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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1205

DATA ON OPTIMUM LENGTH, SHEAR STRENGTH, AND TENSILE STRENGTH OF AGE-HARDENED 17S-T MACHINE-COUNTERSUNK RIVETS IN 75S-T SHEET

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Washington

March 1947

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SUMMARY

A series of tensile-strength and shear-strength tests were made on age-hardened 17S-T rivets machine-countersunk in 75S-T sheet. The riveted joints were constructed by the NACA reverse-driving method of countersunk riveting; the angle of countersink was 60° and the depth of countersink was half the rivet diameter or 1.25 times the sheet thickness, whichever was less. The results of the tests indicated that such joints can be made satisfactorily with regard to both flushness and strength, if the ratio of buck (the length of rivet protruding beyond the surface of the countersunk sheet before driving) to diameter of the rivet is kept between 0.9 and 1.5. Curves are presented giving the rivet strength in terms of the single-sheet thickness for joints in which these limits have been observed.

INTRODUCTION

The use of 17S-T rivets in the age-hardened condition has usually been avoided in the past because such rivets are harder to drive than annealed rivets. With the introduction of higher-strength structural alloys, however, use of stronger rivets has become desirable for developing the full potential strength of a structure, and age-hardened rivets have in some cases been used.

In order to provide data on the strength of age-hardened 17S-T rivets (sometimes designated 17S-TA rivets) and also to study the optimum length of rivet for joining sheets of given thickness by the NACA reverse-driving method of countersunk riveting, a series of shear-strength and tensile-strength tests were made on 17S-TA rivets in 75S-T aluminum-alloy sheet.

For completeness, this report includes full details of test specimens, test procedure, and data obtained. If, however, the reader does not wish to concern himself with these details, he is

referred directly to figure 3 which shows the procedure for driving the rivets, to figure 19 which summarizes the significant results, and to the Conclusions.

TEST SPECIMENS

The specimens used in the tensile-strength tests consisted of two sheets of 75S-T aluminum alloy of equal nominal thicknesses assembled with one 17S-TA rivet, as shown in figure 1. The shear specimens consisted of two sheets of 75S-T aluminum alloy of equal nominal thicknesses assembled into a lap joint by two 17S-TA rivets as shown in figure 2.

The NACA flush-riveting procedure (see fig. 3) was used in the preparation of the specimens. A complete discussion of this procedure is given in reference 1. Briefly, the method consists of inserting a round-head rivet into the uncountersunk end of the hole and upsetting the end of the shank into the countersink. The excess material is milled off with a flush-rivet milling tool similar to the one shown in figure 20 of reference 1. All rivets in the present program were squeezed hydraulically.

The depth of countersink was half the rivet diameter or 1.25 times the sheet thickness, whichever was less. The angle of countersink was 60° and the values of the variables for which tests were made are given in the following table. Shear and tensile specimens were tested for each combination of variables for which an "x" appears.

Rivet diameter (in.)	Rivet length (in.)	Sheet thickness (in.)									
		0.020	0.032	0.040	0.051	0.064	0.081	0.091	0.102	0.125	0.156
1/8	1/4	x	x	x	x	x					
	5/16				x	x	x	x	x		
5/32	1/4	x	x	x	x	x			x		
	5/16	x	x		x	x	x	x		x	
	3/8	x	x		x	x	x		x	x	x
	7/16			x		x	x	x	x	x	x
	1/2	x	x		x	x	x	x	x	x	x
3/16	1/4	x	x		x		x		x		
	5/16	x	x	x	x	x					
	3/8	x	x	x	x	x	x		x		x
	7/16	x	x			x	x	x	x	x	x

TEST PROCEDURE

The test procedure for the tensile specimens was the same as that described in reference 2. The specimens were mounted in the fixtures which are shown in figure 4. The small rods on each of the fixtures pass through the holes in one of the sheets of the specimen and bear against the other sheet. When load is applied, the rods push the sheets apart and thus subject the rivet to tensile load. These specimens were loaded at the rate of 400 pounds per minute until failure, and the maximum load was recorded.

The test procedure for the shear specimens was essentially the same as that described in reference 3. Loads were applied through Templin grips. The slip of one sheet with respect to the other was measured at the edges of the sheets opposite the riveted joint by means of two optical micrometers, one on each side of the specimen, as shown in figure 5. The specimens were subjected to alternate application and release of load; the load, however, was never released below a "zero" value of 50 pounds. The permanent slip that remained after each application of load was recorded, as was also the load causing failure.

All tests were conducted in the 100,000-pound-capacity testing machine in the Langley structures research laboratory. The loads indicated by this machine are within one-half of one percent of the true loads. The sensitivity of the optical micrometers used for reading slip is approximately 0.0002 inch.

Prior to running any test, the specimen was examined and an appraisal was made, based on the appearance of the countersunk head, as to whether the rivet had been too long, too short, or satisfactory for producing a good flush surface.

RESULTS AND DISCUSSION

Results of the tests are given in tables 1 to 3. The yield load in these tables is arbitrarily defined as the shear load per rivet required to produce a permanent slip equal to 4 percent of the rivet diameter; this definition of yield load is the same as that used in reference 1. The three types of failure indicated in the tables are illustrated by figures 6 to 8. In order to show the general tightness characteristics of the rivets, load-slip curves for all the shear specimens are given in figures 9 to 11.

The test results are also presented graphically in figures 12 to 14, in which loads in shear and in tension are plotted against the single-sheet thickness for each rivet diameter and length. In order to avoid unnecessary confusion of the test points, only an average value of yield load is plotted for each sheet thickness. The curves for maximum load are shown as solid lines over the range for which the appraisal before testing indicated that the rivet length was satisfactory.

If a rivet is too short, it does not provide enough material to fill the countersunk cavity; if a rivet is too long, it tends to buckle to one side in driving and leaves an unfilled space on the opposite side of the countersunk cavity. In either case the resulting rivet is not perfectly flush. The requirement of flushness consequently sets limits on the range of sheet thickness over which a given rivet length should be used. A minimum which these limits may assume is indicated by the extent of the solid lines in figures 12 to 14. These solid lines for each rivet length are replotted in figures 15 to 17, which show that the appraisal made on the basis of flushness was evidently sufficient to eliminate any rivet the strength of which was abnormally low in comparison with the main trends of the results. The solid lines therefore denote a range within which the rivets are satisfactory with regard to both flushness and strength. These ranges are shown in figure 18 as horizontal lines for each rivet diameter and length (where tension and shear specimens indicate different ranges, the smaller range was used). Grip length (double-sheet thickness) is used for the abscissa in figure 18 rather than sheet thickness to facilitate easy calculation of buck (rivet length minus grip length).

A study of the data indicated that the limits for obtaining satisfactory rivets corresponded roughly to constant ratios of buck to diameter of the rivet. The limiting buck-to-diameter ratios were found to be approximately 0.9 and 1.5 for all the diameters. In selecting the limits, it was taken into consideration that the horizontal lines in figure 18 represent only minimum ranges that could probably be extended in several cases if additional test data were available.

In order to show the shear and tensile strengths that are achieved with 17S-TA rivets in 75S-T sheet when the buck-to-diameter ratio is within the limits given, a single curve was faired through each of the composite curves of figures 15 to 17, and the single curves are plotted in figure 19. Average curves for the yield load in shear are also shown. Figure 19 indicates that, with a buck-to-diameter ratio in the given optimum range, the shear joints were remarkably tight, as the yield load is in no case substantially less than 90 percent of the failing load.

CONCLUSIONS

Tensile-strength and shear-strength tests were made on riveted joints constructed by the NACA reverse-driving method of countersunk riveting with age-hardened 17S-T rivets (sometimes designated 17S-TA rivets) in 75S-T sheet; the angle of countersink was 60° and the depth of countersink was half the rivet diameter or 1.25 times the sheet thickness, whichever was less. The results of the tests indicated that such joints can be made satisfactorily in regard to both flushness and strength if the ratio of buck (the length of rivet protruding beyond the surface of the countersunk sheet before driving) to diameter of the rivet is kept between 0.9 and 1.5. Curves are presented giving the rivet strength in terms of the single-sheet thickness for joints in which these limits have been observed.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., October 18, 1946

REFERENCES

1. Lundquist, Eugene E., and Gottlieb, Robert: A Study of the Tightness and Flushness of Machine-Countersunk Rivets for Aircraft. NACA RB, June 1942.

2. Schuette, Evan H., Bartone, Leonard M., and Mandel, Mervin W.: Tensile Tests of Round-Head, Flat-Head, and Brazier-Head Rivets. NACA TN No. 930, 1944.

3. Gottlieb, Robert: Test Data on the Shear Strength of Machine-Countersunk Riveted Joints Assembled by an NACA Flush-Riveting Procedure. NACA RB, Dec. 1942.

TABLE 1

TEST RESULTS FOR AGE-HARDENED 17S-T RIVETS MACHINE-COUNTERSUNK IN 75S-T SHEET.
RIVET DIAMETER, 1/8 INCH.

Sheet thickness (in.)	Tension			Shear			
	Appraisal before test	Type of failure (a)	Maximum load per rivet (lb)	Appraisal before test	Type of failure (a)	Yield load per rivet (lb)	Maximum load per rivet (lb)
Rivet length, 1/4 in.							
0.020	Satisfactory	1	160	Satisfactory	1	240	240
.020	-----do-----	1	140	-----do-----	1	220	230
.020	-----do-----	1	105	-----do-----	1	230	230
.020				-----do-----	1	215	215
.032	-----do-----	1	205	-----do-----	1,2	380	400
.032	-----do-----	1	200	-----do-----	1,2,3	420	435
.032	-----do-----	1	230	-----do-----	1,2	375	395
.032	-----do-----	1	235				
.040	-----do-----	1,2	295	-----do-----	3	480	485
.040	-----do-----	1,2	305	-----do-----	3	435	450
.040	-----do-----	1,2	325				
.051	-----do-----	1,2	320	-----do-----	3	370	445
.051	-----do-----	1,2	380	-----do-----	3	390	470
.051	-----do-----	1,2	375	-----do-----	3	470	485
.064	-----do-----	2	645	-----do-----	3	450	555
.064	-----do-----	1,2	610	-----do-----	3	485	510
.064	-----do-----	2	590	-----do-----	3	460	570
Rivet length, 5/16 in.							
0.051	Satisfactory	2	330	Satisfactory	3	565	600
.051	-----do-----	2	370	-----do-----	3	505	505
.051	-----do-----	2	370	-----do-----	3	465	470
.064	-----do-----	2	620	-----do-----	3	555	570
.064				-----do-----	3	515	555
.081	-----do-----	3	790	-----do-----	3	610	640
.081	-----do-----	2	880	-----do-----	3	475	590
.081	-----do-----	2	840	-----do-----	3	510	560
.091	-----do-----	2	975	-----do-----	3	590	640
.091	-----do-----	2	860	-----do-----	3	580	590
.091				-----do-----	3	510	550
.102	-----do-----	2	900	-----do-----	3	615	630
.102	-----do-----	2	950	-----do-----	3	575	600
.102	-----do-----	3	950	-----do-----	3	650	660

[a]Failure types identified in figs. 6 to 8.

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TABLE 2

TEST RESULTS FOR AGE-HARDENED 17S-T RIVETS MACHINE-COUNTERSUNK IN 75S-T SHEET.
RIVET DIAMETER, 5/32 INCH.

Sheet thickness (in.)	Tension			Shear			
	Appraisal before test	Type of failure (a)	Maximum load per rivet (lb)	Appraisal before test	Type of failure (a)	Yield load per rivet (lb)	Maximum load per rivet (lb)
Rivet length, 1/4 in.							
0.020	Satisfactory	1	180	Satisfactory	1	270	270
.020	-----do-----	1	95	-----do-----	1	290	290
.020	-----do-----	1	130	-----do-----	1	310	310
.032	-----do-----	1	230	-----do-----	1,2	470	485
.032	-----do-----	1	225	-----do-----	1,2	455	455
.032	-----do-----	1	285	-----do-----	1,2	470	470
.040	-----do-----	1	355	-----do-----	2	735	765
.040	-----do-----	1	350	-----do-----	2	680	700
.040	-----do-----	1	400	-----do-----	2	740	770
.051	-----do-----	1,2	470	-----do-----	3	705	800
.051	-----do-----	1,2	450	-----do-----	3	740	790
.051	-----do-----	1,2	510	-----do-----	3	810	845
.064	-----do-----	2	665	-----do-----	3	780	805
.064	-----do-----	1,2	645	-----do-----	3	685	770
.064	-----do-----	1,2	755	-----do-----	3	910	920
.064	-----do-----	2	750				
.102	-----do-----	2	1550	Short	3	720	820
.102	Short	2	1190	-do--	3	700	820
.102	-do--	2	1085	-do--	3	740	830
.102	-do--	2	185				
Rivet length, 5/16 in.							
0.020	Long	1	200	Satisfactory	1	240	240
.020	Satisfactory	1	150	-----do-----	1	260	260
.020	Long	1	140	-----do-----	1	250	250
.032	Satisfactory	1	265	-----do-----	1	390	400
.032	-----do-----	1	240	-----do-----	1	385	400
.032	-----do-----	1	205	-----do-----	1	355	410
.051	-----do-----	1	400	-----do-----	3	735	830
.051	-----do-----	1	420	-----do-----	3	745	840
.051	-----do-----	1	480	-----do-----	3	740	800
.064	-----do-----	2	680	-----do-----	3	960	1000
.064	-----do-----	2	680	-----do-----	3	725	850
.064	-----do-----	1,2	720	-----do-----	3	830	900
.064	-----do-----	1,2	720				
.081	-----do-----	2	985	-----do-----	3	780	810
.081	-----do-----	1,2	1110	-----do-----	3	830	860
.081	-----do-----	1,2	1015	-----do-----	3	825	890
.091	-----do-----	2	1140	-----do-----	3	880	905
.091	-----do-----	2	1205	-----do-----	3	820	855
.091	-----do-----	2	1270	-----do-----	3	775	850
.125	Short	2	1375	Short	3	780	870
.125	-do--	2	1120	-do--	3	630	750
.125	-do--	2	1325	-do--	3	670	860

[a] Failure types identified in figs. 6 to 8.

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TABLE 2- Continued.

TEST RESULTS. RIVET DIAMETER, 5/32 INCH.- Continued.

Sheet thickness (in.)	Tension			Shear			
	Appraisal before test	Type of failure (a)	Maximum load per rivet (lb)	Appraisal before test	Type of failure (a)	Yield load per rivet (lb)	Maximum load per rivet (lb)
Rivet length, 3/8 in.							
0.020	Satisfactory	1	100	Long	1	280	280
.020	Long	1	120	-do-	1	215	220
.020	Satisfactory	1	100	-do-	1	230	230
.020				-do-	1	225	225
.032	-----do-----	1,2	210	Satisfactory	1	480	500
.032	-----do-----	1	215	Long	1	380	440
.032	-----do-----	1	210	-do-	1	325	390
.051	-----do-----	1,2	520	Satisfactory	3	780	850
.051	-----do-----	1,2	525	-----do-----	3	780	850
.051	-----do-----	1,2	485	-----do-----	3	780	855
.064	-----do-----	2	800	-----do-----	3	770	840
.064	-----do-----	2	700	-----do-----	3	735	825
.064	-----do-----	2	750	-----do-----	3	730	850
.081	-----do-----	2	1070	-----do-----	3	730	905
.081	-----do-----	2	1040	-----do-----	3	805	875
.081	-----do-----	2	1085	-----do-----	3	880	930
.102	-----do-----	2	1545	-----do-----	3	920	950
.102	-----do-----	3	1500	-----do-----	3	825	900
.102	-----do-----	2	1450	-----do-----	3	890	940
.102				-----do-----	3	870	930
.125	Short	2	1535	-----do-----	3	865	890
.125	--do-	2	1450	Short	3	865	895
.125	Satisfactory	2	1305	--do-	3	815	880
.156	Short	2	1050	--do-	3	720	845
.156	--do-	2	915	--do-	3	750	850
.156	--do-	2	1020	--do-	3	750	850
.156				--do-	3	735	850
Rivet length, 7/16 in.							
0.040	Long	1	360	Long	1	320	530
.040	-do-	1	540	-do-	1	195	475
.040	-do-	1	415	-do-	1	330	530
.064	-do-	1	480	-do-	3	700	915
.064	-do-	1	650	-do-	3	600	850
.064	-do-	1	470	-do-	3	780	880
.081	Satisfactory	1,2	1115	-do-	3	740	845
.081	Long	1	620	-do-	3	715	900
.081	-do-	1	715	-do-	3	680	840
.091	Satisfactory	2	1405	Satisfactory	3	800	890
.091	-----do-----	2	1225	-----do-----	3	780	880
.091	-----do-----	2	1125	-----do-----	3	720	850
.102	-----do-----	2	1600	-----do-----	3	810	890
.102	-----do-----	1,2	1570	-----do-----	3	775	900
.102	-----do-----	2	1440	-----do-----	3	835	925
.125	-----do-----	3	1460	-----do-----	3	920	920
.125	-----do-----	3	1570	-----do-----	3	860	930
.125	-----do-----	2	1480	-----do-----	3	810	890
.156	Short	3	1510	Short	3	925	960
.156	Satisfactory	3	1450	--do-	3	900	970
.156	Short	3	1510	--do-	3	915	970

[a]Failure types identified in figs. 6 to 8.

