

AutoCAD 2000 in 3D - A Monkish Shot Tower

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As you are probably aware, the traditional technology for manufacturing lead shot involves dropping blobs of lead from significant heights such that, as the lead cools during its descent, it forms perfect spherical balls

This tutorial introduces the *concepts* and *techniques* used to build 3D models in AutoCAD 2000. As a vehicle for learning these techniques, we develop a model of a whimsical structure that I have called the *Monkish Shot Tower* after a group of imaginary Monks who have refined the technology of manufacturing lead shot for firearms, and the like. The tower is designed around the perfect number 7, features an external spiral stair, an elaborate canopy on top, and a hole down the centre. The final structure is illustrated in Figure 1 below.

This tutorial will introduce the following concepts and techniques:

- simple solid modelling with solid primitives & CSG operations (the tower);
- construction of complex solid objects (stair and landing);
- user coordinate systems and positioning of objects (external stairs);
- advanced use of the CSG operations (tapering the stairs);
- simple surface modelling (the roof canopy and handrails);
- surface modelling versus solid modelling (the handrails);
- meshed surfaces (the landing "sails" for shading).

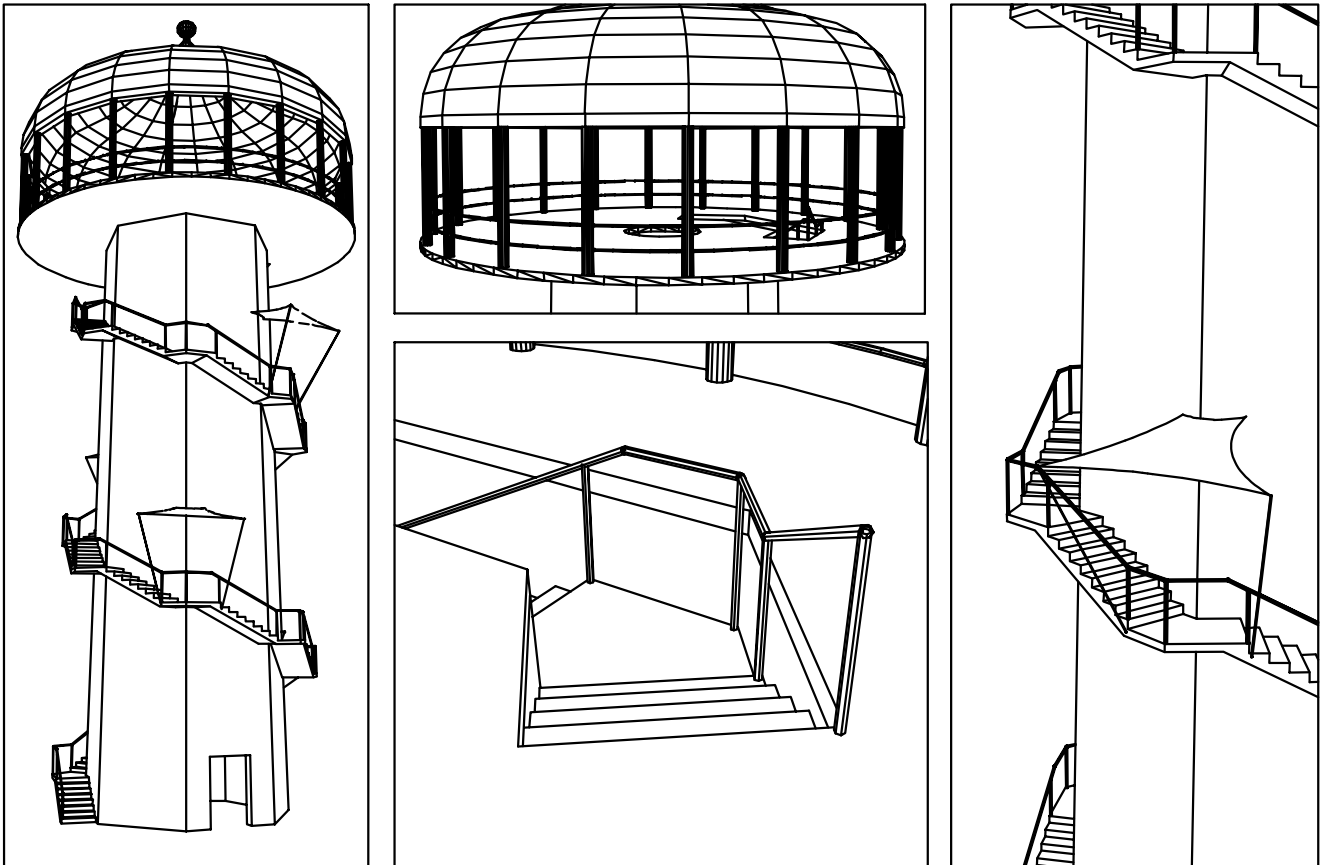


Figure 1 Four Perspective Views of the Monkish Shot Tower

GETTING STARTED

As with every drawing that you produce with AutoCAD you should begin by establishing your drawing area by setting the *Drawing Limits*, *Units* and using *Zoom All* to expand out to a full view of your drawing area. Do that now, setting the limits to **20000 x 15000**.



Layer Control button

Hint:

To create a new layer in this dialogue box, simply click the *New* button and type a name for the layer in the list. To set the colour, click on the colour box adjacent to the corresponding layer.



Pull-down layer list ...

For this model, we will make use of several different *layers* for handling different parts of the model. Begin by calling up the *Layer Control* dialogue box (see button at left) and create two new layers called “Construction” and “Tower”, setting each to a different colour (I used green and white respectively). The *Construction* layer will be used for construction lines that do not form part of the final drawing. The *Tower* layer will contain the central tower.

The last thing to do before beginning the tower is to create a single reference point for this model ... we will do this by placing a *Point* entity on the *Construction* layer at the centre of the drawing area (which will become the centre of the base of the Shot Tower). We will be using *Points* a few times in this drawing as reference markers, so we need to set a *Point Style* that will be easily visible (the normal way AutoCAD marks a point is with a single dot ... we will use an X-shaped cross instead). To do all that, proceed as follows ...

Begin by setting the *current layer* to *Construction* — pull-down the list of layers (illustrated at left) and click on *Construction* ... then proceed as follows ...



Draw point tool ...

<i>Format></i> <i>P</i> oint Style	Select from the <i>pull-down</i> menus — in the resulting dialogue box select the X-shaped cross and then click <i>OK</i> .
[Draw.Point]	Issue the <i>Point</i> command (illustrated) and click a position at about the centre of the drawing area ...
<Esc>	To cancel the command.

CONSTRUCTING THE CENTRAL TOWER

In keeping with the principle that everything in this Shot Tower is designed around the perfect number 7, we will construct a 7-sided polygonal tower, 19.6 metres high (7 levels at 2700), with an outside diameter of 7 metres, and tapering inwards at a gradient of 1:70 (which converts to an angle of 1.3° off the vertical). Proceed as follows:

Set the *current layer* to **Tower** ...



Polygon tool

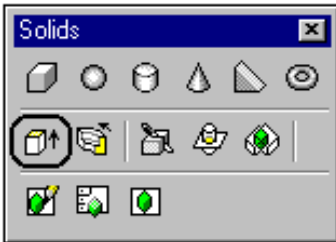


Offset tool

[Draw.Polygon]	Select from the <i>Draw Toolbar</i> .
7 ↵	Number of sides — then use the NODE <i>object snap mode</i> to fix the centre at the point entity just created.
i ↵	Specify an <i>inscribed</i> polygon.
3500 ↵	<i>Radius</i> of the polygon.
[Modify.Offset]	Issue the <i>Offset</i> command (as illustrated).
300 ↵	Offset distance — select the polygon just drawn and then point to the inside to show the side to offset — press ↵ to complete the command.

We now have to extrude these two polygons in the Z-direction to the height required, specifying the 1 in 7 taper as we do so. We will then subtract the inner

one away from the outer one to create a polygonal shell with an empty interior. Once we have done that, we will position a box to serve as the doorway at ground level and subtract that away from the shell to create the opening. That will complete the basic tower! To do all that, proceed as follows ...



Solids Toolbar with the Extrude command highlighted ..

