Rhinoceros®

NURBS modeling for Windows

Training Manual

Level 2

Rhinoceros Version 3.0 Level 2 Training Manual

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Part One: Introduction

1 Introduction

This course guide accompanies the Level 2 training sessions in Rhinoceros. This course is geared to individuals who will be using and/or supporting Rhino.

The course explores advanced techniques in modeling to help participants better understand how to apply Rhino's modeling tools in practical situations.

In class, you will receive information at an accelerated pace. For best results, practice at a Rhino workstation between class sessions, and consult your Rhino reference manual for additional information.

Duration:

3 days

Prerequisites:

Completion of Level I training, plus three months experience using Rhino.

Course Objectives

In Level 2, you learn how to:

- Customize toolbars and toolbar collections
- Create simple macros
- Use advanced object snaps
- Use distance and angle constraints with object snaps
- Construct and modify curves that will be used in surface building using control point editing methods
- Evaluate curves using the curvature graph

Notes:

- Use a range of strategies to build surfaces
- Rebuild surfaces and curves
- Control surface curvature continuity
- Create, manipulate, save and restore custom construction planes
- Create surfaces and features using custom construction planes
- Group objects
- Visualize, evaluate, and analyze models utilizing shading features
- Place text around an object or on a surface
- Map planar curves to a surface
- Create 3-D models from 2-D drawings and scanned images
- Clean up imported files and export clean files
- Use rendering tools

Notes:

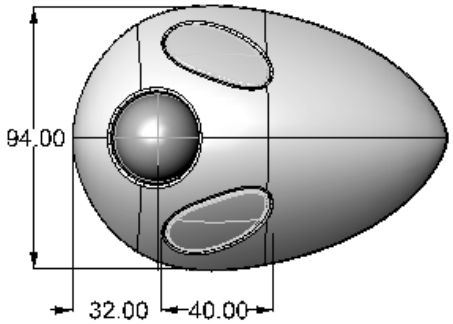
Notes:

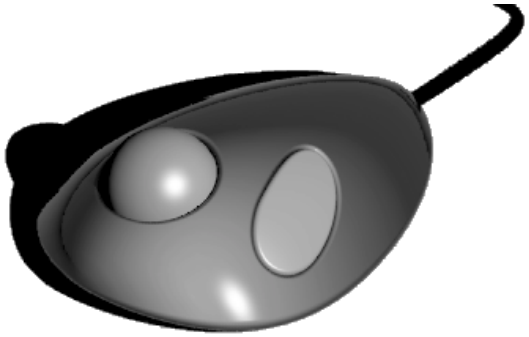
Exercise 1—Trackball Mouse (Warm-up)

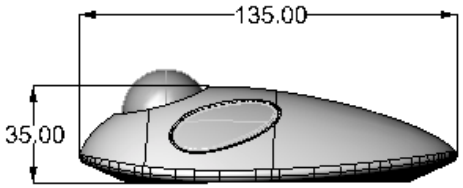
1 Begin a new model, save as **Trackball.3dm**.

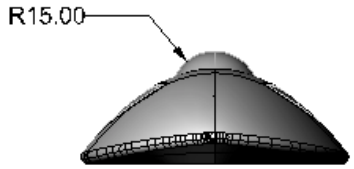
2 Model a trackball mouse on your own.

The dimensions are in millimeters. Use the dimensions as guides only.









Part Two:
Advanced Modeling Techniques

2 Customizing Rhino

The toolbar layout

The toolbar layout is the arrangement of toolbars containing command buttons on the screen. The toolbar layout is stored in a file with the .ws3 extension that you can open and save. Rhino comes with a default toolbar collection and automatically saves the active toolbar layout before closing unless the .ws3 file is read-only. You can create your own custom toolbar collections and save them for later use.

You can have more than one toolbar collection open at a time. This allows greater flexibility to display toolbars for particular tasks.

Rhino's customization tools make it easy to create and modify toolbars and buttons. Adding to the flexibility is the ability to combine commands into macros to accomplish more complex tasks. In addition to toolbar customization, it is possible to set up command aliases and shortcut keys to accomplish tasks in Rhino.

Notes:

Exercise 2 - Customizing Rhino's interface

In this exercise we will create buttons, toolbars, macros, aliases, and shortcut keys that will be available to use throughout the class.

To create a custom toolbar collection:

1 **Open** the model **ZoomLights.3dm**.

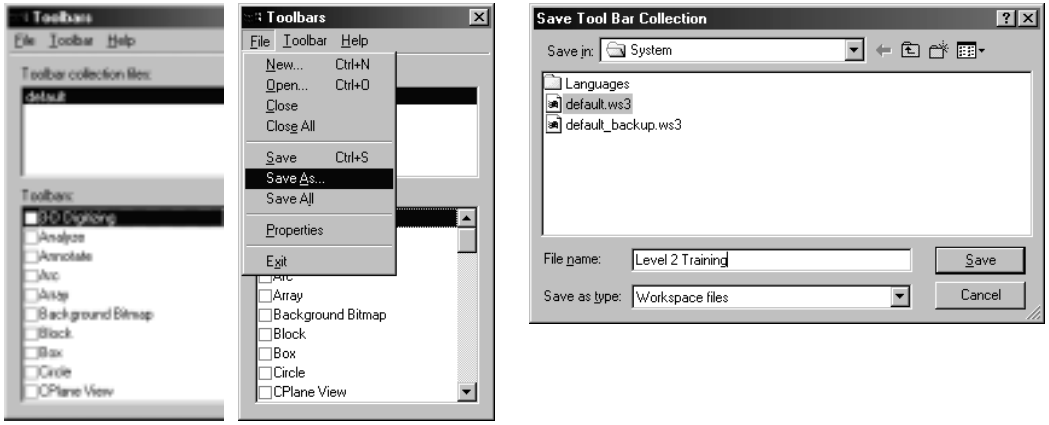
2 From the **Tools** menu, click **Toolbar Layout**.

3 Highlight the **Default** toolbar collection.

4 From the **Toolbars** dialog box **File** menu, click **Save As**.

5 Type **Level 2 Training** in the **File name** box, and click **Save**.

A copy of the current default toolbar collection has been saved under the new name. Toolbar collections are saved with a .ws3 extension. You will use this new toolbar collection to do some customization.



In the **Toolbars** dialog box all the open toolbar collections are listed along with a list of all the individual toolbars for the selected toolbar collection. Check boxes show the current state of the toolbars. A checked box indicates that the toolbar is displayed.

Notes:

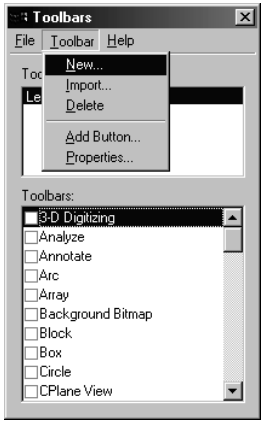
Edit Toolbar Layout

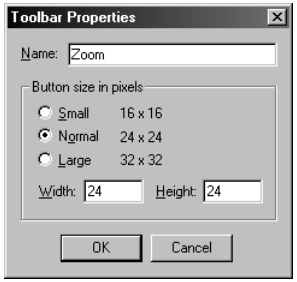
To create a new toolbar:

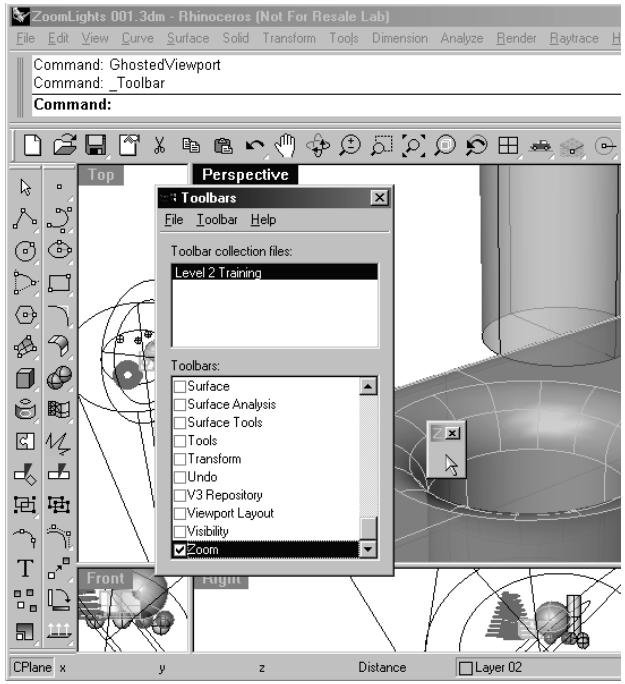
1 In the **Toolbars** dialog box, from the **Toolbar** menu, click **New**.

2 In the **Toolbars Properties** dialog box, name the toolbar **Zoom**, and click **OK**.

A new single button toolbar appears.



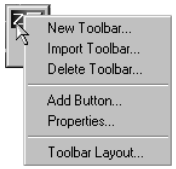




3 Close the Toolbars dialog box.

Another way to work with toolbars is to right-click in the title bar of a floating toolbar.

A popup list of toolbar options and commands displays.



Notes:

To edit the new button:

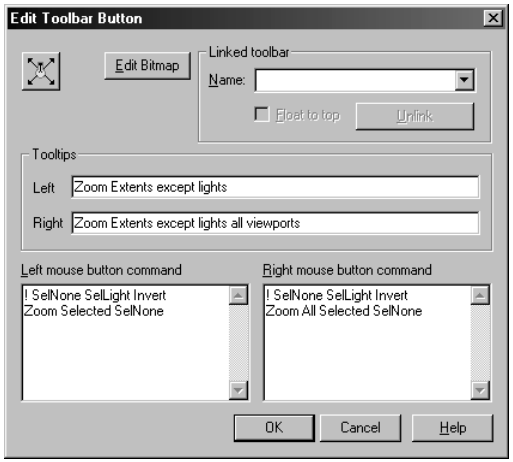
1 Hold down the **Shift** key and right-click the blank button in the new toolbar.

The **Edit Toolbar Button** dialog box appears with fields for commands for the left and right mouse buttons, as well as for the tooltips.

2 In the **Edit Toolbar Button** dialog box, under **Tooltips**, in the **Left** box, type **Zoom Extents except lights**.

3 In the **Right** box, type **Zoom Extents except lights all viewports**.

4 In the **Left Mouse Button Command** box, type **! SelNone SelLight Invert Zoom Selected SelNone**



5 In the **Right Mouse Button Command** box, type **! SelNone SelLight Invert Zoom All Selected SelNone**

To change the bitmap image for the button:

1 In the **Edit Toolbar Button** dialog box, click the **Edit Bitmap** button.

The bitmap editor is a simple paint program that allows editing of the icon bitmap. It includes a grab function for capturing icon sized pieces of the screen, and an import file function.

