LAYOUT DRAFTING & PATTERN MAKING

FOR HEAT & FROST INSULATORS

Hans Siebert

APPRENTICE WORK BOOK & JOURNEYMAN REVIEW MANUAL

©Hans Siebert-2000
Preface

This book has been prepared as a text for use in Heat and Frost Insulator apprenticeship classes. It explains basic methods of drawing patterns for developing sheet metal and other types of protective covers commonly produced for wrap over insulation. The book does not attempt to teach field work-practices or any application methods used in the trade. Learning how to crimp, bead, seam, rivet and apply materials is best accomplished on the job, not from studying a book. However, for the limited purpose of pattern development, this book meets every requirement of an apprenticeship textbook and is, in addition, also well adapted for reference use by journeymen, foremen, and pre-fabrication workers engaged in the designing and/or laying out patterns.

The instructions are easy to follow with numerous practical problems that can be completed straightforwardly and worked without elaborate collections of tools or equipment. The subject-matter deals with common trade problems and the specific methods of presenting the assignments are the result of many years of teaching in apprenticeship classes as well as practical experience gained in the asbestos worker trade.

The format of the book assumes sequential completion of tasks, especially regarding the preparatory work of practicing drawing principles. For the novice, later work in the book assumes knowledge gained in prior effort. For students with prior knowledge many of the projects can be completed without a drawn-out effort on the study of groundwork.

The descriptions are clear and well organized and step-by-step. They stimulate the student to think and reason on his or her own volition as well as simplify the instructor’s participation. The work is so planned that the student can work through assignments without arduous direction and tedious supervision. Numerous illustrative problems are distributed throughout the text. The selected assignments and examples are representative of the kind of problems a worker faces on the job and they serve to enable the mechanic to apply knowledge to new-fangled and uncommon situations.

Finally, no new material is to be found in this book. Although, I have drawn all illustrations myself, the described projects have been scraped together from various sources in the building trades, including from manuscripts and books used in the asbestos workers, sheet metal workers and ironworkers trades. Additionally, ideas for the projects have been collected from apprenticeship programs throughout the industry. Any and all such contributions are thankfully acknowledged.

Hans Siebert  
October 2000
# Table of Contents

## Drawing Principles

- Equipment, Tools, Preparations 5

## Practice Problems in Drawing

- Bisect Straight Line 8
- Erect Perpendiculars 9
- Erect Perpendiculars (Method 2) 10
- Erect Perpendiculars (Method 3) 11
- Draw Parallel Line 12
- Circle Properties 13
- Draw Tangent 14
- Bisect Angle 15
- Draw Equilateral Triangle 16
- Copy an Angle 17
- Copy a Triangle 18
- Copy an Irregular Figure 19
- Construct a Square with Side Given 20
- Construct a Pentagon (Method 1) 21
- Construct a Pentagon (Method 2) 22
- Construct a Hexagon 23
- Construct an Octagon (Method 1) 24
- Construct an Octagon (Method 2) 25
- Construct an Octagon (Method 3) 26
- Draw a Circle Through Points 27
- Find Center of Circle 28
- Describe Segment of Circle 29
- Inscribe Triangle into Circle 30
- Inscribe Circle into Triangle 31
- Draw an Ellipse 32
- Draw an Approximate Ellipse 33
- Draw an Approximate Ellipse (Method 2) 34
- Draw an Ellipse by Intersecting Lines 35
- Draw an Egg-shaped Oval 36
- Draw an Ellipse with Pencil and Thread 37
- Draw a Parabola 38
- Draw a Hyperbola 39
- Draw a Spiral 40
- Draw a Helix 41
- Divide a Straight Line into Equal Parts (Method 1) 42
- Divide a Straight Line into Equal Parts (Method 2) 43

Continued
# Practice Problems in Pattern Development

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction to Developments</td>
<td>44</td>
</tr>
<tr>
<td>Closed Box</td>
<td>45</td>
</tr>
<tr>
<td>Open Box</td>
<td>46</td>
</tr>
<tr>
<td>Square Prism</td>
<td>47</td>
</tr>
<tr>
<td>Tetrahedron</td>
<td>48</td>
</tr>
<tr>
<td>Octahedron</td>
<td>49</td>
</tr>
<tr>
<td>Dodecahedron</td>
<td>50</td>
</tr>
<tr>
<td>Icosahedron</td>
<td>51</td>
</tr>
<tr>
<td>Dovetail Seam</td>
<td>52</td>
</tr>
<tr>
<td>Metal Over Tees (Field Method)</td>
<td>53</td>
</tr>
<tr>
<td>Non-reducing Tee Layout</td>
<td>55</td>
</tr>
<tr>
<td>90-Degree Bend</td>
<td>57</td>
</tr>
<tr>
<td>Gores for Bends (Field Method)</td>
<td>59</td>
</tr>
<tr>
<td>Gores for Bends (Development Method)</td>
<td>64</td>
</tr>
<tr>
<td>Gores for Bends (Analytical Method)</td>
<td>65</td>
</tr>
<tr>
<td>Non-reducing Lateral at any Angle</td>
<td>73</td>
</tr>
<tr>
<td>Reducing Tee at 90 Degrees</td>
<td>75</td>
</tr>
<tr>
<td>Reducing Lateral at any Angle</td>
<td>77</td>
</tr>
<tr>
<td>Cone</td>
<td>79</td>
</tr>
<tr>
<td>Truncated Cone (Transition)</td>
<td>81</td>
</tr>
<tr>
<td>Spheres</td>
<td>83</td>
</tr>
<tr>
<td>Lunes for Spheres (Head Gores)</td>
<td>84</td>
</tr>
<tr>
<td>Lunes for Spherical Tank Head</td>
<td>86</td>
</tr>
<tr>
<td>Cylindrical Tank with Rounded Head (Analytical Method)</td>
<td>88</td>
</tr>
<tr>
<td>Rounded Head Lunes (Shortcut Method)</td>
<td>91</td>
</tr>
<tr>
<td>Round Taper (Off Center)</td>
<td>92</td>
</tr>
<tr>
<td>Round Taper (One Side Straight)</td>
<td>93</td>
</tr>
<tr>
<td>35-Degree Conical End Cap</td>
<td>94</td>
</tr>
<tr>
<td>Square to Square</td>
<td>95</td>
</tr>
<tr>
<td>Square to Round</td>
<td>97</td>
</tr>
<tr>
<td>Butterfly Layout</td>
<td>99</td>
</tr>
</tbody>
</table>

## Table of Decimal to Fraction Conversions

<table>
<thead>
<tr>
<th>Decimal</th>
<th>Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>1/10</td>
</tr>
<tr>
<td>0.2</td>
<td>1/5</td>
</tr>
<tr>
<td>0.3</td>
<td>3/10</td>
</tr>
<tr>
<td>0.4</td>
<td>2/5</td>
</tr>
<tr>
<td>0.5</td>
<td>1/2</td>
</tr>
<tr>
<td>0.6</td>
<td>3/5</td>
</tr>
<tr>
<td>0.7</td>
<td>7/10</td>
</tr>
<tr>
<td>0.8</td>
<td>4/5</td>
</tr>
<tr>
<td>0.9</td>
<td>9/10</td>
</tr>
</tbody>
</table>

## Table of Natural Trigonometric Functions

<table>
<thead>
<tr>
<th>Angle</th>
<th>Sine</th>
<th>Cosine</th>
<th>Tangent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>0.0000</td>
<td>1.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>30°</td>
<td>0.5000</td>
<td>0.8660</td>
<td>0.5774</td>
</tr>
<tr>
<td>45°</td>
<td>0.7071</td>
<td>0.7071</td>
<td>1.0000</td>
</tr>
<tr>
<td>60°</td>
<td>0.8660</td>
<td>0.5000</td>
<td>1.7321</td>
</tr>
<tr>
<td>90°</td>
<td>1.0000</td>
<td>0.0000</td>
<td>Infinity</td>
</tr>
</tbody>
</table>

## Practice Problems for Advanced Studies

<table>
<thead>
<tr>
<th>Problem Number</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>103</td>
</tr>
<tr>
<td>2</td>
<td>104</td>
</tr>
<tr>
<td>3</td>
<td>105</td>
</tr>
<tr>
<td>4</td>
<td>106</td>
</tr>
<tr>
<td>5</td>
<td>107</td>
</tr>
<tr>
<td>6</td>
<td>108</td>
</tr>
<tr>
<td>7</td>
<td>109</td>
</tr>
<tr>
<td>8</td>
<td>110</td>
</tr>
<tr>
<td>9</td>
<td>111</td>
</tr>
<tr>
<td>10</td>
<td>112</td>
</tr>
<tr>
<td>11</td>
<td>113</td>
</tr>
<tr>
<td>12</td>
<td>114</td>
</tr>
<tr>
<td>13</td>
<td>115</td>
</tr>
<tr>
<td>14</td>
<td>116</td>
</tr>
<tr>
<td>15</td>
<td>117</td>
</tr>
<tr>
<td>16</td>
<td>118</td>
</tr>
<tr>
<td>17</td>
<td>119</td>
</tr>
<tr>
<td>18</td>
<td>120</td>
</tr>
<tr>
<td>19</td>
<td>121</td>
</tr>
</tbody>
</table>
Geometric Construction

DRAWING PRINCIPLES

DRAWING EQUIPMENT

Equipment. The following list comprises the equipment required for a course in sheet-metal pattern drafting: Drawing board, 24" x 30", T-square, 30"; 45° triangle, 10"; 30° x 60° triangle, 10"; architect's scale, 12"; 4H drawing pencil; pencil erasing rubber; thumb tacks; detail paper; also a set of drawing instruments consisting of the following items: 5" dividers, 5 1/2" compasses, 3" bow spacers, 3" bow pencil, ruling pen, bow pen and irregular curves.

Paper. The paper generally used for sheet-metal pattern drafting is known as brown detail paper. However, for finished drawings, white craft paper is more suitable. It can be bought of almost any width, in large or small rolls, and is sold by the yard or pound. The paper should be of medium thickness, very strong and tough, because a shop drawing is likely to be subjected to considerable rough usage.

Pencils. For working drawings, full size details, etc., on craft paper, a 4H pencil is quite satisfactory. For developing miter patterns in which the greatest accuracy is required, a 5H pencil is generally used. The accuracy of drawings depends, in a great measure, upon the manner in which the pencils are sharpened. To sharpen the pencil, remove the wood from both ends by means of a sharp knife, exposing about 3/8" of lead. One end should then be sharpened to a round point, and the other to a chisel point or a wedge-shaped end. This operation should be done with a fine file or pencil sharpener. For example, a strip of No. 0 sandpaper, 4" long and 3/4" wide, glued to a thin strip of wood, is quite serviceable. The chisel end of the pencil is used for drawing straight lines, and the conical point for free-hand sketching and marking dimensions. A soft pencil should never be used for drawing, because it becomes dull after drawing just a few lines. Soft pencils make it difficult to draw fine, sharp lines and to keep the paper clean.

Preparation of the Paper.
The paper is fastened to the board with thumb-tacks. Care must be taken to have it lie perfectly flat on the board, so that it will create no wrinkles. To do this, proceed as follows: Place the long edge of the paper parallel with the long edge of the board, the paper being within about three inches of the lower and left-hand edge of the board. Insert a thumb-tack in the upper right-hand
corner and press it in until it is flush with the surface of the paper. Next, place the left hand on the paper near the upper right-hand corner; then slide the hand toward the lower left-hand corner, removing all wrinkles, and insert a thumb tack as before. Lay the left hand on the middle of the sheet and slide it toward the upper left-hand corner; holding it there, press in the third tack. Slide the hand from the center of the paper toward the lower right-hand corner, and insert the fourth tack. This completes the operation.

**PRACTICAL GEOMETRY**

In presenting this subject to the student, no attempt has been made to give a complete course in geometry. Rather, the selected problems are chosen to be of the greatest assistance to the pattern draftsman. They are composed of examples that are used in every-day practice and are arranged in a logical order.

Practical geometry is the science of geometry adapted to practical purposes. Theoretical demonstrations have been omitted. Every student, whose aim it is to become a proficient pattern draftsman, should have a fair knowledge of the subject. The problems on these pages should be carefully studied and worked with great accuracy, as the technical skill acquired in the use of the drawing instruments will be of great value in later work.

**Geometrical Problems**

When the problems herein given have been carefully studied, draw each problem, completing each step in the construction before proceeding to the next. All lines should be as sharp and fine to be consistent with clearness.

It is best to work the assignments in a sequential order because some of the later projects assume knowledge of skills, that have been mastered in preceding attempts.

In the geometrical figures, except for occasional deviations, the given and required lines are shown in full heavy lines, and the construction in full light lines. The drawings on the instruction sheets do not always exactly reflect the specified dimensions, however, the distances within a drawing are proportional to them. This is due to the fact that drawings, manipulated on the sheets by a word processor, have been adjusted to conform to space limitations. Nevertheless, the assignments, when drawn, should reflect the exact dimensions stated in the problems.