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TABLE 2- Concluded.

TEST RESULTS. RIVET DIAMETER, 5/32 INCH.- Concluded.

Sheet thickness (in.)	Tension			Shear			
	Appraisal before test	Type of failure (a)	Maximum load per rivet (lb)	Appraisal before test	Type of failure (a)	Yield load per rivet (lb)	Maximum load per rivet (lb)
Rivet length, 1/2 in.							
0.020	Long	1	90	Long	1	145	200
.020	-do-	1	80	-do-	1	155	180
.020	-do-	1	75	-do-	1	105	145
.032	-do-	1	140	-do-	1	385	440
.032	-do-	1	155	-do-	1	240	350
.032	-do-	1	155	-do-	1	250	350
.051	-do-	1	295	-do-	1,3	230	580
.051	-do-	1	100	-do-	3	285	650
.051	-do-	1	260	-do-	3	300	600
.064	-do-	1,2	325	-do-	3	270	720
.064	-do-	1	400	-do-	3	280	750
.064	-do-	1	610	-do-	3	265	720
.081	-do-	3	710	-do-	3	740	935
.081	-do-	1	950	-do-	3	675	870
.081	-do-	3	1170	-do-	3	540	750
.091	Satisfactory	2	1010	-do-	3	640	810
.091	Long	1	690	Satisfactory	3	630	750
.091	-do-	1	880	-----do-----	3	740	815
.102	-do-	1	875	Long	3	815	890
.102	-do-	3	1390	Satisfactory	3	750	870
.102	-do-	1	1290	-----do-----	3	820	905
.125	Satisfactory	2	1510	-----do-----	3	810	875
.125	-----do-----	2	1490	-----do-----	3	910	950
.125	-----do-----	2	1365	-----do-----	3	850	905
.156	-----do-----	3	1525	-----do-----	3	975	995
.156	-----do-----	3	1410	-----do-----	3	950	960
.156	-----do-----	3	1385	-----do-----	3	980	1000

[a]Failure types identified in figs. 6 to 8.

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TABLE 3

TEST RESULTS FOR AGE-HARDENED 17S-T RIVETS MACHINE-COUNTERSUNK IN 75S-T SHEET.
RIVET DIAMETER, 3/16 INCH.

Sheet thickness (in.)	Tension			Shear			
	Appraisal before test	Type of failure (a)	Maximum load per rivet (lb)	Appraisal before test	Type of failure (a)	Yield load per rivet (lb)	Maximum load per rivet (lb)
Rivet length, 1/4 in.							
0.020	Satisfactory	1	90	Satisfactory	1	270	270
.020	-----do-----	1	145	-----do-----	1	270	270
.020	-----do-----	1	180	-----do-----	1	270	270
.032	-----do-----	1	280	-----do-----	1,2	585	585
.032	-----do-----	1	240	-----do-----	1	550	550
.032	-----do-----	1	235	-----do-----	1,2	550	550
.051	-----do-----	1,2	500	-----do-----	1,2	980	980
.051	-----do-----	1	530	-----do-----	1,2	1000	1025
.051	-----do-----	1	500	-----do-----	1,2	910	955
.081	Short	1	750	Short	1,3	475	1020
.081	-do--	1	285	-do--	3	1070	1200
.081	-do--	1	980	-do--	3	1050	1190
.081	-do--	1	620				
.102	-do--	2	870	-do--	3	710	1070
.102	-do--	2	310	-do--	2,3	440	1050
.102	-do--	2	760	-do--	3	830	1090
.102				-do--	3	780	1065
Rivet length, 5/16 in.							
0.020	Satisfactory	1	90	Satisfactory	1	270	270
.020	-----do-----	1	165	-----do-----	1	245	250
.020	-----do-----	1	160	-----do-----	1	300	300
.032	-----do-----	1	250	-----do-----	1	540	540
.032	-----do-----	1	245	-----do-----	1	360	390
.032	-----do-----	1	225	-----do-----	1	500	500
.040	-----do-----	1	320	-----do-----	1	690	720
.040	-----do-----	1	300	-----do-----	1	730	740
.040	-----do-----	1	300	-----do-----	1	780	805
.040	-----do-----	1	390				
.051	-----do-----	1,2	700	-----do-----	1	900	980
.051	-----do-----	1,2	480	-----do-----	1,2	910	950
.051	-----do-----	1,2	470	-----do-----	1	935	1010
.051	-----do-----	1,2	560				
.064	-----do-----	1,2	710	-----do-----	3	1110	1160
.064	-----do-----	1,2	715	-----do-----	3	960	1060
.064	-----do-----	1,2	800	-----do-----	3	1170	1170

[a] Failure types identified in figs. 6 to 8.

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TABLE 3 - Concluded

TEST RESULTS. RIVET DIAMETER, 3/16 INCH.- Concluded.

Sheet thickness (in.)	Tension			Shear			
	Appraisal before test	Type of failure (a)	Maximum load per rivet (lb)	Appraisal before test	Type of failure (a)	Yield load per rivet (lb)	Maximum load per rivet (lb)
Rivet length, 3/8 in.							
0.020	Long	1	80	Long	1	305	305
.020	-do-	1	200	-do-	1	360	360
.020	Satisfactory	1	145	-do-	1	345	345
.020	Long	1	80				
.032	Satisfactory	1	260	Satisfactory	1	580	580
.032	-----do-----	1,2	250	-----do-----	1	530	530
.032	Long	1	390	-----do-----	1	570	570
.040	Satisfactory	1	348	-----do-----	1	780	790
.040	-----do-----	1,2	405	-----do-----	1	755	760
.040	-----do-----	1	375	-----do-----	1	750	760
.051	-----do-----	2	550	-----do-----	1,2	955	1030
.051	-----do-----	2	520	-----do-----	1	1015	1045
.051	-----do-----	2	470	-----do-----	1,2	945	1030
.064	-----do-----	2	855	-----do-----	3	1075	1140
.064	-----do-----	1,2	915	-----do-----	3	1100	1185
.064	-----do-----	1,2	945	-----do-----	3	1035	1145
.081	-----do-----	2	1070	-----do-----	3	1260	1345
.081	-----do-----	1,2	1220	-----do-----	3	1115	1140
.081	-----do-----	1,2	1175	-----do-----	3	1125	1250
.102	-----do-----	2	1740	-----do-----	3	1000	1115
.102	-----do-----	2	1895	-----do-----	3	1220	1300
.102	-----do-----	2	1495	-----do-----	3	1180	1275
.156	Short	2	1825	Short	3	1090	1275
.156	--do-	2	1740	--do-	3	1245	1250
.156	--do-	2	1805	--do-	3	1160	1240
Rivet length, 7/16 in.							
0.020	Long	1	65	Long	1	300	300
.020	-do-	1	125	-do-	1	300	300
.020	-do-	1	145	-do-	1	310	310
.032	-do-	1	95	-do-	1	615	625
.032	-do-	1	115	-do-	1	585	610
.032	-do-	1	290	-do-	1	700	700
.064	Satisfactory	2	835	Satisfactory	1,2	1100	1200
.064	Long	1	1175	-----do-----	2,3	990	1100
.064	Satisfactory	2	790	-----do-----	3	1060	1200
.064				-----do-----	3	1060	1245
.064				-----do-----	3	1350	1405
.081	-----do-----	2	1150	-----do-----	3	1100	1150
.081	-----do-----	2	1110	-----do-----	3	1000	1240
.081	-----do-----	2	1100	-----do-----	3	1100	1250
.091	-----do-----	2	1550	-----do-----	3	1070	1240
.091	-----do-----	1,2	1370	-----do-----	3	1100	1190
.091	-----do-----	2	1400	-----do-----	3	1060	1155
.102	-----do-----	2	1490	-----do-----	3	1190	1280
.102	-----do-----	2	1590	-----do-----	3	1130	1200
.102	-----do-----	2	1575	-----do-----	3	1050	1190
.102				-----do-----	3	1180	1240
.125	-----do-----	3	2180	-----do-----	3	1130	1230
.125	-----do-----	2	2185	-----do-----	3	1185	1185
.125	-----do-----	3	2085	-----do-----	3	1220	1225
.125	-----do-----	2	1610				
.125	-----do-----	2	1940				
.125	-----do-----	2	2195				
.156	Short	2	1955	Short	3	1040	1200
.156	--do-	2	1880	--do-	3	1200	1345
.156	--do-	2	1985	--do-	3	1150	1250
.156				--do-	3	1130	1250
.156				--do-	3	1120	1250

[a]Failure types identified in figs. 6 to 8.

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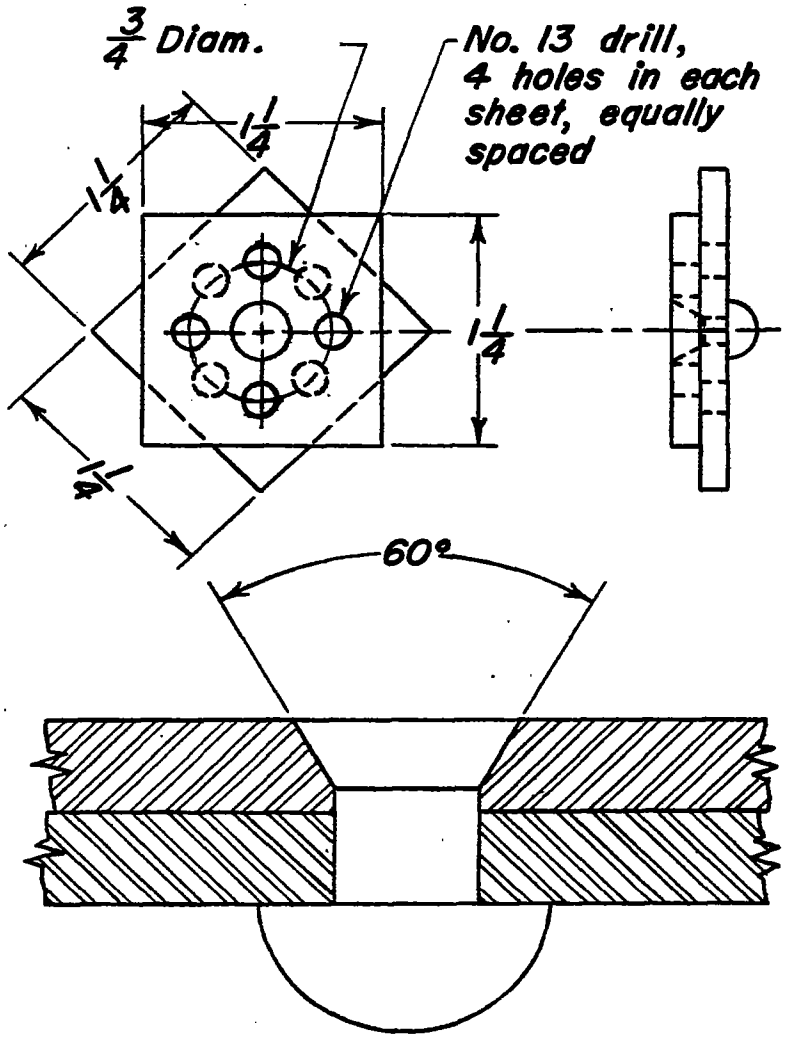

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Figure 1. - Tensile specimen.

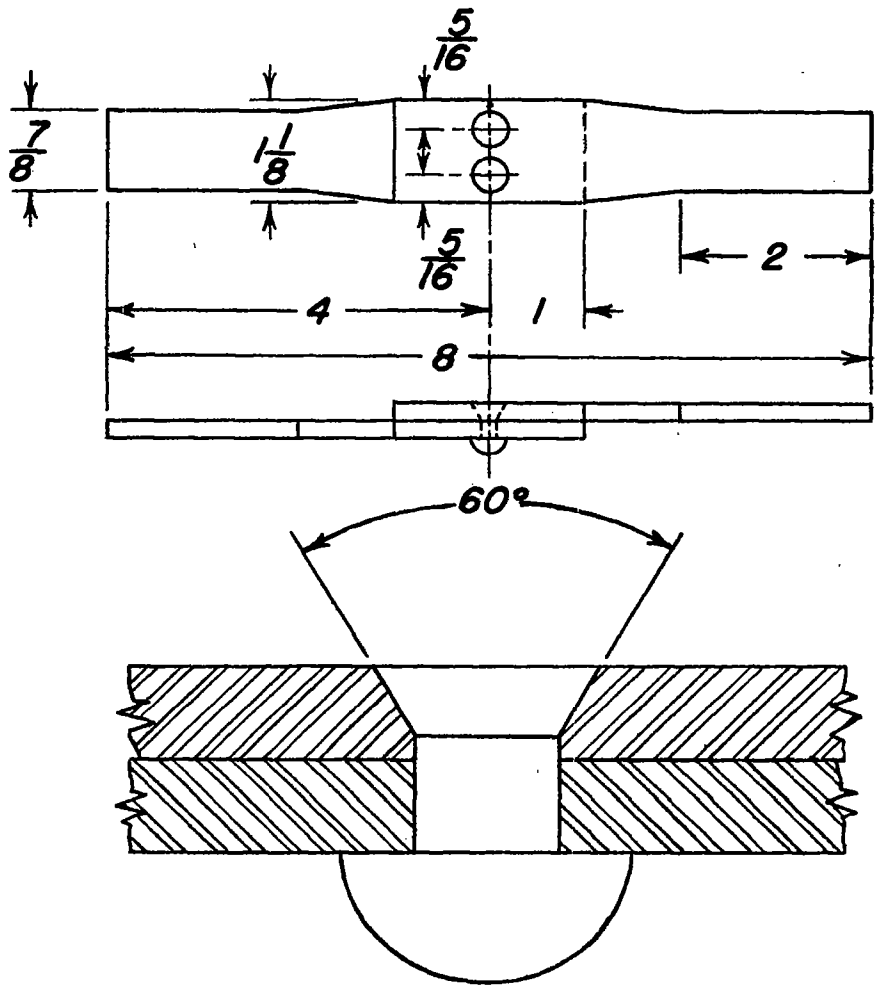

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Figure 2. - Shear specimen.

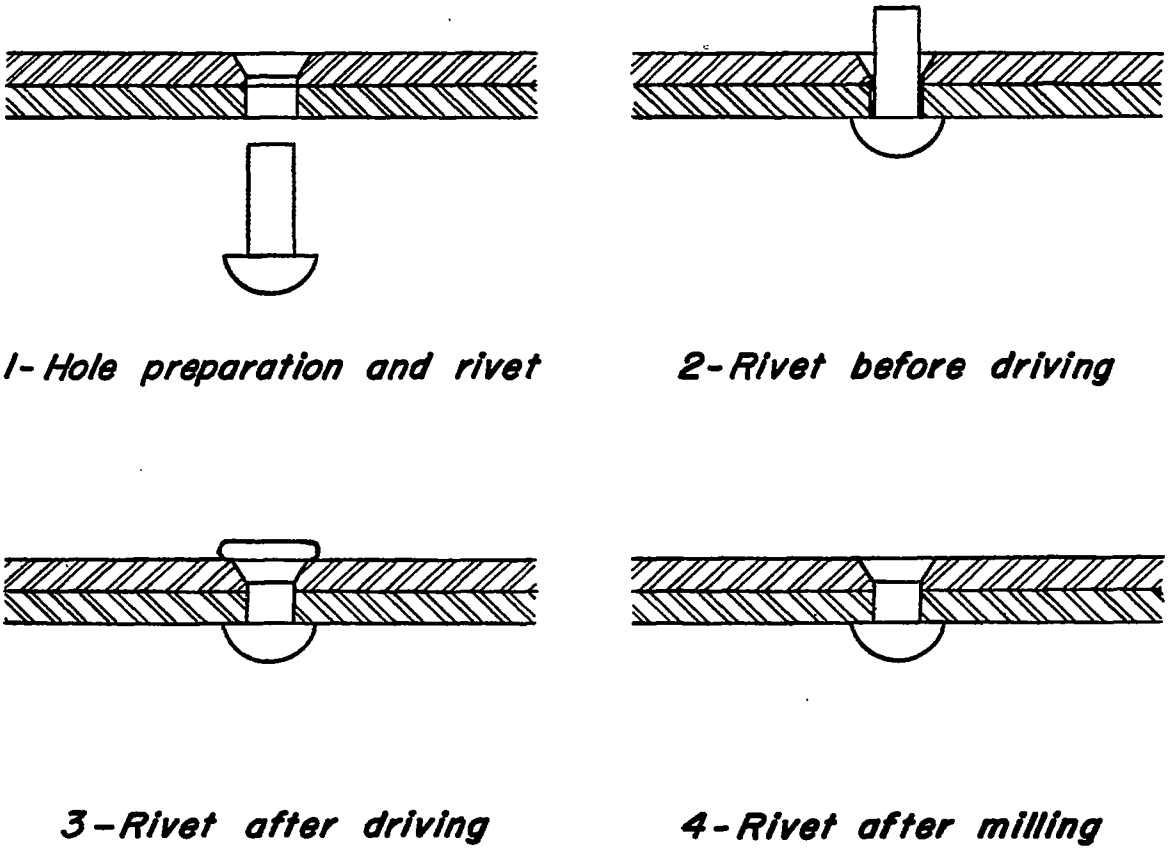

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Figure 3.- NACA flush-riveting procedure.