If the bitmap is too large, only a portion of the center is imported.

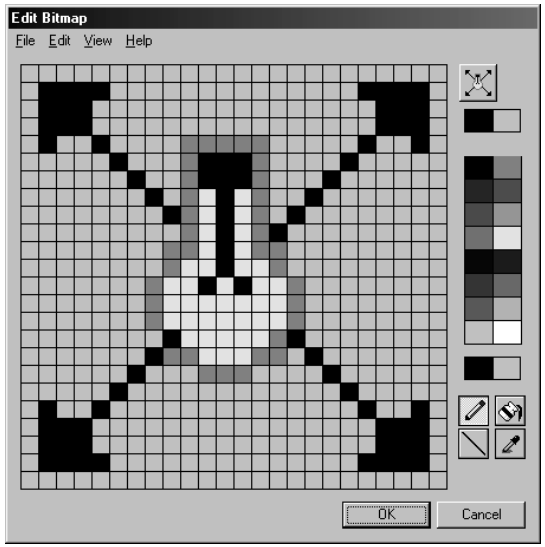
2 From the **File** menu, click **Import Bitmap**, and select the **ZoomNoLights.bmp**.

You can import any bitmap image of the correct pixel dimensions allowing you to make button icons any bitmap images.

Notes:

3 In the **Edit Bitmap** dialog box, make any changes to the picture, and click **OK**.

4 Click OK in the **Edit Toolbar Button** dialog box.



To access the new button, click it in the **Zoom** toolbar or you can link the **Zoom** toolbar from an existing button in another toolbar.

5 Use the button to zoom the model two ways.

You will notice that it ignores the lights when doing a zoom extents.

You can enter the commands or command combinations in the appropriate boxes, using these rules:

- A space is interpreted as **Enter**. Commands do not have spaces (for example, **SelLight**) but you must leave a space between commands
- If your command string refers to a file, toolbar, layer, object name, or directory for which the path includes spaces, the path, toolbar name, or directory location must be enclosed in double-quotes.
- A **!** followed by a space is interpreted as **Cancel**. Generally it is best to begin a button command with **!** if you want to cancel any other command which may be running when you click the button.
- View manipulation commands like **Zoom** can be run in the middle of other commands. For example, you can zoom and pan while picking curves for a loft. Placing the **!** in front of these commands would not be use the full power of these commands.

Notes:

- User input and screen picks are allowed in a macro by putting the **Pause** command in the macro. Commands that use dialog boxes, such as **Revolve**, do not accept input to the dialog boxes from macros. Use the hyphen form of the command (**-Revolve**) to suppress the dialog box and control it entirely from a macro.

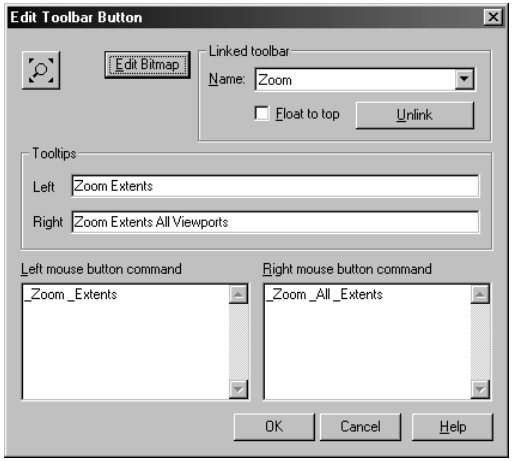
Note: The rules above also apply to scripts run using the **ReadCommandFile** command and pasting text at the command prompt. More sophisticated scripting is possible with the Rhino Script plug-in, but quite a lot can be done with the basic commands and macro rules. Some useful commands to are: **SelLast**, **SelPrev**, **SelName**, **Group**, **SetGroupName**, **SelGroup**, **Invert**, **SelAll**, **SelNone**, **ReadCommandFile**, and **SetWorkingDirectory**.

To link a toolbar to a button:

1 Ctrl+right-click the **Zoom Extents** button in the **Standard** toolbar.

2 Under **Linked toolbar** in the **Name** list, select **Zoom** and click **OK**.

Now the **Zoom Extents** button has a small white triangle in the lower right corner indicating it has a linked toolbar.



3 Click and hold the **Zoom Extents** button to fly out your newly created single button toolbar.

If you close the **Zoom** toolbar you just created, you can always re-open it using the linked button.

4 Try the new linked button.

Notes:

Zoom Extents

To copy a button from one toolbar to another:

1 Hold the **Ctrl** key and move your mouse to the button on the far right of the **Standard** toolbar.

The tooltip indicates that left-click and drag will **copy** the button and right-click and drag will **link** the button in another toolbar.

2 **Copy** the button one space over in the same toolbar.

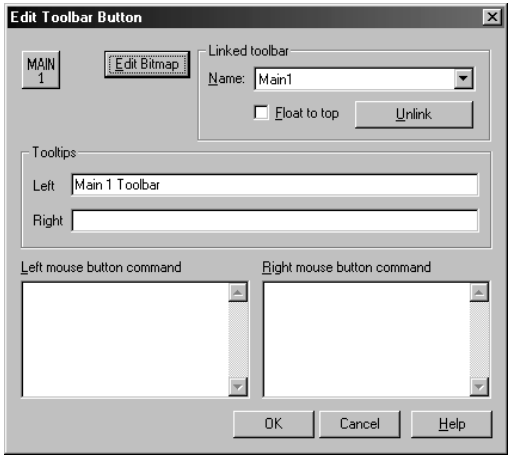
3 In the **OK to duplicate button** dialog box, click **OK**.

4 Hold down the **Shift** key and right-click on the button you copied to edit the button.

5 In the **Edit Toolbar Button** dialog box, under **Linked toolbar** in the **Name** list, select **Main1**.

6 Delete all the text in the boxes for both left and right mouse button commands.

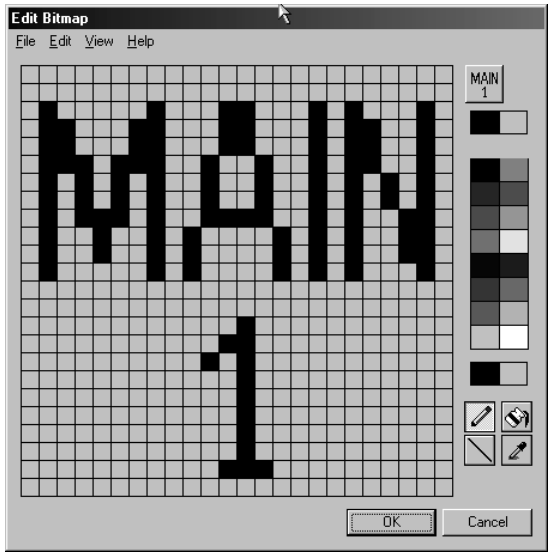
7 Under **Tooltips**, in the **Left** box, type **Main1 Toolbar**.



Notes:

8 Click the **Edit Bitmap** button.

9 In the **Edit Bitmap** dialog box, clear the image, then make a simple icon like the example below.



10 Close all the dialog boxes and return to the Rhino window.

11 Undock the **Main** toolbar and close it.

12 Click on the new button that you just made.

The **Main** toolbar flies out instantly and is available. This allows the viewports to be larger than when the **Main1** toolbar was docked on the side.

13 Fly out the **Main** toolbar and tear it off, so it is displayed (floating).

To add a command to an existing button:

1 Hold the **Shift** key and right click the **Copy** button on the **Main1** toolbar.

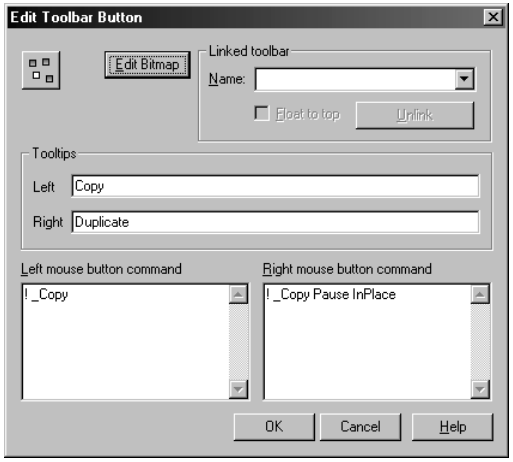
2 In the **Edit Toolbar Button** dialog box, in the **Right Mouse Button Command** box, type **! Copy Pause InPlace**

Notes:

Copy

3 In the **Edit Toolbar Button** dialog box, in the **Right Tooltip** box, type **Duplicate**.

This button will allow you to duplicate objects in the same location. We will use this command several times during the class.



4 Select one of the objects in the model and right click on the **Copy** button.

5 **Move** the selected object so that you can see the duplicate.

Command aliases

The same commands and macros that are available for buttons are also available for command aliases. Command aliases are useful productivity features in Rhino. They are commands and macros which are activated whenever commands are allowed, but are often used as a keyboard shortcut followed by **Enter, Spacebar** or clicking the right mouse button.

To make a command alias:

1 Open the model **Aliases.3dm**.

2 From the **Tools** menu, click **Options**.

3 In the **Rhino Options** dialog box, on the **Aliases** page, add aliases and command strings or macros.

The alias is in the left column and the command string or macro is in the right column. The same rules apply here as with the buttons. Aliases can be used within other aliases' macros or button macros.

Notes:

When making aliases, use keys that are close to each other or repeat the same character 2 or 3 times, so they will be easy to use.

Options

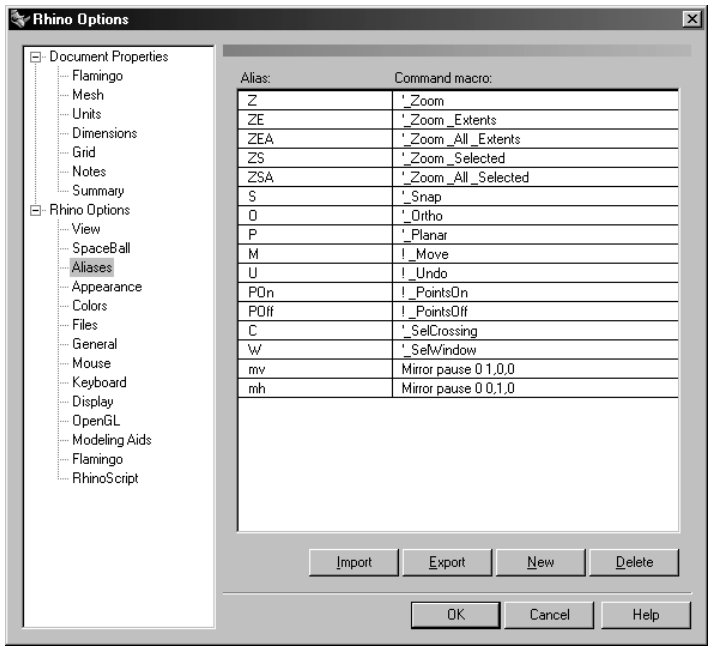
4 Click **New** to make a new alias.

