1.0 GENERAL

1.1 This Design Standard provides information on bending of metal sheet, plate, formed shapes and extruded sections, including - definitions - formulae used to calculate bend allowances, bend deduction, developed length, etc. - and tabular data of standard bend radii to be used for DHI design applications.

1.2 Refer to DS128 for information and limitations on forming of flanges.

1.3 Material

1.3.1 Aluminum and Aluminum alloy sheet stock are most commonly used for formed parts in aircraft production. Corrosion Resistant Steel, Low-Alloy Steel, and Titanium sheet stocks are also used to a lesser extent.

1.4 Forming Process

1.4.1 Forming of metals by bending, basically consists of applying a controlled, localized force to stress the material to a specific degree beyond its yield strength but below its ultimate tensile strength.

1.4.2 Forming methods are all basically alike and can be divided into two classes. Simple bends in one axis only (e.g. flange angles) and Compound bends in two or three axes (e.g. formed or extruded sections or contoured skin panels).

1.4.3 Contour or shape forming involves a reduction of the material thickness in some areas due to stretching of the grain structure in the metal and an increase in thickness in other areas due to compression of the grain structure.

2.0 BENDING DEFINITIONS

2.1 Neutral Surface and Neutral Axis

2.1.1 Neutral Surface is the surface arc where the metal neither stretches nor compresses during the forming

2.1.2 operation. See Figure 1.

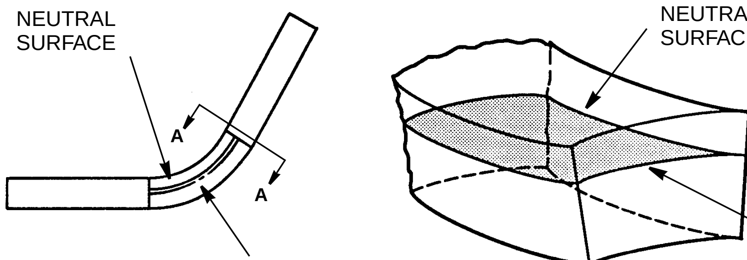


FIGURE 1 - NEUTRAL SURFACE

2.2 Bend Allowance (BA)

2.2.1 Bend Allowance is the length of the bend between the bend lines measured on the Neutral Surface or Axis. See Figure 2.

