from a radius center to the inside surface of the metal. The minimum bend radius depends on the temper, thickness, and type of material. Always use a Minimum Bend Radius Table to determine the minimum bend radius for the alloy that is going to be used. Minimum bend radius charts can be found in manufacturer's maintenance manuals.

Bend tangent line (BL)—the location at which the metal starts to bend and the line at which the metal stops curving. All the space between the bend tangent lines is the bend allowance.

Neutral axis—an imaginary line that has the same length after bending as it had before bending. *[Figure 4-121]* After bending, the bend area is 10 to 15 percent thinner than before bending. This thinning of the bend area moves the neutral line of the metal in towards the radius center. For calculation purposes, it is often assumed that the neutral axis is located at the center of the material, although the neutral axis is not exactly in the center of the material. However, the amount of error incurred is so slight that, for most work, assuming it is at the center is satisfactory.

Mold line (ML)—an extension of the flat side of a part beyond the radius.

Mold line dimension (MLD)—the dimension of a part made by the intersection of mold lines. It is the dimension the part would have if its corners had no radius.

Mold point—the point of intersection of the mold lines. The mold point would be the outside corner of the part if there were no radius.

K-Factor—the percentage of the material thickness where there is no stretching or compressing of the material, such as the neutral axis. This percentage has been calculated and is one of 179 numbers on the K chart corresponding to one of the angles between 0° and 180° to which metal can be bent. *[Figure 4-122]* Whenever metal is to be bent to any angle other than 90° (K-factor of 90° equal to 1), the corresponding K-factor number is selected from the chart and is multiplied

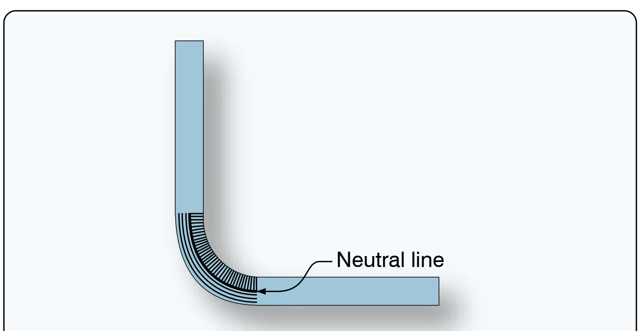


Figure 4-121. *Neutral line.*

by the sum of the radius (R) and the thickness (T) of the metal. The product is the amount of setback (see next paragraph) for the bend. If no K chart is available, the K-factor can be calculated with a calculator by using the following formula: the K value is the tangent of one-half the bend angle.

Setback (SB)—the distance the jaws of a brake must be setback from the mold line to form a bend. In a 90° bend, SB = R + T (radius of the bend plus thickness of the metal). The setback dimension must be determined prior to making the bend because setback is used in determining the location of the beginning bend tangent line. When a part has more than one bend, setback must be subtracted for each bend. The majority of bends in sheet metal are 90° bends. The K-factor must be used for all bends that are smaller or larger than 90°.

SB = K(R+T)

Sight line—also called the bend or brake line, it is the layout line on the metal being formed that is set even with the nose of the brake and serves as a guide in bending the work.

Flat—that portion of a part that is not included in the bend. It is equal to the base measurement (MLD) minus the setback.
Flat = MLD – SB

Closed angle—an angle that is less than 90° when measured between legs, or more than 90° when the amount of bend is measured.

Open angle—an angle that is more than 90° when measured between legs, or less than 90° when the amount of bend is measured.

Total developed width (TDW)—the width of material measured around the bends from edge to edge. Finding the TDW is necessary to determine the size of material to be cut. The TDW is less than the sum of mold line dimensions since the metal is bent on a radius and not to a square corner as mold line dimensions indicate.

Layout or Flat Pattern Development

To prevent any waste of material and to get a greater degree of accuracy in the finished part, it is wise to make a layout or flat pattern of a part before forming it. Construction of interchangeable structural and nonstructural parts is achieved by forming flat sheet stock to make channel, angle, zee, or hat section members. Before a sheet metal part is formed, make a flat pattern to show how much material is required in the bend areas, at what point the sheet must be inserted into the forming tool, or where bend lines are located. Bend lines must be determined to develop a flat pattern for sheet metal forming.

1	0.0087	37	0.3346	73	0.7399	109	1.401	145	3.171
2	0.0174	38	0.3443	74	0.7535	110	1.428	146	3.270
3	0.0261	39	0.3541	75	0.7673	111	1.455	147	3.375
4	0.0349	40	0.3639	76	0.7812	112	1.482	148	3.487
5	0.0436	41	0.3738	77	0.7954	113	1.510	149	3.605
6	0.0524	42	0.3838	78	0.8097	114	1.539	150	3.732
7	0.0611	43	0.3939	79	0.8243	115	1.569	151	3.866
8	0.0699	44	0.4040	80	0.8391	116	1.600	152	4.010
9	0.0787	45	0.4142	81	0.8540	117	1.631	153	4.165
10	0.0874	46	0.4244	82	0.8692	118	1.664	154	4.331
11	0.0963	47	0.4348	83	0.8847	119	1.697	155	4.510
12	0.1051	48	0.4452	84	0.9004	120	1.732	156	4.704
13	0.1139	49	0.4557	85	0.9163	121	1.767	157	4.915
14	0.1228	50	0.4663	86	0.9324	122	1.804	158	5.144
15	0.1316	51	0.4769	87	0.9489	123	1.841	159	5.399
16	0.1405	52	0.4877	88	0.9656	124	1.880	160	5.671
17	0.1494	53	0.4985	89	0.9827	125	1.921	161	5.975
18	0.1583	54	0.5095	90	1.000	126	1.962	162	6.313
19	0.1673	55	0.5205	91	1.017	127	2.005	163	6.691
20	0.1763	56	0.5317	92	1.035	128	2.050	164	7.115
21	0.1853	57	0.5429	93	1.053	129	2.096	165	7.595
22	0.1943	58	0.5543	94	1.072	130	2.144	166	8.144
23	0.2034	59	0.5657	95	1.091	131	2.194	167	8.776
24	0.2125	60	0.5773	96	1.110	132	2.246	168	9.514
25	0.2216	61	0.5890	97	1.130	133	2.299	169	10.38
26	0.2308	62	0.6008	98	1.150	134	2.355	170	11.43
27	0.2400	63	0.6128	99	1.170	135	2.414	171	12.70
28	0.2493	64	0.6248	100	1.191	136	2.475	172	14.30
29	0.2586	65	0.6370	101	1.213	137	2.538	173	16.35
30	0.2679	66	0.6494	102	1.234	138	2.605	174	19.08
31	0.2773	67	0.6618	103	1.257	139	2.674	175	22.90
32	0.2867	68	0.6745	104	1.279	140	2.747	176	26.63
33	0.2962	69	0.6872	105	1.303	141	2.823	177	38.18
34	0.3057	70	0.7002	106	1.327	142	2.904	178	57.29
35	0.3153	71	0.7132	107	1.351	143	2.988	179	114.59
36	0.3249	72	0.7265	108	1.376	144	3.077	180	Inf.

Figure 4-122. *K-factor.*

When forming straight angle bends, correct allowances must be made for setback and bend allowance. If shrinking or stretching processes are to be used, allowances must be made so that the part can be turned out with a minimum amount of forming.

Making Straight Line Bends

When forming straight bends, the thickness of the material, its alloy composition, and its temper condition must be considered. Generally speaking, the thinner the material is, the more sharply it can be bent (the smaller the radius of bend), and the softer the material is, the sharper the bend is. Other factors that must be considered when making straight line bends are bend allowance, setback, and brake or sight line.

The radius of bend of a sheet of material is the radius of the bend as measured on the inside of the curved material. The minimum radius of bend of a sheet of material is the sharpest curve, or bend, to which the sheet can be bent without critically weakening the metal at the bend. If the radius of bend is too small, stresses and strains weaken the metal and may result in cracking.

A minimum radius of bend is specified for each type of aircraft sheet metal. The minimum bend radius is affected by the kind of material, thickness of the material, and temper condition of the material. Annealed sheet can be bent to a radius approximately equal to its thickness. Stainless steel and 2024-T3 aluminum alloy require a fairly large bend radius.

Bending a U-Channel

To understand the process of making a sheet metal layout, the steps for determining the layout of a sample U-channel will be discussed. *[Figure 4-123]* When using bend allowance calculations, the following steps for finding the total developed length can be computed with formulas, charts, or computer-aided design (CAD) and computer-aided manufacturing (CAM) software packages. This channel is made of 0.040-inch 2024-T3 aluminum alloy.

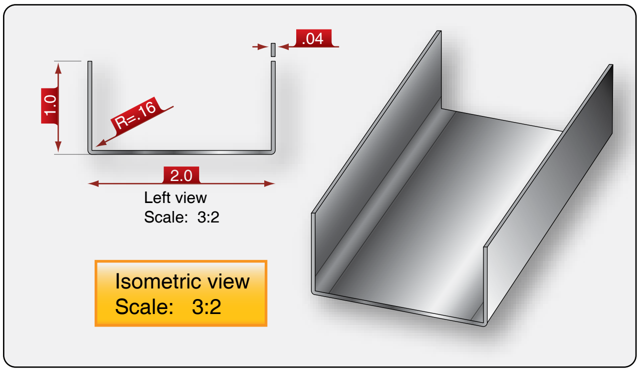


Figure 4-123. *U-channel example.*

Step 1: Determine the Correct Bend Radius

Minimum bend radius charts are found in manufacturers' maintenance manuals. A radius that is too sharp cracks the material during the bending process. Typically, the drawing indicates the radius to use, but it is a good practice to double check. For this layout example, use the minimum radius chart in *Figure 4-124* to choose the correct bend radius for the alloy, temper, and the metal thickness. For 0.040, 2024-T3 the minimum allowable radius is 0.16-inch or 5⁄32-inch.

Step 2: Find the Setback

The setback can be calculated with a formula or can be found in a setback chart available in aircraft maintenance manuals or Source, Maintenance, and Recoverability books (SMRs). *[Figure 4-125]*

CHART 204
MINIMUM BEND RADIUS FOR ALUMINUM ALLOYS

Thickness	5052-0 6061-0 5052-H32	7178-0 2024-0 5052-H34 6061-T4 7075-0	6061-T6	7075-T6	2024-T3 2024-T4	2024-T6
.012	.03	.03	.03	.03	.06	.06
.016	.03	.03	.03	.03	.09	.09
.020	.03	.03	.03	.12	.09	.09
.025	.03	.03	.06	.16	.12	.09
.032	.03	.03	.06	.19	.12	.12
.040	.06	.06	.09	.22	.16	.16
.050	.06	.06	.12	.25	.19	.19
.063	.06	.09	.16	.31	.22	.25
.071	.09	.12	.16	.38	.25	.31
.080	.09	.16	.19	.44	.31	.38
.090	.09	.19	.22	.50	.38	.44
.100	.12	.22	.25	.62	.44	.50
.125	.12	.25	.31	.88	.50	.62
.160	.16	.31	.44	1.25	.75	.75
.190	.19	.38	.56	1.38	1.00	1.00
.250	.31	.62	.75	2.00	1.25	1.25
.312	.44	1.25	1.38	2.50	1.50	1.50
.375	.44	1.38	1.50	2.50	1.88	1.88

Bend radius is designated to the inside of the bend. All dimensions are in inches.

Figure 4-124. *Minimum bend radius (from the Raytheon Aircraft Structural Inspection and Repair Manual).*

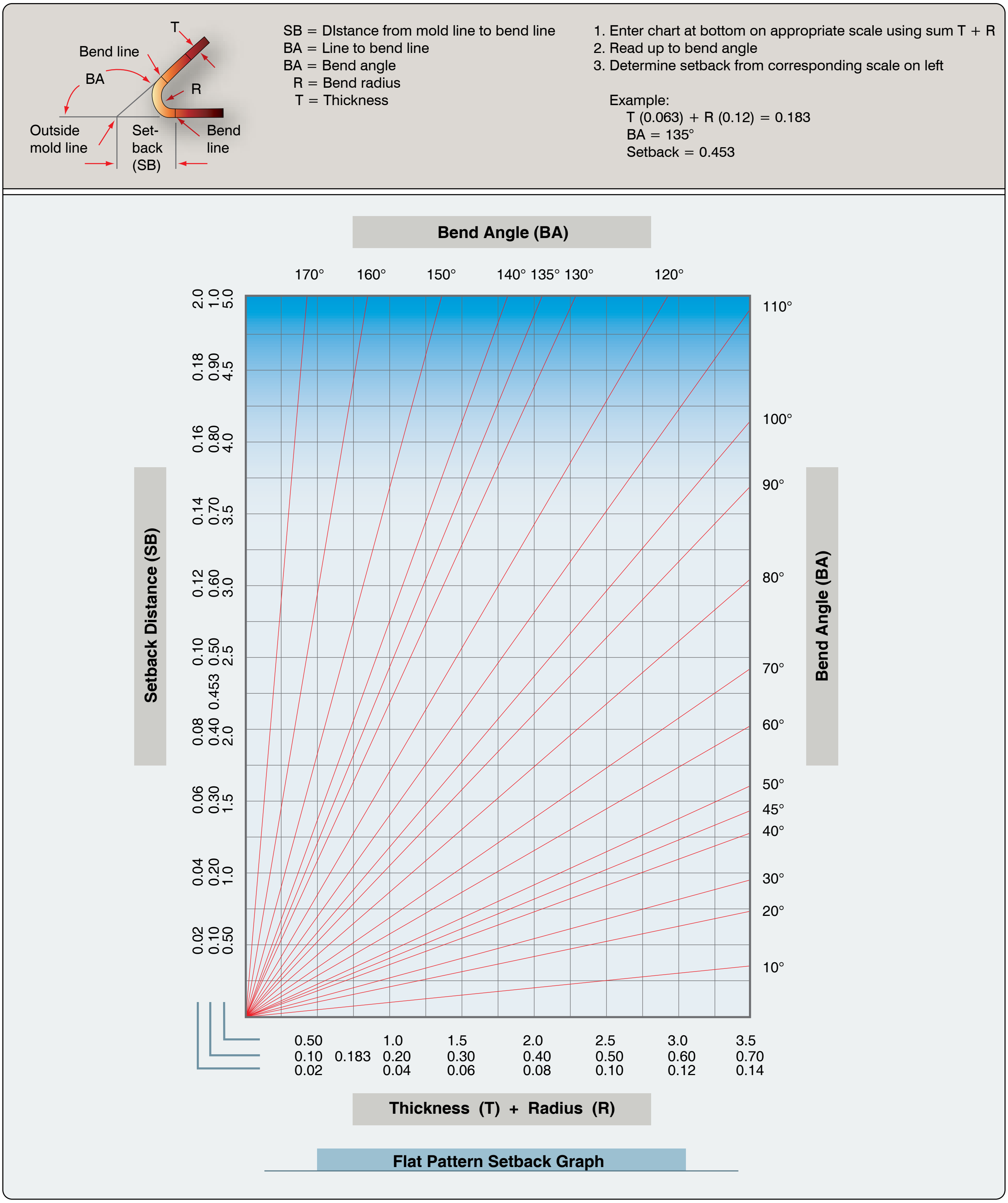


Figure 4-125. *Setback chart.*

Using a Formula to Calculate the Setback

SB = setback

K = K-factor (K is 1 for 90° bends)

R = inside radius of the bend

T = material thickness

Since all of the angles in this example are 90° angles, the setback is calculated as follows:

SB = K(R+T) = 0.2 inches

Note: K = 1 for a 90° bend. For other than a 90° bend, use a K-factor chart.

Using a Setback Chart to Find the Setback

The setback chart is a quick way to find the setback and is useful for open and closed bends, because there is no need to calculate or find the K-factor. Several software packages and online calculators are available to calculate the setback. These programs are often used with CAD/CAM programs. *[Figure 4-125]*

- Enter chart at the bottom on the appropriate scale with the sum of the radius and material thickness.
- Read up to the bend angle.
- Find the setback from corresponding scale on the left.

Example:

- Material thickness is 0.063-inch.
- Bend angle is 135°.
- R + T = 0.183-inch.

Find 0.183 at the bottom of the graph. It is found in the middle scale.

- Read up to a bend angle of 135°.
- Locate the setback at the left hand side of the graph in the middle scale (0.435-inch). *[Figure 4-125]*

Step 3: Find the Length of the Flat Line Dimension

The flat line dimension can be found using the formula:

Flat = MLD – SB

MLD = mold line dimension

SB = setback

The flats, or flat portions of the U-channel, are equal to the mold line dimension minus the setback for each of the sides, and the mold line length minus two setbacks for the center flat. Two setbacks need to be subtracted from the center flat because this flat has a bend on either side.

The flat dimension for the sample U-channel is calculated in the following manner:

Flat dimension = MLD – SB

Flat 1 = 1.00-inch – 0.2-inch = 0.8-inch

Flat 2 = 2.00-inch – (2 × 0.2-inch) = 1.6-inch

Flat 3 = 1.00-inch – 0.2-inch = 0.8-inch

Step 4: Find the Bend Allowance

When making a bend or fold in a piece of metal, the bend allowance or length of material required for the bend must be calculated. Bend allowance depends on four factors: degree of bend, radius of the bend, thickness of the metal, and type of metal used.

The radius of the bend is generally proportional to the thickness of the material. Furthermore, the sharper the radius of bend, the less the material that is needed for the bend. The type of material is also important. If the material is soft, it can be bent very sharply; but if it is hard, the radius of bend is greater, and the bend allowance is greater. The degree of bend affects the overall length of the metal, whereas the thickness influences the radius of bend.

Bending a piece of metal compresses the material on the inside of the curve and stretches the material on the outside of the curve. However, at some distance between these two extremes lies a space which is not affected by either force. This is known as the neutral line or neutral axis and occurs at a distance approximately 0.445 times the metal thickness (0.445 × T) from the inside of the radius of the bend. *[Figure 4-126]*

The length of this neutral axis must be determined so that sufficient material can be provided for the bend. This is called the bend allowance. This amount must be added to the overall length of the layout pattern to ensure adequate material for the bend. To save time in calculation of the bend allowance, formulas and charts for various angles, radii of bends, material thicknesses, and other factors have been developed.

Formula 1: Bend Allowance for a 90° Bend

To the radius of bend (R) add ½ the thickness of the metal (½T). This gives R + ½T, or the radius of the circle of the neutral axis. *[Figure 4-127]* Compute the circumference of this circle by multiplying the radius of the neutral line (R + ½T) by 2π (***Note:*** π = 3.1416): 2π (R + ½T). Since a 90° bend is a quarter of the circle, divide the circumference by 4. This gives:

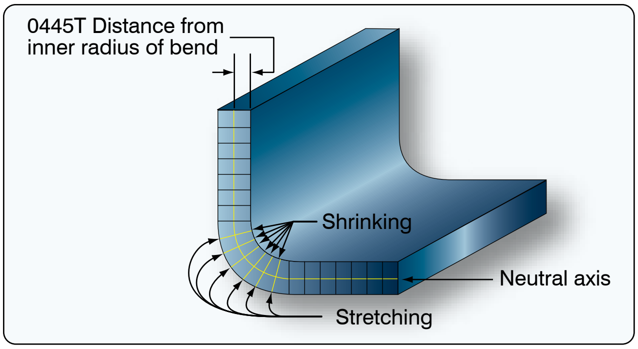


Figure 4-126. *Neutral axis and stresses resulting from bending.*

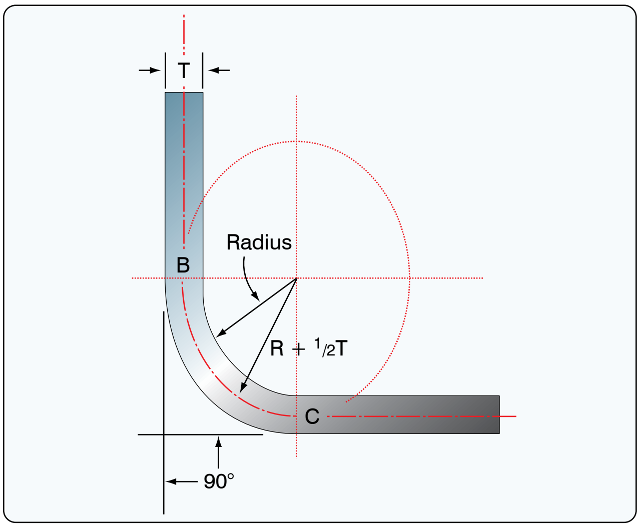


Figure 4-127. *Bend allowance for a 90° bend.*

$$\frac{2\pi\,(R + ½T)}{4}$$

This is the bend allowance for a 90° bend. To use the formula for a 90° bend having a radius of ¼ inch for material 0.051-inch thick, substitute in the formula as follows.

$$\text{Bend allowance} = \frac{(2 \times 3.1416)(0.250 + ½(0.051))}{4}$$

$$= \frac{6.2832(0.250 + 0.0255)}{4}$$

$$= \frac{6.2832(0.2755)}{4}$$

$$= 0.4327$$

The bend allowance, or the length of material required for the bend, is 0.4327 or 7⁄16-inch.

Formula 2: Bend Allowance for a 90° Bend

This formula uses two constant values that have evolved over a period of years as being the relationship of the degrees in the bend to the thickness of the metal when determining the bend allowance for a particular application. By experimentation with actual bends in metals, aircraft engineers have found that accurate bending results could be obtained by using the following formula for any degree of bend from 1° to 180°.

Bend allowance = (0.01743R + 0.0078T)N where:

R = the desired bend radius

T = the thickness of the metal

N = number of degrees of bend

To use this formula for a 90° bend having a radius of .16-inch for material 0.040-inch thick, substitute in the formula as follows:

$$\text{Bend allowance} =$$
$$(0.01743 \times 0.16) + (0.0078 \times 0.040) \times 90 = 0.27 \text{ inches}$$

Use of Bend Allowance Chart for a 90° Bend

In *Figure 4-128,* the radius of bend is shown on the top line, and the metal thickness is shown on the left hand column. The upper number in each cell is the bend allowance for a 90° bend. The lower number in the cell is the bend allowance per 1° of bend. To determine the bend allowance for a 90° bend, simply use the top number in the chart.

Example: The material thickness of the U-channel is 0.040-inch and the bend radius is 0.16-inch.

Reading across the top of the bend allowance chart, find the column for a radius of bend of .156-inch. Now, find the block in this column that is opposite the material thickness (gauge) of 0.040 in the column at the left. The upper number in the cell is (0.273), the correct bend allowance in inches for a 90° bends.

Several bend allowance calculation programs are available online. Just enter the material thickness, radius, and degree of bend and the computer program calculates the bend allowance.

Use of Chart for Other Than a 90° Bend

If the bend is to be other than 90°, use the lower number in the block (the bend allowance for 1°) and compute the bend allowance.

Example:
The L-bracket shown in *Figure 4-129* is made from 2024-T3 aluminum alloy and the bend is 60° from flat. Note that the bend angle in the figure indicates 120°, but that is the number of degrees between the two flanges and not the bend angle

Metal Thickness	RADIUS OF BEND, IN INCHES													
	1/32 .031	1/16 .063	3/32 .094	1/8 .125	5/32 .156	3/16 .188	7/32 .219	1/4 .250	9/32 .281	5/16 .313	11/32 .344	3/8 .375	7/16 .438	1/2 .500
.020	.062 .000693	.113 .001251	.161 .001792	.210 .002333	.259 .002874	.309 .003433	.358 .003974	.406 .004515	.455 .005056	.505 .005614	.554 .006155	.603 .006695	.702 .007795	.799 .008877
.025	.066 .000736	.116 .001294	.165 .001835	.214 .002376	.263 .002917	.313 .003476	.362 .004017	.410 .004558	.459 .005098	.509 .005657	.558 .006198	.607 .006739	.705 .007838	.803 .008920
.028	.068 .000759	.119 .001318	.167 .001859	.216 .002400	.265 .002941	.315 .003499	.364 .004040	.412 .004581	.461 .005122	.511 .005680	.560 .006221	.609 .006762	.708 .007862	.805 .007862
.032	.071 .000787	.121 .001345	.170 .001886	.218 .002427	.267 .002968	.317 .003526	.366 .004067	.415 .004608	.463 .005149	.514 .005708	.562 .006249	.611 .006789	.710 .007889	.807 .008971
.038	.075 .00837	.126 .001396	.174 .001937	.223 .002478	.272 .003019	.322 .003577	.371 .004118	.419 .004659	.468 .005200	.518 .005758	.567 .006299	.616 .006840	.715 .007940	.812 .009021
.040	.077 .000853	.127 .001411	.176 .001952	.224 .002493	.273 .003034	.323 .003593	.372 .004134	.421 .004675	.469 .005215	.520 .005774	.568 .006315	.617 .006856	.716 .007955	.813 .009037
.051		.134 .001413	.183 .002034	.232 .002575	.280 .003116	.331 .003675	.379 .004215	.428 .004756	.477 .005297	.527 .005855	.576 .006397	.624 .006934	.723 .008037	.821 .009119
.064		.144 .001595	.192 .002136	.241 .002676	.290 .003218	.340 .003776	.389 .004317	.437 .004858	.486 .005399	.536 .005957	.585 .006498	.634 .007039	.732 .008138	.830 .009220
.072			.198 .002202	.247 .002743	.296 .003284	.436 .003842	.394 .004283	.443 .004924	.492 .005465	.542 .006023	.591 .006564	.639 .007105	.738 .008205	836 .009287
.078			.202 .002249	.251 .002790	.300 .003331	.350 .003889	.399 .004430	.447 .004963	.496 .005512	.546 .006070	.595 .006611	.644 .007152	.745 .008252	.840 .009333
.081			.204 .002272	.253 .002813	.302 .003354	.352 .003912	.401 .004453	.449 .004969	.498 .005535	.548 .006094	.598 .006635	.646 .007176	.745 .008275	.842 .009357
.091			.212 .002350	.260 .002891	.309 .003432	.359 .003990	.408 .004531	.456 .005072	.505 .005613	.555 .006172	.604 .006713	.653 .007254	.752 .008353	.849 .009435
.094			.214 .002374	.262 .002914	.311 .003455	.361 .004014	.410 .004555	.459 .005096	.507 .005637	.558 .006195	.606 .006736	.655 .007277	.754 .008376	.851 .009458
.102				.268 .002977	.317 .003518	.367 .004076	.416 .004617	.464 .005158	.513 .005699	.563 .006257	.612 .006798	.661 .007339	.760 .008439	.857 .009521
.109				.273 .003031	.321 .003572	.372 .004131	.420 .004672	.469 .005213	.518 .005754	.568 .006312	.617 .006853	.665 .008394	.764 .008493	.862 .009575
.125				.284 .003156	.333 .003697	.383 .004256	.432 .004797	.480 .005338	.529 .005678	.579 .006437	.628 .006978	.677 .007519	.776 .008618	.873 .009700
.156					.355 .003939	.405 .004497	.453 .005038	.502 .005579	.551 .006120	.601 .006679	.650 .007220	.698 .007761	.797 .008860	.895 .009942
.188						.417 .004747	.476 .005288	.525 .005829	.573 .006370	.624 .006928	.672 .007469	.721 .008010	.820 .009109	.917 .010191
.250								.568 .006313	.617 .006853	.667 .007412	.716 .007953	.764 .008494	.863 .009593	.961 .010675

Figure 4-128. *Bend allowance.*

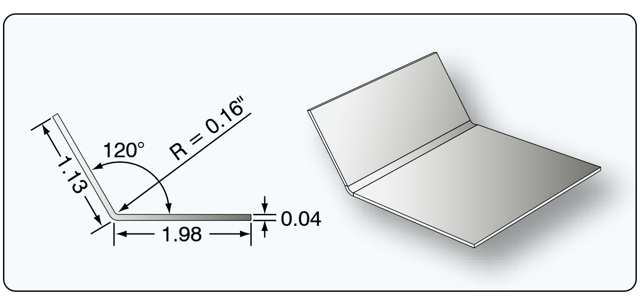


Figure 4-129. *Bend allowance for bends less than 90°.*

from flat. To find the correct bend angle, use the following formula:

Bend Angle = 180° – Angle between flanges

The actual bend is 60°. To find the correct bend radius for a 60° bend of material 0.040-inches thick, use the following procedure.

1. Go to the left side of the table and find 0.040-inch.
2. Go to the right and locate the bend radius of 0.16-inch (0.156-inch).
3. Note the bottom number in the block (0.003034).
4. Multiply this number by the bend angle:
   0.003034 × 60 = 0.18204

Step 5: Find the Total Developed Width of the Material

The total developed width (TDW) can be calculated when the dimensions of the flats and the bend allowance are found. The following formula is used to calculate TDW:

TDW = Flats + (bend allowance × number of bends)

For the U-channel example, this gives:

TDW = Flat 1 + Flat 2 + Flat 3 + (2 × BA)

TDW = 0.8 + 1.6 + 0.8 + (2 × 0.27)

TDW = 3.74-inches

Note that the amount of metal needed to make the channel is less than the dimensions of the outside of the channel (total of mold line dimensions is 4 inches). This is because the metal follows the radius of the bend rather than going from mold line to mold line. It is good practice to check that the calculated TDW is smaller than the total mold line dimensions. If the calculated TDW is larger than the mold line dimensions, the math was incorrect.

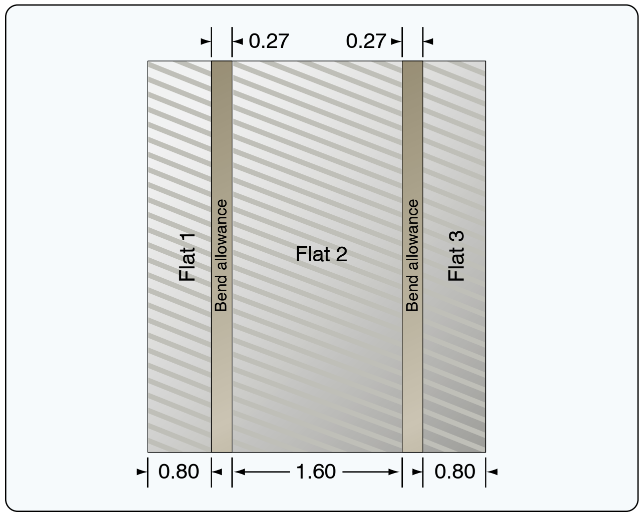


Figure 4-130. *Flat pattern layout.*

Step 6: Flat Pattern Lay Out

After a flat pattern layout of all relevant information is made, the material can be cut to the correct size, and the bend tangent lines can be drawn on the material. *[Figure 4-130]*

Step 7: Draw the Sight Lines on the Flat Pattern

The pattern laid out in *Figure 4-130* is complete, except for a sight line that needs to be drawn to help position the bend tangent line directly at the point where the bend should start. Draw a line inside the bend allowance area that is one bend radius away from the bend tangent line that is placed under the brake nose bar. Put the metal in the brake under the clamp and adjust the position of the metal until the sight line is directly below the edge of the radius bar. *[Figure 4-131]* Now, clamp the brake on the metal and raise the leaf to make the bend. The bend begins exactly on the bend tangent line.