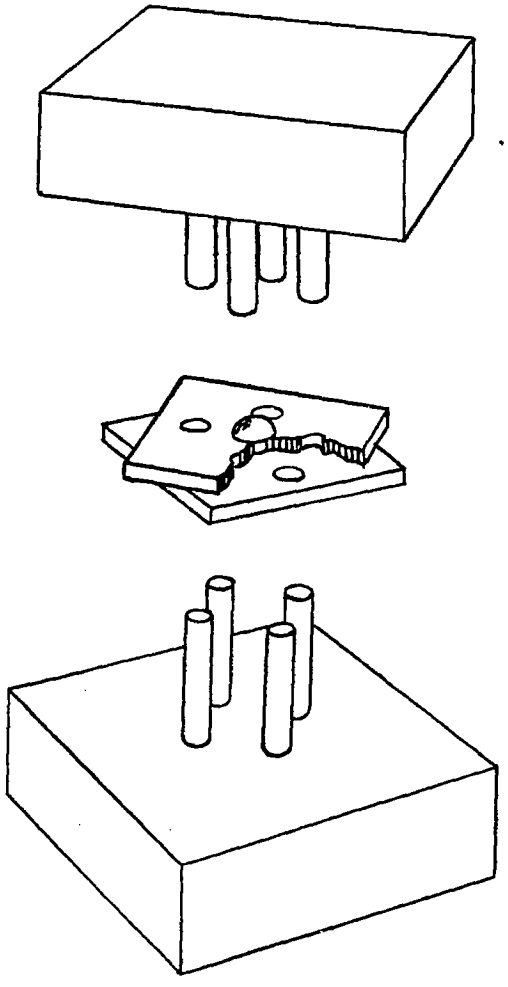

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Figure 4. - Fixtures and specimen for tensile tests.

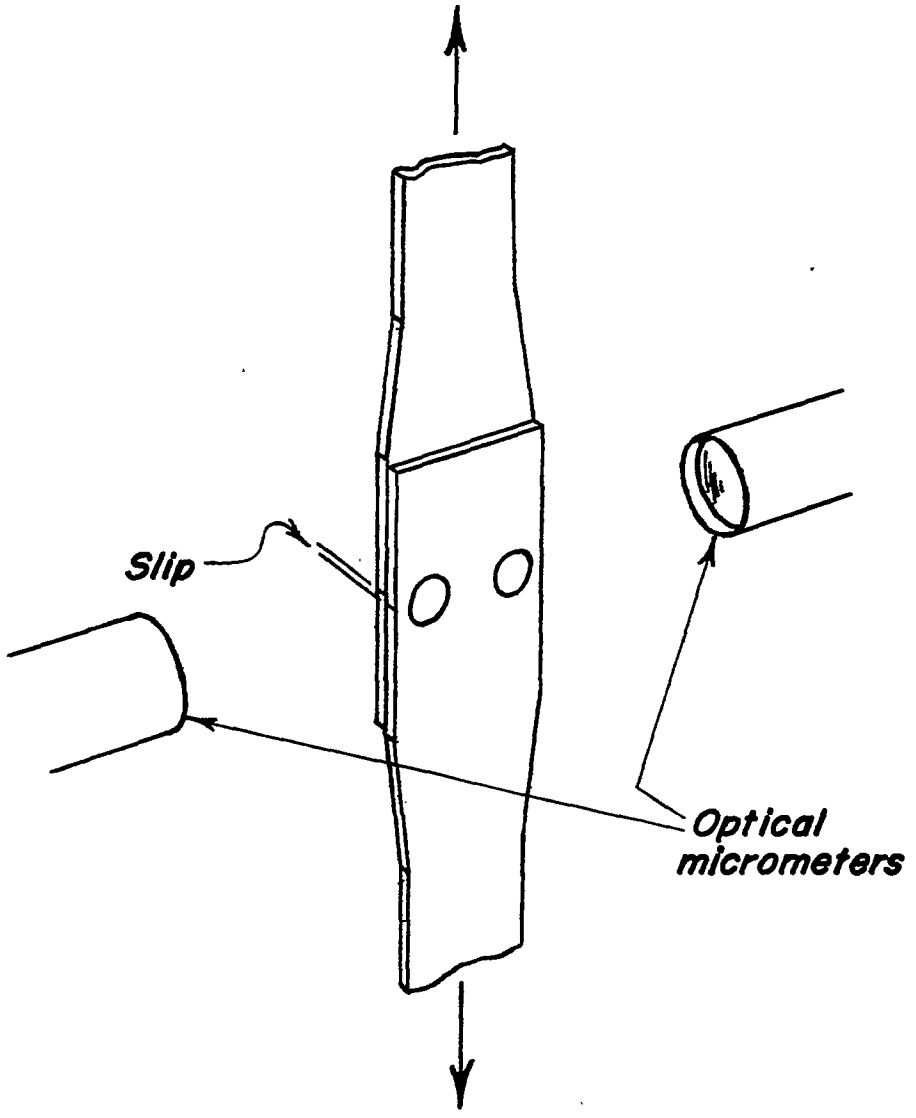

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Figure 5.- Method of measuring slip in shear tests.

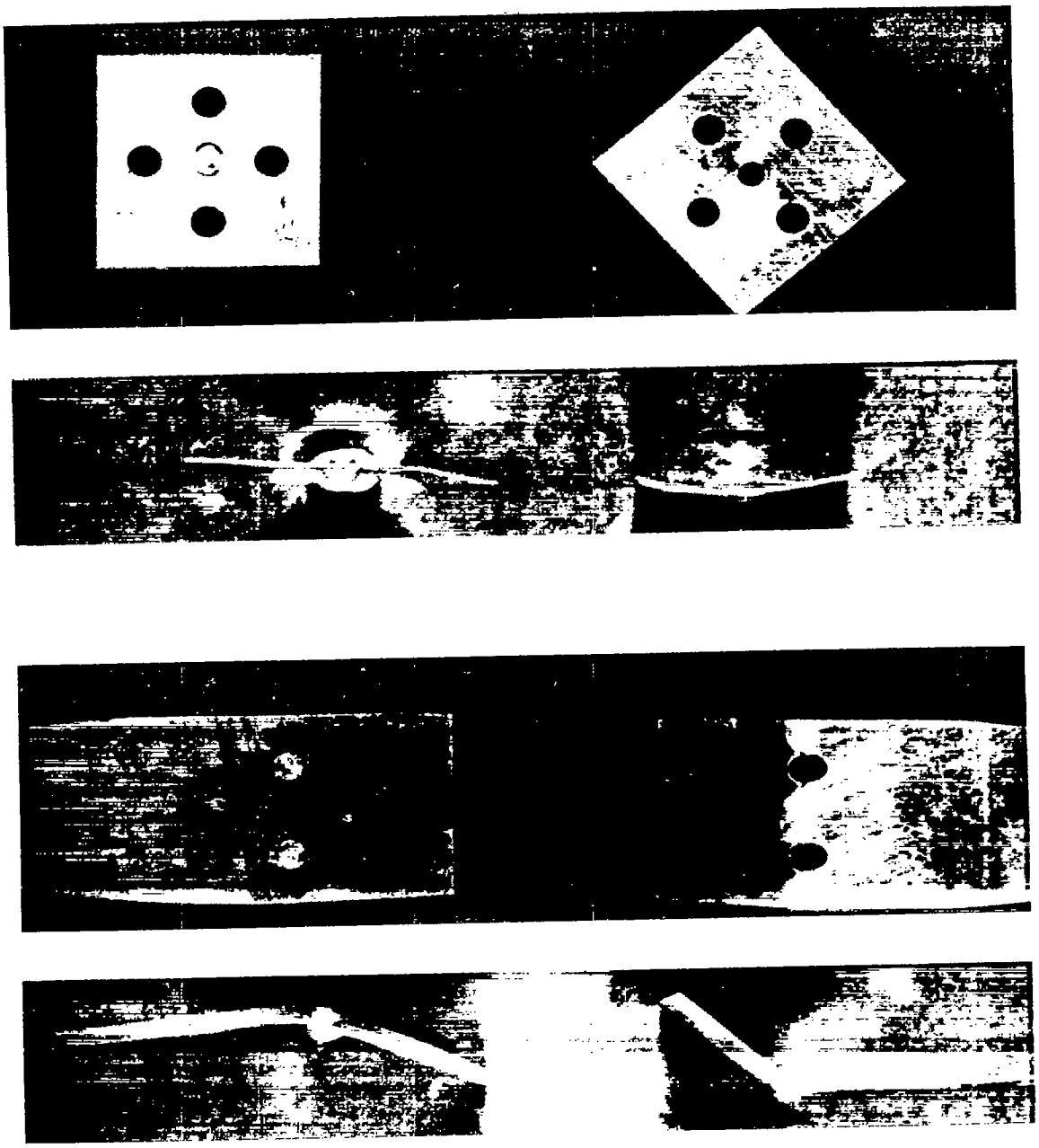

Figure 6.- Type 1 failure; countersunk head pulls through sheet.

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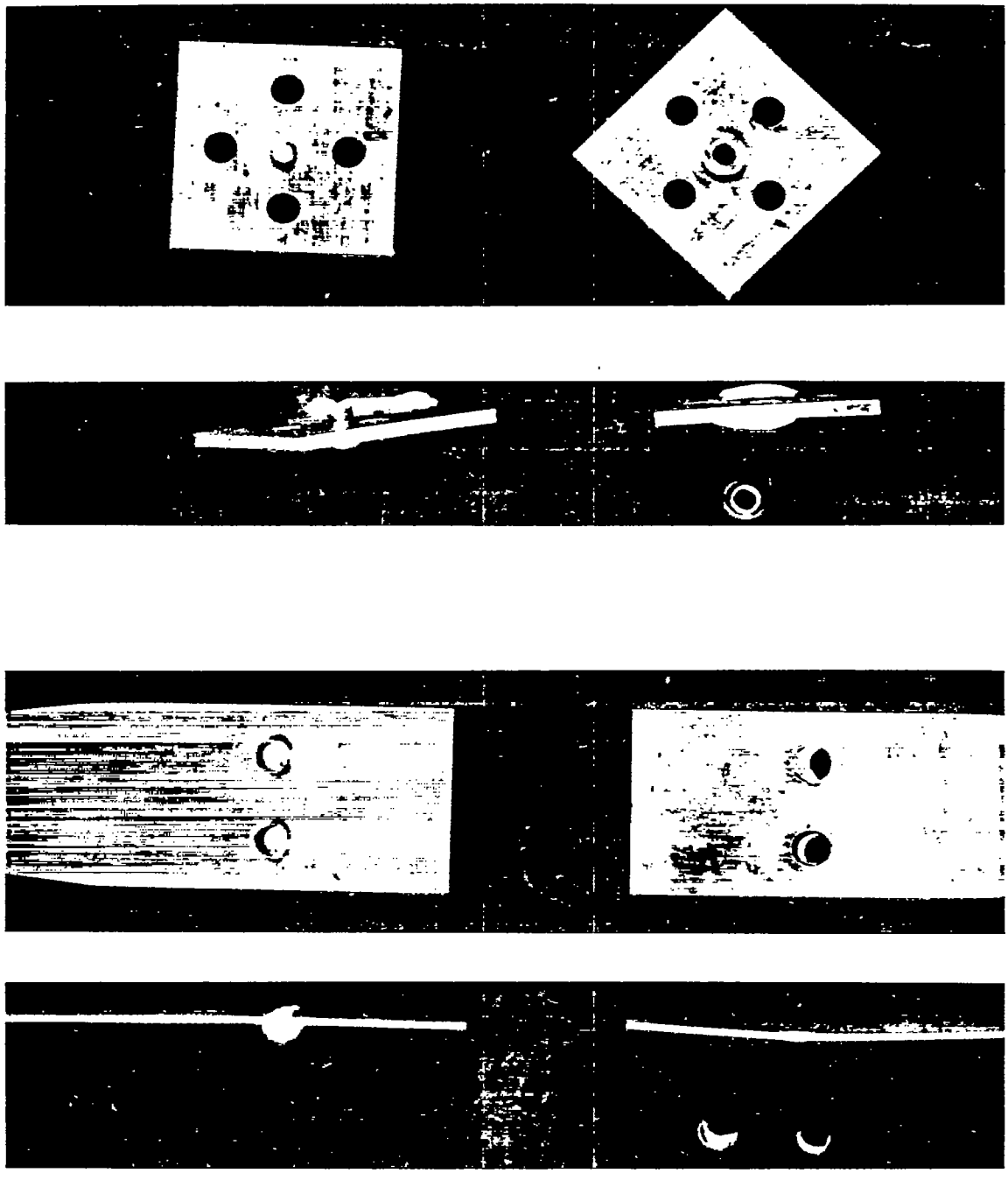

Figure 7.- Type 2 failure; countersunk head shears off.

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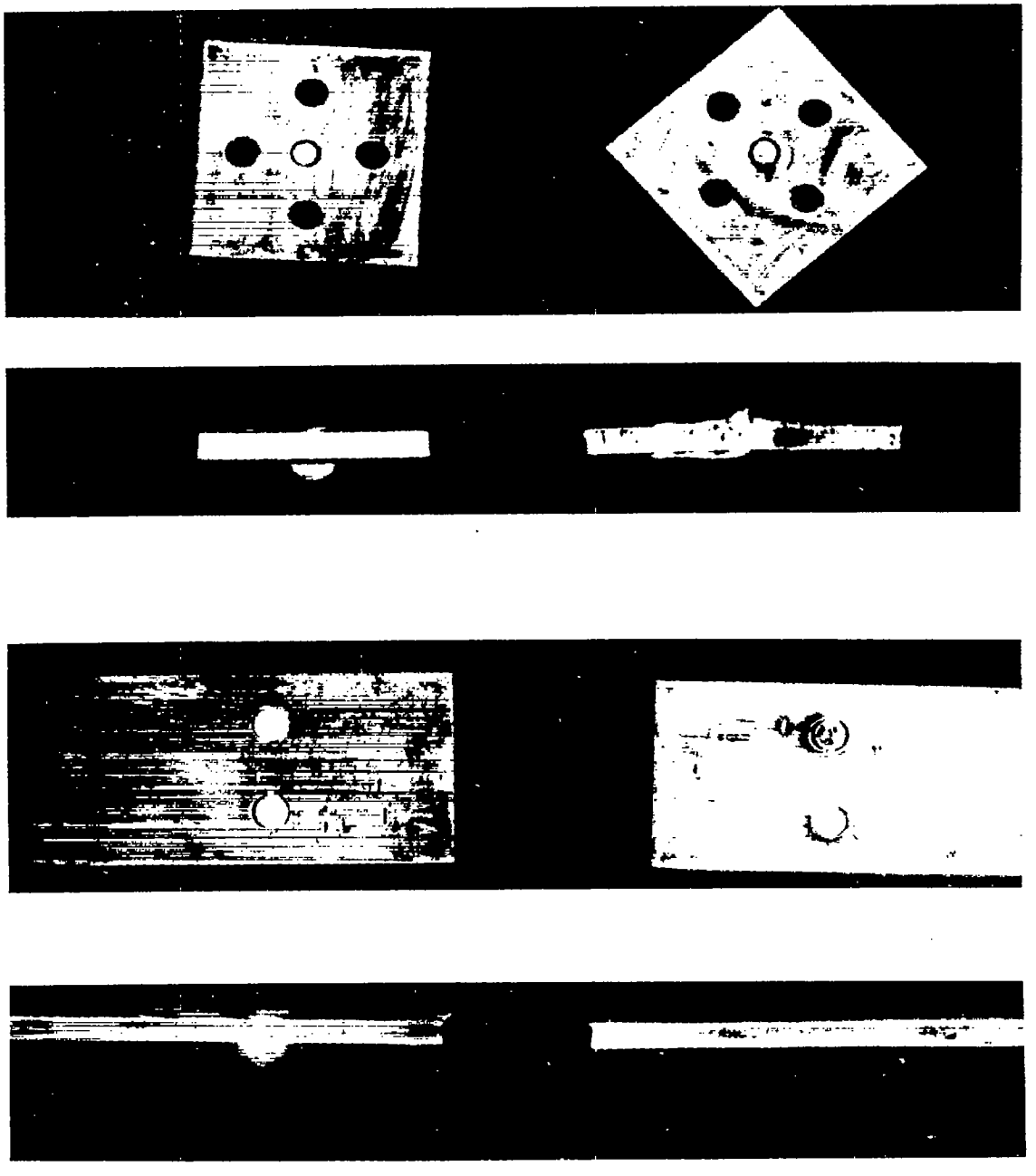

Figure 8.- Type 3 failure; rivet fails in shank.

