A PRELIMINARY INVESTIGATION OF RIVETS AND RIVETED JOINTS IN METAL AIRPLANE CONSTRUCTION.

Thesis by

JOHN L. MAGDEN.

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Introduction

This investigation of revets and riveted joints was started after studying the work done by Wilhelm Pleines in Germany. The results of his research were translated in Technical Memorandums 596-7-8 and 9. His research on riveting in metal airplane construction was a very scientific study, and at first it was felt only neccessary to make a few tests in order to express his results in terms of the Dural and methods used in this country. However as the tests continued more and more questions came up until it became evident that the subject was worthy of further investigation.

The contents of this report is confined to an investigation of the various factors affecting the shearing strength of rivets, the bearing and tearing strength of sheets, and in general the factors affecting the efficiency of the riveted joint.

However the cost of riveting and not the efficiency of the riveted joint, is used by the engineers as a criterian for design.

The labor costs of riveted joints in modern metal airplane construction is of major importance, and any improvement in the efficiency of riveted joints that involves an increase in labor costs will probably not be used.

The present practice is the use of a single riveted lap joint with a maximum efficiency of about 40 or 50 % rather than the use of a more expensive joint with higher efficiency. The tendency is to reduce the number of rivets used in the riveted joint to a minumum that will carry the designed load and still maintain the desired appearence.

Design rules for the spacing of rivets based both on economy and efficiency of the riveted joint would be of value to the engineer. However, design rules of this type would be a function of the riveting methods used. Any simplification of the riveting method would tolerate an increase in efficiency of the riveted joint. To formulate design rules of this type, however, would require more time and research than could be devoted to this report.

Summary.

In order that the results of these tests might be of the most practical value, the test specimens were made at the Douglas Company with the same material and methods used in present metal construction. The material used was 24srt sheet with 17st rivets except in a few specimens that will be mentioned later.

The first two test series were designed to determine the optimum edge distance and pitch in terms of the rivet diameter for a single riveted lap joint.

The third test series was used to determine the ultimate bearing strength of 24srt sheet for various sheet thickness. Tests were made for both lap and butt joints. The lap joint was tested for the following type rivets.-

1. Round head rivets.
2. Countersunk rivets.
3. 3s rivets with welded heads.

Tests were also made showing the variation of bearing strength of the sheet in a lap joint with the head of the rivet.

Test series No. 4 was devoted to the shear of rivets. An attempt was made to classify the following riveting methods by the shearing value of the driver rivet.

1. Hand Riveting.
2. Vibrators (Air Hammer).
3. Pneumatic Squeezers.
4. Spinners.

5. One shot Gun.

6. Automatic Riveter (Eccentric Press).

These tests were made using a lap joint and covered the range of rivets from 3/32 "to 1/4" in diameter. Shearing tests were also made using countersunk rivets and 3s rivets with welded heads. Various diameter of 17st revets were tested in double shear and a test was made showing the variation of shearing value versus sheet thickness for both single and double shear. Also the effect of friction upon the ultimate shearing value of rivets was determined.

Test series No. 5 was used to determine the shearing value and malleability of 17st rivets for various times of ageing.

Test series No. 6 gives the ultimate tensile strength of 24srt sheet for various thickness of sheet from .020 to .128".

Test series No. 7 ---- Because of some question as to the load taken by rivets when placed in line a series of specimens were made up with the Number of rivets in a line varying from 1 to 12. The specimens were tested for ultimate load.

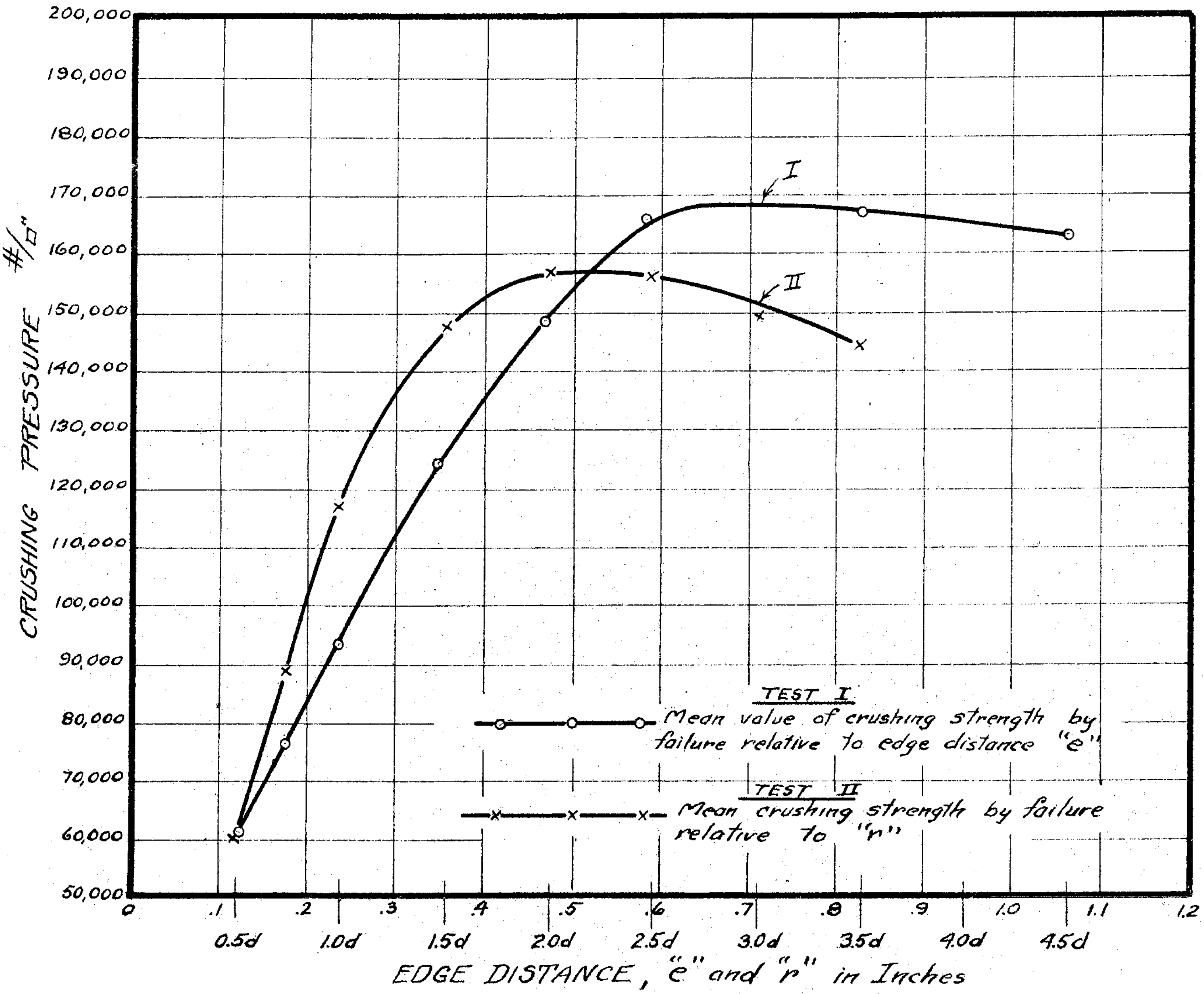
Test Series No. 1 and 2 (Edge distance)

The first two test series were designed to determine the optimum edge distance "e" and "r". (Ref. pages 2,3,4 & 5) in terms of the rivet diameter for a single riveted lap joint. The optimum rivet spacing as determined by the German tests was obtained by using bolted joints. Since the riveted lap joint is most commonly used and since the stress distribution in the two type joints is considerably different, it was considered of interest to investigate the optimum rivet spacing and edge distance in a riveted lap joint.

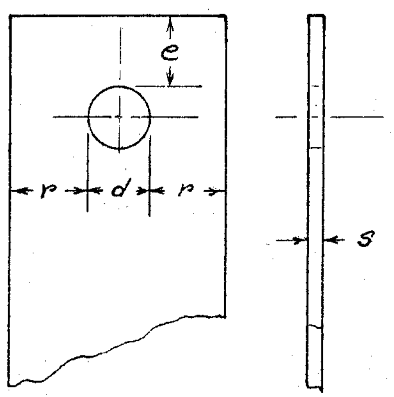
The results of the German tests are shown on page 2. The bearing strength reaches a maximum for e = 2.5d and r = 2.d

The results obtained for a riveted lap joint are given on pages 3 4 & 5 . The increase in bearing strength starts dropping off at e = 1.00d and r = 0.75d, but continues to increase throughout the range of edge distance tested. i.e. up to 4.5d. This can be explained by considering the way in which the lap joint fails in bearing. Due to the eccentricity, the rivet will rotate until the head of the rivet either pulls through the sheet, or the sheet will tear in the "r" direction. Usually the later occurs. Consequently the sheet does not fail in the crushing of the sheet, as it does in the butt joint but rather fails in tear accross the sheet.

GERMAN TESTS



Crushing pressure of sheet in bolted joint for various edge distances.



TEST I

S = Constant = 1.5 mm
d = Constant = 6.0mm
r = Constant = 17.0mm = 2.8 d
e varying from 0.5d to 4.5d

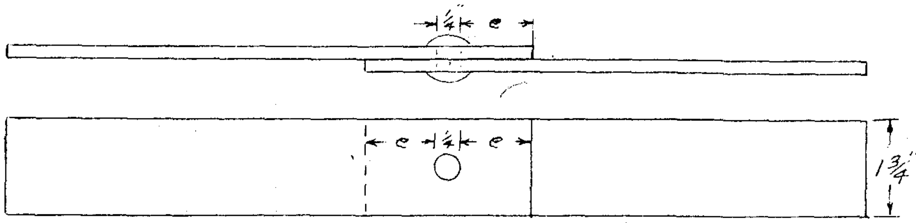
TEST II

S = Constant. = 1.5 mm
d = Constant = 6.0mm
e = Constant = 15.0mm = 2.5d
r varying from 0.5d to 3.5d

TEST SERIES # 1

"OPTIMUM EDGE DISTANCE"

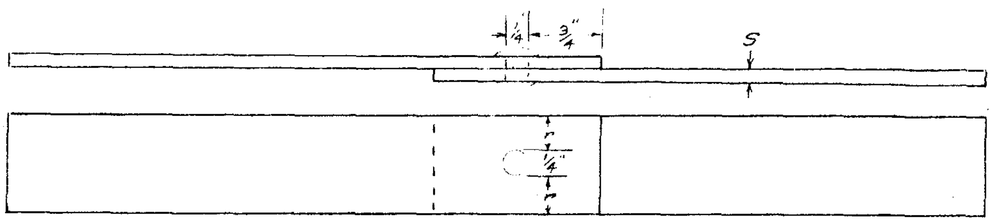
1. ULTIMATE BEARING STRENGTH VS EDGE DISTANCE "e"



SPEC.	EDGE DISTANCE "e"	SHEET THICKNESS "s"	NOMINAL RIVET DIA	DIA. OF DRILLED HOLE	BEARING AREA — "Drilled Hole"	LOAD	ULTIMATE STR IN BEARING #/□"
1	1/8	.0650	1/4	.257	.01670	1270	76,000
AVE							
1	3/16	.0630	1/4	.257	.0162	1518	93,600
2	"	.0644	"	"	.01658	1558	94,000
AVE							93,800
1	1/4"	.0640	1/4"	.257	.01647	1771	105,700
2	"	.0630	"	"	.01620	1865	115,000
3	"	.044	"	"	.01132	1221	108,000
AVE	"						109,600
1	3/8	.0445	1/4	.257	.01143	1252	
2	"	"	"	"	"	1252	
3	"	"	"	"	"	1278	
AVE	"				"	1261	110,200
1	1/2	.0455	1/4	.257	.01170	1321	113,000
2	"	.0460	"	"	.01182	1476	125,000
3	"	.0455	"	"	.01170	1454	124,400
AVE	"						120,800
1	5/8	.0435	1/4	.257	.01120	1266	113,000
2	"	.0520	"	"	.01339	1558	116,400
3	"	.0520	"	"	"	1663	124,500
AVE	"						118,000
1	7/8	.0455	1/4	.257	.01170	1422	121,700
2	"	.0450	"	"	.01157	1387	120,000
3	"	"	"	"	"	1389	120,000
AVE	"						120,600
1	1 1/8	.0520	1/4	257	.01339	1665	124,500
2	"	.0505	"		.01300	1747	134,000
3	"	"	"		"	1774	136,700
AVE	"						131,700

Test Series #2

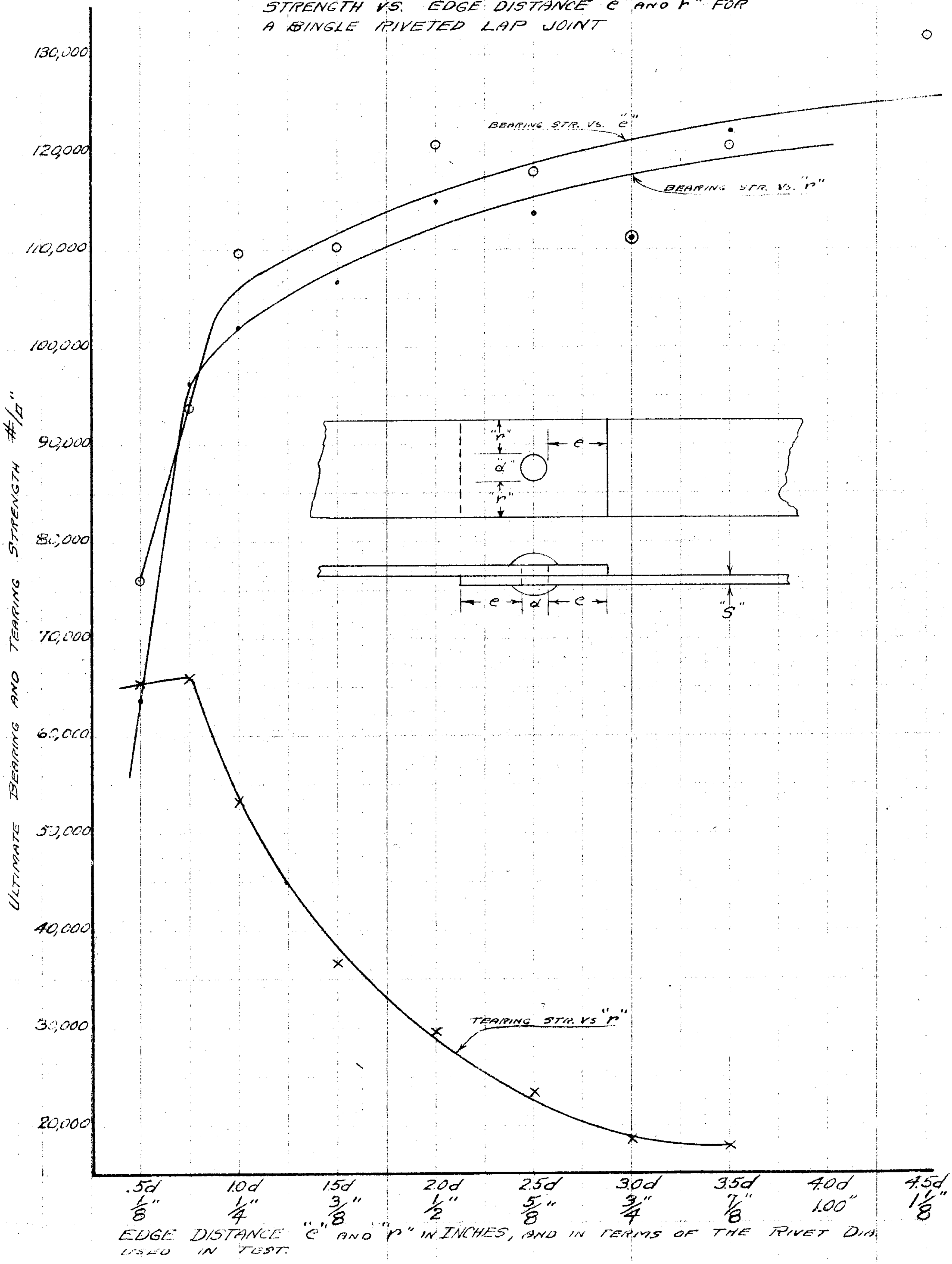
2. Ultimate Bearing and Tearing Strength vs. Edge Distance "r"



