Developments

Learning Objectives

After studying this chapter, you will be able to:

- Explain the purpose of a development.
- List common applications for developed surfaces.
- Describe the principles of parallel line development, radial line development, and triangulation.
- Develop rectangular, oblique, and truncated objects.
- Create an approximate development of a warped surface.

Technical Terms

Development
Parallel line development
Radial line development
Stretchout line
Triangulation
Truncated

A ***development*** in drafting refers to the layout of a pattern on flat sheet stock. The development might be a pattern for a carton, pan, heating or air conditioning duct, hopper, or any other manufactured product that requires folding or rolling of sheet materials. A flat pattern development for a package design is shown in **Figure 15-1**. A development is also known as a *pattern* or a *stretchout*. The heating, ventilation, and air conditioning (HVAC) industry depends heavily upon developments in the design and construction of systems, **Figure 15-2**.

The construction procedures for developments are closely related to those for intersections (intersections are discussed in Chapter 14). In many instances, intersections have to be identified before a development can be completed. This chapter presents the basic principles used in constructing developments, the common types of developments, and their industrial applications.

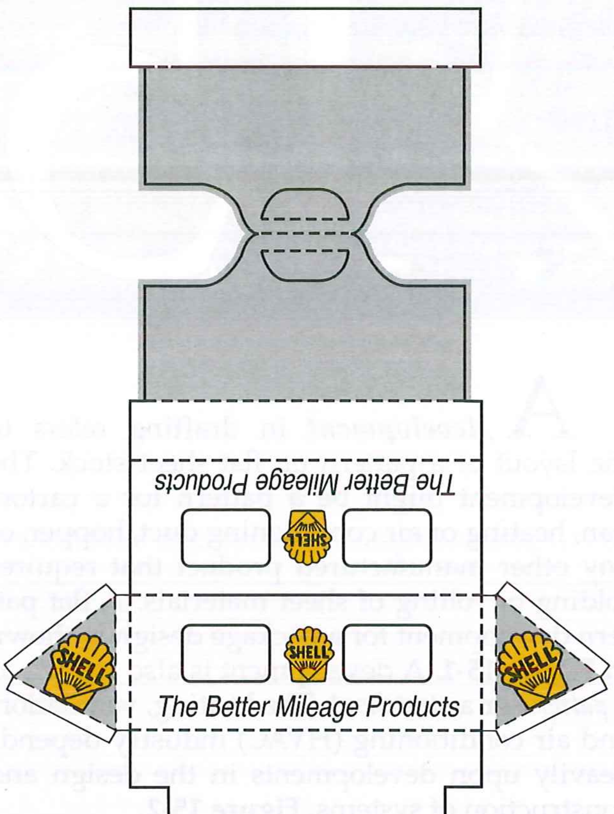

Figure 15-1. Many containers require a flat pattern to be developed. (Chet Johnson, Industrial Designer)

Types of Developments

As is the case with intersections, developments are classified according to the types of surfaces involved. As discussed in Chapter 14, surfaces may be classified as ruled surfaces and double-curve surfaces. Ruled surfaces are subdivided into planes, single-curve surfaces, and warped surfaces. Plane surfaces and single-curve surfaces can be developed. Warped surfaces can only be approximated by flat pattern development. Double-curve surfaces cannot be developed into single-plane surfaces.

Developments are also classified according to the drawing methods used in their construction. The two primary development methods are parallel line development and radial line development. ***Parallel line development*** is used for objects made up of plane surfaces, such as prisms and cylinders. In this type of development, lines are drawn parallel to each other to create the pattern. ***Radial line development*** is used for objects made up of curved edges and nonparallel edges, such as cones and pyramids. In this type of development, lines are drawn radially about a radius point.

Development Procedures

Developments are constructed using standard drafting principles and methods. Some objects can be developed using the principles of orthographic projection, while other objects require auxiliary views or other projection methods. On two-dimensional (2D) drawings, the same drawing principles are applied in both manual and CAD drafting. Manual projection techniques are used in manual drafting, while drawing commands and tools are used in CAD drafting. On three-dimensional (3D)

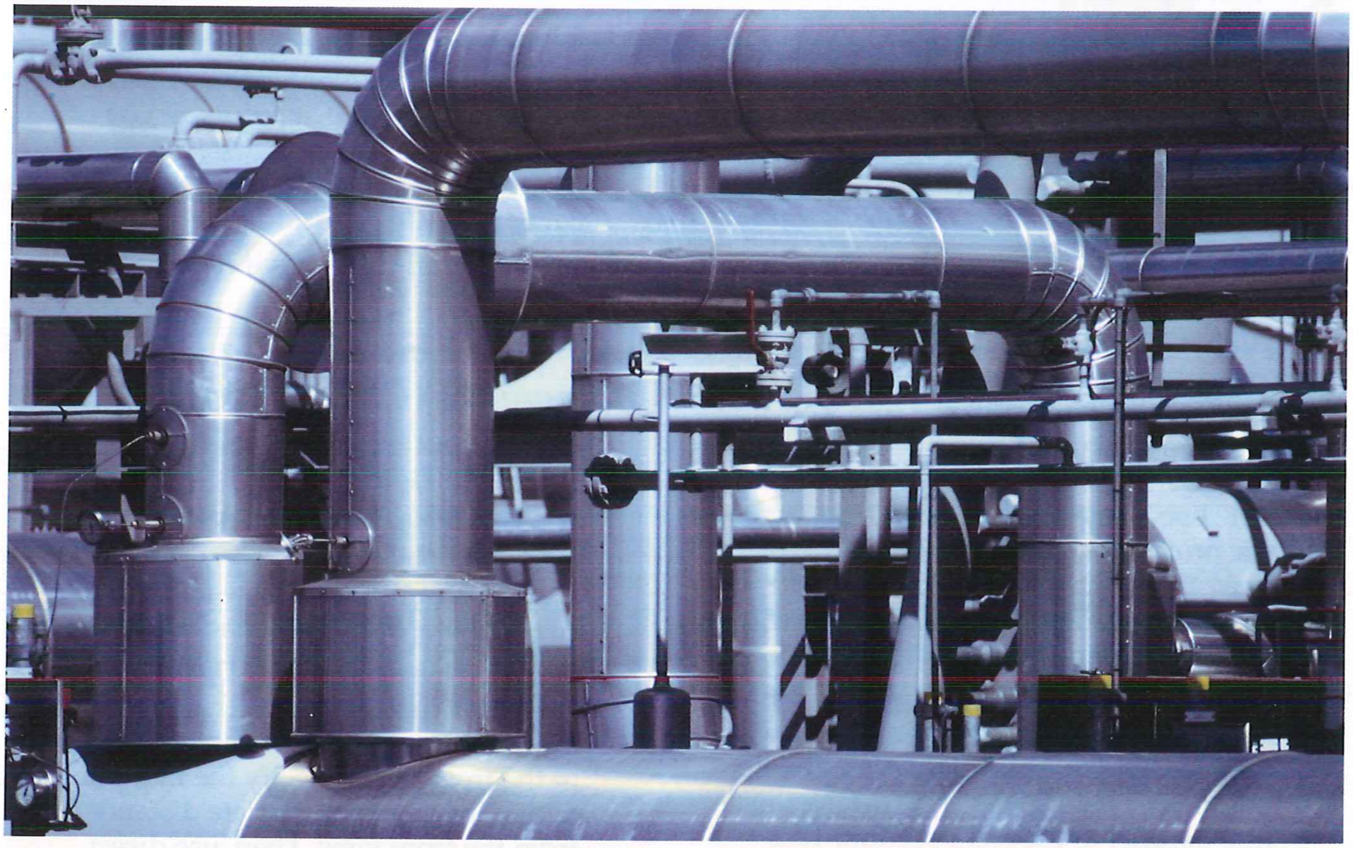

Figure 15-2. Flat patterns are needed to lay out patterns for piping and ductwork.

CAD drawings, more advanced drawing methods may be more common, depending on the type of software used and the manufacturing application. For example, some CAD programs contain tools used to automatically generate 2D patterns from 3D models or user-specified data.

The procedures outlined in the following sections are designed for 2D-based manual and CAD drafting. The procedures include developments of prisms, cylinders, pyramids, and cones, as well as other common shapes that require the generation of patterns for fabrication purposes.

Development of a Rectangular Prism

Using Instruments (Manual Procedure)

The development of a rectangular prism with an inclined bevel is shown in **Figure 15-3**. It is laid out along a ***stretchout line***. This line represents, and is parallel to, the right section of the prism. The prism is developed using parallel line development with the orthographic projection method.

The following procedure is used in manual drafting. The top and front views of the prism are given.

1. Draw an edge view of the right section, below the bevel line, in the front view. Refer to **Figure 15-3A**. Lay off a line to one side of the right section. Make this line parallel to the right section. This will serve as a stretchout line. Refer to **Figure 15-3B**.
2. Identify the corners of the right section, Points A, B, C, and D, in the top and front views. Arrange the points in a clockwise order, since the stretchout will be from an inside view. (Most developments are made from an inside view. This makes the workpiece easier to handle in folding and bending machines. An outside view could be laid out by working in a counterclockwise direction.)
3. The true lengths of the prism along the right section line are shown in the top view. Transfer these measurements to the stretchout line, starting with A-B, B-C, C-D, and D-A. Draw vertical fold lines through these points.
4. The heights of the lateral edges of the prism are projected from the front view. These lines appear true length in this view.
5. Join the points to develop the pattern.
6. Project lines at 90° to form the bevel surface and bottom, if required. Lay off their widths with a compass, using an adjacent side as a radius. Join the points to complete these surfaces.
7. Add material for seams if required.

Using the Line, Xline, and Offset Commands (CAD Procedure)

The top and front views of the prism are given. Refer to **Figure 15-3**.