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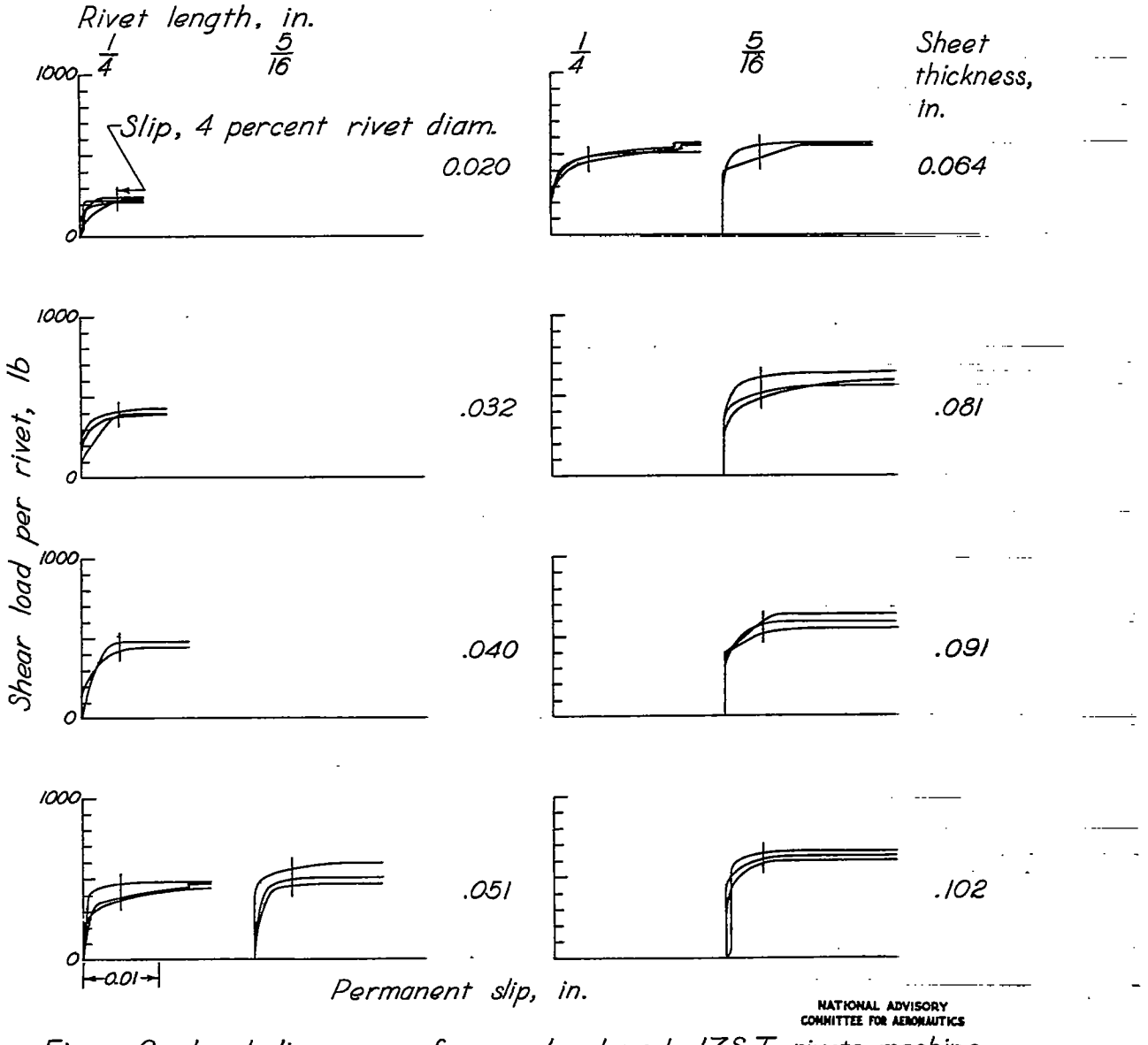


Figure 9.- Load-slip curves for age-hardened 17S-T rivets machine-countersunk in 75S-T sheet. Rivet diameter, $\frac{1}{8}$ inch.

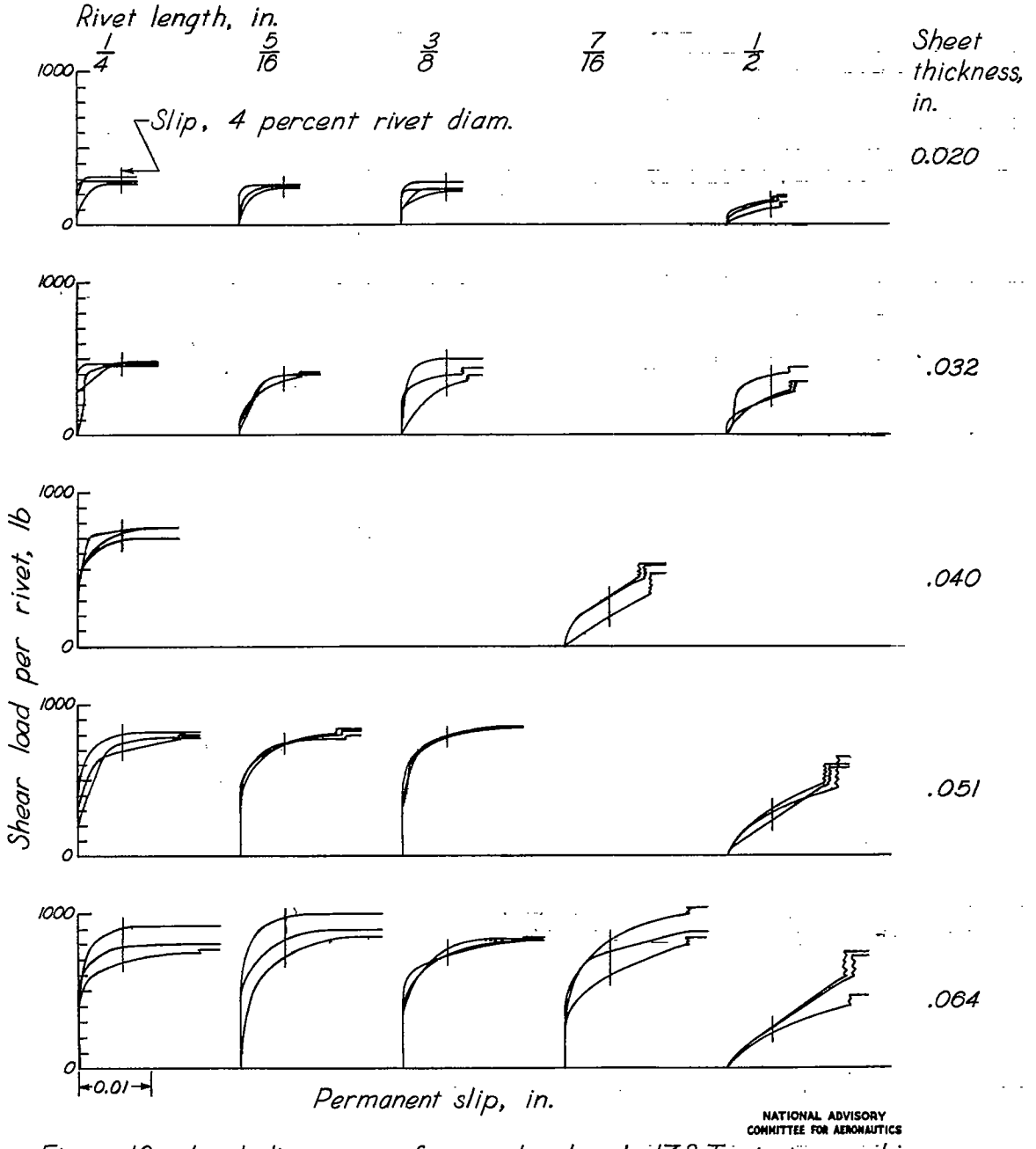


Figure 10. - Load-slip curves for age-hardened 17S-T rivets machine-countersunk in 75S-T sheet. Rivet diameter, $\frac{5}{32}$ inch.

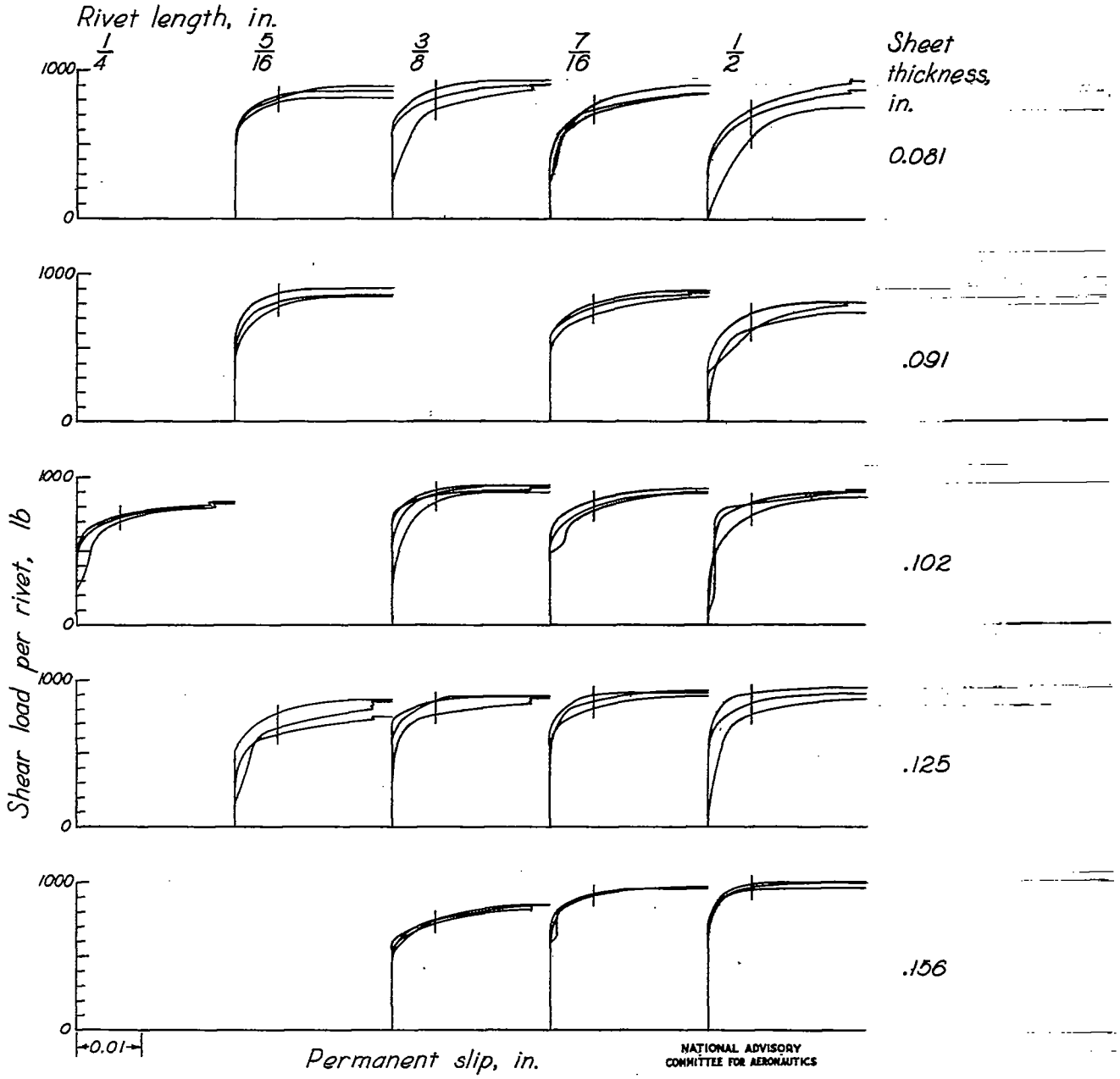


Figure 10.-Concluded.

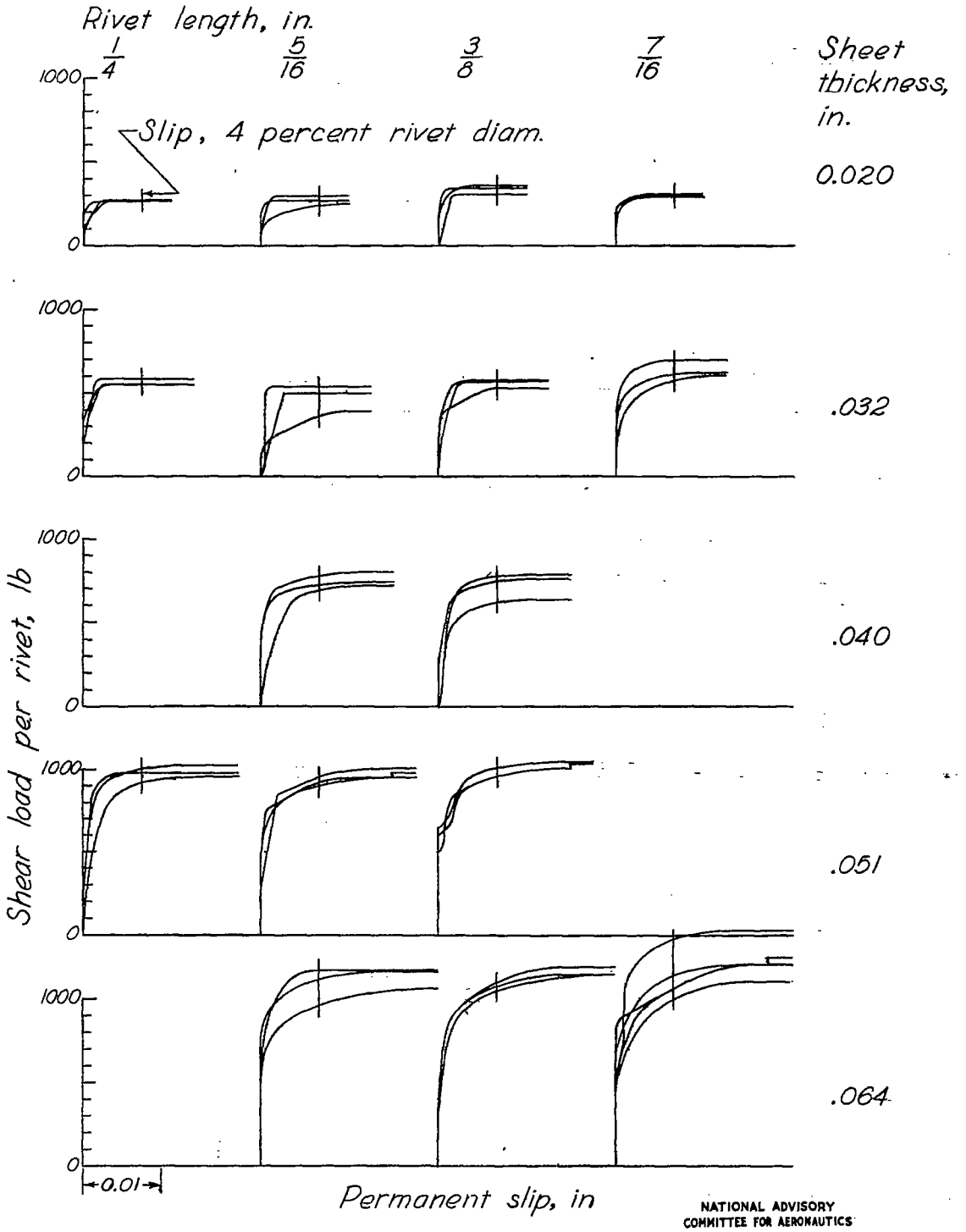


Figure 11.- Load-slip curves for age-hardened 17S-T rivets machine-countersunk in 75S-T sheet. Rivet diameter, $\frac{3}{16}$ inch.

