Part Two
Development of Single Solids - The Five Plutonic Solids

We will now proceed to learn different topics of descriptive geometry using AutoCAD 2D tools and settings.

Throughout this and subsequent learning modules, students are recommended to use the *AutoCAD Descriptive Geometry Template* created in *Section 4* (*Getting Ready To Solve Descriptive Geometry Problems in AutoCAD 2D Environment*) of *Module 1* (*The Basic Concepts & Application of Descriptive Geometry*). The recommended steps are to launch AutoCAD program, open the template file, go to the **File→Save As…** menu to save it as a new file under a different name, in an appropriate folder, and then start to create objects by selecting the appropriate **layer** first. Sometimes, some **Line** and other entities are created first in the **Construction Line** layer; and latter changed into **cut lines** on the **0 layer**; in this case, click-select the lines and then select the **0 layer** from the **Layer** pull-down list in the **Properties** tool bar. To make the instructions brief, information on the selection of appropriate **layers** will be omitted.

Throughout this and subsequent learning modules, brief descriptions on the basic principles, methods and step-to-step process of solving descriptive geometry problems will be presented, following by the **Command Line** text (in `Courier` typeface, the default typeface used in the **Command Line** text) with instructions given inside the brackets [] (in Normal typeface for the text, and **Bold** type face for the names of tools and settings in AutoCAD).

This part includes *Module 2* (*The Development of the Five Plutonic Solids*).

Module 2
The Development of the Five Plutonic Solids

In this module, we will learn how to create flat patterns of the surfaces of the **Five Plutonic Solids**. Convex solids whose faces are all congruent regular polygons are **regular polyhedrons**, also called **Platonic Solids**; and they include **tetrahedron** (with 4 triangle faces), **hexahedron** (cube with 6 square faces**)**, **octohedron** (with 8 triangle faces), **dodecahedron** (with 12 triangle faces), and **icosahedron** (with 20 triangle faces). Since all faces in any of the **Five Plutonic Solids** are congruent regular polygons, the method to draw their developments in AutoCAD is to first draw one regular polygon with **Polygon** tool, and then to copy it several times with the **Copy** tool, and to align the copies in appropriate relationships.

Section 1
The Development of Tetrahedron:

The development of a tetrahedron (*Figure 2-1A*) consists of four equilateral triangular faces. We will draw the development of a tetrahedron made up of four equilateral triangles with 2" side length.

1st Step: Creating the first triangle

To start, launch AutoCAD, open the *AutoCAD Descriptive Geometry Template* file from the *AutoCAD Descriptive Geometry Learning* folder created in *Module 1* of *Part One*, go to the **File→Save As…** menu to save the file as *Module 2-Development of 5 Plutonic Solids* in the same folder, as a **AutoCAD 2004 Drawing [*.dwg]** file. Save often throughout the drafting session.

Turn **ORTHO** and **Endpoint** running **Object Snap** first; then proceed as follows:

`Command: pol` [type *pol* and press the **Enter** key to invoke the **Polygon** tool]
`POLYGON The Enter key number of sides <3>:` [Type 3 for an equilateral triangle, and press the **Enter** key]
`Specify center of polygon or [Edge]: e` [Type e for **Edge** option and press the **Enter** key]
`Specify first corner point or[Chamfer/Elevation/Fillet/Thickness/Width]:` [Click-select a point, the point A in *Figure 2-1B*]

`Specify other corner point or [Dimensions]: 2` [drag the cursor to the right side and type 2 for 2", using **Direct Distance Entry**, or DDE with **ORTHO** on, and press the **Enter** key]

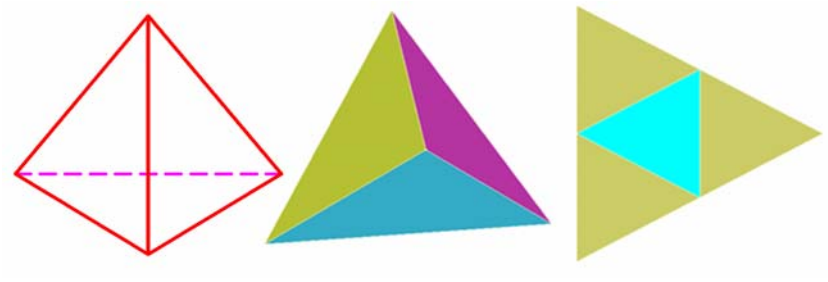

Figure 2-1A: Tetrahedron and development.

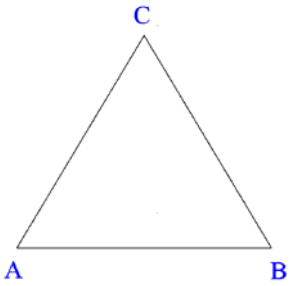

Figure 2-1B: The 1st triangle face.

2nd Step: Copying the first triangle to generate more triangles

Use the **Copy** tool to make several copies of the first triangle face.