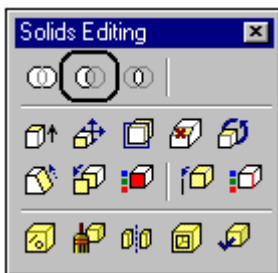
Solid Modelling:

With solid modelling we sculpture objects by assembling the primitives shown on this toolbar using the three CSG operations of Union, Difference (subtract) and Interesection. As you will discover in this tutorial, there is almost nothing that cannot be formed using these tools.

<u>V</u> iew > <u>T</u> oolbars	Open the <i>Toolbars</i> dialogue box, scroll down the list to find the <i>Solids</i> toolbar, and then click on the check-box next to it. Position it anywhere convenient on the screen, taking a moment to examine each tool, and noting the brief description of each on the status line as you move the mouse across them..
[Solids.Extrude]	Pick the <i>Extrude</i> command (as illustrated) — <i>don't forget to watch the prompts on the command line so that you understand the process!</i> — select both polygons and then press ↵ to complete the selection.
19600 ↵	<i>Height</i> of each extrusion.
1.3 ↵	<i>Taper</i> angle.

To see the effect of this in 3D, select View > 3D Views > SE Isometric from the pull-down menus ... this will create a parallel projection (*not a perspective*) of the 3D object looking from the +X / -Y quadrant. You can then use the normal *Pan* and *Zoom* commands to alter the screen display to suit you own purposes, while maintaining that parallel projection. Experiment with this until you have a 3D view of the whole tower near the centre of your drawing area.

The CSG tools are located on the *Solids Editing* Toolbar (illustrated). You can keep this on the screen or you may feel it is easier to execute these commands through the pull-down menus ...



Solids Editing Toolbar

Real-Time Pan & Zoom



These new tools are great for moving around your drawing ... hold down the left button while dragging the mouse up and down.

<u>M</u> odify > <u>S</u> olids Editing > <u>S</u> ubtract	Issue the <i>Subtract</i> command — note that this command allows you to select two sets of objects: the second set are then subtracted from the first — we will have only one object in each set in our case — select the outer shape and press ↵ (the “primary” object), and then select the inner object and press ↵ again (the object to be subtracted from the “primary” one) — <i>don't forget to watch the prompts to understand how this works.</i>
hide ↵	Issue the <i>Hide</i> command — this draws the current view with all hidden lines removed or truncated as necessary — <i>notice that your tower is now one single solid object which is hollow down the centre.</i>

User Coordinate System (UCS):
This is a 3D cartesian coordinate system that operates independently of AutoCAD's fixed World Coordinate System (WCS). It can be positioned and orientated anywhere in space (at any angle). All 2D drawing is always done in the UCS X-Y plane: normally, the UCS is coincident with the WCS!

This means that you can use all the 2D drawing commands that you are used to, only place them anywhere in space by first positioning the UCS. This would allow you, for example, to draw a cross-hatch pattern on a sloping roof plane!

The next step is to punch a doorway through the base of the tower. *Begin by zooming in to the base of the tower with a view similar to that shown in Figure 2, over the page (Hint: use the new real-time pan and zoom tools in the standard toolbar).* To make this process simpler, we will position the UCS (see explanation at left) as illustrated (Figure 2), with the origin at the outside corner of the tower and the X-axis in line with its base. To do that, follow these steps:

ucs ↵	Issue the <i>UCS</i> command to alter the position of the current UCS — <i>notice the command prompt, showing options for saving and restoring UCS settings.</i>
n ↵	Select the <i>New</i> option ... <i>notice the variety of ways that you can define the UCS ... we will use many of these in the course of this tutorial ...</i>

3 ↵	Select the <i>3point</i> option keyword — this is the most versatile option, allowing us to define the new UCS precisely — watching the prompts, proceed as follows ...
ENDpoint	Use the <i>object snap</i> to put the origin at ①.
ENDpoint	Use <i>object snap</i> again to identify a “point on the X-axis” at ②.
ENDpoint	And again, to nominate a point on the “positive Y portion of the XY plane” at ③



Re-oriented UCS icon ...

NOTE: if the UCS icon has been placed at the origin (point ① in Figure 2), then type the command **ucsicon ↵** and then type **n ↵** for “No Origin” .. that will force the icon back to the lower left corner of the screen

Notice that the UCS Icon has now dropped the “W” (no longer World Coordinates) and has been positioned at the new origin, oriented to suit the new UCS. See note at left to move the icon back to the lower left corner of the screen. We now use the *Box* primitive to construct the doorway ... be careful that you use the “corner box” rather than the “centre box” ...

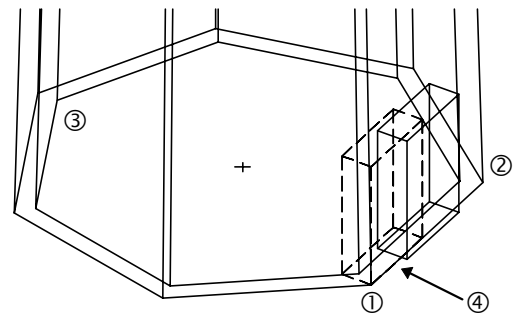


Figure 2 Constructing the Door Opening at the base of the Tower



Box tool in the Solids Toolbar.

[Solids.Box]	Select from the <i>Solids</i> toolbar — AutoCAD will prompt for the corner position of the box ...
ENDpoint	Use the <i>object snap mode</i> to place the corner of the box at ① in Figure 2.
@1400,500, 2100 ↵	Specify the opposite corner of the box as a relative 3D coordinate — alternatively, this could have been done by entering the length, width and height of the box separately.
[Modify.Move]	Issue the normal <i>Move</i> command — select the box just created and press ↵ — set the <i>Base Point</i> at the MIDpoint position marked ④ (on the box just created) and the <i>Second Point</i> at the MIDpoint of line ① - ②
[Modify.Move]	Re-issue the <i>Move</i> command — select the same object and press ↵ and pick any point as the <i>Base Point</i> ...
@0,-100 ↵	Specify the <i>Second Point of the displacement</i> to move the box so that it is centred on the thickness of the wall.
<u>M</u> odify > <u>S</u> olids <u>E</u> dit <u>i</u> ng > <u>S</u> ubtract	Issue the <i>Solids Subtract</i> command – pick the tower first and then press ↵, then pick the box and press ↵ again — you should now have a door opening in the base of the tower!



Move tool

Notice that we deliberately made the box wider than the wall's thickness (500 instead of 300) so that when it was positioned, it protruded from both sides of the wall ... this is especially necessary in this case since the tower is tapered and the wall leans in slightly. **Generally, however, when performing this type of operation, it is prudent to always oversize the subtracted object to ensure that no thin slivers of material are left behind!** If you try to be too precise, you can encounter precision errors.

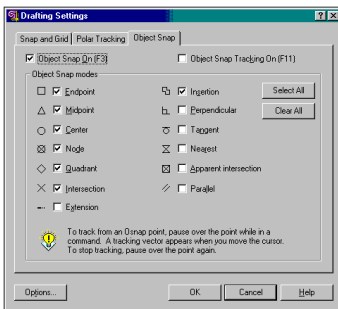
CONSTRUCTING THE EXTERNAL WINDING STAIR

Discussion ...

The decision to taper the tower inwards was deliberate because it leads to some interesting complications in this otherwise simple model. The first of those complications occurs with the stairs since they too have to taper inwards as they climb the tower. We get over this complication very simply. We begin by building the stairs straight up with no taper, each flight hugging the face of an imaginary extrusion (downwards) of the 7-sided polygon that forms the inside edge of the (tapered) top of the tower: this means that at the base of the tower the stairs actually lie partially inside the tower. Once the stairs are complete, we will create another tapered tower in the middle of the stairs and subtract that away from them to create the internal taper — the stairs will then very neatly follow the face of the real tower. We then do the same with the outside taper: we build the flights very wide to begin with, and then at the end of the process we construct a large tapered tower with very thick walls which we can also subtract away from the stairs, thus creating the outer taper. This process is illustrated in Figure 12. *Producing the taper is easy: the harder part is constructing the stairs to begin with ...*

First, we need a few construction lines —

- make the *Construction* layer the *current layer* again,
- reset the *UCS* back to “World” (issue the *UCS* command and then press ↵ to accept the default “World”),
- and *Zoom out* to a view that allows you to see the top of the Tower.