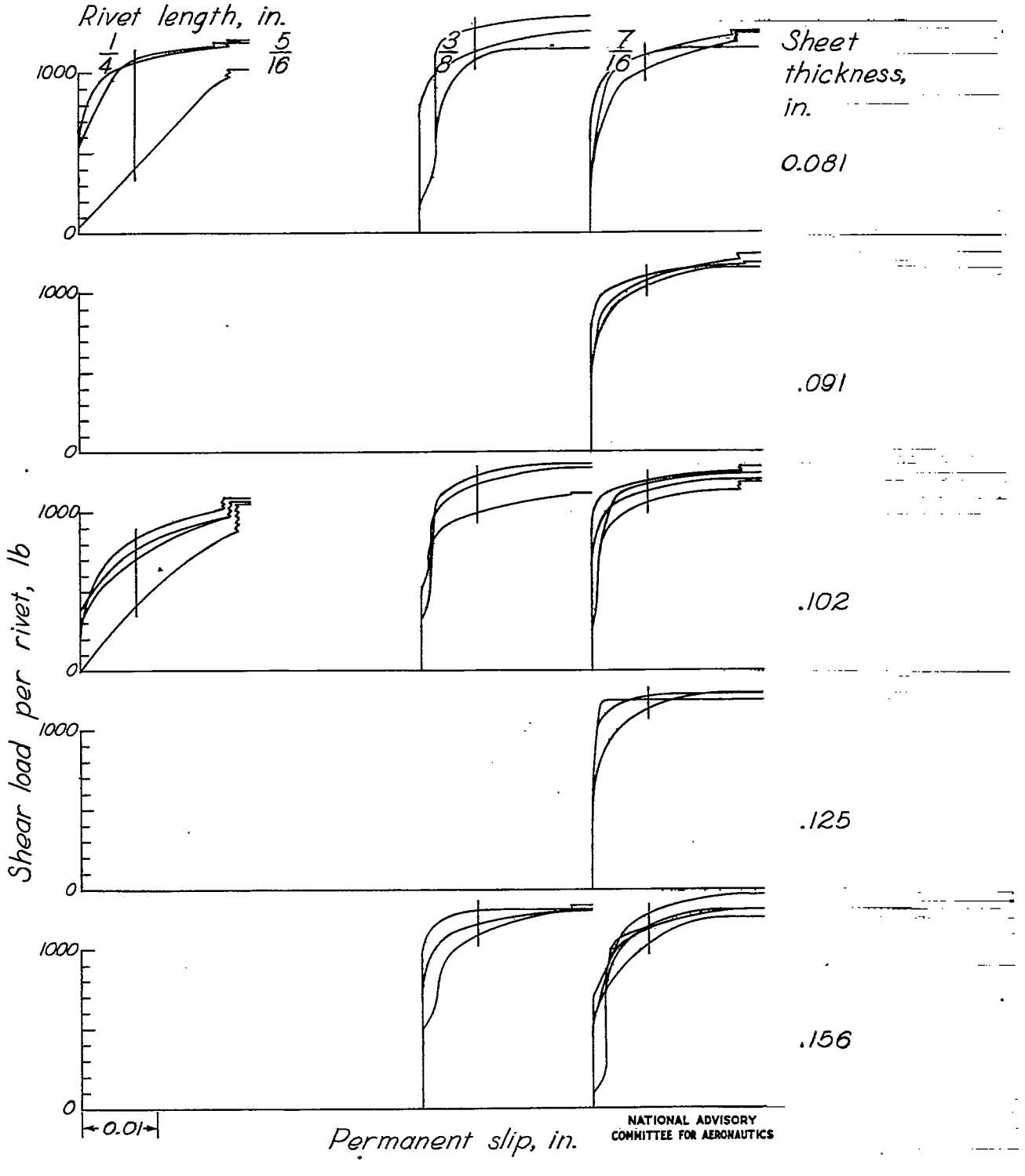
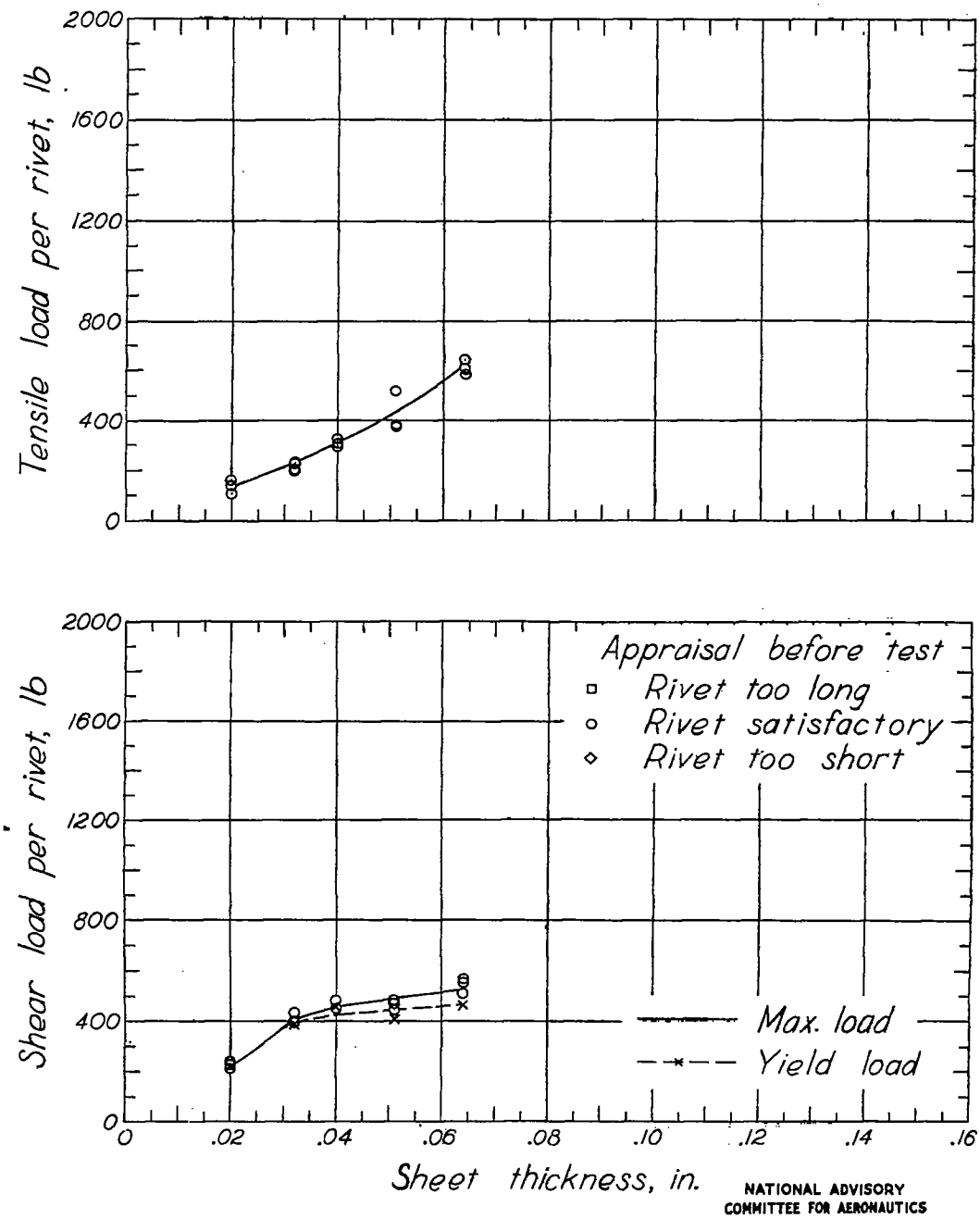
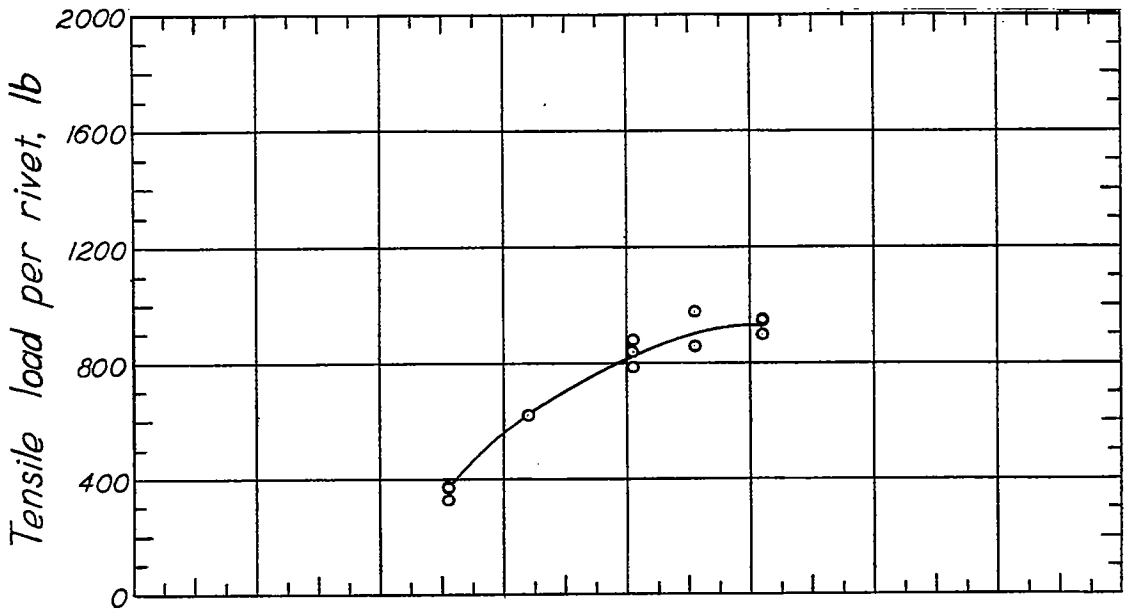


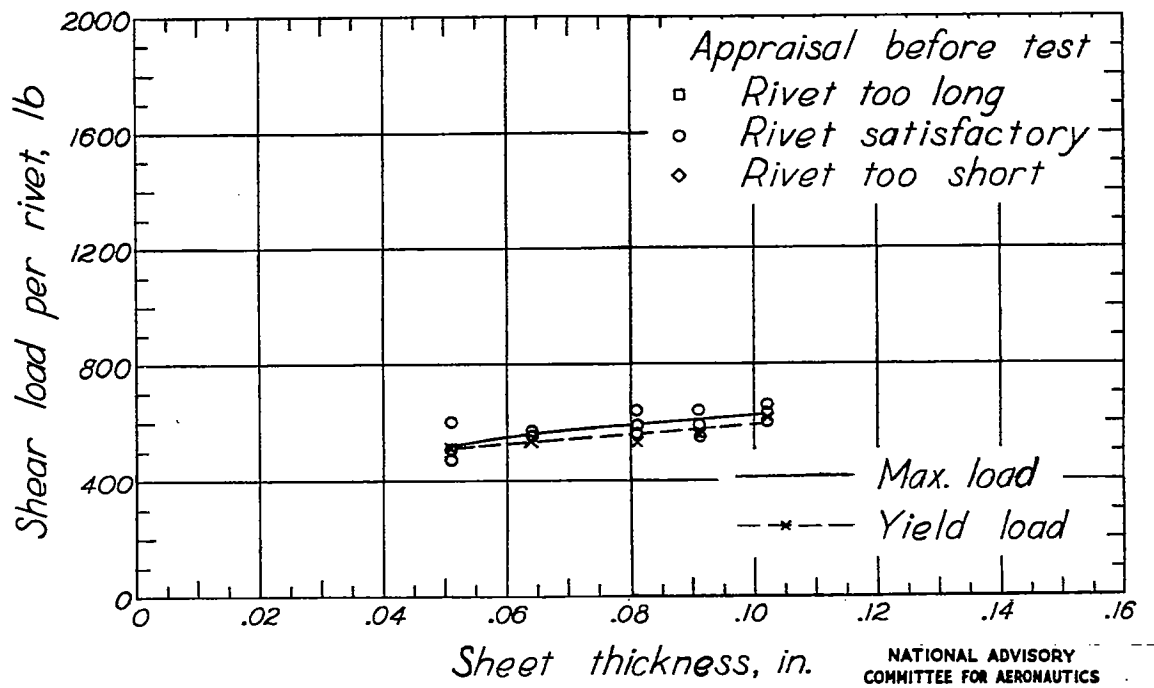
Figure 11.- Concluded.



(a) Rivet length, $\frac{1}{4}$ inch.

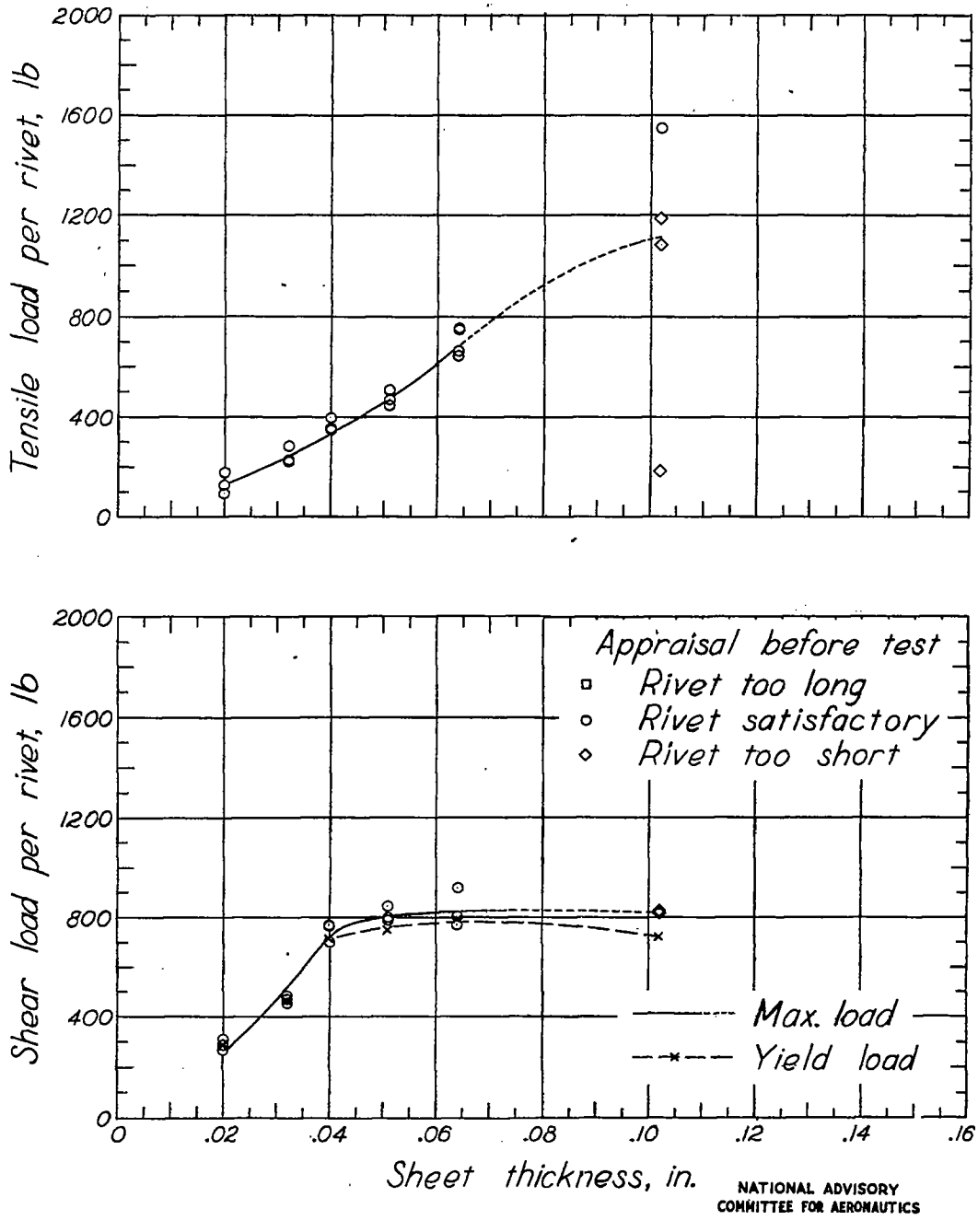
Figure 12.- Test results for age-hardened 17S-T rivets machine-countersunk in 75S-T sheet. Rivet diameter, $\frac{1}{8}$ inch.





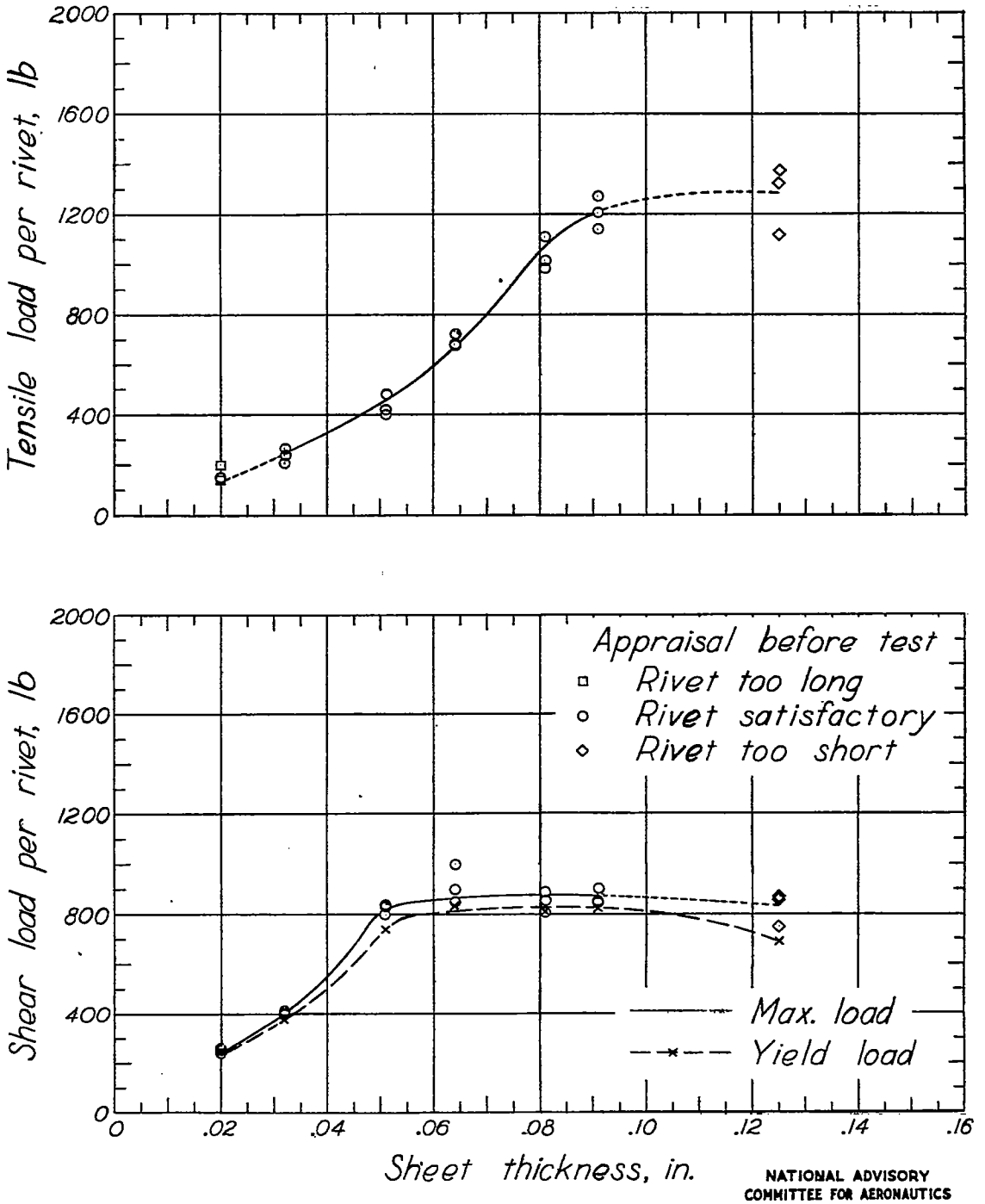
(b) Rivet length, $\frac{5}{16}$ inch.