We will make aliases to mirror selected objects vertically and horizontally across the origin of the active construction plane. These are handy when making symmetrical objects built centered on the origin.

5 Type **mv** in **alias** column. Type **Mirror pause 0 1,0,0** in the command macro column.

6 Click **New** to make another new alias.

7 Type **mh** in **alias** column. Type **Mirror pause 0 0,1,0** in the command macro column.



8 Select some geometry and try the new aliases out. Type **mh** or **mv** and press **Enter**.

If no objects are pre-selected, the **Pause** in the script prompts you to select objects, and a second **Enter** will complete the selection set.

To import command aliases:

1 From the **Tools** menu, click **Commands**, then click **Import Command Aliases**.

2 In the **Import Command Aliases** dialog box, select **Aliases.txt**.

The alias text file contains alias definitions.

3 Open the **Options** dialog box to see the new aliases.

Notes:

Shortcut keys

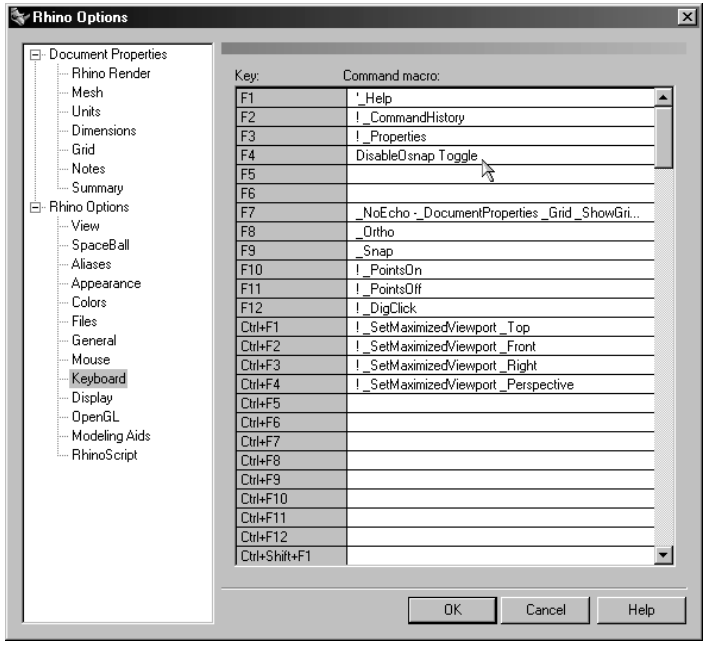
The same commands, command strings, and macros that you can use for buttons are also available for keyboard shortcuts. Shortcuts are commands and macros that are activated by a function key, Ctrl, Alt, and Shift combinations, and an alphanumeric key on the keyboard.

To make a shortcut key:

1 From the **Tools** menu, click **Options**.

2 In the **Rhino Options** dialog box, on the **Keyboard** page, you can add command strings or macros.

There are several shortcut keys that already have commands assigned. The same rules apply here as with the buttons.



3 Click in the column next to the **F4** to make a new shortcut.

4 Type **DisableOsnap Toggle** for the shortcut.

This shortcut will make it easy to toggle the state of running object snaps.

5 Close the dialog box and try it out.

Notes:

Plug-ins

Plug-ins are programs that extend the functionality of Rhino.

Several plug-ins are included and automatically install with Rhino. Many others are available for download from the Rhino website.

To load a plug-in:

1 From the **Tools** menu, click **Plug-in Manager**.

2 In the **Plug-in Manager** dialog box, click **Install**.

3 In the **Load Plug-In** dialog box, click **OrientOnCrv.rhp**.

This plug-in allows you orient an object relative to a curve.

4 Select the cylinder.

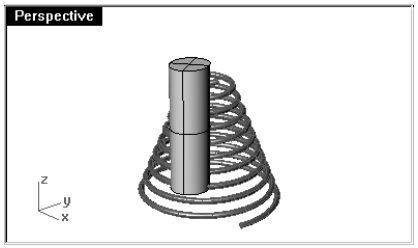
5 Type **OrientOnCrv** and press **Enter**.

6 At the **Base point** prompt, snap to the center of the base of the cylinder.

7 At the **Select path curve** prompt, select the edge of the spiral.

8 At the **New base point on curve** (Copy=*No* Perpendicular=*No*) prompt, move the cylinder along the curve, and click when you get it positioned.

Notice that the cylinder base is aligned to the spiral.



Scripting

Rhinoceros supports scripting using VBScript.

To script Rhino, you must have some programming skills. Fortunately, VBScript are simpler to program than many other languages, and there are materials available to help you get started. VBScript are programming languages developed and supported by Microsoft.

We will not cover how to write a script in this class, but we will learn how to run a script and apply it to a button.

The following script will make a copy of an object and allow you to place it on another layer in one operation.

Notes:

Plug-in Manger

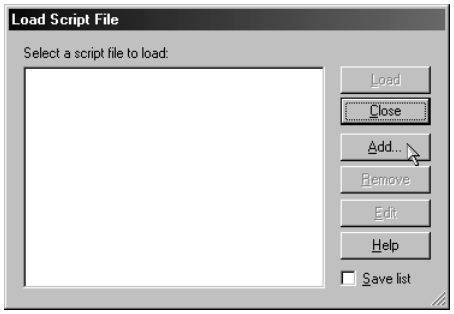
To load a script:

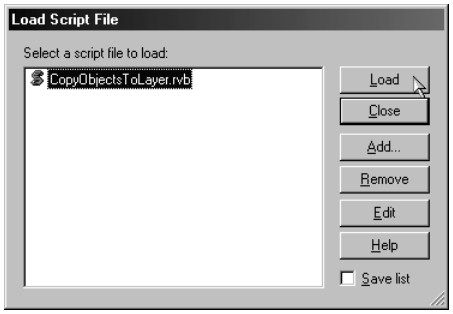
1 On the command line, type **LoadScript** and press **Enter**.

2 In the **Load Script File** dialog box, click **Add**.

3 In the **Open** dialog box, select **CopyObjectsToLayer.rvb**, then click **Open**.

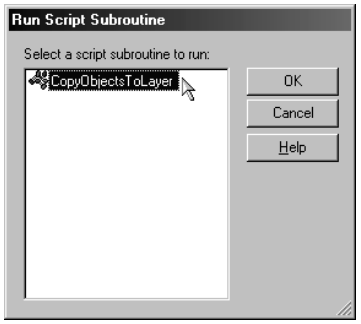
4 In the **Load RhinoScript** dialog box, highlight **CopyObjectsToLayer.rvb**, then click **Load**.





5 At the **Select Objects** prompt, pick the cylinder, and press **Enter**.

6 In the **Copy Objects to Layer** dialog box, click **Layer 01** and then click **OK**.



To edit the script file:

1 On the command line, type **LoadScript** and press **Enter**.

2 In the **Load RhinoScript** dialog box, highlight **CopyObjectsToLayer.rvb**, then click **Edit**.

The last line of the script runs the script. Since we are going to make a button to run the script after it is loaded, you should delete this line.

3 Delete the last line in the script, then close the editor and save the changes.

4 Close the **Load RhinoScript** dialog box.

Notes:

To make a button that will load or run a script:

1 From the **Tools** menu, click **Toolbar Layout**.

2 In the **Toolbars** dialog box, check **Layer** and highlight it.

3 In the **Toolbars** dialog box, from the **Toolbar** menu, click **Add Button**, then close the **Toolbars** dialog box.

4 To edit the new button, hold down the **Shift** key and right-click on the new button that appeared in the **Layer** toolbar.

5 In the **Edit Toolbar Button** dialog box, in the **Left Tooltip**, type **Copy Objects to Layer**.

6 In the **Right Tooltip**, type **Load Copy Objects to Layer Script**.

7 In the **Left Mouse Button Command** box, type **! RunScript /rvb /CopyObjectsToLayer**.

8 In the **Right Mouse Button Command** box, type **! LoadScript /CopyObjectsToLayer.rvb**.

9 In the **Edit Toolbar Button** dialog box, click **Edit Bitmap**.

10 In the **Edit Bitmap** dialog box, from the **File** menu, click **Import**, and **Open** the **CopyObjectsToLayer.bmp**, then click **OK**.

11 In the **Edit Toolbar Button** dialog box, click **OK**.

12 Try the new button.

Template files

A template is a Rhino model file you can use to store basic settings. Templates include all the information that is stored in a Rhino 3DM file: objects, grid settings, viewport layout, layers, units, tolerances, render settings, dimension settings, notes, etc.

You can use the default templates that are installed with Rhino or save your own templates to base future models on. You will likely want to have templates with specific characteristics needed for particular types of model building.

The standard templates that come with Rhino have different viewport layouts or unit settings, but no geometry, and default settings for everything else. Different projects may require other settings to be changed. You can have templates with different settings for anything that can be saved in a model file, including render mesh, angle tolerance, named layers, lights, and standard pre-built geometry.

The **New** command begins a new model with a template (optional). It will use the default template unless you change it to one of the other templates or to any other Rhino model file.

The **SaveAsTemplate** command creates a new template file.

To change the template that opens by default when Rhino starts up, choose **New** and select the template file you would like to have start when Rhino starts, then check the **Use this file when Rhino starts** box.

Notes:

To create a template:

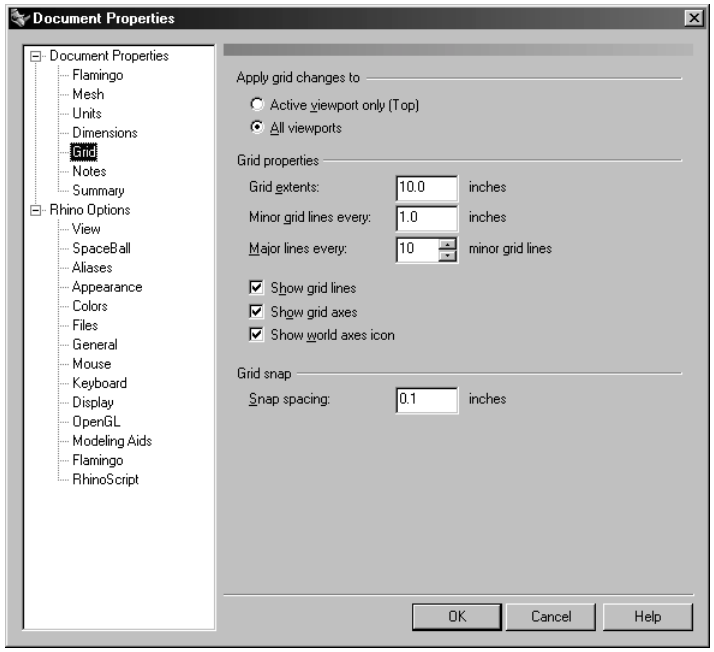
1 Start a new model.