Note: A common mistake is to draw the sight line in the middle of the bend allowance area, instead of one radius away from the bend tangent line that is placed under the brake nose bar.

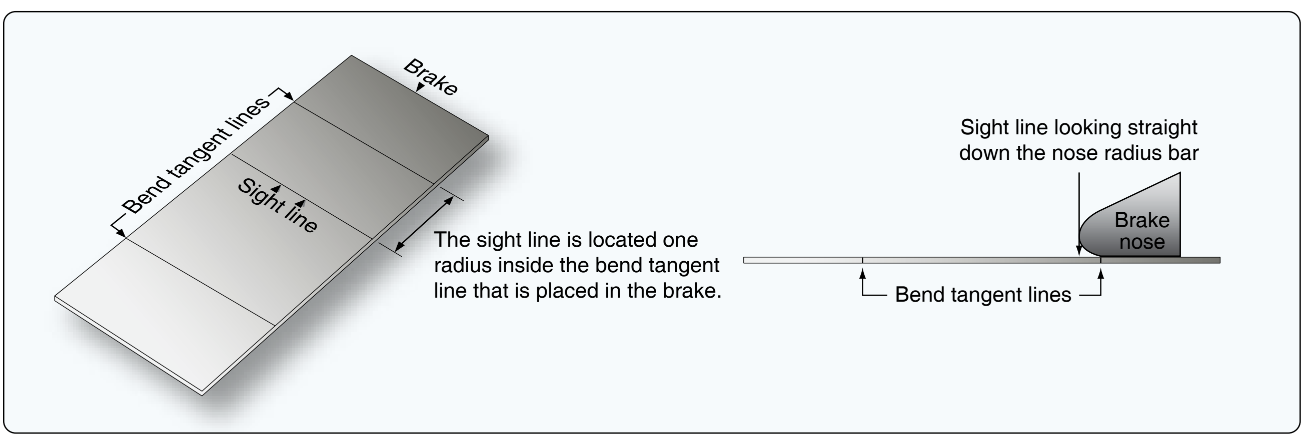


Figure 4-131. *Sight line.*

Using a J-Chart to Calculate Total Developed Width

The J-chart, often found in the SRM, can be used to determine bend deduction or setback and the TDW of a flat pattern layout when the inside bend radius, bend angle, and material thickness are known. *[Figure 4-132]* While not as accurate as the traditional layout method, the J-chart provides sufficient information for most applications. The J-chart does not require difficult calculations or memorized formulas because the required information can be found in the repair drawing or can be measured with simple measuring tools.

When using the J-chart, it is helpful to know whether the angle is open (greater than 90°) or closed (less than 90°) because the lower half of the J-chart is for open angles and the upper half is for closed angles.

To find the total developed width using a J-chart:

- Place a straightedge across the chart and connect the bend radius on the top scale with the material thickness on the bottom scale. *[Figure 4-132]*

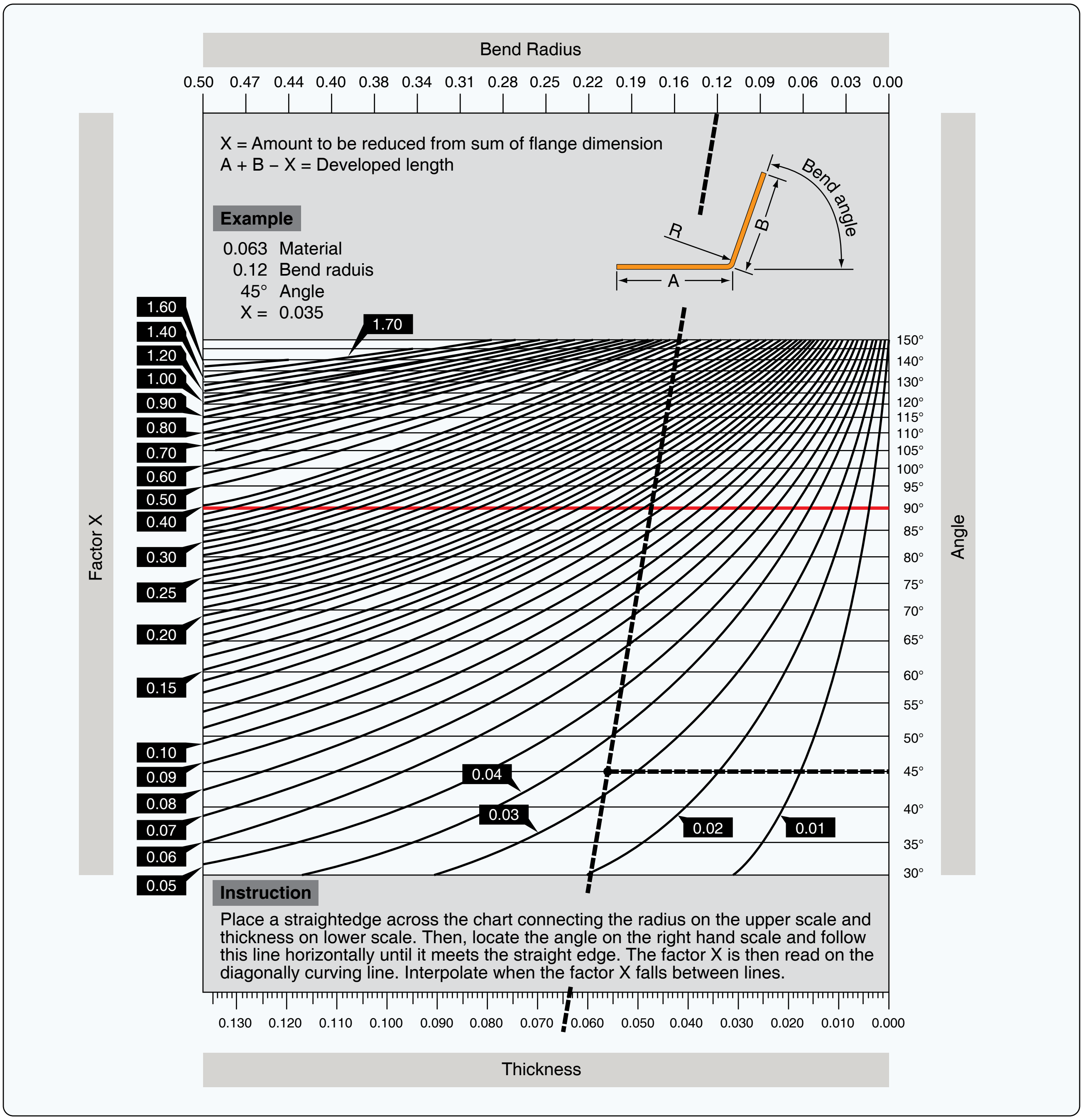


Figure 4-132. *J chart.*

- Locate the angle on the right hand scale and follow this line horizontally until it meets the straight edge.
- The factor X (bend deduction) is then read on the diagonally curving line.
- Interpolate when the X factor falls between lines.
- Add up the mold line dimensions and subtract the X factor to find the TDW.

Example 1

Bend radius = 0.22-inch

Material thickness = 0.063-inch

Bend angle = 90º

ML 1 = 2.00/ML 2 = 2.00

Use a straightedge to connect the bend radius (0.22-inch) at the top of the graph with the material thickness at the bottom (0.063-inch). Locate the 90° angle on the right hand scale and follow this line horizontally until it meets the straightedge. Follow the curved line to the left and find 0.17 at the left side. The X factor in the drawing is 0.17-inch. *[Figure 4-133]*

Total developed width =
(Mold line 1 + Mold line 2) – X factor

Total developed width = (2 + 2) – .17 = 3.83-inches

Example 2

Bend radius = 0.25-inch

Material thickness = 0.050-inch

Bend angle = 45º

ML 1 = 2.00/ML 2 = 2.00

Figure 4-134 illustrates a 135° angle, but this is the angle between the two legs. The actual bend from flat position is 45° (180 – 135 = 45). Use a straightedge to connect the bend radius (0.25-inch) at the top of the graph with the material thickness at the bottom (.050-inch). Locate the 45° angle on the right hand scale and follow this line horizontally until it meets the straight edge. Follow the curved line to the left and find 0.035 at the left side. The X factor in the drawing is 0.035 inch.

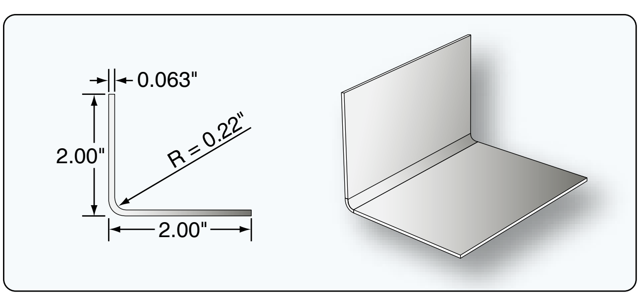


Figure 4-133. *Example 1 of J chart.*

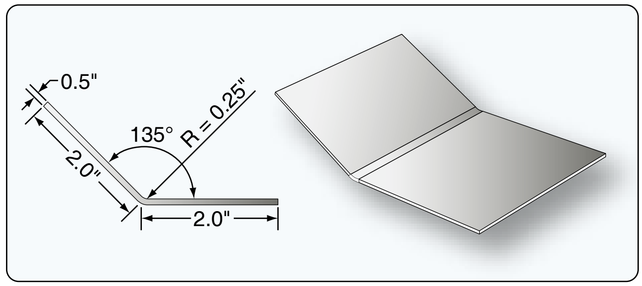


Figure 4-134. *Example 2 of J chart.*

Total developed width =
(Mold line 1 + Mold line 2) – X factor

Total developed width = (2 + 2) – .035 = 3.965-inch

Using a Sheet Metal Brake to Fold Metal

The brake set up for box and pan brakes and cornice brakes is identical. *[Figure 4-135]* A proper set up of the sheet metal brake is necessary because accurate bending of sheet metal depends on the thickness and temper of the material to be formed and the required radius of the part. Any time a different thickness of sheet metal needs to be formed or when a different radius is required to form the part, the operator needs to adjust the sheet metal brake before the brake is used to form the part. For this example, an L-channel made from 2024 –T3 aluminum alloy that is 0.032-inch thick will be bent.

Step 1: Adjustment of Bend Radius

The bend radius necessary to bend a part can be found in the part drawings, but if it is not mentioned in the drawing, consult the SRM for a minimum bend radius chart. This

Figure 4-135. *Brake radius nosepiece adjustment.*

chart lists the smallest radius allowable for each thickness and temper of metal that is normally used. To bend tighter than this radius would jeopardize the integrity of the part. Stresses left in the area of the bend may cause it to fail while in service, even if it does not crack while bending it.

The brake radius bars of a sheet metal brake can be replaced with another brake radius bar with a different diameter. *[Figure 4-136]* For example, a 0.032-inch 2024-T3 L channel needs to be bent with a radius of $\frac{1}{8}$-inch and a radius bar with a $\frac{1}{8}$-inch radius must be installed. If different brake radius bars are not available, and the installed brake radius bar is smaller than required for the part, it is necessary to bend some nose radius shims. *[Figure 4-137]*

Figure 4-136. *Interchangeable brake radius bars.*

If the radius is so small that it tends to crack annealed aluminum, mild steel is a good choice of material. Experimentation with a small piece of scrap material is necessary to manufacture a thickness that increases the radius to precisely $\frac{1}{16}$-inch or $\frac{1}{8}$-inch. Use radius and fillet gauges to check this dimension. From this point on, each additional shim is added to the radius before it. *[Figure 4-138]*

Example: If the original nose was $\frac{1}{16}$-inch and a piece of .063-inch material ($\frac{1}{16}$-inch) was bent around it, the new outside radius is $\frac{1}{8}$-inch. If another .063-inch layer ($\frac{1}{16}$-inch) is added, it is now a $\frac{3}{16}$-inch radius. If a piece of .032-inch ($\frac{1}{32}$-inch) instead of .063-inch material ($\frac{1}{16}$-inch) is bent around the $\frac{1}{8}$-inch radius, a $\frac{5}{32}$-inch radius results.

Step 2: Adjusting Clamping Pressure

The next step is setting clamping pressure. Slide a piece of the material with the same thickness as the part to be bent under the brake radius piece. Pull the clamping lever toward the operator to test the pressure. This is an over center type clamp and, when properly set, will not feel springy or spongy when pulled to its fully clamped position. The operator must be able to pull this lever over center with a firm pull and have it bump its limiting stops. On some brakes, this adjustment has to be made on both sides of the brake.

Place test strips on the table 3 inches from each end and one in the center between the bed and the clamp, adjust clamp

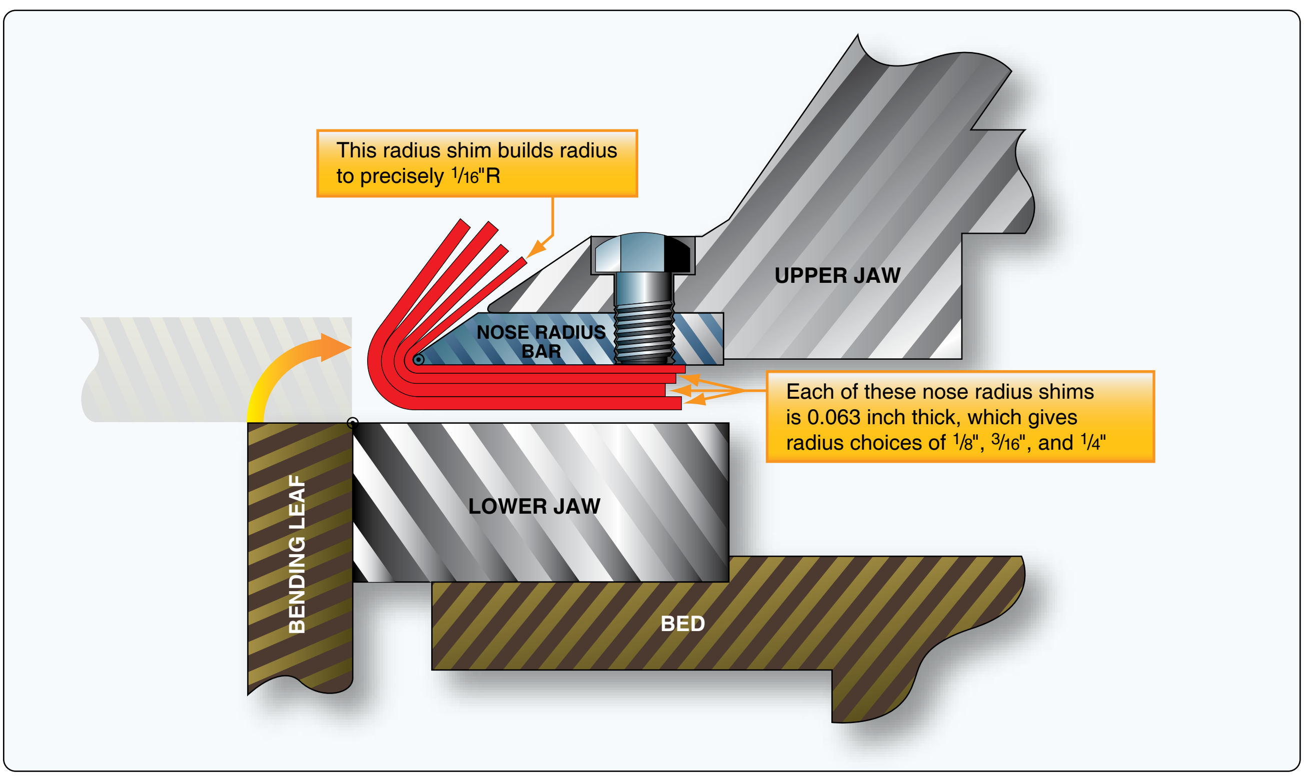


Figure 4-137. *Nose radius shims may be used when the brake radius bar is smaller than required.*

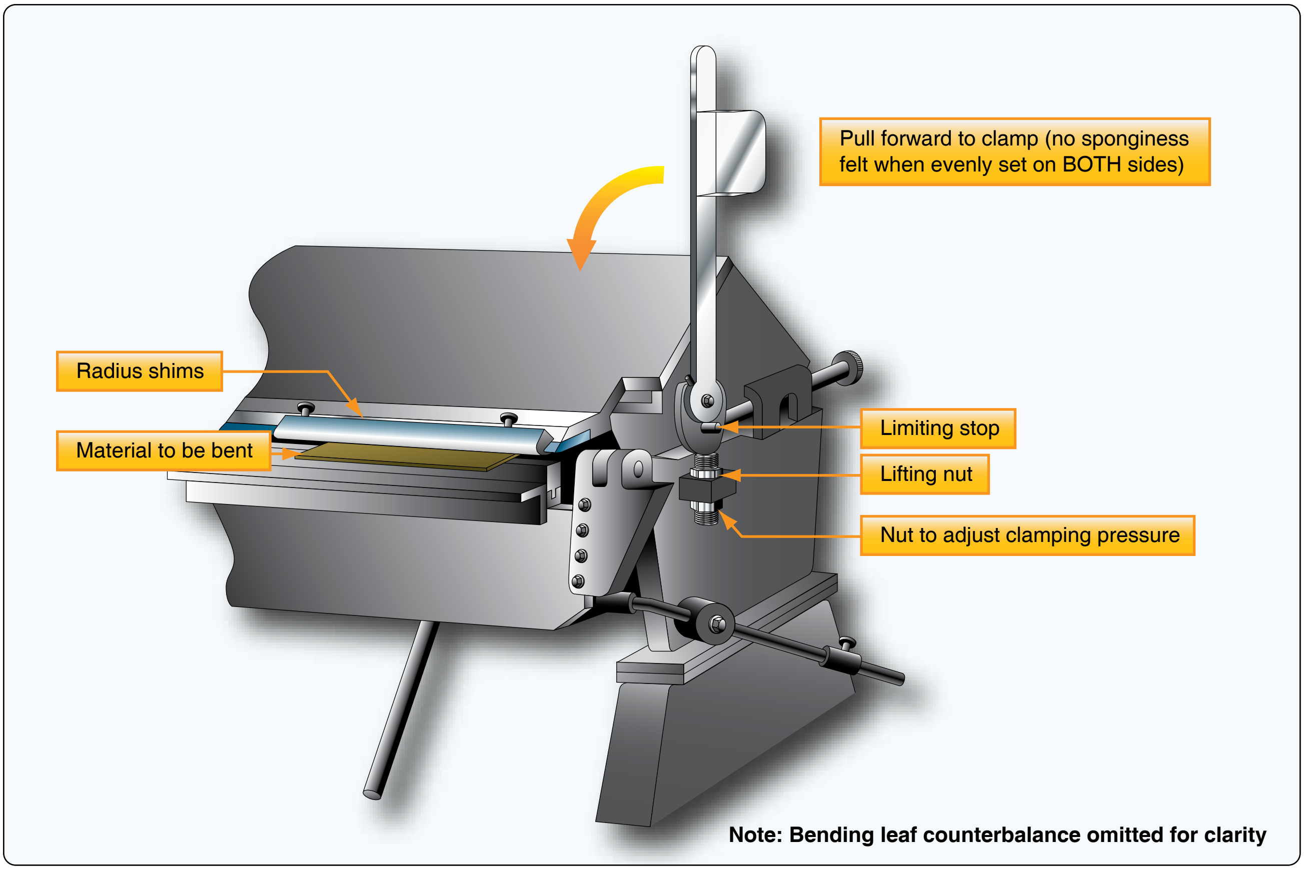


Figure 4-138. *General brake overview including radius shims.*

pressure until it is tight enough to prevent the work pieces from slipping while bending. The clamping pressure can be adjusted with the clamping pressure nut. *[Figure 4-139]*

Step 3: Adjusting the Nose Gap

Adjust the nose gap by turning the large brake nose gap adjustment knobs at the rear of the upper jaw to achieve its proper alignment. *[Figure 4-140]* The perfect setting is obtained when the bending leaf is held up to the angle of the finished bend and there is one material thickness between the bending leaf and the nose radius piece. Using a piece of material the thickness of the part to be bent as a feeler gauge can help achieve a high degree of accuracy. *[Figures 4-140* and *4-141]* It is essential this nose gap be

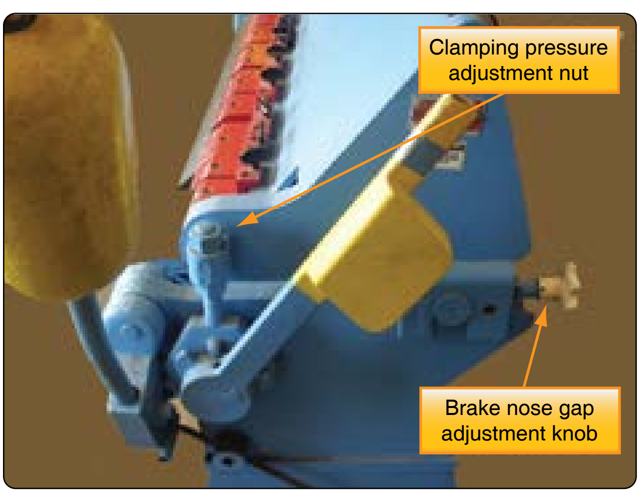


Figure 4-139. *Adjust clamping pressure with the clamping pressure nut.*

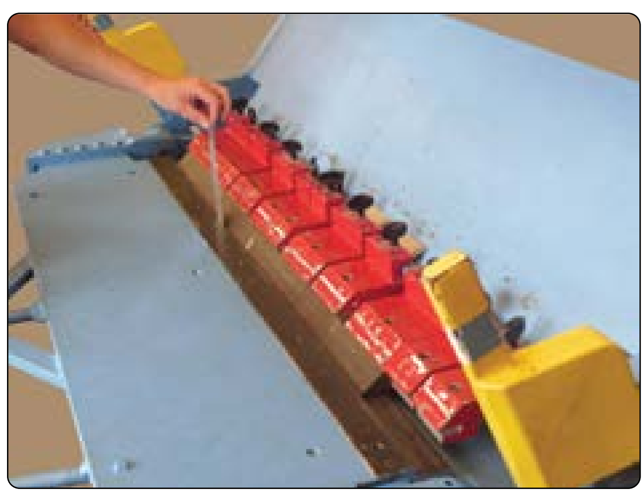


Figure 4-140. *Brake nose gap adjustment with piece of material same thickness as part to be formed.*

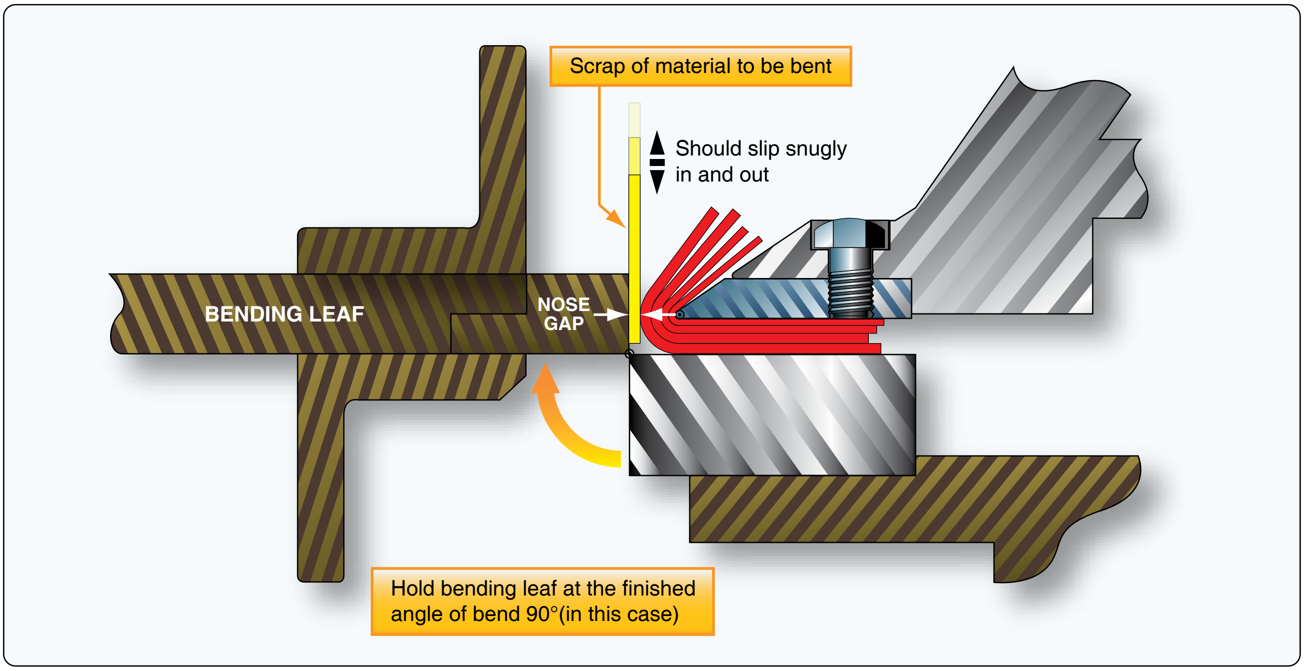


Figure 4-141. *Profile illustration of brake nose gap adjustment.*

perfect, even across the length of the part to be bent. Check by clamping two test strips between the bed and the clamp 3 inches from each end of the brake. *[Figure 4-142]* Bend 90° *[Figure 4-143]*, remove test strips, and place one on top of the other; they should match. *[Figure 4-144]* If they do not match, adjust the end with the sharper bend back slightly.

Folding a Box

A box can be formed the same way as the U-channel described on in the previous paragraphs, but when a sheet metal part has intersecting bend radii, it is necessary to remove material to make room for the material contained in the flanges. This is done by drilling or punching holes at the intersection of the inside bend tangent lines. These holes, called relief holes and whose diameter is approximately twice the bend radius, relieve stresses in the metal as it is bent and prevent the metal from tearing. Relief holes also provide a neatly trimmed corner from which excess material may be trimmed.

Figure 4-142. *Brake alignment with two test strips 3 inches from each end.*

The larger and smoother the relief hole is, the less likely it will be that a crack will form in the corner. Generally, the radius of the relief hole is specified on the drawing. A box and pan brake, also called a finger brake, is used to bend the

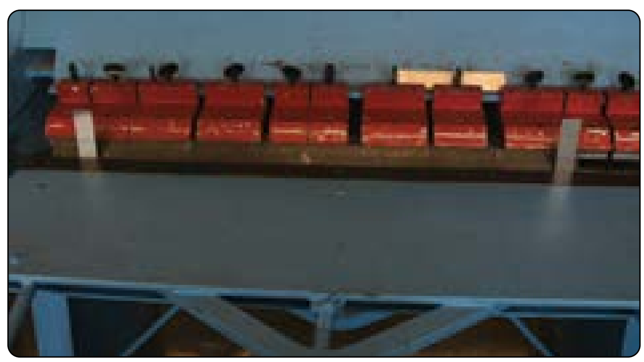


Figure 4-143. *Brake alignment with two test strips bent at 90°.*

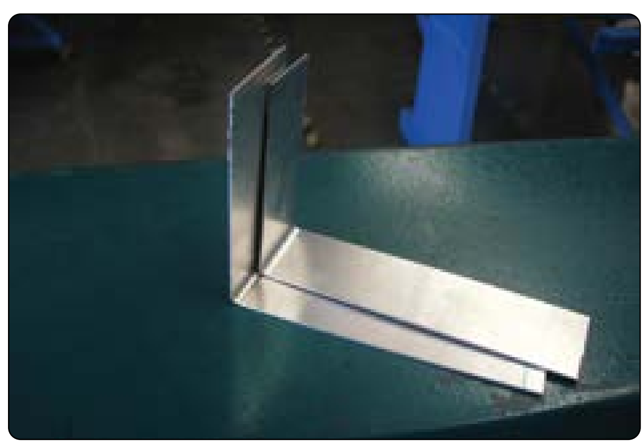


Figure 4-144. *Brake alignment by comparing test strips.*

box. Two opposite sides of the box are bent first. Then, the fingers of the brake are adjusted so the folded-up sides ride up in the cracks between the fingers when the leaf is raised to bend the other two sides.

The size of relief holes varies with thickness of the material. They should be no less than 1/8-inch in diameter for aluminum alloy sheet stock up to and including 0.064-inch thick, or 3/160-inch in diameter for stock ranging from 0.072-inch to 0.128-inch thickness. The most common method of determining the diameter of a relief hole is to use the radius of bend for this dimension, provided it is not less than the minimum allowance (1/8-inch).

Relief Hole Location

Relief holes must touch the intersection of the inside bend tangent lines. To allow for possible error in bending, make the relief holes extend 1/32-inch to 1/16-inch behind the inside bend tangent lines. It is good practice to use the intersection of these lines as the center for the holes. The line on the inside of the curve is cut at an angle toward the relief holes to allow for the stretching of the inside flange.

The positioning of the relief hole is important. *[Figure 4-145]* It should be located so its outer perimeter touches the intersection of the inside bend tangent lines. This keeps any material from interfering with the bend allowance area of the other bend. If these bend allowance areas intersected with each other, there would be substantial compressive stresses that would accumulate in that corner while bending. This could cause the part to crack while bending.

Layout Method

Lay out the basic part using traditional layout procedures. This determines the width of the flats and the bend allowance. It is the intersection of the inside bend tangent lines that index the bend relief hole position. Bisect these intersected lines and move outward the distance of the radius of the hole on this line. This is the center of the hole. Drill at this point and finish by trimming off the remainder of the corner material. The trim out is often tangent to the radius and perpendicular to the edge. *[Figure 4-146]* This leaves an open corner. If the corner must be closed, or a slightly longer flange is necessary, then trim out accordingly. If the corner is to be welded, it is necessary to have touching flanges at the corners. The length of the flange should be one material thickness shorter than the finished length of the part so only the insides of the flanges touch.

Open & Closed Bends

Open and closed bends present unique problems that require more calculations than 90° bends. In the following 45° and a 135° bend examples, the material is 0.050-inch thick and the bend radius is 3/16-inch.