Figure 12.- Concluded.



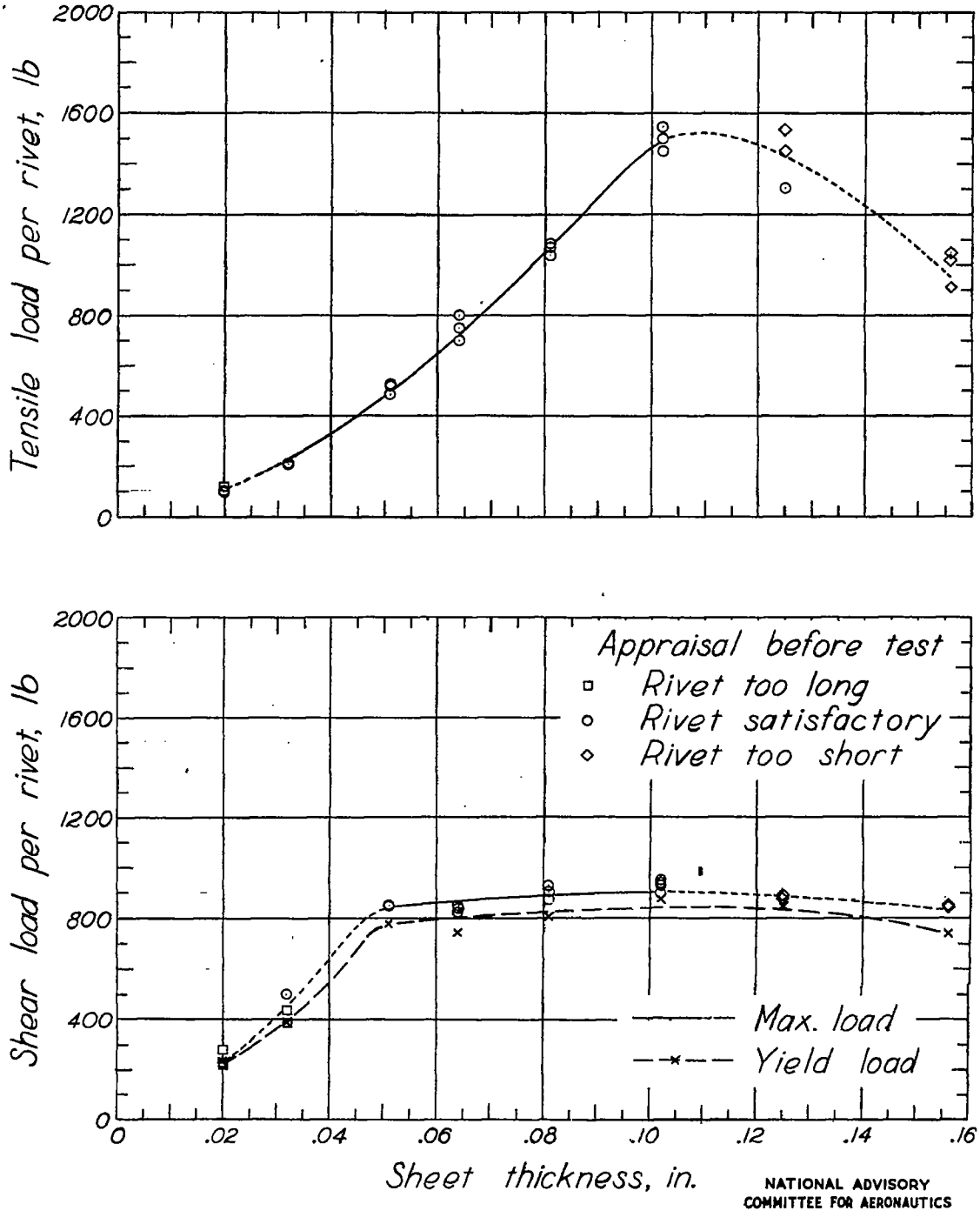
(a) Rivet length, $\frac{1}{4}$ inch.

Figure 13.- Test results for age-hardened 17S-T rivets machine-countersunk in 75S-T sheet. Rivet diameter, $\frac{5}{32}$ inch.



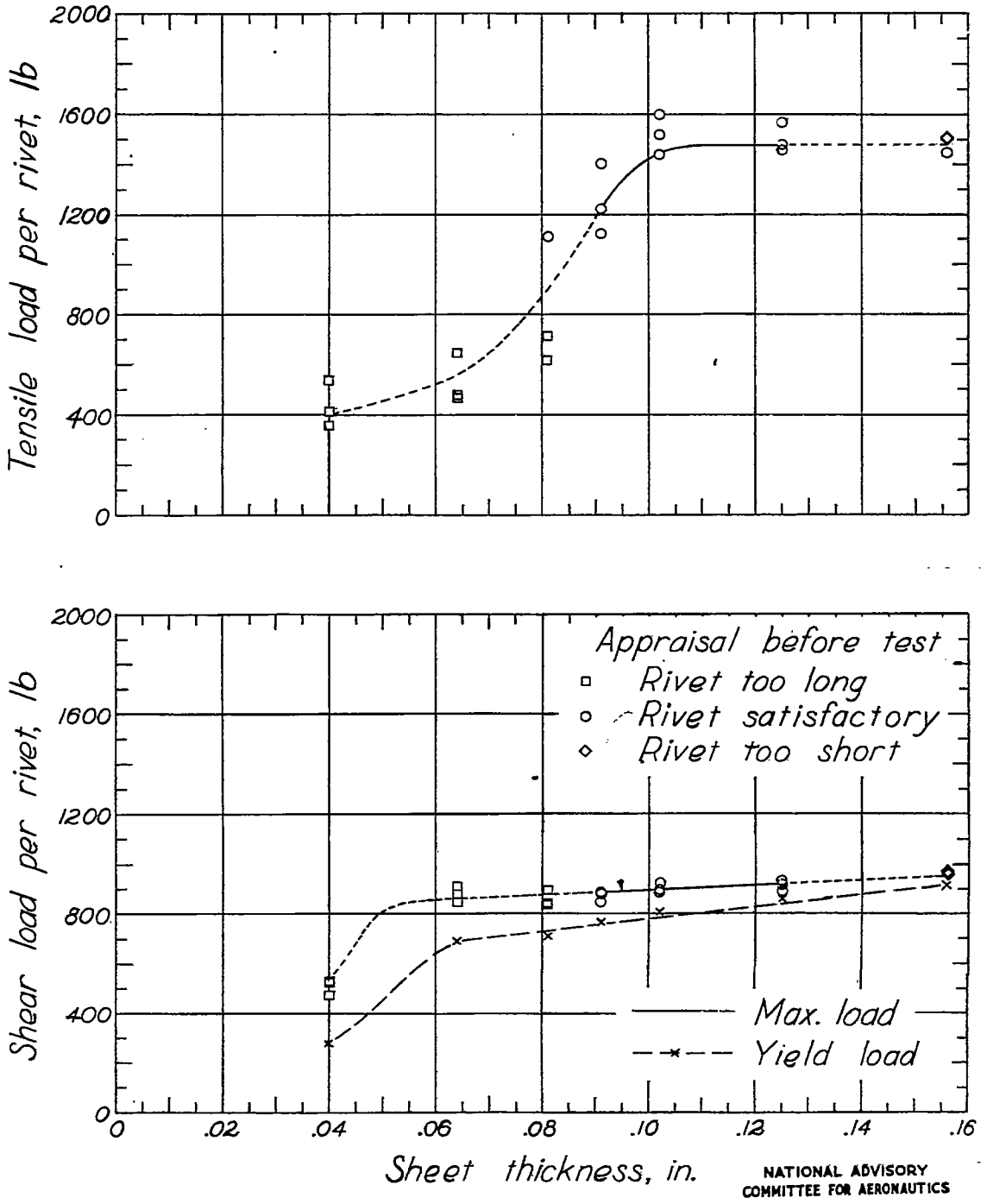
(b) Rivet length, $\frac{5}{16}$ inch.

Figure 13. - Continued.



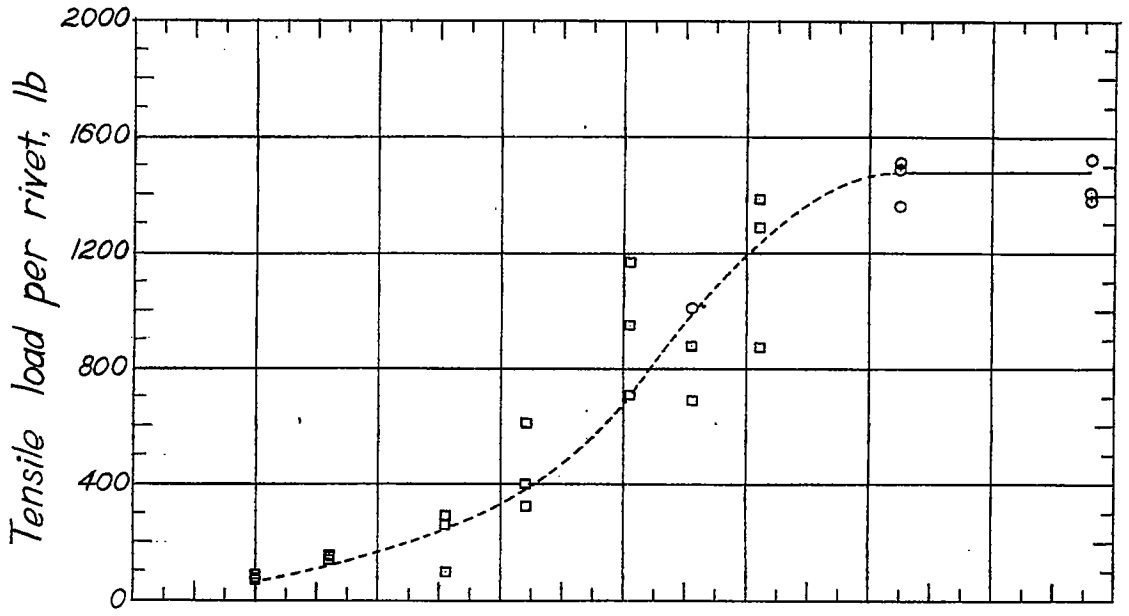
(c) Rivet length, $\frac{3}{8}$ inch.

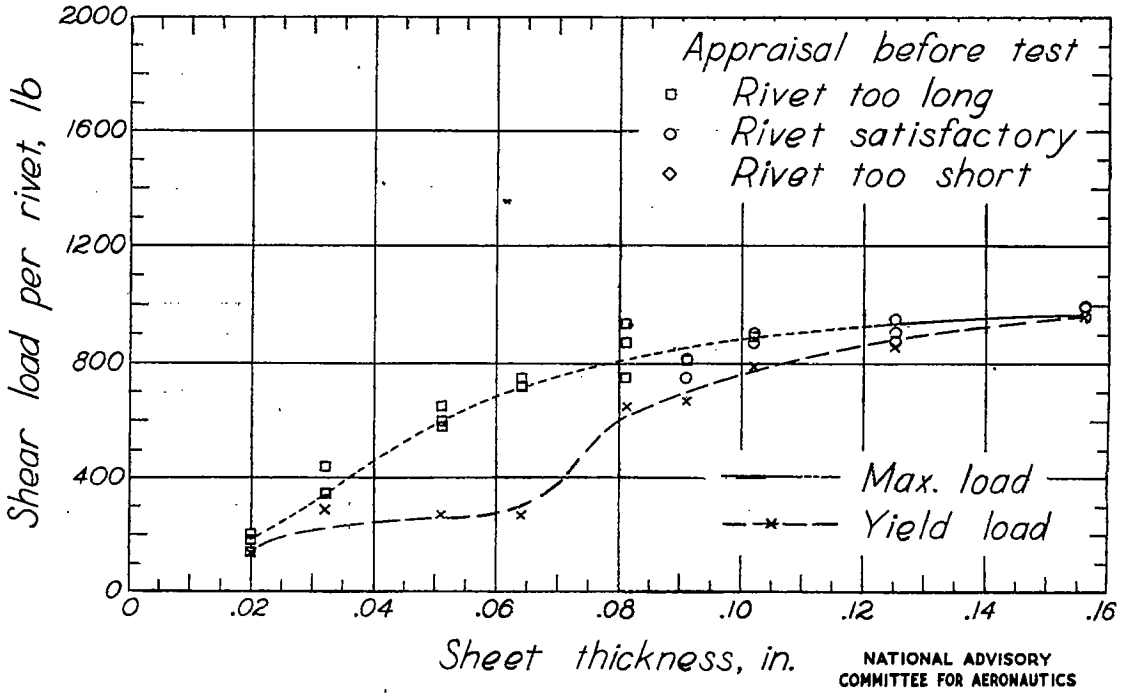
Figure 13.- Continued.



(d) Rivet length, $\frac{7}{16}$ inch.

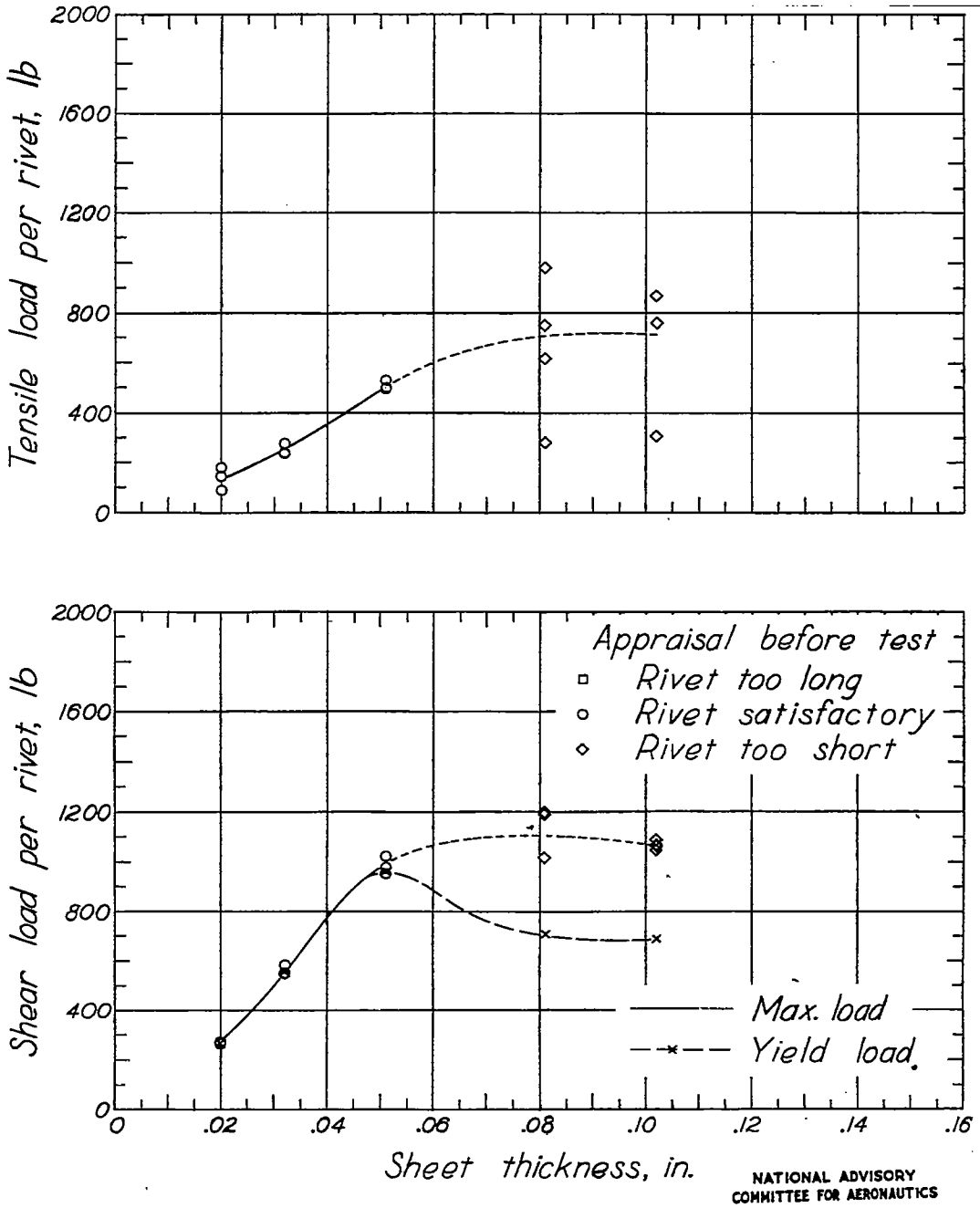
Figure 13. - Continued.