Spec.	Edge Distance "r"	Sheet Thickness "s"	Nom. Rivet Dia.	Dia Drilled Hole	Bearing Area - Drilled dia.	Load	Ultimate Str in Bearing #/□"	Tearing Area	Tearing Str #/□"
1	1/8	.065	1/4	0.257"	.0167	1066	63,800	.01625	65,500
Ave	"	"	"	"	"	"	"	"	"
1	3/16	.065	1/4	0.257	.0167	1670	100,000	.02440	68,500
2	"	"	"	"	"	1625	97,500	"	66,600
3	"	.0450	"	"	.01157	1060	91,700	.01690	62,300
Ave	"		"	"			96,400		66,000
1	1/4	.0645	1/4	.257	.01655	1752	106,000	.03220	54,500
2	"	.0450	"	"	.01157	1164		.02250	51,800
3	"	"	"	"	"	1176	101,000	"	
4	"	"	"	"	"	1161		"	
Ave						1167	102,200		53100
1	3/8	.0450	1/4	.257	.01157	1265		.03375	
2	"	"	"	"	"	1218		"	
3	"	"	"	"	"	1215		"	
Ave						1232	106,900		36,600
1	1/2	.0455	1/4	.257	.01170	1364		.0455	
2	"	"	"	"	"	1322		"	
3	"	"	"	"	"	1357		"	
Ave	"				"	1348	115,000	"	29,600
1	5/8	.0455	1/4	257	.01170	1285		.0569	
2	"	"	"	"	"	1322		"	
3	"	"	"	"	"	1369		"	
Ave	"	"	"	"	"	1325	113,200	"	23,300
1	3/4	.0450	1/4	.257	.01157	1246		.0675	
2	"	"	"	"	"	1319		"	
3	"	—	—	—	—	—		"	
Ave	"					1282	111,000	"	19,000
1	7/8	.0450	1/4	257	.01157	1426	123,200	.0787	18100
2	"	.0455	"	"	.01170	1459	124,500	.0795	18,300
3	"	"	"	"	"	1390	119,000	"	17,500
Ave	"		"	"			122,200		18,000

TEST SERIES #1 & 2

ULTIMATE BEARING STRENGTH AND TEARING STRENGTH VS. EDGE DISTANCE "e" AND "r" FOR A SINGLE RIVETED LAP JOINT



This tearing of the sheet is determined more or less by the stiffness, or resistance of the sheet due to bending. If the edge distances increase the stiffness of the joint increases, and the load at which tearing of the sheet starts will be greater as shown by the curves. The tearing strength of the sheet drops rapidly after the critical value of r = 0.75d. The critical pitch however is determined from the equation $p = (\frac{f_c}{f_t} + 1)d$ (Ref. Page 40) where f_t = tearing ultimate #/□" is a variable and is taken from the curve on page 5 . The value of e = 1.0d seems too small so probably a value of e = 2d or 2.5d would be the best for design use.

Test Series No. 3 (Bearing strength of sheet)

The bearing strength of Dural sheet in bolted and riveted butt joints was determined by German tests, the results of which are shown on page 9 . The somewhat lower bearing strength of the thicker sheets in the case of the riveted joint is perhaps due to the fact that heavier sheets are not always as evenly rolled as thinner sheets. In the bolted joint the sheet is unsupported and there is nothing to prevent local buckling of the sheet in front of the rivet except the stiffness of the sheet itself. Consequently the ultimate load is determined by the local buckling of the sheet for a sheet thickness of less then .045.

The tests made on the bearing strength of 24srt sheet in a butt joint was limited to one sheet thickness. Ref. pages 11 9 24. A sheet of .021 thickness was tested in the center position i.e., S_2 page 24 The average bearing strength was found to be 204,000 #/A" for this sheet thickness. With the sheet in the outside position i.e. S_1 page 24, the bearing strength is little better than that found for a lap joint. The sheet will fail by tearing accross the "r" dimension, similiar to the type failure found in the lap joint.

The ultimate bearing strength of 24srt sheet for various sheet thickness was determined for a lap joint using the following type rivets.

1. Round head rivets.
2. Countersunk rivets.
3. 3 S rivets with welded heads.

The result of these tests are shown on pages 10 9 11

The type of bearing failure occuring in a lap joint has already been discussed. That is the failure occurs in tearing accross the edge distance "r" rather then the crushing of the sheet.

In case of the round head rivet, failure always occured on the side of the joint with the smaller rivet head. From this fact and also because of the type of failure found in the lap joint it was obvious that the size of the rivet head was an important factor in the bearing strength of the joint. As a result tests were made on specimens with various head diameters. The head diameter was varied from .20 to .30, i.e., an increase of 50%. For this range the bearing strength was found to increase by 17%. The driven head or forced head used by the Douglas Company is a flat head and as an average is about 2/3 the diameter of the original head of the rivet. That is, if heading tools were used that would form a head equal in diameter to the original head of the rivet, an increase of 15% in the bearing strength could be realized.

In the case of the countersunk rivet the failure always occured on the countersunk side. The head of the rivet was countersunk in the sheet thus making it easier for the rivet to pull through the sheet. As a result the bearing strength of countersunk rivets when countersunk in the sheet is about 30% less than that found for round head rivets.

The 3S rivets with welded heads failed in tension accross the sheet in two of the three specimens tested. The sheet had been burnt in the third specimen and the rivet pulled through the sheet.

Riveting Methods used by the Douglas Company.

There are six different riveting machines or methods in use at the Douglas Company at the present time, namely --

1. Hand Riveting.
2. Vibrators (Air Hammer).
3. Pneumatic Squeezers.
4. Spinners.
5. One shot gun.

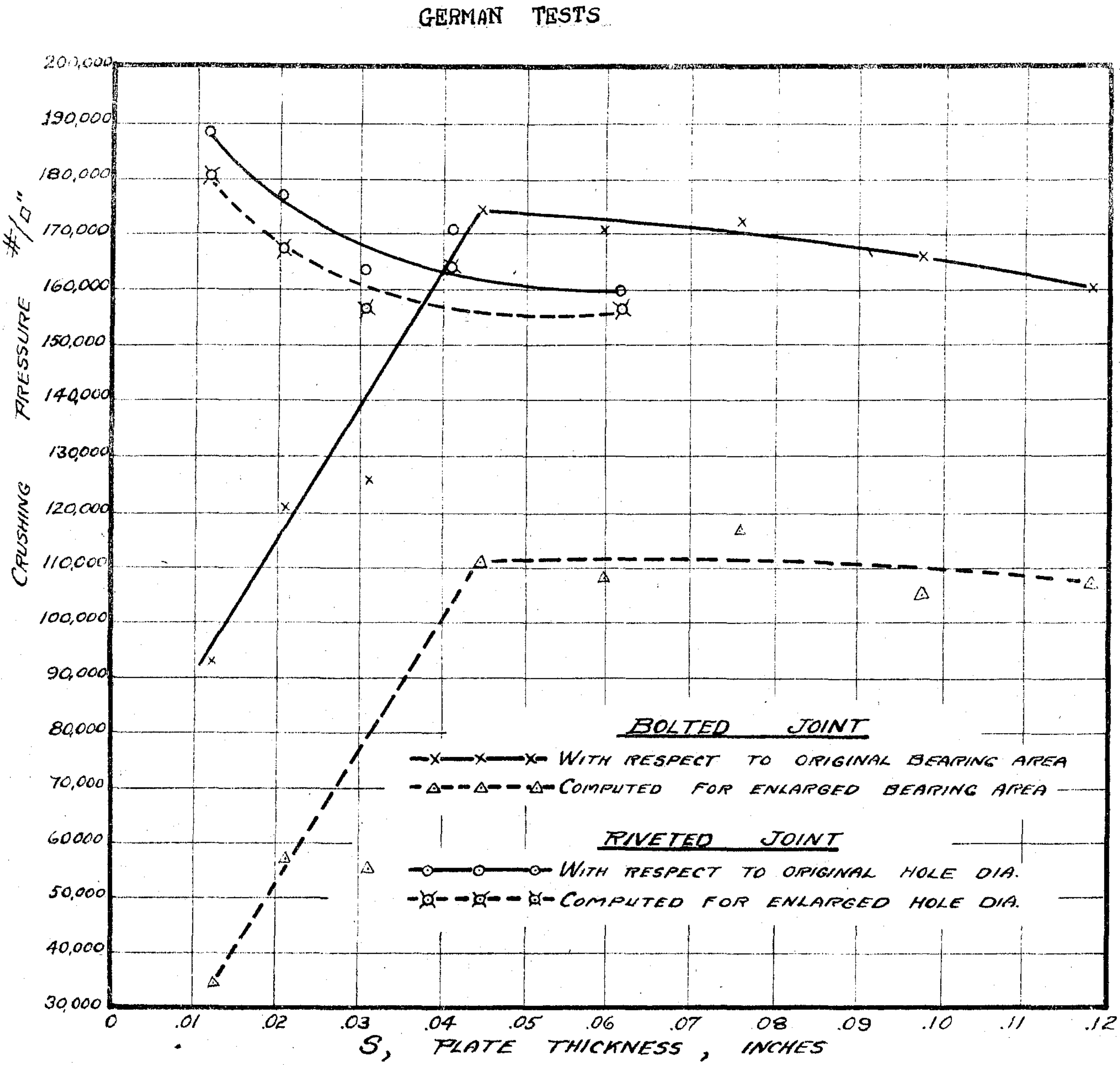


Fig.___Crushing Pressure of thin sheets in bolted and riveted joints.

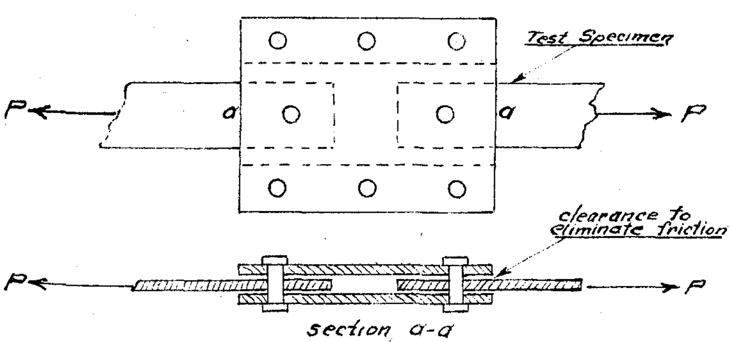


Fig.__Bolt arrangement for testing crushing strength of plates.

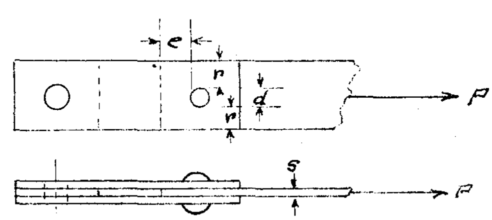


Fig.__Arrangement used for testing crushing strength of riveted joints.

TEST SERIES " 3

BEARING STRENGTH OF 24SRT SHEETS VS. SHEET THICKNESS

ROUND HEAD RIVETS

SPECIMEN	SHEET THICKNESS "S"	NOMINAL DIA. RIVET	DRILLED HOLE DIA.	NOMINAL BEARING AREA	DRILLED BEARING AREA	LOAD	BEARING STRENGTH #/□" NOMINAL	BEARING STRENGTH #/□" Drilled Area
1	.0210	1/8	.1285	.002622	.002700	325		
2	"	"	"	"	"	320		
3	"	"	"	"	"	336		
AVERAGE						327	124,800	121,000
1	.0320	3/16	.1935	.00600	.00619	710		
2	"	"	"	"	"	715		
3	"	"	"	"	"	713		
AVE						713	119,000	115,200
1	.0455	1/4	.257	.01138	.01170	1422	125,000	121,700
2	.0450	"	"	.01125	.01157	1387	123,000	120,000
3	"	"	"	"	"	1389	123,200	120,000
AVE							123,700	120,600
1	.0520	1/4	.257	.01300	.01339	1558'		116,400
2	"	"	"	"	"	1663		124,500
3	"	"	"	"	"	1665		124,500
AVE						1627	125,000	121,800

COUNTERSUNK RIVETS (RIVET HEAD COUNTERSUNK IN SHEET)

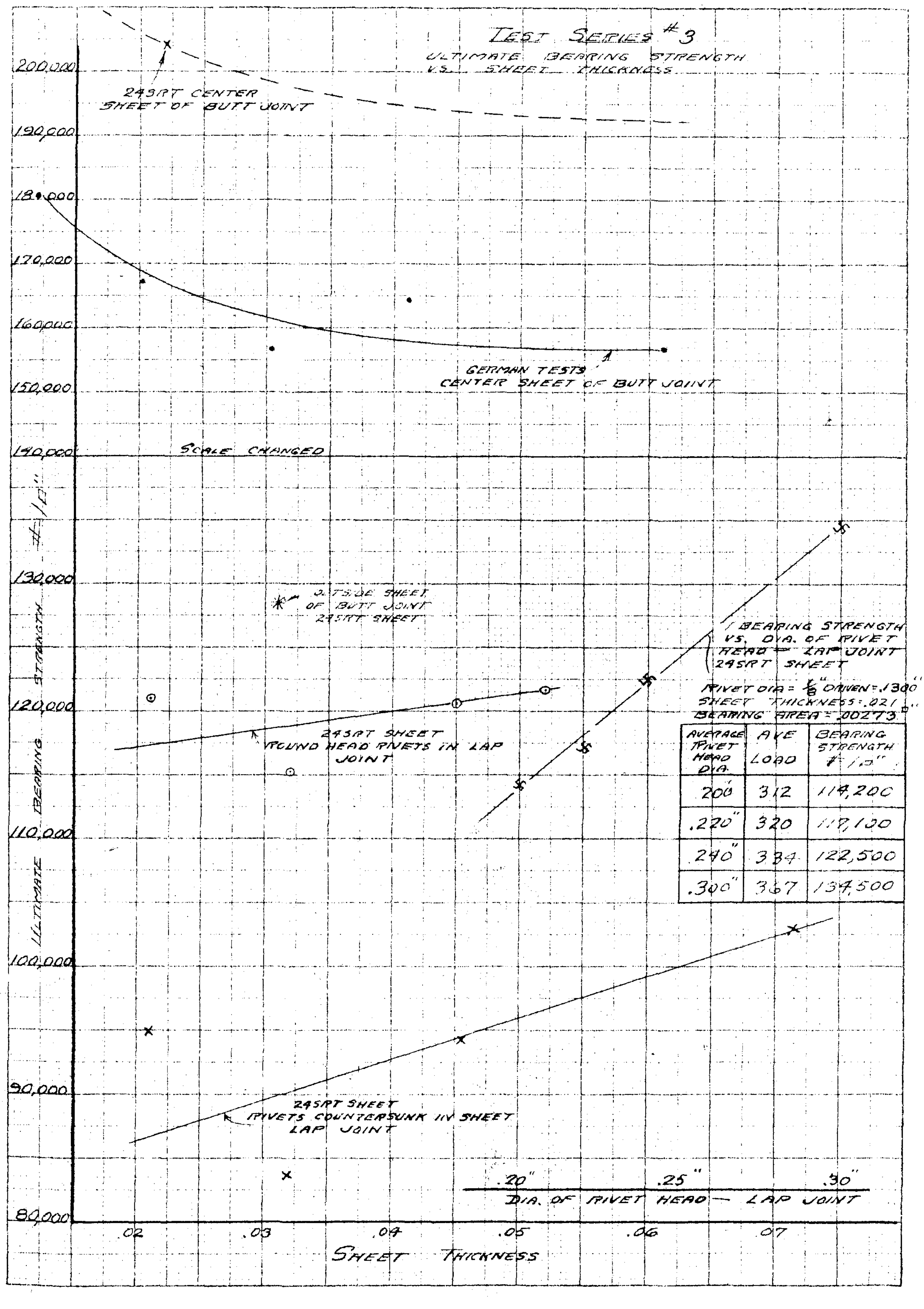
SPECIMEN	SHEET THICKNESS "S"	NOMINAL DIA. RIVET	DRIVEN DIA.	NOMINAL BEARING AREA	DRILLED BEARING AREA	LOAD	BEARING STRENGTH #/□" NOMINAL	BEARING STRENGTH #/□" Drilled Area
1	.021	1/8	.130	.002622	.002730	258		
2	"	"	"	"	"	258		
3	"	"	"	"	"	262		
AVE						259.3	98,700	95,000
1	.031	3/16	.218	.00595	.00675	585	98,400	86,700
2	.033	"	"	.00619	.00720	564	91,200	78,4
3	.031	"	"	.00595	.00675	577	97,000	85,600
AVE							95,530	83,600
△ 1	.046	3/16	.200	.00863	.00920	695	80,500	75,500
2	.045	"	"	.00844	.00900	850	100,800	94,500
3	.0455	"	"	.00853	.00910	855	100,200	94,000
AVE							100,500	94,300
1	.0715	1/4	.262	.01788	.01872	1922	107,800	102,700
□ 2		"						
3	.0710	"	"	.01775	.01860	1918	108,000	103,300
AVE							107,900	103,000