We begin by tracing the *inner* edge of the top of the tower ... to do that, we switch on running object snap ...

Drafting Settings dialogue ...

With Running Object Snap turned on, whenever you are using the mouse to select a point, AutoCAD will highlight and identify the nearest snap point within the snap aperture ... to use that snap point simply click the mouse button ... if the snap is ambiguous, pressing the *Tab* key will cycle through the available snaps at that point.

<i>Tools > Drafting Settings</i>	Call up the <i>Drafting Settings</i> Dialogue box with the Object Snap tab (as illustrated) ... I suggest that you select each of the ones shown in the illustration at left ... <i>note the brief explanation of how to use these if you have not done so before ...</i>
[Draw.Polyline]	Issue the <i>Polyline</i> command — pick each of the 7 vertices around the <u>inside edge</u> of the top of the tower ...
c ↵	Close the polyline.
[Modify.Move]	Use a Window selection rectangle to select the polyline just drawn (you work out why!) and then press ↵ — set the <i>Base Point</i> anywhere you wish (well away from everything to avoid the running object snap) ...
@0,0,-19600 ↵	Second point of the displacement vector.

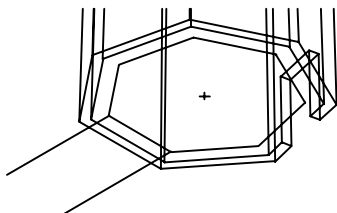


Figure 3

Re-position your view to the bottom of the Tower, then, with *ORTHO* mode turned on (click the *ORTHO* button on the status line), construct two parallel lines of roughly the same length (as illustrated in Figure 3) projecting out from adjacent corners of the polygon just constructed.

Now choose *View > 3D Views > Plan View > World UCS* and then *zoom in* on the ends of those two lines — we will use these lines to set out the stairs in profile as illustrated in Figure 4 (over the page).

[Draw.Line]	Issue the <i>Line</i> command — pick the <i>start point</i> at the bottom end of the rightmost line.
@0,140 ↵	Height of riser (<i>multiple of 7!!!</i>).
@-280,0 ↵	Length of going (<i>another multiple of 7!!!</i>).

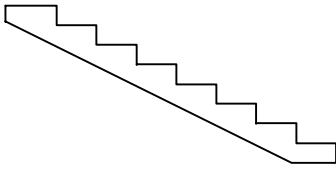


Figure 4

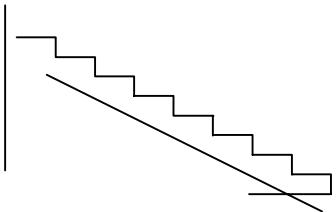


Figure 5

↵	to terminate the <i>Line</i> command.
[Modify.Copy]	Use <i>Window</i> selection to select both the riser and the going lines — press ↵ to complete the selection ...
m ↵	Select the <i>Multiple</i> option ... with using ENDpoint AutoSnap, set the <i>Base Point</i> to the base of the riser line — then place each copy at the left end of each successive going line to form the stair flight — stop just before you reach the second construction line by pressing ↵
[Draw.Line]	Use the <i>Line</i> command (still with ENDpoint AutoSnap) to construct a line joining <u>the bottom of the nosing to the top riser</u> with the <u>bottom of the nosing to the lowest riser</u> .
[Modify.Offset]	Offset the line just constructed down by 140 to form the soffit of the stair flight ...
[Draw.Line]	With ORTHO on, draw a short line from the ENDpoint of the bottom end of the lowest riser back in the Y-direction ...
[Modify.Erase]	Erase the right-most original construction line and the line that was offset to produce the soffit line ... you should end up with something that looks like Figure 5 ..

Using Figures 5 & 4 as a guides (before and after!), use the *Fillet* command (with radius 0) to clean up the stair profile by joining up each of the corners. Next, we use the polyline edit command to convert the stair profile into a single polyline entity as follows ...



Pedit tool (in the Modify II toolbar)

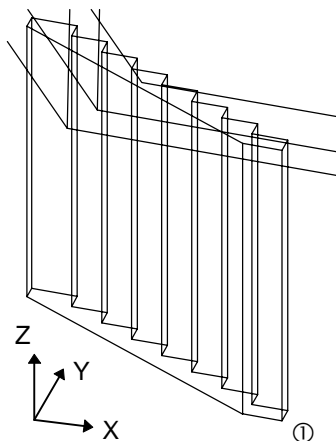


Figure 6

Right Hand Rule:
If you hold your right hand with your thumb pointing in the positive direction along the axis of rotation, then your fingers point in the direction of positive rotation

<i>Modify > Polyline</i>	Issue the Polyline Edit command ... select ANY ONE of the lines that make up the stair profile — <i>AutoCAD will note that it is not a polyline, but will offer to convert it into one</i> (see the <i>Command</i> line) — press ↵ to say “yes” ...
j ↵	Select the <i>Join</i> option — then use <i>Window</i> selection to pick all the lines that make up the stair profile (it doesn't matter that one has been selected twice!) — press ↵ to complete the selection — <i>AutoCAD</i> will then join all those lines to form one polyline ...
↵	Press ↵ to terminate the command.

Now turn off the **Tower** layer, then create a new layer called **Stair** (making it a distinctive colour) and set it as the **Current Layer** before proceeding.

Next, use the *Solid Extrude* command to extrude the polyline to a height of 2500 to form the width of these stairs and then set up a 3D view a little like the one shown in Figure 6 (**Hint:** the SE Isometric view and then Zoom Window gave me a good view). The next step is to rotate the stair into an upright position ...

<i>Modify > 3D Operation > Rotate 3D</i>	Issue the <i>Rotate 3D</i> command — select the stair and press ↵ to complete the selection ...
x ↵	Select the X-axis option (to rotate the stair around that axis) — use ENDpoint to set the axis through the point [1] shown in Figure 6 ...
90 ↵	Rotation angle follows the <i>Right-Hand-Rule</i> ... see explanation at left

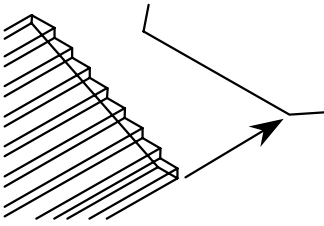


Figure 7

[Modify.Move]	Using [ENDpoint], move the stair using the centre of rotation point as the <i>Base Point</i> and the point on the “construction polygon” as shown in Figure 7 as the <i>Second Point</i> of displacement.
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The next step is to copy and then rotate this flight to create the second flight of stairs. We then need to form the landing between them, then we can duplicate the stair all the way up the tower, and finally union all the parts together to form a single spiral stair. Sound easy?

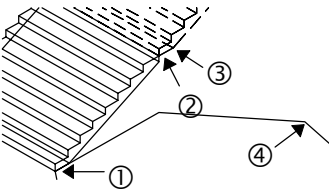
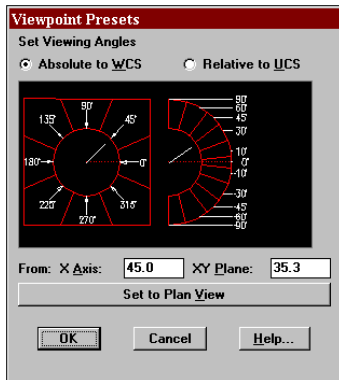


Figure 8

Begin by selecting a *NE Isometric* view & zoom in the view shown in Figure 8.

[Modify.Copy]	Select the stair flight and press ↵ — pick the <i>Base Point</i> ① and <i>Second Point</i> of displacement ② as shown in Figure 8, using the [ENDpoint] object snap mode.
[Modify. 2D Rotate]	We deliberately use 2D rotate because we only want to rotate horizontally — again, pick the stair flight that we wish to rotate and press ↵ — following Figure 8 closely, set the centre of rotation (called the “Basepoint”) to point ② ...
r ↵	When prompted for the rotation angle, choose the <i>Reference</i> option because we want to “point” to the angle of rotation (rather than calculate it, especially as it is a rather odd number) — still using [ENDpoint], pick points ② and ③ as the “reference angle” — for the “new angle”, we want to use the X & Y value (only) of the point marked ④ taking its Z-value from point ② — to do that, proceed as follows ...
.xy ↵	This is called a <i>Point Filter</i> (AutoCAD will only take the XY value of the next point and then prompt you for the Z-value) — pick the point marked ④ — finally pick the point marked ② still using [ENDpoint]).