**Preparation of Plates.** The size of paper recommended for the problems of this course is 15" x 20". The size of each plate is to be 14" x 18", having a border-line all around 1/2" from the edge of the plate, leaving the space inside of the border line 13" x 17".
Divide the plate into two equal parts by means of a horizontal line. Using the scale, divide the length of plate into three equal parts, as shown by the vertical lines. This divides the drawing plate into six rectangular spaces. The problems should be drawn as near the center of each space as possible. See the following example in Fig. 0:

Fig. 0

EXAMPLE OF COMPLETED SET OF DRAWINGS
Fig. 1. To bisect a straight line MN, or the arc of a circle MON. Let MN 3-1/4 inches long be the given line, which it is required to bisect. With centers M and N, and any radius greater than one-half of MN, describe the arcs 1 and 2. Through the points of intersection of these arcs draw a line, and the points of intersection with the given line MN, and the arc MON, shown by OA will give the required points.
Fig. 2. To erect a perpendicular from a given line. Draw the line AB about 3-1/4 inches long. With the point of the compass on A and any radius greater than AB, describe an arc at 1. On B, with the same radius, describe the arc 2. Through the intersection of arcs 1 and 2, draw the line EF. CE and/or CF will be the required perpendicular.
Fig. 3. To erect a perpendicular near the end of a given line. Draw AB 3-3/4 inches long. About 1/2 inch from B locate the point C, from which the perpendicular is to be erected. With C as center and with any convenient radius, describe the arc 1-2. Using the same radius, step off this distance from 1 to 3 and 3 to 4. Using any radius with 3 and 4 as centers, describe arcs 5 and 6 intersecting each other at 7. Draw a line from C through 7, which will give the required perpendicular, at the given point C.
Fig. 4. To erect a perpendicular at the end, of a given line. Draw AC, the given line, 3-3/4 inches long. Set the point of compass on A, and with any radius describe the arc B2. On B with the radius AB, describe the arc 3 intersecting arc B2 at E. Through E draw line BF indefinitely; with radius BE, describe arc 4, intersecting line BF at m. Connect mA, which will be the perpendicular required.
Fig. 5. To draw a line parallel to a given line. Draw AB 3-1/2 inches long. Near the end of the line at 1, set the point of the compass, and with a 2-inch radius, describe arc 2. With the same radius on the point 3, describe the arc 4. Then a line drawn touching the arcs 2 and 4 will be parallel to AB.
Fig. 6. To draw a circle and its properties. Draw AB 3-3/4 inches long. Bisect AB at C. With point of compass at C, and radius CA, describe the circumference of the circle. The diameter of a circle is any straight line drawn through the center to opposite points of the circumference as AB. The radius of a circle is any line as CA and DC, drawn from the center to any point in the circumference; two or more such lines are radii, the plural of radius. An arc of a circle is any part of the circumference as EG. The sector of a circle is the part of a circle included between the radii and the arc, which they intercept, as ACD. A segment of a circle is a part cut off by a chord, as EFG. A chord of a circle is a straight line joining the extremities of an arc, but not passing through the center, as EF.
Fig. 7. To draw a tangent from any given point on a circle. With point of compass at A and radius AB, describe a circle 3-1/2 inches in diameter. Through point B and center A draw a straight line. A perpendicular (see prior task in Fig. 2) drawn through point B will give the required tangent, as CD.
Fig. 8. To bisect a given angle. Draw the given angle ABC. With any convenient radius and B as center, describe the arcs 1 and 2. With the same or a larger radius and 1 and 2 as centers, describe arcs intersecting at 3. Draw a line from 3 to B, which divides the angle ABC into two equal parts. (Note: This problem shows how to obtain the miter line between the two parts of an elbow or sheet-metal molding.)
Fig. 9. To draw an equilateral triangle, one side being given. Draw AB 2-3/4 inches long. With A as center and AB as radius, describe arc 1. With B as center and the same radius, describe arc 2 intersecting the former arc at C. Draw the lines BC and AC, and ABC is the required equilateral triangle.
Fig. 10. To construct an angle similar to a given angle. Let $\angle CAB$ be the given angle. With $A$ as center and with any radius, describe arc 1-2, touching both sides of the angle. Draw line $EF$ equal to $AB$. With $E$ as a center and radius $A2$ of the given angle, describe arc 3-4. With 4 as center and radius 1-2, describe arc 5 intersecting arc 3-4 at $G$. A line drawn from $E$ through point $G$ completes the angle $GEF$, which is equal to $BAC$. 
Fig. 11. To draw a triangle equal to any given triangle. Draw the given triangle ABC and line 1-2 equal to AB. With the radius AC and the center at 1, describe the arc 3. With the center at 2 and the radius BC, describe arc 4 intersecting arc 3 at 5. Draw lines 1-5 and 2-5, which will give the required triangle equal to the given triangle ABC.
Fig. 12. To construct an irregular angular figure similar to a given figure. Draw line AB 3-1/4 inches long and construct trapezium ABCD. To copy this figure in exactly the same size as it is given, draw line 1-2 equal in length to AB. With A as center and Ae as radius, describe arc ef. With the same radius and 1 as center, describe arc 3-4. With e as center, describe the arc g. With the same radius and 3 as center, describe arc 5 intersecting arc 4 at 6. Draw a line from 1 through 6, making 1-7 equal to AD. With B as center, describe arc mn. With the same radius and 2 as center, describe the arc 8-9. With m as center, describe arc h, cutting line BC at o. With the same radius and 8 as center, describe arc 10 intersecting arc 9 at 11. Draw line 2-12 through point 11, and make it equal in length to BC. Draw line 7-12 to complete the trapezium similar to the given trapezium ABCD.
Fig. 13. To construct a square from a given side. Draw line AB 3-1/2 inches, the length of the given side. With A as center and AB as radius, describe arc B-1 indefinitely. With the same radius and B. as center, describe the arc A-2, intersecting arc 1 at C. Bisect AC at D through intersecting arcs at E. With C as center and radius CD, describe arcs 3 and 4, intersecting arcs 1 and 2 at F and G. To complete the square, connect AF, FG and GB.
Fig. 14. To construct a regular pentagon in a given circle. With A as center and with the compasses set to 1-7/8 inches, describe the circle BCDE. Draw the two diameters BD and EC perpendicular to each other. Bisect the radius AB by the line passing through AB at 1. With 1 as center and 1-E as radius, describe the arc, locating point 2. With E as center and the distance E-2 as radius, describe an arc cutting the circumference of the circle at 3 and 4. Using the same radius with 3 and 4 as centers, describe the arcs 5 and 6. Connect points E-4-5-6-3, which completes the pentagon.
Fig. 15. To construct a pentagon from a given side. Let AB be the given side. With A as center and with the compasses set to 1-3/4 inches, describe the semi-circle CEB. Divide CEB into five equal parts, and from A draw lines through the divisions 1-2-E. With AB as radius and E as center, describe the arc 3. With the same radius and B as center, describe the arc 4. Draw the lines E-3, 3-4 and 4-B to complete the figure.
Fig. 16. To construct a hexagon from a given side. Describe a circle with the radius AB 1-7/8 inches, which will be the length of the given side. Draw the diameter BC. With the radius AB and the centers C-B, describe the arcs 1-2-3-4. Connect by straight lines C-1, 1-2, 2-B, B-3, 3-4 and 4-C, which completes the required hexagon.
Fig. 17. To inscribe an octagon within a given circle. With A as center, with the compasses set to 1-7/8 inches, describe the circle 1-2-3-4-5-6-7-8. Let this be the given circle in which to inscribe a regular octagon. Through the center, draw lines BC and DE perpendicular to each other, cutting the circumference of the circle at 1-5 and 7-3. Bisect the angles DAB and DAC, and let the bisector of each angle meet the circumference at 2 and 8. Draw the diameters 8-4 and 2-6. Straight lines drawn from 1-2, 2-3, 3-4, etc., will form the required octagon.
Fig. 18. To inscribe an octagon within a given square. Draw line AB 4 inches long, and construct the given square ABCD. Draw diagonal lines DB and AC. With B as center and BG as radius, describe the arc 1-2. With the same radius and A, D and C as centers, describe arcs 3-4, 5-6, 7-8. Straight lines drawn from 6-2, 2-8, 8-3, etc., will complete the required octagon.
Fig. 19. To construct an octagon, one side being given. Draw line AB 1-1/4 inches long, which is the length of the given side. Extend AB indefinitely, as shown by 1 and 2. From A and B erect indefinite perpendiculars as AC and BD. With A and B as centers, using any radius, draw the arcs 1-3 and 4-2. Bisect the angles 1-A-3 and 4-B-2 by 5-A and 6-B. On these two lines set off A-7 and B-12, equal to AB. From 7 and 12 erect the perpendiculars 7-8 and 12-11, equal to AB. With 8 and 11 as centers and AB as radius, describe arcs 9-10, intersecting perpendiculars AC and BD at 9 and 10. Connect 8-9, 9-10 and 10-11, which completes the required octagon.
Fig. 20. To draw a circle through any three given points not in a straight line. Let CAB be the given points not in a straight line. Draw the lines CA and AB. Bisect the line CA by EF, as shown. Also bisect AB by the line GF, and the intersection of the bisecting lines at F will be the center of the required circle. Then with F as center and FB as radius, describe the circumference through points ABC.
Fig. 21. To find the center of a circle when the circumference is given. Let ABC be the given circle. From any point on the circle as B, with any radius, describe the arc 1-2. Then from the points A and C, with the same radius, describe the intersecting arcs 3-4 and 5-6. Through the points of intersection draw the lines 7-8 and 9-10, which will meet in X. Then X will be the center of the circle.
Fig. 22. To describe the segment of a circle of any given chord and height. Draw the line AB 3-3/4 inches long, which will be the given chord. Draw the perpendicular mn indefinitely, and make Pm the given height 1-1/8 inches long. Connect mB and bisect mB by the line CG, intersecting the perpendicular mn at C. Then C will be the center from which to describe the segment AmB.
Fig. 23. To inscribe an equilateral triangle in a circle. Draw the line $AB$ 3-3/4 inches long, which will be the diameter of the given circle. With $B$ as center and $BC$, the radius of the circle as radius, describe the arc $FCG$. To complete the inscribed triangle, connect by straight lines $FA$, $AG$ and $GF$. 
Fig. 24. To inscribe a circle in a given triangle. Draw the line AB 3-3/4 inches long. Make AC 3 inches, and CB 4 inches in length. Bisect the angles CAB and ACB. The intersection of the bisectors at m will be the center of the circle, which can be described, touching all three sides of the triangle. The sides AB, BC and CA will be tangent to this circle.
Fig. 25. To draw an ellipse when the diameters are given, without using centers. Draw the line 1-A 3-1/2 inches long, which will be the required length. Bisect 1-A at C. Through C draw DE 2-1/4 inches long, the required width. With C as center and C-1 and CE as radii, describe the outer and inner circles, respectively, as shown. Divide one-quarter of the outer circle into any convenient number of parts, in this case, into five, as shown by 1-2-3-4-5-6. Divide the one-quarter inner circle into the same number, as shown from 1’ to 6’. From the points on the smaller circle, draw horizontal lines, and through the points on the larger circles, draw vertical lines. The points a, b, c, d, where the horizontal and vertical lines intersect, are points on the ellipse. Using an irregular curve, trace a line through the points thus obtained, completing one-quarter of the ellipse.
Fig. 26. To draw an approximate ellipse when length and width are given, using circular arcs. Draw the line AB 3-1/4 inches long. Bisect AB at m, and draw the width CD 2-1/8 inches long. On the length AB, set off the width CD from B to 3, and divide the balance 3A into three equal parts, as shown by 1, 2, 3. With m as center and a radius equal to the length of two of these parts, describe arcs cutting AB in E and F. With EF as radius and E and F as centers, intersect arcs at 4 and 5. Draw lines from 4 through E and F as 4-6 and 4-7, and lines from 5 through EF as 5-8 and 5-9. With 4 and 5 as centers and 5-C and 4-D as radii, describe the arcs GDH and OCP. With E and F as centers and radii equal to EA and FB, describe the arcs GAO and PBH, completing the ellipse.
Fig. 27. To draw an approximate ellipse, the major and minor axes being given. For many purposes in sheet metal drawing, it is sufficiently accurate to describe the ellipse by means of circular arcs, and where centers must be used in developing patterns for flaring articles. Draw the major diameter, AB, 3-7/8 inches long, and the minor diameter, CD, 3 inches in length. On the line CD lay off mF and mG, equal to the difference between the major and minor diameters. On the line AB lay off mE and mH equal to three-quarters of mG. Connect points FHGE, and extend the lines. With center E and radius EA, describe arc RAO. With center F and radius FD, describe arc ODP. In a similar manner, describe arcs PBS and SCR from centers G and H. (Note: This is not a practical method when the major diameter is more than twice the minor).
Fig. 28. To draw an ellipse by intersection of lines. Draw the major axis AB 3-1/2 inches long, and the minor axis mA' 2-1/4 inches. Through m parallel to line AB draw line CD. From points A and B erect perpendiculars to line CD. Divide lines AC and DB into a convenient number of equal parts; in this case, four, and draw lines from points 1, 2, 3, etc., to m. Divide An and nB into the same number of equal parts, and draw lines from A' through these points intersecting the similarly numbered lines drawn from the points on the line CA and DB. Through these points of intersection, trace the semi-ellipse AmB.
Fig. 29. To draw an egg-shaped oval with arcs of circles. With a radius of 1 3/8 inches and C as center, describe the circle AmBn. Through the center C, perpendicular to AB, draw the line mn. Through n draw Bn and An indefinitely. On A and B as centers, with AB as radius, describe the arcs BH and AG. With n as center, describe the arc GH to complete the figure.
Fig. 30. To draw an ellipse by means of a pencil and thread. Draw AB, the major axis, 3-3/4 inches long. Bisect AB at m. Through m draw the perpendicular CD 2-1/2 inches long. Take Am one-half the length of the major axis for radius, and with C as center, describe the-arc GH. Drive pins at C, G and H; then, tightly, tie a thread around the three pins CGH. Remove the pin at C, and, placing a pencil at this point, keeping the thread tightly stretched, describe the ellipse.
Fig. 31. To draw a parabola, having given the axis AB and the double ordinate FD. Draw AB 3-1/2 inches long, and FD perpendicular to AB, 4 inches long. Draw EF and CD parallel and equal to AB. Divide EF and BF into the same number of equal parts. From the divisions on BF, draw lines parallel to the axis AB, and from the divisions on EF, draw lines to the vertex A. The points of intersection of these lines 1 and 1, 2 and 2, etc., are points on the required curve through which it may be traced. In like-manner, obtain the opposite side.
Fig. 32. To draw a hyperbola, the axis, a double ordinate and its
distance from the vertex being given. Draw the double ordinate FD
3-3/4 inches long. Perpendicular to FD, draw the axis BA 3-3/8
inches long. On the line AB locate M 1-3/8 inches from the vertex
A. Through M draw EC perpendicular to AB; then draw FE and DC
perpendicular to FD, intersecting FE and DC in E and C. Divide FE
and DC into the same number of equal parts, and from points 1, 2,
3, etc., on FE and CD, draw lines to the vertex M. From points on
FB and BD, draw lines to the vertex A. The intersection of these
lines 1 and 1, 2 and 2, etc., will be points in the required
hyperbola.
Fig. 33. To draw an equable spiral. Draw the line A6 4-5/8 inches long. Bisect A6 at O, and with O as center and OA as radius, describe the circle A-3-6-9. Divide the circle into twelve equal parts, and to the points on the circumference draw radial lines from the center at O. Divide AO into as many equal parts as the spiral is to have revolutions; in this case, two. Divide each space into twelve equal parts, the same number of parts as there are divisions in the circle. With O as center and 0-1, 0-2, 0-3, 0-4, etc., as radii, describe concentric arcs intersecting the similarly numbered radial lines, as shown. Through the points of intersection thus obtained, trace a curved line, completing the required spiral. (A spiral is easily drawn with a string attached to the center of the spiral and the drawing pencil. As the string winds around the pencil, it becomes shorter in length and, as the radius becomes shorter, a spiral is created.)
Fig. 34. The Helix. The Helix is a curve formed by a point moving around a cylinder and at the same time advancing along the line of its axis a fixed distance for each revolution. The distance advanced at one revolution is called the pitch. The line described upon the surface of the cylinder could be imagined as a flexible cord, wound around the cylinder. It is shown in actual practice by the thread of a screw. Let the circle 1-5-9-13, having a diameter of 2-3/4 inches, represent a plan view of the cylinder. Draw the elevation ABC-1 and make C-1, the pitch of the helix, 3-1/2 inches long. Divide C-1 into a number of equal parts; in this case, sixteen, and divide the circle into the same number of equal parts, beginning at point 1, as shown in the drawing. From the points on the circle, as 1, 2, 3, 4, etc., draw vertical lines, intersecting like numbered horizontal lines drawn from similarly numbered points on the pitch line 1-C. Through the points thus obtained, trace the helical curve, representing one revolution.
Dividing a Straight Line Into Equal Parts (First Method). (Fig. 35)