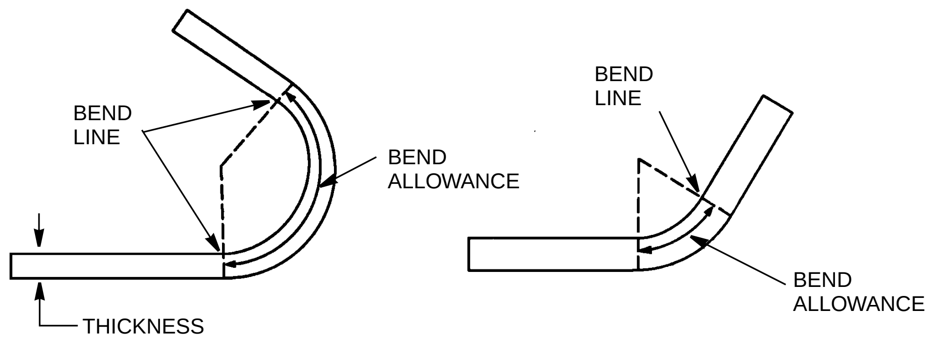


FIGURE 2 - BEND ALLOWANCE

2.3 Set Back (SB)

2.3.1 Set Back is the distance from the bend line to Outer Mould Line (OML). See Figure 3.

2.4 Outside Mould Line (OML)

2.4.1 Outside Mould Line (OML) is the intersection of the outer datum face and the outer flange face. See Figure 3.

2.5 Inside Mould Line (IML)

2.5.1 Inside Mould Line (IML) is the intersection of the inner datum face and inner flange face. See Figure 3.

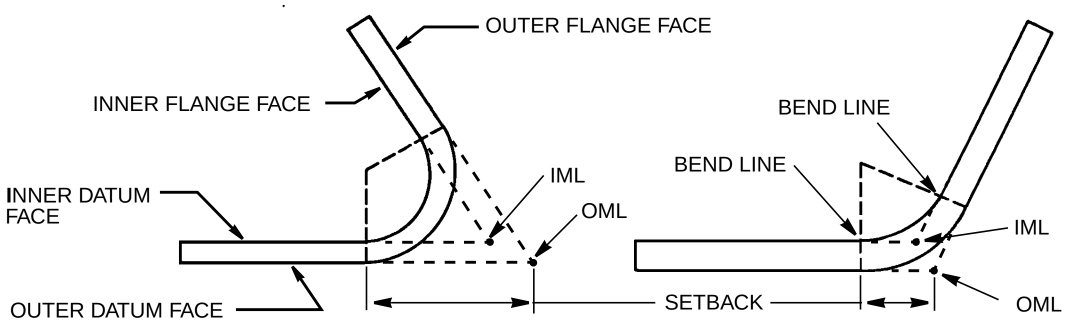


FIGURE 3 - SETBACK - IML/OML

2.6 OML to IML Distance

2.6.1 The OML - IML distance varies from the nominal material thickness as the bevel or flange angle varies from 90^o. This variation is tabulated in Table 10 and the loft layout must be drawn to the tabulated figures and not to the nominal 90^o material thickness. See Figure 4.

2.6.2 Although the OML - IML distance is automatically generated by Computer Aided Drafting programs, the data in Table 10 may be used as reference and is necessary for any hand drawn lofts.