Viewpoint Presets dialogue ...

This dialogue is most easily called up by simply typing `vp ↵`.

BLIPMODE

In case you have forgotten ... “blips” are those small marks that AutoCAD places wherever you pick a point on your drawing ... they can be turned ON or OFF at will by selecting **Tools > Drawing Aids** and clicking the corresponding checkbox.

Now is a good time to learn another way of setting up a 3D view ... we want to position ourselves to look down at the gap where we need to construct the landing. Select `View > 3D Views > Viewpoint Presets ...` you should get the adjacent dialogue box on the screen. The left diagram shows the plan viewing angle (with the small line pointing towards the centre showing the line of sight in plan — this is set to NE at the moment) and the right diagram shows the altitude (again, with a small line to show the current line of sight in elevation — 45 degrees). You can re-position the line of sight on either diagram simply by clicking with the mouse. *Experiment until you get a view similar to that shown in Figure 9 (over the page), remembering that this is still just a parallel projection.*

A Couple of Helpful Hints ...

Now that the model is beginning to get a little complicated, you need to be warned that *Object Snapping in 3D* is a little error-prone at times (although the current version is vastly improved in this regard) ... AutoCAD will sometimes snap to the wrong point for seemingly inexplicable reasons. When that happens, you should not despair — simply cancel the command and start it again, the second time zooming in on the areas concerned so that your pick points can be entirely unambiguous. It is often a good idea to have *BLIPMODE* on (it is normally OFF) because the small “blips” tell you if AutoCAD snapped to the correct point. Remember also that with [ENDpoint] snaps, you don’t need to be right near the end of the entity — you can often find an unambiguous point to pick that is away from the end, but still less than halfway along the length of the line or arc!

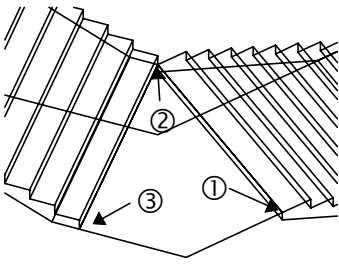


Figure 9

You should know all the commands necessary to construct the landing, so I will simply describe the steps that you should follow:

- the first thing to do is set the UCS onto the plane of the landing — that is easily done using the *3Point* option in the *UCS* command (refer to the illustration on page 9) and placing the origin at 1 in Figure 9, the X-axis point at 2, and the third point (on the XY plane) at 3;
- next, set the current layer to *Construction*;
- construct a short line beginning at 1 and extending to @0,1000;
- construct another line beginning at 1 and ending perpendicular to line 3-2, and then move that line so that it ends at 3;
- Fillet the two lines just drawn to form the outside edge of the landing;
- construct a polyline that joins points 1, 2 and 3 and then join that to the first two lines to form a single closed polyline around the landing;
- set the *Current Layer* to *Stair*;
- finally, use *Solid Extrude* to form the landing slab, but when prompted for the *height* pick point 1 (zoom in if necessary and use |ENDpoint|) and then the point immediately below it on the underside of the stair flight (using |ENDpoint| again) to *SHOW* the depth rather than enter a number.

Your slab was probably extruded upwards (like mine) ... simply use the *Move* command to move it back down to where it belongs.

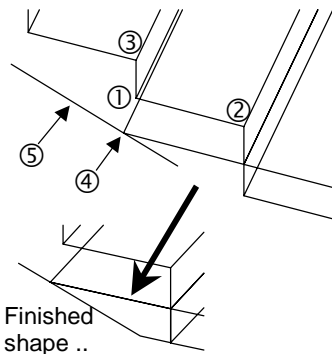


Figure 10

We now have to fill in the gap below the bottom tread of the second flight and the edge of the landing we just created. Using Figure 10 as a guide, follow these simple steps:

- set the *Current Layer* back to *Construction*;
- position the UCS with origin at 1, X-axis point at 2 and YX plane passing through 3;
- construct a line beginning at 4 and extending back up the slope to around point 5 using the |NEARest| object snap — then move that line so that it extends down from position 4 (as shown in the figure);
- construct the other three lines to form the finished shape as illustrated, fillet them and use the *Polyline Edit* command to join them together to form a single polyline;
- set the *Current Layer* to *Stair*, and use *Solid Extrude* with a height of **-2500** to form the required solid.

Once that is complete, use *Solid Union* command (*Modify > Solids Editing > Union*) to merge the second flight, the landing and the section under the bottom tread into one solid object. *Do not include the original flight in the union!!*

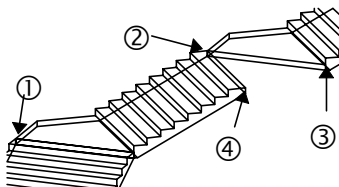


Figure 11

Note:

This whole process of copying and rotating the stair flights to form the whole stair involves a lot of zooming and panning ... once you have completed that process, you should feel more competent about manipulating objects in 3D space.

Now set up a view similar to that shown in Figure 11. Reset the UCS back to *World*, and using the *Copy* command, pick up the second flight and position the copy using positions 1 and 2 as the *Base Point* and *Second Point* respectively. Then, use *2D Rotate* to rotate the copy around the position marked 2 and then use the *Reference* option to show the angle, snapping to points 2, 3 and 4 in that order.

Now repeat that process, this time copying both flights 2 & 3 together to become flights 4 & 5. You can then copy those four flights in one action to create flights 6 through 9. You can almost complete the entire stair by copying those 8 flights to form flights 10 through 17. You will then find that you need to copy the top flight (only) one last time to complete the stair.

Just to see the effect, turn on the Tower layer and then use *View > 3D Views > Front* to see the Tower in elevation view ... you will see the stairs projecting above the tower. *Don't worry about that ... we'll fix it up later.*

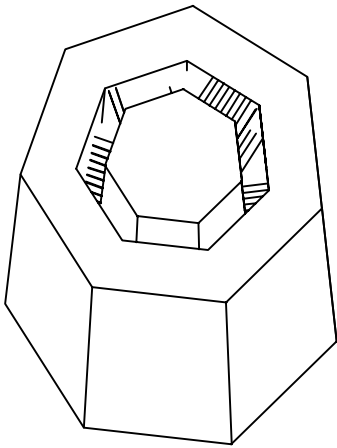
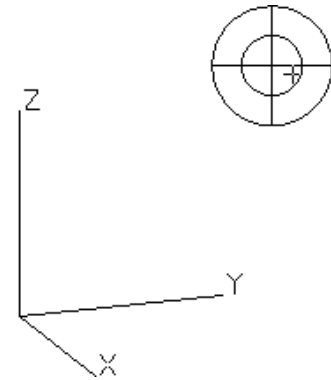


Figure 12

The final step to complete the stairs is to union all the separate flights together and then trim away the sections that are not needed. With *Stairs* as the *Current Layer*, turn off each other layer (click on the “light globe” symbol in the pull-down *Layer Control* tool). Then issue the *Solid Union* command, select all the stair entities and press \downarrow . Turn the *Construction* layer back on, but keep *Stairs* as the *Current Layer*.

Now set up a 3D view that enables you to see the base of the tower and the foot of the stairs at the largest possible scale. Construct three 7-sided polygons, centred at the *Point* entity at the centre of the tower, all *Inscribed*, and with radii of 3510 (10 mm larger than our tower base), 4700 (1200 larger than the base of the tower to be the width of the stairs), and 7000 (being much larger than the outside of the stairs). Extrude each of these polygons to a height of 25000 with a 1.3 degree taper. Next, subtract the middle one (with radius 4700) from the outer one so that we have an outer ring, a middle core and the stair bridging between the two as illustrated in Figure 12. Finally, simply subtract both the outer ring and the middle core away from the stair object to create the tapered stair. Now turn the Tower layer back on and admire what you have achieved so far!

BUILDING THE PLATFORM



3D View Tripod ..