35 RIVETS — WELDED HEADS

SPECIMEN	SHEET THICKNESS "S"	NOMINAL DIA. RIVET	DRILLED HOLE DIA.	NOMINAL BEARING AREA	DRILLED BEARING AREA	LOAD	BEARING STRENGTH #/□" NOMINAL	BEARING STRENGTH #/□" Drilled Area
1	.021	1/8	—	.002622	—	198	75,500	
✳ 2	"	"	—	"	—	539	205,500	
✳ 3	"	"	—	"	—	674	266,500	
AVE								

△ RIVET HEAD SHEARED OFF ✳ SHEET FAILED IN TENSION

□ FAILED IN SHEAR



AVERAGE RIVET HEAD DIA.	AVE LOAD	BEARING STRENGTH #/□"
.200"	312	114,200
.220"	320	117,100
.240"	334	122,500
.300"	367	134,500

6. Automatic Riveter (Eccentric Press).

of which only hand riveting and the vibrators are capable of covering the entire field of riveting. Of these two methods the vibrators are used almost exclusively. Both methods in most cases require two men for operation. One to hold the bucking bar and the other to drive the rivet. They find most of their application to either final assembly or on pieces that cannot be accommodated by a fixed machine. Of course the speed of riveting depends more or less on the specimen being riveted but as a rough approximation it is possible to drive 225 rivets per hour by hand compared with 300 rivets per hour for the vibrators.

The Pneumatic squeezers is operated by compressed air and the rivet is driven by a squeezing process. It is limited to an edge distance of about six inches, consequently it finds application to work such as riveting of metal beams etc. It only requires one man for operation with a rate of riveting of probably around 300 per hour.

The Spinner is nothing more than a modified drill press used to spin the head on long rivets that are unsupported in the middle, as used to rivet through struts, etc. It requires two men for operation, but as can be seen, there field of application is very limited.

The one shot gun and the Automatic rivetes are both fixed machines so consequently are limited to piece work or sub-assemblies that are designed for their accommodation.

The one shot gun is operated by compressed air, and the rivet is driven by a single blow of the heading tool. It has an edge distance of approximately three feet, which enables it to accommodate quite large piece work. It only requires one man for operation and probably is the fastest of all the methods so far discussed.

The eccentric press is actuated by an electric motor. The bucking bar or dolly rests in a chuck which moves up and down in a slide track by means of eccentric blocks. The heading tool is stationary on a bedplate. The rivets are inserted from the top leaving the shank hanging down. The rivet is driven by a squeezing action. The machine only requires one man for operation and has an edge distance of a foot and a half or two feet. Since it punches its own rivet holes it is probably faster than the other methods used.

Test Series No. 4 (Shear of Rivets.)

The diameter of the driven rivet, hence the amount of cold working of the rivet shank, depends somewhat on the diameter of the drilled hole. Therefore it is of value to know the drill sizes used for the various sizes of rivets. These sizes are given in the following table.

Rivet Dia.		Drill Size		Drill Size Minus Nominal Dia.	Drill Size Minus Actual Dia.
Nominal Dia.	Actual Undriven Dia.	No.	Decimal		
3/32 (.09375)	.0925	#40	.0980	.00425	.0055
1/8 (.1250)	.1255	#30	.1285	.0035	.0030
5/32 (.15625)	.1562	#20	.1610	.00475	.0048
3/16 (.1875)	.1885	#10	.1935	.0060	.0050
1/4 (.250)	.2510	#F	.2570	.0070	.0060

From the German tests it was shown possible to obtain a 40% increase in shearing strength of a driven rivet over that of an undriven rivet. This increase was in the ultimate shearing strength in #/A" based on the actual diameter of the rivet. Hence the effect of the enlarged rivet was eliminated. This increase in strength was explained by the cold working of the material in the rivet shank upon riveting. A difference of 25% in the shearing strength of the driven rivets was obtained between hand riveting and riveting with the eccentric press.

The eccentric press workes the shank of the rivet more evenly, than hand riveting, which would account for the increase in strength.

With this possible variation of shearing strength with riveting methods, an attempt was made to classify the various methods as outlined above by the shearing value of the driven rivets.

The tests made were quite complete covering six methods of riveting and various rivet diameter from 3/32 "to 1/4" totaling approximately 190 test specimens. The specimens were lap joints with 17st rivets and the edge distance, "e" was held at a constant ratio of the rivet diameter "d". The design of the specimen is shown on page 19.

The result of these tests are plotted on page 24. Instead of a difference of 25% as expected, a maximum of only 4% was obtained between the various methods of riveting. Also instead of the curve for the unriveted rivet falling 15 to 40 % below the curve for driven rivets the curve fell about 14% above the lowest curve for driven rivets. However as can be seen the curve for undriven rivets drops down for large diameter of rivets. This would indicate an error in the method of testing the undriven rivet. In testing the undriven rivets as shown in the solid curve the rivets for all diameter were tested in a lap joint of constant sheet thickness of 0.125". This value of sheet thickness is close to the value used for 1/4" rivet in the driven rivet tests. This would indicate that the shearing value of the rivet is a function of the sheet thickness. Hence a series of specimens were tested with constant rivet diameter and variable sheet thickness. These results are plotted on page 26. These results show that the shearing value of unriveted rivets in a lap joint will vary about 7% in the ordinary range of sheet thickness of .021 to .125. This accounts partially for the high value for the unriveted rivet, but there is still at least 10% yet to be accounted for. As a second check, a series of specimens were tested for various rivet diameter using the same sheets that were used in the riveted specimens. The rivets were threaded and nuts were used to hold the rivet in position instead of the driven head. The nuts were not tightened but left loose so as not to cause an error due to friction. The results are shown in a dotted curve on the same curve sheet. The test gave a constant shearing value of 37,400#/□" throughout the range of rivet diameter. This is free from the previous error of sheet thickness but still lies about 10% higher then the lowest curve for driven rivets. The last series of specimens were from a different batch of rivets than used in the first group of specimens, which may account for the descrepency.

The shearing value obtained from rivets driven by the eccentric press fall below all the other methods used. This seems to indicate that the metal is weakened from over working. However, these specimens were from still another batch of rivets, so no definite conclusions can be drawn.

All the above curves were shearing values based on the actual diameter of the rivet, (driven or undriven) and hence remove any effect of the enlarged cross-sectional areaof the driven rivet.

The shearing values based on the nominal diameter was too inconsistent to give smooth curves, hence the average value of the four methods listed below were plotted to show the effect of rivet enlargement upon riveting.

Average Stress Based on Nominal Diameter for the Four Following methods of Riveting.

DIA →	3/32 (.09375)	1/8 (.1250)	5/32 (.15625)	3/16 (.1875)	1/4 (.250)
① ONE SHOT GUN	39450 #/□"	38,960	37,750	38,206	37.600
② VIBRATORS	40,200	38,500	38,220	38,870	
③ PNEUMATIC SQUEEZER	39,600	39,400	37,380	38,790	
④ HAND RIVETING	38,700	38,100	38,100	38,300	36,030
AVERAGE	39,490	38,740	37,860	38540	36800

The difference between the undriven rivet diameter and the drilled hole is almost constant throughout the range of rivet diameter. This accounts for the greater percentage enlargement of the small rivets as shown by the curve based on nominal diameter. The difference is even more pronoun ed in the curve taken from the German reports.

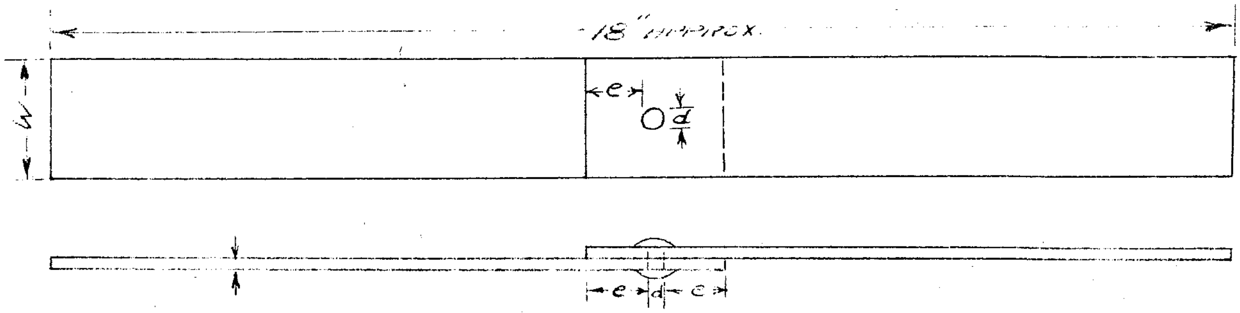
Shearing tests were also made on 17st counter-sunk rivets and 3s welded head rivets. The counter-sunk rivet was counter sunk into the sheet itself which cut down the bearing area of the sheet and gave it a knife edge effect which resulted in about a 30% reduction in the shearing value of the rivet.

Tests were also made on the double shear of rivets in butt joints. The butt joint was designed as shown on Page 25 with 24srt sheet and 17st rivets. In this case the bearing value of the sheet was so high in comparison to the shearing value of the rivets that the sheet thickness required was so thin that the rivet failed in bearing instead of shear. Consequently the shearing allowable of 17st rivets in double shear is about 30 to 35% less than that obtained in single shear. A series of double shear specimens were tested with constant rivet diameter and variable sheet thickness to determine the effect of sheet thickness on the bearing stress of the rivet. The results are plotted on page 26 and show that the shearing value may vary 35% in a 100% change in sheet thickness.

Because of some uncertainty as to the effect that friction in metal joints had on the shearing value of metal, a series of specimens were tested under the arrangement shown on Page 27. The results show that the shearing value varies directly as the tension in the rivet. That is the additional load taken by the joint is just the tension in the rivet times the coefficient of friction. With a tensile stress in the rivet of 1/10 the ultimate shearing strength it is possible to change the ultimate shearing value of the rivet by about 6% or 7%. Hence it is possible that the variation of ultimate shearing strengths of rivets with methods of riveting, may be due partially at least to friction.

TEST SERIES #4a

SINGLE SHEAR STRENGTH VERSUS RIVET DIA.
FOR VARIOUS METHODS OF RIVETING.



No. OF SPECIMENS TESTED FOR EACH METHOD OF RIVETING	3	3	3	3	3
SHEET THICKNESS "S"	.040	.045	.064	.072	.091
RIVET DIA. "d"	3/32"	1/8"	5/32"	3/16"	1/4"
EDGE DISTANCE "e"	3/8	1/2	5/8	3/4"	1"
WIDTH "W"	3/4	1"	1 1/4	1 1/2	2

THE ABOVE SPECIMENS WERE TESTED FOR EACH OF THE FOLLOWING METHODS OF RIVETING, EXCEPT WHERE METHODS WERE UNABLE TO ACCOMMODATE RIVET DIA.

USING: 24SRT DURAL SHEET &
*17ST DURAL RIVETS

1. HAND RIVETING (BRAZIER & ROUND HEADS)
2. HAND RIVETING (COUNTERSUNK HEADS)
3. SPINNERS (BRAZIER & ROUND HEADS)
4. * 3S RIVETS (WELDED HEADS)
5. AUTOMATIC RIVETER (B. & R. HEADS)
6. ONE SHOT GUN (B. & R. HEADS)
7. VIBRATORS (B & R. HEADS)
8. PNEUMATIC SQUEEZERS (B. & R. HEADS)

USING: 24SRT DURAL SHEET &
24ST DURAL RIVETS

1. HAND RIVETING (B. & R. HEADS)
8. PNEUMATIC SQUEEZERS (B & R HEADS)

TEST SERIES #4a

DIMENSIONS OF SPECIMENS FOR TEST SERIES #4 ARE GIVEN ON PG __

#1 HAND RIVETING

17St DURAL BRAZIER HEAD RIVETS

Specimen	Driven Dia.	Nominal Dia.	Driven Area	Nominal Area	Load #	#/□" Driven Area	#/□" Nominal A
1	.0635	1/16	.003164		67	21,200	
2	.0640	.0625	.00322	.003066	67	20,800	
3	.0638	"	.00320		64	20,000	
Average	.0638				66	21,000	21,540
1	.1295	1/8	.01317		475	36,100	
2	.1285	.125	.01298	.01228	447	34,450	
3	.1300	"	.01328		480	36,150	
Average	.1293				467.3	35,570	38,100
1		3/16			1054	35,000	
2	.1960	.1875	.03015	.02762	1066	35,400	
3	.1975	"	.03062		1189	38,800	
Average	.1968				1103	36,400	39,900

Average of 1 & 2 35,200 38,300

Specimen	Driven Dia.	Nominal Dia.	Driven Area	Nominal Area	Load	#/□" Driven A.	#/□" Nominal Area
1	.0985	3/32	.00761		263	34,550	
2	.0983	.09375	.00758	.00690	266	35,100	
3	.0988	"	.00766		273	35,650	
Average	.0985				267.3	35,100	38,700
1	.1610	5/32	.02035		716	35,200	
2	.1618	.15625	.02055	.01919	733	35,700	
3	.1620	"	.02065		742	35,900	
Average	.1616				730.3	35,600	38,100
1	.2560	1/4	.0515		1787	34,700	
2	.2570	.250	.0519	.04913	1750	33,800	
3	.2575	"	.0520		1773	34,150	
Average					1770.7	34,210	36,030

#2 HAND RIVETING

17ST DURAL COUNTERSUNK HEAD RIVETS

1	.1000	3/32	.00785		211	26,400	
2	.1010	.09375	.00802	.00690	240	29,900	
3		"	.00802		242	30,200	
Average					231	29,000	33,500
1	.1625	5/32	.02075		650	31,350	
2	.1620	.15625	.02060	.01919	613	29,800	
3	.1622	"	.02067		500	24,200	
Average					587.7	28,450	30,650
1	.259	1/4	.0526		1381		
2		.250		.04913	1460		
3		"			1425		
Average					1422	27,000	28,900

1		1/8			350		
2	.1305	.125	.01339	.01228	386		
3		"			382		
Average					372.7	27,850	30,350
1	.1970	3/16	.03045		900	29,550	
2	.1965	.1875	.0303	.02762	813	26,850	
3	.1968	"	.0304		815	26,800	
Average					842.7	27,730	30,450

#3 SPINNERS

17ST DURAL BRAZIER HEAD RIVETS

1		3/32			250		
2	.0975	.09375	.00746	.00690	253		
3	.0975	"			254		
Average					252.3	33,850	36,600

1	.1295	1/8	.01317		462	35,100	
2	.1300	.125	.01328	.01228	454	34,200	
3	.1305	"	.01339		465	34,750	
Average	.1300				460.3	34,680	37,500

#4 35 Rivets - Welded Heads

Specimen	Driven Dia.	Nominal Dia	Driven Area	Nominal Area	Load	#/□" Driven Area	#/□" Nominal A
1	.0975	3/32	.00746		93	12,470	
2	.0990	.09375	.00770	.00690	116	15,070	
3	—	"					
Average	.0983				104.5	13,770	15150
1	.1280	1/8			166		
2	.1280	.125	.01288	.01228	197		
3	.1280	"			174		
Average					179	13,900	14,590
1		5/32			270		
2	.1615	.15625	.02046	.01919	253		
3		"			256		
Ave					259.7	12,700	13,520

#5 Automatic Riveter

17ST Dural Brazier Head Rivets

1	.1710	5/32			783		
2	.1710	.15625	.02296	.01919	763		
3	.1710	"			832		
Ave	.1710				793	34,600	41,300

Specimens from Test Series # 1, 2 & 3 That Failed in Shear

17ST Rivets Dia. = 1/4 S = .064

Han. Riveted Brazier Hd.