Draw A-B, the line to be divided, at the desired length. From point A draw a perpendicular line, creating A-C.

Fig. 35

Fig. 36. Place scale (straight-edge) with zero at point B and adjust (rotate) it along line AC until eight equal divisions are included between point B and line A-C (in this case eight inches). Mark the divisions.

Fig. 36

Fig. 37. Draw lines parallel to AC through the division marks to A-C. This creates eight equal divisions in AC.

Fig. 37
Dividing a Straight Line Into Equal Parts (Second Method).
(Fig. 38). Let A-B be the line to divide into equal spaces. Draw B-C from point B at any convenient angle of any length.

Fig. 38

Fig. 39. Use dividers or a scale to step off equal spaces on B-C beginning at point B.

Fig. 39

Fig. 40. Draw a line connecting points A and C. Draw lines through each point on B-C parallel to line A-C to intersect A-B.

Fig. 40
Developments

A three-dimensional sheet-metal object, in most cases, is made from flat sheet. In developing an object to be constructed, several kinds of sheet-metal machines roll, bend, or fold the sheet into the desired shape. The problem is to draw a full size pattern of the flat sheet. This type of drawing is called a development.

The object to be constructed will be made in exactly the same size as the drawing the draftsman makes. Such a drawing is called a pattern. The pattern must, therefore, be drawn to the true dimensions of the object. Depending on the degree of difficulty, the drawing can be done on paper or directly on the metal. The pattern should be drawn as if you were looking at the inside of the object.

The edges of the produced object must be joined in some way. Welding provides the strongest connection, but increases the cost of production. Several methods of folding over the edges on each other, other than welding, have been devised. For example, the edges may be riveted, screwed, or held together with banding. The additional material must be included on the pattern so that the maker will be able to do the folding over, or seaming, as it is called. Various sheet-metal machines perform such seaming operations for metal objects.

Sheet metal objects are hollow. Therefore, the patterns of the objects to be constructed are actually the shapes of the surfaces of those objects. The different methods for developing these patterns can, for convenience, be divided into four categories:

First, Parallel Line Development, which is used in developing regular, continuous shapes whose surfaces do not change along a distance, such as pipes, tanks, cubes and boxes. They are, therefore, termed parallel forms.

Second, Radial Line Development. This type of development is used in creating shapes with surfaces whose extensions converge at a common point, such as cones, truncated cones, tapers, funnels, etc. Such surfaces may have as their base a circle or any other regular geometric figure.

Third, Triangulation. Triangulation is used to develop irregular shapes when pattern drawing cannot be accomplished by using parallel line or radial line developments. Additionally, this method employs diagrams of triangles which serve in creating otherwise unknown distances used to lay out the pattern.

Fourth: Analytical Definition. This method employs mathematical formulas to determine the sizes and shapes to be drawn. Whichever method is used, the best way to gain knowledge of all of these methods is to use them in actual practice.
PRACTICE WORK
SHEET METAL NO. 1

CLOSED BOX

Layout and construct a closed sheet metal box 10" long, 8" wide and 4" high. Carefully make the following layout and then assemble with electric drill and rivet gun, keeping the laps out of sight. The open edges should be exactly over the metal creases. All lengths and 90-degree angles must be carefully measured and portrayed or the box will not have a finished appearance.

The creases in the light gauge metal may be made by placing it over the edge of a wooden block, placing the edge of another wooden block over it and then hammering the 90-degree crease in place.

WARNING: Do not crease thin sheet metal too sharply or it may break.

LAYOUT OF 10" x 8" x 4" CLOSED BOX
OPEN BOX

Layout and construct an open sheet metal box, with extensions of metal on upper edges rolled outward into handles. The dimensions of the box should be several inches. (Make a drawing to be incorporated in the report, showing all dimensions. Assemble using an electric drill and riveter, placing the laps on the outside where they will be less conspicuous than on the inside. The four handles should be rolled over a proper sized cylindrical object. In designing the box the width of the metal for the four handles will depend on the diameter of the cylindrical object on which they are to be rolled.

Following is a sample layout drawing
SQUARE PRISM
Following are three orthographic drawings, a perspective drawing and a layout pattern of a square prism.

Construct such a square prism from sheet metal. Another set of dimensions may be substituted for those in the drawings. The laps shown in the layout pattern should be 1/2" or 3/4" wide and they should be placed out of sight (underneath) the edges to which they are to be connected.

The creases may be set by placing the sheet metal between two wooden blocks, which are pressed together and the metal hammered into a 90-degree crease. Care should be taken that the crease is not too sharp or the sheet metal may break.

Drill hoes and use rivets in connecting the laps to the sides of the prism.
TETRAHEDRON

A regular tetrahedron is a three dimensional figure, the surfaces of which are four equilateral triangles.

Construct a regular tetrahedron of sheet metal in which the edges of the equilateral triangles have a length of from 4" to 8". The width of the laps should be from 1/2" to 3/4". Attach the edges together with rivets.

Note: Make sure that the measurements of edges are made accurately or the edges will not fit together exactly.

Three of the six edges of the tetrahedron are formed by creating creases between the triangles. The remaining three edges are formed by creases between the triangles and laps. These creases may be made with a handbrake or by placing the metal between two wooden blocks, which are pressed together and the metal hammered into a 90-degree crease. The additional angle of a crease may be added after removal from the blocks. Care must be taken that the crease is not too sharp or the sheet metal may break.

The laps should be out of sight under the triangles, the edges of which should be adjusted carefully to fit just over the creases of the laps below.
OCTAHEDRON

A regular octahedron is a three dimensional figure, the surfaces of which are eight equilateral triangles.

Construct a regular octahedron of sheet metal in which the edges of the equilateral triangles have a length of from 4" to 8". The width of the laps should be from 1/2" to 3/4". Attach the edges together with rivets.

Make sure that the measurements of edges are made accurately or the edges will not fit together exactly.

Seven of the 12 edges of the octahedron will be formed by creases between the triangles and the remaining five edges will be formed by creases between the triangles and laps. These creases may be made with a brake or by placing the metal between two wooden blocks which are pressed together and the metal hammered into a 90 degree crease. The additional angle of a crease may be added after removal from the blocks. Care must be taken that the crease is not too sharp or the sheet metal may break.

The laps should be out of sight under the triangles, the edges of which should be adjusted carefully to fit just over the creases of the laps below.
A regular dodecahedron is a three dimensional figure, the surfaces of which are 12 equilateral pentagons.

Construct a regular dodecahedron of sheet metal in which the edges of the pentagons have a length of from 4" to 8". The width of the laps should be from 1/2" to 3/4". Attach the edges together with rivets.
Make sure that the edges are measured accurately so they will fit together exactly.

In the following figure, cut along the dotted lines and crease along the solid lines.

A pentagon may be inscribed in a circle by constructing each side such that it subtends a central angle of 72 degrees. Each interior angle of a regular pentagon is 108 degrees. One pentagon may be cut from sheet metal and used as a template to determine the vertices of the other eleven pentagons making up the layout of the dodecahedron.
ICOSAHEDRON

A regular icosahedron is a three dimensional figure, the surfaces of which consist of 20 equilateral triangles.

Construct a regular icosahedron from sheet metal in which each edge of the equilateral triangles has a value of 4, 5 or 6 inches. The width of the laps should be 1/2", 3/4" or some intermediate value.

An icosahedron has 30 edges and if constructed from the layout of the following figure, 19 of these will be formed by creases between triangles and the remaining 11 from creases between triangles and laps. The positions of the 11 laps, mandatory to be added to the figure, are indicated by L's.
DOVETAIL SEAM

Cut sheet metal for a cylinder about 6 to 8 inches long and about 6 to 8 inches in diameter, allowing for a lap of about 1 inch.

While still flat, divide the circumference of the cylinder on one end into 24 equal segments. This includes one edge of the sheet metal, not including the lap. Mark off a circumferential line on the sheet metal 11 inches from the edge, which was divided into segments and cut from each segment division point 11 inches to the scribed circumferential line. At the circumferential line bend every alternate segment 90 degrees.

Rivet the cylinder together at the 1-inch seam.

Cut a sheet metal flange 3 inches in width, which will just, slip over the cylinder. Its diameter will be 6 inches greater than that of the cylinder. Slip it over the unbent segments until it is flush with the bent segments.

Bend the remaining segments over the flange.

Dovetail Seam
METAL OVER TEES AND REDUCING TEES (Field Application)

Cut the sheet metal for the tee or reducing tee branch, allowing a lap of about two inches, and temporarily attach it in its correct circumferential position to the branch, just touching the run of the tee or reducing tee. Using a marking pen attached by wire to a pencil or nail, follow the curved line of intersection with the pencil while marking a similar curved line on the metal of the branch with the marking pen. Remove the branch metal and cut along the line formed.

Cut the sheet metal for the run of the tee or reducing tee with a lap of about two inches and temporarily attach it around the adjacent pipe covering (or on a section of pipe covering the same size). The branch metal should then be placed around a piece of pipe covering its size (in order to maintain its shape) and the end with the curved cut placed against the metal for the run in the position in which they will fit together. A curved line is then marked on the metal of the run where it touches the branch metal.

Either the branch metal or the run metal may be lapped over the other at the area of overlap, depending upon the aspect in space of the tee or reducing tee and whether or not the metal is expected to shed water.
If the branch metal is to be on top in the overlap, from one to two inches of the run metal within the marked curve must be flared out to extend over the adjacent area of the branch.

If the run metal is to be on top in the overlap, the run metal is cut along the marked curve and the branch metal is cut to flare out over the adjacent area of the run. For this purpose a curved line must be drawn on the branch one or two inches from the cut end and exactly similar to it, and cuts made from the end to it close enough together so that the metal between the cuts can be flared out without noticeably bending the adjacent metal. If this inner curve is not accurate or the cuts not made exactly to it, some of the cuts may be partially visible when the metal is in place.

The metal may be secured into place with pop rivets, sheet metal screws or bands. Caulking putty may be used between the overlaps if the metal is used as weatherproofing. If measurements are not accurate, it is better to make the run metal cutout slightly smaller than the measurements indicate, for it can be enlarged later. In general it appears easier to flare the branch metal out underneath the run metal if water is not a problem.
Draw the side and end views in the desired size as shown in Figures 1 and 2. (Remember, all developments are at a ratio of 1:1, or the exact dimension at which the project is to be constructed).

Divide the half circle above each view into equal spaces (in this case eight), and number each as shown. Project straight lines down from the half circle above the end view to intersect the round pipe. Project straight lines from the intersecting points on the round pipe in the end view to an undetermined length into the side view. Project a straight line down from each point on the half circle above the side view, to intersect the lines projected from the end view, to obtain the V-shaped line 1 to 6 to 11 shown in the side view.

Note: After drawing line 1 to 1 equal to the circumference, lay out only one quarter of the T pattern as 1 to 6 in Figure 3. Add the lap. Then cut out along the curved line 1 to 5. Using this quarter template as a pattern trace the curved cutting line 6 to 11, 11 to 6 and 6 to 1. The use of this method will save time.

To lay out the cutout opening on the round pipe as in Figure 40D, use a piece of sheet metal with a length equal to the circumference of the insulated pipe plus appropriate lap. Obviously, the width must be greater than the diameter of the branch to allow it to be attached over the pipe.
on either side of the branch opening. The opening may be located in the center of the sheet as in Figure 40D or at the overlapping edges of the piece. Divide a distance of 1/2 of the circumference into equal spaces, 1 to 2 to 3 to 4 to 5 to 6 into either direction from the center of the opening. Starting at point 1 (where the widest dart of the opening is located,) transfer one half of the distances from the side view (V-shaped) projections (1 to 11; 2 to 10; 3 to 9; and 4 to 8; 5 to 7; 6 to 6; ) to either side of the centerline in the opening.

