9.1 Sheet Metal Layout and Forming

Definitions

bend radius (BR)—The radius of the *inside* of the bend.

bend allowance—The actual amount of metal used in the bend.

setback(SB)—The distance between the bend tangent line and the mold line.

K—A multiplier used to find the bend allowance for bends of angles other than 90°.

neutral line—The line through a material that has no stresses imposed by a bend; material along the neutral axis neither shrinks nor stretches when the material is bent.

mold line—The extension of the flat side of an object beyond the radius.

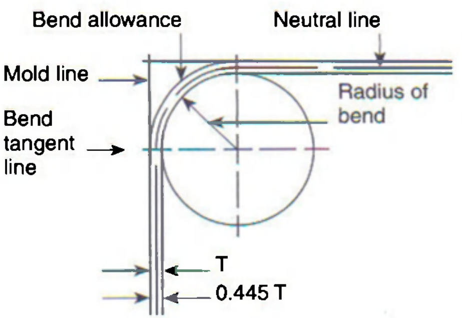
sight line—A line drawn on a sheet metal layout that is placed directly below the nose of the radius bar in a leaf brake.

open angle—A bend in which the metal is bent less than 90°.

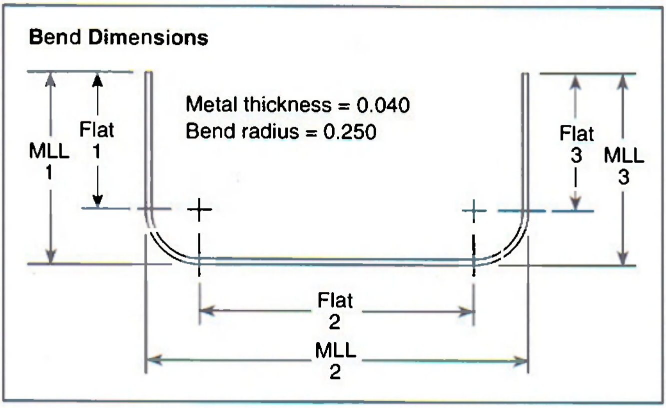
closed angle—A bend in which the metal is bent more than 90°.

bend tangent line—The line in a sheet metal layout that marks the end of a flat surface and the beginning of the bend.

Bend Nomenclature



Layout Procedure



Example

MLL 1 = 1.00 inch
MLL 2 = 2.00 inch
MLL 3 = 1.00 inch

BR = 0.25 inch
Thickness = 0.040 inch

1. Find the setback by adding the bend radius and the metal thickness.

$$SB = (BR + MT) \times K$$
$$= (0.250 + 0.040) \times 1$$
$$= 0.290 \text{ inch}$$

The value of the constant K can be found in the chart on Pages 212 through 214.

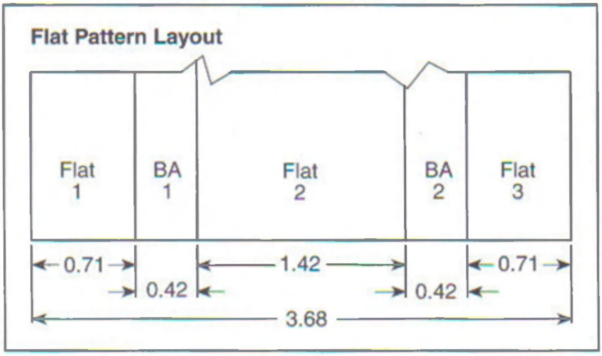
For a 90° bend, K = 1

2. Find the length of flat 1 by subtracting the setback from mold line length 1.

$$\text{Flat } 1 = \text{MLL } 1 - \text{setback}$$
$$= 1.00 - 0.290$$
$$= 0.710$$

3. Find the bend allowance by using the chart on Pages 215 through 217.

Follow the 0.040 metal thickness row across to the column for 1/4-inch bend radius. The top number is the amount of bend allowance for a 90° bend, and the bottom number is the amount of material used for each degree of bend. In the example, a 90° bend in a piece of 0.040 sheet metal using a 1/4-inch bend radius requires 0.421 inch of metal.