Specimen	Driven Dia.	Load
1	0.263	1821
2	0.263	1794
3	0.262	1780
4	0.261	1830
5	0.263	1868
6	0.262	1826
7	0.263	1860
8	0.263	1840
9	0.261	1833
10	0.262	1839
11	0.261	1847
12	0.2625	1798
13	0.260	1866
14	0.262	1810
15	0.262	1864
16	0.2645	1820
17	0.262	1874
18	0.264	1897
19	0.263	1858
20	0.264	1832
21	0.264	1872
22	0.264	1855
23	0.262	1812
24	0.260	1859
25	0.263	1905
26	0.263	1846
27	0.262	1860
28	0.263	1915
29	0.264	1833
30	0.263	1866
31	0.263	1884
Average	0.2625	1847.1

Driven Area = .0541 □"

Nominal Area = .04913

#/□ Driven A = 34,140

#/□ Nominal A = 37,600

#6 One Shot Gun

17ST Dural Brazier Head Rivets

Specimen	Driven Dia	Nominal Dia	Driven Area	Nominal Area	# Load	#/□" Driven Area	#/□" Nominal Area
1	.1000	3/32	.00784	.00690	273	34,800	
2	.0985	.09375	.00762		272	35,700	
3	.1000	"	.00785		272	34,600	
Average	.0995				272.3	35,030	39,400
1	.1615	5/32	.02046	.01919	724		
2	.1615	.15625			728		
3	.1615	"			720		
Average	.1615				724	35,400	37,750
1	.2590	1/4	.0526	.04913	1888	35,820	
2	.2570	.250	.0519		1865	35,950	
3	.2570	"	.0519		1788	34,450	
Average	.2577				1847	35,400	37,600

Specimen	Driven Dia	Nominal Dia	Driven Area	Nominal Area	Load	#/□" Driven Area	#/□" Nominal Area
1	.1300	1/8	.01328	.01228	462	34,800	
2	.1305	.125	.01339		486	36,300	
3	.1305	"	.01339		487	36,400	
Average	.1303				478.3	35,830	38,960
1	.1960	3/16	.03015	.02762	1050	34,860	
2	.1960	.1875	.03015		1067	35,350	
3	.1980	"	.0308		1106	36,090	
Average	.1967				1074.3	35,400	38,900

#7 Vibrators

17ST Dural Brazier Head Rivets

1	.0985	3/32	.00762	.00690	267	35,050	
2	.1005	.09375	.00793		285	35,[illegible]50	
3	.1000	"	.00785		281	35,800	
Average	.0997				277.7	35,600	40,200
1	.1615	5/32	.02046	.01919	748	36,600	
2	.1612	.15625	.02040		738	36,200	
3	.1605	"	.02020		716	35,500	
Average	.1611				734	36,100	38,220

1	.1285	1/8	.01298	.01228	463	35,700	
2	.1295	.125	.01317	.01228	467	35,500	
3	.1300	"	.01328	.01228	489	36,800	
Average	.1293				473	36,000	38,500
1	.1960	3/16	.03015	.02762	1062	35,250	
2	.1953	.1875	.03000		1090	36,350	
3	.1950	"	.02982		1069	35,800	
Average	.1954				1073.7	35,800	38,870

#8 Pneumatic Squeezers

17ST Dural Brazier Head Rivets

1	.0987	3/32	.00765	.00690	268	35,050	
2	.0995	.09375	.00777		277	35,650	
3	.0990	"	.00770		276	35,900	
Average	.0991				273.7	35,530	39,600
1	.1605	5/32	.02022	.01919	708	35,000	
2	.1600	.15625	.02010		695	34,600	
3	.1607	"	.02025		745	36,800	
Average	.1604				716	35,700	37,380

1	.1310	1/8	.01348	.01228	477	35,400	
2	.1305	.125	.01339		488	36,450	
3	.1300	"	.01328		486	36,600	
Average	.1305				483.7	36,150	39,400
1	.1950	3/16	.02985	.02762	1087		
2	.1950	.1875			1074		
3	.1950	"			1052		
Average					1071	35,900	38,790

SHEAR OF 17ST UNDRIVEN RIVETS
CONSTANT SHEET THICKNESS OF .125"

SPEC	NOM. DIA	ACTUAL DIA	ACTUAL AREA	LOAD	#/□" ACTUAL A
1	3/32	.0925	.00671	261	
2	"	"	"	252	
3	"	"	"	268	
AVE				260.3	38,800
1	1/8	.1255	.01238	462	
2	"	"	"	446	
3	"	"	"	477	
AVE				478.3	38,600

SPEC	NOM. DIA	ACTUAL DIA	ACTUAL AREA	LOAD	#/□" ACTUAL A
1	5/32	.1562	.01917	725	
2	"	"	"	742	
3	"	"	"	746	
AVE			"	737.7	38,500
1	3/16	.1885	.02793	1044	
2	"	"	"	1050	
3	"	"	"	1058	
AVE				1050.7	37,650
1	1/4	.2510	.0495	1710	
2	"	"	"	1730	
3	"	"	"	1716	
AVE	"			1718.7	34,700

SHEAR OF 3S RIVETS (UNDRIVEN)
CONST. SHEET THICKNESS OF .125"

1	3/32"	.0925	.00671	92	
2	"	"		106	
3	"	"		—	
AVE				99	14,780
1	1/8"	.1275	.01278	200	
2	"	"	"	190	
3	"	"	"	193	
AVE				194.3	15,200

1	5/32	.1585	.01974	306	
2	"	"	"	303	
3	"	"	"	303	
AVE.				304	15,400

3S RIVETS — HAND RIVETED
"S" SAME AS USED IN TEST SERIES #4

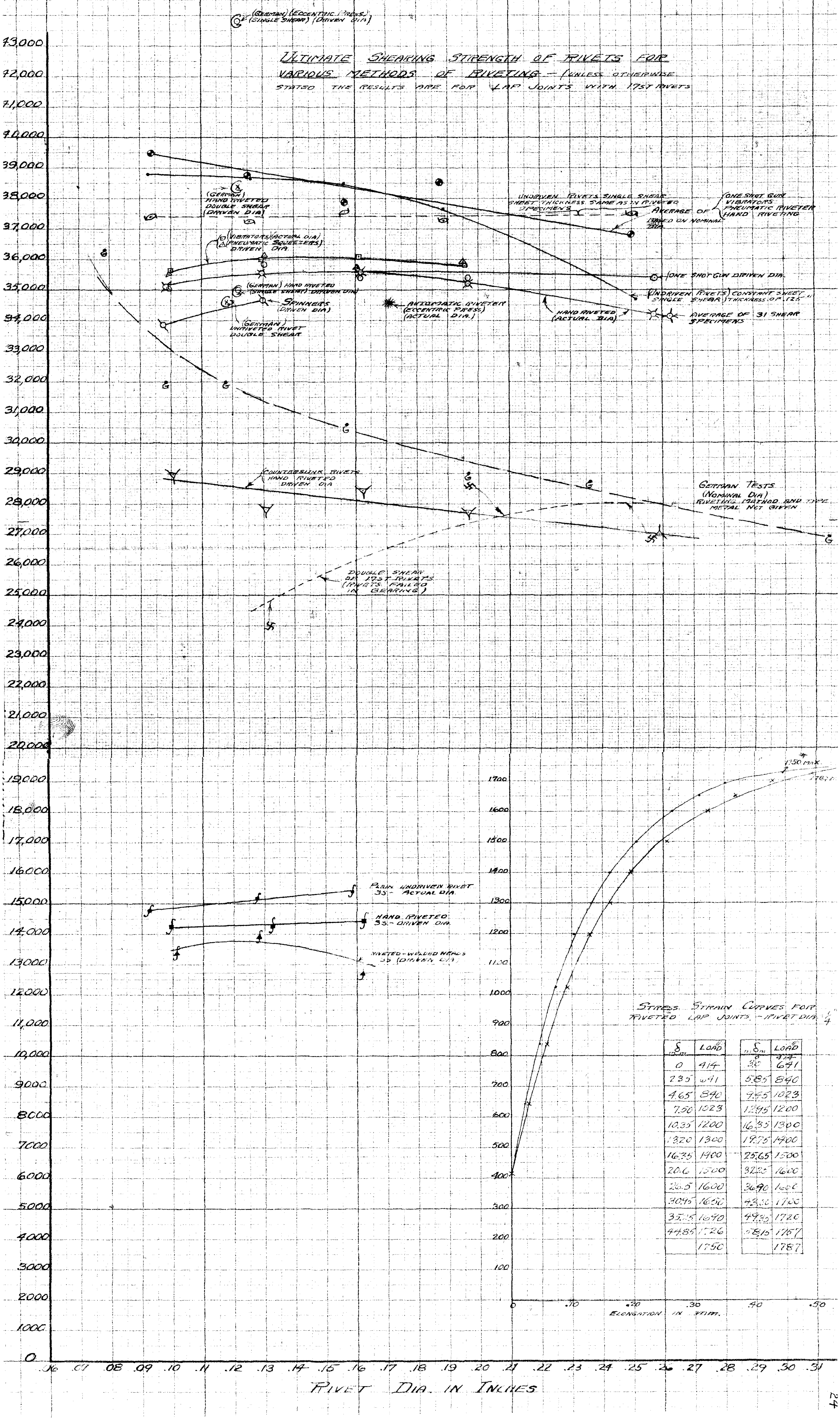
SPEC.	NOM DIA	DRIVEN DIA	DRIVEN AREA	LOAD	#/□" DRIVEN A
1	3/32	.0995	.00778	111	14,300
2	"	.0995	"	111	14,300
3	"	.0990	.00770	109	14,170
AVE				110.3	14,250

SPEC	NOM. DIA	DRIVEN DIA.	DRIVEN AREA	LOAD	#/□" DRIVEN A
1	1/8	.1325	.0138	196	
2	"	"	"	197	
3	"	"	"	198	
AVE				197	14,280
1	5/32	.1625	.02075	298	14,380
2	"	.1628	.0208	301	14,490
3	"	.1628	.0208	301	14,490
AVE					14,450

SHEAR OF 17ST UNDRIVEN RIVETS
SAME SHEET THICKNESS AS USED IN TEST SERIES #4

SPEC	NOM. DIA.	ACTUAL DIA	SHEET THICKNESS	ACTUAL AREA	LOAD #	#/□" ACTUAL A.
1	3/32"	.0935	.040	.00687	258	
2	"	"	"	"	254	
3	"	"	"	"	259	
AVE					257	37,400
1	1/8"	.1255	.045	.01238	458	
2	"		"	"	468	
3	"		"	"	458	
AVE					461	37,250
1	5/32	.1565	.064	.01922	722	
2	"	"	"	"	722	
3		"	"	"	722	
AVE	"			"	722	37,550

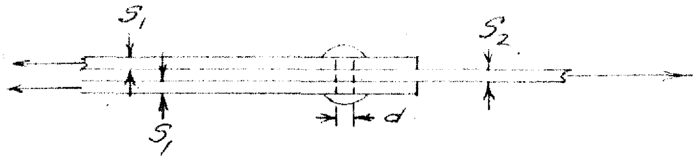
SPEC.	NOM DIA	ACTUAL DIA	SHEET THICKNESS	ACTUAL AREA	LOAD	#/□" ACTUAL A.
1	3/16	.1885	.072	.02790	1044	
2	"	"	"	"	1015	
3	"	"	"	"	1061	
AVE					1040	37,300
1	1/4	.2500	.091	.04910	1840	
2	"	"	"	"	1842	
3	"	"	"	"	1838	
AVE					1840	37,500



δ m/m	LOAD #	δ m/m	LOAD #
0	414	0 / 3.0	414 / 641
2.35	641	5.85	840
4.65	840	9.45	1023
7.50	1023	12.95	1200
10.35	1200	16.35	1300
13.20	1300	19.75	1400
16.35	1400	25.65	1500
20.6	1500	32.25	1600
26.5	1600	36.90	1650
30.95	1650	43.30	1700
35.25	1690	49.35	1720
44.85	1726	58.15	1757
	1750		1787

TEST SERIES # 4b

BUTT JOINT (HAND RIVETED)



DOUBLE SHEAR OF 1/8 17ST RIVETS VS SHEET "S_2"

Spec	S_1	S_2	Nom Dia "d"	True Dia.	Area True "d"	Load	#/□" True "d"	Spec	S_1	S_2	Nom Dia "d"	True Dia	Area True	Load	#/□" True d
* 1	.032	.032	1/8	.1320	.01368	678		1	.032	.045	1/8	.1300	.01327	780	29,300
2	"	"	"	"	"	645		2	"	"	"	.1300	"	779	29,300
3	"	"	"	"	"	644		3	"	"	"	.1290	.01307	760	29,100
Ave	"	"	"	"	"	656	24,000	Ave	"	"	"				29,200
1	.032	.064	1/8	.1240	.01307	848	32,500	1	.032	.072	1/8	.1320	.01368	932	34,100
2	"	"	"	.1320	.01368	897	32,800	2	"	"	"	.1300	.01327	861	32,500
3	"	"	"	.1240	.01307	800	30,600	3	"	"	"	.1320	.01368	950	34,800
Ave	"	"	"				32,000	Ave	"	"	"				33,800