2.7 Refer to Section 3.6 for formula to calculate OML - IML distance for specific material thicknesses and bend angles.

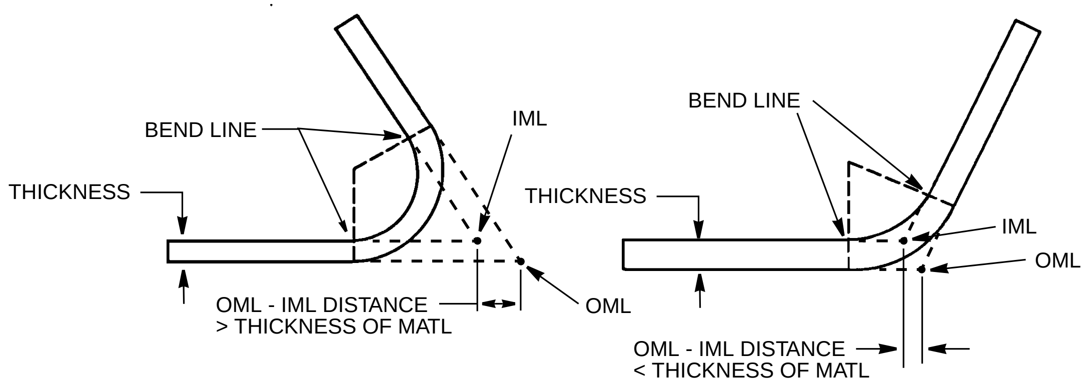


FIGURE 4 - IML - OML DISTANCE

2.8 Bend Radius (R)

2.8.1 Bend Radius refers to the radius on the inner surface of the material as formed. See Figure 5

2.9 Bend Angle (θ)

2.9.1 Bend Angle refers to the number of degrees the material is bent through from the flat condition. See Figure 5.

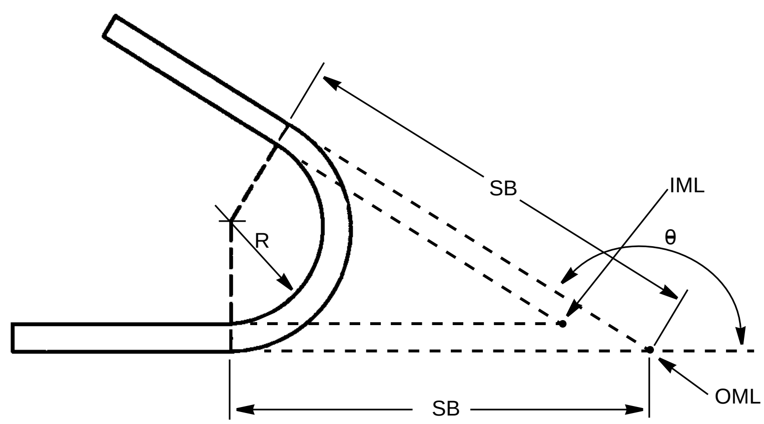


FIGURE 5 - BEND RAD - BEND ANGLE

2.10 Bend Deduction (BD)

2.10.1 Bend Deduction is the amount that must be subtracted from the bend flange length (L2) to develop the true length on the flat pattern. Bend deduction is the difference between twice the Set Back and the Bend Allowance. See Figure 6.

2.11 Developed Length (DL)

2.11.1 Developed Length is the actual length required for the formed part and is equal to the sum of the true lengths minus the Bend Deduction. See Figure 6.

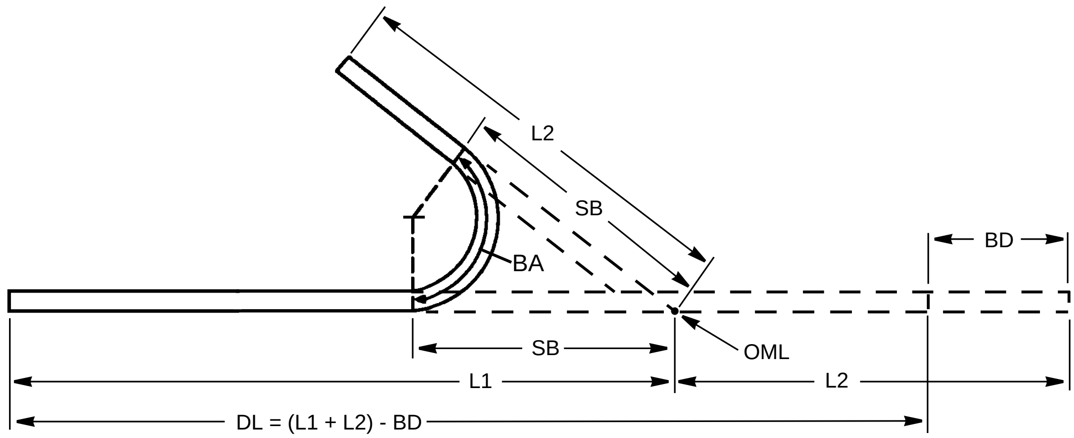


FIGURE 6 - DEVELOPED LENGTH - SINGLE BEND

3.0 BENDING FORMULAE

3.1 The basic formulae used to develop bending data are as follows:

3.2 Bend Allowance (BA)

$BA = (0.01745 \times R + 0.0078 \times T) \times \theta$

R = Bend Radius

T = Material Thickness

θ = Bend Angle in degrees

3.3 Set Back (SB)

3.3.1 $SB = (T + R) \times \tan(\theta/2)$

3.4 Bend Deduction (BD)

3.4.1 $BD = 2\ SB - BA$

3.4.2 Tables 6 and 7 list Bend Deductions applicable to forming 45^o and 90^o flange angles on various material thicknesses and bend radii. Bend deductions for flange angles other than 45^o or 90^o may be selected from the DHI Sheet Metal Bending Handbook - 1992, or calculated using the formulae presented herein.