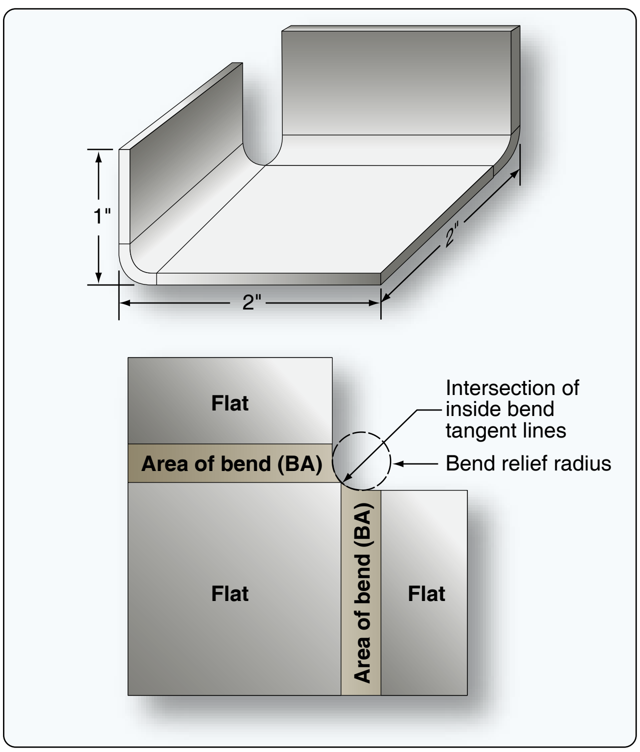


Figure 4-145. *Relief hole location.*

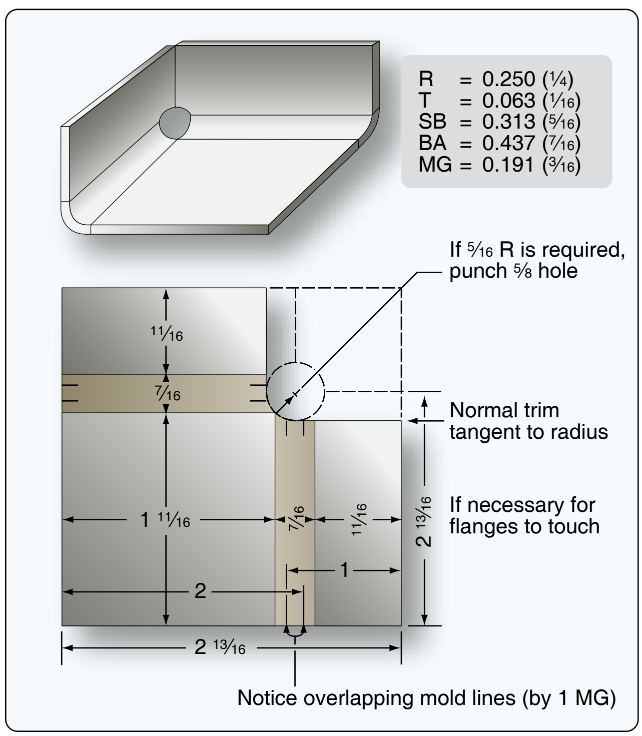


Figure 4-146. *Relief hole layout.*

Open End Bend (Less Than 90°)

Figure 4-147 shows an example for a 45° bend.

1. Look up K-factor in K chart. K-factor for 45° is 0.41421-inch.
2. Calculate setback.

   SB = K(R + T)

   SB = 0.41421-inch(0.1875-inch + 0.050-inch) = 0.098-inch
3. Calculate bend allowance for 45°. Look up bend allowance for 1° of bend in the bend allowance chart and multiply this by 45.

   0.003675-inch × 45 = 0.165-inch
4. Calculate flats.

   Flat = Mold line dimension – SB

   Flat 1 = .77-inch – 0.098-inch = 0.672-inch

   Flat 2 = 1.52-inch – 0.098-inch = 1.422-inch
5. Calculate TDW

   TDW = Flats + Bend allowance

   TDW = 0.672-inch + 1.422-inch + 0.165-inch = 2.259-inch.

Observe that the brake reference line is still located one radius from the bend tangent line.

Closed End Bend (More Than 90°)

Figure 4-148 shows an example of a 135° bend.

1. Look up K-factor in K chart. K-factor for 135° is 2.4142-inch.
2. Calculate SB.

   SB = K(R + T)

   SB = 2.4142-inch(0.1875-inch + 0.050-inch) = 0.57-inch
3. Calculate bend allowance for 135°. Look up bend allowance for 1° of bend in the bend allowance chart and multiply this by 135.

   0.003675-inch × 135 = 0.496-inch
4. Calculate flats.

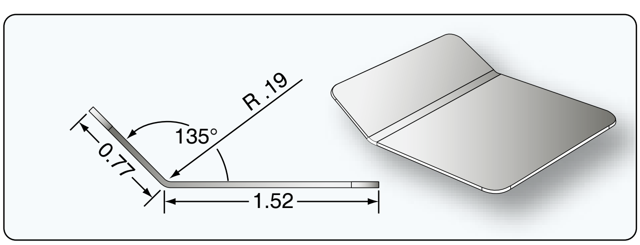


Figure 4-147. *Open bend.*

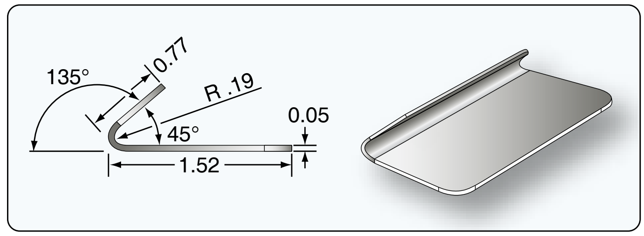


Figure 4-148. *Closed bend.*

   Flat = Mold line dimension – SB

   Flat 1 = 0.77-inch – 0.57-inch = 0.20-inch

   Flat 2 = 1.52-inch – 0.57-inch = 0.95-inch
5. Calculate TDW.

   TDW = Flats + Bend allowance

   TDW = 0.20-inch + 0.95-inch + 0.496-inch = 1.65-inch

It is obvious from both examples that a closed bend has a smaller TDW than an open-end bend and the material length needs to be adjusted accordingly.

Hand Forming

All hand forming revolves around the processes of stretching and shrinking metal. As discussed earlier, stretching means to lengthen or increase a particular area of metal while shrinking means to reduce an area. Several methods of stretching and shrinking may be used, depending on the size, shape, and contour of the part being formed.

For example, if a formed or extruded angle is to be curved, either stretch one leg or shrink the other, whichever makes the part fit. In bumping, the material is stretched in the bulge to make it balloon, and in joggling, the material is stretched between the joggles. Material in the edge of lightening holes is often stretched to form a beveled reinforcing ridge around them. The following paragraphs discuss some of these techniques.

Straight Line Bends

The cornice brake and bar folder are ordinarily used to make straight bends. Whenever such machines are not available, comparatively short sections can be bent by hand with the aid of wooden or metal bending blocks.

After a blank has been laid out and cut to size, clamp it along the bend line between two wooden forming blocks held in a vise. The wooden forming blocks should have one edge rounded as needed for the desired radius of bend. It should also be curved slightly beyond 90° to allow for spring-back.

Bend the metal that protrudes beyond the bending block to the desired angle by tapping lightly with a rubber, plastic, or rawhide mallet. Start tapping at one end and work back and forth along the edge to make a gradual and even bend. Continue this process until the protruding metal is bent to the desired angle against the forming block. Allow for spring-back by driving the material slightly farther than the actual bend. If a large amount of metal extends beyond the forming blocks, maintain hand pressure against the protruding sheet to prevent it from bouncing. Remove any irregularities by holding a straight block of hardwood edgewise against the bend and striking it with heavy blows of a mallet or hammer. If the amount of metal protruding beyond the bending blocks is small, make the entire bend by using the hardwood block and hammer.

Formed or Extruded Angles

Both formed and extruded types of angles can be curved (not bent sharply) by stretching or shrinking either of the flanges. Curving by stretching one flange is usually preferred since the process requires only a V-block and a mallet and is easily accomplished.

Stretching with V-Block Method

In the stretching method, place the flange to be stretched in the groove of the V-block. *[Figure 4-149]* (If the flange is to be shrunk, place the flange across the V-block.) Using a round, soft-faced mallet, strike the flange directly over the V portion with light, even blows while gradually forcing it downward into the V.

Begin at one end of the flange and form the curve gradually and evenly by moving the strip slowly back and forth, distributing the hammer blows at equal spaces on the flange. Hold the strip firmly to keep it from bouncing when hammered. An overly heavy blow buckles the metal, so keep moving the flange across the V-block, but always lightly strike the spot directly above the V.

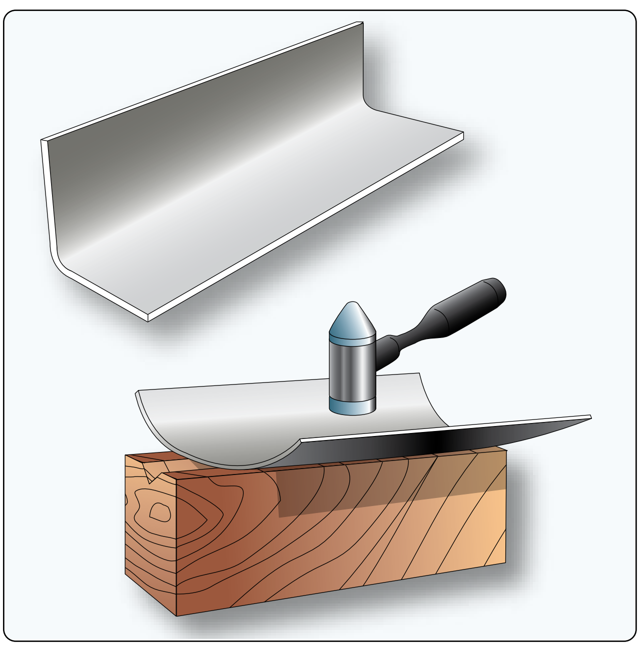


Figure 4-149. *V-block forming.*

Lay out a full-sized, accurate pattern on a sheet of paper or plywood and periodically check the accuracy of the curve. Comparing the angle with the pattern determines exactly how the curve is progressing and just where it needs to be increased or decreased. It is better to get the curve to conform roughly to the desired shape before attempting to finish any one portion, because the finishing or smoothing of the angle may cause some other portion of the angle to change shape. If any part of the angle strip is curved too much, reduce the curve by reversing the angle strip on the V-block, placing the bottom flange up, and striking it with light blows of the mallet.

Try to form the curve with a minimum amount of hammering, for excessive hammering work hardens the metal. Work-hardening can be recognized by a lack of bending response or by springiness in the metal. It can be recognized very readily by an experienced worker. In some cases, the part may have to be annealed during the curving operation. If so, be sure to heat treat the part again before installing it on the aircraft.

Shrinking With V-Block & Shrinking Block Methods

Curving an extruded or formed angle strip by shrinking may be accomplished by either the previously discussed V-block method or the shrinking block method. While the V-block is more satisfactory because it is faster, easier, and affects the metal less, good results can be obtained by the shrinking block method.

In the V-block method, place one flange of the angle strip flat on the V-block with the other flange extending upward. Using the process outlined in the stretching paragraphs, begin at one end of the angle strip and work back and forth making light blows. Strike the edge of the flange at a slight angle to keep the vertical flange from bending outward.

Occasionally, check the curve for accuracy with the pattern. If a sharp curve is made, the angle (cross-section of the formed angle) closes slightly. To avoid such closing of the angle, clamp the angle strip to a hardwood board with the hammered flange facing upward using small C-clamps. The jaws of the C-clamps should be covered with masking tape. If the angle has already closed, bring the flange back to the correct angle with a few blows of a mallet or with the aid of a small hardwood block. If any portion of the angle strip is curved too much, reduce it by reversing the angle on the V-block and hammering with a suitable mallet, as explained in the previous paragraph on stretching. After obtaining the proper curve, smooth the entire angle by planishing with a soft-faced mallet.

If the curve in a formed angle is to be quite sharp or if the flanges of the angle are rather broad, the shrinking block method is generally used. In this process, crimp the flange that is to form the inside of the curve.

When making a crimp, hold the crimping pliers so that the jaws are about ⅛-inch apart. By rotating the wrist back and forth, bring the upper jaw of the pliers into contact with the flange, first on one side and then on the other side of the lower jaw. Complete the crimp by working a raised portion into the flange, gradually increasing the twisting motion of the pliers. Do not make the crimp too large because it will be difficult to work out. The size of the crimp depends upon the thickness and softness of the material, but usually about ¼-inch is sufficient. Place several crimps spaced evenly along the desired curve with enough space left between each crimp so that jaws of the shrinking block can easily be attached.

After completing the crimping, place the crimped flange in the shrinking block so that one crimp at a time is located between the jaws. *[Figure 4-150]* Flatten each crimp with light blows of a soft-faced mallet, starting at the apex (the closed end) of the crimp and gradually working toward the edge of the flange. Check the curve of the angle with the pattern periodically during the forming process and again after all the crimps have been worked out. If it is necessary to increase the curve, add more crimps and repeat the process. Space the additional crimps between the original ones so that the metal does not become unduly work hardened at any one point. If the curve needs to be increased or decreased slightly at any point, use the V-block.

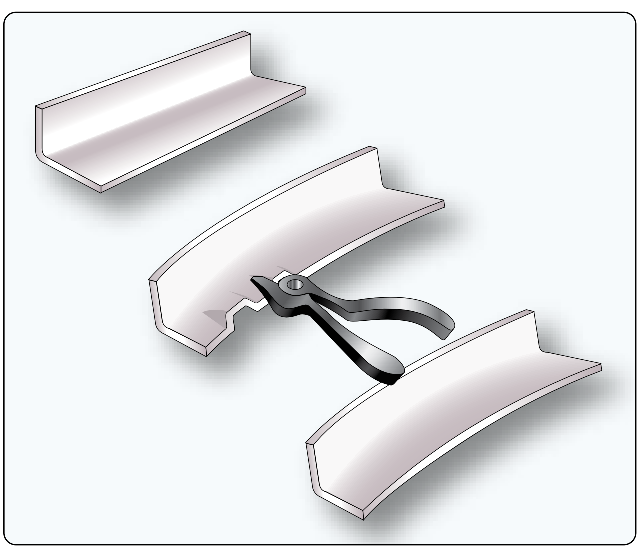


Figure 4-150. *Crimping a metal flange in order to form a curve.*

After obtaining the desired curve, planish the angle strip over a stake or a wooden form.

Flanged Angles

The forming process for the following two flanged angles is slightly more complicated than the previously discussed angles because the bend is shorter (not gradually curved) and necessitates shrinking or stretching in a small or concentrated area. If the flange is to point toward the inside of the bend, the material must be shrunk. If it is to point toward the outside, it must be stretched.

Shrinking

In forming a flanged angle by shrinking, use wooden forming blocks similar to those shown in *Figure 4-151* and proceed as follows:

1. Cut the metal to size, allowing for trimming after forming. Determine the bend allowance for a 90° bend and round the edge of the forming block accordingly.
2. Clamp the material in the form blocks as shown in *Figure 4-151,* and bend the exposed flange against the block. After bending, tap the blocks slightly. This induces a setting process in the bend.
3. Using a soft-faced shrinking mallet, start hammering near the center and work the flange down gradually toward both ends. The flange tends to buckle at the bend because the material is made to occupy less space. Work the material into several small buckles instead of one large one and work each buckle

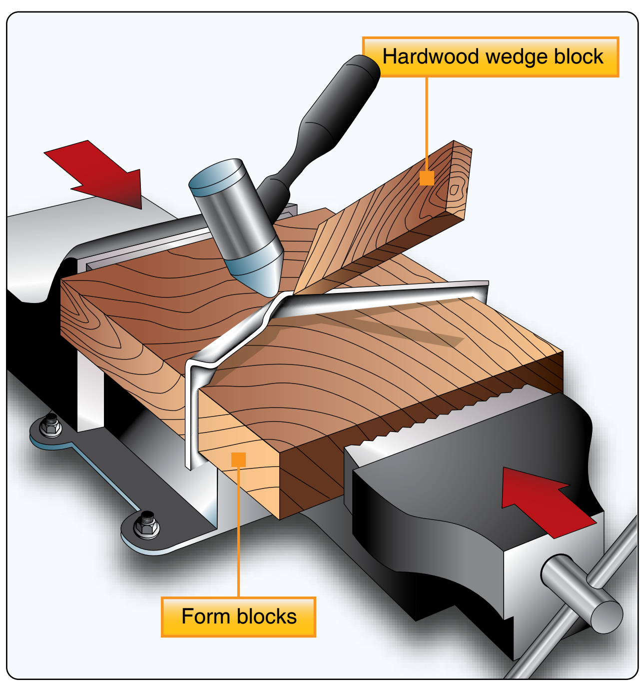


Figure 4-151. *Forming a flanged angle using forming blocks.*

out gradually by hammering lightly and gradually compressing the material in each buckle. The use of a small hardwood wedge block aids in working out the buckles. *[Figure 4-152]*

4. Planish the flange after it is flattened against the form block and remove small irregularities. If the form blocks are made of hardwood, use a metal planishing hammer. If the forms are made of metal, use a soft-faced mallet. Trim the excess material away and file and polish.

Stretching

To form a flanged angle by stretching, use the same forming blocks, wooden wedge block, and mallet as used in the shrinking process and proceed as follows:

1. Cut the material to size (allowing for trim), determine bend allowance for a 90° bend, and round off the edge of the block to conform to the desired radius of bend.
2. Clamp the material in the form blocks. *[Figure 4-153]*
3. Using a soft-faced stretching mallet, start hammering near the ends and work the flange down smoothly and gradually to prevent cracking and splitting. Planish the flange and angle as described in the previous procedure, and trim and smooth the edges, if necessary.

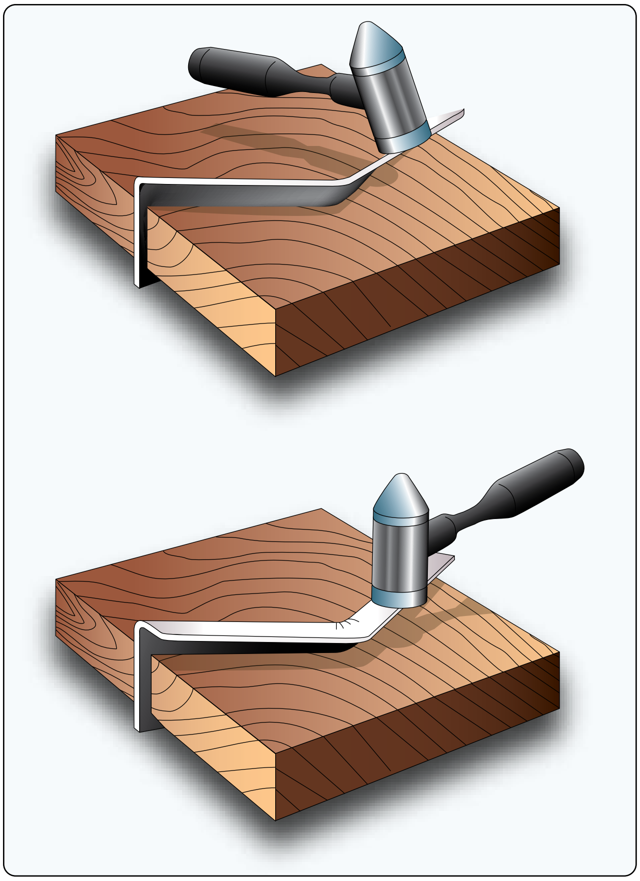


Figure 4-153. *Stretching a flanged angle.*

Curved Flanged Parts

Curved flanged parts are usually hand formed with a concave flange, the inside edge, and a convex flange, the outside edge. The concave flange is formed by stretching, while the convex flange is formed by shrinking. Such parts are shaped with the aid of hardwood or metal forming blocks. *[Figure 4-154]* These blocks are made in pairs and are designed specifically for the shape of the area being formed. These blocks are made in pairs similar to those used for straight angle bends and are identified in the same manner. They differ in that they are made specifically for the particular part to be formed, they fit each other exactly, and they conform to the actual dimensions and contour of the finished article.

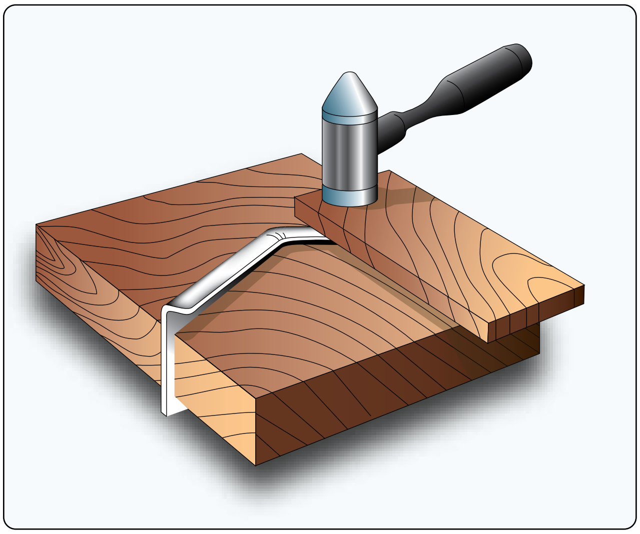


Figure 4-152. *Shrinking.*

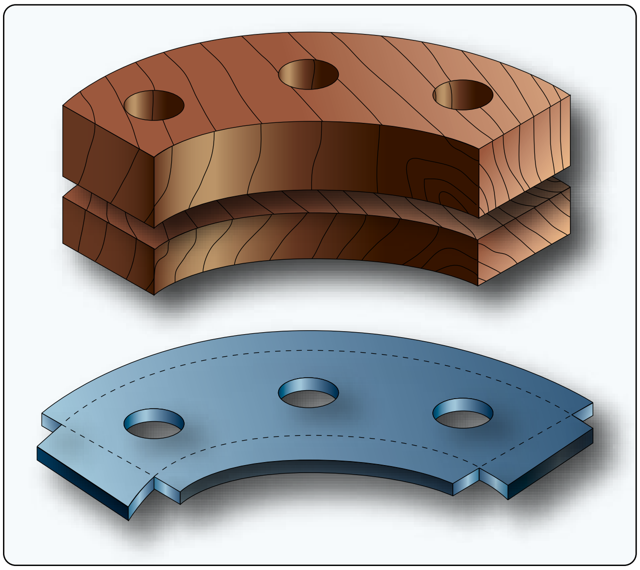


Figure 4-154. *Forming blocks.*

The forming blocks may be equipped with small aligning pins to help line up the blocks and to hold the metal in place or they may be held together by C-clamps or a vise. They also may be held together with bolts by drilling through form blocks and the metal, provided the holes do not affect the strength of the finished part. The edges of the forming block are rounded to give the correct radius of bend to the part, and are undercut approximately 5° to allow for spring-back of the metal. This undercut is especially important if the material is hard or if the bend must be accurate.

The nose rib offers a good example of forming a curved flange because it incorporates both stretching and shrinking (by crimping). They usually have a concave flange, the inside edge, and a convex flange, the outside edge. Note the various types of forming represented in the following figures. In the plain nose rib, only one large convex flange is used. *[Figure 4-155]* Because of the great distance around the part and the likelihood of buckles in forming, it is rather difficult to form. The flange and the beaded (raised ridge on sheet metal used to stiffen the piece) portion of this rib provide sufficient strength to make this a good type to use. In *Figure 4-156*, the concave flange is difficult to form, but the outside flange is broken up into smaller sections by relief holes. In *Figure 4-157*, note that crimps are placed at equally spaced intervals to absorb material and cause curving, while also giving strength to the part.

In *Figure 4-158*, the nose rib is formed by crimping, beading, putting in relief holes, and using a formed angle riveted on each end. The beads and the formed angles supply strength to the part. The basic steps in forming a curved flange follow: *[Figures 4-159* and *160]*

1. Cut the material to size, allowing about ¼-inch excess material for trim and drill holes for alignment pins.
2. Remove all burrs (jagged edges). This reduces the possibility of the material cracking at the edges during the forming process.

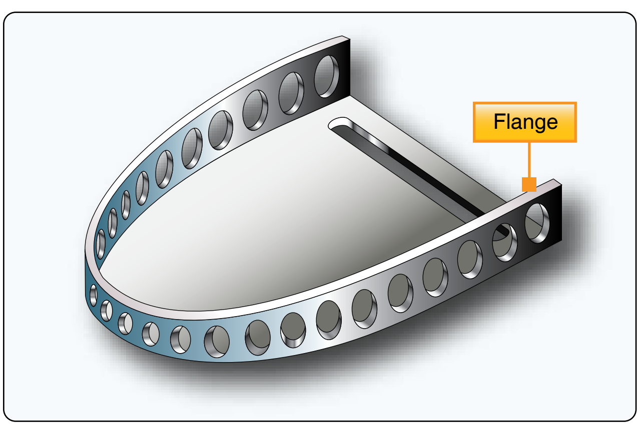


Figure 4-155. *Plain nose rib.*

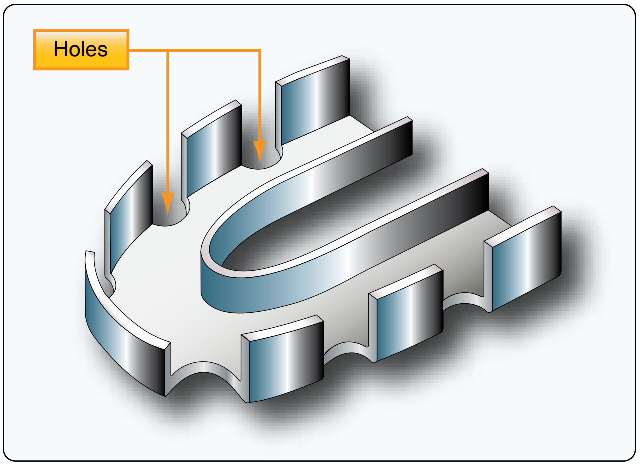


Figure 4-156. *Nose rib with relief holes.*

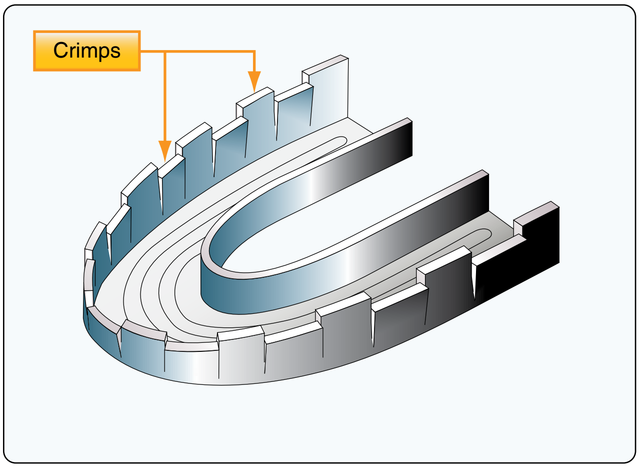


Figure 4-157. *Nose rib with crimps.*

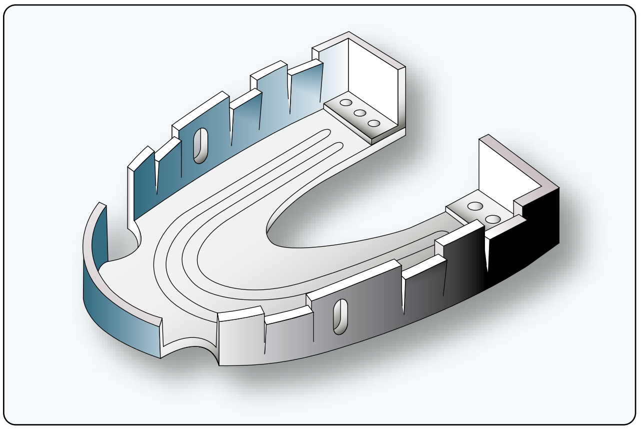


Figure 4-158. *Nose rib using a combination of forms.*

3. Locate and drill holes for alignment pins.
4. Place the material between the form blocks and clamp blocks tightly in a vise to prevent the material from moving or shifting. Clamp the work as closely as possible to the particular area being hammered to

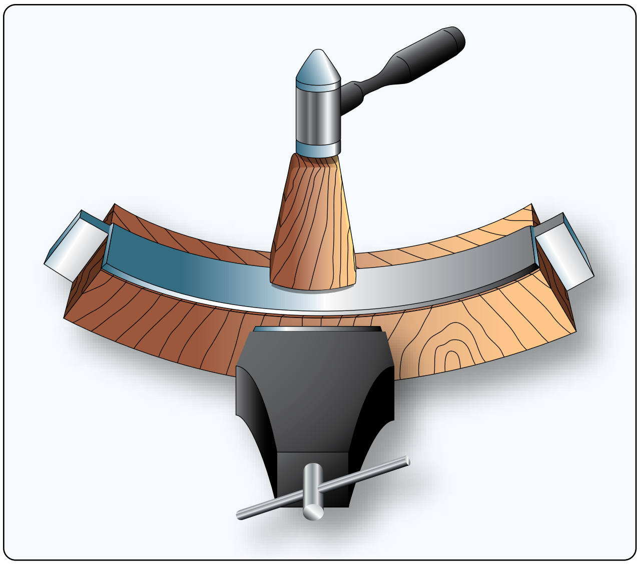


Figure 4-159. *Forming a concave flange.*

prevent strain on the form blocks and to keep the metal from slipping.

Concave Surfaces

Bend the flange on the concave curve first. This practice may keep the flange from splitting open or cracking when the metal is stretched. Should this occur, a new piece must be made. Using a plastic or rawhide mallet with a smooth, slightly rounded face, start hammering at the extreme ends of the part and continue toward the center of the bend. This procedure permits some of the metal at the ends of the part to be worked into the center of the curve where it is needed. Continue hammering until the metal is gradually worked down over the entire flange, flush with the form block. After the flange is formed, trim off the excess material and check the part for accuracy. *[Figure 4-159]*

Convex Surfaces

Convex surfaces are formed by shrinking the material over a form block. *[Figure 4-160]* Using a wooden or plastic shrinking mallet and a backup or wedge block, start at the center of the curve and work toward both ends. Hammer the flange down over the form, striking the metal with glancing blows at an angle of approximately 45° and with a motion that tends to pull the part away from the radius of the form block. Stretch the metal around the radius bend and remove the buckles gradually by hammering on a wedge block. Use the backup block to keep the edge of the flange as nearly perpendicular to the form block as possible. The backup block also lessens the possibility of buckles, splits, or cracks. Finally, trim the flanges of excess metal, planish, remove burrs, round the corners (if any), and check the part for accuracy.