4. Find the length of flat 2 by subtracting two setbacks from mold line length 2.

   Flat 2 = MLL 2 – 2 setbacks

   = 2.00 – 2(0.290)

   = 1.42 inch

5. Bend allowance 2 is the same as bend allowance 1.

   BA 2 = 0.421 inch

6. Find the length of flat 3 by subtracting the setback from mold line length 3.

   Flat 3 = MLL 3 – Setback

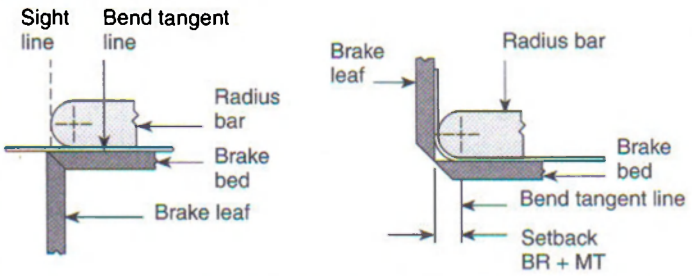
   = 1.00 – 0.290

   = 0.710 inch

7. Cut the material 3.68 inches wide and as long as needed. Mark the bend tangent lines with a sharp-pointed soft lead pencil.

9.1

Correct placement of metal in the brake



1. Clamp the metal in the brake with the bend tangent lines even with the beginning of the radius of the radius bar.
2. You can determine this position by drawing a sight line inside the bend allowance material. Draw this line one bend radius from the bend tangent line.
3. Position the material so this sight line is directly below the edge of the radius block when viewing it perpendicular to the surface of the metal.
4. When the brake leaf is raised, the metal will form smoothly around the radius bar.

9.2 Minimum Bend Radii for 90° Bends in Aluminum Alloys

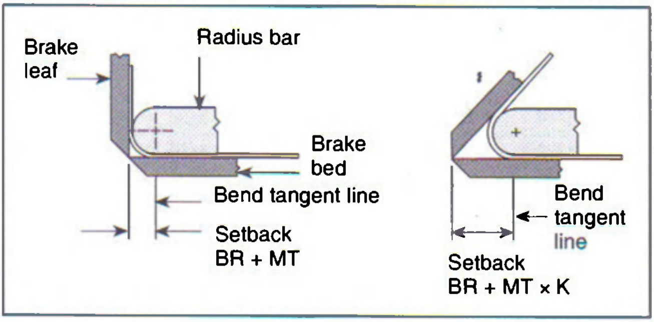
Alloy and Temper	Sheet Thickness							
	0.020	0.025	0.032	0.040	0.050	0.063	0.071	0.080
2024-O[1]	1/32	1/16	1/16	1/16	1/16	3/32	1/8	1/8
2024-T4[1,2]	1/16	1/16	3/32	3/32	1/8	5/32	7/32	1/4
5052-O	1/32	1/32	1/16	1/16	1/16	1/16	1/8	1/8
5052-H34	1/32	1/16	1/16	1/16	3/32	3/32	1/8	1/8
6061-O	1/32	1/32	1/32	1/16	1/16	1/16	3/32	3/32
6061-T4	1/32	1/32	1/32	1/16	1/16	3/32	5/32	5/32
6061-T6	1/16	1/16	1/16	3/32	3/32	1/8	3/16	3/16
7075-O	1/16	1/16	1/16	1/16	3/32	3/32	5/32	3/16
7075-W	3/32	3/32	1/8	5/32	3/16	1/4	9/32	5/16
7075-T6[1]	1/8	1/8	1/8	3/16	1/4	5/16	3/8	7/16

[1] Clad sheet may be bent over a slightly smaller radii than the corresponding tempers of bare alloy sheets.

[2] Immediately after quenching, this alloy may be formed over appreciably smaller radii.

9.2

9.3 Setback



Setback for a 90° bend is the bend radius plus the metal thickness (BR + MT). For any angle other than 90°, the sum of the bend radius and the metal thickness must be multiplied by the value of "K" found in the setback (K) chart below.