`Command: co COPY` [Type co and press the **Enter** key to invoke the **Copy** tool]
`Select objects: 1 found` [Click-select the first triangle]
`Select objects:` [Press the **Enter** key to end selection]
`Specify base point or [Displacement] <Displacement>: [`Click-select point A with the help of **Endpoint** Object Snap]
`Specify second point or <use first point as displacement>:` [Click-select point B with the help of **Endpoint** Object Snap]
`Specify second point or [Exit/Undo] <Exit>:` [Click-select point C with the help of **Endpoint Object Snap**]
`Specify second point or [Exit/Undo] <Exit>:` [Press the **Enter** key to finish]

The basic development of the tetrahedron is complete (*Figure 2-1C*).

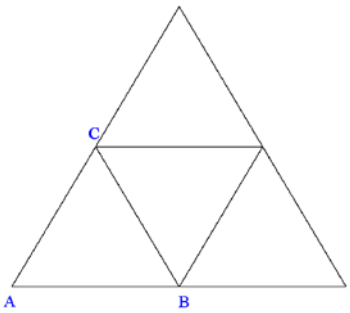

Figure 2-1C: The basic development of a tetrahedron.

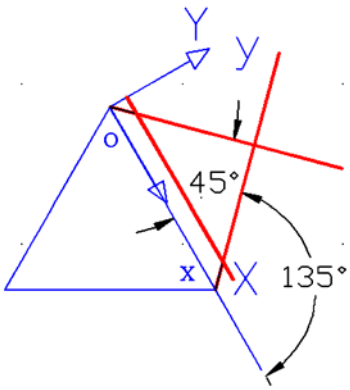

Figure 2-1C: Creating the Offset lap edge and 45° chamfered corner lines.

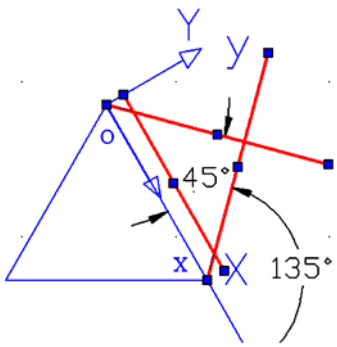

Figure 2-1D: Selecting the lap edge and chamfered lines. Appearance of blue square object Snap marks.

3rd Step: Useing Offset and other tools to draw the .125" wide laps with 45-degree corners and change the line weight of all cutting lines to .035mm

For the convenience of making the 3D folded model with heavy-stock paper, we will add 0.125" or 0.25" thick seam laps with corners chamfered at 45° on the relevant edges of the development patterns, so as to allow the relevant congruent edges to be glued or taped. We will follow this practice throughout all learning modules related to intersection and development. First use the **Offset** tool to create the edge of the laps, as shown in *Figure 2-1C*:

`Command:  OFFSET` [Type o and press the **Enter** key to invoke the **Offset** tool]
`Current settings: Erase source=No  Layer=Source  OFFSETGAPTYPE=0`
`Specify offset distance or [Through/Erase/Layer] <0.250>: .125` [Type .125 for the thickness and press the **Enter** key]
`Select object to offset or [Exit/Undo] <Exit>:` [Click-select the line OX]
`Specify point on side to offset or [Exit/Multiple/Undo] <Exit>:` [click on a point outside of the triangle]
`Select object to offset or [Exit/Undo] <Exit>:` [Press the **Enter** key to finish]

Notice that the laps along some edges are not horizontal. A convenient way to draw 45°corners for the laps in this case is demonstrated in *Figure 2-1C* through *Figure 2-1D*. The **UCS** is first rotated to a convenient position using the **3P** (**3 Points**) option) with the **UCS** tool, then the **Line** tool with **Polar Coordinate Entry** option is used to draw the inclined lines with 45° angles.

`Command: ucs` [Type ucs and press the **Enter** key to invoke the **UCS** settings]

`Current ucs name: *WORLD*`
`The Enter key an option [New/Move/orthoGraphic/Prev/Restore/Save/Del/Apply/?/World]`
`<World>: 3` [Type 3 and press the **Enter** key for the 3P option]
`Specify new origin point <0,0,0>: <Osnap off> <Osnap on>` [Click-select point o for the new origin]
`Specify point on positive portion of X-axis <78.7303,10.8797,0.0000>:` [Click-select point x for the X-Axis]
`Specify point on positive-Y portion of the UCS XY plane` [Click-select any point above o (point y) for the Y-Axis]
`<77.5342,11.8603,0.0000>:`
`Command: l LINE` [Type l and press the **Enter** key to invoke the **Line** tool]
`Specify first point: <Osnap on>` [Click-select point o]
`Specify next point or [Undo]: @1<45` [Type *@1<45*, a **Polar Coordinate Entry** statement]
`Specify next point or [Undo]:` [Press the **Enter** key twice]
`Command: LINE Specify first point:` [Click-select point x]
`Specify next point or [Undo]: @1<135` [Type *@1<135*, a Polar Coordinate Entry statement]
`Specify next point or [Undo]:` [Press the **Enter** key to exit the **Line** tool]

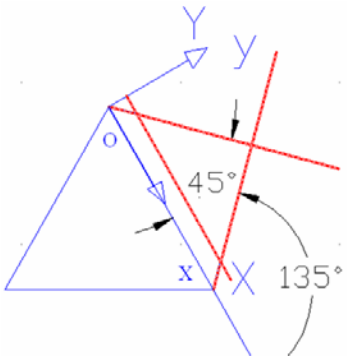

Figure 2-1E: Disappearance of blue square object Snap marks.