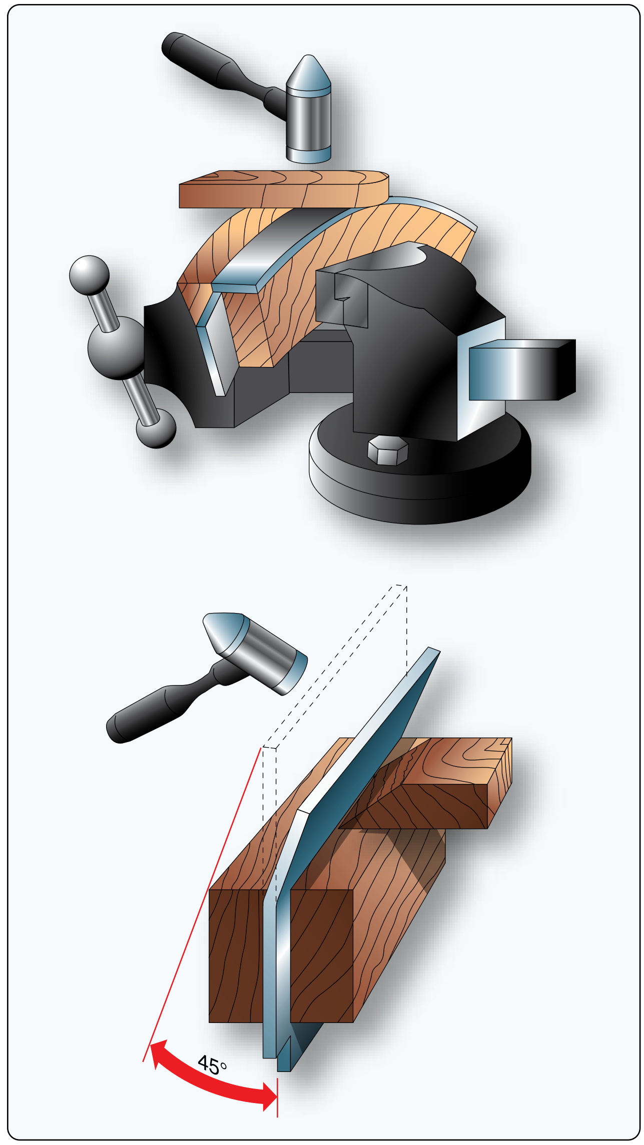


Figure 4-160. *Forming a convex flange.*

Forming by Bumping

As discussed earlier, bumping involves stretching the sheet metal by bumping it into a form and making it balloon. *[Figure 4-161]* Bumping can be done on a form block or female die, or on a sandbag.

Either method requires only one form: a wooden block, a lead die, or a sandbag. The blister, or streamlined cover plate, is an example of a part made by the form block or die method of bumping. Wing fillets are an example of parts that are usually formed by bumping on a sandbag.

Form Block or Die

The wooden block or lead die designed for form block bumping must have the same dimensions and contour as the outside of the blister. To provide enough bucking weight

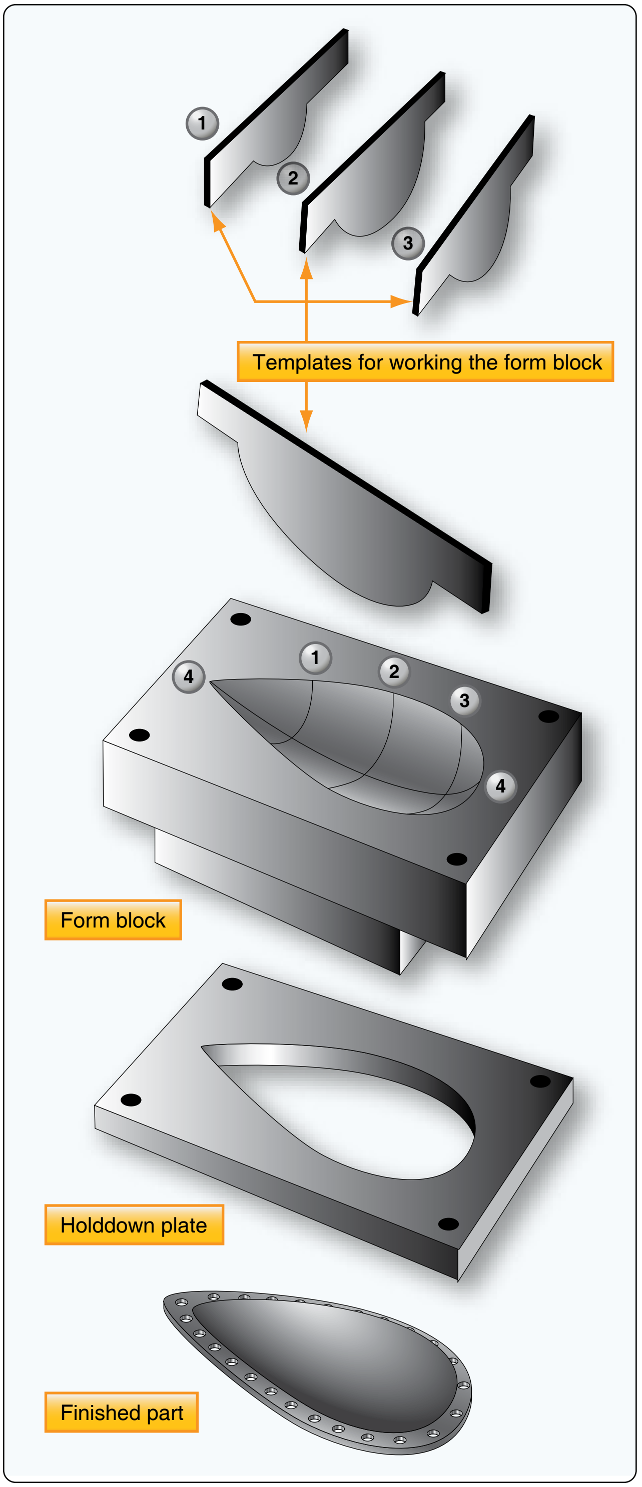


Figure 4-161. *Form block bumping.*

and bearing surface for fastening the metal, the block or die should be at least one inch larger in all dimensions than the form requires.

Follow these procedures to create a form block:

1. Hollow the block out with tools, such as saws, chisels, gouges, files, and rasps.
2. Smooth and finish the block with sandpaper. The inside of the form must be as smooth as possible, because the slightest irregularity shows up on the finished part.
3. Prepare several templates (patterns of the cross-section), as shown in *Figure 4-161* so that the form can be checked for accuracy.
4. Shape the contour of the form at points 1, 2, and 3.
5. Shape the areas between the template checkpoints to conform the remaining contour to template 4. Shaping of the form block requires particular care because the more nearly accurate it is, the less time it takes to produce a smooth, finished part.

After the form is prepared and checked, perform the bumping as follows:

1. Cut a metal blank to size allowing an extra ½ to 1-inch to permit drawing.
2. Apply a thin coat of light oil to the block and the aluminum to prevent galling (scraping on rough spots).
3. Clamp the material between the block and steel plate. Ensure it is firmly supported yet it can slip a little toward the inside of the form.
4. Clamp the bumping block in a bench vise. Use a soft-faced rubber mallet, or a hardwood drive block with a suitable mallet, to start the bumping near the edges of the form.
5. Work the material down gradually from the edges with light blows of the mallet. Remember, the purpose of bumping is to work the material into shape by stretching rather than forcing it into the form with heavy blows. Always start bumping near the edge of the form. Never start near the center of the blister.
6. Before removing the work from the form, smooth it as much as possible by rubbing it with the rounded end of either a maple block or a stretching mallet.
7. Remove the blister from the bumping block and trim to size.

Sandbag Bumping

Sandbag bumping is one of the most difficult methods of hand forming sheet metal because there is no exact forming block to guide the operation. *[Figure 4-162]* In this method, a depression is made into the sandbag to take the shape of the hammered portion of the metal. The depression or pit has a tendency to shift from the hammering, which necessitates periodic readjustment during the bumping process. The degree of shifting depends largely on the contour or shape of the piece being formed, and whether glancing blows must be struck to stretch, draw, or shrink the metal. When forming

Figure 4-162. *Sandbag bumping.*

by this method, prepare a contour template or some sort of a pattern to serve as a working guide and to ensure accuracy of the finished part. Make the pattern from ordinary kraft or similar paper, folding it over the part to be duplicated. Cut the paper cover at the points where it would have to be stretched to fit, and attach additional pieces of paper with masking tape to cover the exposed portions. After completely covering the part, trim the pattern to exact size.

Open the pattern and spread it out on the metal from which the part is to be formed. Although the pattern does not lie flat, it gives a fairly accurate idea of the approximate shape of the metal to be cut, and the pieced-in sections indicate where the metal is to be stretched. When the pattern has been placed on the material, outline the part and the portions to be stretched using a felt-tipped pen. Add at least one inch of excess metal when cutting the material to size. Trim off the excess metal after bumping the part into shape.

If the part to be formed is radially symmetrical, it is fairly easy to shape since a simple contour template can be used as a working guide. The procedure for bumping sheet metal parts on a sandbag follows certain basic steps that can be applied to any part, regardless of its contour or shape.

1. Lay out and cut the contour template to serve as a working guide and to ensure accuracy of the finished part. (This can be made of sheet metal, medium to heavy cardboard, kraft paper, or thin plywood.)
2. Determine the amount of metal needed, lay it out, and cut it to size, allowing at least ½-inch in excess.
3. Place a sandbag on a solid foundation capable of supporting heavy blows and make a pit in the bag with a smooth-faced mallet. Analyze the part to determine the correct radius the pit should have for the forming operation. The pit changes shape with the hammering it receives and must be readjusted accordingly.
4. Select a soft round-faced or bell-shaped mallet with a contour slightly smaller than the contour desired on the sheet metal part. Hold one edge of the metal in the left hand and place the portion to be bumped near the edge of the pit on the sandbag. Strike the metal with light glancing blows.
5. Continue bumping toward the center, revolving the metal, and working gradually inward until the desired shape is obtained. Shape the entire part as a unit.
6. Check the part often for accuracy of shape during the bumping process by applying the template. If wrinkles form, work them out before they become too large.
7. Remove small dents and hammer marks with a suitable stake and planishing hammer or with a hand dolly and planishing hammer.
8. Finally, after bumping is completed, use a pair of dividers to mark around the outside of the object. Trim the edge and file it smooth. Clean and polish the part.

Joggling

A joggle, often found at the intersection of stringers and formers, is the offset formed on a part to allow clearance for a sheet or another mating part. Use of the joggle maintains the smooth surface of a joint or splice. The amount of offset is usually small; therefore, the depth of the joggle is generally specified in thousandths of an inch. The thickness of the material to be cleared governs the depth of the joggle. In determining the necessary length of the joggle, allow an extra $\frac{1}{16}$-inch to give enough added clearance to assure a fit between the joggled, overlapped part. The distance between the two bends of a joggle is called the allowance. This dimension is normally called out on the drawing. However, a general rule of thumb for figuring allowance is four times the thickness of the displacement of flat sheets. For 90° angles, it must be slightly more due to the stress built up at the radius while joggling. For extrusions, the allowance can be as much as 12 times the material thickness, so, it is important to follow the drawing.

There are a number of different methods of forming joggles. For example, if the joggle is to be made on a straight flange or flat piece of metal, it can be formed on a cornice brake. To form the joggle, use the following procedure:

1. Lay out the boundary lines of the joggle where the bends are to occur on the sheet.
2. Insert the sheet in the brake and bend the metal up approximately 20° to 30°.
3. Release the brake and remove the part.
4. Turn the part over and clamp it in the brake at the second bend line.
5. Bend the part up until the correct height of the joggle is attained.

6. Remove the part from the brake and check the joggle for correct dimensions and clearance.

When a joggle is necessary on a curved part or a curved flange, forming blocks or dies made of hardwood, steel, or aluminum alloy may be used. The forming procedure consists of placing the part to be joggled between the two joggle blocks and squeezing them in a vice or some other suitable clamping device. After the joggle is formed, the joggle blocks are turned over in the vice and the bulge on the opposite flange is flattened with a wooden or rawhide mallet. *[Figure 4-163]*

Since hardwood is easily worked, dies made of hardwood are satisfactory when the die is to be used only a few times. If a number of similar joggles are to be produced, use steel or aluminum alloy dies. Dies of aluminum alloy are preferred since they are easier to fabricate than those of steel and wear about as long. These dies are sufficiently soft and resilient to permit forming aluminum alloy parts on them without marring, and nicks and scratches are easily removed from their surfaces.

When using joggling dies for the first time, test them for accuracy on a piece of waste stock to avoid the possibility of ruining already fabricated parts. *[Figure 4-164]* Always keep the surfaces of the blocks free from dirt, filings, and the like, so that the work is not marred.

Lightening Holes

Lightening holes are cut in rib sections, fuselage frames, and other structural parts to decrease weight. To avoid weakening the member by removal of the material, flanges are often pressed around the holes to strengthen the area from which the material was removed.

Lightening holes should never be cut in any structural part unless authorized. The size of the lightening hole and the width of the flange formed around the hole are determined by design specifications. Margins of safety are considered in the specifications so that the weight of the part can be decreased and still retain the necessary strength. Lightening holes may be cut with a hole saw, a punch, or a fly cutter. The edges are filed smooth to prevent them from cracking or tearing.

Flanging Lightening Holes

Form the flange by using a flanging die, or hardwood or metal form blocks. Flanging dies consist of two matching parts: a female and a male die. For flanging soft metal, dies can be of hardwood, such as maple. For hard metal or for more permanent use, they should be made of steel. The pilot guide should be the same size as the hole to be flanged, and the shoulder should be the same width and angle as the desired flange.

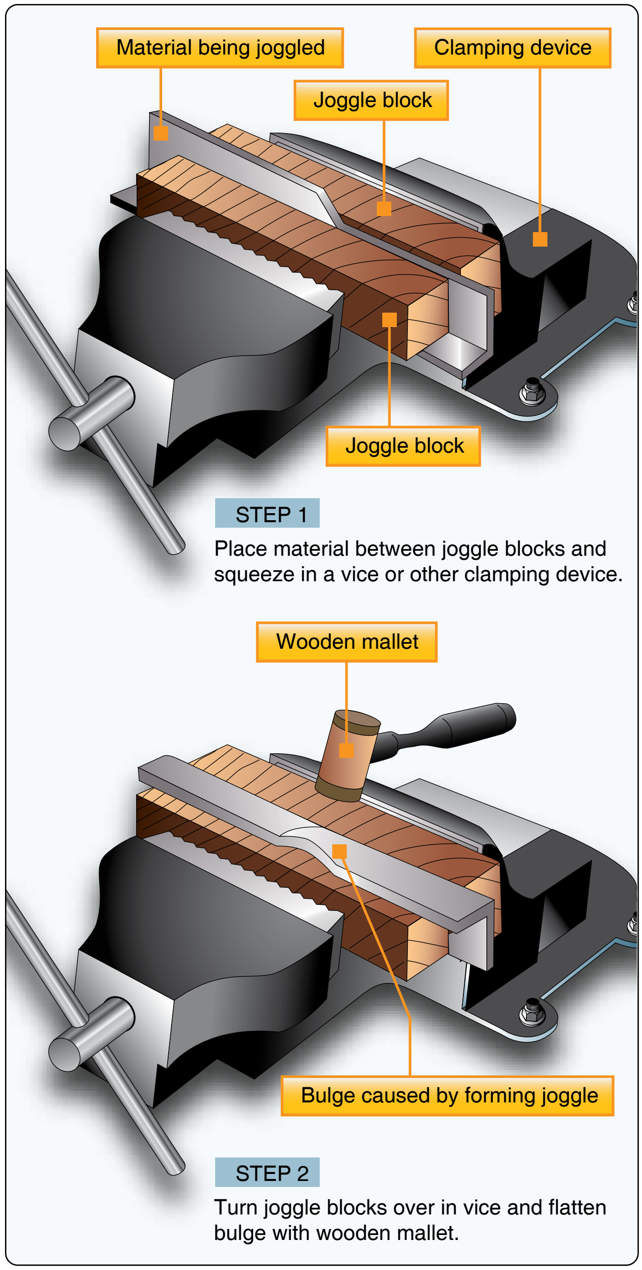


Figure 4-163. *Forming joggle using joggle blocks.*

Figure 4-164. *Samples of joggled metal.*

When flanging lightening holes, place the material between the mating parts of the die and form it by hammering or squeezing the dies together in a vise or in an arbor press (a small hand operated press). The dies work more smoothly if they are coated with light machine oil. *[Figure 4-165]*

Working Stainless Steel

Corrosion-resistant-steel (CRES) sheet is used on some parts of the aircraft when high strength is required. CRES causes magnesium, aluminum, or cadmium to corrode when it touches these metals. To isolate CRES from magnesium and aluminum, apply a finish that gives protection between their mating surfaces. It is important to use a bend radius that is larger than the recommended minimum bend radius to prevent cracking of the material in the bend area.

When working with stainless steel, make sure that the metal does not become unduly scratched or marred. Also, take special precautions when shearing, punching, or drilling this metal. It takes about twice as much pressure to shear or punch stainless steel as it does mild steel. Keep the shear or punch and die adjusted very closely. Too much clearance permits the metal to be drawn over the edge of the die and causes it to become work hardened, resulting in excessive strain on the machine. When drilling stainless steel, use an HSS drill bit ground to an included angle of 135°. Keep the drill speed about one-half that required for drilling mild steel, but never exceed 750 rpm. Keep a uniform pressure on the drill so the feed is constant at all times. Drill the material on a backing plate, such as cast iron, which is hard enough to permit the drill bit to cut completely through the stock without pushing the metal away from the drill point. Spot the drill bit before turning on the power and also make sure that pressure is exerted when the power is turned on.

Working Inconel® Alloys 625 & 718

Inconel® refers to a family of nickel-chromium-iron super alloys typically used in high-temperature applications. Corrosion resistance and the ability to stay strong in high temperatures led to the frequent use of these Inconel® alloys in aircraft powerplant structures. Inconel® alloys 625 and 718 can be cold formed by standard procedures used for steel and stainless steel.

Figure 4-165. *Lightening hole die set.*

Normal drilling into Inconel® alloys can break drill bits sooner and cause damage to the edge of the hole when the drill bit goes through the metal. If a hand drill is used to drill Inconel® alloys 625 and 718, select a 135° cobalt drill bit. When hand drilling, push hard on the drill, but stay at a constant chip rate. For example, with a No. 30 hole, push the drill with approximately 50 pounds of force. Use the maximum drill rpm as illustrated in *Figure 4-166*. A cutting fluid is not necessary when hand drilling.

The following drilling procedures are recommended:

- Drill pilot holes in loose repair parts with power feed equipment before preassembling them.
- Preassemble the repair parts and drill the pilot holes in the mating structure.
- Enlarge the pilot holes to their completed hole dimension.

When drilling Inconel®, autofeed-type drilling equipment is preferred.

Working Magnesium

Warning: Keep magnesium particles away from sources of ignition. Small particles of magnesium burn very easily. In sufficient concentration, these small particles can cause an explosion. If water touches molten magnesium, a steam explosion could occur. Extinguish magnesium fires with dry talc, calcium carbonate, sand, or graphite. Apply the powder on the burning metal to a depth of ½-inch or more. Do not use foam, water, carbon tetrachloride, or carbon dioxide. Magnesium alloys must not touch methyl alcohol.

Magnesium is the world's lightest structural metal. Like many other metals, this silvery-white element is not used in its pure state for stressed application. Instead, magnesium is alloyed with certain other metals (aluminum, zinc, zirconium, manganese, thorium, and rare earth metals) to obtain the strong, lightweight alloys needed for structural uses. When alloyed with these other metals, magnesium, yields alloys with excellent properties and high strength-

Drill Size	Maximum RPM
80–30	500
29–U	300
3/8	150

Figure 4-166. *Drill size and speed for drilling Inconel®.*

to-weight ratios. Proper combination of these alloying constituents provide alloys suitable for sand, permanent mold and die castings, forging, extrusions, rolled sheet, and plate with good properties at room temperature, as well as at elevated temperatures.

Lightweight is the best known characteristic of magnesium, an important factor in aircraft design. In comparison, aluminum weighs one and one half times more, iron and steel weigh four times more, and copper and nickel alloys weigh five times more. Magnesium alloys can be cut, drilled, and reamed with the same tools that are used on steel or brass, but the cutting edges of the tool must be sharp. Type B rivets (5056-F aluminum alloy) are used when riveting magnesium alloy parts. Magnesium parts are often repaired with clad 2024-T3 aluminum alloy.

While magnesium alloys can usually be fabricated by methods similar to those used on other metals, remember that many of the details of shop practice cannot be applied. Magnesium alloys are difficult to fabricate at room temperature; therefore, most operations must be performed at high temperatures. This requires preheating of the metal or dies, or both. Magnesium alloy sheets may be cut by blade shears, blanking dies, routers, or saws. Hand or circular saws are usually used for cutting extrusions to length. Conventional shears and nibblers should never be used for cutting magnesium alloy sheet because they produce a rough, cracked edge.

Shearing and blanking of magnesium alloys require close tool tolerances. A maximum clearance of 3 to 5 percent of the sheet thickness is recommended. The top blade of the shears should be ground with an included angle of 45° to 60º. The shear angle on a punch should be from 2° to 3°, with a 1° clearance angle on the die. For blanking, the shear angle on the die should be from 2° to 3° with a 1° clearance angle on the punch. Hold-down pressures should be used when possible. Cold shearing should not be accomplished on a hard-rolled sheet thicker than 0.064-inch or annealed sheet thicker than ⅛-inch. Shaving is used to smooth the rough, flaky edges of a magnesium sheet that has been sheared. This operation consists of removing approximately 1⁄32-inch by a second shearing.

Hot shearing is sometimes used to obtain an improved sheared edge. This is necessary for heavy sheet and plate stock. Annealed sheet may be heated to 600 °F, but hard-rolled sheet must be held under 400 °F, depending on the alloy used. Thermal expansion makes it necessary to allow for shrinkage after cooling, which entails adding a small amount of material to the cold metal dimensions before fabrication.

Sawing is the only method used in cutting plate stock more than ½-inch thick. Bandsaw raker-set blades of 4- to 6-tooth pitch are recommended for cutting plate stock or heavy extrusions. Small and medium extrusions are more easily cut on a circular cutoff saw having six teeth per inch. Sheet stock can be cut on handsaws having raker-set or straight-set teeth with an 8-tooth pitch. Bandsaws should be equipped with nonsparking blade guides to eliminate the danger of sparks igniting the magnesium alloy filings.

Cold working most magnesium alloys at room temperature is very limited, because they work harden rapidly and do not lend themselves to any severe cold forming. Some simple bending operations may be performed on sheet material, but the radius of bend must be at least 7 times the thickness of the sheet for soft material and 12 times the thickness of the sheet for hard material. A radius of 2 or 3 times the thickness of the sheet can be used if the material is heated for the forming operation.

Since wrought magnesium alloys tend to crack after they are cold-worked, the best results are obtained if the metal is heated to 450 °F before any forming operations are attempted. Parts formed at the lower temperature range are stronger because the higher temperature range has an annealing effect on the metal.

The disadvantages of hot working magnesium are:

1. Heating the dies and the material is expensive and troublesome.
2. There are problems in lubricating and handling materials at these temperatures.

The advantages to hot working magnesium are:

1. It is more easily formed when hot than are other metals.
2. Spring-back is reduced, resulting in greater dimensional accuracy.

When heating magnesium and its alloys, watch the temperature carefully as the metal is easily burned. Overheating also causes small molten pools to form within the metal. In either case, the metal is ruined. To prevent burning, magnesium must be protected with a sulfur dioxide atmosphere while being heated.

Proper bending around a short radius requires the removal of sharp corners and burrs near the bend line. Layouts should be made with a carpenter's soft pencil because any marring of the surface may result in fatigue cracks.

Press brakes can be used for making bends with short radii. Die and rubber methods should be used where bends are to be made at right angles, which complicate the use of a brake. Roll forming may be accomplished cold on equipment designed for forming aluminum. The most common method of forming and shallow drawing of magnesium is to use a rubber pad as the female die. This rubber pad is held in an inverted steel pan that is lowered by a hydraulic press ram. The press exerts pressure on the metal and bends it to the shape of the male die.

The machining characteristics of magnesium alloys are excellent, making possible the use of maximum speeds of the machine tools with heavy cuts and high feed rates. Power requirements for machining magnesium alloys are about one-sixth of those for mild steel.

Filings, shavings, and chips from machining operations should be kept in covered metal containers because of the danger of combustion. Do not use magnesium alloys in liquid deicing and water injection systems or in the integral fuel tank areas.

Working Titanium

Keep titanium particles away from sources of ignition. Small particles of titanium burn very easily. In sufficient concentration, these small particles can cause an explosion. If water touches molten titanium, a steam explosion could occur. Extinguish titanium fires with dry talc, calcium carbonate, sand, or graphite. Apply the powder on the burning metal to a depth of ½-inch or more. Do not use foam, water, carbon tetrachloride, or carbon dioxide.

Description of Titanium

Titanium in its mineral state, is the fourth most abundant structural metal in the earth's crust. It is lightweight, nonmagnetic, strong, corrosion resistant, and ductile. Titanium lies between the aluminum alloys and stainless steel in modulus, density, and strength at intermediate temperatures. Titanium is 30 percent stronger than steel, but is nearly 50 percent lighter. It is 60 percent heavier than aluminum, but twice as strong.

Titanium and its alloys are used chiefly for parts that require good corrosion resistance, moderate strength up to 600 °F (315 °C), and lightweight. Commercially pure titanium sheet may be formed by hydropress, stretch press, brake roll forming, drop hammer, or other similar operations. It is more difficult to form than annealed stainless steel. Titanium can also be worked by grinding, drilling, sawing, and the types of working used on other metals. Titanium must be isolated from magnesium, aluminum, or alloy steel because galvanic corrosion or oxidation of the other metals occurs upon contact.

Monel® rivets or standard close-tolerance steel fasteners should be used when installing titanium parts. The alloy sheet can be formed, to a limited extent, at room temperature. The forming of titanium alloys is divided into three classes:

- Cold forming with no stress relief
- Cold forming with stress relief
- Elevated temperature forming (built-in stress relief)

Over 5 percent of all titanium in the United States is produced in the form of the alloy Ti 6Al-4V, which is known as the workhorse of the titanium industry. Used in aircraft turbine engine components and aircraft structural components, Ti 6Al-4V is approximately 3 times stronger than pure titanium. The most widely used titanium alloy, it is hard to form.

The following are procedures for cold forming titanium 6Al-4V annealed with stress relief (room temperature forming):

1. It is important to use a minimum radius chart when forming titanium because an excessively small radius introduces excess stress to the bend area.
2. Stress relieves the part as follows: heat the part to a temperature above 1,250 °F (677 °C), but below 1,450 °F (788 °C). Keep the part at this temperature for more than 30 minutes but less than 10 hours.
3. A powerful press brake is required to form titanium parts. Regular hand-operated box and pan brakes cannot form titanium sheet material.
4. A power slip roller is often used if the repair patch needs to be curved to fit the contour of the aircraft.

Titanium can be difficult to drill, but standard high-speed drill bits may be used if the bits are sharp, if sufficient force is applied, and if a low-speed drill motor is used. If the drill bit is dull, or if it is allowed to ride in a partially drilled hole, an overheated condition is created, making further drilling extremely difficult. Therefore, keep holes as shallow as possible; use short, sharp drill bits of approved design; and flood the area with large amounts of cutting fluid to facilitate drilling or reaming.

When working titanium, it is recommended that you use carbide or 8 percent cobalt drill bits, reamers, and countersinks. Ensure the drill or reamer is rotating to prevent scoring the side of the hole when removing either of them from a hole. Use a hand drill only when positive-power-feed drills are not available.

The following guidelines are used for drilling titanium:

- The largest diameter hole that can be drilled in a single step is 0.1563-inch because a large force is required.

Larger diameter drill bits do not cut satisfactorily when much force is used. Drill bits that do not cut satisfactorily cause damage to the hole.

- Holes with a diameter of 0.1875-inch and larger can be hand drilled if the operator:
  - Starts with a hole with a diameter of 0.1563-inch.
  - Increases the diameter of the hole in 0.0313-inch or 0.0625-inch increments.
- Cobalt vanadium drill bits last much longer than HSS bits.
- The recommended drill motor rpm settings for hand drilling titanium are listed in *Figure 4-167*.
- The life of a drill bit is shorter when drilling titanium than when drilling steel. Do not use a blunt drill bit or let a drill bit rub the surface of the metal and not cut it. If one of these conditions occurs, the titanium surface becomes work hardened, and it is very difficult to start the drill again.
- When hand drilling two or more titanium parts at the same time, clamp them together tightly. To clamp them together, use temporary bolts, Cleco clamps, or tooling clamps. Put the clamps around the area to drill and as near the area as possible.
- When hand drilling thin or flexible parts, put a support (such as a block of wood) behind the part.
- Titanium has a low thermal conductivity. When it becomes hot, other metals become easily attached to it. Particles of titanium often become welded to the sharp edges of the drill bit if the drill speed is too high. When drilling large plates or extrusions, use a water soluble coolant or sulphurized oil.

Note: The intimate metal-to-metal contact in the metal working process creates heat and friction that must be reduced or the tools and the sheet metal used in the process are quickly damaged and/or destroyed. Coolants, also called cutting fluids, are used to reduce the friction at the interface of the tool and sheet metal by transferring heat away from the tool and sheet metal. Thus, the use of cutting fluids increases productivity, extends tool life, and results in a higher quality of workmanship.

Hole Size (inches)	Drill Speed (rpm)
0.0625	920 to 1830 rpm
0.125	460 to 920 rpm
0.1875	230 to 460 rpm

Figure 4-167. *Hole size and drill speed for drilling titanium.*

Basic Principles of Sheet Metal Repair

Aircraft structural members are designed to perform a specific function or to serve a definite purpose. The primary objective of aircraft repair is to restore damaged parts to their original condition. Very often, replacement is the only way this can be done effectively. When repair of a damaged part is possible, first study the part carefully to fully understand its purpose or function.

Strength may be the principal requirement in the repair of certain structures, while others may need entirely different qualities. For example, fuel tanks and floats must be protected against leakage; cowlings, fairings, and similar parts must have such properties as neat appearance, streamlined shape, and accessibility. The function of any damaged part must be carefully determined to ensure the repair meets the requirements.

An inspection of the damage and accurate estimate of the type of repair required are the most important steps in repairing structural damage. The inspection includes an estimate of the best type and shape of repair patch to use; the type, size, and number of rivets needed; and the strength, thickness, and kind of material required to make the repaired member no heavier (or only slightly heavier) and just as strong as the original.

When investigating damage to an aircraft, it is necessary to make an extensive inspection of the structure. When any component or group of components has been damaged, it is essential that both the damaged members and the attaching structure be investigated, since the damaging force may have been transmitted over a large area, sometimes quite remote from the point of original damage. Wrinkled skin, elongated or damaged bolt or rivet holes, or distortion of members usually appears in the immediate area of such damage, and any one of these conditions calls for a close inspection of the adjacent area. Check all skin, dents, and wrinkles for any cracks or abrasions.