Setback (K) Chart

Degrees	K	Degrees	K
1	0.00873	18	0.15838
2	0.01745	19	0.16734
3	0.02618	20	0.17633
4	0.03492	21	0.18534
5	0.04366	22	0.19438
6	0.05241	23	0.20345
7	0.06116	24	0.21256
8	0.06993	25	0.22169
9	0.07870	26	0.23087
10	0.08749	27	0.24008
11	0.09629	28	0.24933
12	0.10510	29	0.25862
13	0.11393	30	0.26795
14	0.12278	31	0.27732
15	0.13165	32	0.28674
16	0.14054	33	0.29621
17	0.14945	34	0.30573

Degrees	K	Degrees	K
35	0.31530	79	0.82434
36	0.32492	80	0.83910
37	0.33459	81	0.85408
38	0.34433	82	0.86929
39	0.35412	83	0.88472
40	0.36397	84	0.90040
41	0.37388	85	0.91633
42	0.38386	86	0.93251
43	0.39391	87	0.80978
44	0.40403	88	0.96569
45	0.41421	89	0.9827
46	0.42447	90	1.0000
47	0.43481	91	1.0176
48	0.44523	92	1.0355
49	0.45573	93	1.0538
50	0.46631	94	1.0724
51	0.47697	95	1.0913
52	0.48773	96	1.1106
53	0.49858	97	1.1303
54	0.50952	98	1.1504
55	0.52057	99	1.1708
56	0.53171	100	1.1917
57	0.54295	101	1.2131
58	0.55431	102	1.2349
59	0.56577	103	1.2572
60	0.57735	104	1.2799
61	0.58904	105	1.3032
62	0.60086	106	1.3270
63	0.61280	107	1.3514
64	0.62487	108	1.3764
65	0.63707	109	1.4019
66	0.64941	110	1.4281
67	0.66188	111	1.4550
68	0.67451	112	1.4826
69	0.68728	113	1.5108
70	0.70021	114	1.5399
71	0.71329	115	1.5697
72	0.72654	116	1.6003
73	0.73996	117	1.6318
74	0.75355	118	1.6643
75	0.76733	119	1.6977
76	0.78128	120	1.7320
77	0.79543	121	1.7675
78	0.80978	122	1.8040

Degrees	K	Degrees	K
123	1.8418	152	4.0108
124	1.8807	153	4.1653
125	1.9210	154	4.3315
126	1.9626	155	4.5107
127	2.0057	156	4.7046
128	2.0503	157	4.9151
129	2.0965	158	5.1455
130	2.1445	159	5.3995
131	2.1943	160	5.6713
132	2.2460	161	5.9758
133	2.2998	162	6.3137
134	2.3558	163	6.6911
135	2.4142	164	7.1154
136	2.4751	165	7.5957
137	2.5386	166	8.1443
138	2.6051	167	8.7769
139	2.6746	168	9.5144
140	2.7475	169	10.385
141	2.8239	170	11.430
142	2.9042	171	12.706
143	2.9887	172	14.301
144	3.0777	173	16.350
145	3.1716	174	19.081
146	3.2708	175	22.904
147	3.3759	176	26.636
148	3.4874	177	38.188
149	3.6059	178	57.290
150	3.7320	179	114.590
151	3.8667	180	Infinite

9.4 Bend Allowance Chart

The top number in each group of numbers (at the intersections of the metal thickness rows and bend radius columns) is the bend allowance for a 90° bend. The bottom number is the bend allowance for each degree of bend.

Metal thickness	Radius of bend (inches)						
	1/32	1/16	3/32	1/8	5/32	3/16	7/32
0.020	.062	.113	.161	.210	.259	.309	.358
	.000693	.001251	.001792	.002333	.002874	.003433	.003977
0.025	.066	.116	.165	.214	.263	.313	.362
	.000736	.001294	.001835	.002376	.002917	.003476	.004017
0.028	.068	.119	.167	.216	.265	.315	.364
	.000759	.001318	.001859	.002400	.002941	.003499	.004040
0.032	.071	.121	.170	.218	.267	.317	.366
	.000787	.001345	.001886	.002427	.002968	.003526	.004067
0.038	.075	.126	.174	.223	.272	.322	.371
	.000837	.001396	.001937	.002478	.003019	.003577	.004118
0.040	.077	.127	.176	.224	.273	.323	.372
	.000853	.001411	.001952	.002493	.003034	.003593	.004134
0.051		.134	.183	.232	.280	.331	.379
		.001413	.002034	.002575	.003116	003675	.004215
0.064		.144	.192	.241	.290	.340	.389
		.001595	.002136	.002676	.003218	.003776	.004317
0.072			.198	.247	.296	.346	.394
			.002202	.002743	.003284	003842	.004283
0.078			.202	.251	.300	.350	.399
			.002249	.002790	.003331	.003889	.004430
0.081			.204	.253	.302	.352	.401
			.002272	.002813	.003354	.003912	.004453
0.091			.212	.260	.309	.359	.408
			.002350	.002891	.003432	.003990	.004531
0.094			.214	.262	.311	.361	.410
			.002374	.002914	.003455	.004014	.004555
0.102				.268	.317	.367	.416
				.002977	.003518	.004076	.004617