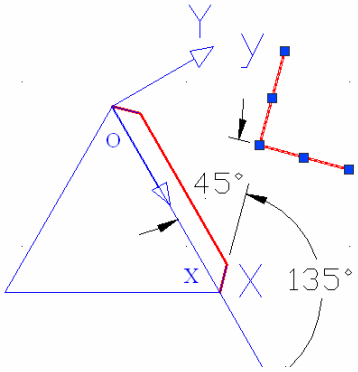

Figure 2-1F: Trimming off the unneeded segments, and selecting the remaining unneeded segments of lines to delete with the Delete key on the keyboard.

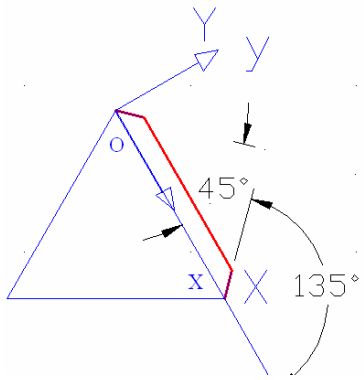

Figure 2-1G: The completed lap on one edge.

Next, use the **Trim** tool to trim off the unneeded segments of the lines to complete the lap (*Figure 2-1D* through *Figure 2-1F*):

`Command: tr` [Type tr and press the **Enter** key to invoke the **Trim** tool]

```
TRIM
Current settings: Projection=UCS, Edge=None
Select cutting edges ...
Select objects or <select all>: 1 found
```
[Click-select the **Offset** lap edge line]
```
Select objects: 1 found, 2 total
```
[Click-select the first chamfered line]
```
Select objects: 1 found, 3 total
```
[Click-select the second chamfered line, blue square **Object Snap** marks appear on the selected lines as shown on *Figure 1-1D*]
```
Select objects:
```
[Press the **Enter** key to end selection; the blue square **Object Snap** marks disappear as shown on *Figure 2-1E*]
```
Select object to trim or shift-select to extend or
[Fence/Crossing/Project/Edge/eRase/Undo]:
```
[Click-select an unneeded side of a line to trim it off]
```
Select object to trim or shift-select to extend or
[Fence/Crossing/Project/Edge/eRase/Undo]:
```
[Click-select another unneeded side of another line to trim it off]
```
Select object to trim or shift-select to extend or
[Fence/Crossing/Project/Edge/eRase/Undo]:
```
[Click-select another unneeded side of another line to trim it off]
```
Select object to trim or shift-select to extend or
[Fence/Crossing/Project/Edge/eRase/Undo]:
```
[Click-select another unneeded side of another line to trim it off, *Figure 2-1F*]
```
Select object to trim or shift-select to extend or
[Fence/Crossing/Project/Edge/eRase/Undo]:
```
[Press the **Enter** key to end trimming]

Next, click-select the two remaining unneeded segments (*Figure 2-1F*) and press the **Delete** key on the keyboard to delete them. The completed lap on one edge is shown on *Figure 2-1G*.

Next, repeat the same steps to add two additional laps and complete the development pattern (*Figure 2-1H*).

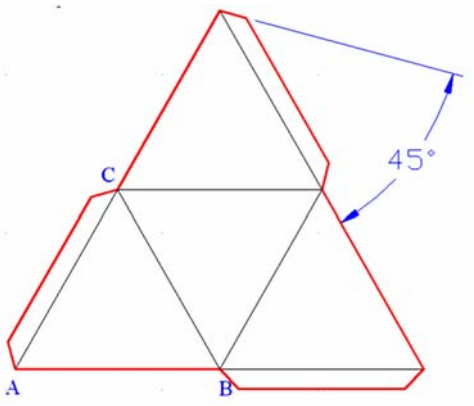

Figure 2-1H: Adding two additional laps and complete the development pattern

4th Step: Checking for mistakes

To check if the development is created correctly, print the drawing file, cut the development with a pair of scissors, fold it up to see if it works!

Section 2
The Development of Hexahedron (cube)

The development of the faces of a hexahedron or cube (*Figure 2-2A*) consists of six square faces. We will draw the development of a hexahedron made up of six squares with 2" side length and with 0.125 wide laps. Turn **ORTHO** and **Endpoint** running **Osnap** on and use **Rectangle**, **Explode**, **Copy** tools to draw the development. Then add laps with the **Offset** and **Line** tools.