Nondestructive inspection methods (NDI) are used as required when inspecting damage. NDI methods serve as tools of prevention that allow defects to be detected before they develop into serious or hazardous failures. A trained and experienced technician can detect flaws or defects with a high degree of accuracy and reliability. Some of the defects found by NDI include corrosion, pitting, heat/stress cracks, and discontinuity of metals.

When investigating damage, proceed as follows:

- Remove all dirt, grease, and paint from the damaged and surrounding areas to determine the exact condition of each rivet, bolt, and weld.

- Inspect skin for wrinkles throughout a large area.
- Check the operation of all movable parts in the area.
- Determine if repair would be the best procedure.

In any aircraft sheet metal repair, it is critical to:

- Maintain original strength,
- Maintain original contour, and
- Minimize weight.

Maintaining Original Strength

Certain fundamental rules must be observed if the original strength of the structure is to be maintained.

Ensure that the cross-sectional area of a splice or patch is at least equal to or greater than that of the damaged part. Avoid abrupt changes in cross-sectional area. Eliminate dangerous stress concentration by tapering splices. To reduce the possibility of cracks starting from the corners of cutouts, try to make cutouts either circular or oval in shape. Where it is necessary to use a rectangular cutout, make the radius of curvature at each corner no smaller than ½-inch. If the member is subjected to compression or bending loads, the patch should be placed on the outside of the member to obtain a higher resistance to such loads. If the patch cannot be placed there, material one gauge thicker than the original shall be used for the repair.

Replace buckled or bent members or reinforce them by attaching a splice over the affected area. A buckled part of the structure shall not be depended upon to carry its load again, no matter how well the part may be strengthened.

The material used in all replacements or reinforcements must be similar to that used in the original structure. If an alloy weaker than the original must be substituted for it, a heavier thickness must be used to give equivalent cross-sectional strength. A material that is stronger, but thinner, cannot be substituted for the original because one material can have greater tensile strength but less compressive strength than another, or vice versa. Also, the buckling and torsional strength of many sheet metal and tubular parts depends primarily on the thickness of the material rather than its allowable compressive and shear strengths. The manufacturer's SRM often indicates what material can be used as a substitution and how much thicker the material needs to be. *Figure 4-168* is an example of a substitution table found in an SRM.

Care must be taken when forming. Heat-treated and cold-worked aluminum alloys stand very little bending without cracking. On the other hand, soft alloys are easily formed, but they are not strong enough for primary structure. Strong alloys can be formed in their annealed (heated and allowed to cool slowly) condition, and heat treated before assembling to develop their strength.

The size of rivets for any repair can be determined by referring to the rivets used by the manufacturer in the next parallel rivet row inboard on the wing or forward on the fuselage. Another method of determining the size of rivets to be used is to multiply the thickness of the skin by three and use the next larger size rivet corresponding to that figure. For example, if the skin thickness is 0.040-inch, multiply 0.040-inch by 3, which equals 0.120-inch; use the next larger size rivet, ⅛-inch (0.125-inch). The number of rivets to be used for a repair can be found in tables in manufacturer's SRMs or in Advisory Circular (AC) 43.13-1 (as revised), Acceptable Methods, Techniques, and Practices—Aircraft Inspection and Repair. *Figure 4-169* is a table from AC 43.13-1 that is used to calculate the number of rivets required for a repair.

Extensive repairs that are made too strong can be as undesirable as repairs weaker than the original structure. All aircraft structure must flex slightly to withstand the forces imposed during takeoff, flight, and landing. If a repaired area is too strong, excessive flexing occurs at the edge of the completed repair, causing acceleration of metal fatigue.

Shear Strength & Bearing Strength

Aircraft structural joint design involves an attempt to find the optimum strength relationship between being critical in shear and critical in bearing. These are determined by the failure mode affecting the joint. The joint is critical in shear if less than the optimum number of fasteners of a given size are installed. This means that the rivets will fail, and not the sheet, if the joint fails. The joint is critical in bearing if more than the optimum number of fasteners of a given size are installed; the material may crack and tear between holes, or fastener holes may distort and stretch while the fasteners remain intact.

Maintaining Original Contour

Form all repairs in such a manner to fit the original contour perfectly. A smooth contour is especially desirable when making patches on the smooth external skin of high-speed aircraft.

Keeping Weight to a Minimum

Keep the weight of all repairs to a minimum. Make the size of the patches as small as practicable and use no more rivets than are necessary. In many cases, repairs disturb the original balance of the structure. The addition of excessive weight in each repair may unbalance the aircraft, requiring adjustment of the trim-and-balance tabs. In areas such as the spinner on the propeller, a repair requires application of balancing patches in order to maintain a perfect balance of the propeller.

Shape	Initial Material	Replacement Material
Sheet 0.016 to 0.125	Clad 2024–T42 (F)	Clad 2024–T3 2024–T3 Clad 7075–T6 (A) 7075–T6 (A)
	Clad 2024–T3	2024–T3 Clad 7075–T6 (A) 7075–T6 (A)
	Clad 7075–T6	7075–T6
Formed or Extruded Section	2024–T42 (F)	7075–T6 (A) (B)

7075–T6	1.00	1.10	1.20	1.78	1.30	1.83	1.20	1.78	1.24	1.84
Clad 7075–T6	1.00	1.00	1.13	1.70	1.22	1.76	1.13	1.71	1.16	1.76
2024–T3	1.00 (A)	1.00 (A)	1.00	1.00	1.09	1.10	1.00	1.10	1.03	1.14
Clad 2024–T3	1.00 (A)	1.00 (A)	1.00	1.00	1.00	1.00	1.00	1.00	1.03	1.00
2024–T42	1.00 (A)	1.00 (A)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.14
Clad 2024–T42	1.00 (A)	1.00 (A)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
7178–T6	1.28	1.28	1.50	1.90	1.63	2.00	1.86	1.90	1.96	1.98
Clad 7178–T6	1.08	1.18	1.41	1.75	1.52	1.83	1.75	1.75	1.81	1.81
5052–H34 (G) (H)	1.00 (A)	1.00 (A)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Notes

- All dimensions are in inches, unless given differently.
- It is possible that more protection from corrosion will be necessary when bare mineral is used to replace Clad material. Refer to 51-10-2.
- It is possible for the material replacement factor to be a lower value for a specific location on the airplane. To get that value, contact Boeing for a case by case analysis.
- Refer to Figure 3 for minimun bend radii.
- Example:
  To refer 0.040 thick 7075–T6 with Clad 7075–T6, multiply the gage by the material replacement factor to get the replacement gage 0. 040 x 1.10 = 0.045.

(A) These materials cannot be used as replacements for the initial material in areas that are pressured.

(B) They also cannot be used in the wing interspar structure at the wing center section structure.

(C) Use the next thicker standard gage when you use a formed section as a replacement for an extrusion.

(D) For all gages of flat sheet and formed sections.

(E) For flat sheet less than 0.071 thick.

(F) For flat sheet 0.071 thick and thicker, and for formed sections.

(G) 2024–T4 and 2024–T42 are equivalent.

(H) A compound to give protection from corrosion must be applied to bare material that is used to replace 5052–H34.

Figure 4-168. *Material substitution.*

When flight controls are repaired and weight is added, it is very important to perform a balancing check to determine if the flight control is still within its balance limitations. Failure to do so could result in flight control flutter.

Flutter & Vibration Precautions

To prevent severe vibration or flutter of flight control surfaces during flight, precautions must be taken to stay within the design balance limitations when performing maintenance or repair. The importance of retaining the proper balance and rigidity of aircraft control surfaces cannot be overemphasized.

Thickness "t" in inches	No. of 2117–T4 (AD) protruding head rivets required per inch of width "W"					No. of Bolts
	Rivet size					
	3/32	1/8	5/32	3/16	1/4	AN–3
.016	6.5	4.9	- -	- -	- -	- -
.020	6.5	4.9	3.9	- -	- -	- -
.025	6.9	4.9	3.9	- -	- -	- -
.032	8.9	4.9	3.9	3.3	- -	- -
.036	10.0	5.6	3.9	3.3	2.4	- -
.040	11.1	6.2	4.0	3.3	2.4	- -
.051	- -	7.9	5.1	3.6	2.4	3.3
.064	- -	9.9	6.5	4.5	2.5	3.3
.081	- -	12.5	8.1	5.7	3.1	3.3
.091	- -	- -	9.1	6.3	3.5	3.3
.102	- -	- -	10.3	7.1	3.9	3.3
.128	- -	- -	12.9	8.9	4.9	3.3

Notes
a. For stringer in the upper surface of a wing, or in a fuselage, 80 percent of the number of rivets shown in the table may be used.
b. For intermediate frames, 60 percent of the number shown may be used.
c. For single lap sheet joints, 75 percent of the number shown may be used.

Engineering Notes
a. The load per inch of width of material was calculated by assuming a strip 1 inch wide in tension.
b. Number of rivets required was calculated for 2117–T4 (AD) rivets, based on a rivet allowable shear stress equal to percent of the sheet allowable tensile stress, and a sheet allowable bearing stress equal to 160 percent of the sheet allowable tensile stress, using nominal hole diameters for rivets.
c. Combinations of shoot thickness and rivet size above the underlined numbers are critical in (i.e., will fail by) bearing on the sheet; those below are critical in shearing of the rivets.
d. The number of AN–3 bolts required below the underlined number was calculated based on a sheet allowable tensile stress of 55.000 psi and a bolt allowable single shear load of 2.126 pounds.

Figure 4-169. *Rivet calculation table.*

The effect of repair or weight change on the balance and CG is proportionately greater on lighter surfaces than on the older heavier designs. As a general rule, repair the control surface in such a manner that the weight distribution is not affected in any way, in order to preclude the occurrence of flutter of the control surface in flight. Under certain conditions, counterbalance weight is added forward of the hinge line to maintain balance. Add or remove balance weights only when necessary in accordance with the manufacturer's instructions. Flight testing must be accomplished to ensure flutter is not a problem. Failure to check and retain control surface balance within the original or maximum allowable value could result in a serious flight hazard.

Aircraft manufacturers use different repair techniques and repairs designed and approved for one type of aircraft are not automatically approved for other types of aircraft. When repairing a damaged component or part, consult the applicable section of the manufacturer's SRM for the aircraft. Usually the SRM contains an illustration for a similar repair along with a list of the types of material, rivets and rivet spacing, and the methods and procedures to be used. Any additional knowledge needed to make a repair is also detailed. If the necessary information is not found in the SRM, attempt to find a similar repair or assembly installed by the manufacturer of the aircraft.

Inspection of Damage

When visually inspecting damage, remember that there may be other kinds of damage than that caused by impact from foreign objects or collision. A rough landing may overload one of the landing gear, causing it to become sprung; this would be classified as load damage. During inspection and sizing up of the repair job, consider how far the damage caused by the sprung shock strut extends to supporting structural members.

A shock occurring at one end of a member is transmitted throughout its length; therefore, closely inspect all rivets, bolts, and attaching structures along the complete member for any evidence of damage. Make a close examination for rivets that have partially failed and for holes that have been elongated.

Whether specific damage is suspected or not, an aircraft structure must occasionally be inspected for structural integrity. The following paragraphs provide general guidelines for this inspection.

When inspecting the structure of an aircraft, it is very important to watch for evidence of corrosion on the inside. This is most likely to occur in pockets and corners where moisture and salt spray may accumulate; therefore, drain holes must always be kept clean.

While an injury to the skin covering caused by impact with an object is plainly evident, a defect, such as distortion or failure of the substructure, may not be apparent until some evidence develops on the surface, such as canted, buckled or wrinkled covering, and loose rivets or working rivets. A working rivet is one that has movement under structural stress, but has not loosened to the extent that movement can be observed. This situation can sometimes be noted by a dark, greasy residue or deterioration of paint and primers around rivet heads. External indications of internal injury must be watched for and correctly interpreted. When found, an investigation of the substructure in the vicinity should be made and corrective action taken.

Warped wings are usually indicated by the presence of parallel skin wrinkles running diagonally across the wings and extending over a major area. This condition may develop from unusually violent maneuvers, extremely rough air, or extra hard landings. While there may be no actual rupture of any part of the structure, it may be distorted and weakened. Similar failures may also occur in fuselages. Small cracks in the skin covering may be caused by vibration and they are frequently found leading away from rivets.

Aluminum alloy surfaces having chipped protective coating, scratches, or worn spots that expose the surface of the metal should be recoated at once, as corrosion may develop rapidly. The same principle is applied to aluminum clad (Alclad™) surfaces. Scratches, which penetrate the pure aluminum surface layer, permit corrosion to take place in the alloy beneath.

A simple visual inspection cannot accurately determine if suspected cracks in major structural members actually exist or the full extent of the visible cracks. Eddy current and ultrasonic inspection techniques are used to find hidden damage.

Types of Damage & Defects

Types of damage and defects that may be observed on aircraft parts are defined as follows:

- Brinelling—occurrence of shallow, spherical depressions in a surface, usually produced by a part having a small radius in contact with the surface under high load.
- Burnishing—polishing of one surface by sliding contact with a smooth, harder surface. Usually there is no displacement or removal of metal.
- Burr—a small, thin section of metal extending beyond a regular surface, usually located at a corner or on the edge of a hole.
- Corrosion—loss of metal from the surface by chemical or electrochemical action. The corrosion products generally are easily removed by mechanical means. Iron rust is an example of corrosion.
- Crack—a physical separation of two adjacent portions of metal, evidenced by a fine or thin line across the surface caused by excessive stress at that point. It may extend inward from the surface from a few thousandths of an inch to completely through the section thickness.
- Cut—loss of metal, usually to an appreciable depth over a relatively long and narrow area, by mechanical means, as would occur with the use of a saw blade, chisel, or sharp-edged stone striking a glancing blow.
- Dent—indentation in a metal surface produced by an object striking with force. The surface surrounding the indentation is usually slightly upset.
- Erosion—loss of metal from the surface by mechanical action of foreign objects, such as grit or fine sand. The eroded area is rough and may be lined in the direction in which the foreign material moved relative to the surface.
- Chattering—breakdown or deterioration of metal surface by vibratory or chattering action. Although chattering may give the general appearance of metal loss or surface cracking, usually, neither has occurred.
- Galling—breakdown (or build-up) of metal surfaces due to excessive friction between two parts having relative motion. Particles of the softer metal are torn loose and welded to the harder metal.
- Gouge—groove in, or breakdown of, a metal surface from contact with foreign material under heavy pressure. Usually it indicates metal loss but may be largely the displacement of material.
- Inclusion—presence of foreign or extraneous material wholly within a portion of metal. Such material is

introduced during the manufacture of rod, bar or tubing by rolling or forging.

- Nick—local break or notch on an edge. Usually it involves the displacement of metal rather than loss.
- Pitting—sharp, localized breakdown (small, deep cavity) of metal surface, usually with defined edges.
- Scratch—slight tear or break in metal surface from light, momentary contact by foreign material.
- Score—deeper (than scratch) tear or break in metal surface from contact under pressure. May show discoloration from temperature produced by friction.
- Stain—a change in color, locally causing a noticeably different appearance from the surrounding area.
- Upsetting—a displacement of material beyond the normal contour or surface (a local bulge or bump). Usually it indicates no metal loss.

Classification of Damage

Damages may be grouped into four general classes. In many cases, the availabilities of repair materials and time are the most important factors in determining if a part should be repaired or replaced.

Negligible Damage

Negligible damage consists of visually apparent, surface damage that do not affect the structural integrity of the component involved. Negligible damage may be left as is or may be corrected by a simple procedure without restricting flight. In both cases, some corrective action must be taken to keep the damage from spreading. Negligible or minor damage areas must be inspected frequently to ensure the damage does not spread. Permissible limits for negligible damage vary for different components of different aircraft and should be carefully researched on an individual basis. Failure to ensure that damages within the specified limit of negligible damage may result in insufficient structural strength of the affected support member for critical flight conditions.

Small dents, scratches, cracks, and holes that can be repaired by smoothing, sanding, stop drilling, or hammering out, or otherwise repaired without the use of additional materials, fall in this classification. *[Figure 4-170]*

Damage Repairable by Patching

Damage repairable by patching is any damage exceeding negligible damage limits that can be repaired by installing splice members to bridge the damaged portion of a structural part. The splice members are designed to span the damaged areas and to overlap the existing undamaged surrounding structure. The splice or patch material used in internal riveted and bolted repairs is normally the same type of material as the damaged part, but one gauge heavier. In a patch repair, filler plates of the same gauge and type of material as that in the damaged component may be used for bearing purposes or to return the damaged part to its original contour. Structural fasteners are applied to members and the surrounding structure to restore the original load-carrying characteristics of the damaged area. The use of patching depends on the extent of the damage and the accessibility of the component to be repaired.

Damage Repairable by Insertion

Damage must be repaired by insertion when the area is too large to be patched or the structure is arranged such that repair members would interfere with structural alignment (e.g., in a hinge or bulkhead). In this type of repair, the damaged portion is removed from the structure and replaced by a member identical in material and shape. Splice connections at each end of the insertion member provide for load transfer to the original structure.

Damage Necessitating Replacement of Parts

Components must be replaced when their location or extent of damage makes repair impractical, when replacement is more economical than repair, or when the damaged part is relatively easy to replace. For example, replacing damaged castings, forgings, hinges, and small structural members, when available, is more practical than repairing them. Some highly stressed members must be replaced because repair would not restore an adequate margin of safety.

Repairability of Sheet Metal Structure

The following criteria can be used to help an aircraft technician decide upon the repairability of a sheet metal structure:

- Type of damage.

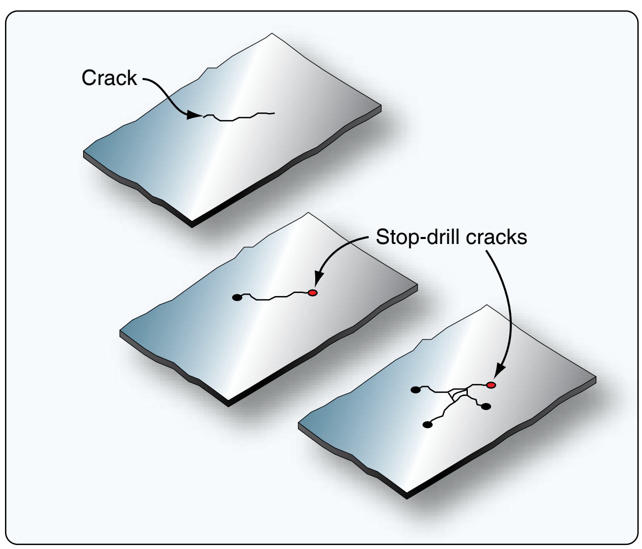


Figure 4-170. *Repair of cracks by stop-drilling.*

- Type of original material.
- Location of the damage.
- Type of repair required.
- Tools and equipment available to make the repair.

The following methods, procedures, and materials are only typical and should not be used as the authority for a repair.

Structural Support During Repair

During repair, the aircraft must be adequately supported to prevent further distortion or damage. It is also important that the structure adjacent to the repair is supported when it is subject to static loads. The aircraft structure can be supported adequately by the landing gear or by jacks where the work involves a repair, such as removing the control surfaces, wing panels, or stabilizers. Cradles must be prepared to hold these components while they are removed from the aircraft.

When the work involves extensive repair of the fuselage, landing gear, or wing center section, a jig (a device for holding parts in position to maintain their shape) may be constructed to distribute the loads while repairs are being accomplished. *Figure 4-171* shows a typical aircraft jig. Always check the applicable aircraft maintenance manual for specific support requirements.

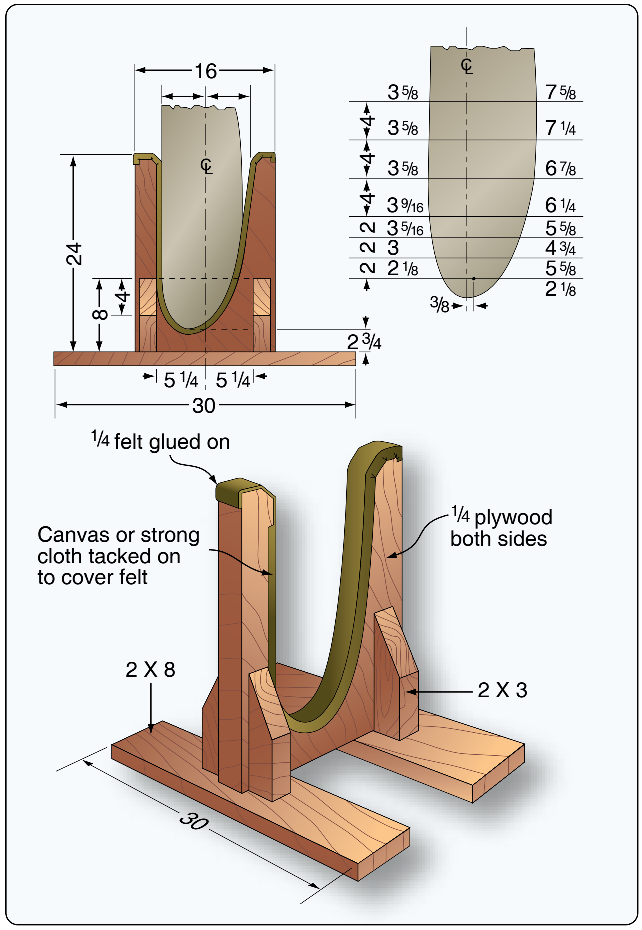


Figure 4-171. *Aircraft jig used to hold components during repairs.*

Assessment of Damage

Before starting any repair, the extent of damage must be fully evaluated to determine if repair is authorized or even practical. This evaluation should identify the original material used and the type of repair required. The assessment of the damage begins with an inspection of riveted joints and an inspection for corrosion.

Inspection of Riveted Joints

Inspection consists of examining both the shop and manufactured heads and the surrounding skin and structural parts for deformities.

During the repair of an aircraft structural part, examine adjacent parts to determine the condition of neighboring rivets. The presence of chipped or cracked paint around the heads may indicate shifted or loose rivets. If the heads are tipped or if rivets are loose, they show up in groups of several consecutive rivets and are probably tipped in the same direction. If heads that appear to be tipped are not in groups and are not tipped in the same direction, tipping may have occurred during some previous installation.

Inspect rivets that are known to have been critically loaded, but that show no visible distortion, by drilling off the head and carefully punching out the shank. If upon examination, the shank appears joggled and the holes in the sheet misaligned, the rivet has failed in shear. In that case, determine what is causing the stress and take necessary corrective action. Countersunk rivets that show head slippage within the countersink or dimple, indicating either sheet bearing failure or rivet shear failure, must be replaced.

Joggles in removed rivet shanks indicate partial shear failure. Replace these rivets with the next larger size. Also, if the rivet holes show elongation, replace the rivets with the next larger size. Sheet failures, such as tearouts, cracks between rivets, and the like, usually indicate damaged rivets, and the complete repair of the joint may require replacement of the rivets with the next larger size.

The presence of a black residue around the rivets is not an indication of looseness, but it is an indication of movement (fretting). The residue, which is aluminum oxide, is formed by a small amount of relative motion between the rivet and the adjacent surface. This is called fretting corrosion, or smoking, because the aluminum dust quickly forms a dark, dirty looking trail, like a smoke trail. Sometimes, the thinning of the moving pieces can propagate a crack. If a rivet is suspected of being defective, this residue may be removed with a general purpose abrasive hand pad, such as those manufactured by Scotch Brite™, and the surface inspected for signs of pitting or cracking. Although the condition indicates the component is under significant stress, it does not necessarily precipitate cracking. *[Figure 4-172]*

Airframe cracking is not necessarily caused by defective rivets. It is common practice in the industry to size rivet patterns assuming one or more of the rivets is not effective. This means that a loose rivet would not necessarily overload adjacent rivets to the point of cracking.

Rivet head cracking is acceptable under the following conditions:

- The depth of the crack is less than ⅛ of the shank diameter.
- The width of the crack is less than 1⁄16 of the shank diameter.
- The length of the crack is confined to an area on the head within a circle having a maximum diameter of 1¼ times the shank diameter.
- Cracks should not intersect, which creates the potential for the loss of a portion of a head.

Inspection for Corrosion

Corrosion is the gradual deterioration of metal due to a chemical or electrochemical reaction with its environment. The reaction can be triggered by the atmosphere, moisture, or other agents. When inspecting the structure of an aircraft, it is important to watch for evidence of corrosion on both the outside and inside. Corrosion on the inside is most likely to occur in pockets and corners where moisture and salt spray may accumulate; therefore, drain holes must always be kept clean. Also inspect the surrounding members for evidence of corrosion.

Damage Removal

To prepare a damaged area for repair:

1. Remove all distorted skin and structure in damaged area.
2. Remove damaged material so that the edges of the completed repair match existing structure and aircraft lines.
3. Round all square corners.
4. Smooth out any abrasions and/or dents.
5. Remove and incorporate into the new repair any previous repairs joining the area of the new repair.

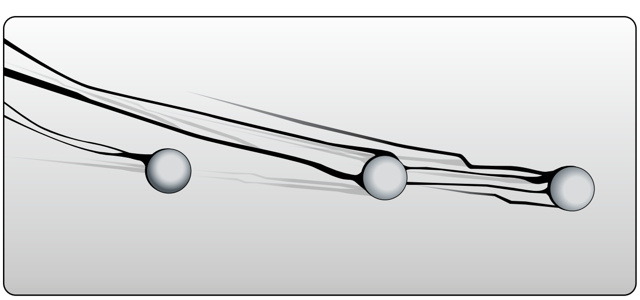


Figure 4-172. *Smoking rivet.*

Repair Material Selection

The repair material must duplicate the strength of the original structure. If an alloy weaker than the original material has to be used, a heavier gauge must be used to give equivalent cross-sectional strength. A lighter gauge material should not be used even when using a stronger alloy.

Repair Parts Layout

All new sections fabricated for repairing or replacing damaged parts in a given aircraft should be carefully laid out to the dimensions listed in the applicable aircraft manual before fitting the parts into the structure.

Rivet Selection

Normally, the rivet size and material should be the same as the original rivets in the part being repaired. If a rivet hole has been enlarged or deformed, the next larger size rivet must be used after reworking the hole. When this is done, the proper edge distance for the larger rivet must be maintained. Where access to the inside of the structure is impossible and blind rivets must be used in making the repair, always consult the applicable aircraft maintenance manual for the recommended type, size, spacing, and number of rivets needed to replace either the original installed rivets or those that are required for the type of repair being performed.

Rivet Spacing & Edge Distance

The rivet pattern for a repair must conform to instructions in the applicable aircraft manual. The existing rivet pattern is used whenever possible.

Corrosion Treatment

Prior to assembly of repair or replacement parts, make certain that all existing corrosion has been removed in the area and that the parts are properly insulated one from the other.

Approval of Repair

Once the need for an aircraft repair has been established, Title 14 of the Code of Federal Regulations (14 CFR) defines the approval process. 14 CFR part 43, section 43.13(a) states that each person performing maintenance, alteration, or preventive maintenance on an aircraft, engine, propeller, or appliance shall use the methods, techniques, and practices prescribed in the current manufacturer's maintenance manual or instructions for continued airworthiness prepared by its manufacturer, or other methods, techniques, or practices acceptable to the Administrator. AC 43.13-1 contains methods, techniques, and practices acceptable to the Administrator for the inspection and repair of nonpressurized areas of civil aircraft, only when there are no manufacturer repair or maintenance instructions. This data generally pertains to minor repairs. The repairs identified in this AC may only be used as a basis for FAA approval for major repairs. The repair data may also be used as approved data, and the AC chapter, page, and paragraph listed in block 8 of FAA Form 337 when:

a. The user has determined that it is appropriate to the product being repaired;
b. It is directly applicable to the repair being made; and
c. It is not contrary to manufacturer's data.

Engineering support from the aircraft manufacturer is required for repair techniques and methods that are not described in the aircraft maintenance manual or SRM.

FAA Form 337, Major Repair and Alteration, must be completed for repairs to the following parts of an airframe and repairs of the following types involving the strengthening, reinforcing, splicing, and manufacturing of primary structural members or their replacement, when replacement is by fabrication, such as riveting or welding. *[Figure 4-173]*

- Box beams
- Monocoque or semimonocoque wings or control surfaces
- Wing stringers or chord members
- Spars
- Spar flanges
- Members of truss-type beams
- Thin sheet webs of beams
- Keel and chine members of boat hulls or floats
- Corrugated sheet compression members that act as flange material of wings or tail surfaces
- Wing main ribs and compression members
- Wing or tail surface brace struts, fuselage longerons
- Members of the side truss, horizontal truss or bulkheads
- Main seat support braces and brackets
- Landing gear brace struts
- Repairs involving the substitution of material
- Repair of damaged areas in metal or plywood stressed covering exceeding six inches in any direction
- Repair of portions of skin sheets by making additional seams
- Splicing of thin sheets
- Repair of three or more adjacent wing or control surface ribs or the leading edge of wings and control surfaces between such adjacent ribs

For major repairs made in accordance with a manual or specifications acceptable to the Administrator, a certificated repair station may use the customer's work order upon which the repair is recorded in place of the FAA Form 337.

Repair of Stressed Skin Structure

In aircraft construction, stressed skin is a form of construction in which the external covering (skin) of an aircraft carries part or all of the main loads. Stressed skin is made from high strength rolled aluminum sheets. Stressed skin carries a large portion of the load imposed upon an aircraft structure. Various specific skin areas are classified as highly critical, semicritical, or noncritical. To determine specific repair requirements for these areas, refer to the applicable aircraft maintenance manual.

Minor damage to the outside skin of the aircraft can be repaired by applying a patch to the inside of the damaged sheet. A filler plug must be installed in the hole made by the removal of the damaged skin area. It plugs the hole and forms a smooth outside surface necessary for aerodynamic smoothness of the aircraft. The size and shape of the patch is determined in general by the number of rivets required in the repair. If not otherwise specified, calculate the required number of rivets by using the rivet formula. Make the patch plate of the same material as the original skin and of the same thickness or of the next greater thickness.

Patches

Skin patches may be classified as two types:

- Lap or scab patch
- Flush patch

Lap or Scab Patch

The lap or scab type of patch is an external patch where the edges of the patch and the skin overlap each other. The overlapping portion of the patch is riveted to the skin. Lap patches may be used in most areas where aerodynamic smoothness is not important. *Figure 4-174* shows a typical patch for a crack and or for a hole.