1. Enter the **Copy** command. Using Ortho mode and object snaps, copy the base of the prism in the front view to create the edge view of the right section.
2. Enter the **Line** command. Draw the stretchout line. Use polar tracking to draw the line parallel to the edge view in the front view. Specify the first point of the line at an appropriate distance from the front view. Then, use direct distance entry to specify the length of the stretchout line. This should be equal to the true length measurements of the four sides of the prism in the top view. Use the **Distance Between Two Points** calculator function to calculate the length of each line and specify the total length as the length of the stretchout line.
3. Enter the **Xline** command. Draw construction lines to establish layout lines for the pattern. Draw the construction lines on a construction layer so that you can freeze it when the drawing is completed. Using Ortho mode, draw a vertical construction line to establish the left edge of the pattern. Enter the **Offset** command. Offset the first line to create the vertical fold lines. Use the **Distance Between Two Points** calculator function to calculate the length of each line in the top view.

4. Enter the **Xline** command. Using Ortho mode, draw horizontal construction lines to locate the heights of the lateral edges of the prism. Locate the first point of each line by selecting the corresponding vertical corner of the prism in the front view.
5. Enter the **Line** command. Using the Intersection object snap, draw lines connecting points where the construction lines intersect to develop the pattern.
6. To create the bevel surface (top surface) and the bottom surface of the pattern, enter the **Offset** command. Offset the inclined line to create the top surface. Use the **Distance Between Two Points** calculator function to calculate the length of the adjacent side and enter the length as the offset distance. Enter the **Line** command and use the Endpoint object snap to draw the sides of the top surface. To create the bottom surface of the pattern, offset the horizontal line segment equal in length to Line CD in the top view. Enter the **Line** command and use the Endpoint object snap to draw the sides of the bottom surface.
7. If seams are required, they can be created by offsetting lines at the appropriate edges and using the **Line** command and polar tracking to draw 45° inclined lines for the seam edges.

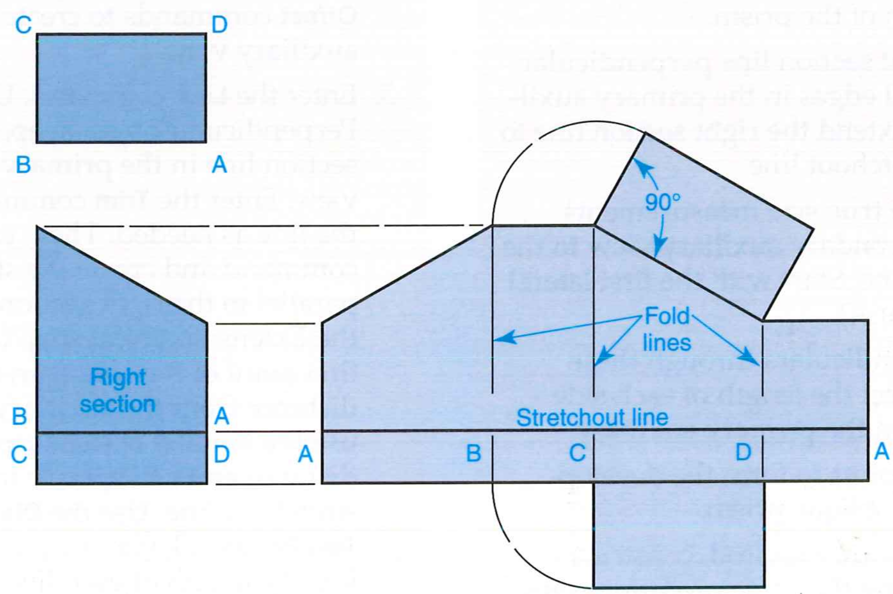

Figure 15-3. A rectangular prism can be developed by using parallel line development with the orthographic projection method.

Development of an Oblique Prism

Using Instruments (Manual Procedure)

The development of a prism that is oblique to all principal planes requires an auxiliary projection. The true size of the right section and the true length of the lateral lines are found in the auxiliary projection. The prism is developed using parallel line development.

Given a prism that is oblique to all principal planes, use the following procedure. See **Figure 15-4**.

1. Construct a primary auxiliary view to determine the true length of the lateral edges.
2. Construct a secondary auxiliary view to determine the true size and shape of the right section of the prism.
3. Draw a right section line perpendicular to the lateral edges in the primary auxiliary view. Extend the right section line to create a stretchout line.
4. Transfer the true size measurements from the secondary auxiliary view to the stretchout line. Start with the first lateral corner (Point A).
5. Draw perpendiculars through these points. Project the length of each side directly from the primary auxiliary.
6. Join these points to form the development of the oblique prism.
7. If end pieces are required, construct them by using the same procedure previously discussed for a rectangular prism.
8. Allow material for seams if required.

Using the Line, Xline, and Offset Commands (CAD Procedure)

The top and front views of the prism are given. Refer to **Figure 15-4**.

1. Using the **Xline** and **Offset** commands, construct a primary auxiliary view. Draw construction lines and offset lines on a construction layer so that you can freeze the layer when the drawing is completed. Draw the reference plane for the primary auxiliary view using the **Xline** command. Use the **Distance Between Two Points** calculator function to calculate offset distances from the top view and offset the reference plane to locate points in the auxiliary view. Using the Perpendicular object snap, draw construction lines from the front view through the offset lines. Then, enter the **Line** command and connect the points to draw the auxiliary view.
2. In a similar fashion, use the **Xline** and **Offset** commands to create the secondary auxiliary view.
3. Enter the **Line** command. Using the Perpendicular object snap, draw a right section line in the primary auxiliary view. Enter the **Trim** command and trim the line as needed. Then, enter the **Line** command and create the stretchout line parallel to the right section line. Use the Extension object snap to specify the first point of the line at an appropriate distance from the auxiliary view. Then, use the Parallel object snap and direct distance entry to specify the length of the stretchout line. Use the **Distance Between Two Points** calculator function to calculate the length of each line in the secondary auxiliary view and specify the total length as the length of the stretchout line.

4. Enter the **Xline** command. Using the Perpendicular object snap, draw a construction line perpendicular to the stretchout line to establish the left edge of the pattern. Enter the **Offset** command. Offset the first line to create the vertical fold lines. Use the **Distance Between Two Points** calculator function to calculate the measurement of each side in the secondary auxiliary view.
5. Enter the **Xline** command. Using the Endpoint and Parallel object snaps, draw construction lines from the sides of the object in the primary auxiliary view to locate the lateral edges of the pattern.
6. Enter the **Line** command. Using the Intersection object snap, draw lines connecting points where the construction lines intersect to develop the pattern.
7. If end pieces and seams are required, construct them by using the **Offset** and **Line** commands as previously discussed.

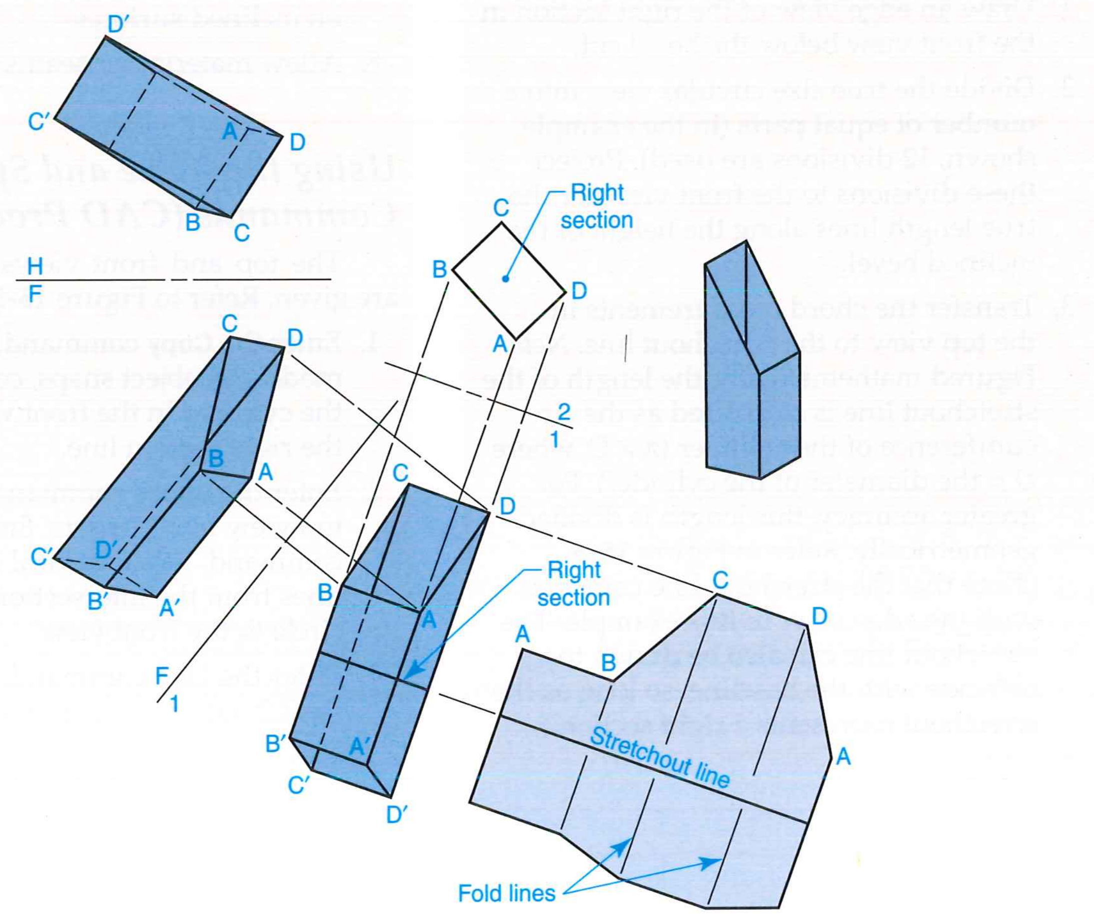

Figure 15-4. An oblique prism can be developed by auxiliary projection and parallel line development.