Figure 40E shows the isometric view of the completed Tee.
METAL FOR BENDS AND ELBOWS
In Figure 41, let A-B-1-C-D-7 be the elevation of a two-piece 90° elbow. First, draw the elevation. Then, below the elevation, describe a circle representing the profile or plan, shown at F. As each half of the pattern is symmetrical, draw a line through the plan F, and divide the upper half of the circle into a number of equal parts, as shown from 1 to 7. From these points perpendicular lines are drawn, intersecting the miter line 1-7 as indicated. Then, at right angles to the vertical arm of the elbow D-7, draw the stretch-out line FG, and upon this line step off twice the number of spaces shown in the plan, which will give the circumference of the elbow. From these points and at a right angle to F-G, draw measuring lines which are intersected by like numbered lines drawn at a right angle to the
cylinder from similarly numbered points on the miter line 1-7 in the elevation. A line traced through points thus obtained will be the pattern for the vertical arm of the elbow, as shown by F-G-L-H-J.

The irregular curve traced through the points of the pattern is the only one required for both pieces of the elbow. To save material, the pattern for the upper segment of the elbow can be obtained in the following manner: The stretch-out (including lap) of both pieces being of equal length, extend the outer lines of the pattern to M and R, as shown in the drawing, and make J-M and R-L equal in length to A-7 in the elevation. Draw a line from M to R; then J-L-R-M will be the pattern for the upper arm of the elbow, having the seam at A-7 on the outside or heel of the elbow. The seam on the lower arm is on the inner side or throat, as shown by C-1 in the elevation. This method of development is applicable to any pieced elbow, no matter what the shape of the pipe may be or the angle required. However, if the location of the seam or lap is desired to be in a straight line and continuous on all segments, make the patterns identical to each other, as shown in segments 1 and 2. The latter method also shows how to provide a lap at the point of contact (miter-line). Only one of the segments requires such a lap.
SHEET METAL GORES FOR BENDS AND ELBOWS (Field Methods)

For well-fitting installation over insulated bends or elbows, it is preferable that the number of gores be equal to the number of insulation miters. The method below describes the designing and cutting of gores from the following data:

1. The circumference (plus lap) of the insulated elbow (e.g., pipe circumference as determined from diameter a-b).
2. The arc length of the “heel” (back) of the elbow at D-C
3. The arc length of the radius of the bend at E-F
4. The arc length of the throat of the elbow at A-B
5. The number of gores to be installed.

Example: (Fig. 42) Layout gore pattern for an 8-inch ASA standard radius, insulated, iron pipe elbow. The elbow is covered with six miter rings and the insulation thickness is 2 inches. The following information is available:

- The diameter of the insulated pipe (a-b) = 12.625 inches or 12 5/8”.
- Bend Radius at heel (X-m) = 18.3125 inches or 18 5/16”.
- Bend Radius to center of Pipe (X-n) = 12 inches.
- Bend radius to throat (X-o) = 5.6785 inches or 5 11/16”.

Fig. 42
The measurements of the miter, including angle of rotation, are 1/6 of the full elbow. A 90-degree elbow with insulation miters attached would look similar to a-b-d-f-e-c in Fig. 43.

To layout the pattern, determine each of the following measurements:

I. **Stretch-out**, l-m-n-o, (The circumference of the pipe covering plus lap): Circumference of pipe covering = (\(\Pi \times D\)) + lap, where \(\Pi = 3.14\) and \(D = 18.3125\). Multiplying the two factors results in 57.53 inches or 57 ½”. Add lap of 1 ½” = 59 inches (answ).

II. **Miter width**, e-f (heel width): The total length of the heel circumference (360 degrees – see Fig. 44) is determined by mathematical formula \((\Pi \times D)\), where \(\Pi = 3.14\) and \(D = 36.625”\).

III. An elbow being 90 degrees represents one fourth of the circumference and one miter represents one sixth of the elbow. Therefore, to obtain the heel width value, we divide the total circumference by 24. The calculations are as follows: Dimension of miter at heel = \(3.14 \times 36.625/24 = 4.79\) inches or 4 13/16” (ans).

IV. **Miter width**, c-d, (along the bend radius): Using the above formula \((\Pi \times D/24)\) – where \(\Pi = 3.14\) and \(D = 24”\), we obtain the result of 3.14 inches or 3 1/8” (ans).

V. **Miter width**, a-b, (along the throat): (Using \(\Pi \times D/24\)) – \(3.14 \times 12.643/24 = 1.655\) inches or 1 5/8” (ans).
Design Gore Pattern (Fig. 45): Using the values obtained above, draw the elevation view of the miter a-b-c-d-e-f. Perpendicular to the miter-line e-f, draw line X-M to a convenient length (i.e., equal or greater than circumference of pipe covering plus lap). Along X-M draw the rectangle G-H-I-K, making the area somewhat wider than miter-width e-f and longer than the circumference of the pipe covering. This is to accommodate for laps. Divide this rectangle into four equal distances, each distance representing one quarter of the circumference of the pipe covering. At the end of the pattern, mark off an additional 2 inches for end lap. From points a, b, c, d, e, and f on the elevation project straight lines through division marks G-H, I-J, K-L and M-L in the stretch-out. Connecting the intersections of these marks with the projection lines will yield a rough outline of the gore.
Note: The method explained to this point does not yield a totally accurate pattern and should be modified by adding a slight curve to the part that covers the convex portion of the miter and be removing and equally shaped curve from the concave part. An experienced mechanic will be able to estimate at the amounts needed. However, an exact shape of the curve can be obtained by using parallel line projection.

Gores are sheet-metal protection over insulated pipe bends or elbows that are fitted circumferentially to the bend in such a manner that the protection of the exposed edges of the strips standard to the surface of the bend form planes perpendicular to the centerline of the pipe bend. This is equivalent to saying that the exposed edges of such strips, when in place, present a straight line when viewed directly from the side. However, when flattened out on a level surface, the edges of gores are curved lines. These curved lines can be projected accurately by using parallel line projection, which is covered in a separate problem. The measurements in the above layout represent widths at four different locations around the circumference of the miter which have been taken from the greatest width of the miter, namely the heel; from the intermediate width at the bend radius (half way between the
greatest width and the throat width at the three o’clock/nine o’clock position); and the smallest width, which is at the miter’s throat. The span between each of these divisions on the stretch-out represents one quarter of the length of the gore or one quarter of the circumference of the pipe covering. Thus, the gore measurements (widths) are only accurate at these three places. (See e-f, c-d and a-b in fig. 46). By using additional projection lines to equally spaced intermediate positions between the four lines, as shown with lines 1-g, 2-h, and 3-i, it is possible to develop an accurate curve. Note that creating such a curve adds a small amount of space to the widths at the convex portion of the gore and subtracts an equal amount of space from the concave portion.

Since one half of the gore is a mirror image of the other, only two quarters are represented in the layout of fig. 46. When establishing locations for offsets, the projection distances of the first quarter, once completed, can be used to finish all remaining seven quarters, including those on the mirror image. By creating a pattern from the results at the first quadrant, the entire layout can be completed using the pattern by turning it over or flipping it sideways 180 degrees. The above drawing utilizes four spaces or three extra points between the measured lines. Essentially, the more projection lines are used, the more accurate the resulting curve will be. Experience or tolerance-requirements will dictate how many individual divisions are deemed to be sufficient.
PRACTICE WORK
SHEET METAL NO. 13

SHEET METAL GORES FOR BENDS AND ELBOWS (Parallel Line Projection)

For precise work, the divisions creating a curved edge on gores should be projected from a plan and side view, as shown in fig. 47.

Draw the plan and side views in the desired sizes. Divide the plan view into equal spaces as shown in 1-2-3-4-5-6-7-8-9. Only one half of the view is necessary, since the other half is a mirror image. Draw the stretch-out pattern using the same centerline as the side view and divide into the number of equal spaces used in the plan view. Each of the spaces must be equal in length to the spaces on the half circle of the plan view. On the stretch-out also make allowance for laps at the side and end. Project straight lines from the points 1 through 9 in the plan view to intersect the side view as shown. The projection lines create points 1-9 on the side view from which straight lines are then projected at right angles through the grid lines, a-b-c-d-e-f-g-h-i, of the stretch-out. Drawing connections between the points of intersection of the projection lines, 1 through 9, with the grid lines, marked a through i, will yield the precise curvature as well as the outline of the pattern. Include a constant width of lap along one entire curved side and another lap at the end of the gore.
PRACTICE WORK
SHEET METAL NO. 14

DESIGN GORES FOR MITERS USING A CALCULATOR.

The student is referred to the section on metal gores for bends and elbows, which describes the cutting of gores from the following data:

1. The radius of the bend.
2. The angle of the miters.
3. The outside diameter of the pipe covering. (These are the same dimensions that are used in the miter formula.)

Calculate, layout and cut gores to fit over the miters of an insulated ASA butt-welded elbow from the dimensions of a miter only, but cut the gores for end laps at 90 or 270 degrees instead of at the point of minimum width (the throat of the elbow). This will permit a 3 o'clock end lap on an elbow connecting a vertical and horizontal pipe. This procedure reduces waste, for the second curved cut of one gore will serve as the first curved cut of the next gore. In the case of an elbow or bend connecting two horizontal pipes, a 3 o'clock lap can be secured only by gores that lap at the minimum or maximum widths, and if the gores are cut using the second curved cut of one for the first curved cut of the next gore, the laps would alternate from throat to back. Crimp the side laps, which are to extend under the adjacent gores, but only for the convex
half of the metal joint. This is the outer half. The laps should not be crimped for the concave half of the metal joint, which is the inner half. The line between the smooth part and the crimped part of a metal gore is to be positioned accurately, over the seam between two adjoining miters. For this reason, during the crimping operation, the metal gore should be held in a position so that the crimped lap bends slightly from the smooth metal.

A bead is put on the outer side of the gore. It prevents the otherwise flat metal from opening up slightly. The bead requires about 3/16” additional width of the gore. In some cases the bead is extended only over the outside half of the gore (opposite the crimp), but the bead can be extended over the entire length of the gore, forming an interlocking device for the end lap. The outer edge of the bead may buckle when the gore is bent around the elbow. To prevent this buckling, bend the gore into the circular position before putting it through the beading machine.

Position the gores over the miters such that the crimped parts extend only over the adjoining miters on the outside half. The side lap (going around the entire circumference) should be the same at the throat as at the widest point. Fastening can be accomplished with a pin riveter. When sheet metal gores are used for weatherproofing in the field, putty may be placed between the metal along the laps.

Layout and cut gores to fit over the insulation miters of an ASA butt-welded elbow by applying width measurements obtained by calculation or from table of miter measurements, adding width for the crimp and the bead. The length of the gore should be determined from the circumference of the pipe covering, without adding for the end lap. (This should be done after the pattern has been fully drawn.) The circumference of a miter should be divided into four equal number of parts and the miter widths measured at these points, using the heel, 3’oclock, throat and 9 o’clock, respectively, and transferred to the layout on the sheet metal. After adding additional width for crimp and bead, draw a smooth curve through the layout points and cut the gore. Try it on the miter, and if it fits, similar gores can be cut, crimped, beaded and positioned in place. Check the throat of the elbow and note if the exposed widths of the gores are equal. The crimping has a tendency to pull the gore out of shape.
Metal protection over insulated pipe bends or elbows may be overlapping strips fitted circumferentially to the bend in such a manner that the projection of the exposed edges of the strips normal to the surface of the bend form planes perpendicular to the centerline of the pipe bend. This is equivalent to saying that the exposed edges of such strips, when in place, present a straight line.
when viewed directly from the side. Such sheet metal strips are called gores. However, when flattened out on a level surface, the edges of gores are curved lines. The problem is how to cut these curves from a flat piece of sheet metal.

The student is referred to sheet metal project no. 12 for a look at parallel-line projection to review the mechanical method of creating curves from orthographic views of miters.

The solid lines of figure 49 constitute the projection of a gore (in place on a pipe bend or elbow) on a plane equidistant from the pipe bend. It is most convenient to have gores be the same size to just cover the outer surface of the insulation miters on the bend, with a constant amount added for lap, for this solves the double curvature problem. Such gores are applicable only when the insulated bend or elbow has an inside arc (throat). When stretched out on a flat surface the half gore visible in figure 1 would look like ABCD of Figure 50, the other half being a mirror image to the left of line AC. (The gore should also include a transverse lap added at BD and a longitudinal lap extending the curve CD downward by the amount of the lap. Laps are not shown in the figures.)

The increase in width of the non-lapping part of the gore from its minimum value BD to its maximum value AC is \((AC - BD)\) and the increase in width of one half the gore on one side of centerline PQ is \((AC - BD)/2\). The increase in width of one side of the gore in the first quadrant (90 degrees) is \((AC - BD)/4\).

For the development of a gore which will fit a specified insulated pipe bend or elbow, a half circle is constructed on line AB of figure 49, with the center at Y, and the first quadrant of this half circle is divided into a number of equal arcs (in this case four arcs of 22 1/2 degrees each), forming the points u, v, w and y. These points are projected on the line AB to points U, V, W and Y, respectively. The segments BU, UV, VW and WY are the apparent lengths (when viewed from the side) of the segments whose actual lengths are Bu, uv, vw and wy respectively, in figure 49.

When two straight intersecting lines, such as AB and CD of figure 49, partially bound an area, the width of the area at any point is proportional to the distance from the point of intersection 0. Therefore, in order for the projection AB (in figure 49) of an edge of the gore to appear straight, equal segments Nu, uv, vw and wy of the stretched out gore in figure 50 must vary in width proportionally to BU, UV, VW and WY, respectively. The factor of proportionality is \(FB/AF\).
If figure 50, is scaled such that AB represents the total increase in width of one side of the gore, then BU is the increase in width of the first 22 1/2 degrees, UV the increase in width of the second 22 1/2 degrees, VW the increase in width of the third 22 1/2 degrees and WY the increase in the fourth 22 1/2 degrees of the first quadrant. It is simpler to consider the change in width of one side of the gore from the line MN, which is half way between lines AR and FB. The offsets from the line ON, at equal intervals, are then, beginning at Y in each direction, zero, YW, YV, YU and YB of figure 49. These offsets Form the curve AYB, which has mirror images over lines AC and PQ, completing the non-lapping part of the gore.