2 Select the **Inches.3dm** file as the template.

3 From the **Render** menu, click **Current Renderer**, then click **Flamingo Raytrace**.

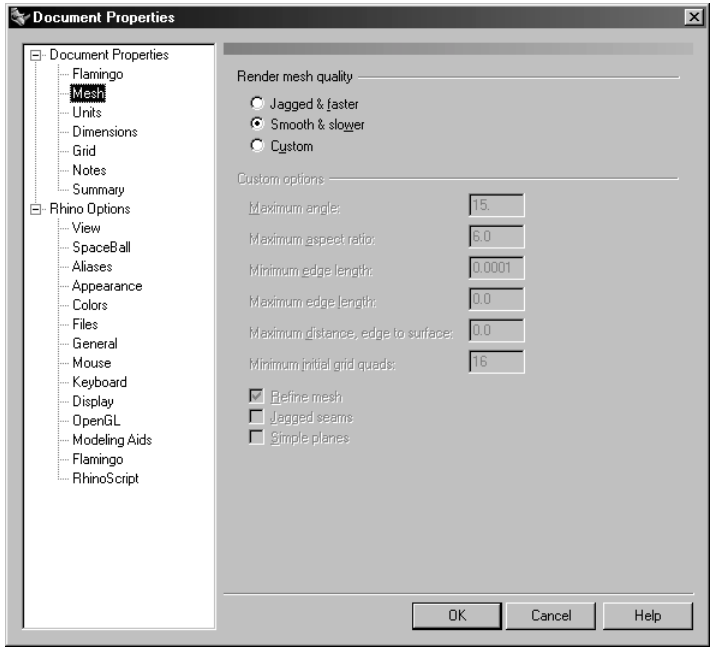
4 From the **File** menu, click **Properties**.

5 In the **Document Properties** dialog box, on the **Grid** page, change the **Grid Snap spacing** to **.1**, the **Minor gridlines every** to **1**, the **Major lines every** to **10**, and the **Grid extents** to **10**.



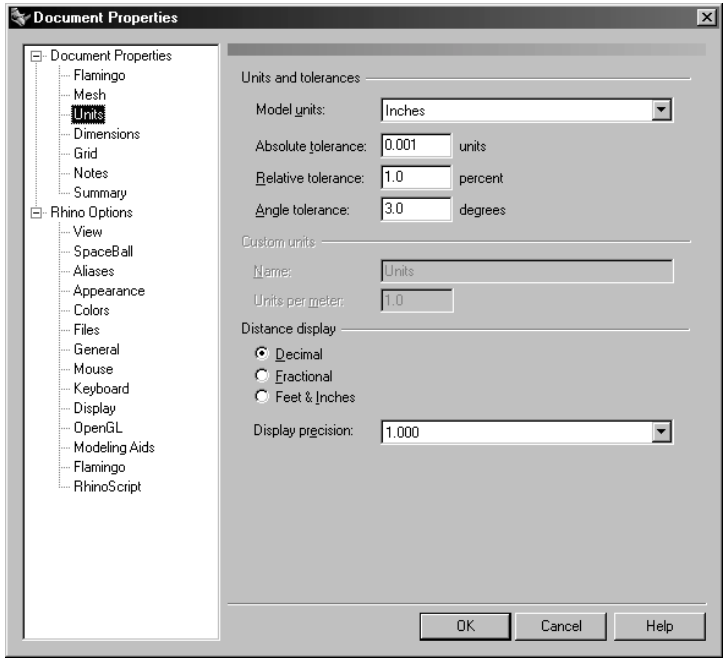
Notes:

6 On the **Mesh** page change the setting to **Smooth and slower**.



Notes:

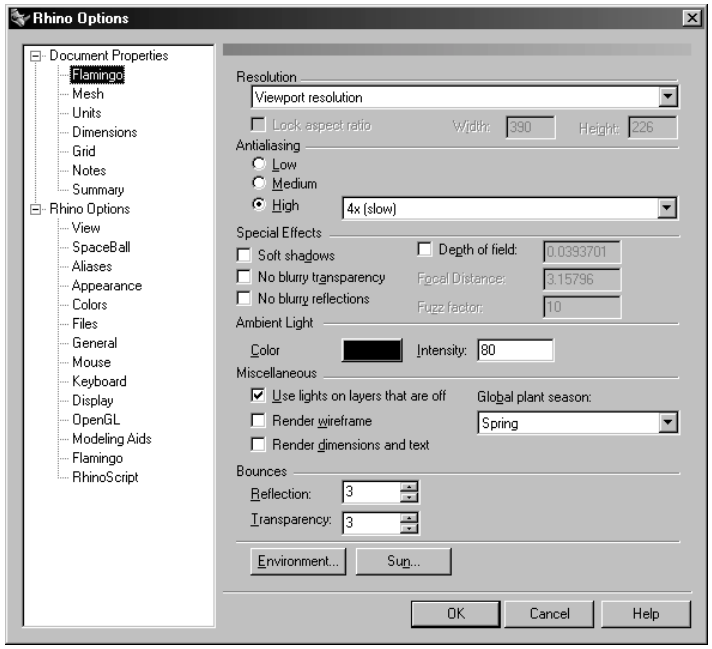
7 On the **Units** page change the **Absolute tolerance** to **0.001**.



Notes:

8 On the **Flamingo** page, check **Use lights on layers that are off**.

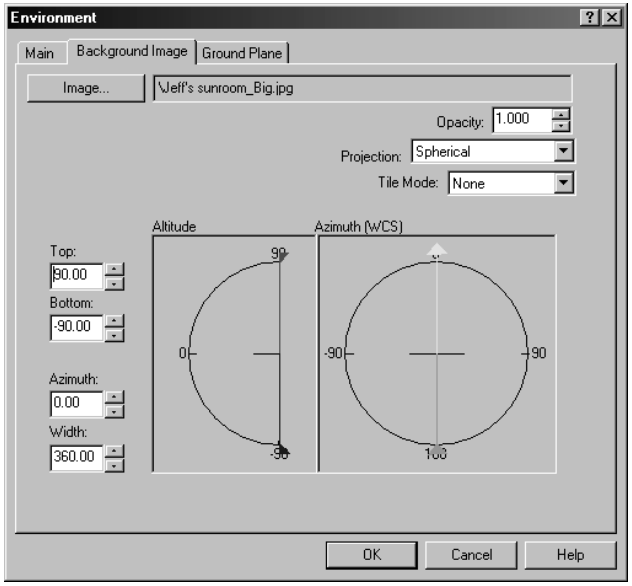
9 On the **Flamingo** page click **Environment,** check **Ground plane** and accept the default material.



Notes:

10 In the **Environment** dialog box, on the **Main** page, check **Background image**.

11 On the **Background image** page, select **Jeff'sSunroom.bmp** for the background, under the **Projection** dropdown select **Spherical**.



12 Click **OK** to close the **Environment** dialog box.

13 Click **OK** to close the **Document Properties** dialog box.

14 With the **Perspective** viewport active, press **F7** to toggle the grid off.

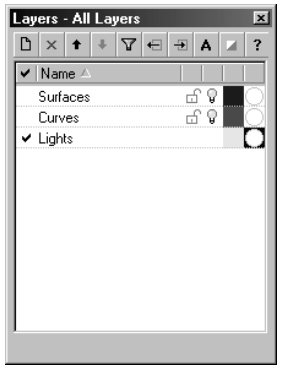
Notes:

15 Open the **Layers** dialog box and rename **Layer 05** to **Lights**, **Layer 04** to **Curves**, and **Layer 03** to **Surfaces**.

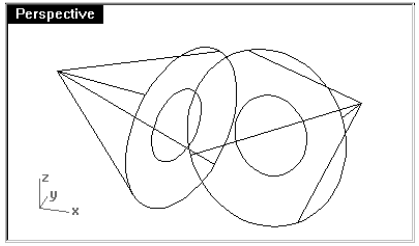
Make the **Lights** layer current.

Delete **Default**, **Layer 01** and **Layer 02** layers**.**

Close the dialog box.



16 Set up two spotlights so that they point at the origin and are approximately 45 degrees from the center and tilted 45 degrees from the construction plane.



17 To make the **Curves** layer the only visible layer, from the **Edit** menu, click **Layers**, then click **One Layer On**.

18 From the **File** menu, click **Save As Template** and navigate to the templates directory.

Name the template **Inches_SmallProduct_001.3dm**.

This file with all of its settings is now available any time you start a new model. You should make custom templates for the kind of modeling that you do regularly to save set up time.

Notes:

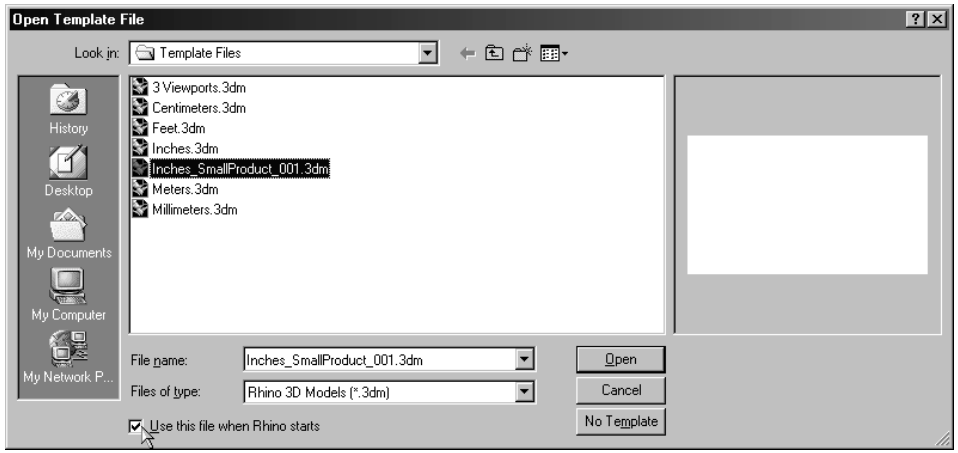
One Layer ON

To set a default template:

1 From the **File** menu, click **New**.

2 Select the template you want to use as the default template.

3 In the **Template File** dialog box, check the **Use this file when Rhino starts** checkbox.



Notes:

3 NURBS Topology

NURBS surfaces always have a rectangular topology. Rows of surface points and parameterization are organized in two directions, basically crosswise to each other. This is not always obvious when creating or manipulating a surface. Remembering this structure is useful in deciding which strategies to use when creating or editing geometry.