When repairing cracks or small holes with a lap or scab patch, the damage must be cleaned and smoothed. In repairing cracks, a small hole must be drilled in each end and sharp

US Department of Transportation
Federal Aviation Administration

MAJOR REPAIR AND ALTERATION
(Airframe, Powerplant, Propeller, or Appliance)

OMB No. 2120-0020
Exp: 01/31/2023

Electronic Tracking Number

For FAA Use Only

INSTRUCTIONS: Print or type all entries. See Title 14 CFR §43.9, Part 43 Appendix B, and AC 43.9-1 (or subsequent revision thereof) for instructions and disposition of this form. This report is required by law (49 U.S.C. §44701). Failure to report can result in a civil penalty for each such violation. (49 U.S.C. §46301(a))

1. Aircraft	Nationality and Registration Mark	Serial No.	
	Make	Model	Series
2. Owner	Name *(As shown on registration certificate)*	Address *(As shown on registration certificate)* Address City State Zip Country	

3. For FAA Use Only

4. Type		**5. Unit Identification**			
Repair	Alteration	Unit	Make	Model	Serial No.
☐	☐	AIRFRAME	————	*(As described in Item 1 above)*	————
☐	☐	POWERPLANT			
☐	☐	PROPELLER			
☐	☐	APPLIANCE	Type Manufacturer		

6. Conformity Statement

A. Agency's Name and Address	B. Kind of Agency	
Name	☐ U. S. Certificated Mechanic	☐ Manufacturer
Address	☐ Foreign Certificated Mechanic	C. Certificate No.
City State	☐ Certificated Repair Station	
Zip Country	☐ Certificated Maintenance Organization	

D. I certify that the repair and/or alteration made to the unit(s) identified in item 5 above and described on the reverse or attachments hereto have been made in accordance with the requirements of Part 43 of the U.S. Federal Aviation Regulations and that the information furnished herein is true and correct to the best of my knowledge.

Extended range fuel per 14 CFR Part 43 App. B ☐	Signature/Date of Authorized Individual

7. Approval for Return to Service

Pursuant to the authority given persons specified below, the unit identified in item 5 was inspected in the manner prescribed by the Administrator of the Federal Aviation Administration and is ☐ Approved ☐ Rejected

BY	☐ FAA Flt. Standards Inspector	☐ Manufacturer	☐ Maintenance Organization	☐ Persons Approved by Canadian Department of Transport
	☐ FAA Designee	☐ Repair Station	☐ Inspection Authorization	Other *(Specify)*

Certificate or Designation No.	Signature/Date of Authorized Individual

Figure 4-173. *FAA Form 337, Major Repair and Alteration (Airframe, Powerplant, Propeller, or Appliance).*

NOTICE

Weight and balance or operating limitation changes shall be entered in the appropriate aircraft record. An alteration must be compatible with all previous alterations to assure continued conformity with the applicable airworthiness requirements.

8. Description of Work Accomplished

(If more space is required, attach additional sheets. Identify with aircraft nationality and registration mark and date work completed.)

Nationality and Registration Mark	Date

Additional Sheets Are Attached

Figure 4-173. *FAA Form 337, Major Repair and Alteration (Airframe, Powerplant, Propeller, or Appliance) continued.*

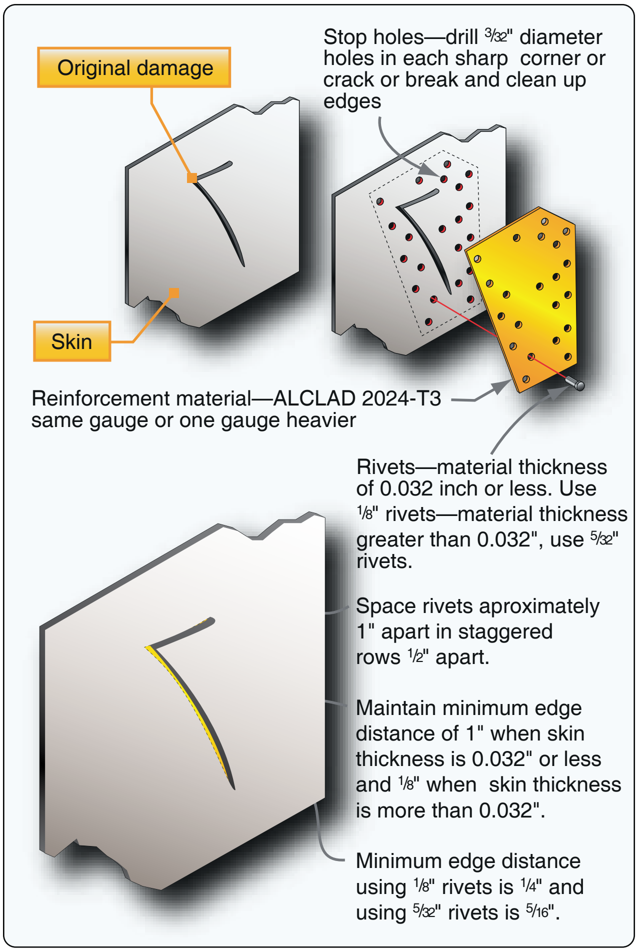


Figure 4-174. *Lap or scab patch (crack).*

bend of the crack before applying the patch. These holes relieve the stress at these points and prevent the crack from spreading. The patch must be large enough to install the required number of rivets. It may be cut circular, square, or rectangular. If it is cut square or rectangular, the corners are rounded to a radius no smaller than ¼-inch. The edges must be chamfered to an angle of 45° for ½ the thickness of the material, and bent down 5° over the edge distance to seal the edges. This reduces the chance that the repair is affected by the airflow over it. These dimensions are shown in *Figure 4-175*.

Flush Patch

A flush patch is a filler patch that is flush to the skin when applied it is supported by and riveted to a reinforcement plate which is, in turn, riveted to the inside of the skin. *Figure 4-176* shows a typical flush patch repair. The doubler is inserted through the opening and rotated until it slides in place under the skin. The filler must be of the same gauge and material as the original skin. The doubler should be of material one gauge heavier than the skin.

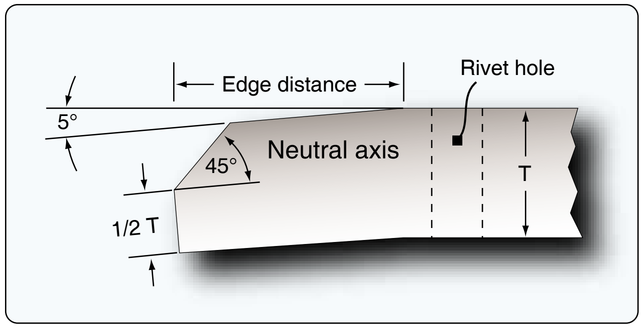


Figure 4-175. *Lap patch edge preparation.*

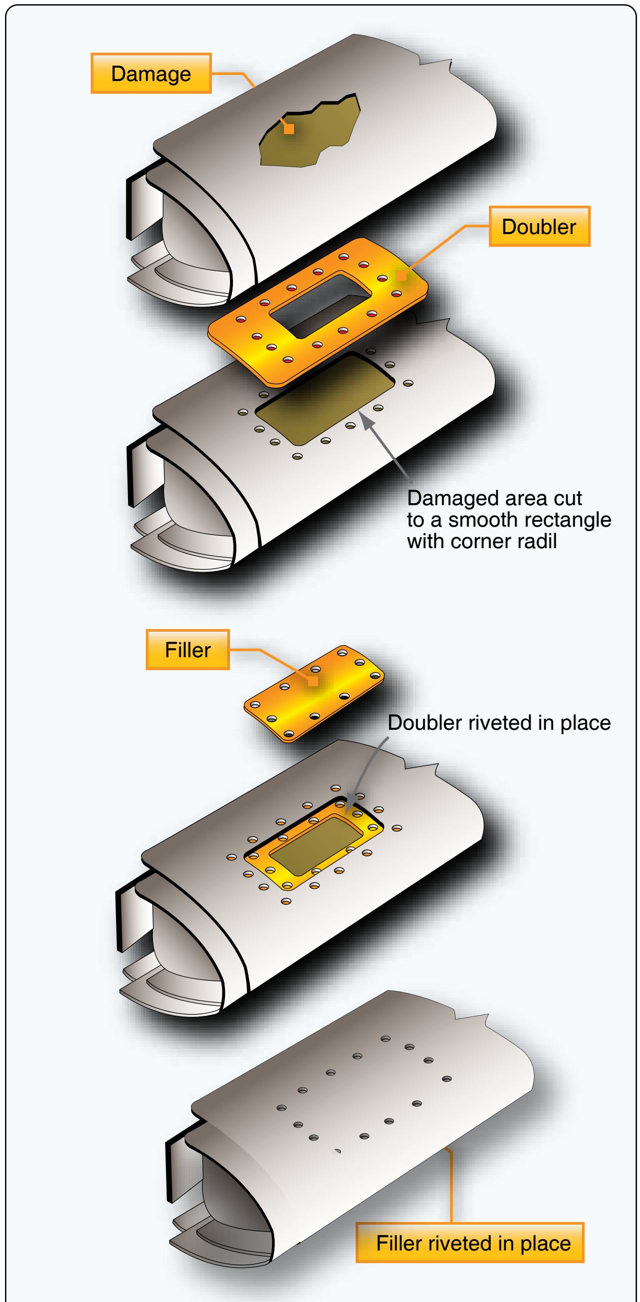


Figure 4-176. *Typical flush patch repair.*

Open & Closed Skin Area Repair

The factors that determine the methods to be used in skin repair are accessibility to the damaged area and the instructions found in the aircraft maintenance manual. The skin on most areas of an aircraft is inaccessible for making the repair from the inside and is known as closed skin. Skin that is accessible from both sides is called open skin.

Usually, repairs to open skin can be made in the conventional manner using standard rivets, but in repairing closed skin, some type of special fastener must be used. The exact type to be used depends on the type of repair being made and the recommendations of the aircraft manufacturer.

Design of a Patch for a Non-pressurized Area

Damage to the aircraft skin in a non-pressurized area can be repaired by a flush patch if a smooth skin surface is required or by an external patch in noncritical areas. *[Figure 4-177]* The first step is to remove the damage. Cut the damage to a round, oval, or rectangular shape. Round all corners of a rectangular patch to a minimum radius of 0.5-inch. The minimum edge distance used is 2 times the diameter and the rivet spacing is typically between 4-6 times the diameter. The size of the doubler depends on the edge distance and rivet spacing. The doubler material is of the same material as the damaged skin, but of one thickness greater than the damaged skin. The size of the doubler depends on the edge distance and rivet spacing. The insert is made of the same material and thickness as the damaged skin. The size and type of rivets should be the same as rivets used for similar joints on the aircraft. The SRM indicates what size and type of rivets to use.

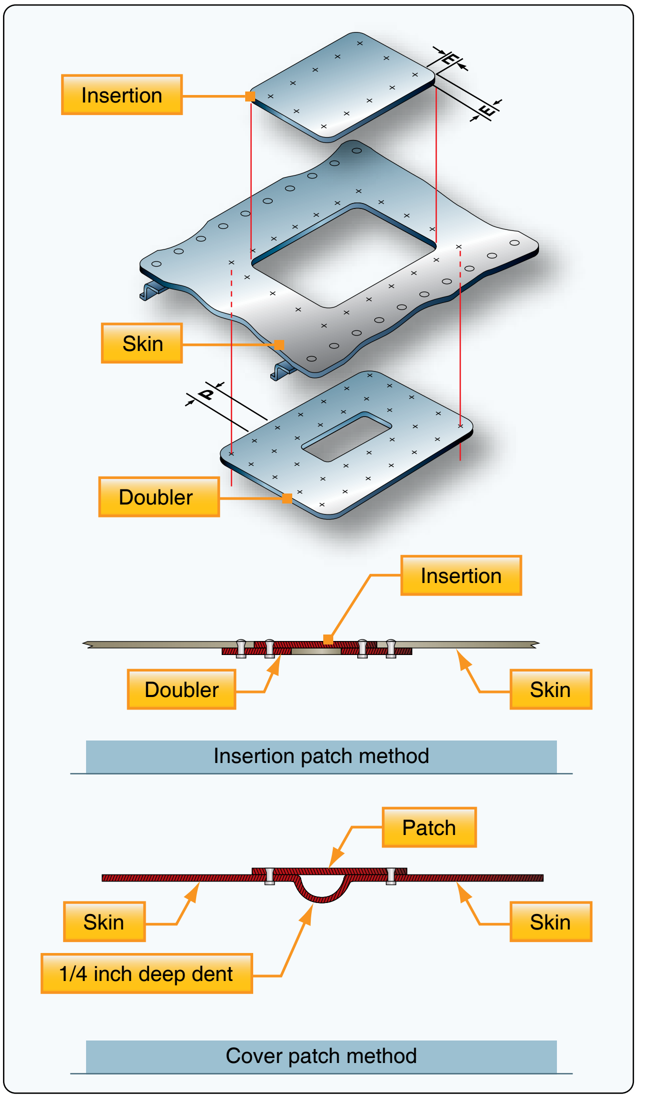


Figure 4-177. *Repair patch for a non-pressurized area.*

Typical Repairs for Aircraft Structures

This section describes typical repairs of the major structural parts of an airplane. When repairing a damaged component or part, consult the applicable section of the manufacturer's SRM for the aircraft. Normally, a similar repair is illustrated, and the types of material, rivets, and rivet spacing and the methods and procedures to be used are listed. Any additional knowledge needed to make a repair is also detailed. If the necessary information is not found in the SRM, attempt to find a similar repair or assembly installed by the manufacturer of the aircraft.

Floats

To maintain the float in an airworthy condition, periodic and frequent inspections should be made because of the rapidity of corrosion on metal parts, particularly when the aircraft is operated in salt water. Inspection of floats and hulls involves examination for damage due to corrosion, collision with other objects, hard landings, and other conditions that may lead to failure.

Note: Blind rivets should not be used on floats or amphibian hulls below the water line.

Sheet-metal floats should be repaired using approved practices; however, the seams between sections of sheet metal should be waterproofed with suitable fabric and sealing compound. A float that has undergone hull repairs should be tested by filling it with water and allowing it to stand for at least 24 hours to see if any leaks develop. *[Figure 4-178]*

Corrugated Skin Repair

Some of the flight controls of smaller general aviation aircraft have beads in their skin panels. The beads give some stiffness to the thin skin panels. The beads for the repair patch can be formed with a rotary former or press brake. *[Figure 4-179]*

Replacement of a Panel

Damage to metal aircraft skin that exceeds repairable limits

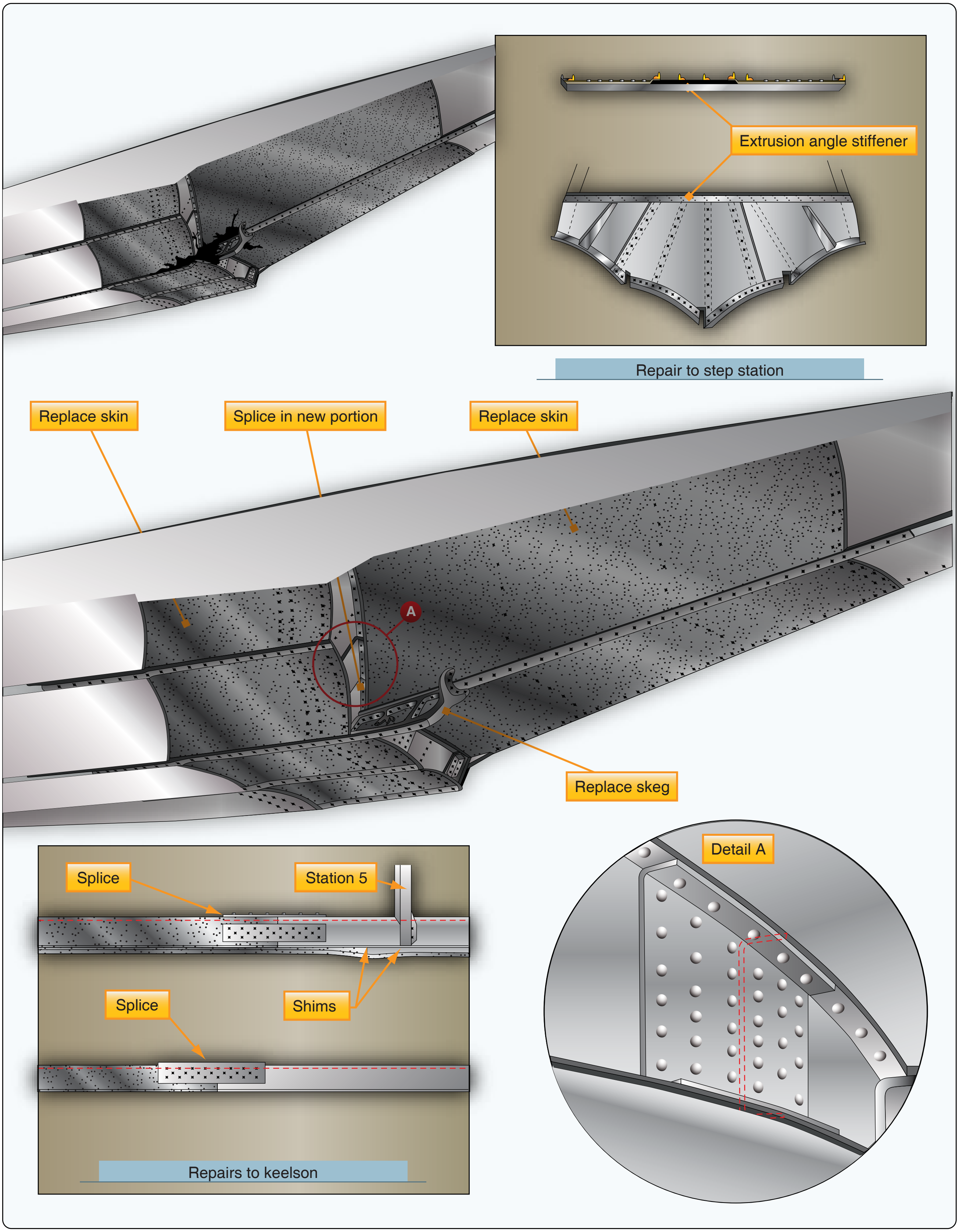


Figure 4-178. *Float repair.*

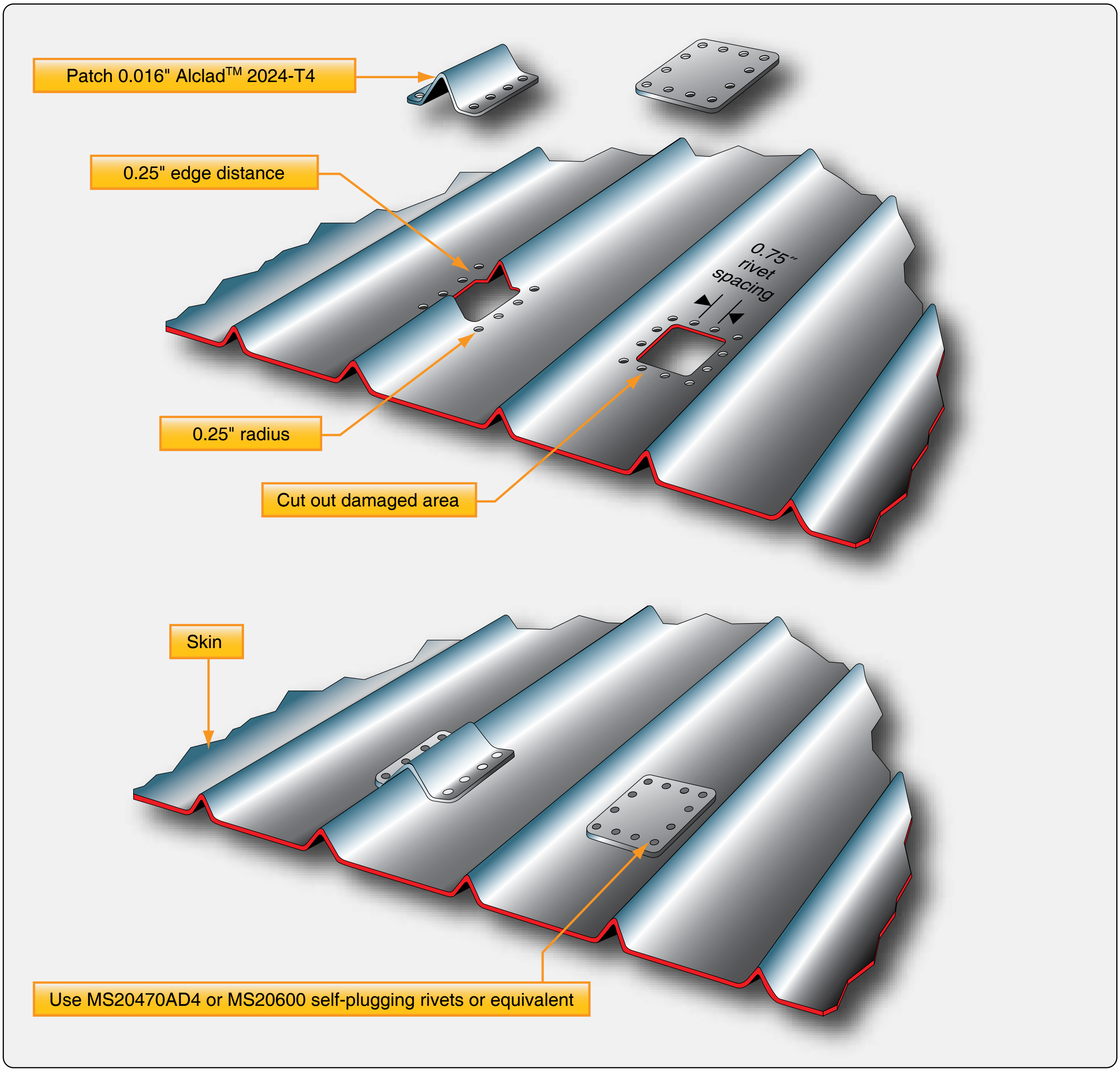


Figure 4-179. *Beaded skin repair on corrugated surfaces.*

requires replacement of the entire panel. *[Figure 4-180]* A panel must also be replaced when there are too many previous repairs in a given section or area.

In aircraft construction, a panel is any single sheet of metal covering. A panel section is the part of a panel between adjacent stringers and bulk heads. Where a section of skin is damaged to such an extent that it is impossible to install a standard skin repair, a special type of repair is necessary. The particular type of repair required depends on whether the damage is repairable outside the member, inside the member, or to the edges of the panel.

Outside the Member

For damage that, after being trimmed, has 8½ rivet diameters or more of material, extend the patch to include the manufacturer's row of rivets and add an extra row inside the members.

Inside the Member

For damage that, after being trimmed, has less than 8½ manufacturer's rivet diameters of material inside the members, use a patch that extends over the members and an extra row of rivets along the outside of the members.

Edges of the Panel

For damage that extends to the edge of a panel, use

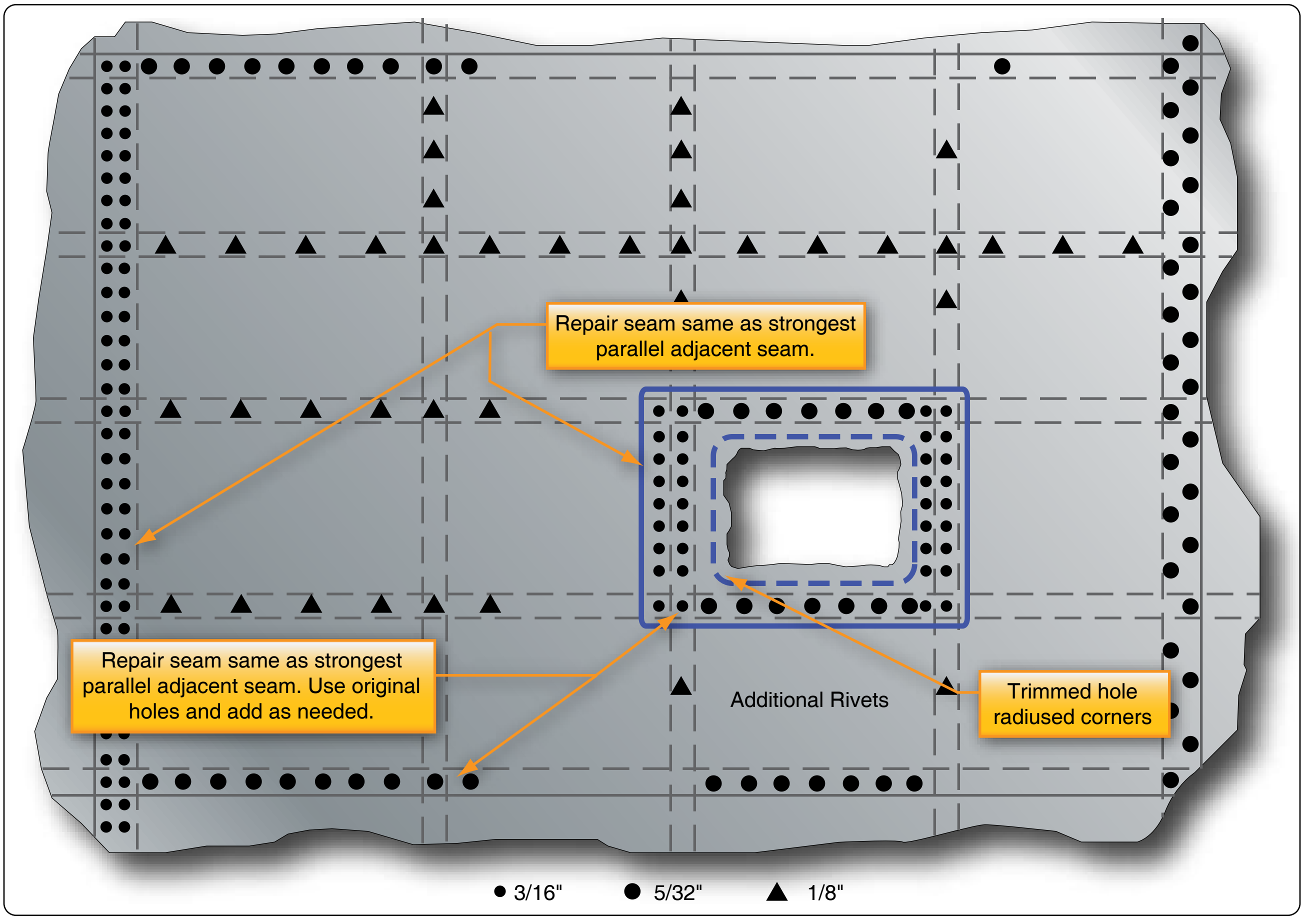


Figure 4-180. *Replacement of an entire panel.*

only one row of rivets along the panel edge, unless the manufacturer used more than one row. The repair procedure for the other edges of the damage follows the previously explained methods.

The procedures for making all three types of panel repairs are similar. Trim out the damaged portion to the allowances mentioned in the preceding paragraphs. For relief of stresses at the corners of the trim-out, round them to a minimum radius of ½-inch. Lay out the new rivet row with a transverse pitch of approximately five rivet diameters and stagger the rivets with those put in by the manufacturer. Cut the patch plate from material of the same thickness as the original or the next greater thickness, allowing an edge distance of 2½ rivet diameters. At the corners, strike arcs having the radius equal to the edge distance.

Chamfer the edges of the patch plate for a 45° angle and form the plate to fit the contour of the original structure. Turn the edges downward slightly so that the edges fit closely. Place the patch plate in its correct position, drill one rivet hole, and temporarily fasten the plate in place with a fastener. Using a hole finder, locate the position of a second hole, drill it, and insert a second fastener. Then, from the back side and through the original holes, locate and drill the remaining holes. Remove the burrs from the rivet holes and apply corrosion protective material to the contacting surfaces before riveting the patch into place.

Repair of Lightening Holes

As discussed earlier, lightening holes are cut in rib sections, fuselage frames, and other structural parts to reduce the weight of the part. The holes are flanged to make the web stiffer. Cracks can develop around flanged lightening holes, and these cracks need to be repaired with a repair plate. The damaged area (crack) needs to be stop drilled or the damage must be removed. The repair plate is made of the same material and thickness as the damaged part. Rivets are the same as in surrounding structure and the minimum edge distance is 2 times the diameter and spacing is between four to six times the diameter. *Figure 4-181* illustrates a typical lightening hole repair.

Repairs to a Pressurized Area

The skin of aircraft that are pressurized during flight is highly stressed. The pressurization cycles apply loads to the skin, and the repairs to this type of structure requires more rivets

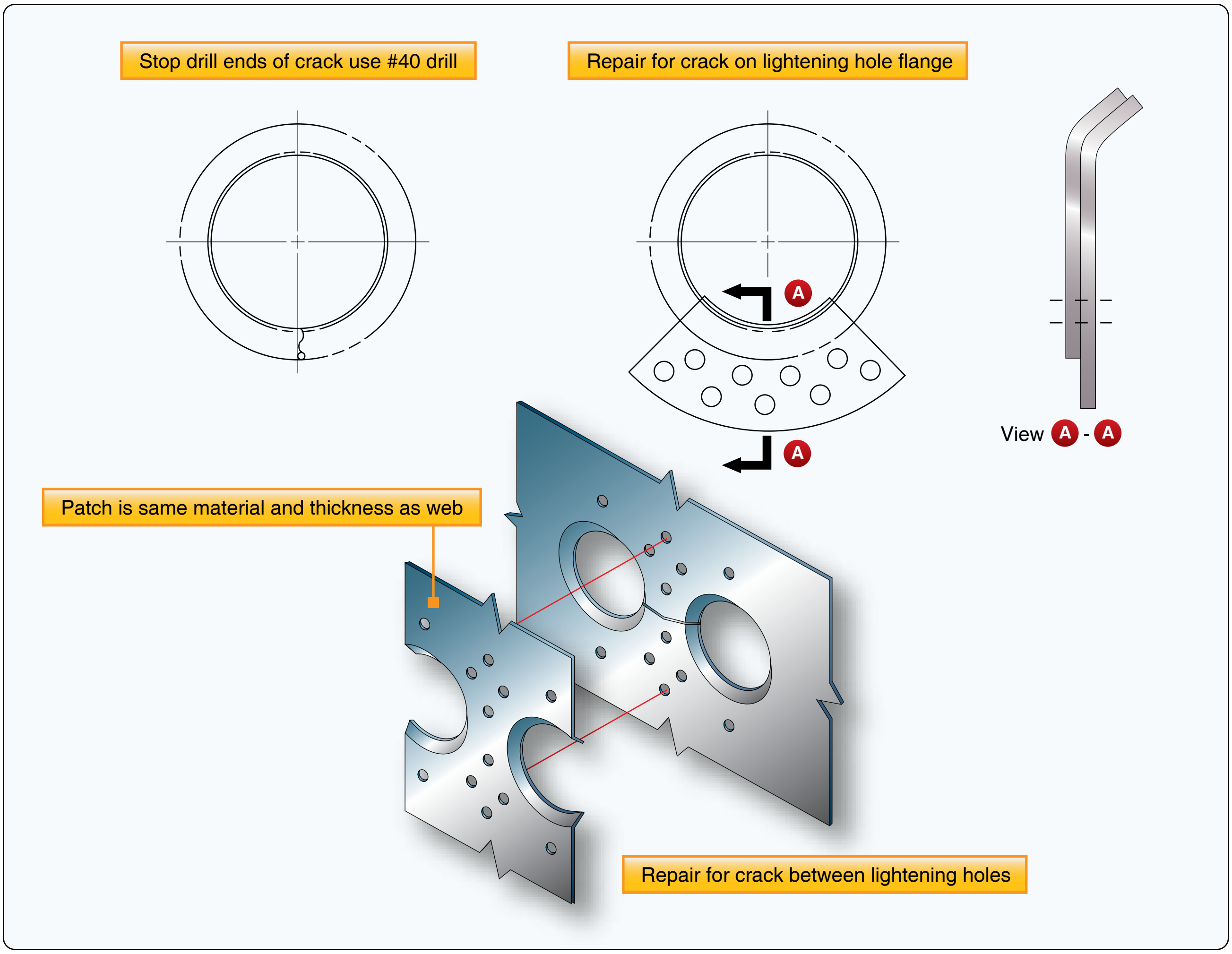


Figure 4-181. *Repair of lightening holes.*

than a repair to a nonpressurized skin. *[Figure 4-182]*

1. Remove the damaged skin section.
2. Radius all corners to 0.5-inch.
3. Fabricate a doubler of the same type of material as, but of one size greater thickness than, the skin. The size of the doubler depends on the number of rows, edge distance, and rivets spacing.
4. Fabricate an insert of the same material and same thickness as the damaged skin. The skin to insert clearance is typically 0.015-inch to 0.035-inch.
5. Drill the holes through the doubler, insertion, and original skin.
6. Spread a thin layer of sealant on the doubler and secure the doubler to the skin with Clecos.
7. Use the same type of fastener as in the surrounding area, and install the doubler to the skin and the insertion to the doubler. Dip all fasteners in the sealant before installation.