Development of a Cylinder with an Inclined Bevel

Using Instruments (Manual Procedure)

A cylinder with an inclined bevel is developed by parallel line development. The stretchout line represents, and is parallel to, the right section of the cylinder, **Figure 15-5**. Given the top and front views with the inclined bevel appearing as an edge, use the following procedure.

1. Draw an edge view of the right section in the front view below the bevel cut.
2. Divide the true size circular view into a number of equal parts (in the example shown, 12 divisions are used). Project these divisions to the front view for the true length lines along the height of the inclined bevel.
3. Transfer the chord measurements in the top view to the stretchout line. *Note:* Figured mathematically, the length of the stretchout line is calculated as the circumference of the cylinder ($\pi \times D$, where D = the diameter of the cylinder). For greater accuracy, this length is divided geometrically. Refer to **Figure 15-5**. (Note that the stretchout line coincides with the edge view in this example. The stretchout line can also be drawn to coincide with the baseline, so long as the stretchout represents a right section.)
4. Draw perpendiculars through the points of intersection on the stretchout line.
5. Project the baseline across the full length of the stretchout. Project the height of each true length line in the front view to its corresponding line in the stretchout.
6. Sketch a smooth freehand curve between these points. Finish the curve with an irregular curve.
7. A base cover is drawn as a circle and is the same size as the right section. The cover for the inclined bevel is constructed as an ellipse. Refer to Chapter 12 for a discussion on constructing ellipses on inclined surfaces.
8. Allow material for seams if required.

Using the Xline and Spline Commands (CAD Procedure)

The top and front views of the cylinder are given. Refer to **Figure 15-5**.

1. Enter the **Copy** command. Using Ortho mode and object snaps, copy the base of the cylinder in the front view to create the right section line.
2. Enter the **Divide** command. Divide the top view into 12 parts. Enter the **Xline** command. Draw vertical construction lines from the intersection points on the circle to the front view.
3. Enter the **Line** command. Draw the stretchout line. Use polar tracking to

draw the line parallel to the edge view in the front view. Specify the first point of the line at an appropriate distance from the front view. Then, use direct distance entry to specify the length of the stretchout line. Use the **Properties** command to determine the circumference of the cylinder and specify the value as the length of the stretchout line. Enter the **Copy** command. Using Ortho mode, copy the stretchout line to create the baseline of the pattern. Use the Extension object snap to copy the line so that it coincides with the base of the cylinder in the front view.

4. Enter the **Divide** command. Divide the stretchout line into 12 parts.
5. Enter the **Xline** command. Draw vertical construction lines through the points of intersection on the stretchout line. Draw horizontal construction lines through the points of intersection in the front view.
6. Enter the **Spline** command. Draw a spline through the points where the construction lines intersect in the stretchout. Enter the **Line** command. Draw the left and right edges of the stretchout.
7. If end pieces are required, a base cover can be drawn using the **Circle** command and a cover for the inclined bevel can be drawn using the **Ellipse** command.
8. If seams are required, construct them by using the **Offset** and **Line** commands as previously discussed.

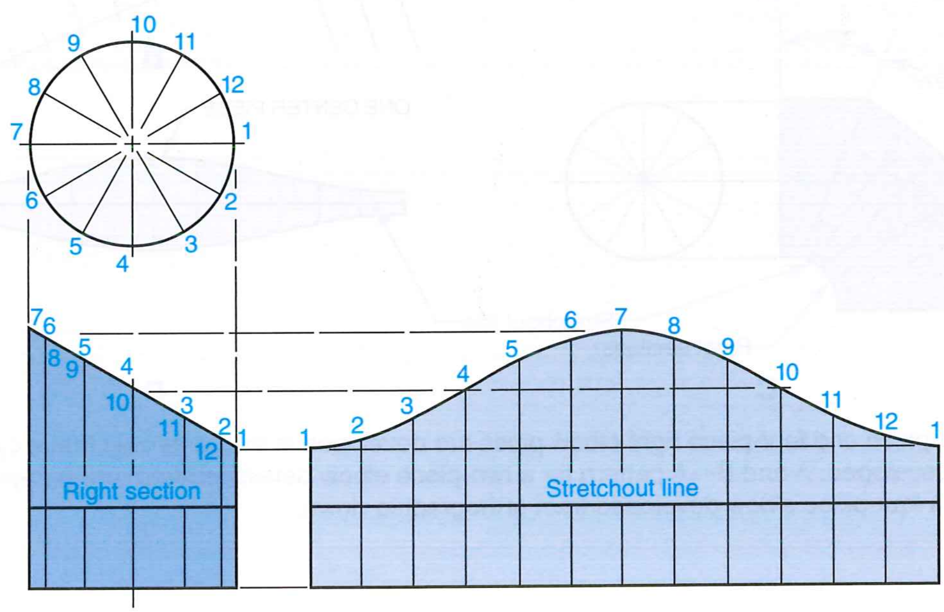

Figure 15-5. Developing a cylinder with an inclined bevel.

Development of a Two-Piece and Four-Piece Elbow Pipe

The procedure for the development of a two-piece or four-piece right elbow pipe is the same as that for a cylinder with an inclined bevel. Mating pieces are laid out using parallel line development as shown in **Figure 15-6**. The stretchout for the two-piece elbow was drawn by calculating the circumference mathematically and dividing the distance geometrically, **Figure 15-6B**. If you are drawing manually, use manual projection techniques to develop the pattern. If you are using a CAD system, use the **Xline** and **Spline** commands as previously discussed.

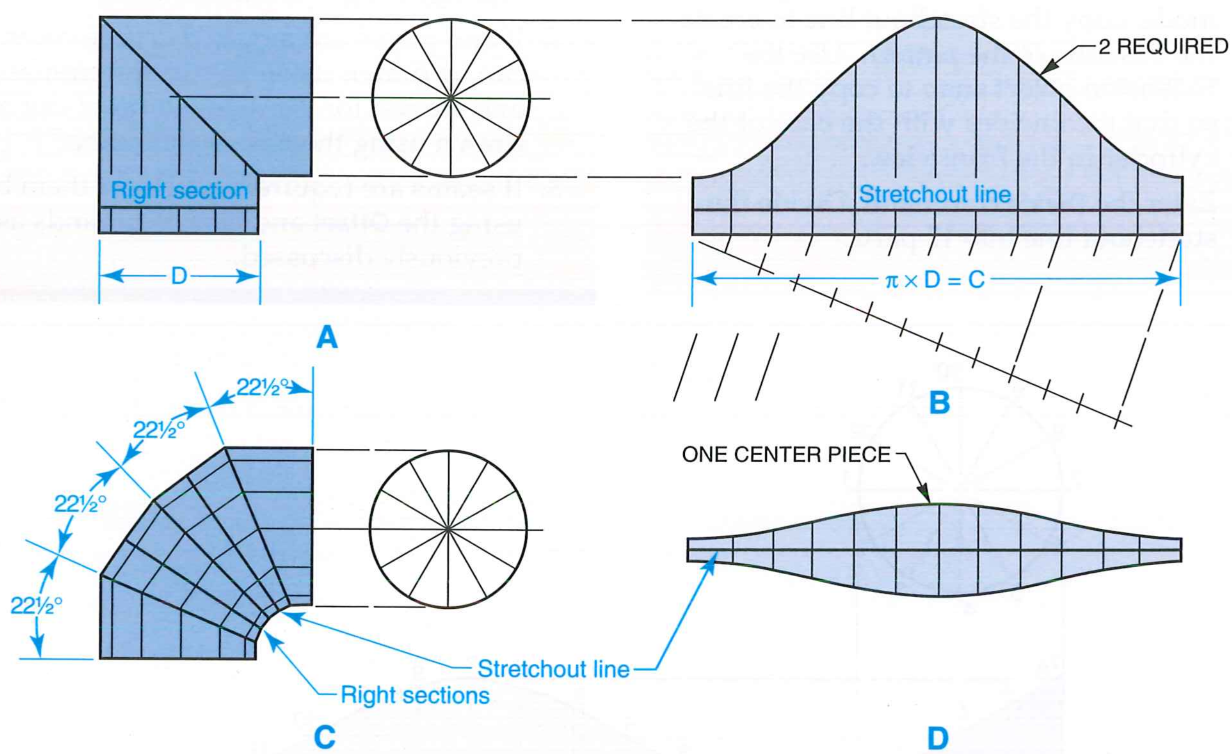

Figure 15-6. Two-piece and four-piece right elbow pipes are developed in the same way that a cylinder with an inclined bevel is developed. A and B—A pattern for a two-piece elbow developed from orthographic views. C and D—A pattern for a four-piece elbow developed from orthographic views.

Development of an Oblique Cylinder

The procedure for laying out an oblique cylinder is similar to that for a cylinder with an inclined bevel. The chief difference is that the true lengths of the oblique cylinder must be found in an auxiliary view, **Figure 15-7**. Parallel line development is used. The end covers, if required, are developed from a secondary auxiliary view. If you are drawing manually, use manual projection techniques to develop the pattern. If you are using a CAD system, use the **Xline**, **Line**, and **Offset** commands to construct the auxiliary view(s), and use the **Xline** and **Spline** commands to develop the pattern as previously discussed.