Exercise 3 - Topology

This exercise will demonstrate how NURBS topology is organized and discuss some special cases that need to be considered when creating or editing geometry.

1 **Open** the model **Topology.3dm**.

There are several surfaces and curves visible on the current layer.

2 Turn on the **control points** of the simple rectangular plane on the left.

It has four control points, one at each corner—this is a simple untrimmed planar surface that shows the rectangular topology.

3 Now turn on the **control points** of the second, more curvy surface.

There are many more points, but it is clear that they are arranged in a rectangular fashion.

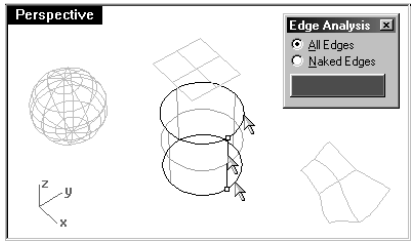
4 Now select the **cylinder**.

It appears as a continuous circular surface, but it also has a rectangular boundary.

Notes:

Control Points On

5 Use the **ShowEdges** command *(Analyze menu: Edge Tools > click Show Edges)* to highlight the surface edges.

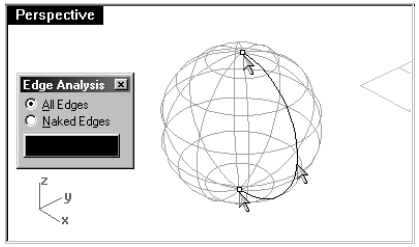


Notice that there is a seam highlighted on the cylinder. The seam that is highlighted represents two edges of the rectangle, while the other two edges are circular at the top and the bottom. The rectangular topology is present here, also.

6 Now select the sphere.

It appears as a closed continuous object, but it also has a rectangular boundary.

7 Use the **ShowEdges** command to highlight the edges.



Notice that there is a seam highlighted on the sphere. The seam that is highlighted represents two edges of the rectangle, while the other two edges are collapsed to a single point at the poles. The rectangular topology is present here, also, though very distorted.

When all of the points of an untrimmed edge are collapsed into a single point, it is called a *singularity*. A singularity is a special case, but as a general rule it is better not to stack one control point on top of another. If internal points of an edge are collapsed or stacked into a single point, Rhino gives an error message with the **Check** or **SelBadObjects** commands.

8 With the sphere selected, press **F11** followed by **F10**.

The **control points** of the first two surfaces have been turned off (**F11**) and those of the sphere have been turned on (**F10**).

9 With the **Point** object snap on, **Zoom Target** very tight in on one of the poles of the sphere.

10 Press **F11** to turn off the points.

11 Select the sphere.

12 Start the **Smooth** *(Transform menu: Smooth)* command.

Notes:

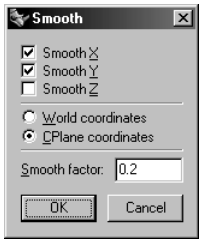
Show Edges

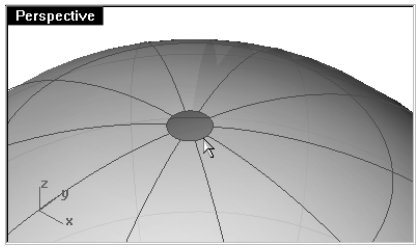
Zoom Target
(right mouse button option)

Smooth

13 In the **Smooth** dialog box, uncheck **Smooth Z**, then click **OK**.

A hole appears at the poles of the sphere.





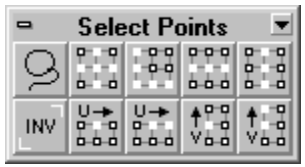
ShowEdges will highlight this as an edge as well.

14 Use the **Home** key to **Zoom** back out.

This is the fastest way to step back through view changes.

To select points:

1 Open the **Select Points** toolbar.



2 Turn on the points for the sphere.

3 Select a single point at random on the sphere.

4 From the toolbar, click **Select U**.

An entire row of points is selected.

Select U

5 Clear the selection by clicking in an empty area and select another point on the sphere.

6 From the toolbar, click **Select V**.

A row of points in the other direction of the rectangle is selected. This arrangement into U and V directions is always the case in NURBS surfaces.

Select V

7 Try the other buttons in this toolbar on your own.

Notes:

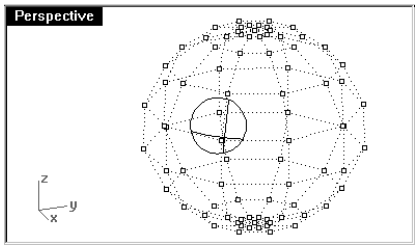
Exercise 4—Trimmed NURBS

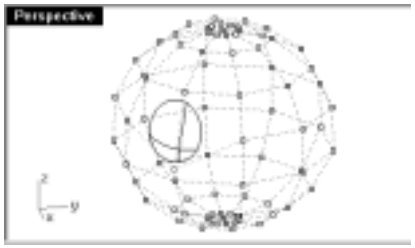
1 **Open** the model **Trimmed NURBS.3dm**.

This surface has been trimmed out of a much larger surface. The underlying four sided surface data is still available after a surface has been trimmed, but it is limited by the trim curves (edges) on the surface.

2 Select the surface and turn on the control points.

Control points can be manipulated on the trimmed part of the surface or the rest of the surface, but notice that the trimming edges also move around as the underlying surface changes. The trim curve always stays on the surface.



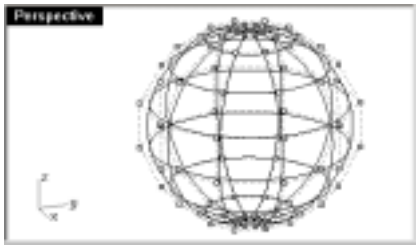


To remove the trims from a surface:

1 Start the **Untrim** *(Surface menu: Surface Edit Tools > Untrim)* command.

2 At the **Select boundary to detach** prompt, select the edge of the surface.

The original underlying surface appears and the trim boundary disappears.



3 Use the **Undo** command to return to the previous trimmed surface.

Notes:

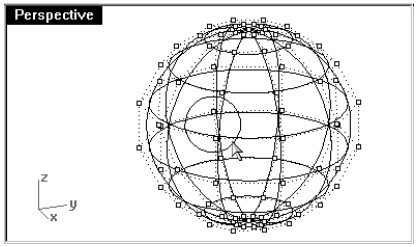
Untrim

To detach a trimming curve from a surface:

1 Start the **Untrim** command with the **KeepTrimObjects** option set to *Yes (Surface menu: Surface Edit Tools > Detach Trim)*.

2 At the **Select boundary to detach** prompt, select the edge of the surface.

The original underlying surface appears. The boundary edges are converted to curves, which are no longer associated with the surface.



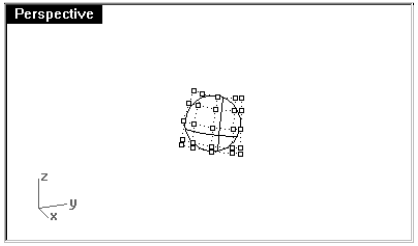
3 **Undo** to return to the previous trimmed surface.

To shrink a trimmed surface:

1 Start the **ShrinkTrimmedSrf** command *(Surface menu: Surface Edit Tools > Shrink Trimmed Surface)*.

2 At the **Select trimmed surfaces to shrink** prompt, select the surface and press **Enter** to end the command.

The underlying untrimmed surface is replaced by a one with a smaller range that matches the old surface exactly in that range. You will see no visible change in the trimmed surface. Only the underlying untrimmed surface is altered.



Notes:

Detach Trim

Undo

Shrink Trimmed Surface

4 Curve Creation

We will begin this part of the course by reviewing a few concepts and techniques related to NURBS curves that will simplify the learning process during the rest of the class. Curve building techniques have a significant effect on the surfaces that you build from them.

Curve degree

The degree of a curve is related to the extent of the influence a single control point has over the length of the curve.

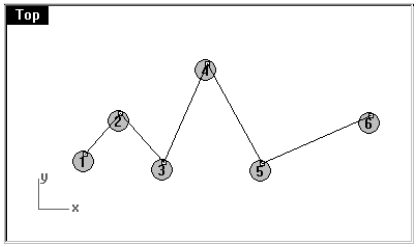
For higher degree curves, the influence of any single point is less in a specific part of the curve but affects a longer portion of the curve.

In the example below, the five curves have their control points at the same six points. Each curve has a different degree. The degree can be set with the Degree option in the **Curve** command.

Exercise 5—Curve Degree

1 Open the model **Curve Degree.3dm**.

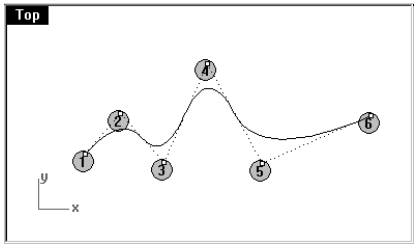
2 Use the **Curve** command *(Curve menu: Free-Form > Control Points)* with **Degree** set to **1**, using the **Point** object snap to snap to each of the points.



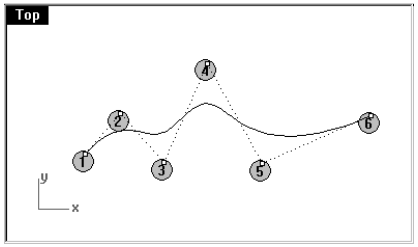
Notes:

Curve

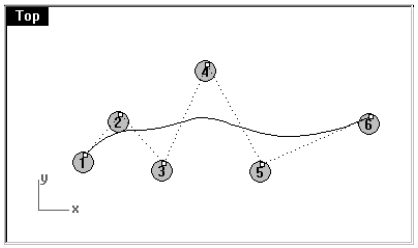
3 Use the **Curve** command with **Degree** set to **2**, using the **Point** object snap to snap to each of the points.



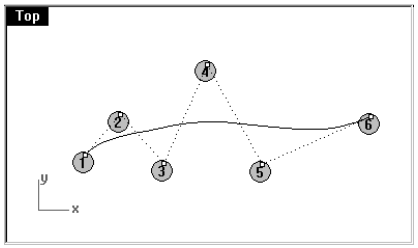
4 Use the **Curve** command with **Degree** set to **3**, using the **Point** object snap to snap to each of the points.