Stringer Repair

The fuselage stringers extend from the nose of the aircraft to the tail, and the wing stringers extend from the fuselage to the wing tip. Surface control stringers usually extend the length of the control surface. The skin of the fuselage, wing, or control surface is riveted to stringers.

Stringers may be damaged by vibration, corrosion, or collision. Because stringers are made in many different shapes, repair procedures differ. The repair may require the use of preformed or extruded repair material, or it may require material formed by the airframe technician. Some repairs may need both kinds of repair material. When repairing a stringer, first determine the extent of the damage and remove the rivets from the surrounding area. *[Figure 4-183]* Then, remove the damaged area by using a hacksaw, keyhole saw, drill, or file. In most cases, a stringer repair requires the use of insert and splice angle. When locating the splice angle on the stringer during repair, be sure to consult the applicable structural repair manual for the repair piece's position. Some stringers are repaired by placing the splice angle on the inside, whereas

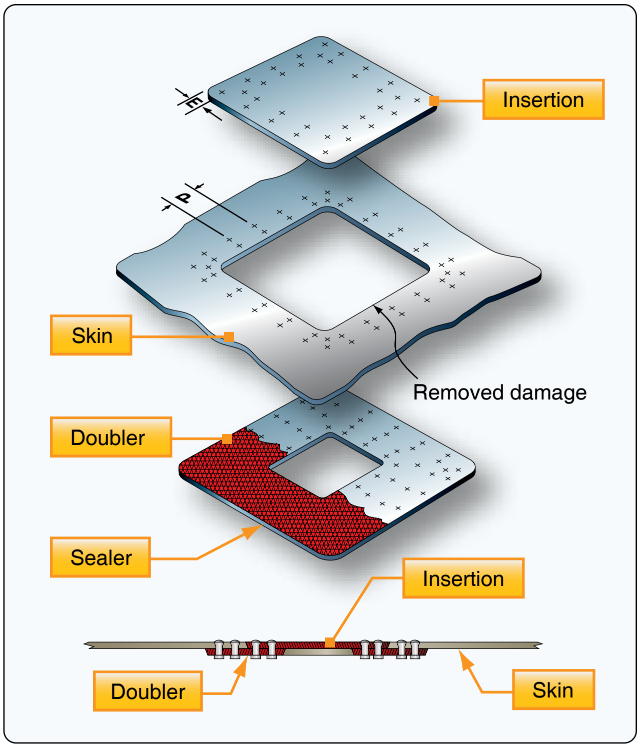


Figure 4-182. *Pressurized skin repair.*

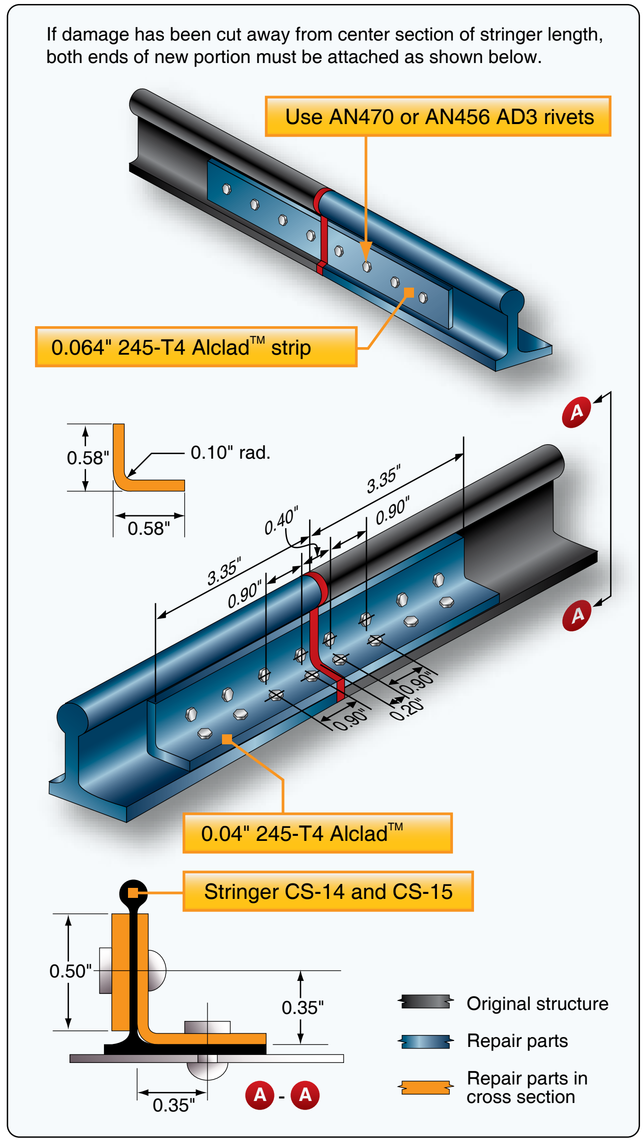


Figure 4-183. *Stringer repair.*

others are repaired by placing it on the outside.

Extrusions and preformed materials are commonly used to repair angles and insertions or fillers. If repair angles and fillers must be formed from flat sheet stock, use the brake. It may be necessary to use bend allowance and sight lines when making the layout and bends for these formed parts. For repairs to curved stringers, make the repair parts so that they fit the original contour.

Figure 4-184 shows a stringer repair by patching. This repair is permissible when the damage does not exceed two-thirds of the width of one leg and is not more than 12 inches long. Damage exceeding these limits can be repaired by one of the following methods.

Figure 4-185 illustrates repair by insertion where damage exceeds two-thirds of the width of one leg and after a portion of the stringer is removed. *Figure 4-186* shows repair by insertion when the damage affects only one stringer and exceeds 12 inches in length. *Figure 4-187* illustrates repair by an insertion when damage affects more than one stringer.

Former or Bulkhead Repair

Bulkheads are the oval-shaped members of the fuselage that give form to and maintain the shape of the structure. Bulkheads or formers are often called forming rings, body frames, circumferential rings, belt frames, and other similar names. They are designed to carry concentrated stressed loads.

There are various types of bulkheads. The most common type is a curved channel formed from sheet stock with stiffeners added. Others have a web made from sheet stock with extruded angles riveted in place as stiffeners and flanges. Most of these members are made from aluminum alloy. Corrosion-resistant steel formers are used in areas that are exposed to high temperatures.

Bulkhead damages are classified in the same manner as other damages. Specifications for each type of damage are established by the manufacturer and specific information is given in the maintenance manual or SRM for the aircraft. Bulkheads are identified with station numbers that are very

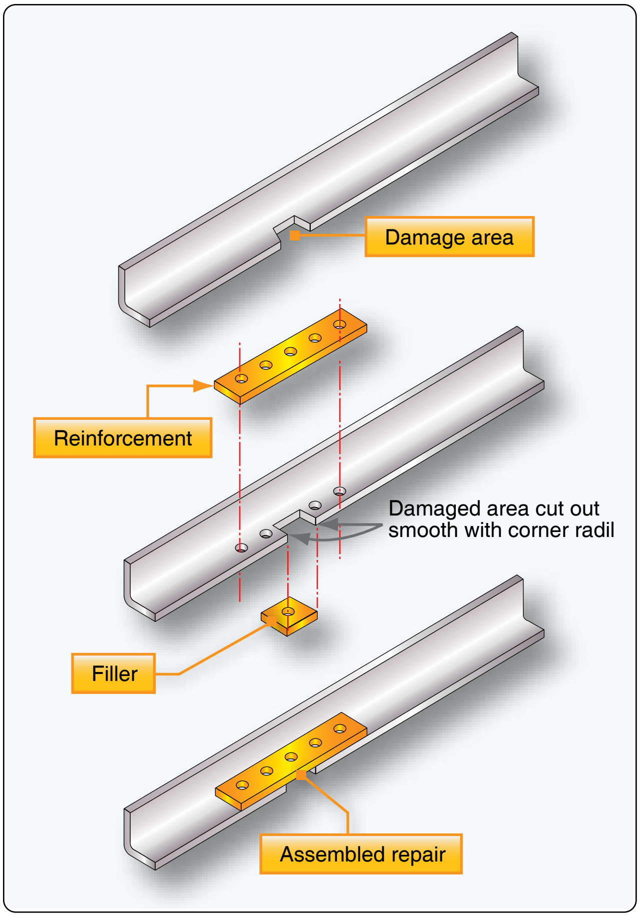


Figure 4-184. *Stringer repair by patching.*

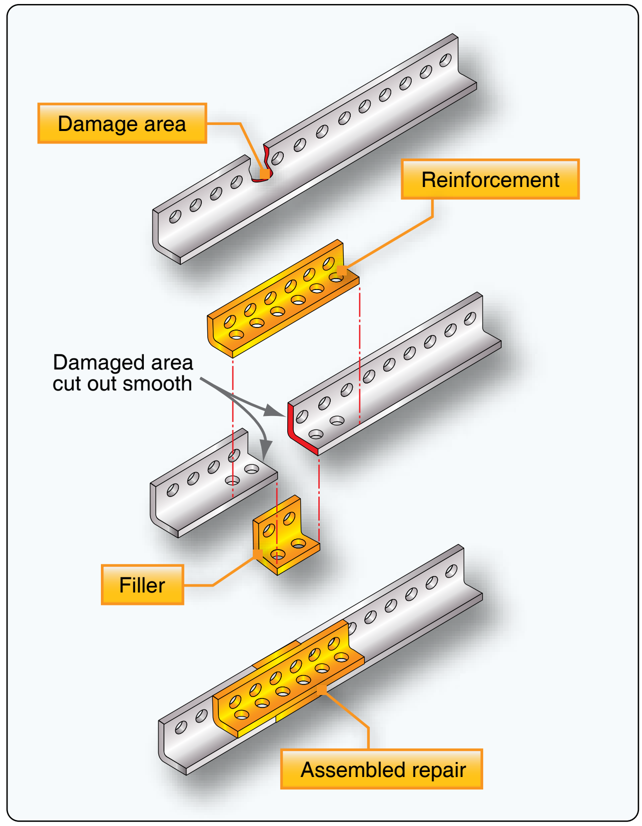


Figure 4-185. *Stringer repair by insertion when damage exceeds two-thirds of one leg in width.*

helpful in locating repair information. *Figure 4-188* is an example of a typical repair for a former, frame section, or bulkhead repair.

1. Stop drill the crack ends with a No. 40 size drill.
2. Fabricate a doubler of the same material but one size thicker than the part being repaired. The doubler should be of a size large enough to accommodate ⅛-inch rivet holes spaced one inch apart, with a minimum edge distance of 0.30-inch and 0.50-inch spacing between staggered rows. *[Figure 4-189]*
3. Attach the doubler to the part with clamps and drill holes.
4. Install rivets.

Most repairs to bulkheads are made from flat sheet stock if spare parts are not available. When fabricating the repair from flat sheet, remember the substitute material must provide cross-sectional tensile, compressive, shear, and bearing strength equal to the original material. Never substitute material that is thinner or has a cross-sectional area less than the original material. Curved repair parts made from flat sheet must be in the "0" condition before forming, and then must be heat treated before installation.

Longeron Repair

Generally, longerons are comparatively heavy members that serve approximately the same function as stringers. Consequently, longeron repair is similar to stringer repair. Because the longeron is a heavy member and more strength is needed than with a stringer, heavy rivets are used in the repair. Sometimes bolts are used to install a longeron repair, due to the need for greater accuracy, they are not as suitable as rivets. Also, bolts require more time for installation.

If the longeron consists of a formed section and an extruded angle section, consider each section separately. A longeron repair is similar to a stringer repair, but keep the rivet pitch between 4 and 6 rivet diameters. If bolts are used, drill the bolt holes for a light drive fit.

Spar Repair

The spar is the main supporting member of the wing. Other components may also have supporting members called spars that serve the same function as the spar does in the wing. Think of spars as the hub, or base, of the section in which they are located, even though they are not in the center. The spar

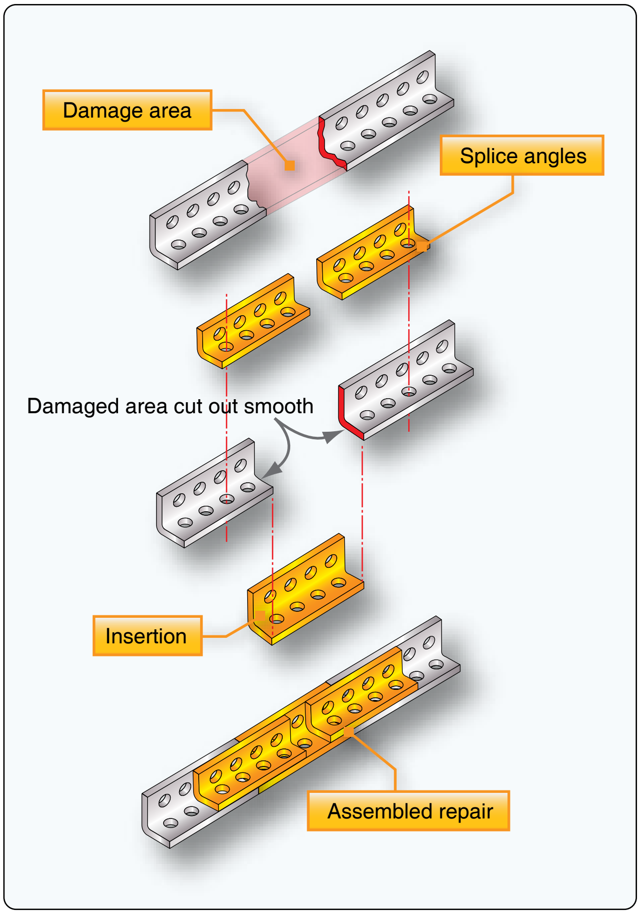


Figure 4-186. *Stringer repair by insertion when damage affects only one stringer.*

is usually the first member located during the construction of the section, and the other components are fastened directly or indirectly to it. Because of the load the spar carries, it is very important that particular care be taken when repairing this member to ensure the original strength of the structure is not impaired. The spar is constructed so that two general classes of repairs, web repairs and cap strip repairs, are usually necessary.

Figures 4-189 and *4-190* are examples of typical spar repairs. The damage to the spar web can be repaired with a round or rectangular doubler. Damage smaller than 1-inch is typically repaired with a round doubler and larger damage is repaired with a rectangular doubler.

1. Remove the damage and radius all corners to 0.5-inch.
2. Fabricate doubler; use same material and thickness. The doubler size depends on edge distance (minimum of 2D) and rivet spacing (4-6D).
3. Drill through the doubler and the original skin and secure doubler with Clecos.
4. Install rivets.

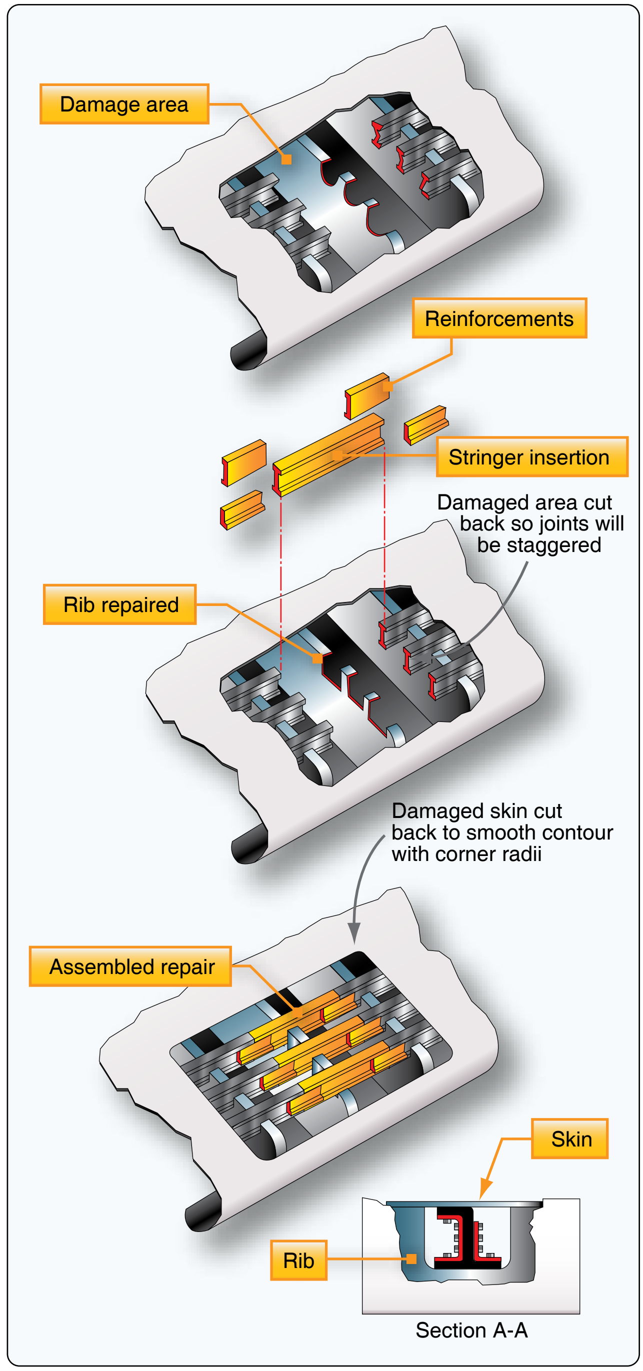


Figure 4-187. *Stringer repair by insertion when damage affects more than one stringer.*

Rib & Web Repair

Web repairs can be classified into two types:

1. Those made to web sections considered critical, such as those in the wing ribs.
2. Those considered less critical, such as those in elevators, rudders, flaps, and the like.

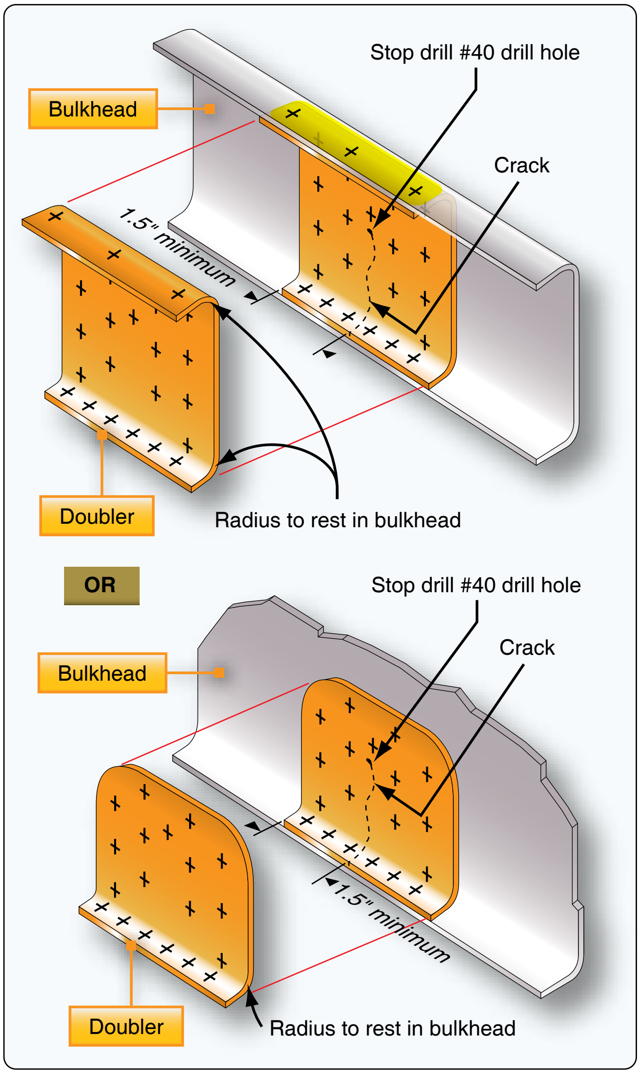


Figure 4-188. *Bulkhead repair.*

Web sections must be repaired in such a way that the original strength of the member is restored. In the construction of a member using a web, the web member is usually a light gauge aluminum alloy sheet forming the principal depth of the member. The web is bounded by heavy aluminum alloy extrusions known as cap strips. These extrusions carry the loads caused by bending and also provide a foundation for attaching the skin. The web may be stiffened by stamped beads, formed angles, or extruded sections riveted at regular intervals along the web.

The stamped beads are a part of the web itself and are stamped in when the web is made. Stiffeners help to withstand the compressive loads exerted upon the critically stressed web members. Often, ribs are formed by stamping the entire piece from sheet stock. That is, the rib lacks a cap strip, but does have a flange around the entire piece, plus lightening holes in the web of the rib. Ribs may be formed with stamped beads for stiffeners, or they may have extruded angles riveted on the web for stiffeners.

Most damages involve two or more members, but only one member may be damaged and need repairing. Generally, if the web is damaged, cleaning out the damaged area and installing a patch plate are all that is required.

The patch plate should be of sufficient size to ensure room for at least two rows of rivets around the perimeter of the damage that includes proper edge distance, pitch, and transverse pitch for the rivets. The patch plate should be of material having the same thickness and composition as the original member. If any forming is necessary when making the patch plate, such as fitting the contour of a lightening hole, use material in the "0" condition and then heat treat it after forming.

Damage to ribs and webs that requires a repair larger than a simple plate probably needs a patch plate, splice plates, or angles and an insertion. *[Figure 4-191]*

Leading Edge Repair

The leading edge is the front section of a wing, stabilizer, or other airfoil. The purpose of the leading edge is to streamline the forward section of the wings or control surfaces to ensure effective airflow. The space within the leading edge is sometimes used to store fuel. This space may also house extra equipment, such as landing lights, plumbing lines, or thermal anti-icing systems.

The construction of the leading edge section varies with the type of aircraft. Generally, it consists of cap strips, nose ribs, stringers, and skin. The cap strips are the main lengthwise extrusions, and they stiffen the leading edges and furnish a base for the nose ribs and skin. They also fasten the leading edge to the front spar.

The nose ribs are stamped from aluminum alloy sheet or machined parts. These ribs are U-shaped and may have their web sections stiffened. Regardless of their design, their purpose is to give contour to the leading edge. Stiffeners are used to stiffen the leading edge and supply a base for fastening the nose skin. When fastening the nose skin, use only flush rivets.

Leading edges constructed with thermal anti-icing systems consist of two layers of skin separated by a thin air space. The inner skin, sometimes corrugated for strength, is perforated to conduct the hot air to the nose skin for anti-icing purposes.

Damage can be caused by contact with other objects, namely, pebbles, birds, and hail. However, the major cause of damage is carelessness while the aircraft is on the ground.

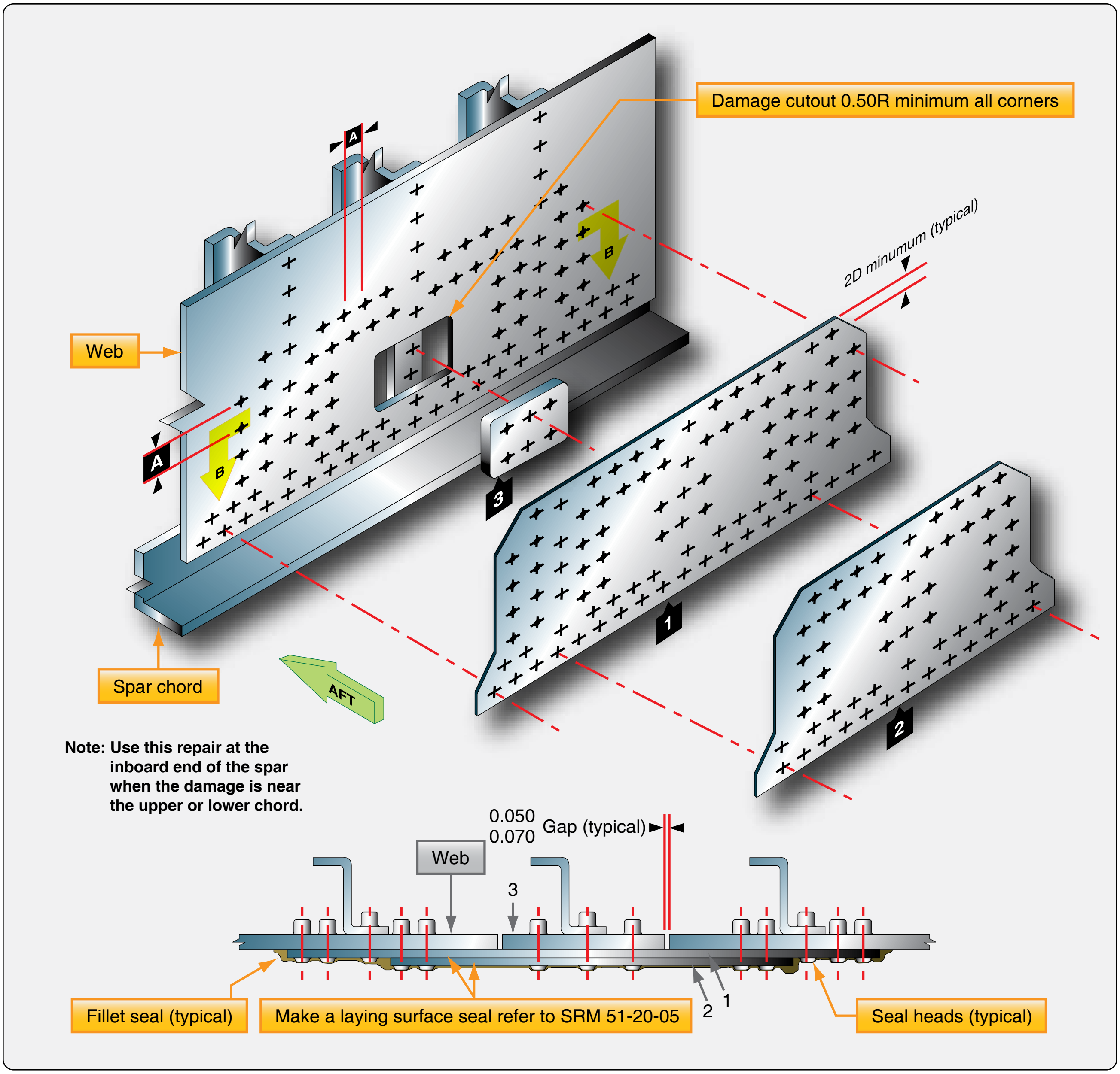


Figure 4-189. *Wing spar repair.*

A damaged leading edge usually involves several structural parts. FOD probably involves the nose skin, nose ribs, stringers, and possibly the cap strip. Damage involving all of these members necessitates installing an access door to make the repair possible. First, the damaged area has to be removed and repair procedures established. The repair needs insertions and splice pieces. If the damage is serious enough, it may require repair of the cap strip and stringer, a new nose rib, and a skin panel. When repairing a leading edge, follow the procedures prescribed in the appropriate repair manual for this type of repair. *[Figure 4-192]* Repairs to leading edges are more difficult to accomplish than repairs to flat and straight structures because the repair parts need to be formed to fit the existing structure.

Trailing Edge Repair

A trailing edge is the rear-most part of an airfoil found on the wings, ailerons, rudders, elevators, and stabilizers. It is usually a metal strip that forms the shape of the edge by tying the ends of a rib section together and joining the upper and lower skins. Trailing edges are not structural members, but they are considered to be highly stressed in all cases.