1st Step: Creating the first square, create two copies and explode them

To start, create a square with the **Rectangle** tool:

`Command: rec` [Type rec and press the **Enter** key to invoke the **Rectangle** tool]
`RECTANGLE`
`Specify first corner point or [Chamfer/Elevation/Fillet/Thickness/Width]:` [Click-select a point]
`Specify other corner point or [Dimensions]: @2,2` [Type @2,2 to complete a 2" wide square, and press the **Enter** key]

Next, create two copies of the square:

`Command: co` [Type co and press the **Enter** key to invoke the **Copy** tool]
`COPY`
`Select objects: 1 found` [Click-select the square]
`Select objects:` [Press the **Enter** key to end selection]
`Specify base point or [Displacement] <Displacement>:` [Click-select any point inside or close to the square and press the **Enter** key]
`Specify second point or <use first point as displacement>:` [Click-select any convenient point at a reasonable distance from the original square; a copy of the square face is added]
`Specify second point or [Exit/Undo] <Exit>:` [Click-select any convenient point at a reasonable distance from the original square; another copy of the square face is added]
`Specify second point or [Exit/Undo] <Exit>:` [Press the **Enter** key to finish]

Next, explode the squares:

`Command:` [Click-select the three copies of the square]
`Command: x` [Type x and press the **Enter** key to invoke the **Explode** tool]
`EXPLODE 1 found` [Press the **Enter** key to explode the **Rectangle** poliline squares into single line segments]

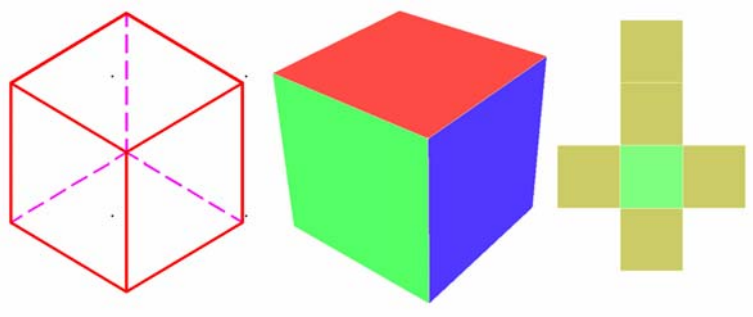

Figure 2-2A: Hexahedron and development.

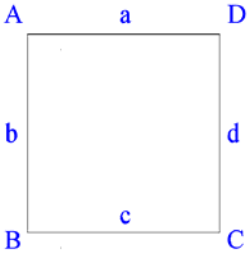

Figure 2-2B: The 1st square face.

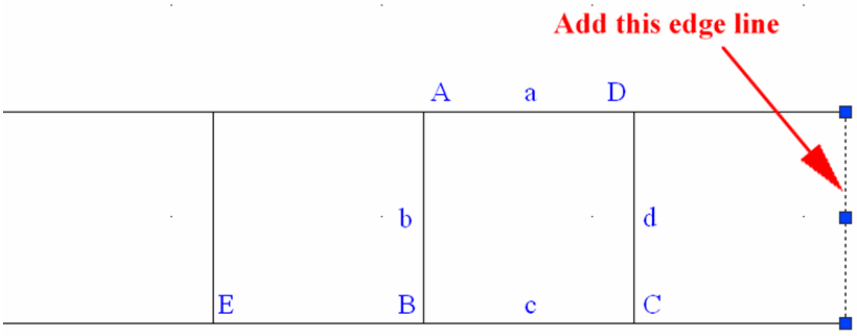

Figure 2-2C: Completing the first four faces (the 1st, and the congruent faces to the left and the right)

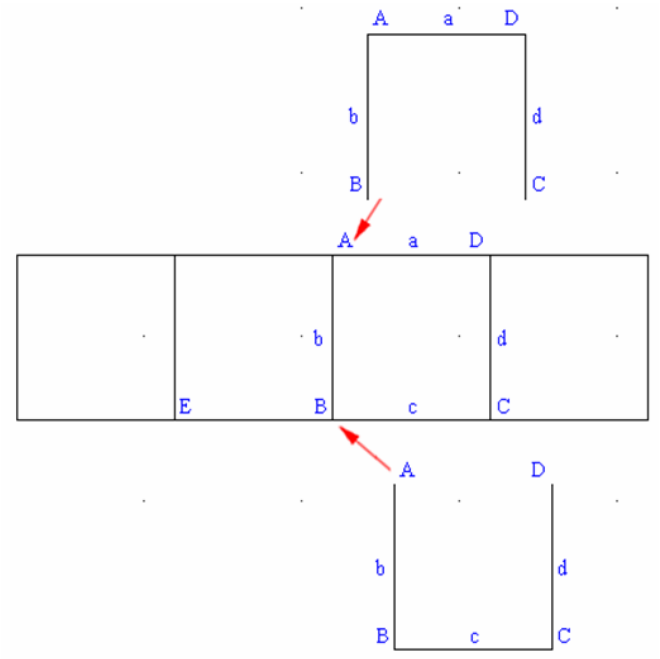

Figure 2-2D: Moving the top and bottom squares.