FAILURE IN RIVET BEARING, ALSO * ABOVE

Spec	S_1	S_2	Nom Dia "d"	True Dia.	Area True "d"	Load	#/□"	Spec	S_1	S_2	Nom Dia "d"	True Dia	Area True	Load	#/□"
1	.045	.064	3/16	.1970	.03045	1769		1	.045	.091	1/4	.2560	.05140	2711	
2	"	"	"	"	"	1733		2	"	"	"	"	"	2757	
3	"	"	"	"	"	1745		3	"	"	"	"	"	2720	
Ave	"	"	"	"	"	1749	28,600	Ave	"	"	"	"	"	2744	26,800

BEARING STRENGTH OF SHEET

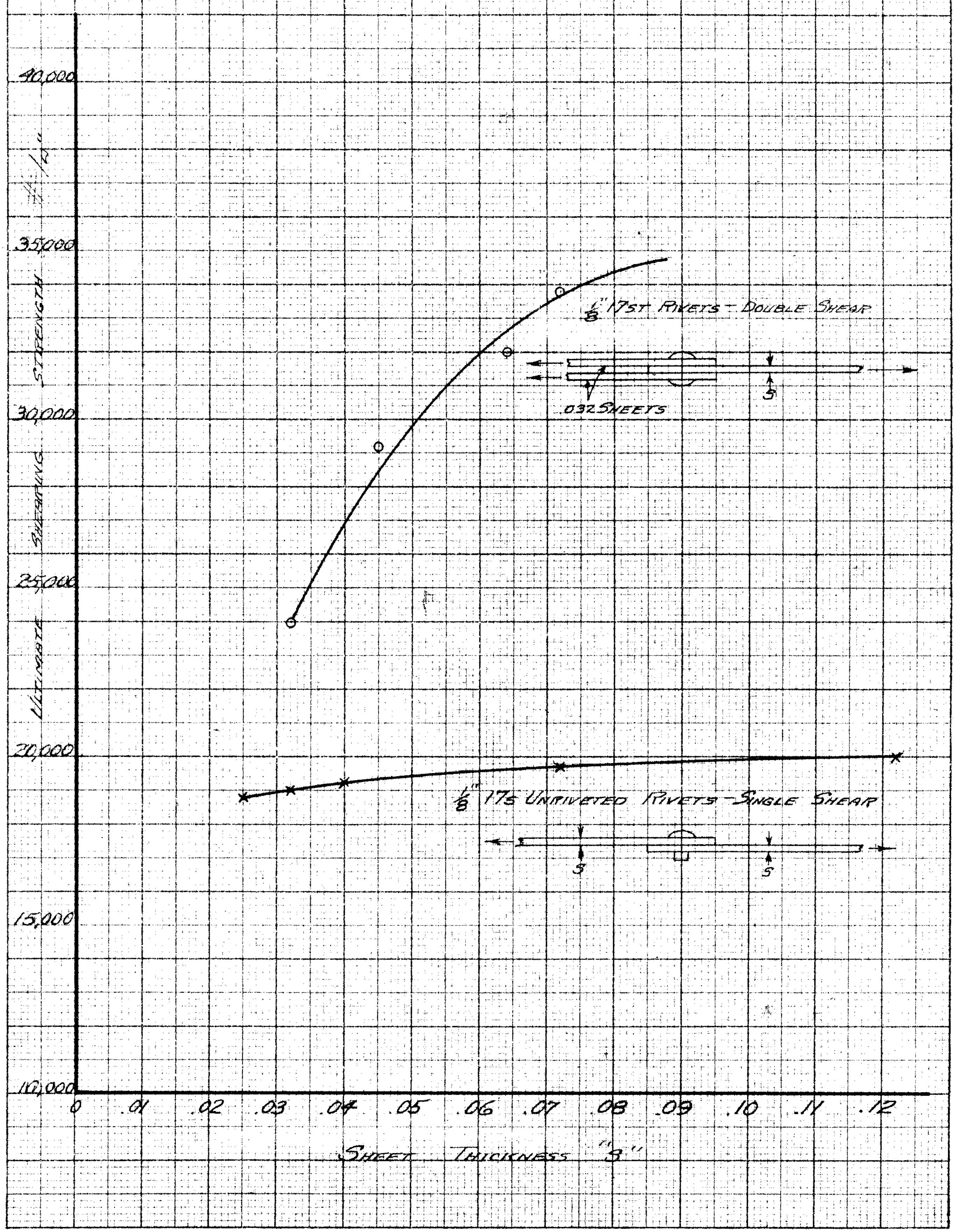
Spec	S_1	S_2	Nom Dia "d"	True Dia.	Area	Load	#/□"	Spec	S_1	S_2	Nom Dia "d"	True Dia	Area	Load	#/□"
1	.032	.0220	1/8	.132	.0029	590		1	.0310	.091	3/16	.1910	.00592	1506	
2	"	"	"	"	"	609		2	"	"	"	"	"	1528	
3	"	"	"	"	"	576		3	"	"	"	"	"	1530	
Ave	"	"	"	"	"	592	204,000	Ave	"	"	"	"	"	1521	128,500

SINGLE SHEAR OF 1/8 17S UNRIVETED RIVETS VS SHEET THICKNESS

Spec.	Sheet Thickness "S"	Dia. Rivet	Area	Load	#/□"
1	.1220	.1245	.01219	243	
2	"	"	"	242	
3	"	"	"	245	
4	"	"	"	245	
5	"	"	"	246	
Ave	"	"	"	244	20,000
1	.072	"	"	242	
2		"	"	240	
3		"	"	238	
Ave		"	"	240	19,700

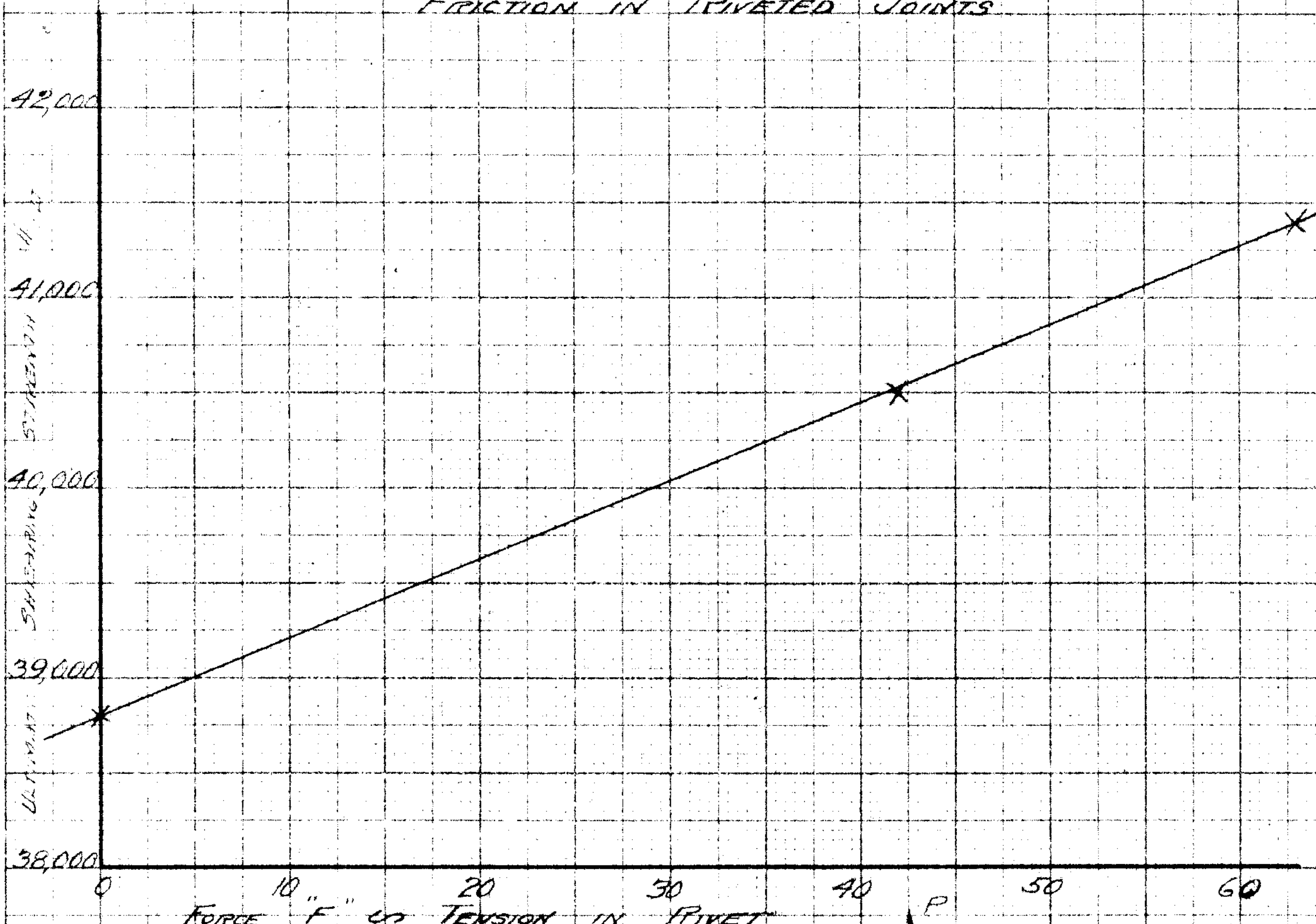
Spec.	Sheet Thickness "S"	Dia. Rivet	Area	Load	#/□"
1	.040	.1245	.01219	234	
2	"	"	"	234	
3	"	"	"	237	
Ave	"	"	"	235	19,300
1	.032	"	"	233	
2	"	"	"	232	
3	"	"	"	231	
Ave	"	"	"	232	19,050
1	.025	"	"	232	
2	"	"	"	226	
3	"	"	"	230	
Ave	"	"	"	229	18,800

THE EFFECT OF SHEET THICKNESS ON THE SHEAR OF RIVETS

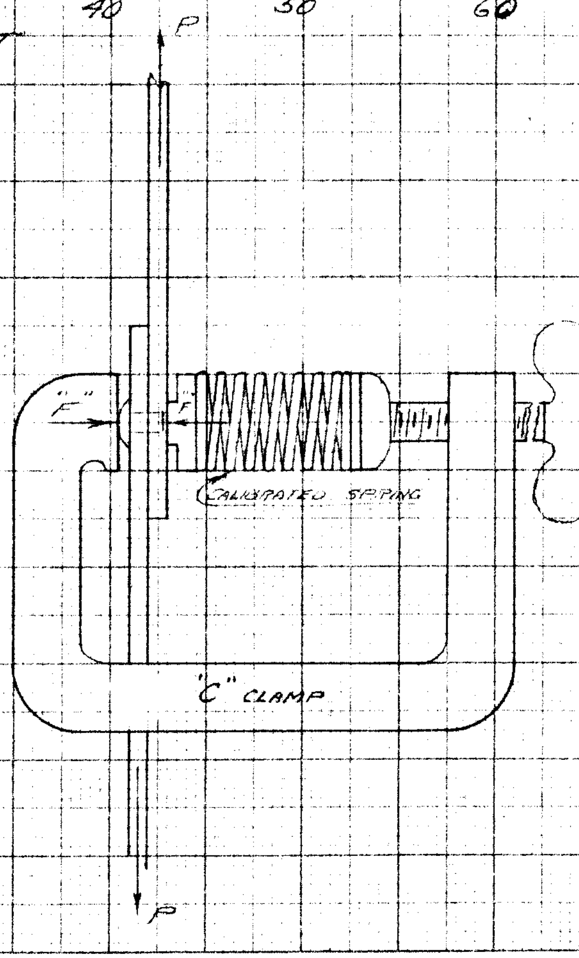


TEST SERIES #4c

FRICTION IN RIVETED JOINTS



SPECIMEN	NOMINAL RIVET DIA	NOMINAL RIVET AREA	SHEAR LOAD "P"	SHEAR #/□"	FORCE "F" or TENSION IN RIVET	TENSION IN RIVET #/□"
1	1/8	.01228	476		0	
2	.125	"	476		0	
3	"	"	477		0	
4	"	"	477		0	
AVE	"	"	476.5	38,800	0	0
1	"	"	496		42	
2	"	"	496		42	
3	"	"	500		42	
4	"	"	497		42	
AVE	"	"	497.3	40,500	42	3420
1	"	"	510		63	
2	"	"	509		63	
3	"	"	507		63	
AVE	"	"	508.7	41,400	63	5220



Test Series No. 5

Tests conducted by Mr. Webster of the Douglas Company several years ago led to the investigation made in this test series. He found from malleability tests on rivets of various ageings, that a rivet of twelve hours ageing was more malleable than one of three hours ageing.

At first it was thought that the malleability would show up in shearing tests. A batch of rivets were tested in double shear using the shearing blocks shown on page 33 . The result of this test is plotted on the same page. As can be seen from the curve the rivet passes through a critical stage between the ages of 6 and 20 hours. During this critical period most any shearing value may be expected within certain limits. The scatter seems to lie above the value of 36,000 #/□". The shearing value remains more or less constant at this value after an ageing of 27 hours. The heat treatment of the rivets is given on the curve sheet. After quenching, the rivets were dried with a contrifugal drier and immediately placed into an ice box, where they remained until aging was started. They were aged at a more or less constant tempature of 20° C.

Since the malleability did not show up in the shearing tests as expected a second batch of rivets were tested by the same test blocks used by Mr. Webster. The rivet specimen was placed between two compression blocks as shown on page 36. The deflection of the rivet for various loadings was measured by two Ames Dials as shown. An average of the two readings was taken as the true compression of the rivet shank. The ames Dials were an intergal part of the block, consequently there was no error due to slippage. The results show considerable scatter throughout most of the ages tested, however decreases around the ageing time of 100 hours. A couple of the specimens were as malleable at 20 hours as when first taken from the ice box. The heat treatment for this batch of rivets is given on the curve sheet, and the ageing took place at approximately 25°C.

Test Series No.6(Tensile Strength)

A series of specimens were tested to determine the tensile strength of 24srt for various sheet thickness. The results are shown on page 37. The interesting feature of the test was the fact that every specimen failed by shear at approximately 45°.

Test Series No 7. (Shear of Rivets in a line)

Information regarding the load taken by rivets placed in a line in a riveted joint is of value especially since the design practice is contrary to the elastic theory.

Tests were made on specimens with the number of rivets in a line varying from one to twelve. The results of the tests is shown on page 39 and agrees with design practice. The drop off of the ultimate load per rivet is small, even for twelve rivets in a line. If we are designing for ultimate load a rivet will contribute approximately the same strength to a joint regardless of the number of rivets in a line. However if we design on the elastic limit the result is somewhat different.

The Germans have found that a rivet hole has already passed a 2% deformation(elasticlimit) at about one fourth its ultimate load, also it has been shown by tests (Ref. Proceedings A. S. C. E. Nov. 1932) that when rivets are placed in a row the second rivet receives very little load until the first rivet has passed its elastic limit. If this is the case we would expect the first rivet in a row of ten rivets to pass its elastic limit at a value of three or four percent the ultimate load of the joint. If there is a reversal of the load in a multi-riveted joint of this type the end rivets would probably become loose at relative small loads.

In order to test hole enlargements in a multi-riveted joint, specimens have been made with varous number of rivets in a row which will accommodate both tension and compression. The specimens have not yet been tested, but it is planned to vayy both the magnitude of the reversing load and the number of times of reversals, after which the heads of the rivets will be milled off and the hole enlargements measured.

Test Series #5a

Shearing Value of ¼" 17ST Dural Rivets For Various Times of Ageing. Shearing Value is For Undriven Rivets in Double Shear Tests.