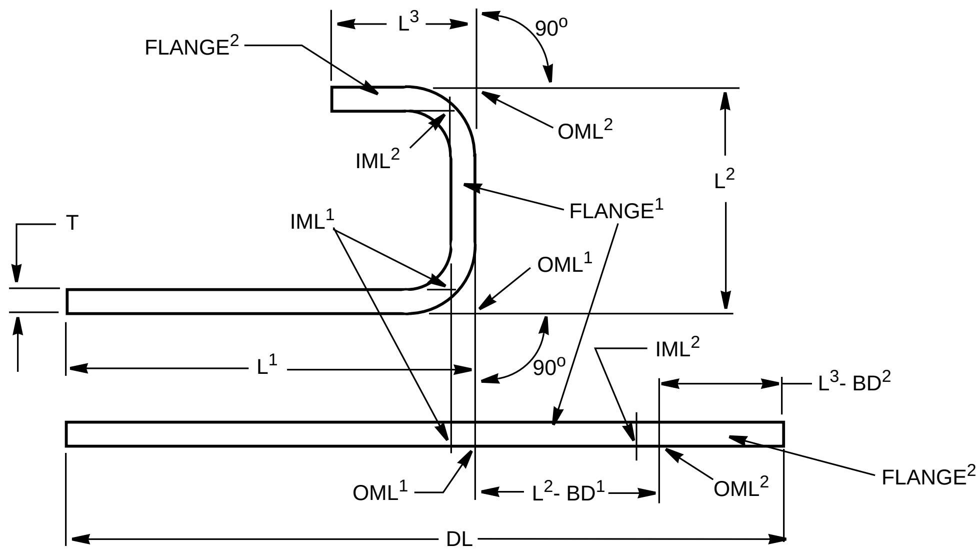
3.5 Developed Length (DL)

3.5.1 Single Bend - DL = (L1 + L2) - BD. REF FIGURE 6

3.5.2 Double Bend - DL = (L1 + L2 + L3) - (BD1 + BD2) REF FIGURE 7

3.5.3 Triple Bend - DL = (L1 + L2 + L3 + L4) - (BD1 + BD2 + BD3)

3.5.4 "n" Bend - DL = [L1 + L2 +... + L (n +1)] - (BD1 +BD2 +... + BDn)



3.6 OML - IML Distance

3.6.1 Dist = T x tan $(\theta/2)$

3.6.2 Ref Table 10 for listing of OML - IML distance for standard material gauges (.016 to .080) for Bend Angles between 40 and 126 degrees.

FIGURE 7 - DEVELOPED LENGTH - MULTIPLE BENDS

4.0 STANDARD BEND RADII

4.1 Reasons for Standard Bend Radii

4.1.1 The use of standard bend radii in design is important for the following purposes:

1) To reduce the susceptibility to stress corrosion cracking in bare aluminum alloys. Clad aluminum alloys are immune to stress corrosion cracking.

2) To facilitate repeatable, economical, manufacturing producibility.

4.2 Bend Radii Tables

4.2.1 The standard bend radii varies with the alloy, its temper, and the thickness of the material. Refer to Tables 1 to 5 for standard bend radii to be called up on the drawing.

4.2.2 **NOTES** on bending of Aluminum Alloys. These notes are to be read in conjunction with TABLE 1, TABLE 2 and TABLE 3.

1) The bending of bare aluminum alloys is restricted to those alloys and their respective tempers listed in TABLE 1 and TABLE 2. Consult Materials Technology where design limitations require another alloy, temper or thickness of bare material to be bent.

2) For bare aluminum alloy plate machined on one or both faces and requiring subsequent bending, elevated temperature bending shall be specified. Materials Technology shall be consulted for applicable details.

3) Cold bending of any aluminum alloy plate (i.e. material thickness greater than 0.190) is prohibited unless approved by Materials Technology.

4) The bend radii shown in Tables 2 and 3 shall be used wherever possible. Where a smaller bend radius is required for a specific design application, Material Technology approval shall be obtained.

5) Minimum bend radii are for use only across the direction of the grain. Note - control of grain direction on sheet metal parts which are fabricated on N/C drill/routers, is virtually impossible due to the variable orientation introduced by the automatic nesting programs.

TABLE 1 - **STANDARD BEND RADII - ALUMINUM ALLOYS - ELEVATED TEMPERATURE FORMING** - NOTE 1

MATERIAL THICKNESS	BARE ALLOYS		CLAD ALLOYS
	2014-T351/T4/T6/ 2024-T351/T4 7075-T73	7075-T651 7075-T6	7075-T6
.090	---	.56	.56
.100	---	.62	.62
.125	---	.88	.88
.160	---	1.12	1.12
.190	---	1.25	---
.250	1.75	2.50	---
.375	3.00	4.12	---
.500	4.50	6.00	---

NOTES
1. REFER TO NOTES IN SECTION 4.2 FOR ADDITIONAL INFORMATION AND RESTRICTIONS.