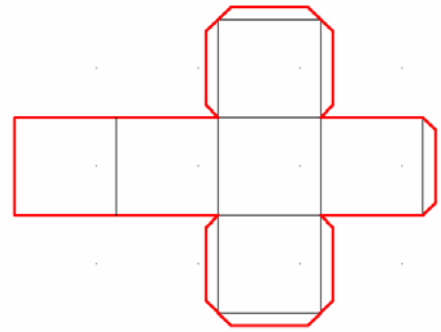

Figure 2-2E: The completed development.

Next, click-select the line segment d of the original square (*Figure 2-2B*) and press the **Delete** key on the keyboard to delete it. Repeat the same step for the line segment c of one copy of square, and for the line segment of another copy of square.

2nd Step: Click-selecting edge lines a, b, and c of the exploded original square and use the Copy tool to create several congruent square faces

`Command: co` [Type co and press the **Enter** key to invoke the **Copy** tool]
`COPY`
`Select objects: 1 found` [Click-select the set of three sides of the square, lines a, b, and c]
`Select objects:` [Press the **Enter** key to end selection]
`Specify base point or [Displacement] <Displacement>:` [Click-select point C with the help of **Endpoint** Object Snap and press the **Enter** key]
Specify second point or <use first point as displacement>: [Click-select point B with the help of **Endpoint** Object Snap; a copy of the square face is added to the left of the original]
`Specify second point or [Exit/Undo] <Exit>:` [Click-select point E with the help of **Endpoint Object Snap;** a copy of the square face is added to the left of the first copy]
`Specify second point or [Exit/Undo] <Exit>:` [Press the **Enter** key to finish]

Repeat the same steps to add one copy to the right of the original square; then use the **Line** tool to add the missing right edge line (*Figure 2-2C*)

Next, use the **Move** tool to move the two copies of the square (top and bottom, as shown on *Figure 2-2D*) to the original copy:

Command: m [Type m and press the **Enter** key to invoke the **Move** tool]
MOVE
Select objects: 1 found [Click-select one line segment of the top copy of square]
Select objects: 1 found, 2 total [Click-select another line segment of the top copy of square]
Select objects: 1 found, 3 total [Click-select the third line segment of the top copy of square]
Select objects: [Press the **Enter** key to end selection]
Specify base point or [Displacement] <Displacement>: [Click-select the point B of the top copy of square]
Specify second point or <use first point as displacement>: [Click-select the point A of the original square]
Specify second point or <use first point as displacement>: [Press the **Enter** key to invoke the **Move** tool again]
Command: MOVE
Select objects: 1 found [Click-select one line segment of the bottom copy of square]
Select objects: 1 found, 2 total [Click-select another line segment of the bottom copy of square]
Select objects: 1 found, 3 total [Click-select the third line segment of the **top** copy of square]
Select objects: [Press the **Enter** key to end selection]
Specify base point or [Displacement] <Displacement>: [Click-select the point A of the top bottom of square]
Specify second point or <use first point as displacement>: [Click-select the point B of the original square]
Specify second point or <use first point as displacement>: [Press the **Enter** key twice to exit the **Move** tool]

3rd Step: Using the Offset and other tools to draw the 0.125" wide laps

Use similar skills explored as in Section 1 to accomplish this task (*Figure 2-2E*).

4th Step: Checking for mistakes

To check if the development is created correctly, print the drawing file, cut the development with a pair of scissors, fold it up to see if it works!

Section 3
The Development of Octahedron

The development of an octahedron consists of eight equilateral triangular faces. Notice that the arrangement of the triangular faces in the development pattern can vary (*Figure 2-3A*).

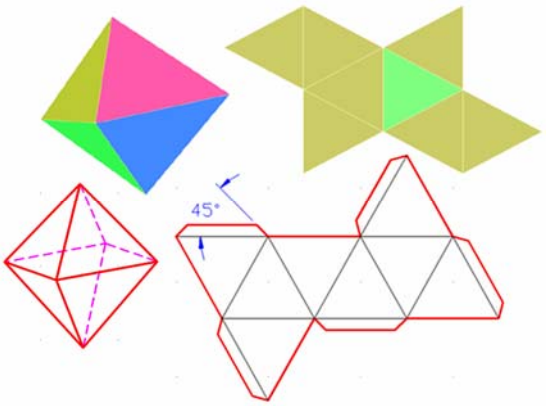

Figure 2-3A: Octahedron and two different arrangements of the triangular faces in the development pattern.