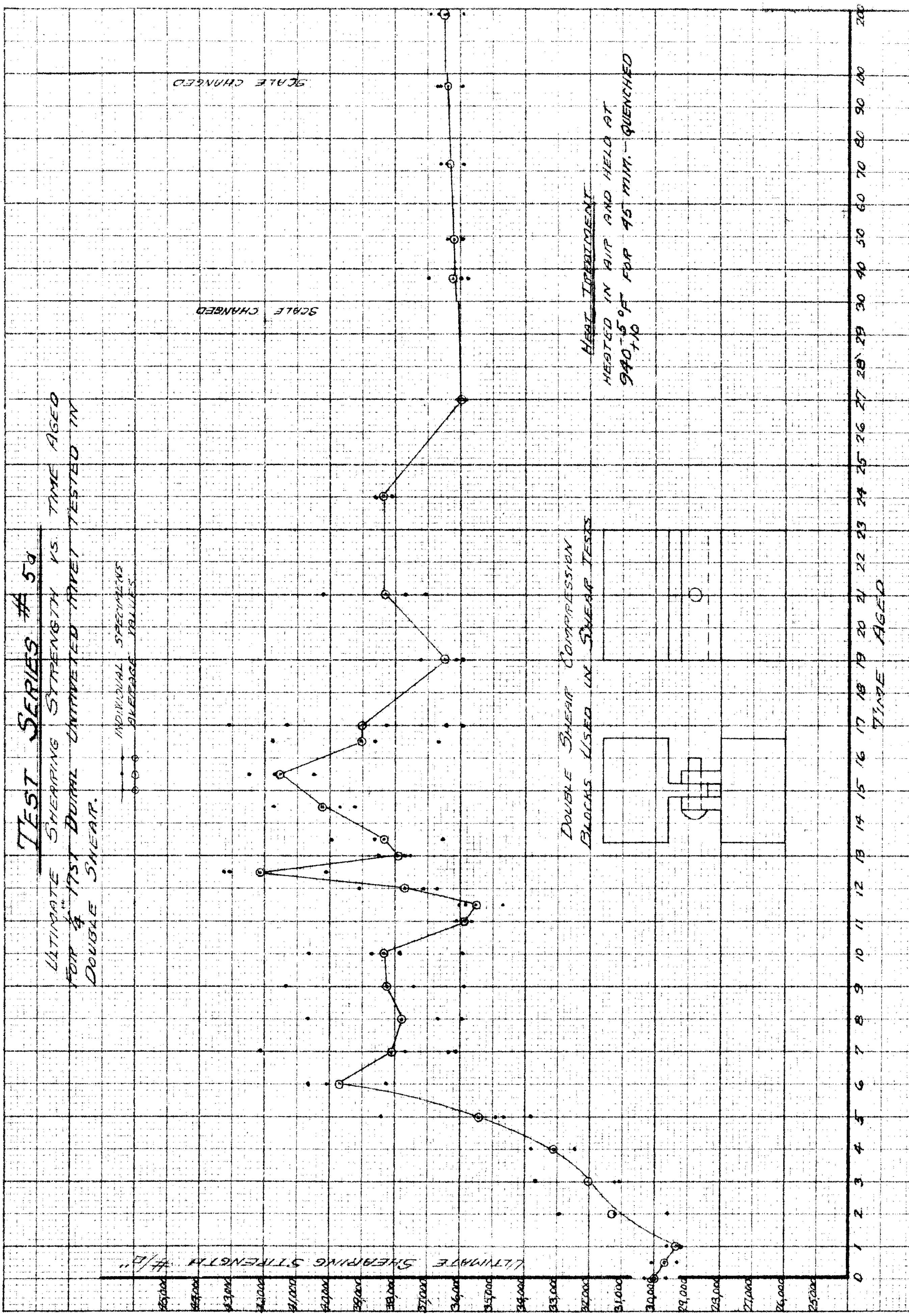
Average True Dia. = .2465   Area = .04772 □"

Time Aged Hours	Specimen	Load #	Shearing Strength #/□"
0	1	2892	30,300
0	2	2828	29,630
0	3	2864	30,010
	Ave.	2861	29,980
½	1	2796	29,310
½	2	2838	29,740
½	3	2875	30,120
	Ave	2836	29,715
1	1	2827	29,620
1	2	2790	29,230
1	3	2787	29,200
	Ave	2801	29,350
2	1	2828	29,630
2	2	2978	31,200
2	3	3145	32,950
	Ave	2984	31,270
3	1	2972	31,140
3	2	3218	33,720
3	3	2980	31,220
	Ave	3057	32,030
4	1	3161	33,120
4	2	3100	32,480
4	3	3228	33,820
	Ave	3163	33,140
5	1	3309	34,670
5	2	3229	33,830
5	3	3668	38,430
5	4	3333	34,920
	Ave	3385	35,470
6	1	3828	40,110
6	2	3882	40,680
6	3	3650	38,240
	Ave.	3787	39,679

Time Aged	Specimen	Load #	Shearing Strength #/□"
7	1	3602	37,740
7	2	4023	42,150
7	3	3471	36,370
7	4	3450	36,150
	Ave	3636	38,100
8	1	3435	35,990
8	2	3500	36,670
8	3	3886	40,720
	Ave.	3607	37,790
9	1	3430	35,940
9	2	3650	38,240
9	3	3950	41,390
9	4	3573	37,440
	Ave.	3651	38,250
10	1	3700	38,770
10	2	3882	40,680
10	3	3433	35,970
10	4	3615	37,880
	Ave	3658	38,330
11	1	3430	35,940
11	2	3448	36,130
11	3	3400	35,630
	Ave	3426	35,900
11½	1	3422	35,860
11½	2	3439	36,030
11½	3	3308	34,660
	Ave	3390	35,520
12	1	3738	39,170
12	2	3547	37,170
12	3	3506	36,740
	Ave	3597	37,690

TIME AGED HOURS	SPECIMENS	LOAD #	SHEARING STRENGTH #/□"
12½	1	4115	43,120
12½	2	3829	40,120
12½	3	4125	43,220
	AVE	4023	42,150
13	1	3587	37,580
13	2	3600	37,720
13	3	3675	38,510
	AVE.	3621	37,940
13½	1	3489	36,560
13½	2	3815	39,970
13½	3	3687	38,630
	AVE	3664	38,390
14½	1	3984	41,740
14½	2	3790	39,710
14½	3	3744	39,230
	AVE	3839	40220
15½	1	3865	40,500
15½	2	4058	42,520
15½	3	3980	41,700
	AVE	3968	41,580
16½	1	3500	36,670
16½	2	3989	41,800
16½	3	3684	38,600
	AVE	3724	39,020
17	1	3480	36,460
17	2	4118	43,150
17	3	3948	41,370
17	4	3653	38,280
17	5	3433	35,970
	AVE	3726	39,040
19	1	3434	35,980
19	2	3446	36,110
19	3	3553	37,230
	AVE	3478	36,440

TIME AGED HOURS	SPECIMEN	LOAD #	SHEARING STRENGTH #/□"
21	1	3541	37,100
21	2	3841	40,250
21	3	3600	37,720
	AVE	3661	38,360
24	1	3669	38,440
24	2	3637	38,110
24	3	3685	38,610
	AVE	3664	38,390
27	1	3419	35,820
27	2	3433	35,970
27	3	3445	36,100
27	4	3433	35,970
	AVE.	3433	35,970
37	1	3415	35,780
37	2	3433	35,970
37	3	3532	37010
	AVE	3460	36,250
49	1	3477	36,400
49	2	3429	35,900
49	3	3459	36,200
	AVE	3455	36,200
72	1	3482	36,450
72	2	3425	35,900
72	3	3497	36,600
	AVE	3468	36,300
96	1	3499	36,620
96	2	3431	35,950
96	3	3502	36,690
	AVE	3477	36,400
192	1	3503	36,700
192	2	3528	36,970
192	3	3430	35,900
192	4	3482	36,450
	AVE	3485	36,480


TEST SERIES #5a
ULTIMATE SHEARING STRENGTH VS. TIME AGED
FOR 1/4" 17ST DURAL UNRIVETED RIVET TESTED IN DOUBLE SHEAR.
INDIVIDUAL SPECIMENS
AVERAGE VALUES
DOUBLE SHEAR COMPRESSION BLOCKS USED IN SHEAR TESTS
HEAT TREATMENT
HEATED IN AIR AND HELD AT 940 +10 -5 °F FOR 45 MIN. - QUENCHED
SCALE CHANGED
SCALE CHANGED
TIME AGED
ULTIMATE SHEARING STRENGTH #/□"

TEST SERIES 5b

TIME AGED HOURS 0		0		0		0		1/2		1		1 1/2	
mm DEFLECTION "δ"	LOAD #	δ mm	LOAD #	δ mm	LOAD #	δ mm	LOAD #	δ mm	LOAD #	δ mm	LOAD #	δ mm	LOAD #
.0	100	0	100	0	100	0	100	0	100	0	100	0	100
.15	500	0.16	500	0.23	500	0.28	500	0.22	500	0.14	500	0.23	500
.82	1000	0.86	1000	0.99	1000	0.81	1000	0.90	1000	0.79	1000	0.90	1000
2.13	1500	2.36	1500	2.65	1500	2.08	1500	2.29	1500	2.01	1500	2.33	1500
4.04	2000	4.30	2000	4.36	2000	4.05	2000	4.01	2000	3.88	2000	4.27	2000
5.16	2500	5.37	2500	5.41	2500	5.18	2500	5.09	2500	5.07	2500	5.30	2500
6.08	3000	6.18	3000	6.14	3000	6.04	3000	5.90	3000	5.89	3000	6.08	3000

2		2 1/2		3 1/4		3 3/4		4		4 1/4		4 3/4	
0	100	0	100	0	100	0	100	0	100	0	100	0	100
0.21	500	0.18	500	0.23	500	0.05	500	0.16	500	0.15	500	0.15	500
0.90	1000	0.75	1000	0.81	1000	0.56	1000	0.68	1000	0.63	1000	0.67	1000
2.30	1500	1.98	1500	1.96	1500	1.69	1500	1.82	1500	1.76	1500	1.78	1500
4.09	2000	3.92	2000	3.81	2000	3.49	2000	3.75	2000	3.78	2000	3.65	2000
5.28	2500	5.10	2500	4.88	2500	4.63	2500	4.85	2500	4.83	2500	4.73	2500
6.09	3000	5.90	3000	5.75	3000	5.49	3000	5.68	3000	5.63	3000	5.63	3000

5 1/4		5 1/2		5 3/4		6 1/2		6 3/4		7 3/4		8 3/4	
0	100	0	100	0	100	0	100	0	100	0	100	0	100
0.20	500	0.16	500	0.14	500	0.30	500	0.15	500	0.14	500	0.16	500
0.90	1000	0.70	1000	0.66	1000	0.66	1000	0.73	1000	0.66	1000	0.60	1000
2.62	1500	1.78	1500	1.82	1500	1.79	1500	1.82	1500	1.76	1500	1.72	1500
4.40	2000	3.55	2000	3.76	2000	3.76	2000	3.76	2000	3.83	2000	3.75	2000
5.48	2500	4.66	2500	4.84	2500	4.84	2500	4.90	2500	4.96	2500	4.91	2500
6.13	3000	5.59	3000	5.73	3000	5.68	3000	5.72	3000	5.79	3000	5.72	3000

9 3/4		10 1/4		10 3/4		11 3/4		12		12 1/2		13	
0	100	0	100	0	100	0	100	0	100	0	100	0	100
0.23	500	0.13	500	0.10	500	0.12	500	0.18	500	0.17	500	0.12	500
0.78	1000	0.62	1000	0.56	1000	0.58	1000	0.75	1000	0.63	1000	0.61	1000
2.05	1500	1.70	1500	1.60	1500	1.68	1500	1.82	1500	1.76	1500	1.66	1500
4.06	2000	3.30	2000	3.29	2000	3.38	2000	3.66	2000	3.77	2000	3.54	2000
5.20	2500	4.62	2500	4.60	2500	4.55	2500	4.87	2500	4.93	2500	4.73	2500
6.06	3000	5.57	3000	5.55	3000	5.51	3000	5.72	3000	5.70	3000	5.59	3000

13 1/6		13 1/2		14 1/6		19 1/3		20 1/3		22 1/2		24	
0	100	0	100	0	100	0	100	0	100	0	100	0	100
0.04	500	0.14	500	0.11	500	0.22	500	0.17	500	0.26	500	0.15	500
0.46	1000	0.63	1000	0.58	1000	0.81	1000	0.65	1000	0.88	1000	0.59	1000
1.51	1500	1.77	1500	1.63	1500	2.40	1500	1.75	1500	2.29	1500	1.70	1500
3.23	2000	3.90	2000	3.31	2000	4.34	2000	3.72	2000	4.13	2000	3.64	2000
4.33	2500	4.94	2500	4.48	2500	5.34	2500	4.80	2500	5.28	2500	4.86	2500
5.23	3000	5.75	3000	5.38	3000	6.13	3000	5.63	3000	6.13	3000	5.67	3000

Test Series # 56

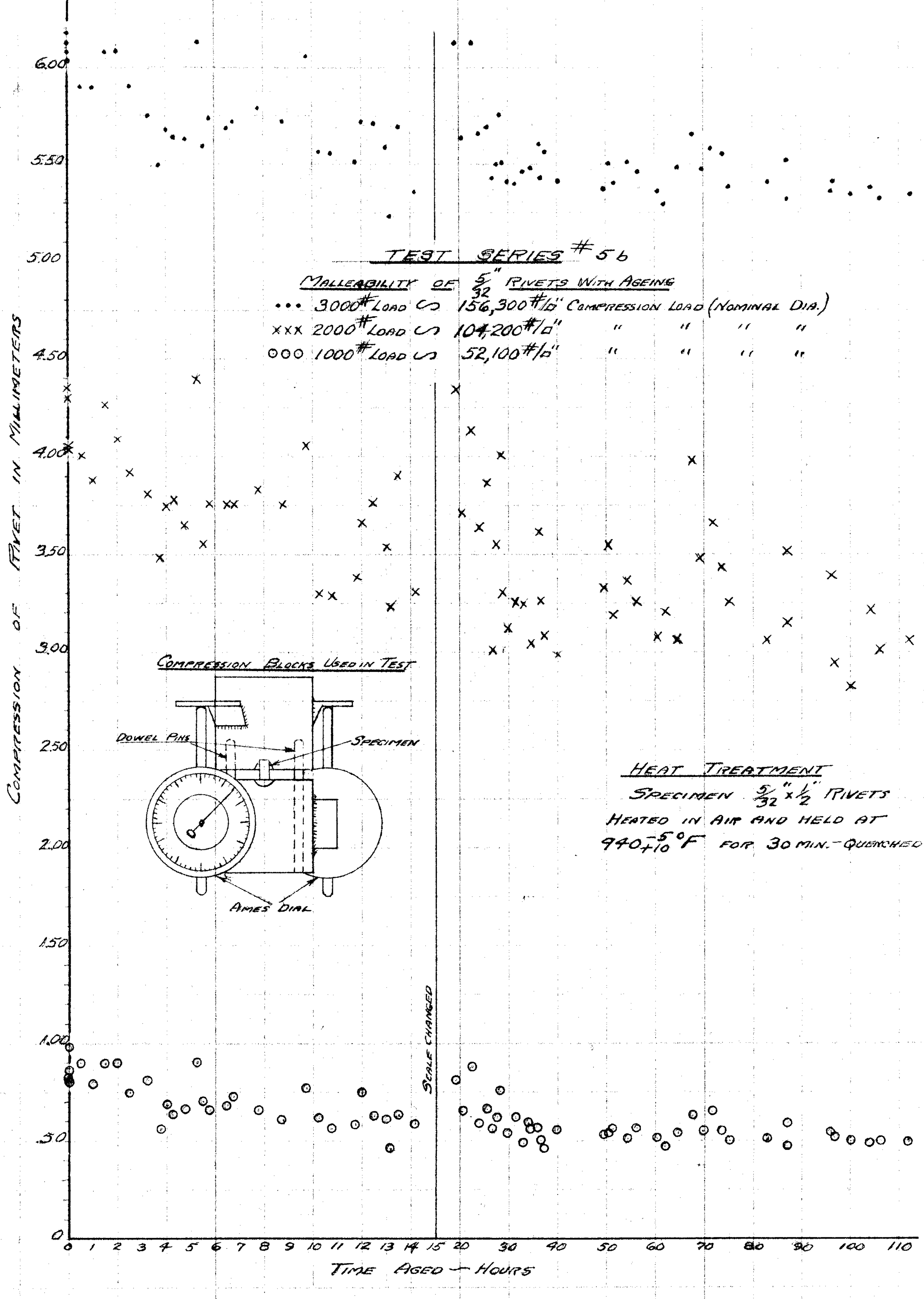
25½		26½		27½		28¼		28½		29¾		31¼	
δmm	Load #	δmm	Load #	δmm	Load #	δmm	Load #	δmm	Load #	δmm	Load #	δmm	Load #
0	100	0	100	0	100	0	100	0	100	0	100	0	100
0.18	500	0.12	500	0.13	500	0.39	500	0.12	500	0.07	500	0.18	500
0.66	1000	0.56	1000	0.62	1000	0.76	1000	0.52	1000	0.53	1000	0.62	1000
1.73	1500	1.59	1500	1.60	1500	1.94	1500	1.56	1500	1.51	1500	1.60	1500
3.87	2000	3.01	2000	3.55	2000	4.10	2000	3.30	2000	3.12	2000	3.27	2000
4.89	2500	4.37	2500	4.66	2500	5.07	2500	4.58	2500	4.43	2500	4.49	2500
5.68	3000	5.42	3000	5.50	3000	5.76	3000	5.51	3000	5.40	3000	5.40	3000