5 Use the **Curve** command with **Degree** set to **4**, using the **Point** object snap to snap to each of the points.



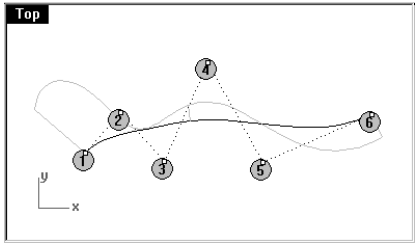
6 Use the **Curve** command with **Degree** set to **5**, using the **Point** object snap to snap to each of the points.

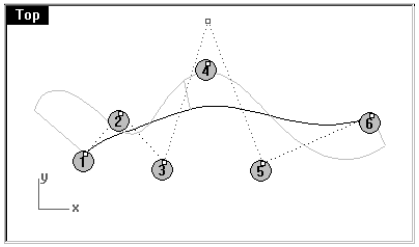


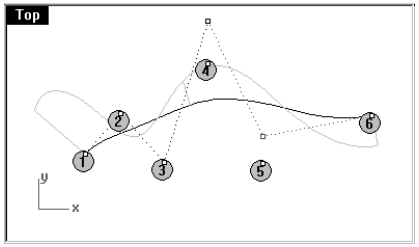
Notes:

7 Use the **CurvatureGraphOn** command *(Analyze menu: Curve > Curvature Graph On)* to turn on the curvature graph for one of the curves. The graph indicates the curvature continuity and the rate of change in the curve.

Degree 1 curves have no curvature. Degree 2 curves have continuous tangency. Degree 3 curves have continuous curvature. In Degree 4 curves, the rate of change of curvature is continuous. In Degree 5, the rate of change of the rate of change is continuous.







8 View the curvature graph as you drag some control points.

Note the change in the curvature hairs as you move points.

9 Repeat this process for each of the curves.

Notes:

Curvature Graph On

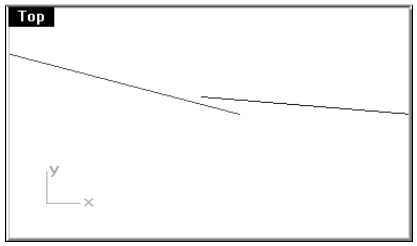
Curve and surface continuity

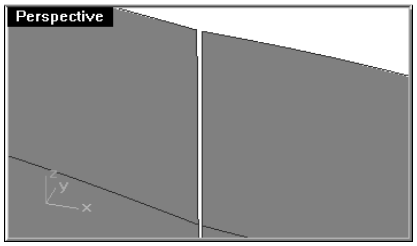
Since creating a good surface so often depends upon the quality of the input curves, it is worthwhile investigating some of the characteristics of both.

For most curve building and surface building purposes we can talk about four useful levels of continuity:

Not continuous

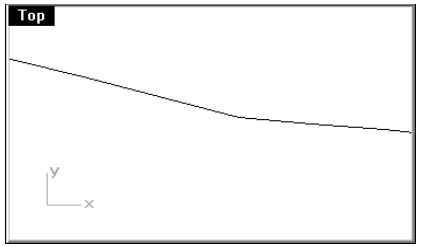
The curves or surfaces do not meet at their end points or edges. Where there is no continuity, the objects cannot be joined.

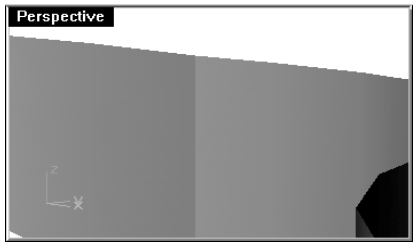




Positional continuity (G0)

Curves meet at their end points, surfaces meet at their edges.



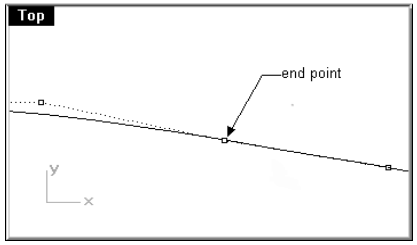


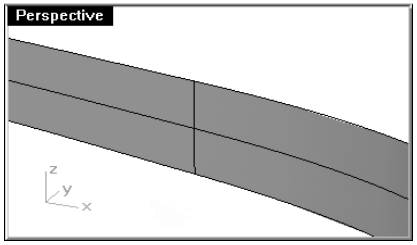
Positional continuity means that there is a kink at the point where two curves meet. The curves can be joined in Rhino into a single curve but there will be a kink and the curve can still be exploded into at least two sub-curves. Similarly two surfaces may meet along a common edge but will show a kink or seam, a hard line between the surfaces. For practical purposes, only the end points of a curve or the last row of points along an edge of an untrimmed surface need to match to determine G0 continuity.

Notes:

Tangency continuity (G1)

Curves or surfaces meet and the directions of the tangents at the endpoints or edges is the same. You should not see a crease or a sharp edge.

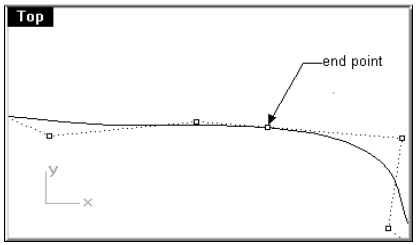


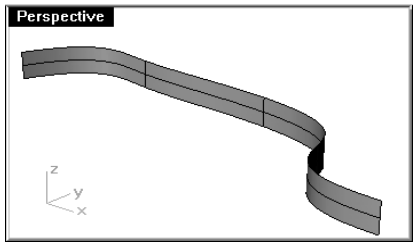


Tangency continuity means that there is no kink between curves or surfaces but rather a smooth transition. The clearest example of G1 continuity is a radial fillet between curves or surfaces. In tangency continuity the end control point and the next control point on a curve, or the edge row and the next row of points of a surface determine the tangency condition.

Curvature continuity (G2)

Curves or surfaces meet, their tangent directions are the same and the radius of curvature is the same for each at the end point.





Curvature continuity is the smoothest of the cases we are considering. It means that the surface or curve changes more smoothly than with tangency continuity. There is no abrupt change in direction from one curvature to the next. In G1 continuity the curvature changes at a single point. For example, the transition from a straight line to a tangent arc takes place at a given point. With G2 continuity this change happens over a distance in the curves, so that curves and surfaces tend to have a more smooth (organic) and less mechanical look to them. Many product designs make use of G2 continuity.

Note: There are higher levels of continuity possible. For example, G3 continuity means that not only are the conditions for G2 continuity met, but also that the rate of change of the curvature is the same on both curves or surfaces at the common end points or edges. G4 means that the rate of change of the rate of change is the same. Rhino has tools to build such curves and surfaces, but fewer tools for checking and verifying such continuity than for G0-G2.

Notes:

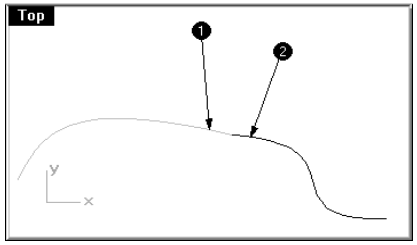
Exercise 6 - Geometric Continuity

1 Open the model **Curve Continuity.3dm**.

The two curves are clearly not tangent. Verify this with the continuity checking command **GCon**.

2 Start the **GCon** command *(Analyze menu: Curve > Geometric Continuity)*.

3 Click near the common ends (**1** and **2**) of each curve.



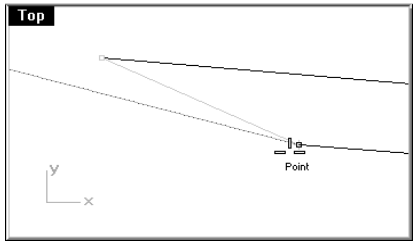
Rhino displays a message on the command line indicating the curves are not touching at the ends.

Curve end difference = 0.0304413
Tangent difference in degrees = 10.2772
Radius of curvature difference = 126.531
Curvature direction difference in degrees = 10.2772
Curve ends are out of tolerance.

To make the curves have position continuity:

1 Turn on the control points for both curves and zoom in on the common ends.

2 Turn on the **Point** object snap and drag one of the end points onto the other.



Notes:

G?

Geometric Continuity

3 Repeat the **GCon** command.

The command line message is different now:

Curve end difference = 0
Tangent difference in degrees = 10.3069
Radius of curvature difference = 126.771
Curvature direction difference in degrees = 10.3069
Curves are G0.

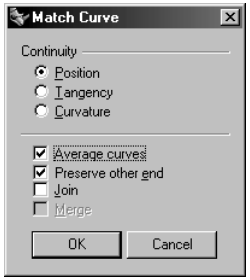
4 **Undo** the previous operation.

5 Start the **Match** command *(Curve menu: Curve Edit Tools > Match)*.

6 At the **Select open curve to change - pick near end** prompt, pick near the common end of one of the curves.

7 At the **Select open curve to match - pick near end** (SurfaceEdge) prompt, pick near the common end of the other curve.

8 In the **Match Curve** dialog box, check **Position**, **Average Curves**, and **Preserve other end**.



9 Repeat the **GCon** command.

The command line message indicates:

Curve end difference = 0
Tangent difference in degrees = 10.2647
Radius of curvature difference = 126.708
Curvature direction difference in degrees = 10.2647
Curves are G0.

Notes:

Match

Exercise 7 - Tangent Continuity

In this part of the exercise, we will make the two curves have G1 continuity. G1 continuity is determined by the end points and the second points of the curves. These two points determine the tangent direction of the end of a curve and since G1 continuity requires that the tangent direction be the same for both curves, it is sufficient to have the two last points on each curve, four all together, fall in line with each other. The two end points must be in the same place and the next control point on each curve must fall in a line with those end points. This can be done by manipulating the points directly or by using the **Match** command.

We will use **Move**, **SetPt**, **Zoom Target**, **PointsOn** (**F10**), **PointsOff** (**F11**) and the object snaps **End**, **Point**, **Along**, **Between** and the **Tab** lock to accomplish this.

First, we will create some aliases that will be used in this exercise.

To make Along and Between aliases:

Along and **Between** are one-time object snaps that are available in the **Tools** menu under **Object snaps**. They can only be used after a command has been started and apply to one pick. We will create new aliases for these object snaps.