Damage to a trailing edge may be limited to one point or extended over the entire length between two or more rib sections. Besides damage resulting from collision and

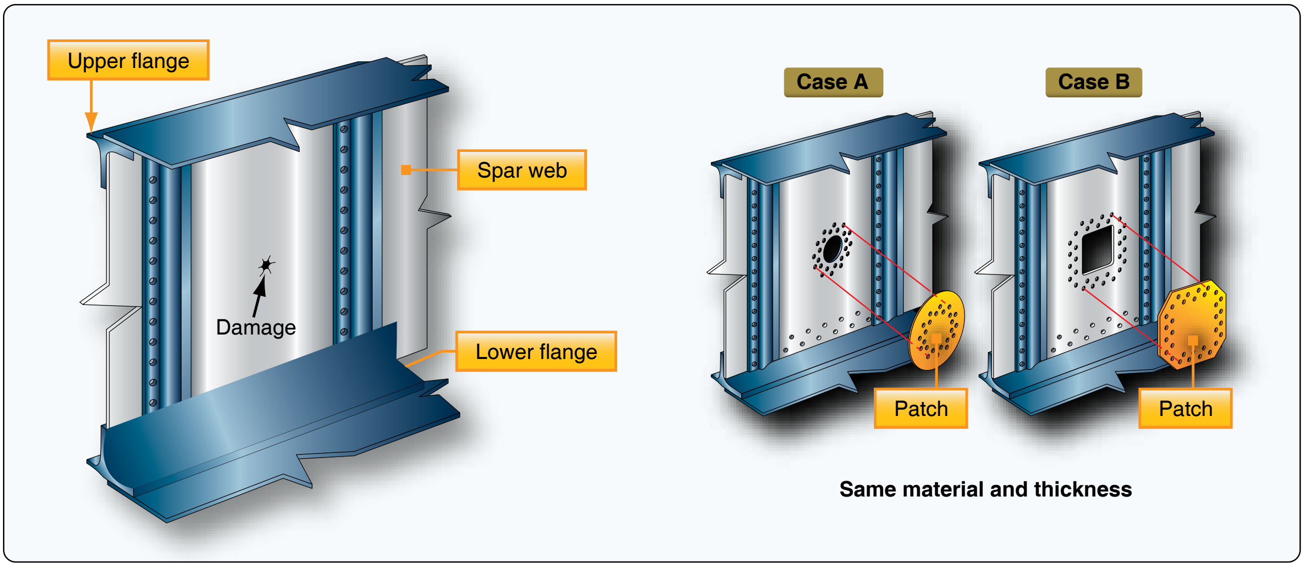


Figure 4-190. *Wing spar repair.*

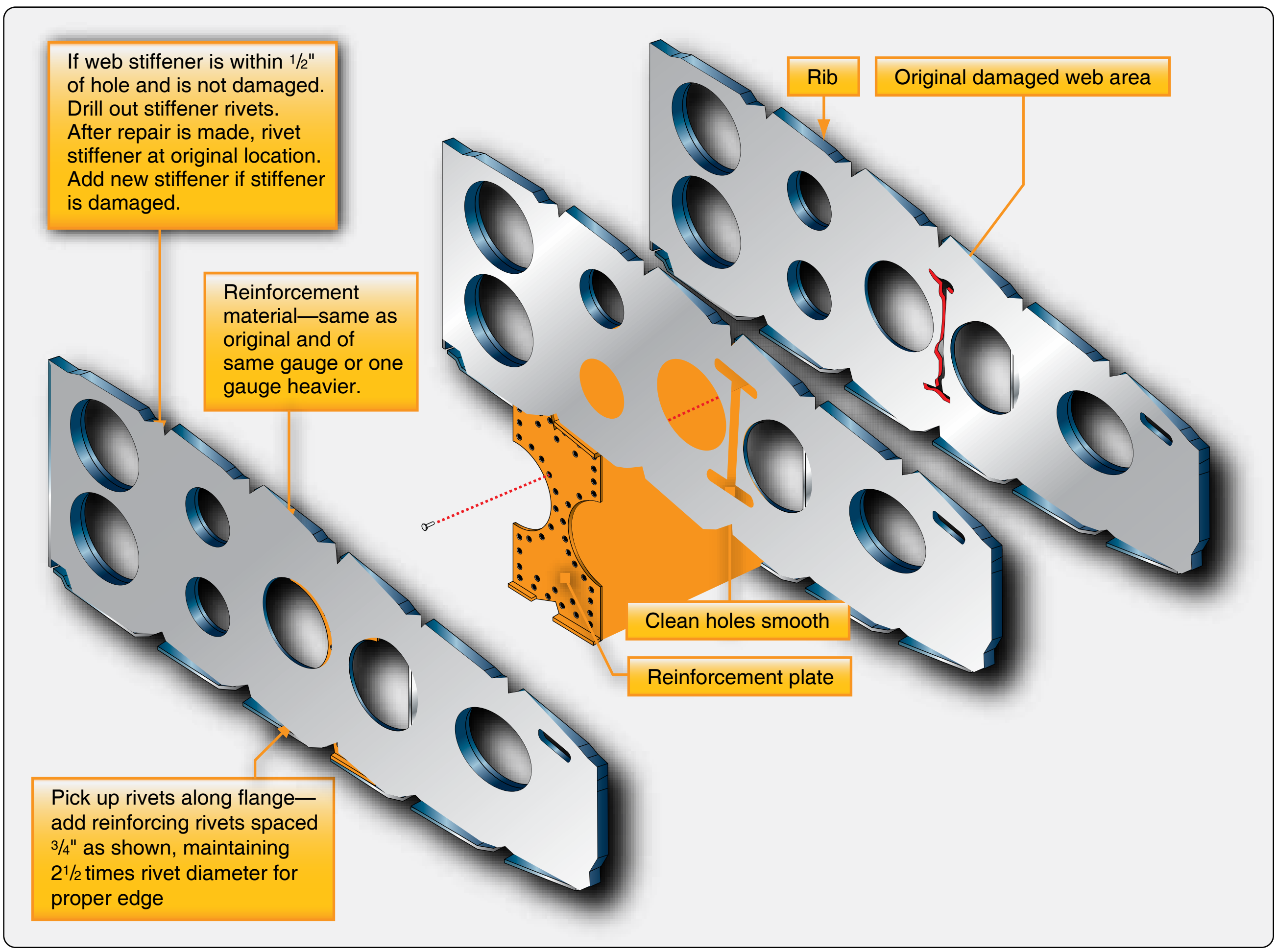


Figure 4-191. *Wing rib repair.*

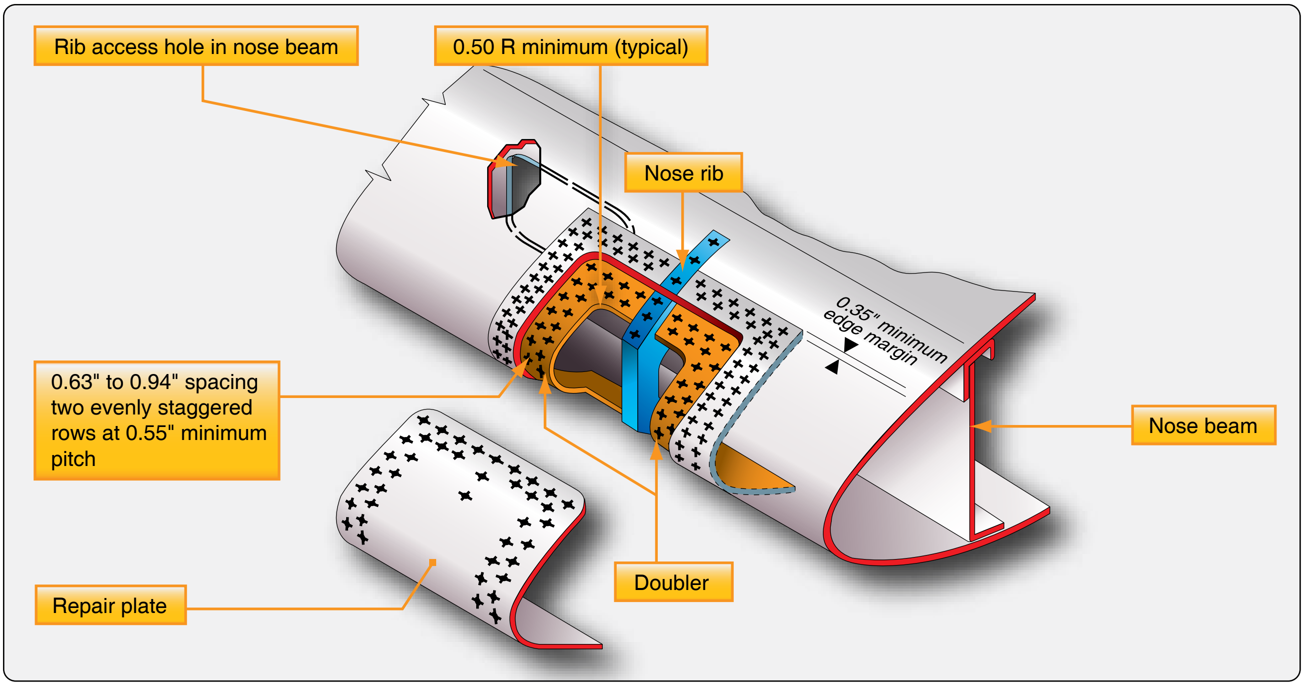


Figure 4-192. *Leading edge repair.*

careless handling, corrosion damage is often present. Trailing edges are particularly subject to corrosion because moisture collects or is trapped in them.

Thoroughly inspect the damaged area before starting repairs, and determine the extent of damage, the type of repair required, and the manner in which the repair should be performed. When making trailing edge repairs, remember that the repaired area must have the same contour and be made of material with the same composition and temper as the original section. The repair must also be made to retain the design characteristics of the airfoil. *[Figure 4-193]*

Specialized Repairs

Figures 4-194 through *4-198* are examples of repairs for various structural members. Specific dimensions are not included since the illustrations are intended to present the basic design philosophy of general repairs rather than be used as repair guidelines for actual structures. Remember to consult the SRM for specific aircraft to obtain the maximum allowable damage that may be repaired and the suggested method for accomplishing the repair.

Inspection Openings

If it is permitted by the applicable aircraft maintenance manual, installation of a flush access door for inspection purposes sometimes makes it easier to repair the internal structure as well as damage to the skin in certain areas. This installation consists of a doubler and a stressed cover plate. A single row of nut plates is riveted to the doubler, and the doubler is riveted to the skin with two staggered rows of rivets. *[Figure 4-199]* The cover plate is then attached to the doubler with machine screws.

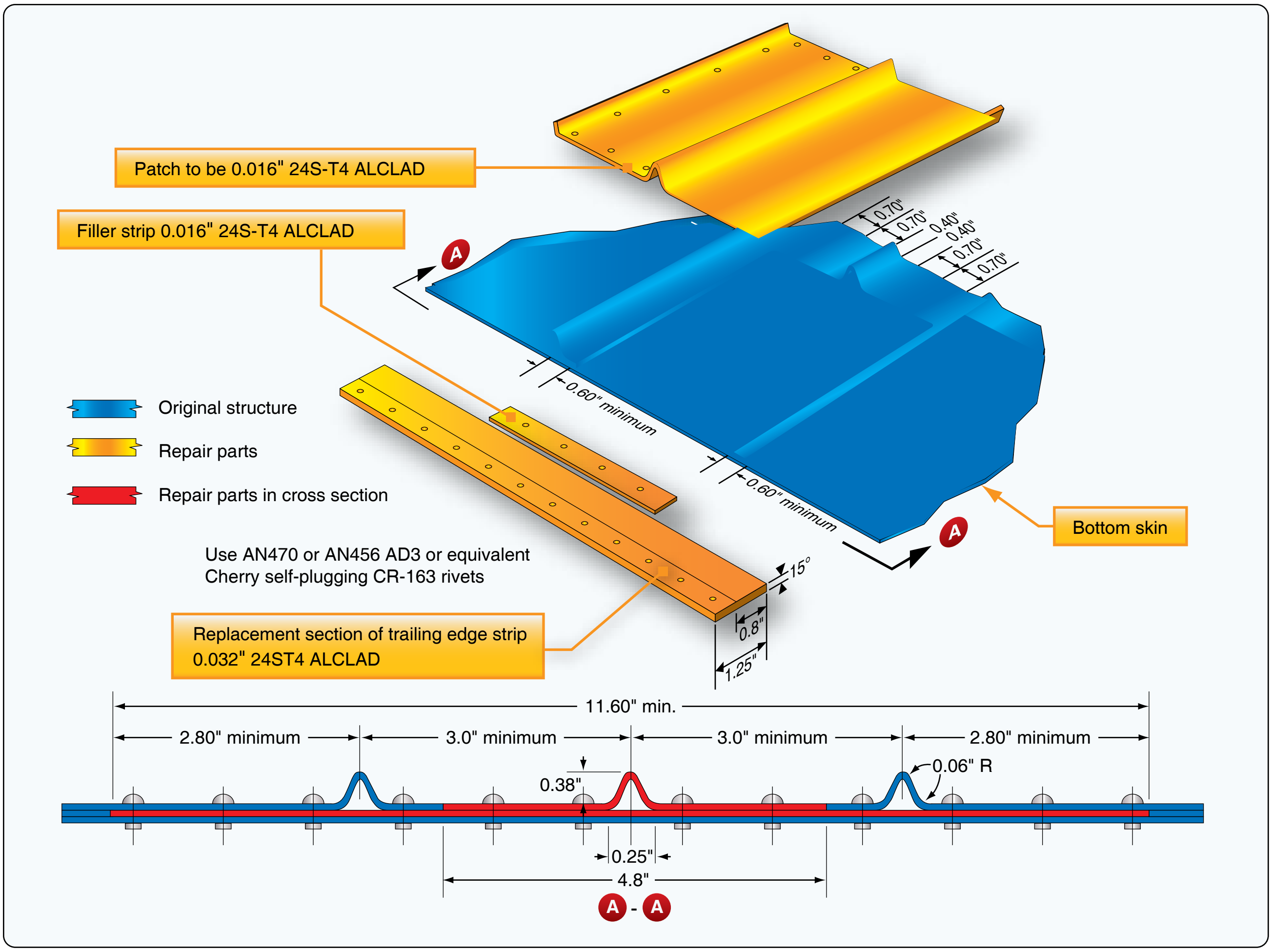
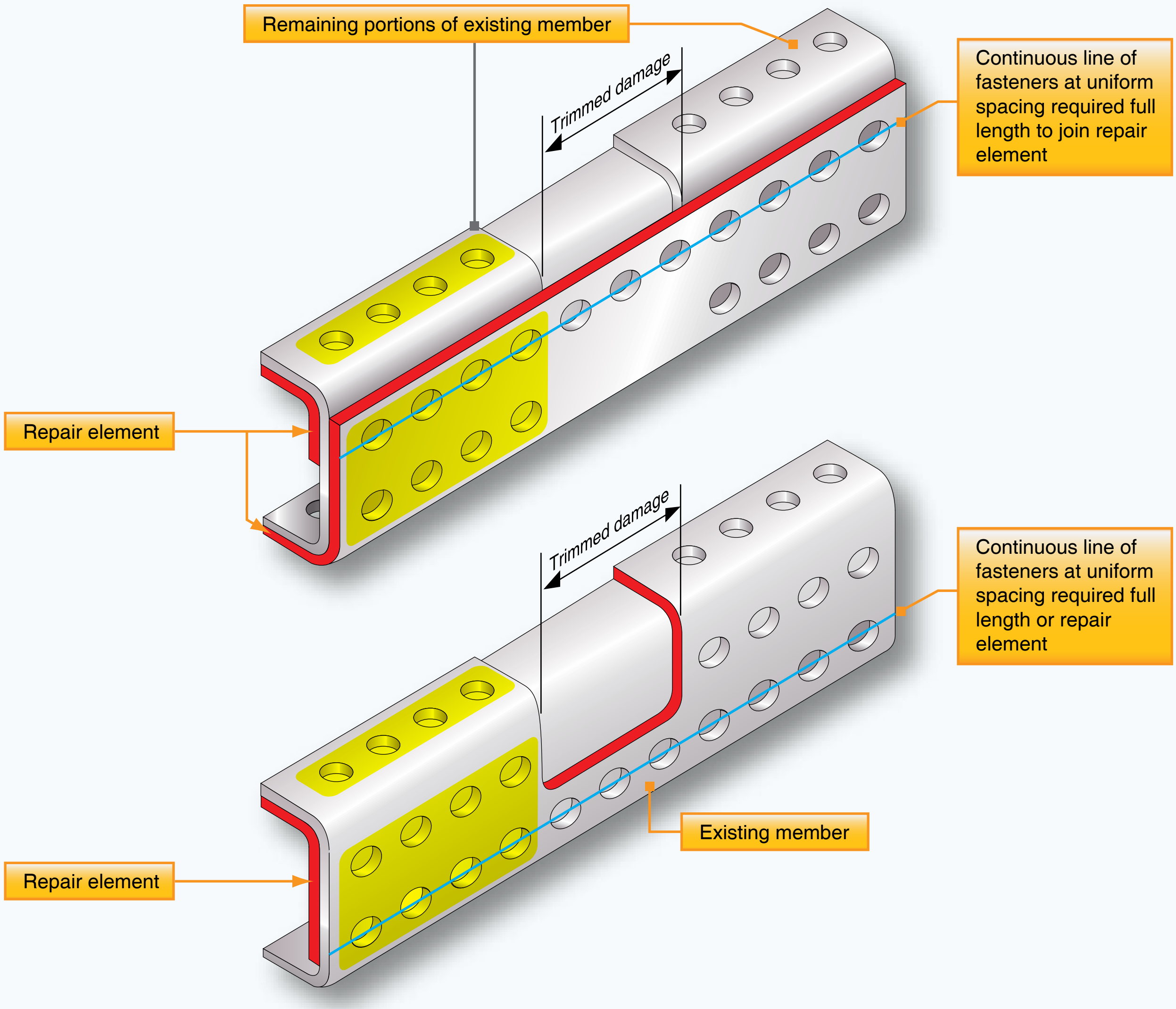


Figure 4-193. *Trailing edge repair.*



The required quantity of fasteners used to install the repair element is equal on both sides of the trimmed damage.

Figure 4-194. *C-channel repair.*

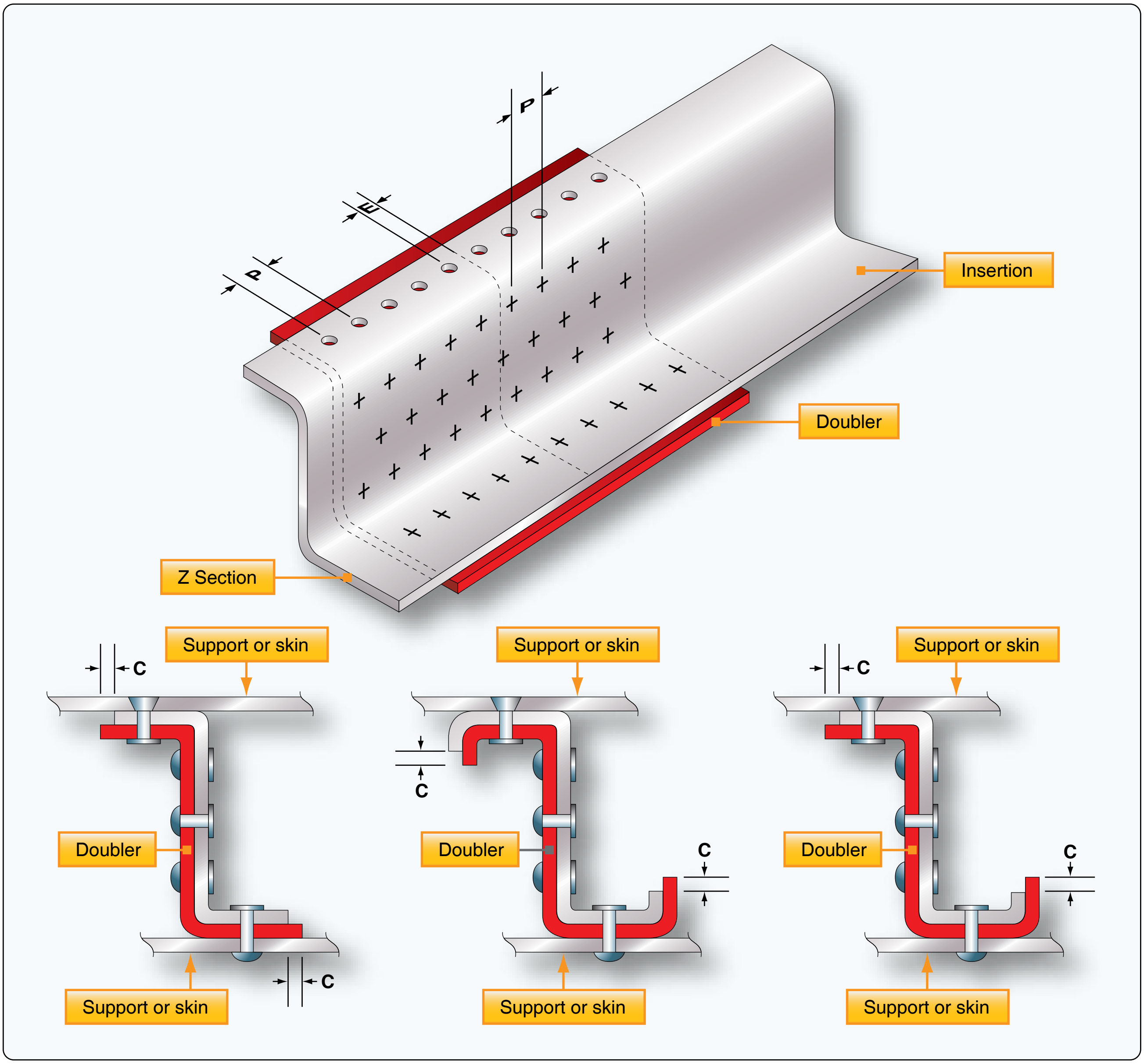


Figure 4-195. *Primary Z-section repair.*

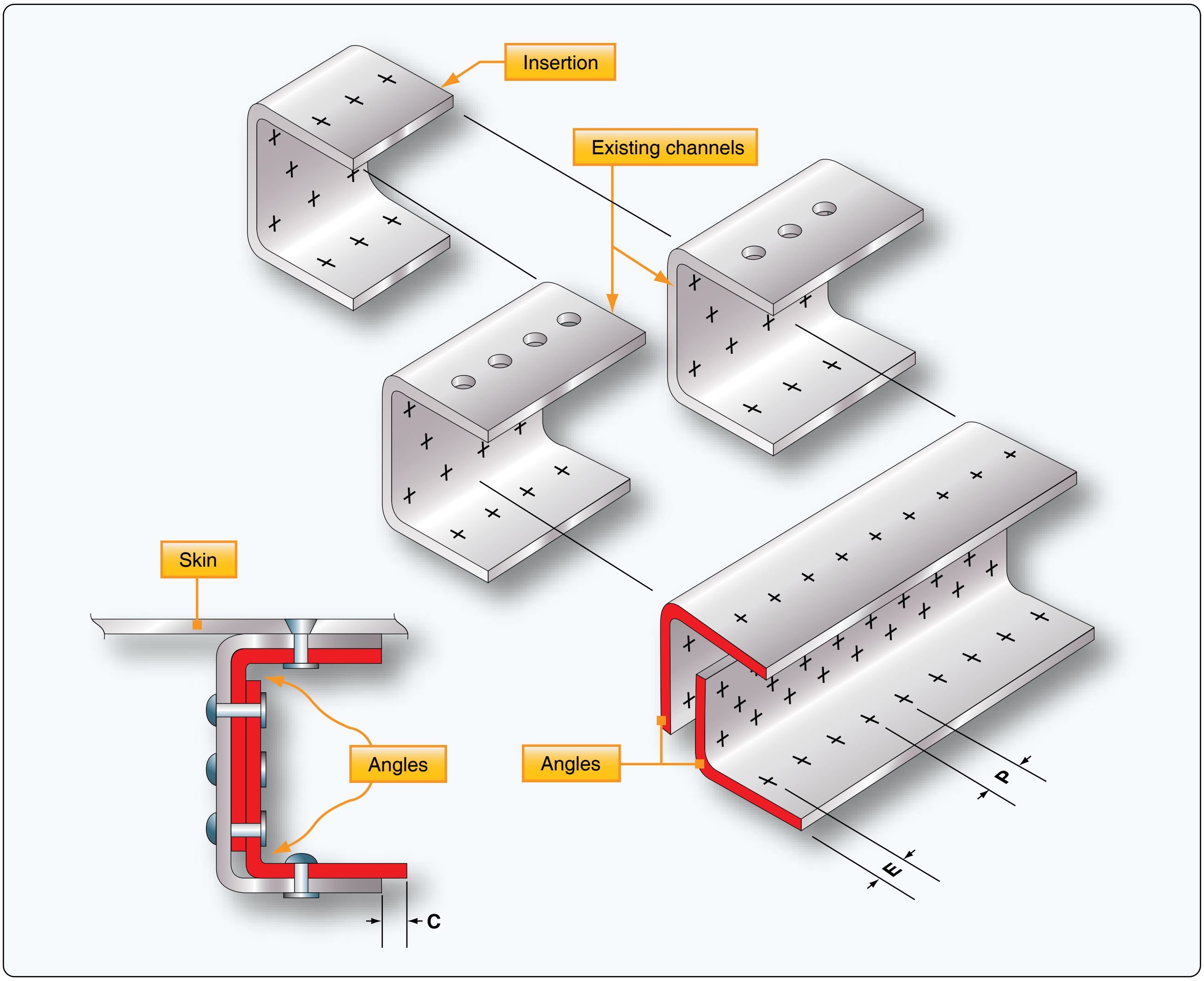


Figure 4-196. *U-channel repair.*

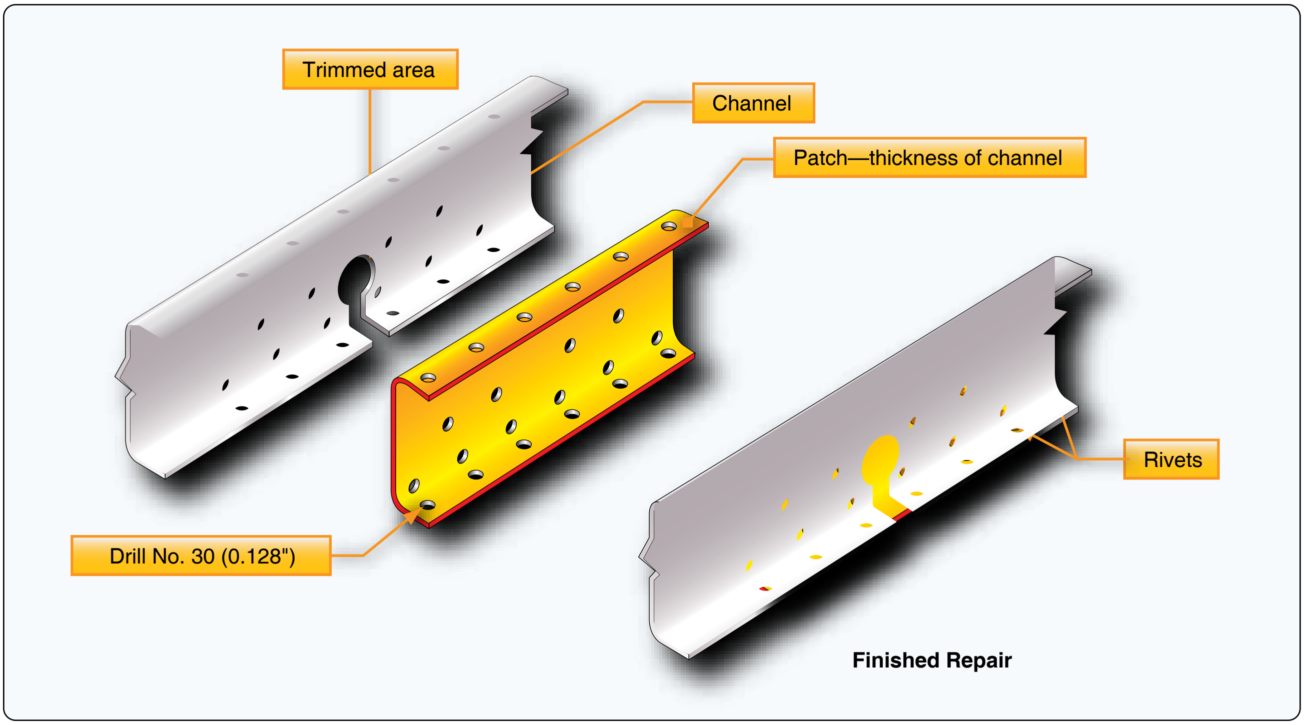


Figure 4-197. *Channel repair by patching.*

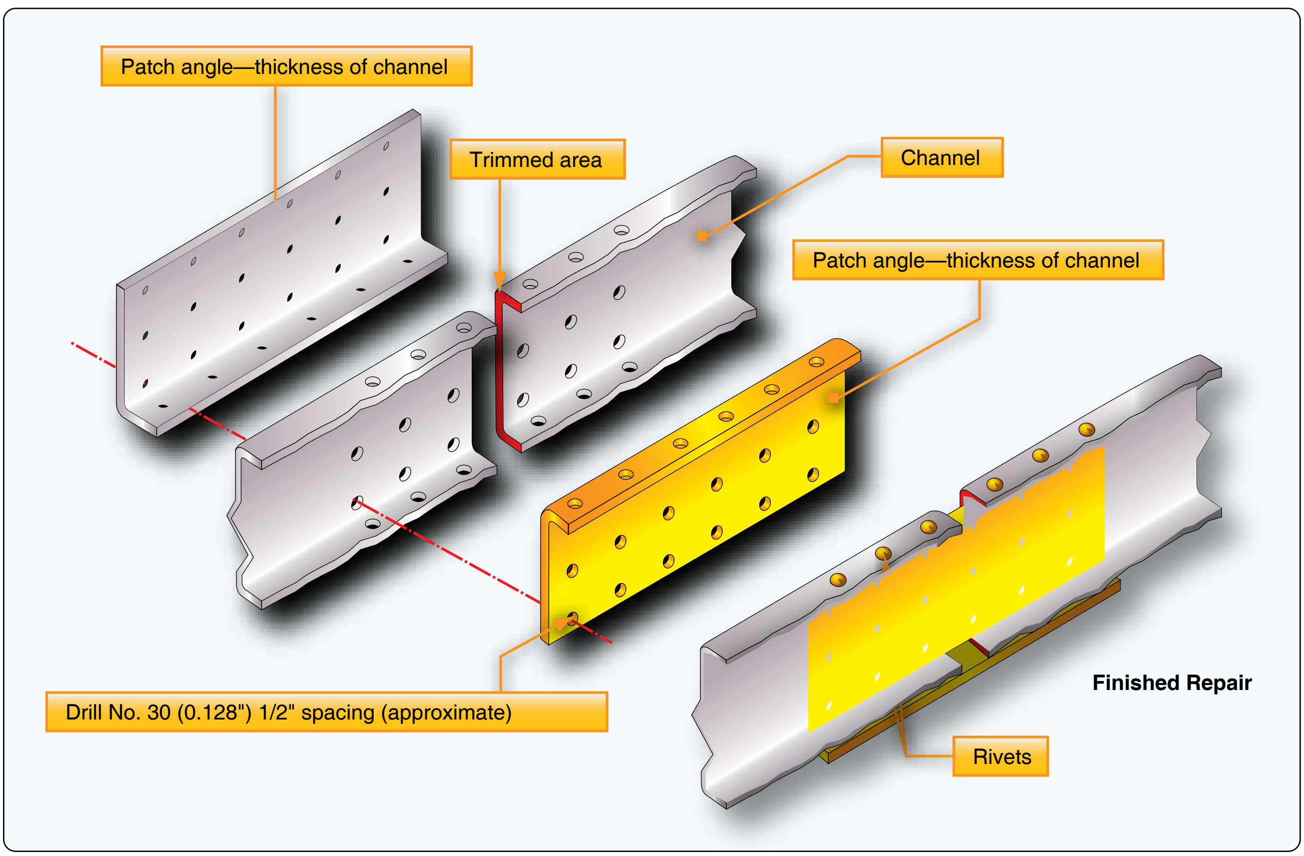


Figure 4-198. *Channel repair by insertion.*