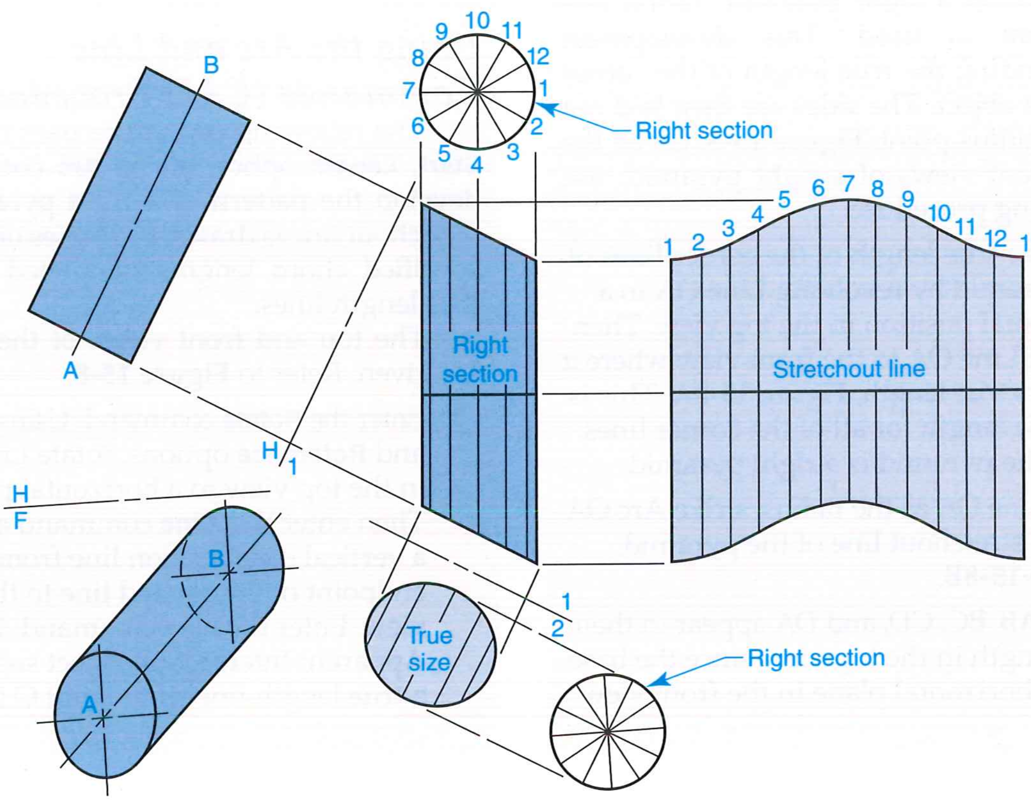

Figure 15-7. In the development of an oblique cylinder, the true lengths must be found in auxiliary projection. The development procedures are similar to those used for the development of a cylinder with an inclined bevel.

CAD Development of a Right Pyramid

Using Instruments (Manual Procedure)

To develop a right pyramid, radial line development is used. This development involves finding the true length of the corner lines of the object. The sides are then laid out around a radius point, **Figure 15-8**. Given the top and front views of a right pyramid, use the following procedure.

1. Find the true length of the corner lines of the pyramid by revolving Line OA to a horizontal position in the top view. Then project Line OA to the front view where it appears true length, **Figure 15-8A**. This is the true length for all of the corner lines, since the pyramid is a right pyramid.
2. With Line OA as the radius, strike Arc OA for the stretchout line of the pyramid, **Figure 15-8B**.
3. Lines AB, BC, CD, and DA appear in their true length in the top view since the base is in a horizontal plane in the front view. Lay off Line AB as a chord on Arc OA. Join the endpoints with Point O to form the triangular side OAB.
4. Continue with the other baselines to form the remaining triangular sides.
5. Lay out the base, if required, adjacent to one of the triangular sides.
6. Allow material for seams if required.

Using the Arc and Line Commands (CAD Procedure)

The following procedure uses the **Center, Start, Length** option of the **Arc** command to develop the pattern of a right pyramid. The stretchout line is drawn as a series of arcs with specified chord lengths calculated from the true length lines.

The top and front views of the pyramid are given. Refer to **Figure 15-8**.

1. Enter the **Rotate** command. Using the **Copy** and **Reference** options, rotate Line OA in the top view to a horizontal position. Then enter the **Xline** command and draw a vertical construction line from the endpoint of the rotated line to the front view. Enter the **Line** command. Using the Apparent Intersection object snap, draw a true length line from Point O in the

front view to the apparent intersection between the baseline of the pyramid and the vertical construction line.

2. Enter the **Copy** command. Copy the true length line anywhere to the right of the top and front views to form one edge of the stretchout. Referring to **Figure 15-8**, this is Line OA in the stretchout.
3. Working in a counterclockwise direction, develop the stretchout using the **Center, Start, Length** option of the **Arc** command. To draw the triangular side OAB, enter the **Arc** command and specify Point O as the center point. Specify Point A as the start point. Then, calculate the chord length by using the **Distance Between Two Points** calculator function to calculate the length of Line AB in the top view. Enter the **Line** command and use object snaps to draw Chord AB and Line OB. This forms the triangular side OAB.
4. In a similar fashion, use the **Arc** and **Line** commands to create the remaining triangular sides.
5. If the base is required, use the **Offset** and **Line** commands to construct a rectangular base adjacent to one of the triangular sides.
6. If seams are required, construct them by using the **Offset** and **Line** commands as previously discussed.

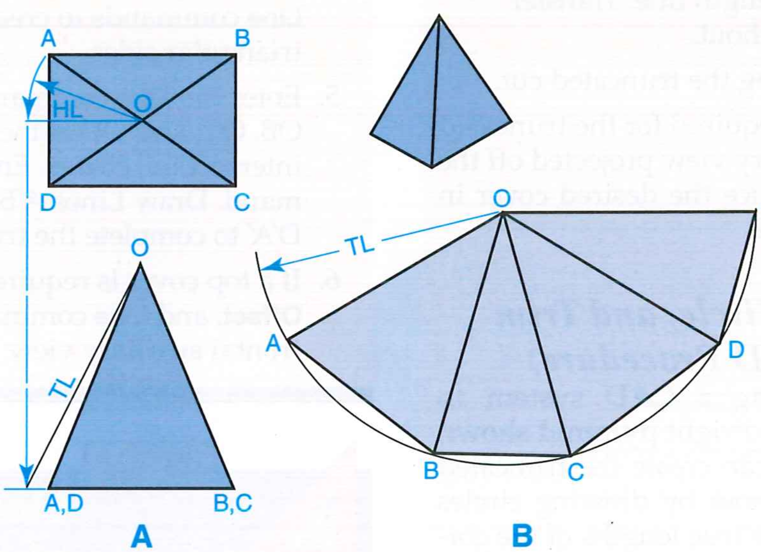

Figure 15-8. To develop a pyramid, the true length lines are laid out around a radius using radial line development.

Development of a Truncated Right Pyramid

Using Instruments (Manual Procedure)

The truncated right pyramid shown in **Figure 15-9** is developed in the same manner as any other right pyramid. However, the truncated portion must also be located. ***Truncated*** means that the apex of the pyramid is "cut off." The following additional steps are necessary to locate the truncated portion.

1. Project the true lengths of the corner lines from the truncated plane horizontally to the true length line. Transfer these to the stretchout.
2. Join the lines along the truncated cut.

If a top cover is required for the truncated cut, a primary auxiliary view projected off the front view will produce the desired cover in its true size and shape.

Using the Arc, Circle, and Trim Commands (CAD Procedure)

If you are using a CAD system to develop the truncated right pyramid shown in **Figure 15-9**, you can create the truncated portion in the stretchout by drawing circles with radii equal to the true lengths of the corner lines from the truncated plane. First, locate the true length line in the front view as shown in **Figure 15-9**. Then proceed as follows.

1. Enter the **Xline** command. Draw construction lines to project the true lengths of the corner lines from the truncated plane (at Points A′, B′, C′, and D′) in the front view.
2. Enter the **Copy** command. Copy the true length line (Line OA) anywhere to the right of the top and front views to form one edge of the stretchout. Enter the **Circle** command. Specify Point O as the center point and draw circles with radii equal to the true lengths of the lines from the truncated plane (radial values A′, B′, C′, and D′).
3. Working in a counterclockwise direction, develop the stretchout using the **Center, Start, Length** option of the **Arc** command and the **Line** command. To draw Arc AB on the stretchout, enter the **Arc** command and specify Point O as the center point. Specify Point A as the start point. Then, calculate the chord length by using the **Distance Between Two Points** calculator function to calculate the length of Line AB in the top view. Enter the **Line** command and use object snaps to draw Chord AB and Line OB. (Lines OB and OA will intersect the circles drawn in the previous step).
4. In a similar fashion, use the **Arc** and **Line** commands to create the remaining triangular sides.
5. Enter the **Trim** command. Trim Lines OA, OB, OC, and OD at the points where they intersect the circles. Enter the **Line** command. Draw Lines A′B′, B′C′, C′D′, and D′A′ to complete the truncated portion.
6. If a top cover is required, use the **Xline**, **Offset**, and **Line** commands to construct a frontal auxiliary view.

Development of a Pyramid Inclined to the Base

The development of a pyramid inclined to its base is shown in **Figure 15-10**. The procedure is very similar to the development of a right pyramid, except that the sides vary in their true lengths due to the offset of the apex.

The true lengths are determined by rotating the corner lines of the lateral sides in the top view into a horizontal line. The lines are then projected to the front view, **Figure 15-10A**. Each surface is laid out in the development as a triangle with three sides given, starting with a side involving the

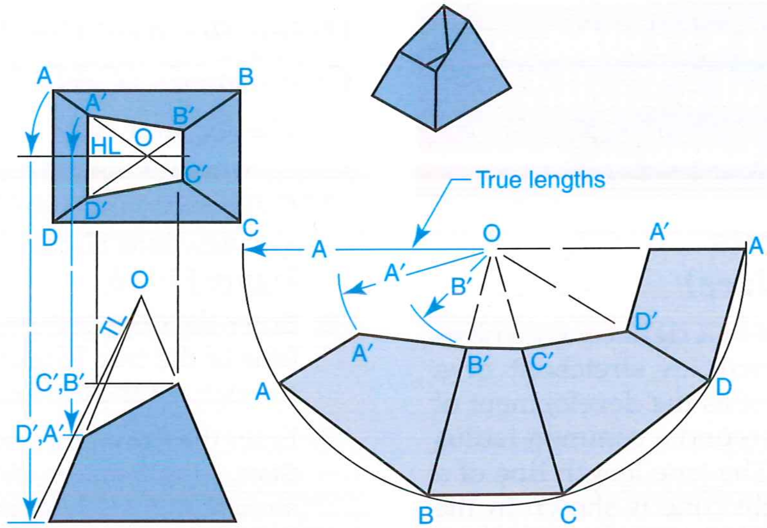

Figure 15-9. A truncated pyramid is developed in the same manner as a right pyramid. The truncated portion must also be located.

shortest seam (Seam OA′A), **Figure 15-10B**. If you are drawing manually, use a compass and manual projection techniques. If you are using a CAD system, project true length lines using the **Rotate** and **Xline** commands. You can create the stretchout using the **Arc** and **Line** commands as previously discussed or you can draw each side as a triangle using the **Line** and **Circle** commands. To create the truncated portion of the pyramid, use the **Circle** and **Trim** commands as previously discussed.