TABLE 2 - STANDARD BEND RADII - BARE ALUMINUM ALLOYS - ROOM TEMPERATURE FORMING

MATERIAL THICKNESS	BARE ALUMINUM ALLOY				
	5052-H32	5052-H34	6061-0	6061-T4 6061-T42	6061-T6 6061-T62
.016	.03	.03	.03	.03	.03
.020	.03	.06	.03	.03	.06
.025	.06	.06	.06	.06	.09
.032	.06	.09	.06	.09	.09
.040	.06	.09	.06	.09	.12
.050	.09	.12	.09	.12	.12
.063	.09	.16	.09	.16	.16
.071	.09	.16	.09	.16	.19
.080	.12	.19	.12	.19	.25
.090	.12	.25	.12	.19	.25
.100	.16	.25	.16	.25	.25
.125	.16	.31	.16	.25	.31
.160	.25	.38	.25	.31	.44
.190	.31	.44	.31	.44	.62
REFER TO NOTES IN SECTION 4.2 FOR ADDITIONAL INFORMATION AND RESTRICTIONS					

SEE ENGINEERING STANDARDS APPROVAL RECORD FOR ORIGINAL SIGNATURES AND CHANGE SUMMARY

TABLE 3 - STANDARD BEND RADII - CLAD ALUMINUM ALLOYS - ROOM TEMPERATURE FORMING (NOTE 1)

MATERIAL THICKNESS	CLAD ALLOYS			
	2024-O	2024-W 7075-O 7075-W	2014-T3 2024-T3 2024-T42	7075-T6 7075-T62 7075-T73
.016	.03	.03	.06	.09
.020	.03	.03	.06	.09
.025	.06	.06	.09	.12
.032	.06	.06	.09	.16
.040	.06	.09	.12	.19
.050	.09	.09	.16	.25
.063	.09	.12	.19	.31
.071	.09	.12	.25	.38
.080	.12	.16	.25	.38
.090	.12	.19	.31	NOTE 2
.100	.16	.19	.31	
.125	.16	.25	.38	
.160	.25	.31	.44	
.190	.31	.38	.50	

NOTES: 1. REFER TO NOTES IN SECTION 4.2 FOR ADDITIONAL INFORMATION AND RESTRICTIONS.
2. HOT FORM - REFER TO TABLE 1.

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APPROVED: 27 OCT 1998:

TABLE 4 - STANDARD BEND RADII - CARBON STEEL - LOW ALLOY STEEL & CORROSION RESISTANT STEEL

MATERIAL THICKNESS	1020, 1025 4130 ANNEALED	1095 ANNEALED	4130 COND 'N'	CORROSION RESISTANT STEEL 301, 321, 347		
				ANNEALED	1/4 HARD	1/2 HARD
.016	---	.03	---	---	---	---
.020	.03	.03	.06	.03	.06	.06
.025	.06	.06	.09	.06	.06	.09
.032	.06	.09	.09	.06	.06	.09
.040	.06	.09	.12	.06	.09	.12
.050	.09	.12	.16	.09	.12	.16
.063	.09	.12	.19	.09	.12	.16
.080	.12	.16	.25	.09	.16	.19
.090	.12	.19	.31	.12	.19	.25
.100	.16	.25	.38	.16	.25	.25
.125	.19	.25	.44	.16	.25	.31
.160	.25	.31	.50	.19	.31	.44

TABLE 5 - STANDARD BEND RADII - TITANIUM

MATERIAL SPECIFICATION	MATERIAL THICKNESS	BEND RADIUS	
		COLD FORMING	HOT FORMING
MIL-T-9046 CP-1	UP TO .125	4.0 T	3.0 T
MIL-T-9046 CP-2	UP TO .125	3.5 T	2.5 T
MIL-T-9046 CP-3	UP TO .125	3.0 T	2.0 T
MIL-T-9046 A-1	UP TO .125	4.5 T	3.5 T