33		34½		36¼		36½		37⅓		40		49½	
0	100	0	100	0	100	0	100	0	100	0	100	0	100
.08	500	0.11	500	0.15	500	0.09	500	0.04	500	0.13	500	0.13	500
.49	1000	0.56	1000	0.56	1000	0.50	1000	0.46	1000	0.56	1000	0.53	1000
.53	1500	1.56	1500	1.62	1500	1.51	1500	1.41	1500	1.53	1500	1.51	1500
3.25	2000	3.04	2000	3.62	2000	3.27	2000	3.08	2000	2.98	2000	3.34	2000
4.60	2500	4.46	2500	4.80	2500	4.53	2500	4.56	2500	4.35	2500	4.50	2500
5.47	3000	5.48	3000	5.60	3000	5.42	3000	5.56	3000	5.41	3000	5.37	3000

50½		51⅓		54⅓		56⅓		60¼		62		64¾	
0	100	0	100	0	100	0	100	0	100	0	100	0	100
0.12	500	0.12	500	0.10	500	0.14	500	0.11	500	0.08	500	0.12	500
0.54	1000	0.57	1000	0.51	1000	0.57	1000	0.51	1000	0.47	1000	0.54	1000
1.55	1500	1.55	1500	1.56	1500	1.53	1500	1.48	1500	1.46	1500	1.51	1500
3.56	2000	3.18	2000	3.37	2000	3.26	2000	3.07	2000	3.20	2000	3.06	2000
4.68	2500	4.48	2500	4.63	2500	4.51	2500	4.41	2500	4.43	2500	4.54	2500
5.50	3000	5.40	3000	5.51	3000	5.46	3000	5.35	3000	5.28	3000	5.48	3000

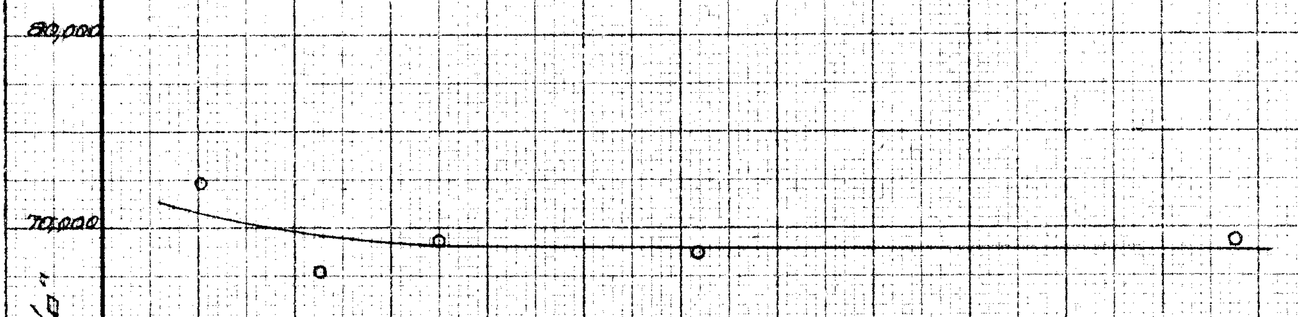
67½		69½		71½		73½		75		83		87	
0	100	0	100	0	100	0	100	0	100	0	100	0	100
0.20	500	0.14	500	0.20	500	0.10	500	0.08	500	0.11	500	0.10	500
0.63	1000	0.55	1000	0.66	1000	0.55	1000	0.50	1000	0.51	1000	0.59	1000
1.72	1500	1.53	1500	1.71	1500	1.48	1500	1.50	1500	1.50	1500	1.59	1500
3.98	2000	3.49	2000	3.67	2000	3.43	2000	3.26	2000	3.07	2000	3.52	2000
5.02	2500	4.68	2500	4.84	2600	4.66	2500	4.55	2500	4.48	2500	4.63	2500
5.66	3000	5.47	3000	5.59	3000	5.55	3000	5.38	3000	5.40	3000	5.52	3000

87		96		96½		100		104		106		112	
0	100	0	100	0	100	0	100	0	100	0	100	0	100
0.10	500	0.13	500	0.10	500	0.12	500	0.15	500	0.11	500	0.10	500
0.47	1000	0.54	1000	0.52	1000	0.50	1000	0.49	1000	0.50	1000	0.50	1000
1.44	1500	1.54	1500	1.48	1500	1.40	1500	1.47	1500	1.51	1500	1.43	1500
3.15	2000	3.39	2000	2.94	2000	2.82	2000	3.21	2000	3.02	2000	3.07	2000
4.38	2500	4.58	2500	4.35	2500	4.33	2500	4.40	2500	4.37	2500	4.36	2500
5.31	3000	5.35	3000	5.41	3000	5.34	3000	5.38	3000	5.32	3000	5.33	3000

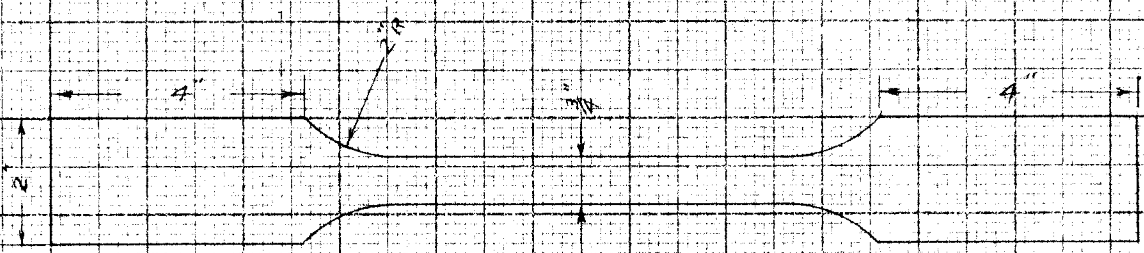

TEST SERIES #5b
MALLEABILITY OF 5/32" RIVETS WITH AGEING
••• 3000# LOAD ∽ 156,300#/□" COMPRESSION LOAD (NOMINAL DIA.)
××× 2000# LOAD ∽ 104,200#/□" " " " "
ooo 1000# LOAD ∽ 52,100#/□" " " " "
COMPRESSION BLOCKS USED IN TEST
DOWEL PINS
SPECIMEN
AMES DIAL
HEAT TREATMENT
SPECIMEN 5/32" x 1/2" RIVETS
HEATED IN AIR AND HELD AT
940 +10 -5 °F FOR 30 MIN.-QUENCHED
SCALE CHANGED
COMPRESSION OF RIVET IN MILLIMETERS
TIME AGED — HOURS
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
.50
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 20 30 40 50 60 70 80 90 100 110

TEST SERIES #6

ULTIMATE TENSILE STRENGTH OF 24 SRT DURAL SHEET vs. SHEET THICKNESS



Specimen	WIDTH "W"	SHEET THICKNESS "S"	AREA	LOAD	#/□"
1	.7510	.0201	.0151	1075	71,200
2	.7510	.0201	.0151	1100	72,800
3	.7510	.0201	.0151	1108	73,900
Average					72,470



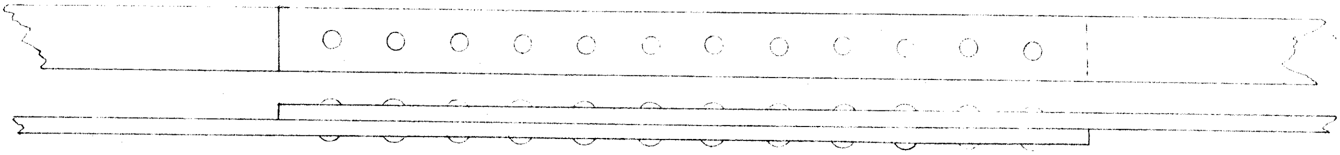
Specimen	WIDTH "W"	SHEET THICKNESS "S"	AREA	LOAD	#/□"
1	.7510	.0325	.0244	1646	67,500
2	.7510	.0328	.02462	1671	67,900
3	.7510	.0329	.02472	1671	67,700
Ave					67,700
1	.7510	.0448	.03365	2325	69,100
2	.7510	.0444	.03335	2323	69,800
3	.7510	.0450	.03380	2333	69,100
Ave					69330

Specimen	WIDTH "W"	SHEET THICKNESS "S"	AREA	LOAD	#/□"
1	.07510	.0720	.0541	3780	69,800
2	.07510	.0715	.0537	3700	68,900
3	.07510	.0715	.0537	3610	67,200
Ave					68,630
1	.07510	.1280	.0962	6660	69,300
2	.07510	.1275	.0958	6640	69,300
3	.07510	.1275	.0958	6670	69,700
Ave					69430

TEST SERIES # 7

SHEAR OF MULTIPLE RIVETS IN A ROW

3/16" – 17ST RIVETS – 17SRT SHEET



Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	1	3/16 .1875	.1990	1107#	1107	40,000	35,600

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	2	.1875	.1990	2222	1111	40,250	35,700

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
* 1	3	.1875	.1990	2960	990	35,800	
2	3	"	"	3120	1040	37,600	
Ave.		"	"		1040	37600	33,450

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	4	.1875	.1990	4330	1080		
2	4	"	"	4300	1075		
3	4	"	"	4220	1055		
Ave.		"	"		1070	38,750	34,400

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	5	.1875	.1990	5470	1095		
2	5	"	"	5420	1085		
3	5	"	"	5240	1050		
Ave					1077	38,950	34,600

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	6	.1875	.1990	6250	1040		
2	6	"	"	6290	1048		
3	6	"	"	6410	1068		
Ave					1051	38,050	33,800

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	7	.1875	.1990	7660	1094		
2	7	"	"	7560	1080		
3	7	"	"	7510	1073		
Ave					1082	39,200	34,800

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	8	.1875	.1990	8530	1066		
2	8	"	"	8590	1074		
3	8	"	"	8540	1067		
Ave					1069	38,700	34,400

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	9	.1875	.1990	9410	1045		
2	9	"	"	9440	1049		
3	9	"	"	9460	1051		
Ave.					1048	37,950	33,700

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	10	.1875	.1990	10,300	1030		
2	10	"	"	10,700	1070		
3	10	"	"	10,230	1023		
Ave					1041	37,750	33,500

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	11	.1875	.1990	11,660	1060		
2	11	"	"	11,160	1014		
3	11	"	"	11,960	1087		
Ave					1054	38,200	33,900

Specimen	Number Rivets "n"	Nominal Dia Rivets	Driven Dia Rivets	Load "P"	P/n	#/□" Nominal	#/□" Driven
1	12	.1875	.1990	12,690	1057		
2	12	"	"	12,660	1055		
3	12	"	"	12,490	1040		
Ave					1051	38,050	33,800

NOMINAL AREA = .02762

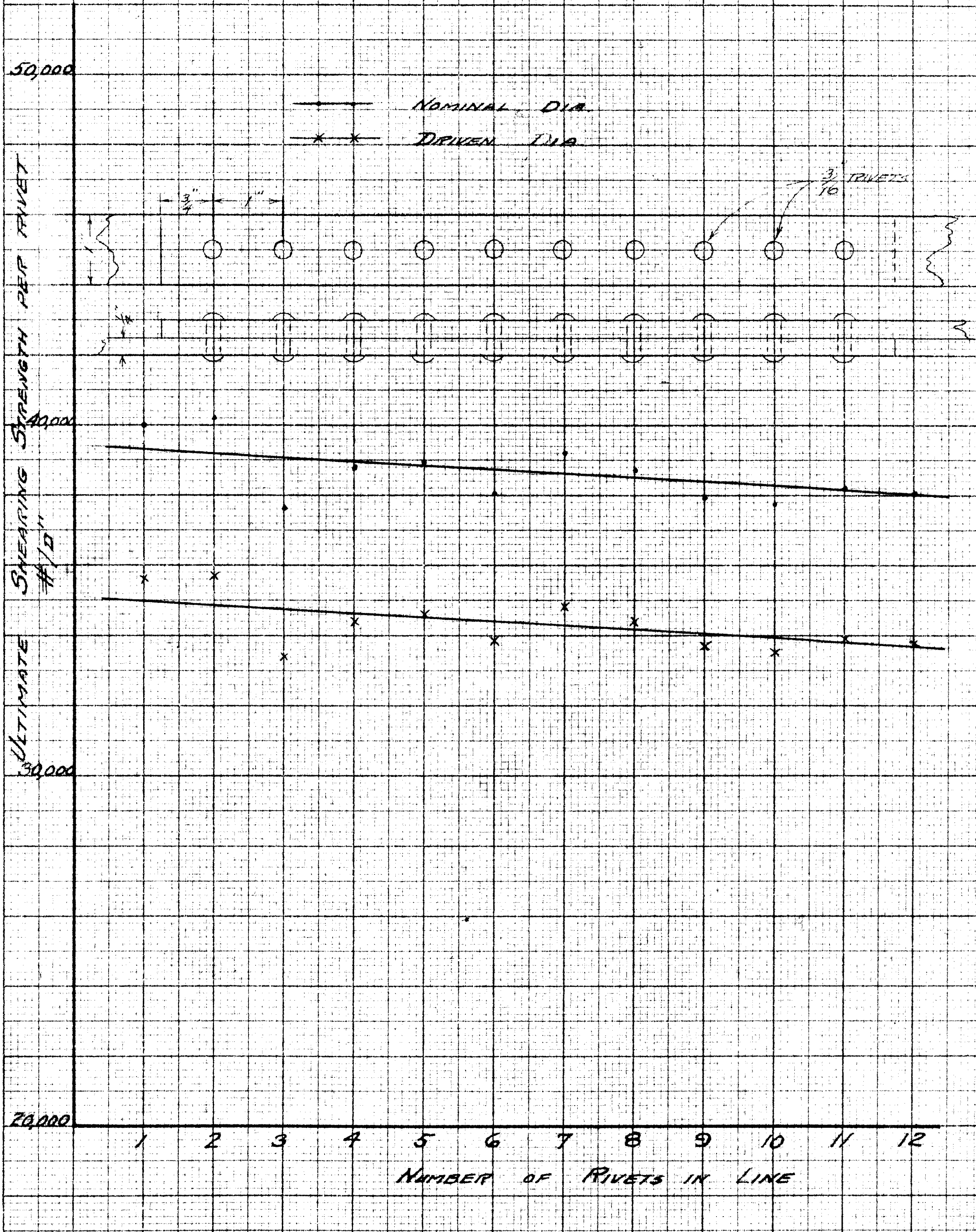
DRIVEN AREA = .0311

* RIVETS DID NOT FAIL SIMULTANEOUSLY

TEST SERIES #7

MULTIPLE RIVETED JOINT

SINGLE SHEAR OF 17ST RIVETS IN A LINE



Discussion.