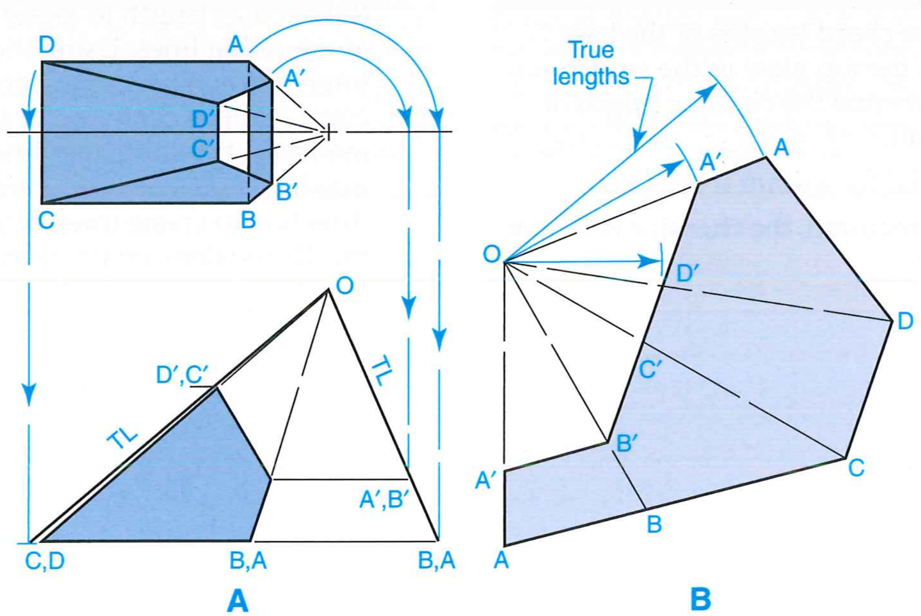

Figure 15-10. To develop a truncated pyramid inclined to its base, true length lines are first projected. These lines are of different lengths. The development is laid out by constructing triangles and then locating the truncated portion.

Development of a Right Cone

Using Instruments (Manual Procedure)

The development of a right cone involves radial line development. A stretchout of a cone can be thought of as the development of a series of triangles around a common radius point, **Figure 15-11**. The true length line of a side element of a right cone is shown in the front view as Line O1, **Figure 15-11A**. The base circle is divided into a number of equal parts and transferred to the radial arc in the stretchout. This will give the circular length of the development. The baseline of the development is drawn as an arc rather than as a series of chords, since all elements of the lateral surface of the cone are the same length.

Given the top and front views of a right cone, use the following procedure.

1. Divide the base circle into a number of equal parts. Refer to **Figure 15-11A**.
2. With the true length line (Line O1) as the radius, draw an arc as a stretchout line. Refer to **Figure 15-11B**.
3. Transfer the chord lengths of the base circle from the top view to the stretchout line to determine the circular length of development.
4. Add material for a seam if required.

If a base is required, the true size is shown in the top view.

Using the Arc, Circle, and Line Commands (CAD Procedure)

The top and front views of the cone are given. Refer to **Figure 15-11**.

1. Enter the **Divide** command. Divide the top view into 12 parts. Refer to **Figure 15-11A**.
2. Enter the **Copy** command. Copy Line O7 (one of the true length lines) anywhere to the right of the top and front views.
3. Enter the **Arc** command. Using the **Center, Start, Length** option, draw an arc as a stretchout line. Refer to **Figure 15-11B**. Specify Point O as the center point and the endpoint of the true length line as the start point. Specify a length that exceeds the circular length of the pattern. Draw the arc in a counterclockwise direction.
4. To transfer the chord lengths from the top view to the stretchout line, enter the **Circle** command. Specify the center point as the endpoint of the true length line (Point 1) on the stretchout. To specify the radius, use the **Distance Between Two Points** calculator function to calculate one of the chord lengths in the top view. Enter the value to create the circle. Then, enter the **Copy** command. Copy the circle around the circular length to locate the endpoints of the radial lines. Using the Center and Intersection object snaps, copy the first circle from its center point to where it intersects the stretchout line. Continue making copies in a counterclockwise direction to create intersection points for the 12 divisions on the circular length.

5. Enter the **Line** command. Draw the radial lines from the intersection points to Point O.
6. Enter the **Trim** command. Trim the stretch-out arc to the right edge of the pattern. Enter the **Erase** command and erase the construction circles.
7. If a seam is required, construct it by using the **Offset** and **Line** commands as previously discussed. A base can be created by drawing a circle equal in diameter to the top view.

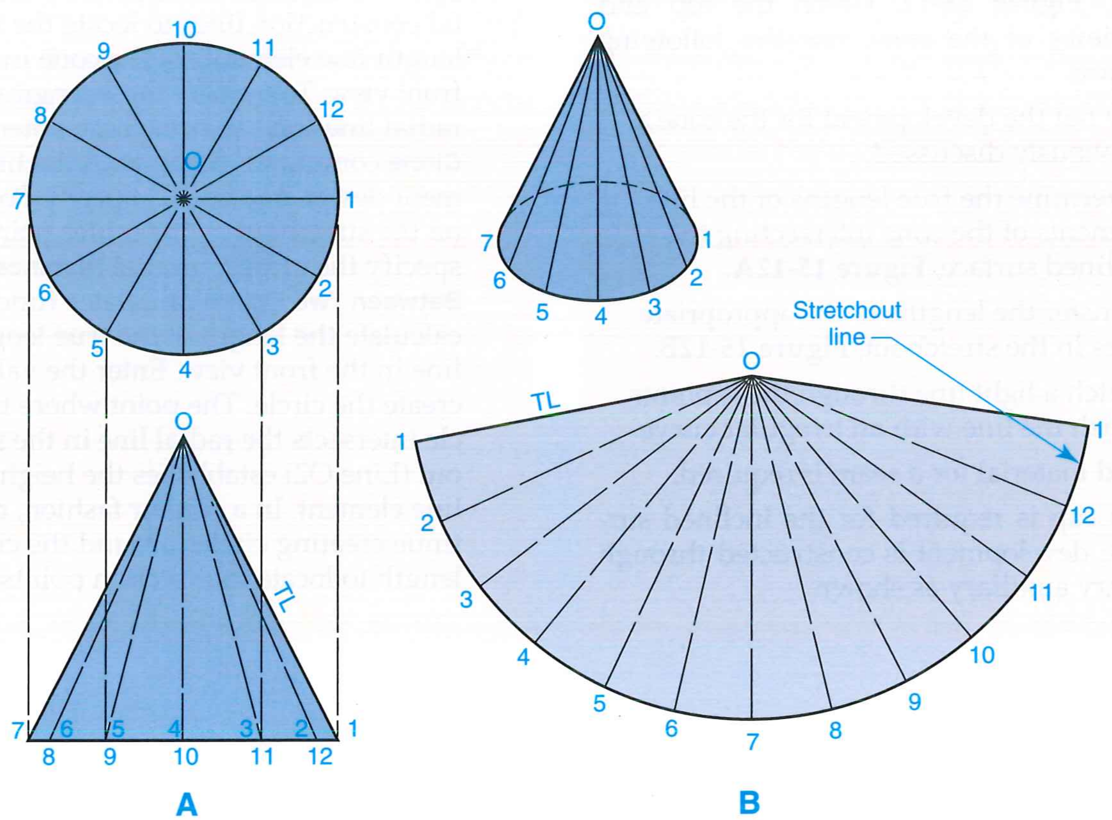

Figure 15-11. To develop a right cone, the chord lengths are laid out on a radial stretchout line.

Development of a Truncated Right Cone

Using Instruments (Manual Procedure)

The development of a truncated right cone is similar to that of a right cone. Additional layout steps are required for the truncated portion, **Figure 15-12**. Given the top and front views of the cone, use the following procedure.

1. Lay out the development for the cone as previously discussed.
2. Determine the true lengths of the line elements of the cone intersecting the inclined surface, **Figure 15-12A**.
3. Transfer the lengths to the appropriate lines in the stretchout, **Figure 15-12B**.
4. Sketch a light line through these points. Finish the line with an irregular curve.
5. Add material for a seam if required.

If a cap is required for the inclined surface, the development is constructed through a primary auxiliary as shown.

Using the Arc, Circle, and Spline Commands (CAD Procedure)

The top and front views of the cone are given. Refer to **Figure 15-12**.

1. Using the **Arc**, **Circle**, and **Line** commands, develop the cone layout as previously discussed. The true length line in the front view can be drawn by using the Apparent Intersection object snap to extend Line 1-1′ to the apex.
2. Enter the **Xline** command. Draw horizontal construction lines to locate the true length line elements of the cone in the front view. To transfer these lengths to the radial lines on the stretchout, enter the **Circle** command. Begin with the line element designated as 2-2′. Specify Point 2 on the stretchout as the center point. To specify the radius, use the **Distance Between Two Points** calculator function to calculate the length of the true length line in the front view. Enter the value to create the circle. The point where the circle intersects the radial line in the stretchout (Line O2) establishes the height of the line element. In a similar fashion, continue creating circles around the circular length to locate intersection points.