Before going on to the next stage to construct the platform at the top of the tower, I want to take a couple of minutes to introduce the other tool that can be used to select 3D parallel views of your model. This tool is called up by selecting *View > 3D Views > VPOINT* (or using the command *vpoint* \downarrow) and results in a display illustrated in the left margin. This is the original method provided with AutoCAD for setting up quick views — the *Viewpoint Presets* dialogue was introduced with *Release 12* and is probably a bit easier to use.

To use the *Tripod*, imagine the object in the top right to be a flattened globe of the world viewed from above. Position the mouse pointer near the very centre point — this is the “north pole” and creates a view looking down the Z-axis (see the axes in the centre of the screen). As you move out toward the inner ring, you are moving toward the “equator”, and as you move around within that inner ring, you are moving around and above the object (again, watch the axes change as you move around). The outer ring represents the south pole (rather flattened out!). As you move about between the inner and outer rings, you are looking up from underneath the XY plane. If you move outside the outer ring, then the view is meaningless.

Experiment with the tripod to move around and examine the model so far. When you are ready to proceed, turn all layers on and zoom in on the base of the tower so that you can see the original reference point we created.

[Modify.Copy]	Select the original reference point entity, press \downarrow to complete the selection, and then pick a <i>Base Point</i> anywhere.
@0,0,19600 \downarrow	Relative vector to place a copy of the reference point at the top of the tower.

Now change your view so that you are looking down onto the top of the tower. You will have noticed that the last flight of stairs extends above the top of the tower! Since we are now going to work up here for a while, it makes sense to move the UCS onto the plane of the top of the tower ... using the UCS flyout illustrated at the left, click on *Origin UCS* and then use the *[NODE]* snap mode to pick the reference point at the top of the tower. The axes are now orientated the same way as the WCS, but the origin has been moved.

NOTE ON UCS:
The major UCS tools are contained in a flyout on the Standard Toolbar ... you will use these a lot in this tutorial ...

Previous UCS

World UCS

Object UCS

Face UCS

View UCS

Origin UCS

Z-Axis UCS

3 Point UCS

Rotate UCS about X

Rotate UCS about Y

Rotate UCS about Z

Apply UCS

The procedure necessary to construct the platform involves commands with which you should already be familiar, so I will simply list the steps you should follow:

- Set the *Current Layer* to *Stair*, and construct a large cylinder, centred at the new origin, and large enough to fully enclose the top of the stair (say, 6000 radius and 10000 high) — subtract that away from the stair to truncate the top flight level with the top of the tower.
- Create a new layer called *Platform* and make it the *Current Layer*.
- Construct a cylinder centred at the origin, 6000 radius and 140 high.

The next step is to cut a hole in the platform above the stairs ... you can see that illustrated in Figure 1 where the stairs reach the top of the tower.

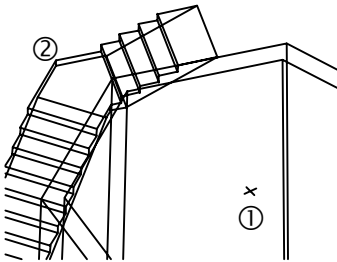


Figure 13

NOTE: To save you looking back over the notes, the steps are 140 high with a 280 tread width ...



Don't forget to save your model since we have just completed a fairly lengthy section!!

- Set the *Current Layer* to *Construction* and, using Figure 13 as a guide, construct a 7-sided polygon centred at the origin 1 with an inscribed radius set by using the *.xy* point filter with |ENDpoint| and picking the outer-most point 2 on the top-most landing of the stair (and then picking any point on the XY plane of the UCS to specify the Z-value).
- Switch back to the *Platform* layer and use that polygon, along with the outside edge of the top of the tower, to construct a polyline around the opening that needs to be created above the head of the stair — use Figure 1 to see roughly where I placed the opening — you can size yours how you like, provided you allow enough headroom over the stairs! (**Hint:** you need about 15 risers to create enough headroom: that is, the short top flight, the full flight below that, and the first few steps of the flight below that.)
- Extrude the polyline up to height of 200 and move it down by about 20 so that it protrudes both above and below the platform slab (*remember the earlier comment about avoiding thin slivers of material?*), and then subtract it away from the platform slab.
- Finally, cut a circular hole about 2000 in diameter at the centre of the platform slab (through which the blobs of molten lead would be dropped!).

That about does it for the platform ... in the next section you will learn how to do some simple surface modelling.

SURFACE MODELLING - COLUMNS, PLATFORM HANDRAILS AND ROOF

Surface Modelling

In surface modelling, all objects are represented by sets of connected planar surface patches, usually each defined by 3 or 4 edges. These patches are, of course, opaque. In AutoCAD, the patches are represented by an entity called a 3Dface.

3Dfaces can be constructed separately, but more commonly are created as part of either a primitive or a mesh. Thus AutoCAD has commands to construct simple surface primitives (like boxes, cones, spheres, wedges, etc.). It also has four commands that create complex surface meshes that don't actually enclose volume in the way that the primitives do: ruled surfaces, tabulated surfaces, surfaces of revolution and edge surfaces. We will use three of these in our model!

We choose now to construct the columns and handrails that enclose the platform as surface objects (called meshes). They could be constructed as solids just as easily, but the way AutoCAD represents curved solids tips the balance in favour of surfaces. To get a feel for that, do a "hide" looking at the platform you just created — notice that the curved edge is triangulated, which would look a bit strange on a round column or handrail. To cancel the hide, use the *Regen* command.

A brief comment on strategy at this point: because the columns and handrails are very repetitive, we will create one column with two pieces of handrail attached to it, save that as a *block* and then simply insert *instances* of that block all around the platform. That will conserve memory space since the complex geometry is only being stored once, but being used around 20 times.

It would be appropriate now to close the Solids toolbar and open the Surface toolbar instead.

Begin by moving the *UCS* origin up by 140 to the top of the platform slab (but keeping it at the centre). Then create a new layer called **PlatformColumns**, set the *Current Layer* to *Construction*, and freeze all the other layers except *Platform*, *Construction* and *PlatformColumns* (so that they are invisible & ignored by AutoCAD).

We will model the columns as a *tabulated surface mesh*. These are meshes that are created by projecting (or extruding) a curved entity (referred to as the *path*) along a *direction vector*. In our case, the path will be a circle in the plane of the platform, and the direction vector will be a line up the centre of the column (see Figure 14). Note that the direction vector must be a simple line, but does not have to be perpendicular to the plane of the path. Equally, the path does not have to be closed for a tabulated surface mesh. Ours is actually a very simple application of a tabulated surface!

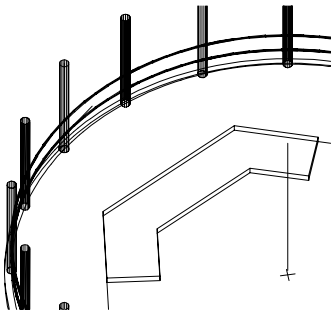


Figure 14

(This is a view of the completed handrails and columns to give some idea of where we are heading.)

The curved handrail segments will be modelled as *surfaces of revolution*. These take a generating “path” (in our case it will be a circle) and sweep it through an arc (up to 360 degrees) around an axis. We will use a vertical axis positioned at the centre of the platform (as illustrated in Figure 14 at left). As with the tabulated surface mesh, the generating path does not have to be closed — as you will see later, the canopy roof over this platform is also created as a surface of revolution using an open polyline as the path.

We need to begin by drawing some construction lines (illustrated in Figure 15 over the page):

- Draw the axis line from the centre top of the platform (should be the origin of the current UCS) straight up to a height of around **4000**.
- Draw a circle, centred at the base of the axis line with a radius of **5850**.
- Draw another circle centred at the “west quadrant” point of that larger circle, with a radius of **100** — use the |QUAdrant| snap mode and pick the large circle near where it intersects the negative-X UCS axis.
- Draw a line (to become a *direction vector*), beginning at that same quadrant point, and extending straight up (Z-direction) to a height of **2700** (the height of our columns).
- Draw another line beginning at that quadrant point and extending **1000** in the Y-direction (**@0,1000,0**).
- Move the last line drawn up in the Z-direction by **450** — we will use it to construct the lower handrail.
- We now want to temporarily re-position the UCS so that its Z-axis follows the small line we just created — use the ZAxis option in the UCS command (see page 9) and, using |ENDpoint| place the UCS origin at the start of that line and the “point on the Z-axis” at the other end.
- Issue the Circle command, specifying the centre as 0,0 and the radius as 20 — a small circle should appear on the columns axis 450 above the floor and “facing” along the direction of the edge of the platform (see Figure 15).
- Reset the UCS back to its previous position (using the Previous option!).
- Copy the small circle up 450 for the top handrail.