TABLE 6 - BEND DEDUCTION - 45° FLANGE ANGLE

BEND RADIUS	MATERIAL THICKNESS									
	0.016	**0.020**	**0.025**	**0.032**	**0.040**	**0.050**	**0.063**	**0.080**	**0.100**	**0.125**
0.032	0.009	0.011								
0.063	0.010	0.012	0.015	0.018	0.022					
0.094	0.012	0.014	0.016	0.019	0.023	0.028	0.034			
0.125			0.017	0.021	0.024	0.029	0.035	0.044		
0.156				0.022	0.026	0.031	0.037	0.045	0.054	
0.187					0.027	0.032	0.038	0.046	0.056	0.068
0.250						0.035	0.041	0.049	0.059	0.070
0.312							0.044	0.052	0.061	0.073
0.375								0.054	0.064	0.076
0.437										

TABLE 7 - BEND DEDUCTION - 90° FLANGE ANGLE

BEND RADIUS	MATERIAL THICKNESS									
	0.016	**0.020**	**0.025**	**0.032**	**0.040**	**0.050**	**0.063**	**0.080**	**0.100**	**0.125**
0.032	0.035	0.040								
0.063	0.048	0.053	0.060	0.069	0.079					
0.094	0.061	0.066	0.073	0.082	0.092	0.105	0.122			
0.125			0.086	0.095	0.106	0.119	0.135	0.158		
0.156				0.109	0.119	0.132	0.149	0.171	0.197	
0.187					0.132	0.145	0.162	0.184	0.210	0.243
0.250						0.172	0.189	0.211	0.237	0.270
0.312							0.216	0.238	0.264	0.296
0.375								0.265	0.291	0.323
0.437										

5.0 Contour Bending Constant Section Angles

Contour bending is applicable to constant section angles made of bent sheet metal or extruded angle. It is done by one of the following operations:

a) Shrink Bending

b) Stretch Bending

5.1 Shrink Bending

5.2 Minimum radii of curvature given in TABLE 8 may be used in the design of shrink bent angles. Figure 8-A shows contour bending on bent sheet metal and Figure 8-B shows bending of extruded angle.

TABLE 8 - MINIMUM RADII FOR SHRINK BENT ANGLES

MATERIAL THICKNESS	LEG LENGTH					
	1/2	5/8	3/4	7/8	1	1-1/4
	R = MINIMUM RADII OF CURVATURE					
.040	1.12	2.00	3.00	3.25	3.25	3.25
.050	1.25	1.50	2.00	3.00	3.25	3.25
.063	1.25	1.50	1.75	2.50	3.25	3.25
.071	1.25	1.50	1.75	2.00	3.00	3.25
.080	1.25	1.50	1.75	2.00	2.50	3.25
.090	1.25	1.50	1.63	2.00	2.38	3.25
.100	1.25	1.50	1.63	2.00	2.25	3.25
.125	1.25	1.50	1.50	2.00	2.12	3.00
.160	1.25	1.38	1.50	2.00	2.00	2.88
.190	1.25	1.25	1.50	2.00	2.00	2.75

NOTE: THESE VALUES APPLY ONLY TO ALUMINUM ALLOYS IN TEMPER "O" AND CONDITION "W", COMMERCIALLY PURE TITANIUM AND ANNEALED CORROSION RESISTANT STEEL.