However all the above projection work can be eliminated by calculating the offsets as follows:

In figure 49

\[ YW = Yw \sin 22 \frac{1}{2} \text{ degrees.} \]
\[ YV = Yv \sin 45 \text{ degrees.} \]
\[ YU = Yu \sin 67 1/2 \text{ degrees.} \]

The radii Yw, Yv and Yu of figure 49 are each equal to YE of figure 50, which is \( (AC - BD)/4 \) and therefore the offsets are

First:  \( (AC - Bd)/4 \sin 22 1/2^\circ = (AL - B0)/4 \times .37 \)
Second: \( (AC - Bd)/4 \sin 45^\circ = (AC - BD)/4 \times .71 \)
Third: \( (AC - BD)/4 \sin 67 1/2^\circ = (AC - BD)/4 \times .93 \)

In laying out a gore it is best that each gore covers an insulation miter, as this eliminates the curvature problem. The maximum width of the gore is then

\[ W = 0.01745 \times \theta \times (R + \frac{1}{2} D) + L \]

and the minimum width is

\[ w = 0.01745 \times \theta \times (R - \frac{1}{2} D) + L, \]

where \( \theta \) is the angle of the miter to be covered, R the radius of the pipe bend or elbow, D the outside diameter of the pipe covering and L the longitudinal lap.

A straight centerline equal to the circumference of the insulated pipe is drawn on the sheet metal. At its midpoint the maximum width of the gore W is drawn perpendicular to the centerline. Lines equal to w, the minimum width of the gore, are drawn at each end of the
centerline. A line one half way between the point of maximum width and the point of minimum width is drawn parallel to the centerline and divided into 16 equal segments, each segment representing 22 1/2 degrees of arc. The calculated offsets from the points on this line are drawn, starting one fourth of the way (90 degrees) from either end. A curve is drawn connecting the ends of the offsets.

A mirror image of this curve across the centerline is extended by the width of the longitudinal lap. A transverse lap is added at one end of the gore, which is then carefully cut out along the curves and end lines. Additional gores are cut using the first one as a template. A bead may be placed on the visible edge of the gore and the lap (on the other side) crimped. An interlocking bead may be substituted for a lap. It should be noted that a bead on the sheet metal reduces the width slightly. In case a 90-degree bend or elbow includes half miters on the ends, the gores must correspond, the half gores each having one straight edge.

The gores may be held in place with pop rivets.

Example: A 10-inch ASA butt-welded elbow is covered with nine insulation miters made from pipe covering of 15 inch outside diameter. Design gores with a transverse lap of 2 inches and a longitudinal lap of 1/2 inch.

\[
W = 0.01745 \times 10 \times ((15 + 7.5) + 0.5 = 4.42 = 4\ 7/16. \\
w = 0.01745 \times 10 \times (15 - 7.5) + 0.5 = 1.81 = 1\ 13/16 \\
C = 15 \times 3.14 = 47.1.
\]

Divided into 16 segments each segment is

\[
47.1/16 = 2.94 = 2\ 15/16.
\]

\[
(W - w)/4 = (4.42 - 1.81)/4 = .65 = 21/32
\]

The line parallel to the centerline from which the offsets are measured is .65 from the edge of the gore at the point of maximum width.

The offsets are

\[
.65'' \times .38 = .25 = 1/4''.
\]
\[
.65'' \times .71 = .46 = 15/32''.
\]
\[
.65'' \times .92 = .60 = 19/32''.
\]
\[
.65'' \times 1.00 = .65 = 21/32''.
\]
In the above example, the offsets, consisting of a total of four, are spaced at every 22 1/2 degrees of rotation in each quadrant. When very large gores are designed, the number of offsets per quadrant should be increased to six or eight. With six offsets the calculations would be based on 15-degree increments, namely sin 15, sin 30, sin 45, sin 60, sin 75 and sin 90 degrees. With eight offsets, the degree increments would using sin 11 1/4; sin 22 1/2; 33 3/4; sin 45; sin 56 1/4; sin 67 1/2; sin 78 3/4 and sin 90 degrees.

The trigonometric function values of expedient angles (sin 15°, sin 22.5°, sin 30°, etc.) can easily be found with a scientific calculator and offsets for various sizes of gores can be calculated quickly. Some examples are shown below. The angles and sine values in the tables can be applied over and over, for they remain constant. Table 1, 2 and 3 show examples of 15-degree, 22.5-degree and 11.25-degree intervals (6, 4 and 8 intervals) respectively:

**Using 15-degree alternation 6 intervals) with a 2 1/4 inch width as an example:**

<table>
<thead>
<tr>
<th>Angle of rotation along quadrant</th>
<th>Sin Value of Angle</th>
<th>Example Width</th>
<th>Offsets (in decimals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sin 0</td>
<td>0.00</td>
<td>2.25&quot;</td>
<td>0.00&quot;</td>
</tr>
<tr>
<td>Sin 15</td>
<td>0.26</td>
<td>2.25&quot;</td>
<td>0.58&quot;</td>
</tr>
<tr>
<td>Sin 30</td>
<td>0.50</td>
<td>2.25&quot;</td>
<td>1.13&quot;</td>
</tr>
<tr>
<td>Sin 45</td>
<td>0.71</td>
<td>2.25&quot;</td>
<td>1.59&quot;</td>
</tr>
<tr>
<td>Sin 60</td>
<td>0.87</td>
<td>2.25&quot;</td>
<td>1.95&quot;</td>
</tr>
<tr>
<td>Sin 75</td>
<td>0.97</td>
<td>2.25&quot;</td>
<td>2.17&quot;</td>
</tr>
<tr>
<td>Sin 90</td>
<td>1.00</td>
<td>2.25&quot;</td>
<td>2.25&quot;</td>
</tr>
</tbody>
</table>

**TABLE 1**

**Using 22 1/2-degree alternation (4 intervals) with a 1 1/2 inch width as an example:**

<table>
<thead>
<tr>
<th>Degrees of rotation along quadrant</th>
<th>SIN Value</th>
<th>Example Width</th>
<th>Offsets (in decimals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sin 0.0</td>
<td>0.00</td>
<td>1.50&quot;</td>
<td>0.00&quot;</td>
</tr>
<tr>
<td>Sin 22.5</td>
<td>0.38</td>
<td>1.50&quot;</td>
<td>0.57&quot;</td>
</tr>
<tr>
<td>Sin 45.0</td>
<td>0.71</td>
<td>1.50&quot;</td>
<td>1.06&quot;</td>
</tr>
<tr>
<td>Sin 67.5</td>
<td>0.92</td>
<td>1.50&quot;</td>
<td>1.39&quot;</td>
</tr>
<tr>
<td>Sin 90.0</td>
<td>1.00</td>
<td>1.50&quot;</td>
<td>1.50&quot;</td>
</tr>
</tbody>
</table>

**TABLE 2**

**Using 11.25-degree alternation (8 intervals) with a 3 inch width as an example:**
Summary:

The values used in calculating offsets are determined by the formula

\[ \text{Offset} = \frac{(W - w)}{4} \times \sin \theta, \]

where \( W \) is the miter-width at the heel and \( w \) is the miter-width at the throat. \( \sin \theta \) is the trigonometric value of the angle of rotation along the quadrant, which locates the offsets. To design the stretch-out pattern the following sizes are used: Circumference of the pipe covering from which miters are produced, plus lap, equals the length of the stretch-out and \( W \) (miter width at heel) plus lap equals the width of stretch-out.

<table>
<thead>
<tr>
<th>Degrees of rotation along quadrant</th>
<th>SIN Value</th>
<th>Example Width</th>
<th>Offsets (in decimals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sin 0.00</td>
<td>0.00</td>
<td>3.00”</td>
<td>0.00”</td>
</tr>
<tr>
<td>Sin 11.25</td>
<td>0.20</td>
<td>3.00”</td>
<td>0.59”</td>
</tr>
<tr>
<td>Sin 22.50</td>
<td>0.38</td>
<td>3.00”</td>
<td>1.15”</td>
</tr>
<tr>
<td>Sin 33.75</td>
<td>0.56</td>
<td>3.00”</td>
<td>1.67”</td>
</tr>
<tr>
<td>Sin 45.00</td>
<td>0.71</td>
<td>3.00”</td>
<td>2.12”</td>
</tr>
<tr>
<td>Sin 56.25</td>
<td>0.83</td>
<td>3.00”</td>
<td>2.49”</td>
</tr>
<tr>
<td>Sin 67.50</td>
<td>0.92</td>
<td>3.00”</td>
<td>2.77”</td>
</tr>
<tr>
<td>Sin 78.75</td>
<td>0.98</td>
<td>3.00”</td>
<td>2.94”</td>
</tr>
<tr>
<td>Sin 90.00</td>
<td>1.00</td>
<td>3.00”</td>
<td>3.00”</td>
</tr>
</tbody>
</table>
PRACTICE WORK
SHEET METAL NO. 15

NON-REDUCING LATERAL, INTERSECTING AT ANY ANGLE (FIG. 51).

Draw the side view with one half circle at the end of the branch and two quarter circles at the ends of the body (see View A). Divide the half-circle and the two quarter-circles into equal spaces. From the points at the arcs project straight lines to the miter lines PX and PN. Draw the branch pattern (view B) at a length equal to AB (= diameter of pipe covering) times 3.14 plus lap. The width should be such that the short side of the metal on the branch (N-B) is at least two inches long. Divide the entire length of the branch pattern into spaces each space being equal to one of the spaces on the half circle in view A. From the intersecting points on the miter line PX and PN project straight lines to the parallels on the branch pattern. Draw the body pattern (view C) at a length equal to AB.
times 3.14 plus lap. The width of the body pattern should be at least 4 inches greater than the dimensions of the branch entering the body. On the body pattern draw the spaces equal in distance and number to those found on the half circles in view A. From the points of intersection on miter lines PX and PN draw projection lines to the parallels 1 through 5, and to 5 through 9. The points on the body pattern and on the branch pattern which are intersected by the projection lines mark the edge of the cut out and curvature, respectively.
PRACTICE WORK
SHEET METAL NO. 16

UN-EQUAL SIZE OF PIPES (REDUCING TEE) INTERSECTING AT 90 DEGREES (FIG. 52).

Draw the elevation and side views in their relative positions to each other as shown. Establish equal division points on the half circles of both views. Locate the miter line 1', 2', 3', 4', 5', 6', 7' in the elevation by projecting lines from points 1, 2, 3, 4, 5, 6 and 7 of the half circles in both, side and elevation views.

Describe the stretch-out area (including lap) for the small pipe (branch) as shown. Divide length of stretch-out area into the number of equal spaces indicated by the half circles. Project straight lines from the half circle of the side view onto the large pipe arc and then at right angle through the grid lines of the small pipe (branch) stretch-out. Connect the resulting points of intersection on the grid to obtain the shape of the small pipe pattern.

Describe the stretch-out area for the large pipe (main body) of the tee as shown. Using dividers, from the side view, (large pipe arc) transfer the spaces between the points a-b, b-c, c-d, e-f and f-g to the stretch-out outline as shown. (Note that these spaces are not equal to each other – see part A). Project straight lines from the equal division points of the half circle in the elevation to intersect through a-b, b-c, c-d, d-e, e-f and f-g on the stretch-out of the large pipe. Connecting the points of intersection on the stretch-out grid, as shown, produces the shape of the pattern of the large pipe. Add laps as needed.
Fig. 52
PRACTICE WORK
SHEET METAL NO. 17

REDUCING LATERAL (SMALL PIPE CONNECTED TO LARGE PIPE AT AN ANGLE (FIG. 53):

Draw the elevation and side views in relative positions to each other as shown. Draw half circles on the end of the small pipe on both views. Establish equal division points on these half circles and locate the miter line 1’, 2’, 3’, 4’, 5’, 6’, 7’ in the elevation by projecting lines from points 1, 2, 3, 4, 5, 6 and 7 of the half circles in both, side and elevation views.

Describe the stretch-out area (including lap) for the small pipe (branch) as shown. Divide length of stretch-out area into the number of equal spaces indicated by the half circles. Project straight lines from the half circle of the side view onto the large pipe arc and then at right angle through the grid lines of the small pipe (branch) stretch-out. Connect the resulting points of intersection on the grid to obtain the shape of the small pipe pattern.
Describe the stretch-out area for the large pipe (main body) of the reducing lateral as shown. Using dividers, from the side view, (large pipe arc) transfer the spaces between the points, a-b, b-c, c-d, e-f and f-g to the stretch-out outline to obtain the grid spacing. (Note that these spaces are not equal to each other – see part A). Project straight lines from the equal division points of the half circle in the elevation to intersect through a-b, b-c, c-d, d-e, e-f and f-g on the stretch-out of the large pipe. Connecting the points of intersection on the stretch-out grid, as shown, produces the shape of the pattern of the large pipe. Add laps as needed.
PRACTICE WORK

SHEET METAL NO. 18

DEVELOP CONE BY RADIAL LINES (FIG. 54)

For the radial lines to be effective, all lines must radiate from a common center. Additionally, the amount of slant of those lines must be relatively large, since most radial line developments begin by drawing the side view and then extending the side lines until they meet the peak. Arcs are then projected from this point. If the side taper is so slight that the peak is several feet from the fitting, it is obviously impractical to use radial lines, since the radius needed to swing the arc is too long and, consequently, difficult to use.