Metal thickness	Radius of bend (inches) 1/32	1/16	3/32	1/8	5/32	3/16	7/32
0.109				.273	.321	.372	.420
				.003031	.003572	.004131	.004672
0.125				.284	.333	.383	.432
				.003156	.003697	.004256	.004797
0.156					.355	.405	.453
					.003939	.004497	.005038
0.188						.417	.476
						.004747	.005288

Metal thickness	Radius of bend (inches) 1/4	9/32	5/16	11/32	3/8	7/16	1/2
0.020	.406	.455	.505	.554	.603	.702	.799
	.004515	.005056	.005614	.006155	.006695	.007795	.008877
0.025	.410	.459	.509	.558	.607	.705	.803
	.004558	.005098	.005657	.006198	.006739	.007838	.008920
0.028	.412	.461	.511	.560	.609	.708	.805
	.004581	.005122	.005680	.006221	.006762	.007862	.008944
0.032	.415	.463	.514	.562	.611	.710	.807
	.004608	.005149	.005708	.006249	.006789	.007889	.008971
0.040	.421	.469	.520	.568	.617	.716	.813
	.004675	.005215	.005774	.006315	.006856	.007955	.009037
0.051	.428	.477	.527	.576	.624	.723	.821
	.004756	.005297	.005855	.006397	.006934	.008037	.009119
0.064	.437	.486	.536	.585	.634	.732	.830
	.004858	.005399	.005957	.006498	.007039	.008138	.009220
0.072	.443	.492	.542	.591	.639	.738	.836
	.004924	.005465	.006023	.006564	.007105	.008205	.009287
0.078	.447	.496	.546	.595	.644	.745	.840
	.004963	.005512	.006070	.006611	.007152	.008252	.009333
0.081	.449	.498	.548	.598	.646	.745	.842
	.004969	.005535	.006094	.006635	.007176	.008275	.009357
0.091	.456	.505	.555	.604	.653	.752	.849
	.005072	.005613	.006172	.006713	.007254	.008353	.009435
0.094	.459	.507	.558	.606	.655	.754	.851
	.005096	.005637	.006195	.006736	.007277	.008376	.009458

Metal thickness	Radius of bend (inches)						
	1/4	9/32	5/16	11/32	3/8	7/16	1/2
0.102	.464	.513	.563	.612	.661	.760	.857
	.005158	.005699	.006257	.006798	.007339	.008439	.009521
0.109	.469	.518	.568	.617	.665	.764	.862
	.005213	.005754	.006312	.006853	.007394	.008493	.009575
0.125	.480	.529	.579	.628	.677	.776	.873
	.005338	.005878	.006437	.006978	.007519	.008618	.009700
0.156	.502	.551	.601	.650	.698	.797	.895
	.005579	.006120	.006679	.007220	.007761	.008860	.009942
0.188	.525	.573	.624	.672	.721	.820	.917
	.005829	.006370	.006928	.007469	.008010	.009109	.010191
0.250	.568	.617	.667	.716	.764	.863	.961
	.006313	.006853	.007412	.007953	.008494	.009593	.010675

The empirical formula for bend allowance for each degree of bend is:

Bend Allowance = (0.01743 R) + (0.0078 T)
R = Bend Radius
T = Metal Thickness

9.4

9.5 Rivets and Riveting

Solid rivets are the most widely-used fastening devices for sheet metal aircraft construction.