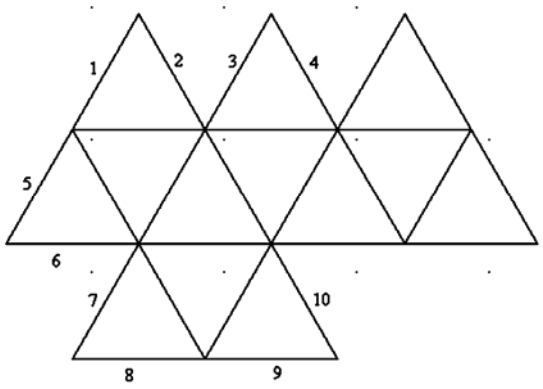

Figure 2-3B: Creating faces with Polygon and Copy tools.

1st Step: Creating an equilateral triangle

To draw the development of an octahedron based on triangular faces with 2" side length and 0.125" wide laps, we will first use **Polygon** tool with **Edge** option and the assistance of the **Endpoint Object Snap**. To start, press **F8** to turn **ORTHO** on; and turn **Endpoint** running **Object Snap** on with the **Drafting Settings** window, and proceed as follows:

`Command: pol` [Type pol and press the **Enter** key to invoke the **Polygon** tool]
`POLYGON Enter number of sides <4>:` [Type 3 for triangle and press the **Enter** key]
`Specify center of polygon or [Edge]: e` [Type e for the **Edge** option and press the **Enter** key]
`Specify first endpoint of edge:` [Click-select a point to start]

`Specify second endpoint of edge: 2` [Type 2 for a equilateral triangle with 2" side length and press the **Enter** key to finish]

2nd Step: Creating multiple copies of equilateral triangles

Next, use the **Copy** tool to create several triangles as shown, with the help of the **Endpoint Object Snap**, so as to attach the adjacent corners of the triangular faces (*Figure 2-3B*).

3rd Step: Completing the development

Next, explode all triangles, and delete lines 1, 2, 3, 4, ...9, 10 (*Figure 2-3B*) to obtain the basic development pattern. Use the **Explode** tool and the **Delete** key on the keyboard to complete this step. Refer to the *1st Step* of *Section 2* of this module to review the usage of the **Explode** tool if necessary.

Next, add 0.125" wide laps to relevant edges (*Figure 2-3C*)

4th Step: Checking for mistakes

To check if the development is created correctly, print the drawing file, cut the development with a pair of scissors, fold it up to see if it works!

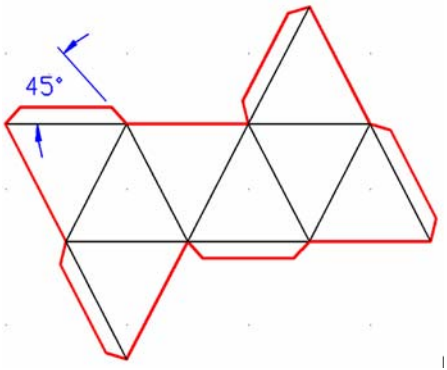

Figure 2-3C: The completed development.

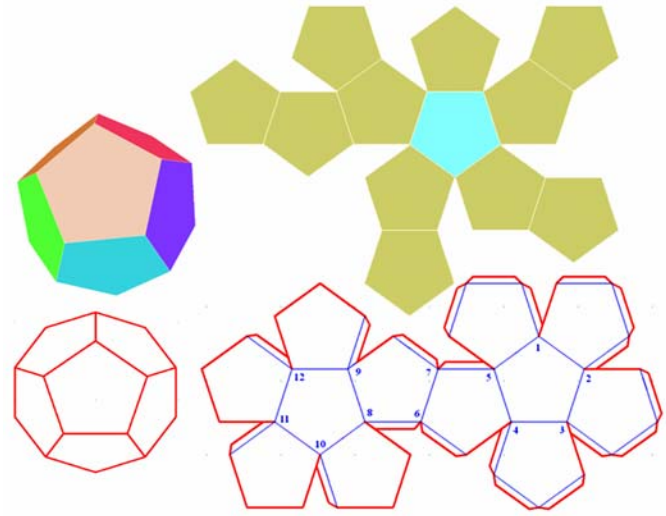

Figure 2-4A: Dodecahedron and two different arrangements of the triangular faces in the development pattern.

Section 4
The Development of Dodecahedron

The development of a dodecahedron consists of twelve pentagonal faces. Notice that the arrangement of the pentagonal faces in the development pattern can vary (*Figure 2-4A*).

1st Step: Creating the first pentagon

To draw the development of a dodecahedron (*Figure 2-4A*) based on pentagonal faces with 2" side length and .0125" wide laps, we will use the **Polygon** tool with **Edge** option and the help of the **Endpoint Object Snap** to first draw a pentagon (*Figure 2-4B*). To start, press **F8** on the keyboard to turn **ORTHO** on. Turn the **Endpoint** running **Object Snap** on.