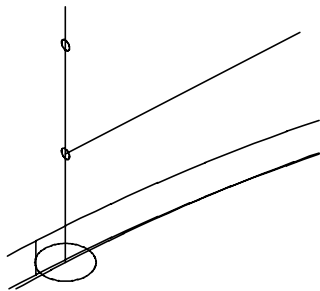


Figure 15

That completes all the construction lines that we need — zoom in to a view that looks like that shown in Figure 15.

Set the Current Layer to PlatformColumns. We’ll draw the handrails first ...



Revolved Surface tool

[Surfaces. Revolved Surface]	Issue the command from the <i>Surfaces</i> toolbar (illustrated) — select one of the “handrail” circles, and then pick the axis line (at the centre of the platform) near its lower end (zooming out if necessary)...
↶	Accept the default start angle.
-20 ↶	Specify the <i>End Angle</i> as a negative number because we want to form the handrails in a clockwise direction.

Repeat the process for the second handrail. Zoom in on one of the handrails and notice how the facets have been formed. Normally, AutoCAD constructs 6 facets in each direction ... is that what happened here?

With the columns, it would be nice if they were constructed with more than 6 facets. To control the number of facets used, we set the value of an internal variable called SURFTAB1 for the "first" mesh direction and SURFTAB2 for the second. Since the column mesh is uni-directional (one-way curvature), we only need to change SURFTAB1 ...



Tabulated Surface tool.

surftab1 ↵	Simply typing the name of an internal variable initiates a command to change that variable ... note that the default value shown in parentheses is always its current value ...
15 ↵	Set the value to 15 ... that will give us a fairly good column!
[Surfaces. Tabulated Surface]	Issue the command and simply pick first the circle (path) and then the vertical line (direction vector). <i>Notice how the railing butts into the column ... AutoCAD provides no easy tools to clean up those joints between surface objects.</i>

The next step is to make this unit into a block ...



Block Tools (Draw toolbar) ...

Notice that the two buttons are the same except that the one at the top has a "page" behind it — that one is the **Insert Block** command — the other is the **Make Block** command (to create a new block) ...



Array command in the Modify toolbar ...

[Draw. Make Block]	Issue the <i>Make Block</i> command ... name the block " Column " ... then click the buttons to set the <i>insertion point</i> (use the QUadrant snap mode and click on the large circle near the base of the column) and to select the objects (pick the column and both handrails and then press ↵). Finally, select the <i>Delete</i> option (<i>we could use the "Convert to Block" option, but I want you to go through the exercise of inserting the block this time!</i>).
[Draw. Insert Block]	Issue the <i>Insert Block</i> command — in the dialogue box, select <i>Column</i> and the option to specify the Insertion Point on the screen — <i>set all scale factors to 1 and the rotation to 0 before clicking OK</i> — use QUadrant to locate the <i>Insertion Point</i> for the block.
[Modify.Array]	Issue the <i>Array Copy</i> command — select the block just inserted and press ↵ ...
p ↵	Select the <i>Polar</i> option.
0,0 ↵	Specify the <i>Centre Point of the Array</i> at the current UCS origin ...
20 ↵	<i>Number of Items</i> (this is the <u>total number</u> including the original!) ...
↵	Accept default value for <i>Angle to Fill</i> (ie. 360) ...
y ↵	Yes, rotate each copy!

We now have 20 copies of the column block arrayed around the perimeter of the platform, each of which will be an instance of that block, rather than a full copy. If we had left out the "block / insert" phase of that procedure, then we would have 20 copies ... it would look the same, but very much less efficient.

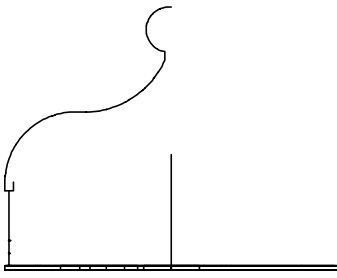


Figure 16

The last step in this section of the tutorial is to draw the roof canopy. Figure 16 shows how I set up mine with the *PlatformColumns* layer turned off. Once I get you started, you can make your roof any shape you wish ...

- Begin by creating a new layer called **Roof** and make it the *Current Layer*.
- Move the UCS up 2700 in the Z-direction, then rotate it about the X-axis so that the X-axis is horizontal and the Y-axis is vertical.
- Select “plan view” ... this will actually be an elevation view because we have rotated the UCS.
- Then, draw a profile for your canopy roof, making sure that you provide some kind of bulkhead that sits on the perimeter columns. (**Hint:** remember that the columns have a diameter of 200 and create construction lines as necessary to ensure that the peak of your roof lies exactly above the centre of the tower.)
- Set **SURFTAB1** to **20** so that the facets line up with the columns.
- Once you have created your profile, revolve it around the vertical axis through 360 degrees.

CONSTRUCTING THE STAIR HANDRAIL

Discussion ...

We construct the handrail as surface objects for the same reason that we gave for the columns on the tower platform. In this case, however, we encounter again some complications that result from the decision to taper the tower. These are by no means insurmountable, but it did take me several false starts before I discovered an efficient (??) way of doing it accurately. *I'll be interested to hear from anyone who can suggest any improvements to the following process!*

When you analyse the taper problem with respect to the stair handrail, you realise that each flight of stairs is the same length and height (because the going and riser doesn't change), but as you move higher up the tower, the landings become smaller and their plan shape changes slightly. To accommodate this, we will construct the handrail in two parts (illustrated in Figure 17 over the page, including blow-up views of the joints), one for the stair flight and an upstand element to be positioned at the outside corner of each landing. These handrail elements are designed with “open ends” so that they can be joined up “on site” with lengths of tube (we will use the *Tabulated Surface* command to achieve those connections), which vary at every landing. As we did on the tower platform, we will construct these handrails as blocks that can be simply inserted at the appropriate position on each flight or landing.

We again begin by drawing some construction lines. You should *freeze* every layer except for *Stair* and *Construction*, making the latter the *Current Layer*. You should also, at this point, create a new layer called **Handrail**. Set the UCS back to World and select a *plan view*, zooming in on a convenient area of empty “ground”. We will draw the profile of the flight handrail first, flat on the ground (like we did with the stair), then rotate it up in to an upright position when we need to. Note that the handrail should be 760 above the nosing of the stair, and 900 high on the landings. The height from the top of the first step to the landing is 980 and the flight length (nosing to nosing) is 1960. Go through the following steps, using lines only (no polylines):

- Draw a line using the following sequence of coordinates (starting at the lower right of your screen):
 - @500<180**
 - @760<90**
 - @-1960,980**
 - @760<270**
 - @1000<180**