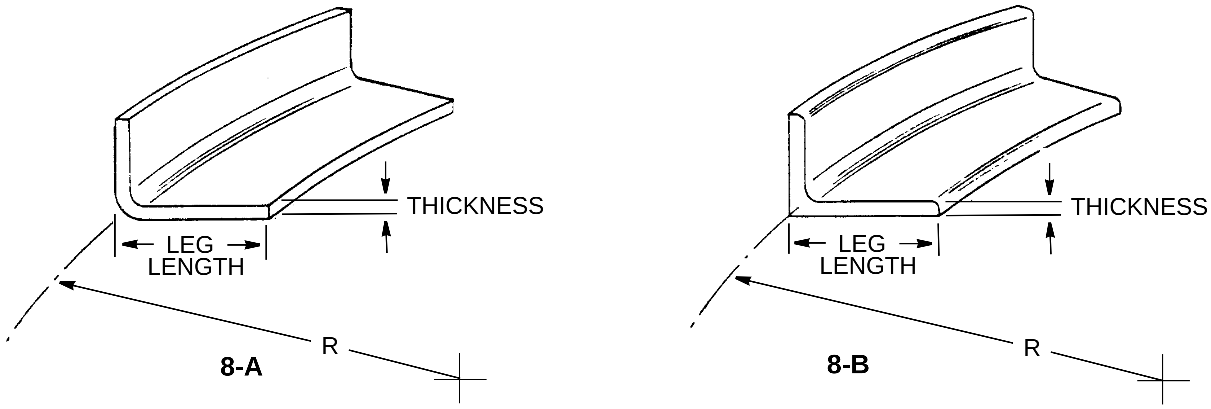

FIGURE 8 - SHRINK BENDING

5.3 Stretch Bending

5.3.1 Minimum radii of curvature given in TABLE 9 may be used in the design of stretch bent angles. Figure 9-A shows contour bending on sheet metal angle and Figure 9-B shows bending on extruded angle.

5.3.2 NOTE: When minimum radii are used, the stretched leg will shrink approximately 15% in cross sectional area.

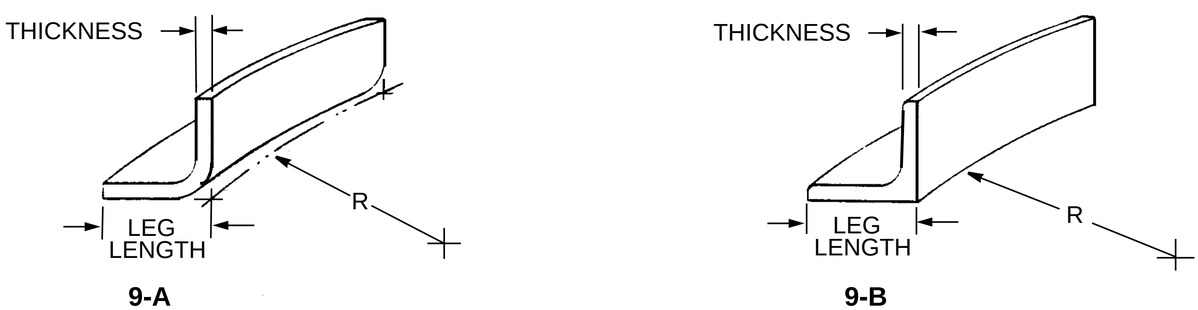

FIGURE 9 - STRETCH BENDING

TABLE 9 - MINIMUM RADII FOR STRETCH BENT ANGLE

MATERIAL THICKNESS	LEG LENGTH					
	1/2	5/8	3/4	7/8	1	1-1/4
APPLICABILITY - ALUMINUM ALLOYS IN TEMPER "O" AND CONDITION "W"						
.040	1.12	1.75				
.050	1.00	1.50	2.12			
.063	1.00	1.25	1.75	2.50	3.12	5.12
.071	0.88	1.25	1.63	2.25	2.75	4.25
.080	0.88	1.25	1.50	2.12	2.63	3.88
.090	0.88	1.12	1.38	1.88	2.63	3.50
.100		1.12	1.38	1.75	2.25	3.12
.125		1.12	1.25	1.50	2.00	2.75
.160						2.50
.190						2.12
APPLICABILITY -2014-T3, 2024-T3, 2024-T4, 6061-T4, ANNEALED CORROSION RESISTANT STEEL AND COMMERCIALLY PURE TITANIUM.						
.040	2.00	2.50				
.050	1.88	2.38	3.00			
.063	1.75	2.25	2.88	3.50	4.12	5.75
.071	1.63	2.12	2.75	3.38	4.00	5.63
.080		2.12	2.75	3.38	4.00	5.50
.090		2.12	2.62	3.25	4.00	5.38
.100		2.00	2.50	3.12	3.88	5.25
.125			2.38	3.00	3.75	5.12
.160						4.88
.190						4.75