Draw the plan and elevation views ABC. Using the distance AB of the elevation as a divider setting, swing an indefinite arc around center A1 to establish a base stretch-out arc. Mark off B1-A1 to create a starting edge for the pattern. Measure and mark off the circumference of the cone (as shown in the plan view) along the pattern stretch-out arc to establish the length of arc B1-C7-B1. This distance is marked off on the arc with a flexible rule. From
end point B1 draw a straight line to the center A1, establishing the second edge of the stretch-out pattern. Add the appropriate amount of lap along one of the edges of the pattern. This completes the layout of a cone pattern.
PRACTICE WORK
SHEET METAL NO. 19

DEVELOP TRUNCATED CONE BY RADIAL LINES (FIG. 55)

Draw the plan view and elevation view d-e-B-C, showing the small and large diameters of the truncated cone. Using the distance A-B of the elevation as a divider setting, swing an indefinite arc around center A1 to establish the large stretch-out arc. Mark off B1-A1 to create a starting edge for the pattern. Using the distance A-d of the elevation as a divider setting, swing an indefinite arc around center A1 to establish the small stretch-out arc d1-e1-d1. Measure and mark off the circumference of the base (large diameter B-C as shown in the plan view) of the cone along the pattern stretch-out arc to establish the length of arc B1-C7-B1. From point B1 draw a straight line to A1. The segment d1-B1 along this line establishes the second edge of the stretch-out pattern. Add the appropriate amount of lap along one of the edges of the pattern. This completes the layout of a truncated cone pattern.
Note on marking distances along a curved line: In laying out curved patterns, the distances along an arc can be marked by use of a flexible rule, by stepping off equal (small) distances which have been obtained for divider setting; or by mathematical formula that uses the angle of rotation of the arc. The latter is accomplished by first obtaining an angle measurement with a protractor:

![Diagram of arc and angle measurement](image)

**Fig. 56**

Example: The following formula is used to determine the angle of an arc:

\[ \phi = 57.3 \times \frac{W}{R} \]

Where \( \phi \) is the angle subtending an arc; 57.3 is a constant number representing 90 degrees; \( W \) is the length of the arc; and \( R \) is the radius of the arc.

In the example showing in Fig. 18, let \( W \) be 21 inches and \( R \) be 10 inches. Substituting these values in the formula we get:

\[ \phi = 57.3 \times \frac{21}{10} = 120 \text{ degrees}. \]

Applying this method to problem No. 18 simplifies the layout of the stretch-out pattern considerably, as follows: Start by establishing the center point \( A1 \) in a convenient location. Using the length of \( AB \) in the elevation view draw a straight line into any direction obtaining line \( A1-B1 \). Using a protractor, aim and draw another straight line from \( A1 \) at an angle rotated by 120 degrees from \( A1-B1 \). This establishes the stretch-out angle \( B1-A1-B1 \). Next, set the divider at distance \( AB \) of the elevation view and using \( A1 \) as center, swing an arc through both legs of the stretch-out angle. This establishes the large arc \( B1-C1-B1 \). Next set the divider at \( Ad \) of the side view. Using \( A1 \) as center, swing the small arc \( d1-e1-d1 \) through both legs of angle \( B1-A1-B1 \). Add lap along line segment \( d1-B1 \). This completes layout of the pattern of a truncated cone.
SPHERES
A plane, which passes through the center of a sphere, intersects the surface of the sphere, forming a circle. As no larger circle can be drawn on the surface of the sphere, this is called a great circle.

![Image of a sphere with labeled parts: North Pole, South Pole, Equator, Zones, Parallels, Meridians, and Lunes.]

On the surface of a sphere the shortest distance between two points is called a geodesic. If such a line is continued, it will form a great circle. Thus on the surface of a sphere the shortest distance between two points is part of a great circle.

Any two opposite points on the surface of a sphere are called poles. The top and bottom poles are called the north and south poles respectively.

The great circle equidistant from the north and south poles is called the equator.

Smaller circles on the surface of the sphere, parallel to the equator, are called parallels. The surface between any two parallels, or between a parallel and the equator is called a zone, such as the torrid and temperate zones on the earth's surface.

All great circles through the north and south poles are called meridians. The surface between any two meridians is called a lune.
DEVELOP LUNES FOR INSULATED HALF-SPHERE (GORES FOR SPHERICAL TANK HEAD)

The length of a half lune (from the equator to the North Pole) is \( C/4 \), where \( C \) is the circumference of the hemisphere. An additional amount (one half inch) should be added to the lower end of the half lune for the lap or tab, but the top end may be cut off so as to underlay the disk at the North Pole by one inch.

The width of a metal lune at any latitude north of the equator is

\[
W_\theta = W \cos \theta + L
\]

where \( \theta \) is the angle of latitude, \( W_\theta \) is the width of the lune at the latitude \( \theta \), \( L \) is the combined width of the side lap and the bead, and \( W \) is the width of the lune at the equator. If the sphere is insulated with beveled blocks, \( W \) is the outside width of a block at the equator. Otherwise \( W \) is an appropriate width, somewhat more than \( .7\sqrt{R} \) (\( R \) = the radius of the insulated sphere in inches – if feet are used as a unit, use the formula \( .2\sqrt{R} \)).

A line, equal to the distance from the equator to the North Pole, should be drawn on the metal and divided into a number of equal segments, say six, each representing 15 degrees. The widths of the lune at latitudes 15°, 30°, 45°, etc., will be \( W \cos 15° \), \( W \cos 30° \), \( W \cos 45° \), etc., respectively, one half of which should be offset from one side of the centerline and the side lap added, and the other half plus the width of the bead offset from the other side of the centerline. (Note: do not include values for lap and bead in these calculations as that would reduce the amount of lap along the length of the lune similar to the lune itself. The lap should remain unchanged along the entire distance from equator to North Pole, or if full lunes are used, from North Pole to South Pole).

The amount of metal necessary for the tab or lap should be added to the bottom end (equator). The top end of the lune should be cut off leaving about one inch of metal to extend under the disk, covering the North Pole. The side lap may be slightly crimped (except the last inch, which extends under the disk), but crimping has a tendency to distort the metal lune, particularly at its narrower end. A bead is placed on the opposite side, which also should not extend under the disk. The metal lune should be held in a circular position while being beaded in order to prevent buckling of the
outer edge of the bead. Additional lunes should be cut using the first one as a template.

Each lune should be attached at the equator with a sheet metal screw through the tab, and then pulled up tight with the small end, extending under the disk at the North Pole, where it should be attached to the disk with a sheet metal screw. The crimped side lap should be entirely over the adjacent insulation block (if it is a blocked sphere). The next lune should just cover the crimped lap. If openings tend to form, adjacent lunes may be attached to each other with pin rivets or metal screws. When rivets or screws are used, they should be neatly spaced around the head to form concentric circles. All beads should form meridians, which should point directly to the North Pole.
PRACTICE WORK
SHEET METAL NO. 21

DEVELOP LUNE FOR A VERTICAL TANK WITH SPHERICAL HEAD (FIG. 58)

Swing an indefinite arc representing the circumference of the tank head. Draw centerlines c-a and a-b, thereby obtaining a quarter circle. The quarter circle will represent the actual length of a half lune (from equator to North Pole).

Divide the quarter circle into equal distances, in this case 6. Note that these distances each represent 15° increments along the quarter circle. Determine an appropriate width*) for the lune at m-n and project lines from m and n to the center at c. From the points along the arc b-a, each representing 15° latitude from the previous point, draw lines perpendicular to centerline c-b, intersecting both, lines c-m and c-n. Draw the centerline a-b in the stretch-out equal to b-a in the plan view. Divide the stretch-out into the number of equal spaces chosen along the arc of the plan view and number 1’, 2’, 3’, etc. This will create the stretch-out grid. Using dividers or projection lines, transfer the distances marked 1, 2, 3, 4, 5, 6, 7 in the plan view to the corresponding points in the stretch-out grid. Connecting the end points of the transferred distances with each other along both sides of a-b will create the pattern of the lune. Add an appropriate amount of lap along one side after the pattern has been completed.
*) Note: To create a line W, which is tangent to a circle, just long enough so its extremes never deviate from the curve of the arc for more than 1/16 of an inch, use the following formulas:

(Use \( \frac{2}{\sqrt{R}} \), if the units are in feet and \( \frac{7}{\sqrt{R}} \), if the units are in inches.)

Example 1: A sphere is 10.6 feet in diameter. R being 5.3 feet the square root of 5.3 feet is 2.3 feet. Multiply this result by 0.2 = 0.46 ft. This result can be rounded up or down to a convenient value, in this case 1/2 ft.

Example 2: A sphere is 98 inches in diameter. R being 49 inches the square root of R is 7 in. This result multiplied by 0.7 = 4.9 in. This result can be rounded up or down to a convenient value, in this case 5 in.
In the illustration of a section through the center of the head of an insulated cylindrical tank, the curvature of the arc BOC is constant. The curvature of arcs AB and CE are also constant but at much greater angle than that of arc BOC. In the illustration the points A, B, O, C and E are on the surface of the insulation, which follows the contour of the metal of the tank. The radius of curvature of arcs AB and CE is r and the radius of curvature of arc BOC is R. The rise b is from the chord BC = b to the arc BOC at the center point O. AE = the diameter of the insulated cylindrical tank. A and E are the points where the head curvature ends and they are usually not directly over the weld in the metal.
Thus the central part of the head is part of a sphere while the double curved area near the perimeter of the head is part of a 360° pipe bend. Ideally, tapered metal strips on the rounded head of an insulated cylindrical tank should be a combination of gore and lune, the gore part extending from A to B and the lune part from B to O.

Design pattern for lune to fit the bulging tank top, (Fig. 60): The tank head surface B-O is part of a larger circle showing only an angle of 30 degrees. Divide the distance B-O into a number of equal spaces, representing equal amounts of rotation, in this case 4. On a full circle the individual increments are 7.5 degrees each. Determine an appropriate width (W1) for the lune at point B, using the following formula: 

$$W_1 = \frac{R}{4}$$

where R is the diameter of the insulated tank or D-A, as measured in inches. (Note: this value would be the same as at point A. Due to the small proportional difference from the center D of points A and B, the width can be made equal at both places.) Next, measure the distance of the tank head from points A to B to O. Using these measurements, draw the straight line A-B-O and divide the portion B-O into four equal spaces. Using the value of W1, determine the widths of the lune at W2, W3 and W4 (The end of the lune is obviously 0 and does not need to be determined.)

Example: An insulated tank has a diameter of 128 inches. Therefore, 

$$W_1 = \frac{64 \sqrt{2}}{4} = 5.6$$

Round this number up to 6 inches. The lune being designed covers part of a sphere, which has starts at a parallel that circles the sphere at 60 degrees latitude. Therefore the values of distances W1, W2, W3, and W4 are continuations of a lune that
would begin at the equator having a width of \( W_0 \), or, in terms of latitude, at \( 0^\circ \) latitude. Using the formula for appropriate width, we determined \( W_1 \), at point B, to be 6 inches. Using 6 inches as the width of the latitude 60 degrees, we calculate the width, \( W_0 \), at the equator, or \( 0^\circ \), to be:

\[
W_0 = \frac{W_1}{\cos 60^\circ} = \frac{6}{0.5} = 12''
\]

Using 12 inches as \( W_0 \) to determine the remaining widths at \( W_2 \), \( W_3 \) and \( W_4 \), etc., we obtain the following results (see table in Fig. 61 – convert decimals to inches):

<table>
<thead>
<tr>
<th>Width No.</th>
<th>Degrees of rotation along circle (°)</th>
<th>( \cos ) Value</th>
<th>Equator Value</th>
<th>Widths in Decimals</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_5 )</td>
<td>90.0</td>
<td>0.00</td>
<td>12</td>
<td>0.00</td>
</tr>
<tr>
<td>( W_4 )</td>
<td>82.5</td>
<td>0.13</td>
<td>12</td>
<td>1.57</td>
</tr>
<tr>
<td>( W_3 )</td>
<td>75.0</td>
<td>0.26</td>
<td>12</td>
<td>3.11</td>
</tr>
<tr>
<td>( W_2 )</td>
<td>67.5</td>
<td>0.38</td>
<td>12</td>
<td>4.59</td>
</tr>
<tr>
<td>( W_1 )</td>
<td>60.0</td>
<td>0.50</td>
<td>12</td>
<td>6.00</td>
</tr>
<tr>
<td>( W_0 )</td>
<td>0.0</td>
<td>1.00</td>
<td>12</td>
<td>12.00</td>
</tr>
</tbody>
</table>

Transfer the distances obtained for \( W_1 \) through \( W_4 \) to the respective locations in Fig. 61 and connect the outline to establish the pattern of the lune. Add allowance for lap, bead and crimp. This completes the layout for a lune to cover the tank head.
PRACTICE WORK
SHEET METAL NO. 23

CYLINDRICAL TANK WITH ROUNDED HEAD (SHORTCUT ALTERNATIVE)

**Steps:**

1. Figure A: Find the width of the gore (AB) and the length of the gore (CD).
2. Draw line AB equal to the width of the gore and add for lap (e.g., 3/4").
3. Mark C at the center of AB and draw the centerline CD equal to the length of the gore.
4. Divide the length of the gore (CD) in half. Then divide the lower half into quarters as shown in Fig. B. Draw the line grid and number the lines 1 through 5.
5. Set dividers from C to B on line 1 and drop this distance down and mark it on each side of the centerline of line 2.
6. Set dividers from the centerline on line 2 to the intersection of line BD. Drop this distance down to line 3 on either side of the centerline. Continue this method down to line 5 in each case taking the measurement from the previous line.
7. Connect the points created in this manner on both sides of the centerline with a smooth curve. Continue the smooth curve to D.
PRACTICE WORK
SHEET METAL NO. 24

ROUND TAPER OFF CENTER (FIG. 62):

Draw lines down from the plan view to cross lines C-D and 1-7 in the elevation. Draw the half circle 1 to 7, and divide it into equal spaces. Draw a line from point 1 to C and another from point 7 to D. Continue the two lines to cross each other, to establish point A. Draw a straight line down from point A to intersect line 1-7, to establish point B. Use point B as a center to draw the arcs from points 1, 2, 3, 4, 5, and 6, to intersect line 1-7.