`Command: pol` [Type pol and press the **Enter** key to invoke the **Polygon** tool]
`POLYGON Enter number of sides <3>: 5` [Type 5 for a pentagon and press the **Enter** key]
`Specify center of polygon or [Edge]: e` [Type e and press the **Enter** key for the **Edge** option]
`Specify first endpoint of edge: Specify second endpoint of edge: 2` [Type 2 and press the **Enter** key for 2" side length. Press F8 to turn **ORTHO** off]

2nd Step: Using Polygon tool with Edge option to draw additional pentagons to complete the development

Invoke the **Polygon** tool again, click-selecting the following pairs of points as **first endpoint of edge** and **second endpoint of edge** at **Command Line** prompt: 1-2, 2-3, 3-4, 4-5, 5-1 to create the first set of additional pentagons A, B, C, D and E; and then 6-7, 8-9, 8-10, 10-11, 11-12, 12-9 to create the second set of additional pentagons F, G, H, I and J; pentagon K is automatically enclosed by the second set of pentagons (*Figure 1-4C*).

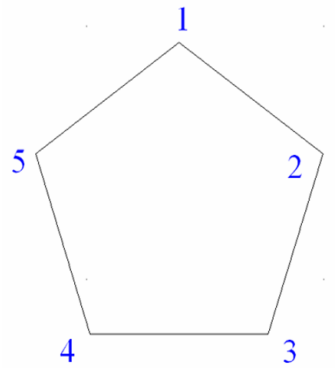

Figure 2-4B: The first pentagon created with the Polygon tool with Edge option.

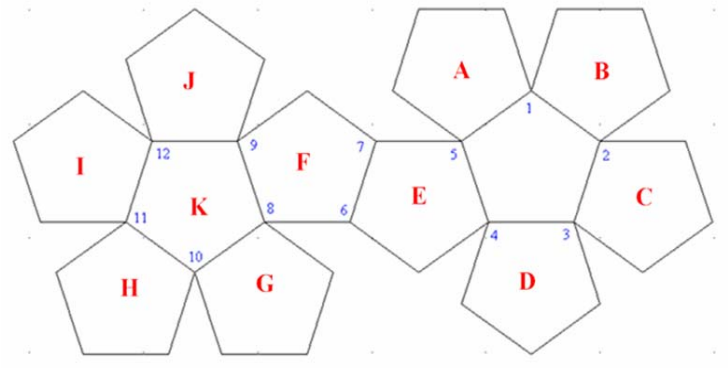

Figure 2-4C: Creating the first and second sets of additional pentagons.

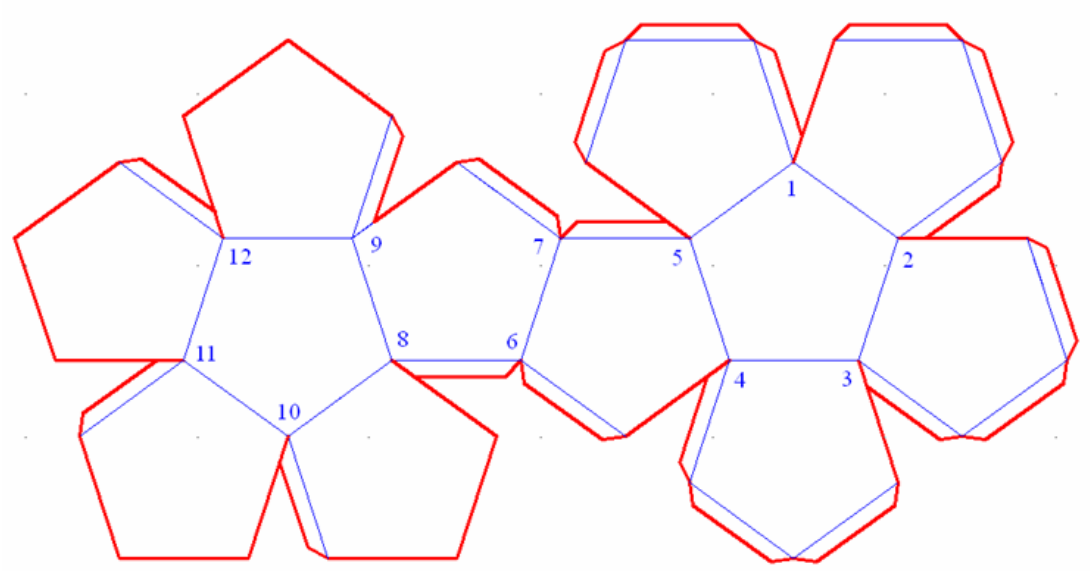

Figure 2-4C: Adding laps.

3rd Step: Adding laps on the appropriate edges of the development

Use **Offset**, **Line**, **Trim**, and **UCS** tools to draw the 0.125" wide laps on the appropriate edges of the development as shown on *Figure 2-4D*, with the same steps explored in the *3rd Step* of *Section 1* of this module.

4th Step: Checking for mistakes

To check if the development is created correctly, print the drawing file, cut the development with a pair of scissors, fold it up to see if it works!

Section 5
The Development of Icosahedron

The development of an icosahedron consists of twenty congruent equilateral triangular faces (*Figure 2-5A*).