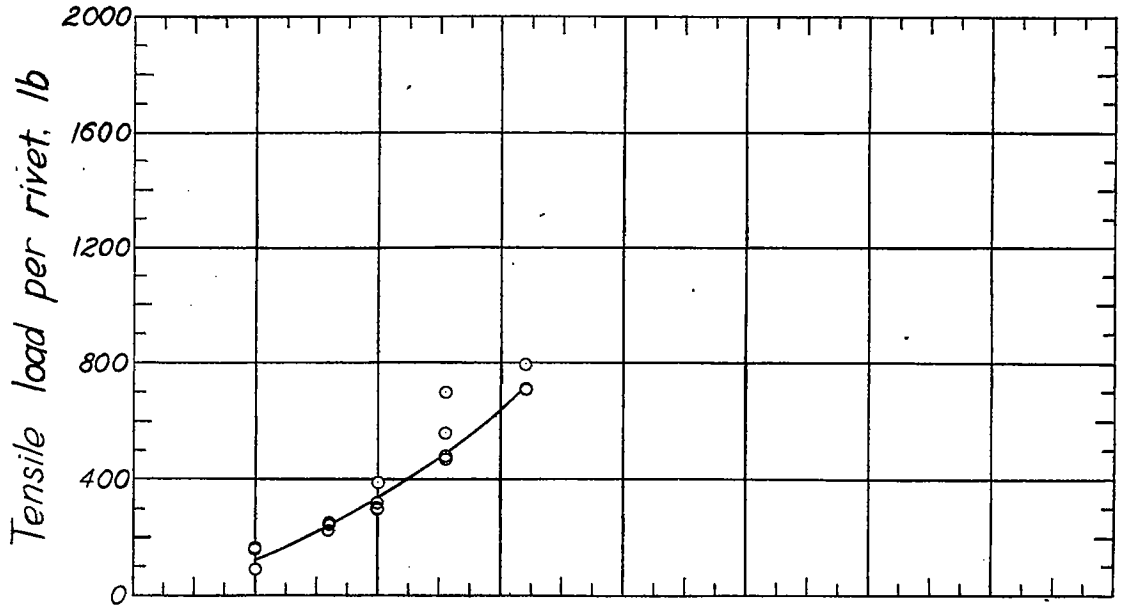
(e) Rivet length, $\frac{1}{2}$ inch.

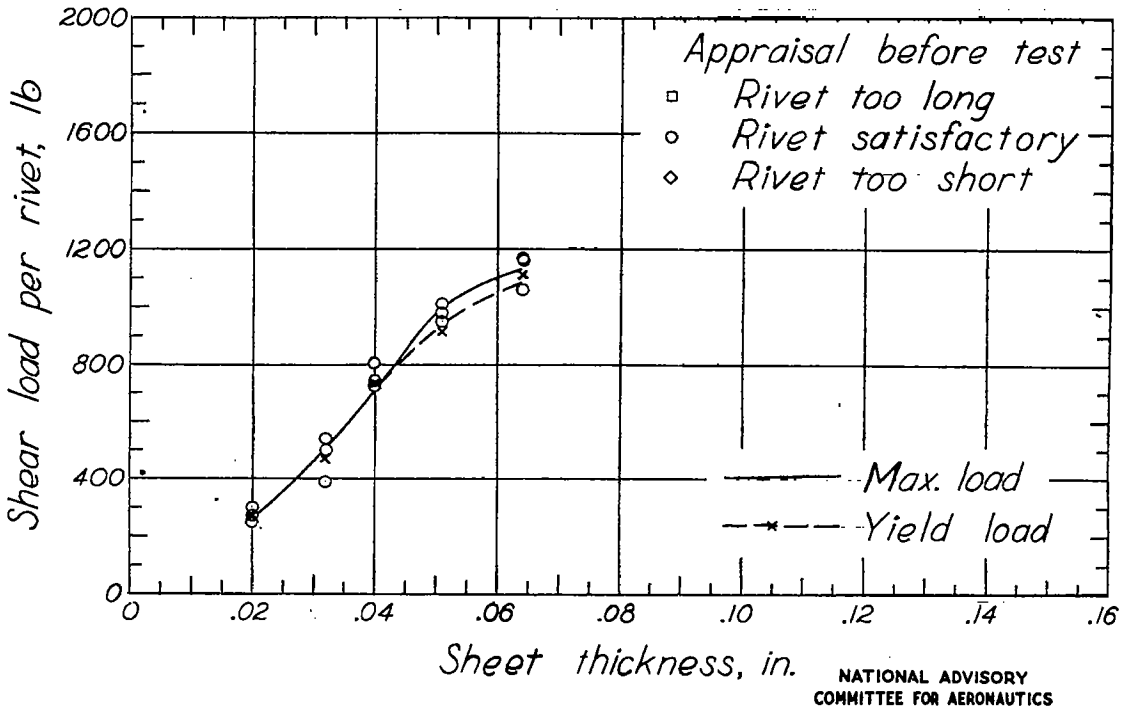
Figure 13. - Concluded.



(a) Rivet length, $\frac{1}{4}$ inch.

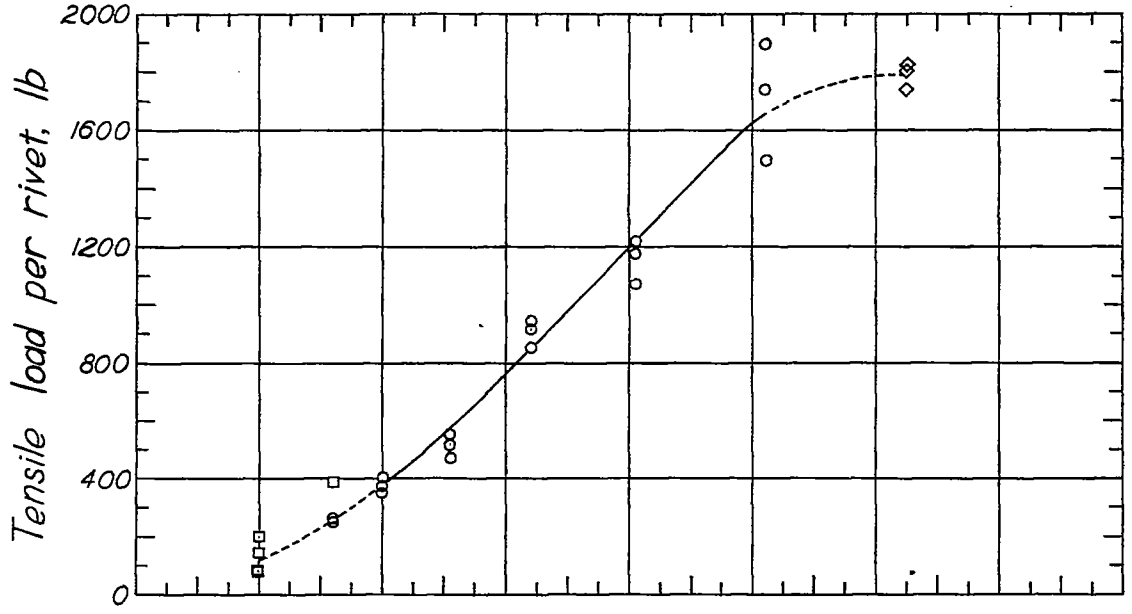
Figure 14.-Test results for age-hardened 17S-T rivets machine-countersunk in 75S-T sheet. Rivet diameter, $\frac{3}{16}$ inch.

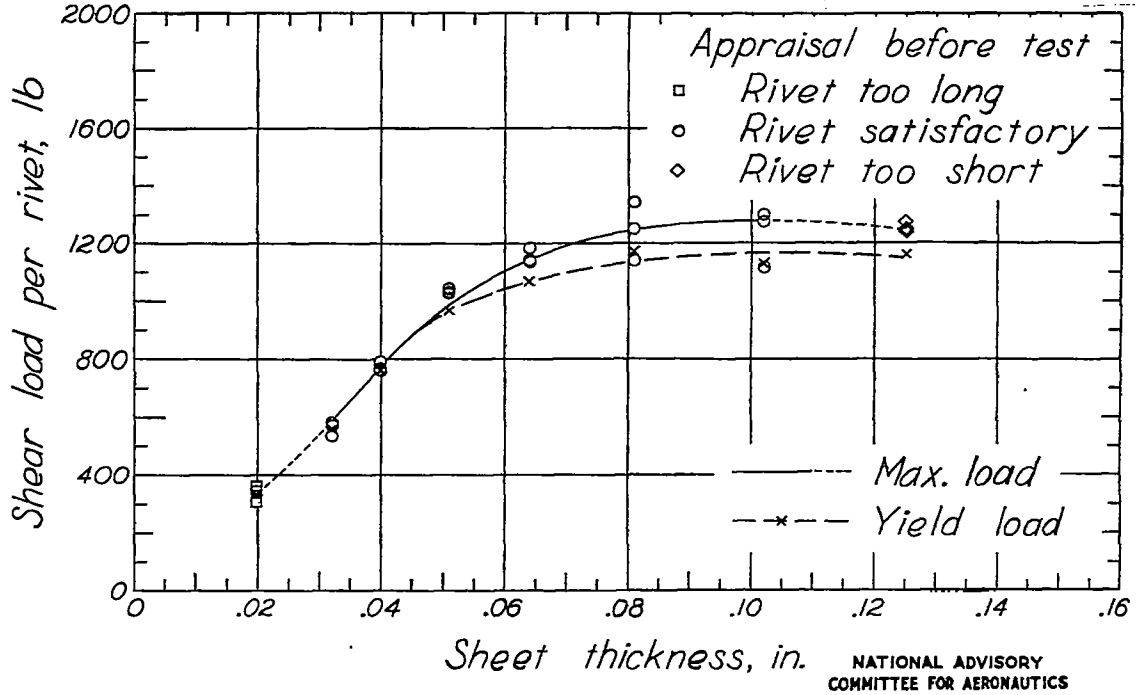




(b) Rivet length, $\frac{5}{16}$ inch.

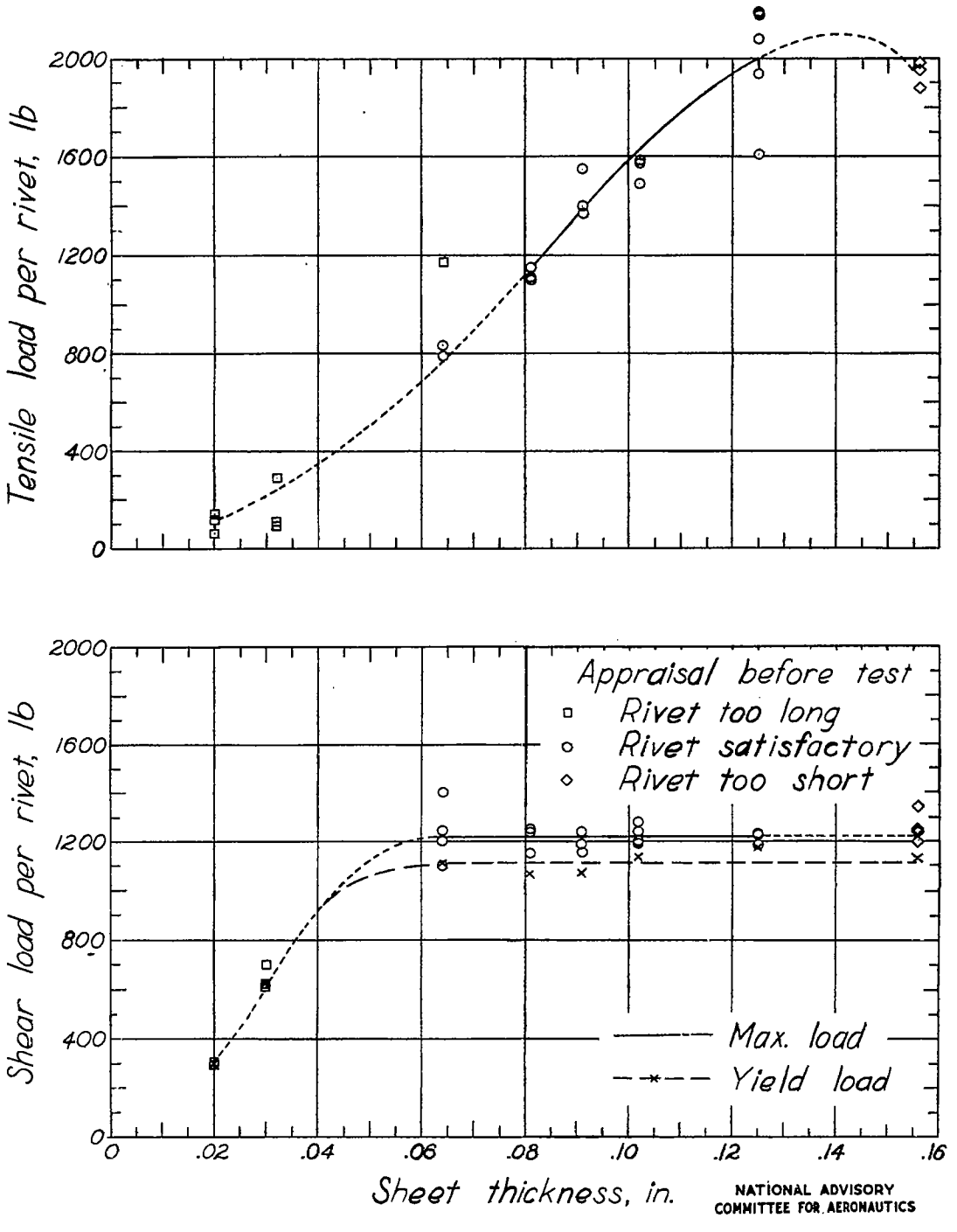
Figure 14.- Continued.





(c) Rivet length, $\frac{3}{8}$ inch.

Figure 14.- Continued.



(d) Rivet length, $\frac{7}{16}$ inch.

Figure 14.- Concluded.

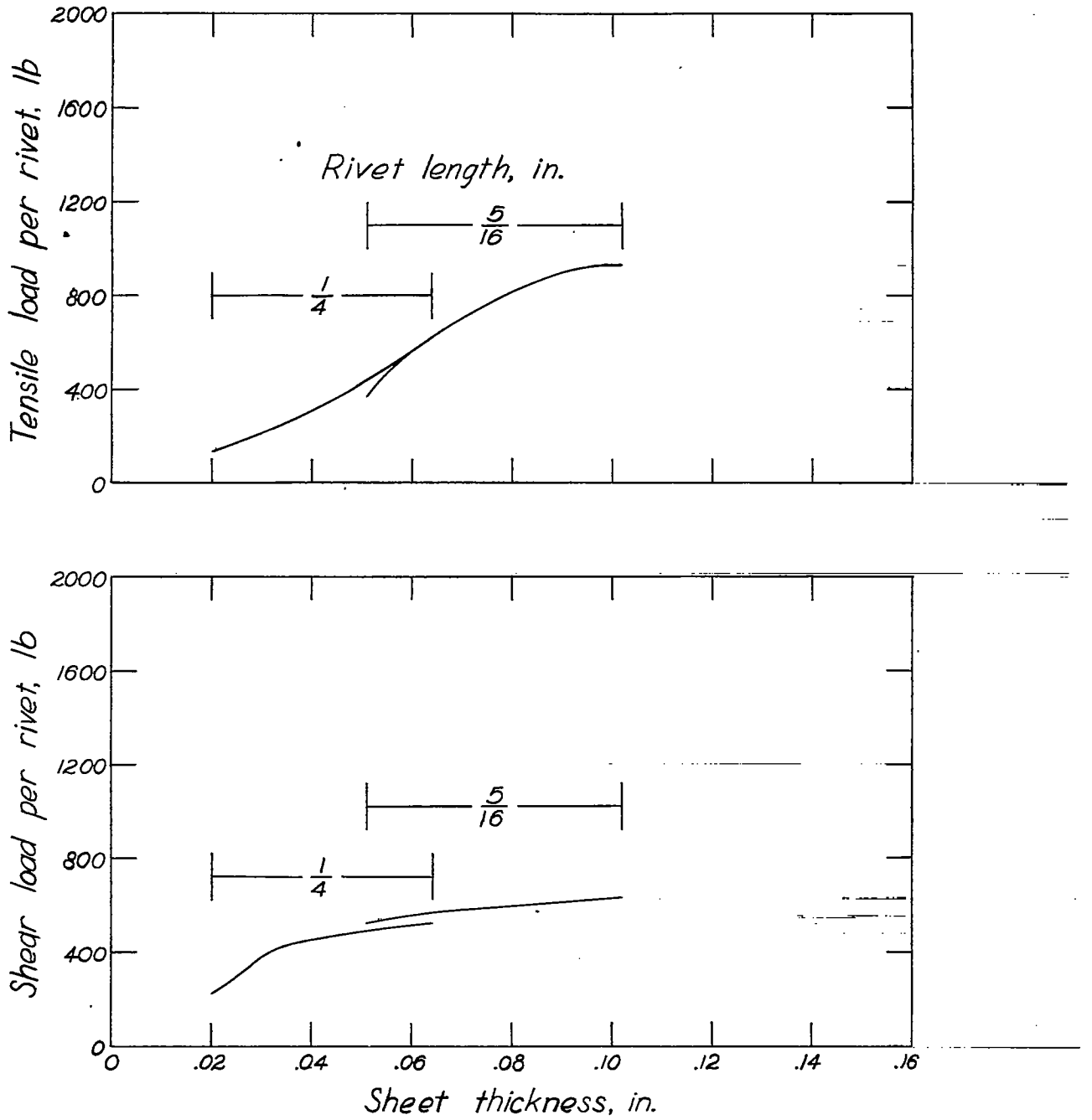


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Figure 15.- Strength of age-hardened 17S-T rivets machine-countersunk in 75S-T sheet, with lengths satisfactory for flushness. Rivet diameter, $\frac{1}{8}$ inch.