3. Enter the **Trim** command. Trim the radial lines to the points where they intersect the construction circles. Enter the **Erase** command. Erase the construction circles.
4. Enter the **Spline** command. Draw a spline through the endpoints of the trimmed lines to complete the truncated portion.
5. If a seam is required, construct it by using the **Offset** and **Line** commands as previously discussed. A cap can be created by constructing a frontal auxiliary view.

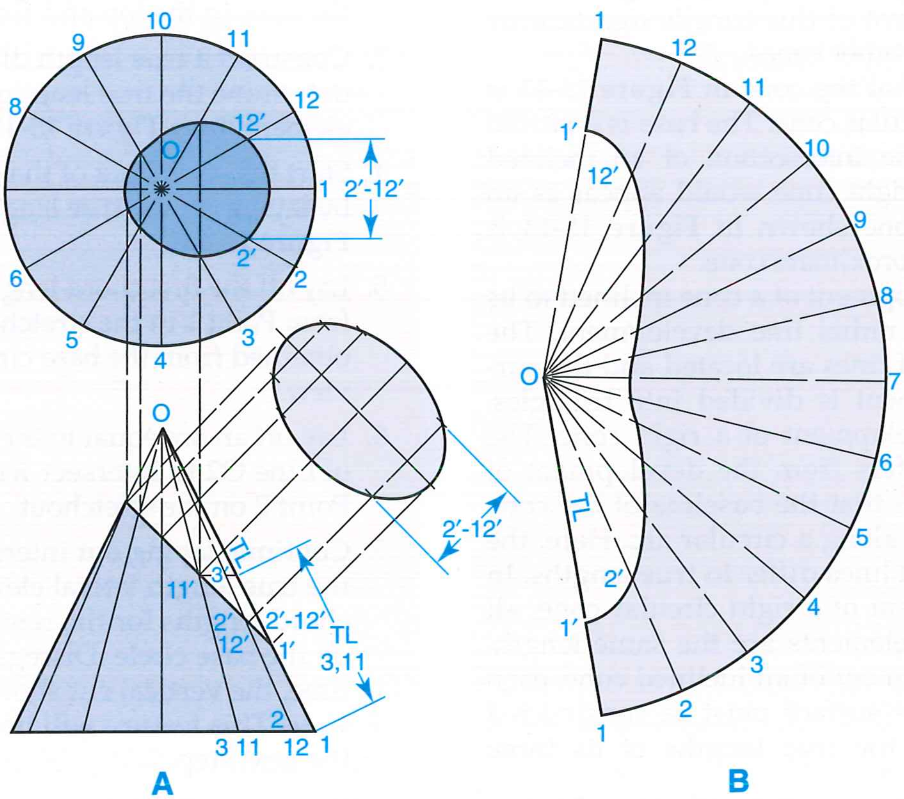

Figure 15-12. A truncated right cone is developed in the same manner as a right cone. The truncated portion must also be located.

Development of a Truncated Cone Inclined to the Base

Using Instruments (Manual Procedure)

A truncated cone that is inclined to its base may be developed as shown in **Figure 15-13**. The development of this cone is significantly different from other cones.

Observe that the cone in **Figure 15-13** is not a right circular cone. The base is a partial true circle. The intersection of an inclined plane with a right cone would appear as an ellipse. The cone shown in **Figure 15-13** is actually an approximate cone.

The development of a cone inclined to its base involves radial line development. The true lengths of lines are located and the surface development is divided into triangles, as in the development of a right cone. The procedure differs from the development of a right cone in that the baseline of the cone is not laid out along a circular arc. Here, the lateral element lines differ in true lengths. In the development of a right circular cone, all of the lateral elements are the same length. In the development of an inclined cone, each triangle on the surface must be constructed by laying off the true lengths of its three sides (the two element lines and a chord length). This type of development is called ***triangulation***.

Given the top and front views, use the following procedure.

1. Divide the circular base (the top view) into a number of equal parts. Project these points to the baseline in the front view, **Figure 15-13A**.
2. Also project these points to the apex of the cone in the top and front views.
3. Construct a true length diagram to determine the true lengths of the lateral element lines, **Figure 15-13B**.
4. Start the stretchout of the development by laying off the true length of Line O1, **Figure 15-13C**.
5. Lay off the first chord length arc (Arc 1-2) from Point 1 in the stretchout. This is obtained from the base circle in the top view.
6. Lay off an arc equal to the true length of Line O2 to intersect with Arc 1-2 at Point 2 on the stretchout.
7. Continue laying out intersecting arcs of the true length lateral element lines and chord lengths for the remaining points on the base circle. Disregard, at this time, the vertical cut shown in the front view. This feature will be projected in the next step.

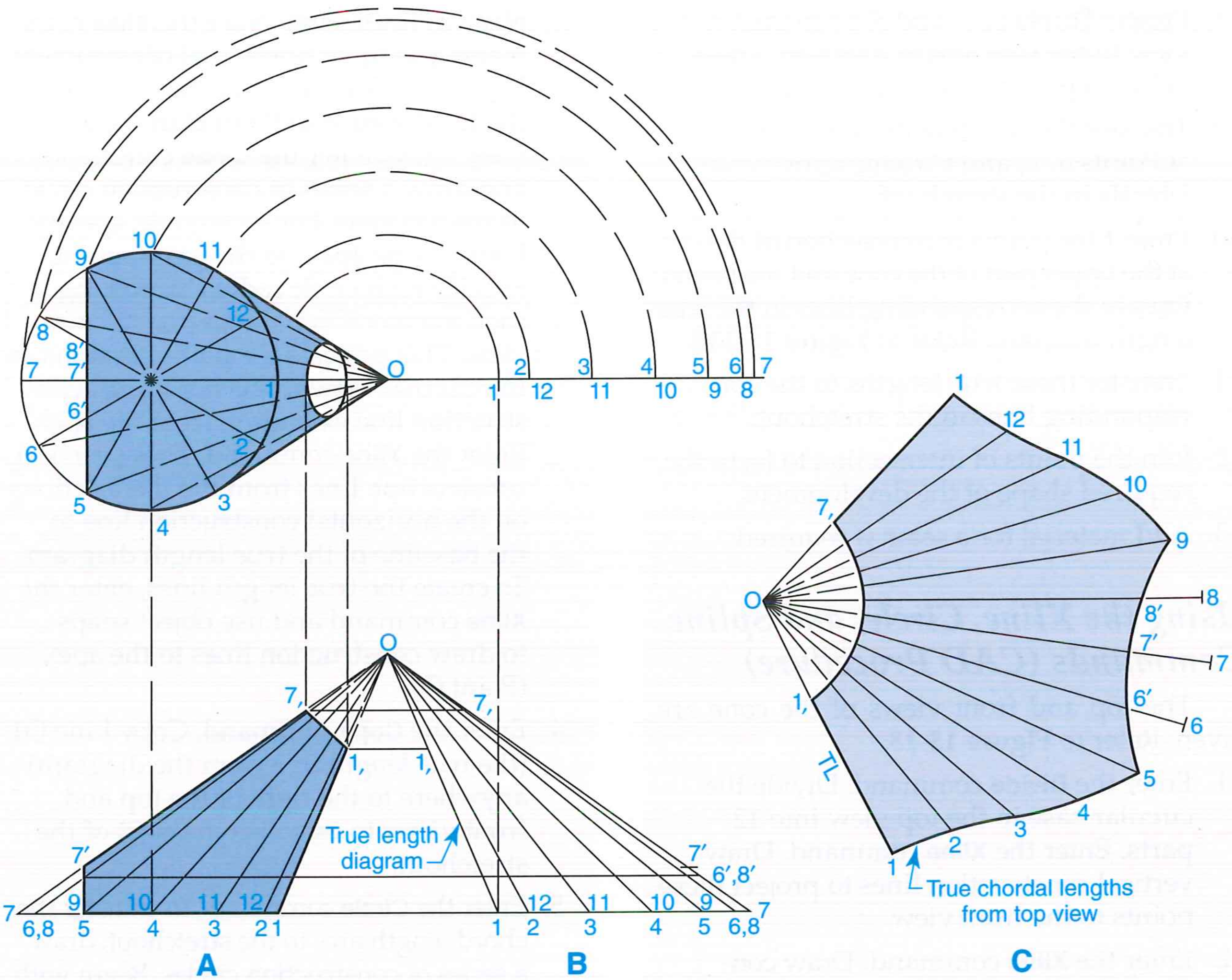

Figure 15-13. A cone inclined to its base is developed using radial line development. The procedure is different from that of other cones. The cone shown here is a truncated cone inclined to its base. The truncated portion must also be located in the stretchout.

8. Project Points 6′, 7′, and 8′ from the front view to the true length diagram. These points represent the vertical cut.
9. Transfer the true length lines located at Points 6′, 7′, and 8′ to the appropriate laterals in the stretchout.
10. Project the points of intersection of the cut at the upper part of the cone and the lateral lines to the corresponding lines in the true length diagram. Refer to **Figure 15-13B**.
11. Transfer these true lengths to the corresponding lines in the stretchout.
12. Join the points of intersection to form the required shape of the development.
13. Add material for a seam if required.

Using the Xline, Circle, and Spline Commands (CAD Procedure)

The top and front views of the cone are given. Refer to **Figure 15-13**.