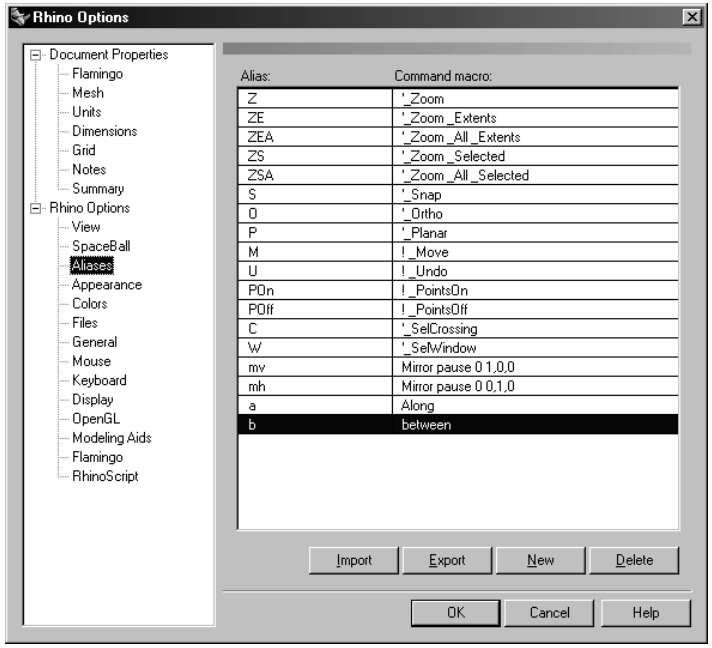
1. In the **Rhino Options** dialog box on the **Aliases** page click the **New** button, and then type **a** in the **Alias** column and **Along** in the **Command macro** column.
2. Type **b** in the **Alias** column, and **Between** in the **Command macro** column.

Notes:

Along

Between

3 Close the **Rhino Options** dialog box.



To change the continuity by adjusting control points using the Between object snap:

1 Use the **OneLayerOn** command to turn on only the **Curves 3d layer**.

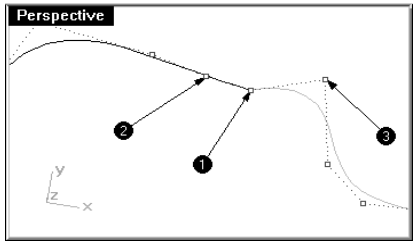
2 Check the continuity of the curves with the **GCon** command.

3 Turn on the **control points** for both curves.

4 Window select the common end points of both curves (1).

5 Use the **Move** command *(Transform menu: Move)* to move the points.

6 At the **Point to move from** (Vertical) prompt, snap to the same point (1).



Notes:

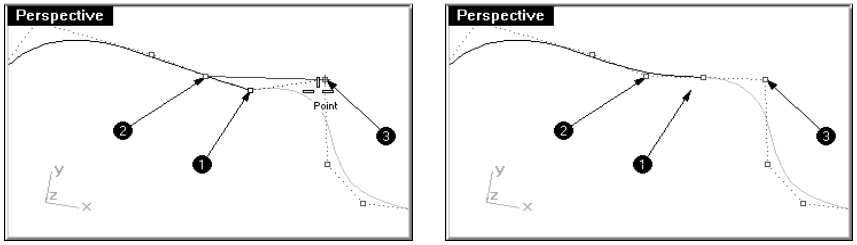
One Layer ON

Move

7 At the **Point to move to** prompt, type **b** and press **Enter** to use the **Between** object snap.

8 At the **First point** prompt, select the second point (2) on one curve.

9 At the **Second point** prompt, select the second point (3) on the other curve.



The common points are moved in between the two second points, aligning the four points.

10 Check the continuity.

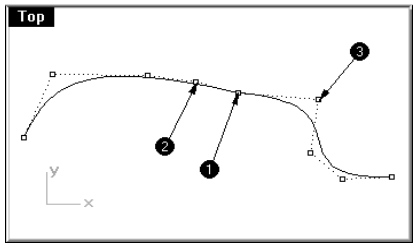
To change the continuity by adjusting control points using the Along object snap:

1 **Undo** the previous operation.

2 Select one of the second points (2 or 3).

3 Use the **Move** command *(Transform menu: Move)* to move the point.

4 At the **Point to move from** (Vertical) prompt, snap to the point (2 or 3).

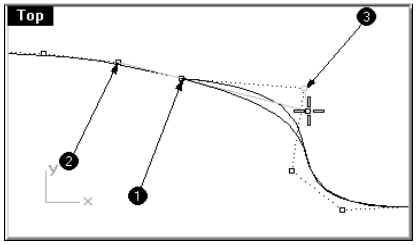


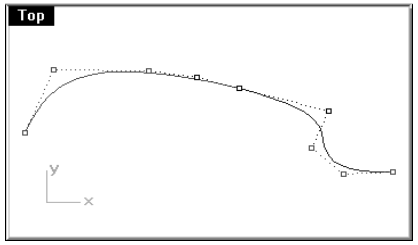
5 At the **Point to move to** prompt, type **a** and press **Enter** to use the **Along** object snap.

6 At the **Start of tracking line** prompt, snap to the second point (3 or 2) on the other curve.

Notes:

7 At the **End of tracking line** prompt, snap to the common points (1).





The point tracks along a line that goes through the two points, aligning the four points. Click to place the point.

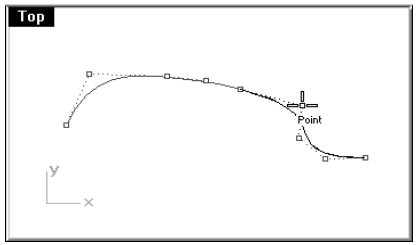
8 Check the continuity.

G1 continuity can be maintained by making sure that any point manipulation of the critical four points takes place along the line on which they all fall.

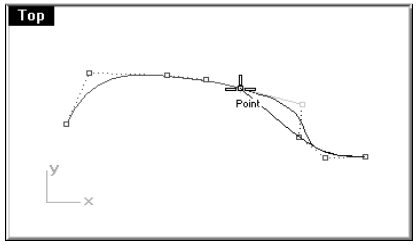
Once you have G1 continuity you can still edit the curves near their ends without losing continuity.

To edit the curves without losing continuity:

1 Select the end points or either of the second points on the curves.

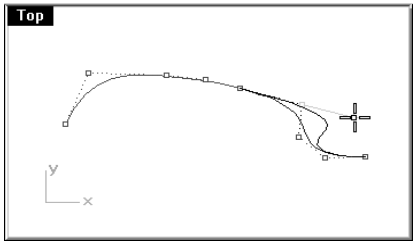


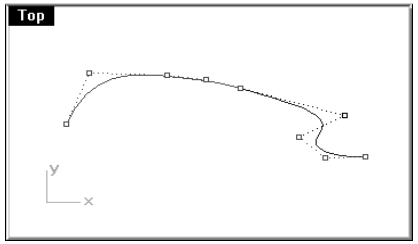
2 Turn on the **Point** object snap only and drag (or **Move**) the point to another of the four tangency points.



Notes:

3 When the point is dragged or moved over the next point and the object snap flag appears, do not click; instead press and release the **Tab** key and then continue dragging.





The movement of the point is now constrained to the line between the original location and the point in space where the tab key was pressed ensuring that G1 continuity is maintained.

Pressing the **Tab** key again before finally placing the point would release the **Tab** direction lock, losing the guarantee of continuity.

4 Press the left mouse button to place the point.

Exercise 8 - Curvature Continuity

Curvature continuity (G2) is more complicated, because it involves the last three points on a curve. Their arrangement is only in a straight line like G1 continuity when the curve being matched is a straight line or has no curvature at the end.

Maintaining G2 continuity when directly manipulating points is more complicated than it is for G1.

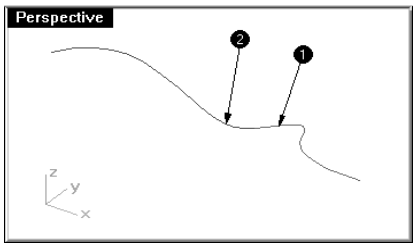
For establishing G2 continuity the **Match** command must be used.

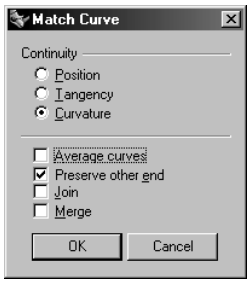
To match the curves:

1 Turn on the **3D curve** layer and make it current.

2 Turn off the **2D curve** layer.

3 Use the **Match** command *(Curve menu: Curve Edit Tools > Match)* to match the magenta (1) curve to the red (2) curve.

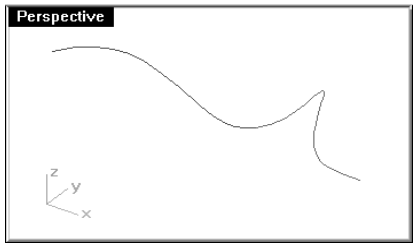




Notes:

Match Surface

When you use **Match** with **Curvature** checked on these particular curves, the third point on the curve to be changed is constrained to a position calculated by Rhino to establish the desired continuity.



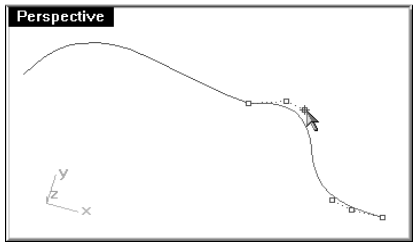
The curve being changed is significantly altered in shape. Moving the third point by hand will break the G2 continuity at the ends, though G1 will be maintained.

Advanced techniques for controlling continuity

There are two additional methods to edit curves while maintaining continuity in Rhino. (1) The **EndBulge** command allows the curve to be edited while maintaining continuity. (2) Adding knots will allow more flexibility when changing the curve's shape.

To edit the curve with end bulge

1. Right click on the **Copy** button to make a duplicate of the magenta curve and then **Lock** it.
2. Start the **EndBulge** command *(Edit menu: Adjust End Bulge)*.
3. At the **Select curve or surface to adjust** prompt, select the red curve.



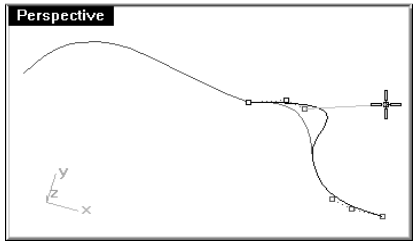
Note: The **EndBulge** command converts any curve that has fewer than six control points to a degree 5 curve with six control points.

Notes:

Adjust End Bulge

4 At the **Select point to move** (PreserveCurvature=*Yes*) prompt, select the third point and drag it and click to place the point, and the press **Enter** to end the command.

The G2 continuity is preserved.



To add a knot:

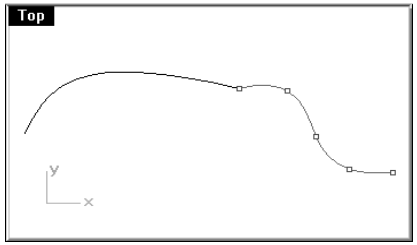
Adding a knot or two to the curve will put more points near the end so that the third point can be nearer the end. Knots are added to curves and surfaces with the **InsertKnot** command.