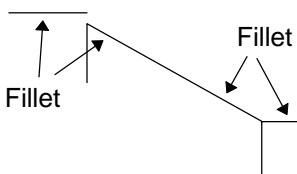


Figure 18

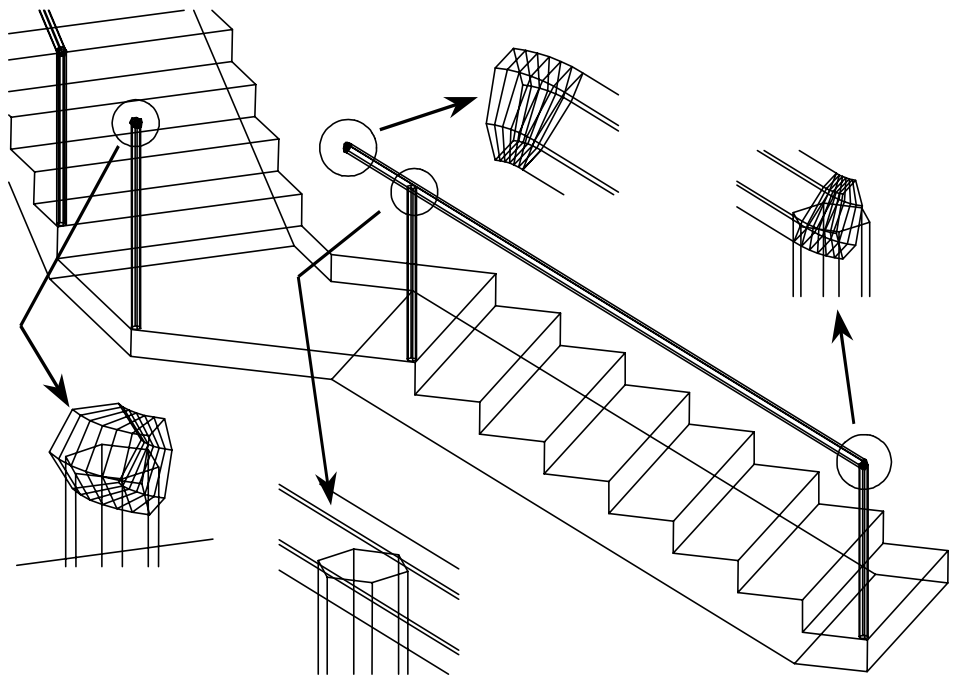


Figure 17 Handrail Components and Details.

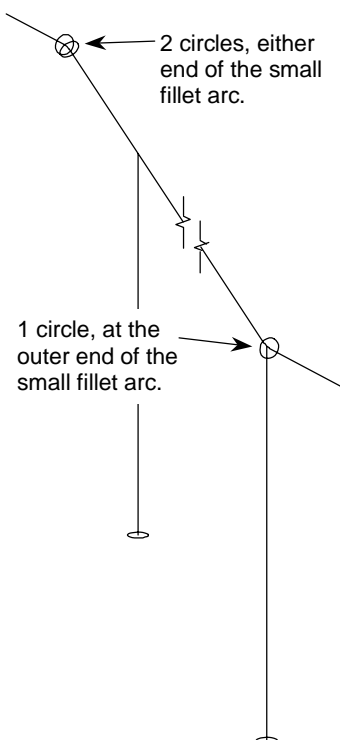


Figure 19

- Now take the first line in that sequence and move it up 760 in the Y-direction.
- Take the last line in the sequence and move it up 900 in the Y-direction — your drawing will now look like Figure 18.
- Set the *Fillet* radius to 40 and then fillet the lines indicated in Figure 18.
- Use *3D Rotate* to stand the handrail up (exactly the same as we did with the stair!).
- Set up a circle with radius 20 at each of the 5 positions indicated on Figure 19 — the two at the base of the vertical supports are easy — the others will require you to set up the UCS using the *ZAxis* option on each of the 3 straight line segments so that the circle is correctly orientated.
- Set the *UCS* back to “world” and make *Handrail* the *Current Layer*.
- Set *SURFTAB1* back to 6.
- Use the *Tabulated Surface* command to create the two posts and the long railing between the posts.
- Make *Construction* the *Current Layer* again and turn off *Handrail*.
- Zoom in on one of the two fillet arcs (at either end of the long rail). We are going to construct an axis line so that we can then use the *Revolved Surface* tool to create the bends in the railing. Construct one line, beginning from the [CENTre] of one of the fillet arc and extending to @0,-500,0 — repeat that step at the other end of the long rail.
- Set the *Current Layer* to *Handrail*, and use the *Revolved Surface* command to create the curved sections of handrail, first picking the circle at the end of the curve (known as the path) and then picking the axis at the end nearest the arc — the *Starting Angle* will be 0 in both cases — the *End Angle* will probably be 26.56 [ie. $\tan^{-1}(140/280)$] for the “top end” of the handrail and -26.56 at the “low end” — if the surface is drawn in the wrong direction, undo and repeat the process using the opposite angle!

The next step is to convert this handrail element into a block. We must first reposition and rotate the UCS so that the block is defined with a convenient orientation for later insertion onto the stairs. We are also going to store this as a “nested block”: we will first create a block consisting of just the handrail itself (calling that “FlightRail”); we will then create a second block made up from the

block FlightRail plus the two construction circles that were created at the open ends of this handrail (calling this “FlightMaster”). That way, we can insert FlightMaster onto the stair, explode it so that we then have the block FlightRail in place, plus the two construction circles that we will use to form the rails on each landing. To do that, follow these steps:

- Zoom in on the base of the lower end of the handrail.
- Issue the *UCS* command, select the Rotate about Z option (to rotate around the Z-axis), setting the rotation angle to **90**.
- Re-issue the *UCS* command, this time using the *Origin* option — use the *From* object snap to position the UCS origin at the point **@-25,-25** relative to the centre of the base of the handrail (this will be the *Insertion Point* for this block and will correspond to the outside corner of the bottom tread of each stair flight).
- Issue the *Block* command, name the block **FlightRail**, specify the *Insertion Point* (as **0,0**), then select the five tubular elements that make up the rail.
- Now *Insert* that block at the position **0,0** and accept the default *X-scale*, *Y-scale* and *Rotation* settings.
- Issue the *Block* command again, this time naming the block **FlightMaster**, setting the *Insertion Point* at **0,0** again, but this time selecting the block *FlightRail* plus the two circles (on the *Construction* layer) that we created at the two open ends of the handrail.

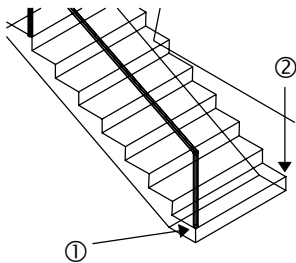


Figure 20

Set the UCS back to “world” and zoom in on the bottom tread of the stairs. Using Figure 20 as a guide, insert the block *FlightMaster*, positioning it at the outer top corner of that tread **1**, accepting the default scale factors, but picking point **2** when prompted for the rotation. *If you zoom in on the top of the flight, you will notice that the top upstand of this handrail is not positioned correctly on the first landing!* This is because of the 1:70 taper: the landing is offset by some 18 mm relative to the bottom step. The solution to this is simple: first, we will rotate this block around its insertion point to get it to the right position; then we will explode it and re-create the block in that rotated state so that we can insert it correctly on each flight. To do that, follow this procedure:

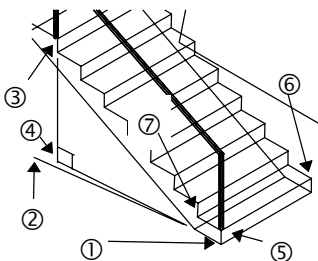


Figure 21

- Using Figure 21 as a guide, issue the 2D-Rotate command, select the inserted handrail, and, when prompted for the *Base Point*, use the *.xy* filter of the block’s *Insertion Point* (plus a point on the current UCS as the Z-value) to indicate the centre of rotation (this is point **1** in Figure 21).
- When prompted for the *Angle*, type **r ↵** (for “Reference”), and then use the *.xy* filter again to pick **1**, then, with ORTHO on, pick any point in the negative-X direction as the second point (say point **2** in Figure 21), and finally use the *.xy* filter and |Endpoint| and pick point **3** (followed by any point on the UCS plane to provide the Z-value) to yield point **4**.
- The handrail should now be properly positioned. Position the UCS on the top face of the bottom step with the origin at **5**, the X-axis through **6**, and the Y-PLANE through **7**.
- Explode the FlightMaster block.
- Now re-create the FlightMaster block with the *Insertion Point* at **0,0** and selecting the rotated block and the two circles on the *Construction* layer.
- Finally, insert that new block on the bottom flight in the same way we did before (as per Figure 20) — *is it correctly positioned this time?*

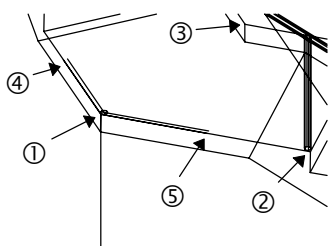


Figure 22

The next step is to construct the upstand element that will sit on the outer corner of the landing. Zoom in on the first landing, setting up a view like Figure 22. We will first set up the construction lines shown in that figure ...