1. Enter the **Divide** command. Divide the circular base in the top view into 12 parts. Enter the **Xline** command. Draw vertical construction lines to project these points to the front view.
2. Enter the **Xline** command. Draw construction lines from the projected points to the apex of the cone (Point O) in the top and front views. Use the Endpoint and Apparent Intersection object snaps.
3. Construct a true length diagram to determine the true lengths of the lateral element lines. First, enter the **Xline** command and draw horizontal construction lines from Point 1 on the baseline in the front view and Point O in the top view. Then, enter the **Circle** command and draw a series of construction circles in the top view. For each circle, specify Point O (the apex) as the center point. Specify each circle radius by picking each intersection point on the circular view. This projects the point locations on the circular view to the horizontal construction line extending from the apex. Enter the **Xline** command. Draw vertical construction lines from the intersections on the horizontal construction line to the baseline of the true length diagram. To create the true length lines, enter the **Xline** command and use object snaps to draw construction lines to the apex (Point O).
4. Enter the **Copy** command. Copy Line O1 (the true length line from the diagram) anywhere to the right of the top and front views to establish the start of the stretchout.
5. Enter the **Circle** command. To transfer the chord length arcs to the stretchout, draw a series of construction circles. Begin with Arc 1-2. Specify Point 1 on the stretchout as the center point. To specify the radius, use the **Distance Between Two Points** calculator function to calculate the corresponding chord length distance in the top view. Enter the value to create the

circle. Enter the **Circle** command again and specify Point O as the center point. To specify the radius, use the **Distance Between Two Points** calculator function to calculate the true length of Line O2 in the true length diagram. Enter the value to create the circle. The intersection of the two construction circles locates Point 2 on the stretchout.

6. In a similar fashion, locate Points 3, 4, and 5 on one end of the stretchout. Also locate Points 9, 10, 11, 12, and 1 on the other end (the points for the vertical cut will be located in the next step). After locating each point, enter the **Spline** command. Draw two splines through the circle intersections to create the outer arcs on the stretchout. Enter the **Line** command. Draw lines from the intersection points to Point O to create the radial lines.
7. Enter the **Xline** command. Draw horizontal construction lines to project Points 6′, 7′, and 8′ from the front view to the true length diagram. Use object snaps as needed.
8. Enter the **Circle** command. To transfer the true length lines located at Points 6′, 7′, and 8′ to the stretchout, draw a series of construction circles. Begin at Point 5 on the stretchout. Calculate the chord length distance of Arc 5-6 from the top view for the radius of the first circle. For the second circle, specify Point O as the center point and specify the radius by calculating the true length of Line O6′. The intersection of the two circles locates Point 6′ on the stretchout. In a similar fashion, locate Points 7′ and 8′.
9. Enter the **Spline** command. Draw a spline connecting Points 5, 6′, 7′, 8′, and 9 on the stretchout. Enter the **Line** command. Draw lines from the intersection points to Point O to create the remaining radial lines.
10. To project the truncated portion at the top of the cone, enter the **Xline** command. Draw horizontal construction lines from the cut surface in the front view to intersect the lines in the true length diagram. Then, enter the **Circle** command and create a series of construction circles on the stretchout. For each circle, specify Point O as the center point. Specify the radial values by calculating the length of each true length line defining the truncated portion of the cone. Enter the **Trim** command. Trim the radial lines to the points where they intersect the construction circles. Enter the **Spline** command. Draw a spline through the endpoints of the trimmed lines to complete the truncated portion.
11. Enter the **Erase** command. Erase the construction circles.
12. If a seam is required, construct it by using the **Offset** and **Line** commands as previously discussed.

Development of Transition Pieces

Using Instruments (Manual Procedure)

Transition pieces are used to join pipes or ducts of different cross-sectional shapes. For example, a transition piece is needed to join a square duct to a round duct, **Figure 15-14**. Transition pieces are developed by dividing the surface into triangles. The true lengths of the lateral elements are found and are then transferred to a stretchout.

Given the top and front views for a transition piece, use the following procedure. Refer to **Figure 15-14**.

1. Divide the circular opening in the top view into a number of equal parts, **Figure 15-14A**.
2. Project these division points to the edge view of the circular opening in the front view.
3. Connect the points of the four quadrants of the circle to the adjacent corners of the base in the top and front views. These lines represent bend lines in the transition piece.
4. Determine the true lengths of the bend lines by using the corner points in the top view (Points A and B) as centers. Rotate the lengths of the lines into a plane parallel to the frontal plane (Plane AB). Then project these lines by drawing perpendiculars to the height line in the front view. Join these points with the corner points (Points A and B) where the lines appear true length.
5. Make a seam in a flat section of the development by starting the stretchout with the layout of the true length of Line 1-O, **Figure 15-14B**.
6. Strike two true length intersecting arcs, Arcs 1-A and O-A (O-A is shown true length in the top view) to form Triangle 1AO.
7. Strike two true length intersecting arcs, Arc 1-2 (shown true length in the top view) and A-2, to form an adjacent triangle (Triangle 1A2).
8. Continue with the layout of successive adjacent triangles to complete the development.
9. Allow material for a seam if required.

Using the Xline, Circle, and Spline Commands (CAD Procedure)

The top and front views of the transition piece are given. Refer to **Figure 15-14**.

1. Enter the **Divide** command. Divide the circular opening in the top view into 12 parts.
2. Enter the **Xline** command. Draw vertical construction lines from the division points to the front view.
3. Enter the **Xline** command. Draw construction lines to connect the division points of the circle to the adjacent corners of the base in the top and front views. The resulting lines represent the bend lines.
4. Enter the **Xline** command. Draw a horizontal construction line through Points A and B in the top view to create a construction plane. Draw a horizontal construction line through the endpoints of the top of the transition piece in the front view to create a height line. Next, enter the **Circle** command. Using Points A and B in the top view as center points, project the true lengths of the bend lines. Specify the radial values by picking the intersection points on the circle. Each resulting circle will intersect the construction plane.
5. Enter the **Xline** command. Draw vertical construction lines from the intersection points on the construction plane to

the height line in the front view. Draw construction lines from the intersection points on the height line to the baseline corner points (Points A and B) to create the true length lines.

6. Enter the **Copy** command. Copy Line 1-0 anywhere to the right of the top and front views to establish the edge of the stretchout.
7. Enter the **Circle** command. Draw two circles to locate points for drawing Triangle 1AO. To draw the first circle, specify Point 1 as the center point. Specify the radius by using the **Distance Between Two Points** calculator function to calculate the true length of Line 1-A. Enter the value to create the circle. Enter the **Circle** command again and specify Point O as the center point. Specify the radius by using the **Distance Between Two Points** calculator function to calculate the length of Line O-A in the top view. Enter the value to create the circle. Enter the **Line** command. Draw lines from the endpoints of Line 1-0 to the intersection of the circles to form Triangle 1AO.
8. Enter the **Circle** command. Draw two circles to locate Point 2 on the stretchout. Specify Points 1 and A as the center points. Specify the radial values by calculating the length of Arc 1-2 in the top view and the true length of Line A2. The intersection of the circles locates Point 2.
9. In a similar fashion, locate points along the upper curve of the stretchout and construct the edges forming the lower portion of the stretchout.
10. Enter the **Spline** command. Draw a spline through the points along the upper portion of the stretchout.
11. If a seam is required, construct it by using the **Offset** and **Line** commands as previously discussed.

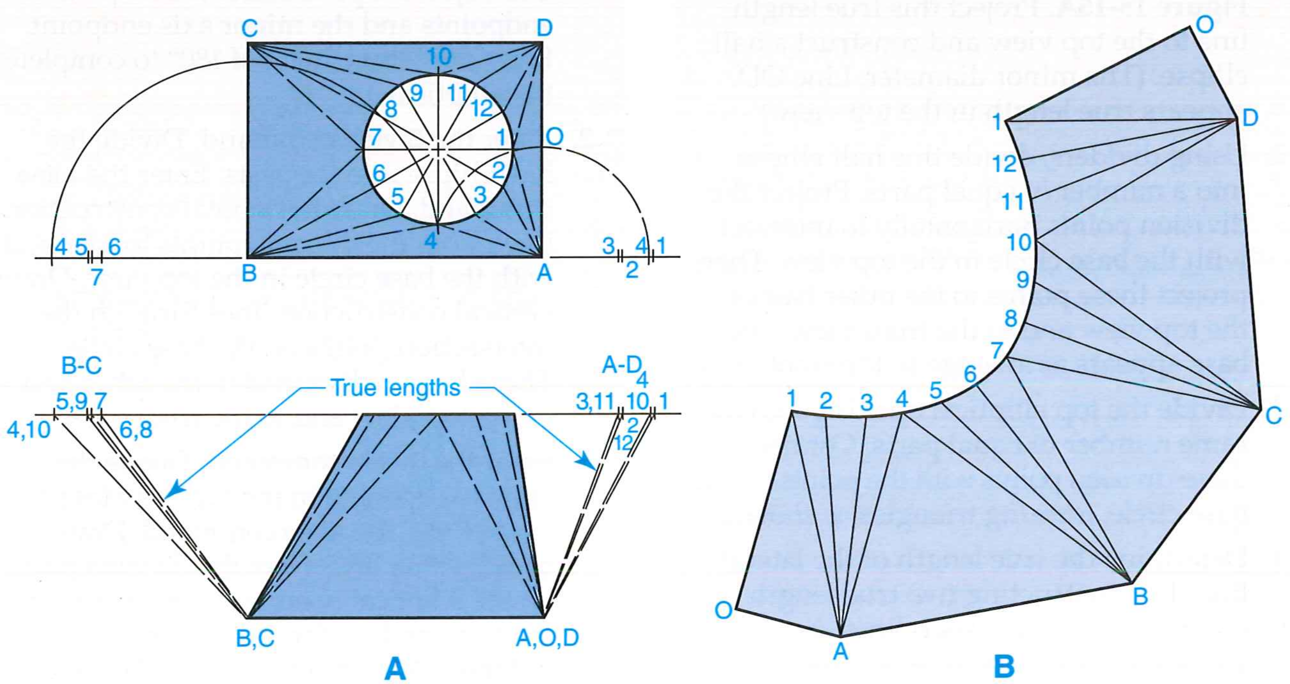

Figure 15-14. A square-to-round transition piece is developed by dividing the surface into triangles and locating points in the stretchout.

Development of a Warped Surface

Using Instruments (Manual Procedure)

A warped surface is a ruled surface that cannot be developed into a single plane. However, an approximation can be developed into a single plane by triangulation.