Alternatives to Riveting

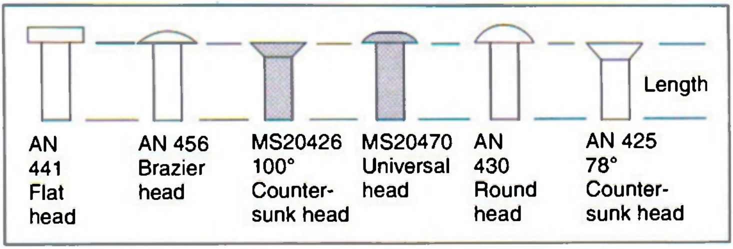
- Milled skins reduce the number of stringers and stiffeners, and eliminate the need for many rivets.
- Composite structure is bonded and does not require rivets.
- Welding has not proven to be a viable alternative because of the nature of sheet aluminum alloy.

Aircraft Solid Rivets

Most of the rivets used in aircraft structure range in diameter from 3/32-inch to 1/4-inch and most are made of an aluminum alloy. They are available with either a protruding head or a flush head.

Rivet Head Shapes

After WW II, aircraft manufactures adopted the universal head rivet to replace all protruding head rivets, and the 100° countersunk head rivet to be used for almost all flush riveting requirements.



- AN 441 — Used in internal structure
- AN 456 — Replaced with MS20470
- MS20426 — Most widely-used flush rivet
- MS20470 — Most widely used protruding head rivet
- AN 430 — Replaced with MS20470
- AN 425 — Replaced with MS20426

Rivet Material

- Nonstructural applications of 1100 or 3003 aluminum may be riveted with the soft 1100 (A) rivet.
- Bare or clad 2024-T4 aluminum alloy is generally riveted with 2117 (AD) rivets. AD rivets may be driven as they are received from the manufacturer without additional heat treatment.
- When greater strength is needed than can be provided by an AD rivet, a 2017 (D) or 2024 (DD) rivet may be used. Both D and DD rivets require heat treatment before they are driven. These rivets are soft enough to drive immediately after they are removed from the quench bath, but will begin to harden within 10 minutes if left at room temperature. The hardening can be delayed for several days if they are immediately stored in a sub-zero refrigerator.
- Magnesium structural parts may be joined with 5056 aluminum alloy (B) rivets. B rivets may be driven as received from the manufacturer.
- High-strength aluminum alloy with zinc as its chief alloying agent must be riveted with 7050-T73 and 7075-T73 rivets.
- Titanium structure must be riveted with titanium rivets.

Rivet Diameter

- Diameter chosen must allow a riveted joint to fail by the rivets shearing rather than the sheet metal tearing at the rivet holes.
- A general rule of thumb is for the rivet diameter to be three times the thickness of the thickest sheet being joined.
- Refer to the charts on Pages 212–215 to select the diameter and number of rivets to use in a repair.
- The columns in these charts represent the rivet diameter, and the rows the metal thickness. The numbers represent the number of rivets per inch for a single lap splice.
- One number in each column is underlined. A riveted joint using rivets listed below the underlined number will fail by the rivets shearing, and those above this underline will fail by tearing out of the rivet holes.

Rivet head markings identify the metal of which the rivet is made.

Head Mark	Alloy	Code
Plain	1100	A
Recessed dot	2117 T	AD
Raised dot	2017 T	D
Raised double dash	2024 T	DD
Raised cross	5056 H	B
Three raised dashes	7075 T73	
Raised circle	7050 T73	E
Recessed large and small dots	Titanium	
Recessed dash	Corrosion resistant steel	F
Recessed triangle	Carbon steel	

Number of Rivets or Bolts Required for Single-Lap Splices in Bare 2017, Clad 2017, Clad 2024-T3 Sheet, and 2024-T3 Plate, Bar, Rod, Tube and Extrusions						
Thickness of metal (inches)	Number of AD protruding head rivets needed per inch width "W"					No. of Bolts
	Rivet Diameter					
	3/32	**1/8**	**5/32**	**3/16**	**1/4**	**AN-3**
0.016	6.5	4.9				
0.020	**6.5**	4.9	3.9			
0.025	6.9	**4.9**	3.9			
0.032	8.9	4.9	3.9	3.3		
0.036	10.0	5.6	**3.9**	3.3	2.4	
0.040	11.1	6.2	4.0	**3.3**	2.4	
0.051		7.9	5.1	3.6	**2.4**	3.3
0.064		9.9	6.5	4.5	2.5	3.3
0.081		12.5	8.1	5.7	3.1	3.3
0.091			9.1	6.3	3.5	3.3
0.102			10.3	7.1	3.9	**3.3**
0.128			12.9	8.9	4.9	3.3

NOTES:
1. For stringers in the upper surface of a wing, or in a fuselage, 80% of the number of rivets shown may be used.
2. For intermediate frames, 60% of the number of rivets shown may be used.
3. For single-lap sheet joints, 75% of the number shown may be used.