- Set the *Current Layer* to *Construction*, and use the *UCS* command with the *3point* option to position the *Origin* at **1**, the X-axis at **2** and the *point on the XY plane* at **3**.
- Beginning at **1**, construct a line to **@0,0,-900**.

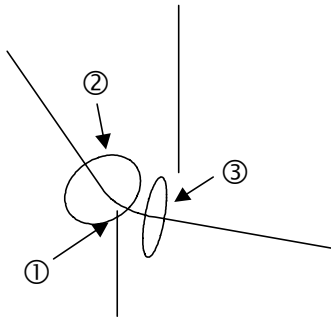


Figure 23

- Also beginning at ①, construct two separate lines that terminate using the |NEArest| snap mode at roughly the positions ④ and ⑤ respectively (the length of these lines is not important).
- Offset those last two lines by **25 mm** as shown (you will need to turn off the *Stair* layer temporarily for this and the next couple of steps!).
- Construct a **20** radius circle, centred at the intersection of the two offset lines — *you should now have all the lines shown in Figure 22!* **Erase the two lines that intersect at the centre of the circle.**
- Now move the three lines that converge on ① so that the bottom point of the 900 long “vertical” line is positioned at the centre of the circle just created.
- Zoom in on the top of that re-positioned vertical line and use the *Fillet* command (still with radius 40) to construct a fillet arc between the two horizontal lines that converge at ① in Figure 23 — *now reset the fillet radius back to 0 since we won’t need that again!*
- Construct an axis line beginning at the centre of the fillet arc just created and extending up **@0,0,100**.
- Now re-position the UCS using the ZAxis option so that you can construct the circle at ② with radius 20 — then repeat that process to construct the 20 radius circle at ③.
- Zoom out a bit and set the UCS back to the top of the landing as it was at the start of this sequence. Turn on the *Stair* layer again.
- Set the *Current Layer* to *Handrail* and create the two handrail components using a *Tabulated Surface* and a *Revolved Surface* (using an *Included Angle* of 51.43 degrees, ie. 360/7).

That completes the upstand component of the handrail. *You are now to follow the same procedure as with FlightRail to create a nested block (calling it “UpstandMaster”) consisting a block called “Upstand” plus the two construction circles positioned at the open ends of the curved horizontal rail.* Note that with the current UCS, the *Insertion Point* would be **0,0**.

Once you have done that, set the UCS back to “world” and erase the construction lines used to create the handrail. Then set the *Current Layer* to *Handrail* and execute the following procedure for each stair landing all the way up the tower:

- Insert both blocks *UpstandMaster* and *FlightMaster* in the appropriate positions on the landing, using |ENDpoint| to accurately set the insertion point and rotation of each block.
- Explode both blocks ONCE.
- Turn off the *Handrail* layer and set the *Current Layer* to *Construction*.
- Use the |CENTre| snap mode to construct two lines between the centre points of the circles that have to be connected up with a handrail tube.
- Set the *Handrail* layer as the *Current Layer* even though it is turned off — *AutoCAD will warn you that you have done that ... simply click the OK button!* We do this so that we can see the construction lines & circles that we are going to join up to complete the rail.
- Use the *Tabulated Surface* command (on the *Surfaces* toolbar) to construct each of the two lengths of handrail, picking the corresponding construction circles & lines — *the new rails will not appear because the Current Layer (Handrail) is invisible, but they will be created!*
- TURN ON the *Handrail* layer again to check that the new rails were created successfully. (**Hint:** if the tabulated surface was constructed in the wrong direction, undo it and generate the surface from the circle at the other end of the line.)

This process is rather tedious because it has to be repeated about 16 times!

You will find it fairly quick once you get into it ... you may even find a few shortcuts ... for example, I found that selecting the Explode option in the Insert Block dialogue made things quicker ...

- Use *Realtime Zoom* to move between landings ... *there should be no need to rotate your view, provided you can see all the points that you need to carry out this procedure at each level.*

This step will test your skills at creating extruded pipework on your own!

When you have inserted all the rails, you will find that the top one is too long because the top flight of stairs on to the platform is shorter. All you need to do is turn on the *Platform* layer (so you can see what you are doing!), explode the *FlightMaster* block, re-position the upstand element, and replace the straight rail. That should complete the handrail.

SHADING CANOPIES OVER THE STAIR LANDINGS

We now have one last touch to add to our model. Conscious that our Monks have to carry heavy burdens up this long winding stair, I have stretched out a piece of shadecloth over every third landing — who said a monk's life was all discomfort! This simple element will introduce you to a couple of useful tricks.

Begin by creating a new layer called "ShadeCloth", freezing all layers except *Stair*, *Construction* and *ShadeCloth*, and setting *Construction* as the *Current Layer*. Then, zoom in on a view of the third landing from the bottom similar to that shown in Figure 24. Follow these steps:

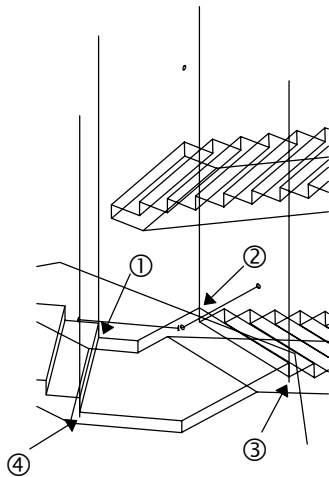


Figure 24

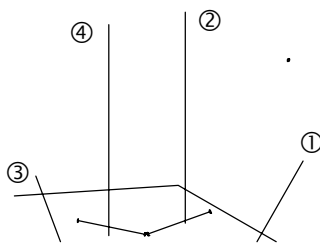


Figure 25



Edge Surface tool

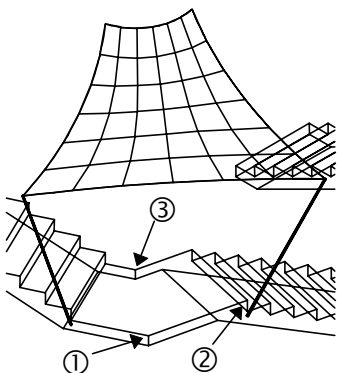


Figure 26

- Construct four vertical construction lines 3000 long at the points marked ①, ②, ③ & ④ — *the last two points are 50 mm below the bottom of the step.*
- Position the *UCS* so that the *Origin* is at ④ and the *X-axis* follows the direction of the outside edge of the landing (do this in two steps: use the *3point* option to set up the *UCS* on the landing, then move the origin to ④) — use *3DRotate* to rotate the line 30 degrees away from the landing — repeat this process for the line that starts at ③, this time with the *Y-axis* following the edge of the landing.
- Position the *UCS* so that the *Origin* lies at ③ (Figure 24) and the *Z-axis* runs up the (now sloping) line — construct a 10 mm radius circle centred at ③ (which we will extrude later to form a pole to support the tarpaulin) — do the same at point ④.
- Now, turn off the *Stair* layer, set the *Current Layer* to *ShadeCloth* and use Figure 25 as a guide to position the *UCS* with the *Origin* at ①, the *X-axis* passing through ②, and with ③ representing a point on the positive-*Y* portion of the *XY* plane — use *Draw > Arc > Start, End, Direction* (from the pull down menus) to construct arcs between ① & ② and ① & ③, being careful to use *|ENDpoint|* to lock accurately to those points, and judging the curvature of the arcs by eye.
- Repeat the last step with the *UCS* origin at ④, constructing arcs ④-③ and ④-②.
- Use the *Edge Surface* command to construct the surface mesh picking the 4 arcs just created — *if AutoCAD says that the four edges don't touch, it is because you did not set the UCS and use |ENDpoint| snapping to construct the arcs.*
- Now use the *Tabulated Surface* command to construct the poles.
- Next, create a new layer called **HideMesh** and move the surface mesh (only) to that layer — *later we can turn off that layer so that the mesh is invisible but still makes our shadecloth tarpaulin opaque when the hidden lines are removed.*
- Finally, turn ON the *Stair* layer and turn OFF the *Construction* layer, then use Figure 26 to position the *UCS* with *Origin* at ①, *X-axis* through ② and *XY plane* through ③ — make the two poles, four arcs and the mesh into a block called **Tarp**, and with the *Current Layer* set to *ShadeCloth*, insert that block on every third landing (except the one just below the platform).

ALL DONE!!