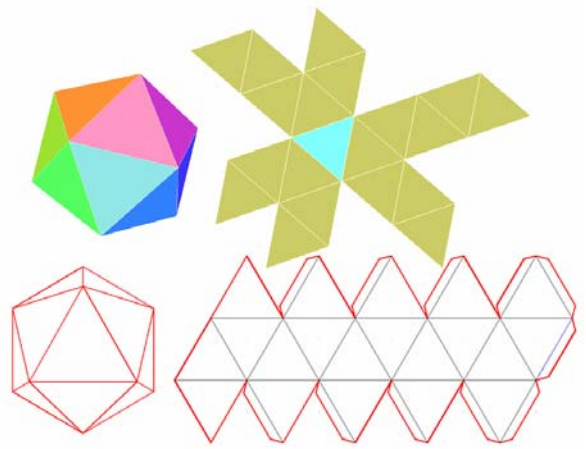

Figure 2-5A: Development of an icosahedron.

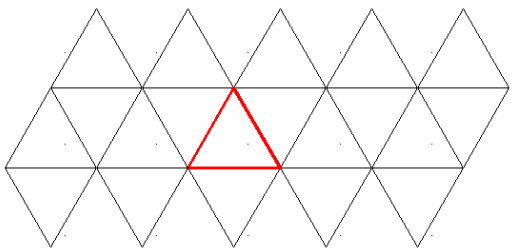

Figure 2-5B: The first triangle (with red and thick outline) and the additional copies.

1st step: Creating the first equilateral triangle

To draw the development of an icosahedron based on triangular faces with 2" side length and .25" wide laps, use the **Polygon** tool. To start, press the **F8** key to turn **ORTHO** on; and turn the **Endpoint** running **Osnap** on in the **Drafting Settings** window; then proceed as follows:

`Command: pol` [type pol and press The Enter key to invoke the Polygon tool]
`POLYGON The Enter key number of sides <4>:` [Type 3 for triangle and press the **Enter** key]
`Specify center of polygon or [Edge]: e` [Type e for the **Edge** option and press the **Enter** key]
`Specify first endpoint of edge:` [Click-select a point to start]
`Specify second endpoint of edge: 2` [Drag the mouse horizontally and type 2 for an equilateral triangle with 2" side length; press the **Enter** key]

The first triangle is created.

2nd Step: Creating additional triangles

To complete the development, use the **Copy** tool to create additional triangles (*Figure 2-5B*).

3rd Step: Adding the 0 .125" wide laps

First use the **Explode** tool to explode all triangles; and then use the **Offset**, **Line**, **UCS**, **Copy** and **Mirror** tools to create the 0 .125" wide laps on the appropriate edges (*Figure 2-5C*).

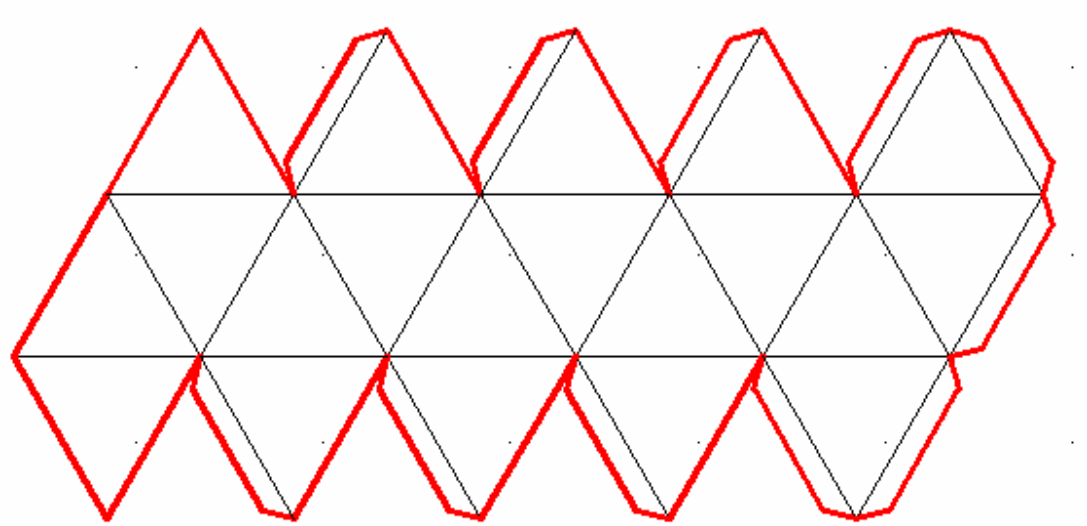

Figure 2-5C: Adding laps.

4th Step: Checking for mistakes:

To check if the development is created correctly, print the drawing file, cut the development with a pair of scissors, fold it up to see if it works!

This completes the Modules 2. Congratulations! You have learned how to:

- Create the 3D models and flat patterns of sheet metal parts wrapping the volume of right-axis cones (regular, frustum and truncated.