Use point A as a center to draw an arc from each intersecting point on line 1-7 in the elevation to the taper pattern. Set the dividers to span anyone space in the elevation. Place one point of the dividers on arc 1', and swing the other leg of the dividers to cross arc 2'; continue swinging the dividers from one arc to the next until the full circumference is set out as 1' to 7' and 7' to 1'. Draw the connections through the intersecting points from 1' to 1' to obtain the pattern curve.

Use point A as a center to draw the arcs from each intersecting point on line C-D, to cross their respective lines in the taper pattern. Draw the curve through the intersecting points to represent the top diameter.

The X in the plan view in Fig. 62 is drawn to show the amount that the small opening is off center.
PRACTICE WORK
SHEET METAL NO. 25

ROUND TAPER WITH ONE SIDE STRAIGHT

Draw the elevation and one half of the plan view as shown in Fig. 63 (It is not necessary to draw the full plan view showing on top. It was added only for orientation). Divide the large half-circle into equal spaces. Use point 10 as a center to draw the arcs from points 2, 3, 4, 5, 6, 7, 8 and 9 to intersect line 1-10.

Use point A as a center to draw an indefinite arc from each intersecting point on line 1-10 in the elevation to the taper pattern. Set the dividers to span the width of any one space in the large half circle of the elevation. Place one point of the dividers on arc 10' and swing the other leg of the dividers to cross arc 9'. Continue swinging the dividers from one arc to the next until the full circumference is set out as from 10' to 1', and 1' to 10'. Connect the resulting points of intersection to complete the curve 10'-10', which represents the large circumference of the taper.

Draw a line from each point on the curve 10' to 10' to point A. Use point A as a center to draw an arc from each intersecting point on line B-C in Figure 1, to intersect their respective lines in the taper pattern. Connect the resulting points of intersection to complete the curve representing the small circumference of the taper.
35-DEGREE CONICAL (END CAP).

1. Find the diameter of the insulated pipe AB and add to this value 1/5th of the diameter plus twice the amount of lap. Divide the result by 2 to determine the divider setting N-A' shown in the Pattern.
2. Use the setting N-A' with N as center, to swing the large 360° arc A'-B'-A'.
3. Find the diameter of the un-insulated pipe and add to this value 1/5th of the diameter. Divide the result by 2 to obtain the divider setting N-C' for the small arc shown in the Pattern.
4. Use the setting N-C' and with N as center swing a 360° arc from C'-D'-C'.
5. From N draw any straight line to the outside arc establishing point P.
6. With a 72° rotation from P on the large arc draw a second line from N to establish point O on the outside arc.
7. Parallel to N-O mark a line y-k to add lap.
8. Make all cuts only along solid lines to obtain the pattern.
9. Lap line m-P over x-O. Bringing these two edges together will reduce the large and small arcs to fit over the insulation and create a 35° bulge, as shown in the Elevation. (Note: Since 72° is 1/5 of 360°, and since you added 1/5th to the original diameters (and, thus, to the circumferences); you reduced this amount again by taking out the 72° when cutting the pattern). Use the 72° cut out piece for future patterns.
PRACTICE WORK  
SHEET METAL NO. 27  

SQUARE TO SQUARE  

While irregular forms are largely curved surfaces, the method of triangulation is best illustrated by its application to a project having flat surfaces, as shown in Figure 64. Both bases are square, and, in this case, parallel, but diagonally turned in relation to each other, as may be seen from the drawing.

Draw the elevation and plan view, in which a, b, c, d represent the square base, and 1, 2, 3, 4 the plan view of the square top, each side of which shows its true length. Next, connect the top and base by drawing lines from and to the corners in the plan view, as shown. These lines represent the bases of the triangles, which must be constructed so as to find the true lengths of these lines. This is accomplished by constructing, in each case, a right-angled triangle, whose base is equal to the length of any foreshortened line in the plan view, and its altitude to the vertical height of the same line shown in the elevation view. The hypotenuse of such a triangle will then be equal to the true length of the line. In this case, the lines, b-1, c-2, d-3, a-4, etc., are all of the same length. The vertical height AB is the same in the case of each line. A constructed triangle will be sufficient to indicate the true lengths of these lines, and is pieced together as follows: Draw any horizontal line as mn, and from m erect the perpendicular mh equal to the altitude AB in the elevation.

All of the lines connecting the corners in the plan view are equal. Therefore, only one triangle is necessary. Take the distance from b to 1 in the plan view and place it, as shown, from m to n, and draw the line hn. This line represents the true length of the lines b-1, c-2, d-3, etc., in the plan view.

The pattern is to be drawn in one piece, with a seam through 1-e as shown in the plan view. Take this distance 1-a and place it, as shown, from m to g, and then draw a line from h to g, which will be the true length of the seam line 1-e. The true lengths of all the lines in the plan view have now been established. When drawing the triangles in their respective positions of the pattern the adjacent triangles must be completed in the same order as they are shown on the plan view.

Draw any horizontal line as cd in the pattern, equal to cd in the plan view. With a radius equal to hn in the triangles and c and d in the pattern as centers, describe arcs intersecting each other at 3. Draw lines from c to 3 and 3 to d. Then c-d-3 is the correct development of the surface c-3-d in the plan view. The adjacent triangles c-2-3 and d-3-4 are constructed next. With 3-2 in the plan view as radius, and 3 in
the pattern as center, describe the arcs 2 and 4. These arcs are then intersected by arcs described from c and d as centers, with a radius equal to hn in the diagram of triangles. Connect the points of intersection to create triangles c-3-2 and d-3-4, which correspond to similarly numbered surfaces in the plan view.

With a radius equal to cb and da in the plan view, and c and d in the pattern as centers, describe the arcs b and a, which are intersected by arcs described from 2 and 4 as centers and hn in the triangles as radius. Draw lines from 2 to b to c and 4 to a to d in the pattern, which is the pattern for the sides d-4-a and c-2-b in the plan view. Likewise develop the surfaces of the figure shown by 4-a-1 and 2-b-1 in the plan view. Then, with a radius equal to ae in the plan view and a and b in the pattern as centers, describe the arcs m and m. These are intersected by arcs described from 1 and 1 as centers and hg in the diagram of triangles as radius. Draw the lines b to m to 1 and a to m to 1, completing the pattern.
PRACTICE WORK
SHEET METAL NO. 28

SQUARE-TO-ROUND TRANSITION SECTION (FIG. 65):

Figure 65 shows the elevation, plan and half pattern of a square-to-round transition. Start by drawing the square a-b-c-d, which represents the plan view of the top, and circle e-5-1-g, which shows the plan of the base of the transition. Because the circle is located in the center of the square, the four quarters of the transition are symmetrical. Only a quarter of it needs to be divided into a number of equal parts, as shown by the figures 1, 2, 3, 4, 5. From these points draw lines to the corner a. These lines will form the bases of a series of triangles.
whose altitude is equal to the vertical height of the transition and whose hypotenuses will be the real distances from a in the base to the points assumed in the curve of the round end.

Next, draw the elevation ABCD, as shown. To find the true lengths of the lines 1-a, 2-a, 3-a, etc., in the plan view, construct a diagram of triangles as follows: First draw the line G to H, and from G lay off the distances, shown by the lines in the plan view, thus making G-1 equal to a-1, G-2 equal to a-2, G-3 equal a-3, etc. At right angles to HG, draw GF, in height equal to the straight height of the transition, as shown in the elevation, and connect the points on the line G H and F. Also set off the distance m-5 from G, and draw the line F-n, which will give the true length of the seam line m-5 in the plan view.

To develop the half pattern, first draw any line, as a’-b’, equal in length to a-b in the plan view. With F-1 of the diagram of triangles as radius and a’ and b’ as centers, describe arcs intersecting each other, thus establishing point 1 of the half pattern. Next, with the points a’ and b’ as common centers and radii equal to the true lengths of the lines a-1, a-2, a-3, etc., of the plan view, as shown in the diagram of triangles, describe arcs of indefinite lengths. Set the dividers to the length of one of the equal spaces on the quarter circle in the plan view, and, commencing at point 1 in the half pattern, step off a number of spaces on each side to correspond to those shown on the quarter-circle in the plan view (in this case from 1 to 5). Through the obtained points trace a line, as shown from 5 to 1 to 5. With a’ and b’ of the half pattern as centers, and am of the plan view as radius, describe short arcs, which intersect other arcs, using 5 and 5 as centers, and Fn of diagram of triangles as radius. This establishes the points m’ and m’ of the half pattern.

Next, connect the various points by drawing lines from 5 to m’ to a’ and 5 to m’ to b’, completing the half pattern for the tapering body of the transition section shown by ABCD in the elevation.
SHORT RADIUS ELLBOW WITHOUT THROAT (BUTTERFLY) LAYOUT: Fig. 66

With M-M as the center of the insulated pipes and bend, draw the plan view A-B-E-F-C-D-N. Within the plan view also indicate the portion N-E-F, sorting out pipes from the bend. Divide the bend arc into the number of desired miters over which gores are to be fitted. From point 5 on line N-E and point e on line N-F draw straight lines meeting at O, creating the angle 5-O-e at 45°. (Note: Compared to the horizontal line (A-B), line 5-O should be drawn at a rotation of +22.5° and line e-O at +67.5°, where the plus sign indicates a clockwise direction. A minus sign would indicate a counterclockwise direction.) Connect the points e and 5, located along the center line of the bend, completing the triangle O-e-5.

Along sides AB and CD draw half circles and divide into equal spaces (in this case 8). From points 1 through 9 on the half circles draw parallel lines intersecting the lines 0-5 and 5-E as well as 0-e and e-F, The points thus formed on 0-5 and 0-e are then connected with straight lines forming lines 1-a, 2-b, 3-c, 4-d and 5-c.

Divide the arc E-F (= heel of bend) into equal parts, designating segment 9-m-I-5' as the plan view of one miter. Using N as center, draw arcs through points 5, 6, 7, 8 and 9 on line N-E extending through line e-F. This will establish lines i-5', j-6', k-7' and 1-8 of the gore plan view.

To create the throat pattern, draw a straight line (X-Y) with a length equal to the spaces of the half circle plus an additional 2 (in this case the total is 10). Divide this line into equal spaces and with the thus formed points as center and the distances 1-a, 2-b, 3-c, 4-d and 5-e of the plan view marked...
off perpendicular to this line create the respective distances 1-a, 2-b, 3-c, etc., on the throat-pattern grid. Connect the ends of these lines to each other (e through e and 5 through 5). This will produce the pattern 5-e-5-e. Using one of the equal spaces along line XY as the minor axis and 5-e as the major axis, complete both ends of the pattern by drawing the semi-ellipses e-X-5 and e-Y-f. This finishes the throat pattern. To complete the gore pattern, draw a straight line (Q-Z) with the length equal to 1/2 of the circumference of the insulated pipe. Divide Q-Z into equal spaces and with this line as centers, transfer the distances of arcs m-9’, 1-8’, k-7’, j-6’ and i-5’ of the plan view to the points thus created. Connecting the ends i, j, k, l, m, etc., on one side and 5’, 6’, 7’, 8’, 9’, etc., on the other side of the drawing will complete the gore pattern. On all patterns, add for laps and/or seaming, as needed.
### FRACTIONS TO DECIMALS CONVERSION TABLE

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Decimal</th>
<th>Fraction</th>
<th>Decimal</th>
<th>Fraction</th>
<th>Decimal</th>
<th>Fraction</th>
<th>Decimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/64</td>
<td>0.015625</td>
<td>17/64</td>
<td>0.265625</td>
<td>33/64</td>
<td>0.515625</td>
<td>49/64</td>
<td>0.765625</td>
</tr>
<tr>
<td>1/32</td>
<td>0.03125</td>
<td>9/32</td>
<td>0.28125</td>
<td>17/32</td>
<td>0.53125</td>
<td>25/32</td>
<td>0.78125</td>
</tr>
<tr>
<td>3/64</td>
<td>0.046875</td>
<td>19/64</td>
<td>0.296875</td>
<td>35/64</td>
<td>0.546875</td>
<td>51/64</td>
<td>0.796875</td>
</tr>
<tr>
<td>1/16</td>
<td>0.0625</td>
<td>5/16</td>
<td>0.3125</td>
<td>9/16</td>
<td>0.5625</td>
<td>13/16</td>
<td>0.8125</td>
</tr>
<tr>
<td>5/64</td>
<td>0.078125</td>
<td>21/64</td>
<td>0.328125</td>
<td>37/64</td>
<td>0.578125</td>
<td>53/64</td>
<td>0.828125</td>
</tr>
<tr>
<td>3/32</td>
<td>0.09375</td>
<td>11/32</td>
<td>0.34375</td>
<td>19/32</td>
<td>0.59375</td>
<td>27/32</td>
<td>0.84375</td>
</tr>
<tr>
<td>7/64</td>
<td>0.109375</td>
<td>23/64</td>
<td>0.359375</td>
<td>39/64</td>
<td>0.609375</td>
<td>55/64</td>
<td>0.859375</td>
</tr>
<tr>
<td>1/8</td>
<td>0.125</td>
<td>3/8</td>
<td>0.375</td>
<td>5/8</td>
<td>0.625</td>
<td>7/8</td>
<td>0.875</td>
</tr>
<tr>
<td>9/64</td>
<td>0.140625</td>
<td>25/64</td>
<td>0.390625</td>
<td>41/64</td>
<td>0.640625</td>
<td>57/64</td>
<td>0.890625</td>
</tr>
<tr>
<td>5/32</td>
<td>0.15625</td>
<td>13/32</td>
<td>0.40625</td>
<td>21/32</td>
<td>0.65625</td>
<td>29/32</td>
<td>0.90625</td>
</tr>
<tr>
<td>11/64</td>
<td>0.171875</td>
<td>27/64</td>
<td>0.421875</td>
<td>43/64</td>
<td>0.671875</td>
<td>59/64</td>
<td>0.921875</td>
</tr>
<tr>
<td>3/16</td>
<td>0.1875</td>
<td>7/16</td>
<td>0.4375</td>
<td>11/16</td>
<td>0.6875</td>
<td>15/16</td>
<td>0.9375</td>
</tr>
<tr>
<td>13/64</td>
<td>0.203125</td>
<td>29/64</td>
<td>0.453125</td>
<td>45/64</td>
<td>0.703125</td>
<td>61/64</td>
<td>0.953125</td>
</tr>
<tr>
<td>7/32</td>
<td>0.21875</td>
<td>15/32</td>
<td>0.46875</td>
<td>23/32</td>
<td>0.71875</td>
<td>31/32</td>
<td>0.96875</td>
</tr>
<tr>
<td>15/64</td>
<td>0.234375</td>
<td>31/64</td>
<td>0.48438</td>
<td>47/64</td>
<td>0.734375</td>
<td>63/64</td>
<td>0.984375</td>
</tr>
<tr>
<td>1/4</td>
<td>0.250</td>
<td>1/2</td>
<td>0.500</td>
<td>3/4</td>
<td>0.750</td>
<td>1</td>
<td>1.000</td>
</tr>
</tbody>
</table>
### TABLE OF NATURAL TRIGONOMETRIC FUNCTIONS