SEE ENGINEERING STANDARDS APPROVAL RECORD FOR ORIGINAL SIGNATURES AND CHANGE SUMMARY

DRAWN	B. McDONALD	**BENDING, METAL SHEET, PLATE, SHAPES & EXTRUDED SECTIONS**	**DS 130**
CHECKED	W. SIMMONS		
STRESSED	S. CHENG		SHEET: **14**
APPROVED	S. HAMID		

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TABLE 10 - OML - IML DISTANCE VARIATION

BEND ANGLE	MATERIAL THICKNESS							
	.016	**.020**	**.025**	**.032**	**.040**	**.050**	**.063**	**.080**
40	.006	.007	.009	.012	.015	.019	.023	.029
42	.006	.008	.010	.012	.015	.020	.025	.031
44	.006	.008	.010	.013	.016	.021	.026	.032
46	.007	.008	.011	.014	.017	.022	.027	.034
48	.007	.009	.011	.014	.018	.023	.028	.036
50	.007	.009	.012	.015	.019	.024	.030	.037
52	.008	.010	.012	.016	.020	.025	.031	.039
54	.008	.010	.013	.016	.020	.026	.033	.041
56	.009	.011	.013	.017	.021	.027	.034	.043
58	.009	.011	.014	.018	.022	.028	.035	.044
60	.009	.012	.014	.018	.023	.029	.037	.046
62	.010	.012	015	.019	.024	.031	.038	.048
64	.010	.012	.016	.020	.025	.032	.040	.050
66	.010	.013	.016	.021	.026	.033	.042	.052
68	.011	.013	.017	.022	.027	.034	.043	.054
70	.011	.014	.018	.022	.028	.036	.045	.056
72	.012	.015	.018	.023	.029	.037	.046	.058
74	.012	.015	.019	.024	.030	.038	.048	.060
76	.013	.016	.020	.025	.031	.040	.050	.063
78	.013	.016	.020	.026	.032	.041	.052	.065
80	.013	.017	.021	.027	.034	.043	.054	.067
82	.014	.017	.022	.028	.035	.044	.056	.070
84	.014	.018	.023	.029	.036	.046	.058	.072
86	.015	.019	.023	.030	.037	.048	.060	.075
88	.015	.019	.024	.031	.039	.049	.062	.077
90	**.016**	**.020**	**.025**	**.032**	**.040**	**.050**	**.063**	**.080**
92	.017	.021	.026	.033	.041	.053	.066	.083
94	.017	.021	.027	.034	.043	.055	.069	.085
96	.018	.022	.028	.036	.044	.057	.071	.089
98	.018	.023	.029	.037	.046	.059	.074	.092
100	.019	.024	.030	.038	.048	.061	.076	.095
102	.020	.025	.031	.040	.049	.063	.079	.099
104	.020	.026	.032	.041	.051	.065	.082	.102
106	.021	.027	.033	.042	.053	.068	.085	.106
108	.022	.028	.034	.044	.055	.070	.088	.110
110	.023	.029	.036	.046	.057	.073	.091	.114
112	.024	.030	.037	.047	.059	.076	.095	.119
114	.025	.031	.038	.049	.062	.079	.099	.123
116	.026	.032	.040	.051	.064	.082	.102	.128
118	.027	.033	.042	.053	.067	.085	.107	.133
120	.028	.035	.043	.055	.069	.088	.111	.139
122	.029	.036	.045	.058	.072	.092	.115	.144
124	.030	.038	.047	.060	.075	.096	.120	.150
126	.031	.039	.049	.063	.079	.100	.126	.157

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DRAWN	B. McDONALD	**BENDING, METAL SHEET, PLATE, SHAPES & EXTRUDED SECTIONS**	**DS 130**
CHECKED	W. SIMMONS		
STRESSED	S. CHENG		SHEET: **15**
APPROVED	S. HAMID		

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