On pages 44 and 45 charts have been plotted for a riveted lap joint based on the following formulas for rivet failure.

Shearing $F = \frac{\pi d^2}{4} f_s$ F = force taken per rivet
f = shearing ultimate
d = diameter of rivet.

Bearing $F = Sdf_b$ f_b = bearing ultimate
S = sheet thickness

Tearing $F = (P-d)Sf_t$ f_t = tearing ultimate
P = pitch of rivets

Critical Dia. $d = \frac{4}{\pi} \frac{f_b}{f_s} S$

Critical Pitch $P = (\frac{f_b}{f_t} + 1)d$

The values of fs, fb, and ft used were taken from test results on pages 5, 11 & 24 and are as follows.

Using 24srt sheet and 17st round head rivets.

f_s = 35,000 #/□" f_b = 110,000 #/□"

f_t was taken from the curve on page 5 since it is a function of the rivet pitch.

Using 24srt sheet and 17st countersunk rivets, (where the rivet head is countersunk into the sheet)

f_s = 27.000 #/□" f_b = 80000 #/□"

f_t as before was taken from page 5.

The value for the edge distance "e" was taken as 2.0d in both cases.

In reading the charts one usually starts with the plate thickness and follows that line along until it intersects the shear curve. This gives the critical rivet diameter. The nearest available rivet diameter is chosen (preferably larger) and the strength read off on the scale of ordinates at the lift, the ordinate of the plate thickness line being used if the rivet diameter is above the critical figure, while the ordinate of the shear parabola is chosen if the diameter is below the critical. To find the pitch and edge distance "e", read down from the chosen diameter, and take the nearest convenient pitch larger than that given by the graph.

If a riveted lap joint is designed by the use of these charts, or by the same equations used in constructing these charts, the joint will have approximately equal strength in all the places in which failure usually occurs. This combination gives the riveted joint the maximum efficiency that can be obtained for the type of joint and values of f_s, f_b, and f_t used. This is the combination that would be used in design unless economy is the design factor. In such a case the pitch of the rivets would probably be increased to themaximum value that would still permit the joint to carry the designed load and at the same time keep its desired appearance.

Economy seems to be of major importance in the present design practice of riveted joints. Not only is the simplest type of riveted joint used (which has low efficiency) but the practice is to reduce the eff. still further by increasing the pitch to a maximum. A change from this kind of design practice will probably come through a simplification of the riveting methods.

It would be interesting at this point to see the affect of changing the values fs, fb, and ft, in a single riveted lap joint, while designing the joint to give maximum efficiency. That is, the following equations will be the criterian for design.

$$\frac{\pi d^2}{4} f_s = s d f_b = (P-d) s f_t$$

Under these conditions it is interesting to note that the shearing ultimate "f_s", of the rivets used has no affect what so ever on the efficiency of the riveted joint. This is evident from the equation for efficiency. The efficiency of a single riveted lap joint will be -

$$\text{Eff.} = \frac{(P-d) f_t}{P F_t} \times 100$$

where F_t is the ultimate tinsile strength of the sheet.

Subsituting the critical values for "p" and "d" we have - $\text{Eff.} = \dfrac{100}{F_t\left(\frac{1}{f_t}+\frac{1}{f_b}\right)}$

The affect of doubleing fs, fb, and ft, separately is shown on page 46. The sheet thickness "S" was assumed constant throughout. The values given are based on unity as the orginal value.

An increase in bearing strength seems to be the most desirable since it not only increases the efficiency but reduces the labor cost by increasing the pitch. However the weight of rivets used and weight of joint is increased due to the increase in rivet diameter required.

A high tearing value is very desirable for efficiency but has unfavorable cost and weight increase.

A low shearing value is desirable for economy, but it increases the weitht of the rivets and joint by increasing the rivet diameter required. The efficiency is unchanged.

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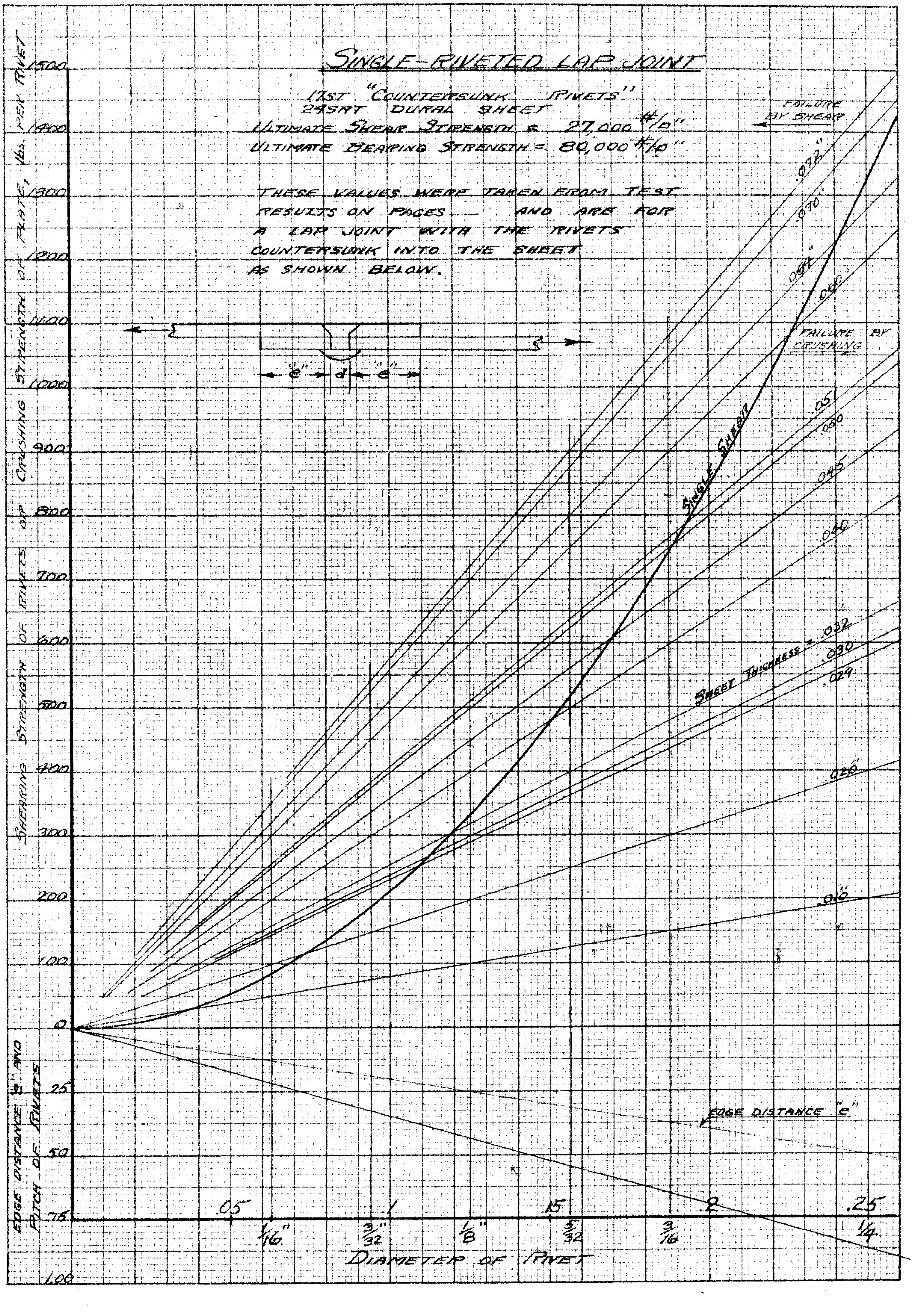
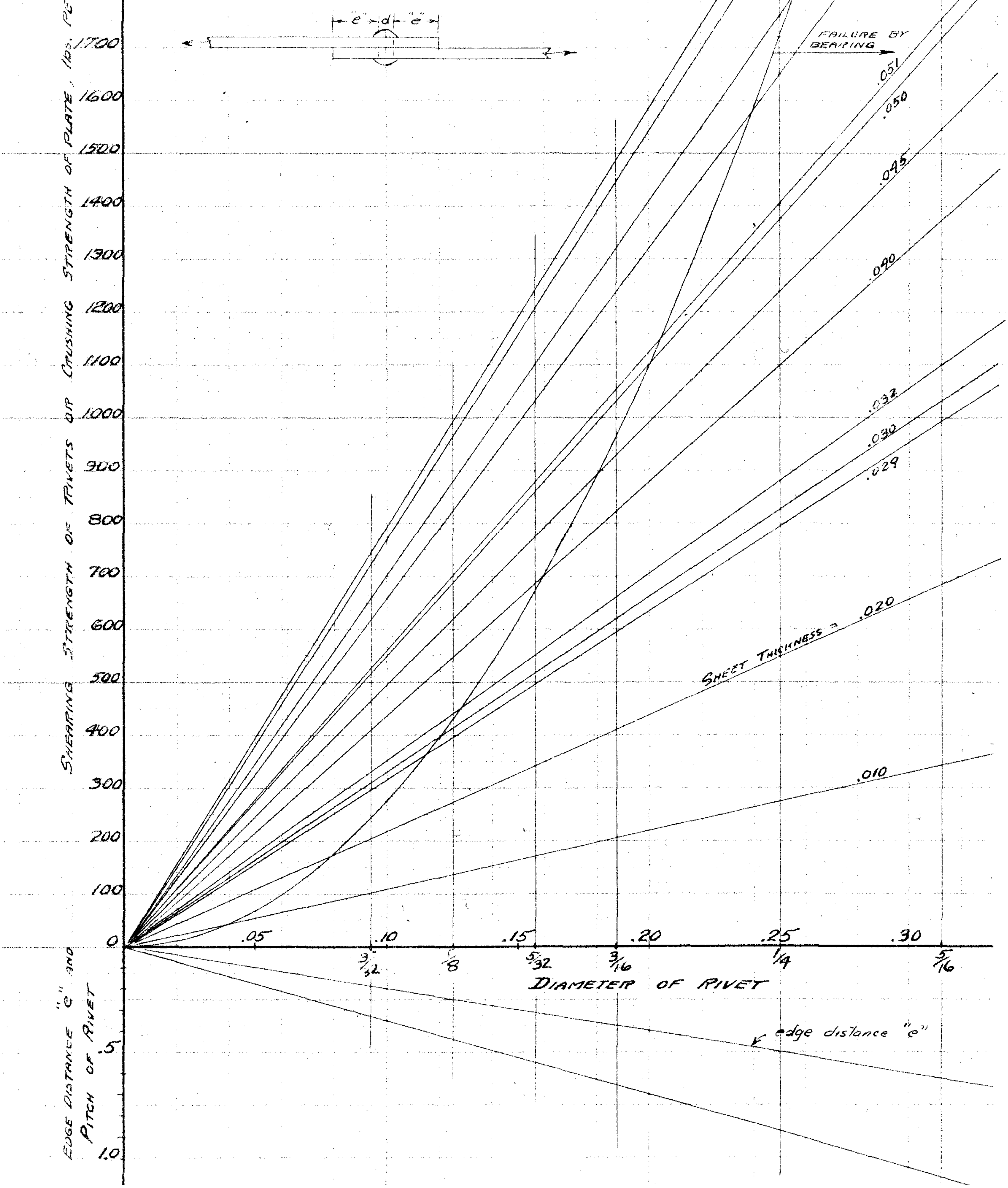

SINGLE-RIVETED LAP JOINT
17ST "COUNTERSUNK RIVETS"
24SRT DURAL SHEET
ULTIMATE SHEAR STRENGTH = 27,000 #/□"
ULTIMATE BEARING STRENGTH = 80,000 #/□"
THESE VALUES WERE TAKEN FROM TEST RESULTS ON PAGES ___ AND ARE FOR A LAP JOINT WITH THE RIVETS COUNTERSUNK INTO THE SHEET AS SHOWN BELOW.
"e"
d
"e"
FAILURE BY SHEAR
FAILURE BY CRUSHING
SINGLE SHEAR
SHEET THICKNESS = .032
.072"
.070"
.064"
.060
.051
.050
.045
.040
.030
.029
.020
.010
EDGE DISTANCE "e"
BEARING STRENGTH OF RIVETS OR CRUSHING STRENGTH OF PLATE, lbs. PER RIVET
EDGE DISTANCE "e" AND PITCH OF RIVETS
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
25
50
75
1.00
.05
.1
.15
.2
.25
1/16"
3/32"
1/8"
5/32
3/16
1/4
DIAMETER OF RIVET

SINGLE RIVETED LAP JOINT

17ST ROUND OR BRAZIER HEAD RIVETS
24SRT DURAL SHEET.

ULTIMATE SHEARING STRENGTH = 35,000 #/□"
ULTIMATE BEARING STRENGTH = 110,000 #/□"

THESE VALUES WERE TAKEN FROM TEST RESULTS ON PAGES ____



THE AFFECT OF CHANGING f_s, f_b & f_t

		SHEARING STRENGTH "f_s" DOUBLED ASSUMING "S" CONSTANT	BEARING STRENGTH "f_b" DOUBLED ASSUMING "S" CONSTANT AND USING $f_t = 60{,}000$ #/□" $f_{b_1} = 100{,}000$ #/□" $F_t = 65{,}000$ #/□" $f_{b_2} = 200{,}000$ #/□"	TEARING STRENGTH "f_t" DOUBLED ASSUMING "S" CONSTANT AND USING $f_b = 100{,}000$ #/□" $f_{t_1} = 30{,}000$ #/□" $F_t = 65{,}000$ #/□" $f_{t_2} = 60000$ #/□"
1	DIA. OF RIVET	1/2	2	1
2	LOAD PER. RIVET	1/2	4	1
3	PITCH OF RIVETS	1/2	3.25	0.62
4	NUMBER RIVETS REQ.	2	0.31	1.62
5	LABOR COST OF RIVETING	2	0.31	1.62
6	WEIGHT OF RIVETS REQ.	1/3	1.86	1.62
7	Wt. of overloping sheet (edge distance "e")	1/2	2	1
8	Efficiency of JOINT	1	1.22	1.62

References

1. Pleines , Wilhelm : Riveting in Metal Airplane Construction. Technical Memorandums No. 596-7-8-9

2. Hilbes, W : Riveted Joints in Thin Plates. Technical Memorandum No. 590

3. ______________ : Multi. Riveted Joints Proccedings A. S. C. E. Nov. 1932

4. Aluminum Co. of America. : The riveting of Aluminum.