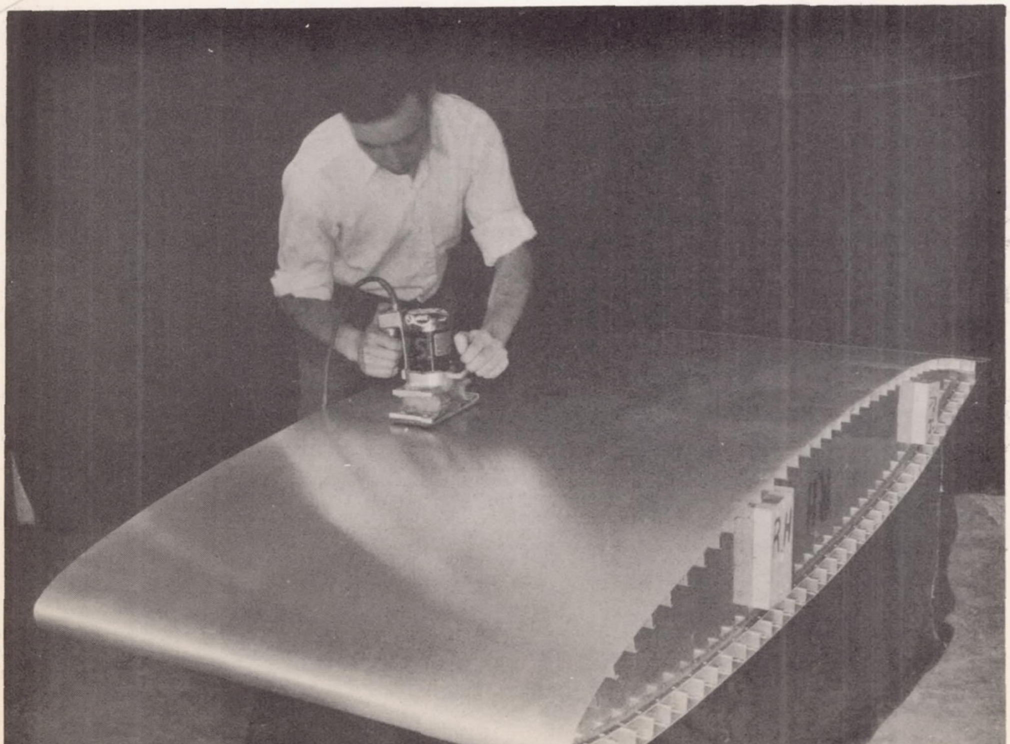

Figure 23.- Vibrating-surfacing tool used to finish the rivet heads after the protruding portion has been removed.