Number of Rivets or Bolts Required for Single-Lap Splices in 5052 (All Hardness) Sheet						
Thickness of metal (inches)	Number of AD protruding head rivets needed per inch width "W"					No. of Bolts
	Rivet Diameter					
	3/32	**1/8**	**5/32**	**3/16**	**1/4**	**AN-3**
0.016	6.3	4.7				
0.020	6.3	4.7	3.8			
0.025	6.3	4.7	3.8			
0.032	**6.3**	4.7	3.8	3.2		
0.036	7.1	4.7	3.8	3.2	2.4	
0.040	7.9	**4.7**	3.8	3.2	2.4	
0.051	10.1	5.6	**3.8**	3.2	2.4	
0.064	12.7	7.0	4.6	**3.2**	2.4	
0.081		8.9	5.8	4.0	**2.4**	3.2
0.091		10.0	6.5	4.5	2.5	3.2
0.102		11.2	7.3	5.1	2.8	**3.2**
0.128			9.2	6.4	3.5	3.2

NOTES:
1. For stringers in the upper surface of a wing, or in a fuselage, 80% of the number of rivets shown may be used.
2. For intermediate frames, 60% of the number of rivets shown may be used.
3. For single-lap sheet joints, 75% of the number shown may be used.

Examples of Rivet Selection

— Use the chart on Page 221 to find the minimum number of rivets needed to make a splice on an intermediate frame using a single-lap joint, 2024 clad sheet aluminum 0.040-inch thick, with 1/8-inch 2117-AD rivets.

1. At the intersection of the 1/8-inch rivet column and the 0.040-inch metal thickness row, notice that 6.2 rivets per inch are needed for full strength. This choice is below the underlined number in this column, indicating the joint will fail by the rivets shearing, as it should, rather than the rivet holes tearing out.
2. According to NOTE 2, an intermediate frame requires only 60% of this number, therefore 3.72 rivets per inch is required for the splice.

— Use the chart on Page 222 to find the minimum number of rivets needed to make a single-lap joint in 5052-H36 sheet aluminum 0.064-inch thick, with 5/32-inch 2117-AD rivets.

1. At the intersection of the 5/32-inch rivet column and the 0.064-inch metal thickness row, notice that 4.6 rivets per inch are needed for full strength. This choice is below the line in this column, indicating the joint will fail by the rivets shearing, as it should, rather than the rivet holes tearing out.
2. A single-lap sheet joint requires only 75% of this number, therefore 3.45 rivets per inch is required for the joint.

9.5

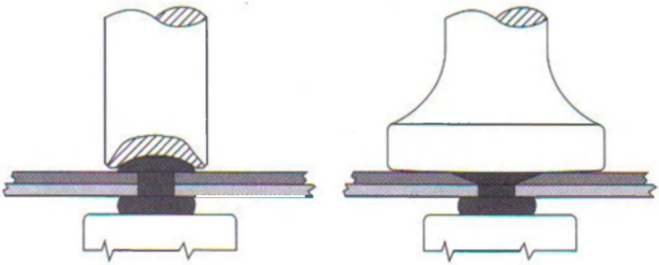
Rivet Length

Determining the length of a rivet for a properly formed shop head

- The shop head on a rivet should have a diameter of one and one-half times the diameter of the shank, and its thickness should be one-half of the shank diameter.
- To get this size head, the shank should stick through the material by a distance of one and one-half times the shank diameter.

Riveting Tools

Rivet Sets



- Rivet sets fit over the manufactured head of a rivet and are driven by the rivet gun.
- For protruding-head rivets, the cup in the rivet set should have a slightly larger radius than the head of the rivet.
- The rivet set for driving flush rivets is slightly crowned and highly polished so it will not mark the skin.