The transition piece shown in **Figure 15-15** is a transition from a right circular cylinder on an incline to an elliptical opening at the top. The surface is divided into a number of triangles whose sides appear as straight lines in the views. However, these triangles will actually be slightly curved when the development is fabricated.

Given the top and front views, use the following procedure to approximate the development of the warped surface.

1. Determine the true size of the elliptical base by rotating the major diameter (Line AG) in the front view to the horizontal plane, **Figure 15-15A**. Project this true length line to the top view and construct a half ellipse. (The minor diameter, Line OD, appears true length in the top view.)
2. Using dividers, divide this half ellipse into a number of equal parts. Project the division points horizontally to intersect with the base circle in the top view. Then project these points to the other half of the top view and to the front view. The base appears as an edge in the front view.
3. Divide the top elliptical opening into the same number of equal parts. Connect these division points with the points on the base circle, forming triangles as shown.
4. Determine the true length of the lateral lines by constructing two true length diagrams. This will keep lines separate and identifiable. The true horizontal lengths between the baseline segments (on the half ellipse) and the top opening segments are shown in the top view.
5. Construct the stretchout by starting with Line A1 (shown in its true length in the front view). Lay off Triangle 1A2 as a triangle with three sides given. Refer to **Figure 15-15B**.
6. Continue to lay off adjacent triangles in their true length until all are complete.
7. Draw lines forming irregular curves by connecting Points 1 through 7 and A through G.
8. Allow material for a seam if required.

Using the Xline, Circle, and Spline Commands (CAD Procedure)

The top and front views of the transition piece are given. Refer to **Figure 15-15**.

1. Enter the **Rotate** command. Using the **Copy** and **Reference** options, rotate Line AG in the front view to the horizontal plane. Enter the **Xline** command. Draw a vertical construction line from the endpoint of this line to the top view. Next, enter the **Ellipse** command and use the **Arc** option to construct a half ellipse. Use object snaps to select the major axis endpoints and the minor axis endpoint. Enter a rotation angle of 180° to complete the elliptical arc.
2. Enter the **Divide** command. Divide the half ellipse into six parts. Enter the **Xline** command. Draw horizontal construction lines from the division points to intersect with the base circle in the top view. Draw vertical construction lines through the intersection points on the base circle. These lines will extend to the other half of the top view and to the front view.
3. Enter the **Divide** command. Divide the elliptical opening in the top view into 12 parts. Enter the **Xline** command. Draw construction lines from the division points on the elliptical opening to the points on the base circle to form the triangles shown in **Figure 15-15A**. Draw vertical construction lines through the division points on the elliptical opening to locate the division points in the front view.

4. Using the **Xline** and **Offset** commands, construct two true length diagrams. Enter the **Xline** command. Draw the height line as a horizontal construction line. Draw horizontal construction lines from the intersection points on the base. Draw a vertical construction line through the height line on each side of the front view. Then, enter the **Offset** command and offset the vertical construction lines to locate the horizontal length distances in the diagram. Use the **Distance Between Two Points** calculator function to calculate the offset distances from the top view. Enter the **Xline** command and draw the true length lines between the height line and the offset intersection points.
5. Enter the **Copy** command. Copy Line A1 anywhere to the right of the top and front views to establish the edge of the stretchout. Enter the **Circle** command and locate intersection points to create Triangle 1A2. For the first circle, specify Point 1 as the center point. Specify the radius by using the **Distance Between Two Points** calculator function to calculate the length of Arc 1-2 in the top view. For the second circle, specify Point A as the center point. Specify the radius by using the **Distance Between Two Points** calculator function to calculate the true length of Line A2 in the front view. The intersection of the two circles locates Point 2 on the stretchout. Enter the **Line** command and use object snaps to draw Line A2.
6. In a similar fashion, construct successive triangles to develop the pattern. This will locate points defining the upper and lower curves of the stretchout. Refer to **Figure 15-15B**.
7. Enter the **Spline** command. Draw a spline through the points along the upper and lower portions of the stretchout.
8. If a seam is required, construct it by using the **Offset** and **Line** commands as previously discussed.

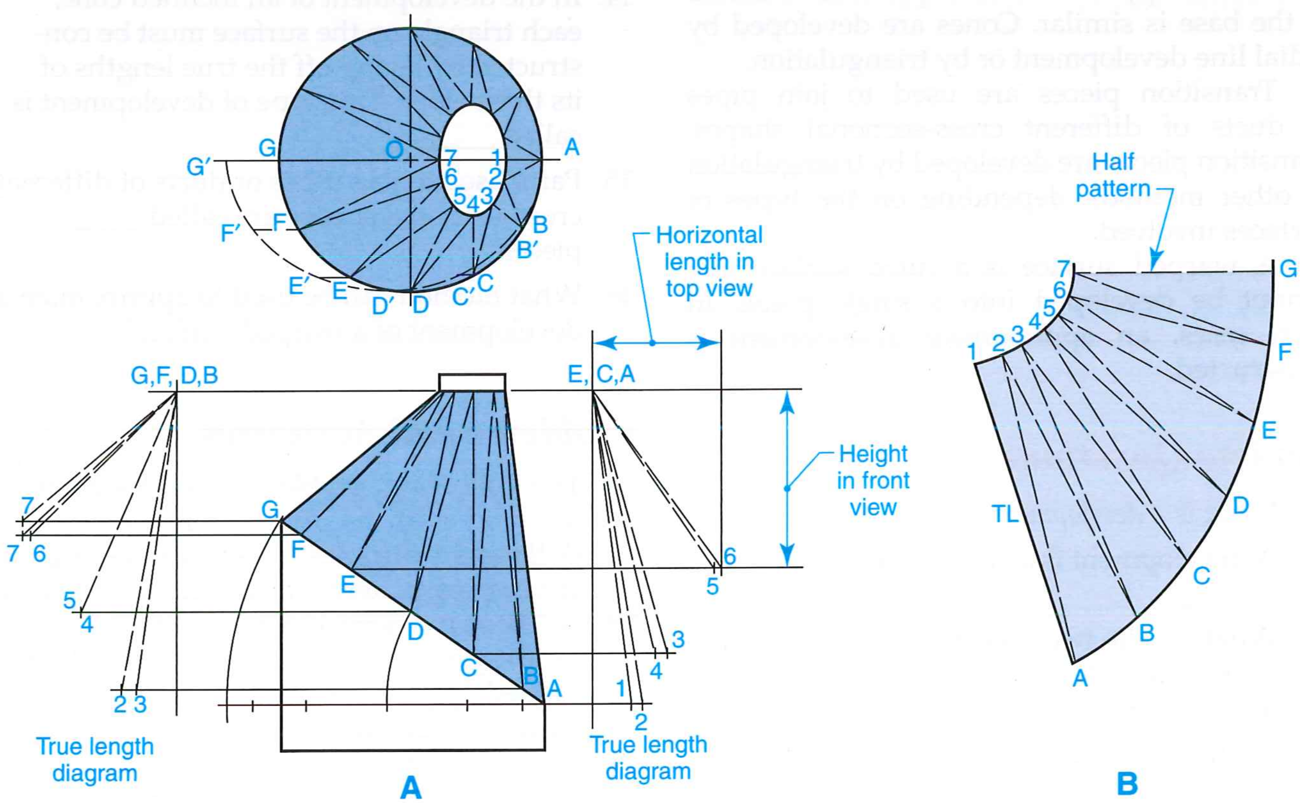

Figure 15-15. The development of a warped surface can be approximated through triangulation.

Chapter Summary

A development in drafting refers to the layout of a pattern on flat sheet stock. Developments are closely related to intersections, because in many instances, intersections have to be identified before a development can be completed. Plane surfaces and single-curve surfaces can be developed. Warped surfaces can only be approximated.

The drafting procedures used to construct developments depend on the types of surfaces involved. Developments are constructed using parallel line development, radial line development, or triangulation.

Right-angle objects are developed by laying out the true length lines on a stretchout line. The development of a prism that is oblique to all principal planes requires an auxiliary projection. The development of a cylinder with an inclined bevel is laid out along a stretchout line. The same procedure is used for the development of a two-piece or four-piece right elbow.

A right pyramid is developed by radial line development. This involves finding the true length of the corner lines. The development of a truncated pyramid and a pyramid inclined to the base is similar. Cones are developed by radial line development or by triangulation.

Transition pieces are used to join pipes or ducts of different cross-sectional shapes. Transition pieces are developed by triangulation or other methods, depending on the types of surfaces involved.

A warped surface is a ruled surface that cannot be developed into a single plane. In such cases, an approximate development is constructed.

Review Questions

1. What is a *development*?
2. A development is also known as a _____ or a _____.
3. What are the two classifications of surfaces as related to developments?
4. What are the two primary types of drawing methods used to construct developments?
5. _____ line development is used for objects made up of plane surfaces, such as prisms and cylinders.
6. _____ line development is used for objects made up of curved edges and nonparallel edges, such as cones and pyramids.
7. The development of a rectangular prism with an inclined bevel is laid out along a _____ line.
8. The development of a prism that is oblique to all principal planes requires an _____ projection.
9. What method is used to develop a cylinder with an inclined bevel?
10. What method is used to develop a right pyramid?
11. A pyramid is _____ when the apex of the geometrical shape is "cut off."
12. What method is used to develop a right cone?
13. In CAD drafting, what command is used to divide a circle into any number of equal parts?
14. In the development of an inclined cone, each triangle on the surface must be constructed by laying off the true lengths of its three sides. This type of development is called _____.
15. Parts used to join pipes or ducts of different cross-sectional shapes are called _____ pieces.
16. What method can be used to approximate a development of a warped surface?

Problems and Activities

The following problems are designed to provide you with an opportunity to practice the skills and principles involved in laying out and developing patterns for various geometrical forms. These problems can be completed manually or using a CAD system. Draw each problem as assigned by your instructor.

Draw the given views for each problem. The problems are shown on 1/4″ graph paper