<table>
<thead>
<tr>
<th>ANGLE</th>
<th>SINE</th>
<th>COSINE</th>
<th>TANGENT</th>
<th>ANGLE</th>
<th>SINE</th>
<th>COSINE</th>
<th>TANGENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1°</td>
<td>0.0175</td>
<td>0.9998</td>
<td>0.0175</td>
<td>46°</td>
<td>0.7193</td>
<td>0.6947</td>
<td>0.7193</td>
</tr>
<tr>
<td>2°</td>
<td>0.0349</td>
<td>0.9994</td>
<td>0.0349</td>
<td>47°</td>
<td>0.7314</td>
<td>0.6820</td>
<td>0.7314</td>
</tr>
<tr>
<td>3°</td>
<td>0.0523</td>
<td>0.9986</td>
<td>0.0523</td>
<td>48°</td>
<td>0.7431</td>
<td>0.6691</td>
<td>0.7431</td>
</tr>
<tr>
<td>4°</td>
<td>0.0698</td>
<td>0.9976</td>
<td>0.0698</td>
<td>49°</td>
<td>0.7547</td>
<td>0.6561</td>
<td>0.7547</td>
</tr>
<tr>
<td>5°</td>
<td>0.0872</td>
<td>0.9962</td>
<td>0.0872</td>
<td>50°</td>
<td>0.7660</td>
<td>0.6428</td>
<td>0.7660</td>
</tr>
<tr>
<td>6°</td>
<td>0.1045</td>
<td>0.9945</td>
<td>0.1045</td>
<td>51°</td>
<td>0.7771</td>
<td>0.6293</td>
<td>0.7771</td>
</tr>
<tr>
<td>7°</td>
<td>0.1219</td>
<td>0.9925</td>
<td>0.1219</td>
<td>52°</td>
<td>0.7880</td>
<td>0.6157</td>
<td>0.7880</td>
</tr>
<tr>
<td>8°</td>
<td>0.1392</td>
<td>0.9903</td>
<td>0.1392</td>
<td>53°</td>
<td>0.7986</td>
<td>0.6018</td>
<td>0.7986</td>
</tr>
<tr>
<td>9°</td>
<td>0.1564</td>
<td>0.9877</td>
<td>0.1564</td>
<td>54°</td>
<td>0.8090</td>
<td>0.5878</td>
<td>0.8090</td>
</tr>
<tr>
<td>10°</td>
<td>0.1736</td>
<td>0.9848</td>
<td>0.1736</td>
<td>55°</td>
<td>0.8192</td>
<td>0.5736</td>
<td>0.8192</td>
</tr>
<tr>
<td>11°</td>
<td>0.1908</td>
<td>0.9816</td>
<td>0.1908</td>
<td>56°</td>
<td>0.8290</td>
<td>0.5592</td>
<td>0.8290</td>
</tr>
<tr>
<td>12°</td>
<td>0.2079</td>
<td>0.9781</td>
<td>0.2079</td>
<td>57°</td>
<td>0.8387</td>
<td>0.5446</td>
<td>0.8387</td>
</tr>
<tr>
<td>13°</td>
<td>0.2250</td>
<td>0.9744</td>
<td>0.2250</td>
<td>58°</td>
<td>0.8480</td>
<td>0.5299</td>
<td>0.8480</td>
</tr>
<tr>
<td>14°</td>
<td>0.2419</td>
<td>0.9703</td>
<td>0.2419</td>
<td>59°</td>
<td>0.8572</td>
<td>0.5150</td>
<td>0.8572</td>
</tr>
<tr>
<td>15°</td>
<td>0.2588</td>
<td>0.9659</td>
<td>0.2588</td>
<td>60°</td>
<td>0.8660</td>
<td>0.5000</td>
<td>0.8660</td>
</tr>
<tr>
<td>16°</td>
<td>0.2756</td>
<td>0.9613</td>
<td>0.2756</td>
<td>61°</td>
<td>0.8746</td>
<td>0.4848</td>
<td>0.8746</td>
</tr>
<tr>
<td>17°</td>
<td>0.2924</td>
<td>0.9563</td>
<td>0.2924</td>
<td>62°</td>
<td>0.8829</td>
<td>0.4695</td>
<td>0.8829</td>
</tr>
<tr>
<td>18°</td>
<td>0.3090</td>
<td>0.9511</td>
<td>0.3090</td>
<td>63°</td>
<td>0.8910</td>
<td>0.4540</td>
<td>0.8910</td>
</tr>
<tr>
<td>19°</td>
<td>0.3256</td>
<td>0.9455</td>
<td>0.3256</td>
<td>64°</td>
<td>0.8988</td>
<td>0.4384</td>
<td>0.8988</td>
</tr>
<tr>
<td>20°</td>
<td>0.3420</td>
<td>0.9397</td>
<td>0.3420</td>
<td>65°</td>
<td>0.9063</td>
<td>0.4226</td>
<td>0.9063</td>
</tr>
<tr>
<td>21°</td>
<td>0.3584</td>
<td>0.9336</td>
<td>0.3584</td>
<td>66°</td>
<td>0.9135</td>
<td>0.4067</td>
<td>0.9135</td>
</tr>
<tr>
<td>22°</td>
<td>0.3746</td>
<td>0.9272</td>
<td>0.3746</td>
<td>67°</td>
<td>0.9205</td>
<td>0.3907</td>
<td>0.9205</td>
</tr>
<tr>
<td>23°</td>
<td>0.3907</td>
<td>0.9205</td>
<td>0.3907</td>
<td>68°</td>
<td>0.9272</td>
<td>0.3746</td>
<td>0.9272</td>
</tr>
<tr>
<td>24°</td>
<td>0.4067</td>
<td>0.9135</td>
<td>0.4067</td>
<td>69°</td>
<td>0.9336</td>
<td>0.3584</td>
<td>0.9336</td>
</tr>
<tr>
<td>25°</td>
<td>0.4226</td>
<td>0.9063</td>
<td>0.4226</td>
<td>70°</td>
<td>0.9397</td>
<td>0.3420</td>
<td>0.9397</td>
</tr>
<tr>
<td>26°</td>
<td>0.4384</td>
<td>0.8988</td>
<td>0.4384</td>
<td>71°</td>
<td>0.9455</td>
<td>0.3256</td>
<td>0.9455</td>
</tr>
<tr>
<td>27°</td>
<td>0.4540</td>
<td>0.8910</td>
<td>0.4540</td>
<td>72°</td>
<td>0.9511</td>
<td>0.3090</td>
<td>0.9511</td>
</tr>
<tr>
<td>28°</td>
<td>0.4695</td>
<td>0.8829</td>
<td>0.4695</td>
<td>73°</td>
<td>0.9563</td>
<td>0.2924</td>
<td>0.9563</td>
</tr>
<tr>
<td>29°</td>
<td>0.4848</td>
<td>0.8746</td>
<td>0.4848</td>
<td>74°</td>
<td>0.9613</td>
<td>0.2756</td>
<td>0.9613</td>
</tr>
<tr>
<td>30°</td>
<td>0.5000</td>
<td>0.8660</td>
<td>0.5000</td>
<td>75°</td>
<td>0.9659</td>
<td>0.2588</td>
<td>0.9659</td>
</tr>
<tr>
<td>31°</td>
<td>0.5150</td>
<td>0.8572</td>
<td>0.5150</td>
<td>76°</td>
<td>0.9703</td>
<td>0.2419</td>
<td>0.9703</td>
</tr>
<tr>
<td>32°</td>
<td>0.5299</td>
<td>0.8480</td>
<td>0.5299</td>
<td>77°</td>
<td>0.9744</td>
<td>0.2250</td>
<td>0.9744</td>
</tr>
<tr>
<td>33°</td>
<td>0.5446</td>
<td>0.8387</td>
<td>0.5446</td>
<td>78°</td>
<td>0.9781</td>
<td>0.2079</td>
<td>0.9781</td>
</tr>
<tr>
<td>34°</td>
<td>0.5592</td>
<td>0.8290</td>
<td>0.5592</td>
<td>79°</td>
<td>0.9816</td>
<td>0.1908</td>
<td>0.9816</td>
</tr>
<tr>
<td>35°</td>
<td>0.5736</td>
<td>0.8192</td>
<td>0.5736</td>
<td>80°</td>
<td>0.9848</td>
<td>0.1736</td>
<td>0.9848</td>
</tr>
<tr>
<td>36°</td>
<td>0.5878</td>
<td>0.8090</td>
<td>0.5878</td>
<td>81°</td>
<td>0.9877</td>
<td>0.1564</td>
<td>0.9877</td>
</tr>
<tr>
<td>37°</td>
<td>0.6018</td>
<td>0.7986</td>
<td>0.6018</td>
<td>82°</td>
<td>0.9903</td>
<td>0.1392</td>
<td>0.9903</td>
</tr>
<tr>
<td>38°</td>
<td>0.6157</td>
<td>0.7880</td>
<td>0.6157</td>
<td>83°</td>
<td>0.9925</td>
<td>0.1219</td>
<td>0.9925</td>
</tr>
<tr>
<td>39°</td>
<td>0.6293</td>
<td>0.7771</td>
<td>0.6293</td>
<td>84°</td>
<td>0.9945</td>
<td>0.1045</td>
<td>0.9945</td>
</tr>
<tr>
<td>40°</td>
<td>0.6428</td>
<td>0.7660</td>
<td>0.6428</td>
<td>85°</td>
<td>0.9962</td>
<td>0.0872</td>
<td>0.9962</td>
</tr>
<tr>
<td>41°</td>
<td>0.6561</td>
<td>0.7547</td>
<td>0.6561</td>
<td>86°</td>
<td>0.9976</td>
<td>0.0698</td>
<td>0.9976</td>
</tr>
<tr>
<td>42°</td>
<td>0.6691</td>
<td>0.7431</td>
<td>0.6691</td>
<td>87°</td>
<td>0.9986</td>
<td>0.0523</td>
<td>0.9986</td>
</tr>
<tr>
<td>43°</td>
<td>0.6820</td>
<td>0.7314</td>
<td>0.6820</td>
<td>88°</td>
<td>0.9994</td>
<td>0.0349</td>
<td>0.9994</td>
</tr>
<tr>
<td>44°</td>
<td>0.6947</td>
<td>0.7193</td>
<td>0.6947</td>
<td>89°</td>
<td>0.9998</td>
<td>0.0175</td>
<td>0.9998</td>
</tr>
<tr>
<td>45°</td>
<td>0.7071</td>
<td>0.7071</td>
<td>0.7071</td>
<td>90°</td>
<td>1.0000</td>
<td>0.0000</td>
<td>1.0000</td>
</tr>
</tbody>
</table>
PRACTICE PROBLEMS:

FIG. 67

Tee Intersecting Cylinders of Equal Diameters at 90°

PROBLEM:
Develop A + B
Roof Flange on the Ridge of a Pitched Roof

FIG. 68

PROBLEM:
Develop full pat. for A + B
FIG. 69

PROBLEM:
Develop A
FIG. 70

Square Tee Intersecting a Round Pipe at a Quarter Turn on a 60° Angle

PROBLEM:
Develop A + B
FIG. 71

Square Tee Intersecting a Round Pipe at a Quarter Turn

PROBLEM:
Develop A + B
FIG. 72

90° Four Piece Round Elbow

PROBLEM:
Develop patterns
FIG. 73
Offset Reducer

PROBLEM.
Develop pattern

3"

0.9"

6"
FIG. 74

PROBLEM:
Develop pattern

Tapering Y-Branch

4” D. → 3’ → 90° → 6” D.
FIG. 75

PROBLEM:
Develop full pattern
FIG. 76

Square to Round Off Center
Inclined Base

PROBLEM:
Develop 1/2 pattern
FIG. 77

PROBLEM:
Develop 1/2 pattern
Problem: Develop Pattern

FIG. 78

Cylinder intersecting cone at 90°
Tankhead Gores (Lunes)

FIG. 79

ELEV. VIEW

PLAN VIEW

4"

FIG. 79

PROBLEM:
Develop pat. A
FIG. 80

Square Tee Intersecting Round
Pipe at 60° & Off Center

PROBLEM:
Develop A + B
Fig. 81

Problem:
Develop \( A + B \)

Round Tee Intersecting Pipe at a 60° Angle on a Tangent
FIG. 82

PROBLEM:
Develop A + B

Tee Intersecting Cylinder of Unequal Diameter at 90°
Problem:
Develop Pattern

Figure 83

Cylinder Intersecting Cone
at 90°
Fig. 84

Tank Head Gores

PLAN VIEW

For 1

For 2

Blank For 3

ELEV. VIEW

Fig. 84

Problem:
Develop pattern for 1 · 2 · 3
Fig. 85
Problem:
Develop Pattern A + B