Bucking Bars

Bucking bar selection	
Rivet Diameter (inch)	**Bucking Bar Weight (pounds)**
3/32	2 to 3
1/8	3 to 4
5/32	3.5 to 4.5
3/16	4 to 5
1/4	5 to 6.5

- The rivet set is held tightly against the manufactured head of the rivet, and a bucking bar of hardened and polished steel is held squarely against the end of the rivet shank. The blows from the rivet gun cause the bucking bar to bounce on the end of the rivet shank and flatten it.
- The shape of a bucking bar must be chosen so it can fit squarely on the end of the rivet, and the weight of the bar must be compatible with the rivet diameter.

Installing Flush Rivets

- If the top skin is thicker than the head of the rivet, it should be countersunk to a depth that will cause the top of the rivet to be flush with the skin.

- It is permissible, but not recommended, to countersink the top skin if its thickness is the same as the thickness of the rivet head.

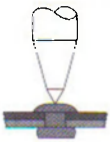
- If the top skin is thinner than the rivet head, the skin should be dimpled either by coin or radius dimpling.

Blind Rivet Code

When team riveting, with the gunner unable to see or hear the bucker, this code serves for communications:

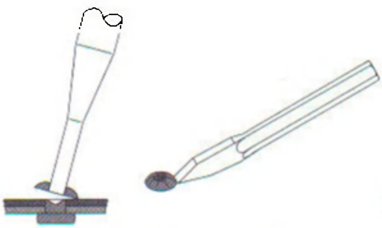
One Tap — Start riveting
Two Taps — Rivet OK
Three Taps — Bad rivet, mark it and move to next one.

Removal of Damaged Rivets

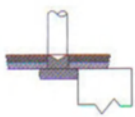


Make center punch mark in center of manufactured head.

Drill through head with drill one size smaller than used for rivet.

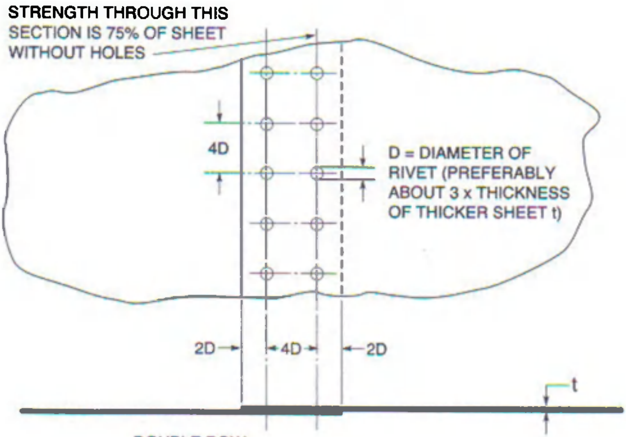


Use pin punch the size of the hole, pry the head off rivet or use cape chisel to cut head off.

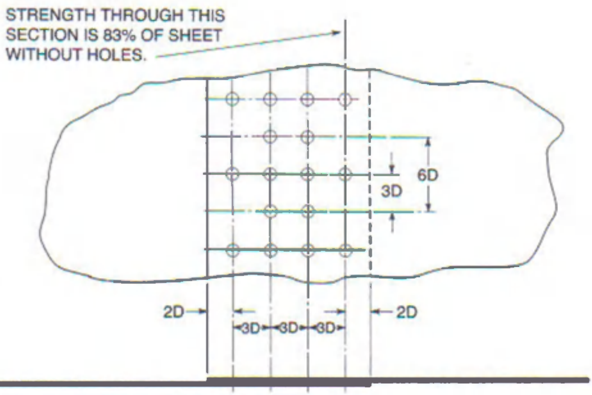


Buck up metal with bucking bar beside shop head and use pin punch to drive shank from the metal.

Minimum Rivet Spacing and Edge Distance



DOUBLE ROW



TRIPLE OR MULTIPLE ROWS

You must determine that the repaired structure will be at least as strong and rigid as the original, and if the repair is made to an external skin it must have no adverse effect on the airflow. To obtain proper strength from a riveted joint, the rivet spacing and edge distance shown here must be observed. If a rivet hole has been damaged when a rivet is being replaced, the next size larger rivet may be used provided the rivet spacing and edge distance are within the limits shown here.