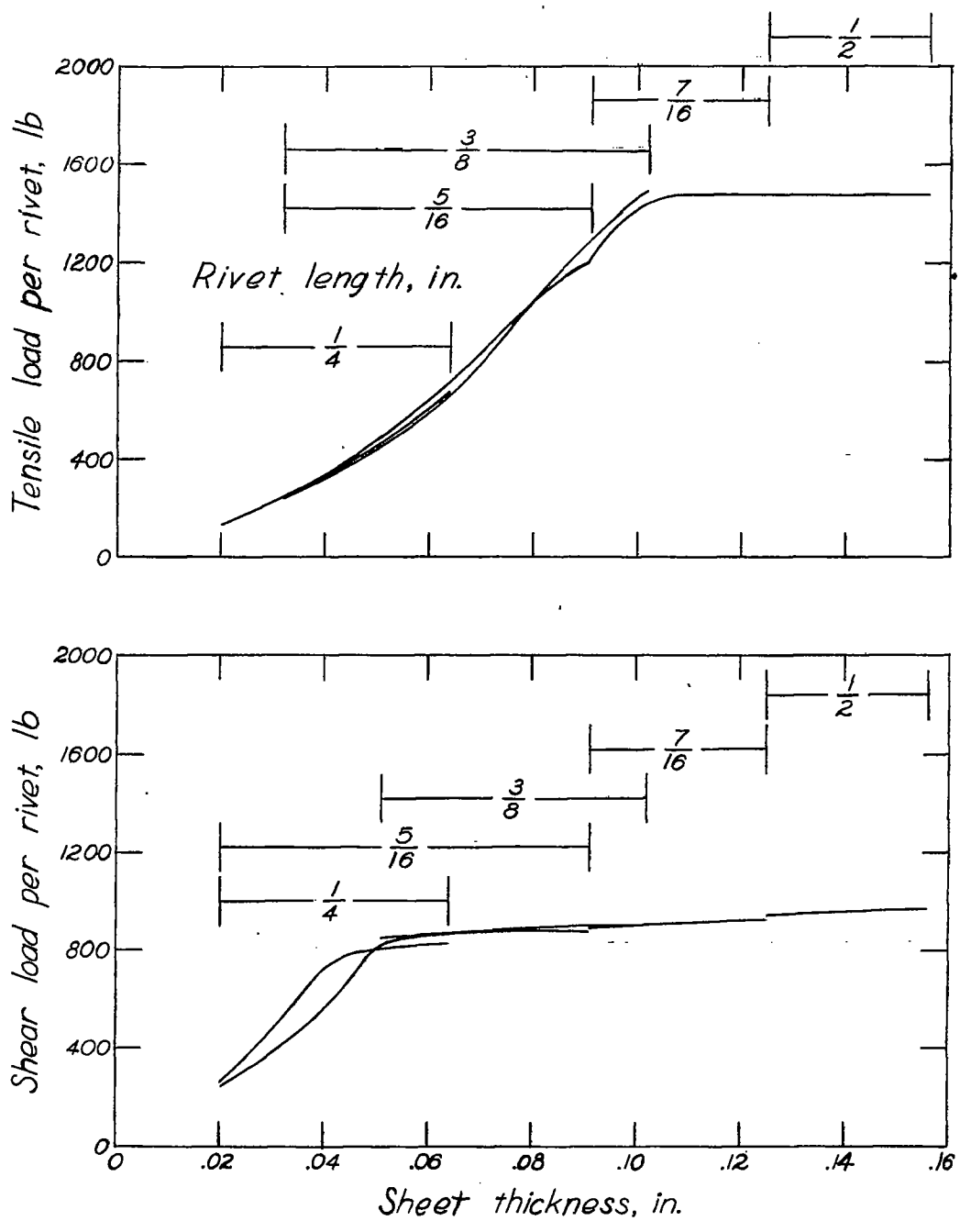

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Figure 16.- Strength of age-hardened 17S-T rivets machine-countersunk in 75S-T sheet, with lengths satisfactory for flushness. Rivet diameter, $\frac{5}{32}$ inch.

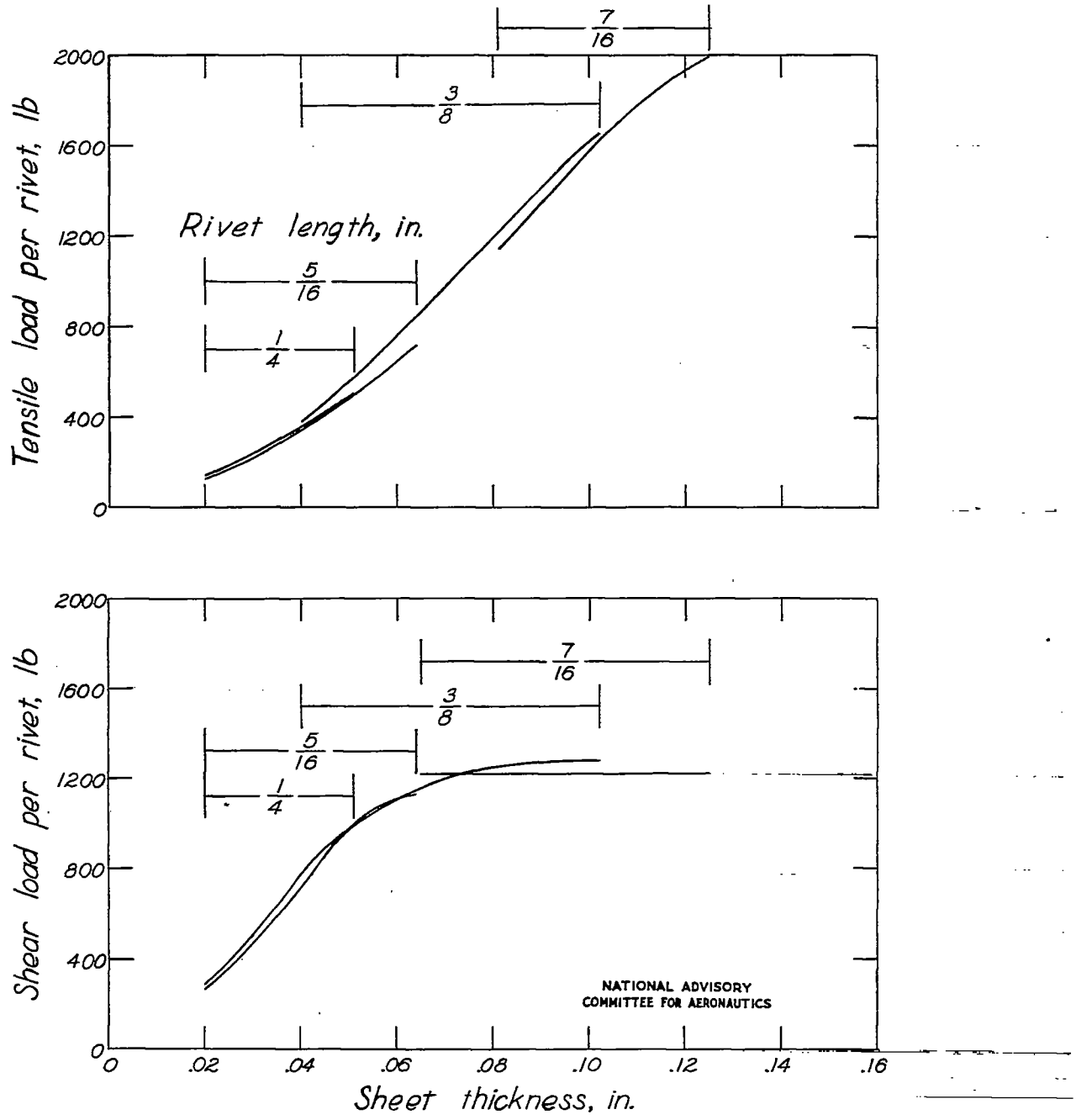

Figure 17.- Strength of age-hardened 17S-T rivets machine-countersunk in 75S-T sheet, with lengths satisfactory for flushness. Rivet diameter, $\frac{3}{16}$ inch.

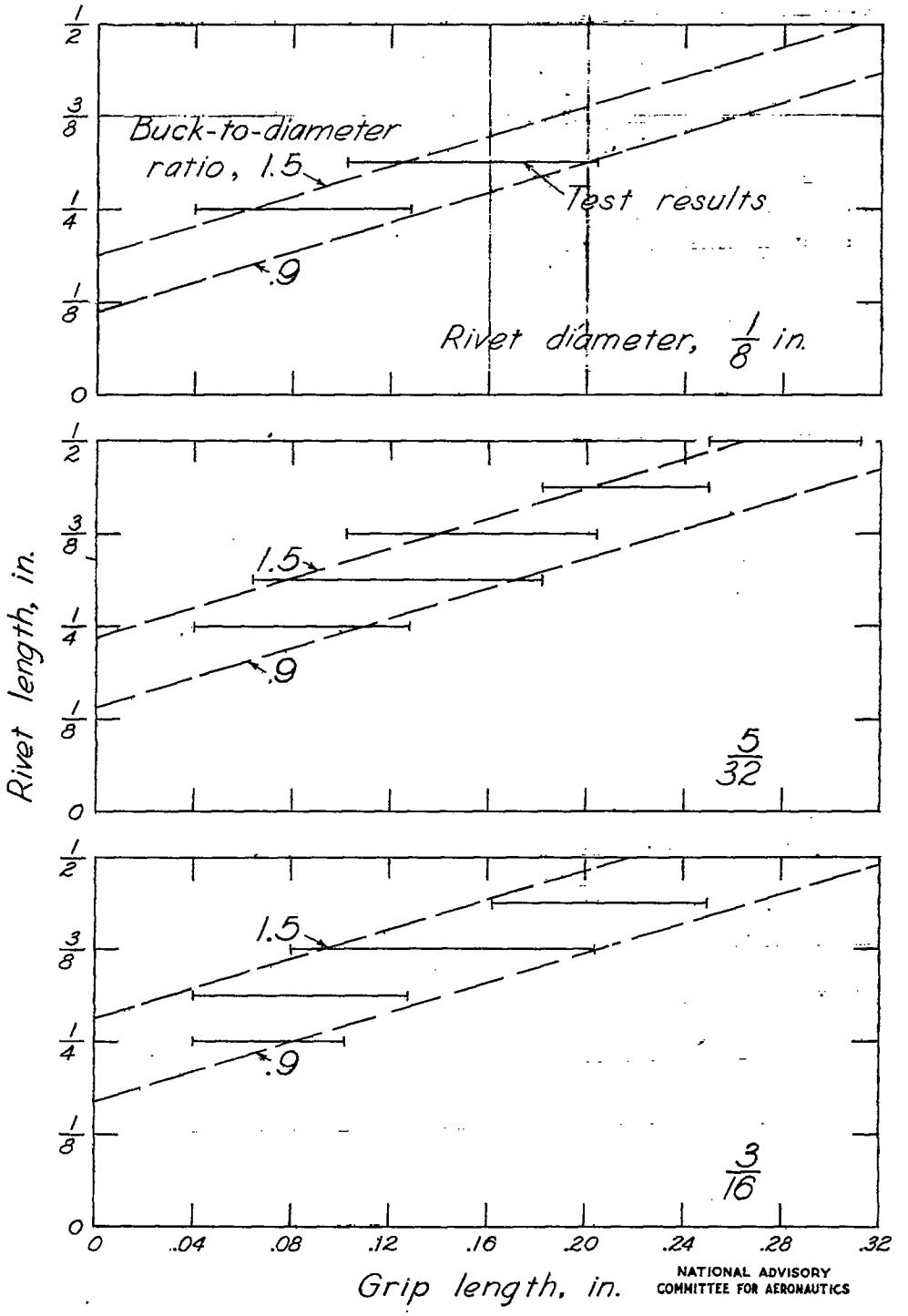

Figure 18.- Limiting combinations of rivet length and grip length for age-hardened 17S-T rivets machine-countersunk in 75S-T sheet.

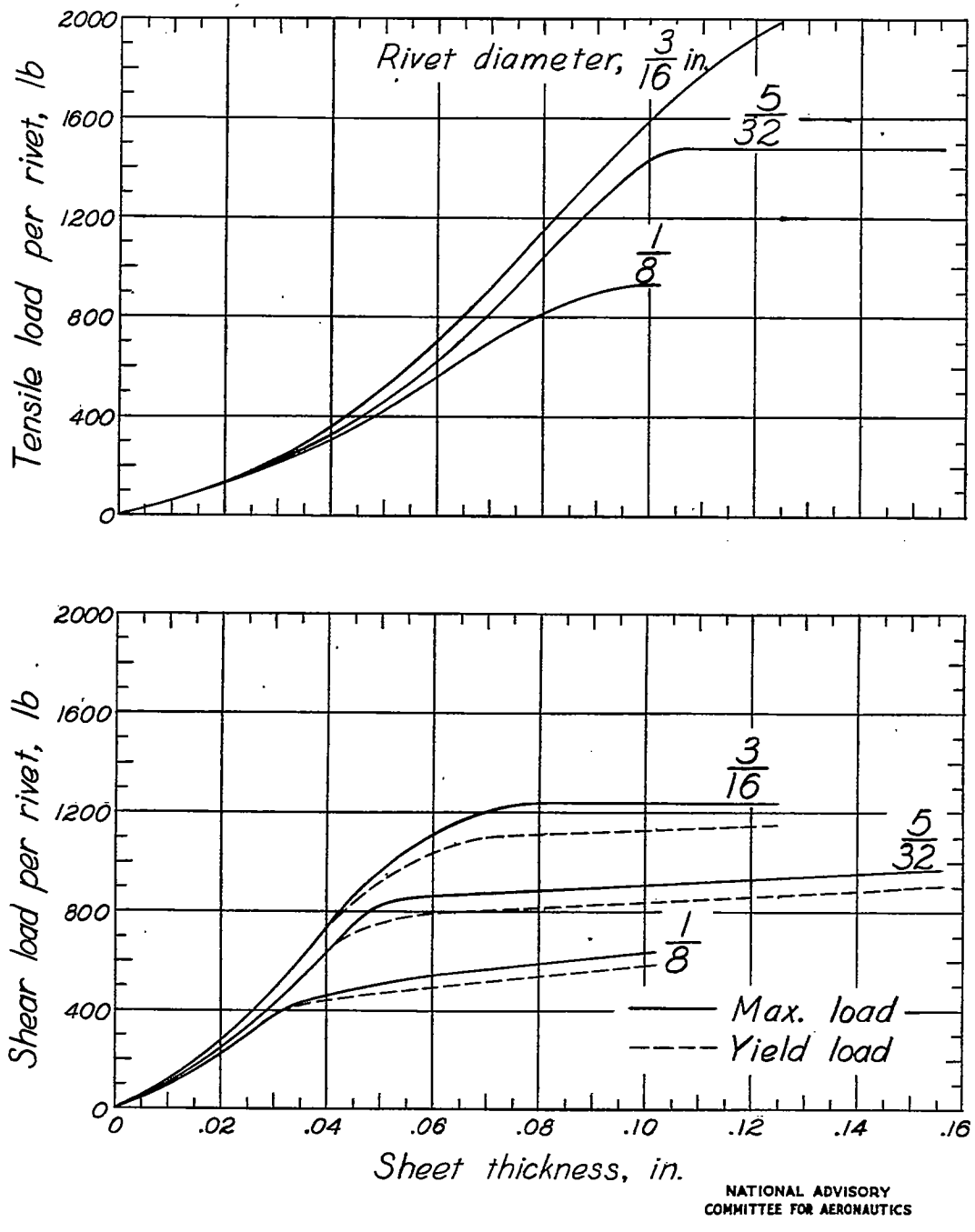

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Figure 19.- Strength of age-hardened 17S-T rivets machine-countersunk in 75S-T sheet, with a ratio of buck to diameter in the optimum range, between 0.9 and 1.5.