1 **Undo** your previous adjustments.

2 Start the **InsertKnot** command *(Edit menu: Control Points > Insert Knot)*.

3 At the **Select curve or surface for knot insertion** prompt, select the red curve.

4 At the **Point on curve to add knot** (Automatic Symmetrical=*No*) prompt, pick a location on the curve to add a knot in between the first two points.

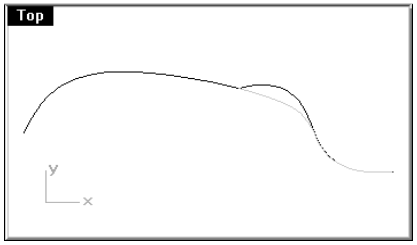


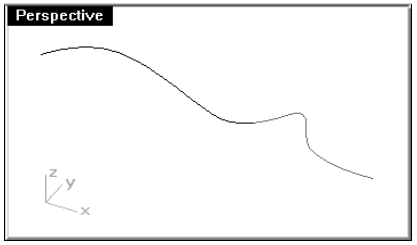
Notes:

Insert Knot

5 **Match** the curves after inserting a knot into the red curve.

In general a better behaved curve will result if the new knots are placed roughly halfway between existing knots, which are highlighted during the **InsertKnot** command.





Notes:

5 Surface Continuity

The continuity characteristics for curves can also be also applied to surfaces. Instead of dealing with the end point, second, and third points, entire rows of points at the edge, and the next two positions away from the edge are involved. The tools for checking continuity between surfaces are different from the simple **GCon** command.

Analyze surface continuity

Rhino takes advantage of the OpenGL display capability to create false color displays for checking curvature and continuity within and between surfaces. These tools are located in the **Analyze** menu, under **Surface**. The tool which most directly measures G0-G2 continuity between surfaces is the **Zebra** command. Zebra analysis simulates reflection of a stripped background on the surface.

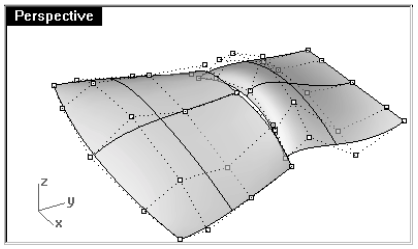
Note: An OpenGL graphics accelerator card is not necessary to use these tools, although they may work faster with OpenGL acceleration.

Notes:

Exercise 9 - Surface Continuity

1 **Open** the model **Surface Continuity.3dm**.

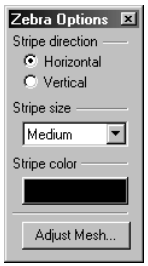
2 Turn on points on both surfaces.

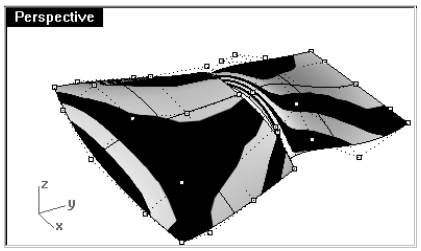


To check the continuity between the surfaces using Zebra analysis:

1 Start the **Zebra** command *(Analyze menu: Surface > Zebra)*.

The surfaces are colored by stripes.



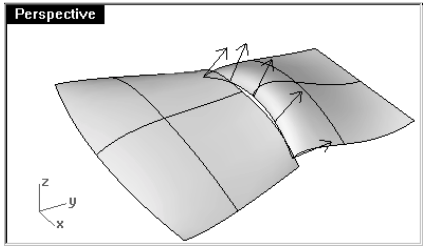


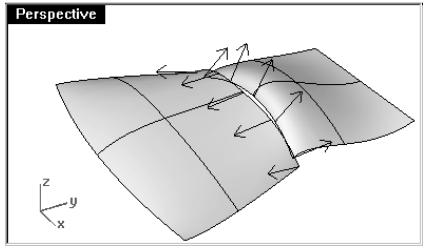
2 Close the **Zebra Options** window.

3 Start the **MatchSrf** command *(Surface menu: Surface Edit Tools > Match)*.

4 At the **Select untrimmed surface edge to change** prompt, select the edge of the red surface nearest the black surface.

5 At the **Select target surface edge** prompt, select the edge of the black surface nearest the red surface.





Notes:

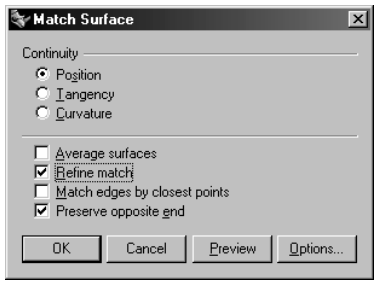
Zebra

Match Surface

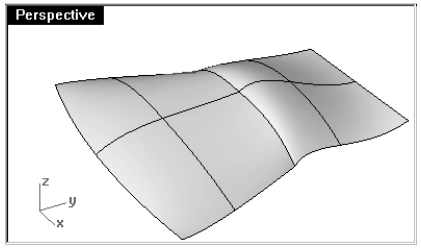
6 In the **Match Surface** dialog box, choose **Position** as the desired continuity.

Make sure **Average** is unchecked and **Preserve opposite end** is checked.

Click **OK**.



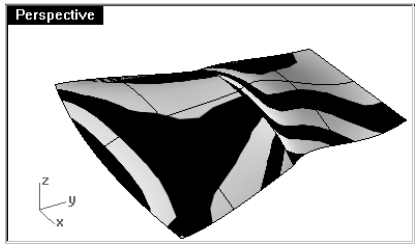
The edge of the red surface is pulled over to match the edge of the black one.



7 **Join** the surfaces.

8 Check the polysurface with **Zebra** analysis.

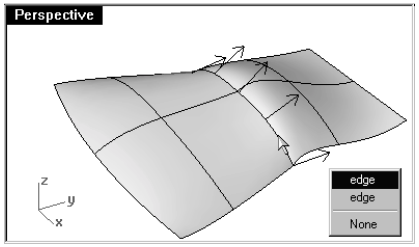
There is no particular correlation between the stripes on one surface and the other except that they touch. This indicates G0 continuity.

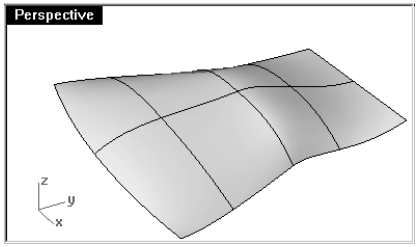


Notes:

9 **Explode** the polysurface, and use the **MatchSrf** command *(Surface menu: Surface Edit Tools > Match)* again with the **Tangency** option.

When you pick the edge to match you will get direction arrows that indicate which surface edge is being selected. The surface that the direction arrows are pointing toward is the surface whose edge is selected.

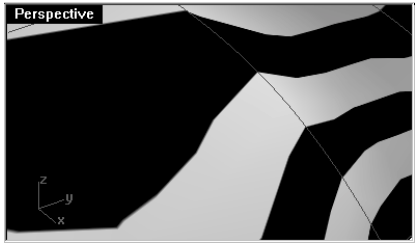


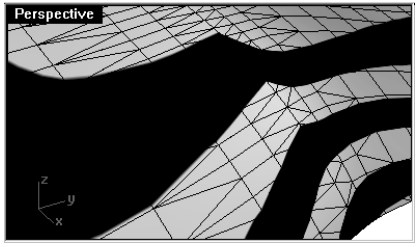


10 **Join** the surfaces and check the results with **Zebra** analysis.

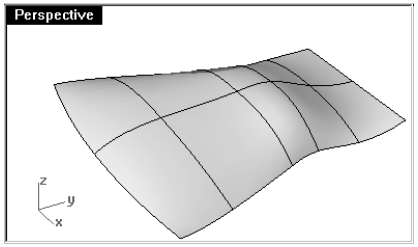
11 Adjust the controls in the **Zebra Options** window so that the stripes are thinner and alternate the direction between vertical and horizontal to get the most informative display.

This time there is a correlation between the surfaces. If the stripes are chunky and angled over the surface, use the Adjust mesh button to make a finer mesh setting for the display. The ends of the stripes on each surface meet the ends on the other cleanly though at an angle. This indicates G1 continuity.





12 Explode the polysurface, and use the **MatchSrf** command *(Surface menu: Surface Edit Tools > Match)* with the **Curvature** option.



Notes:

13 **Join** the surfaces and check the results with **Zebra** analysis.

The stripes now align themselves smoothly across the seam. Each stripe connects smoothly to the counterpart on the other surface. This indicates Curvature (G2) continuity.

Note: Doing these operations one after the other may yield different results than going straight to Curvature without first using position. This is because each operation changes the surface near the edge, so the next operation has a different starting surface.

Add knots to control surface matching

As in matching curves, **MatchSrf** will sometimes distort the surfaces more than is acceptable in order to attain the desired continuity. We will add knots to surfaces to limit the influence of the **MatchSrf** operation. The new second and third rows of points will be closer to the edge of the surface.

Surfaces can also be adjusted with the **EndBulge** command.

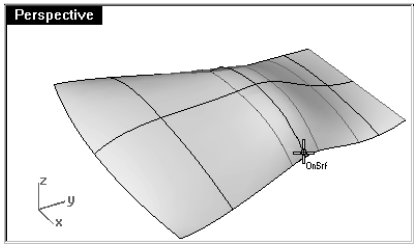
To add a knot to a surface:

1 **Undo** the previous operation.

2 Use the **InsertKnot** command to insert a row of knots near each end of the red surface.

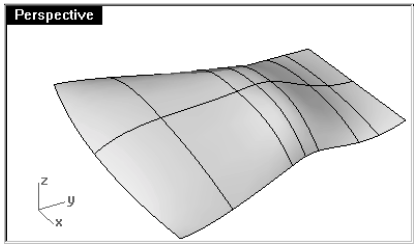
When this command is used on a surface, it has more options. You can choose to insert a row of knots in the U-direction, the V-direction, or both.

Choose **Symmetrical** to add knots at opposite ends of a surface.



Notes:

3 Use **MatchSrf** to match the surface to the other.

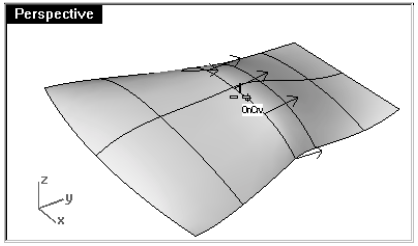


To adjust the surface using end bulge:

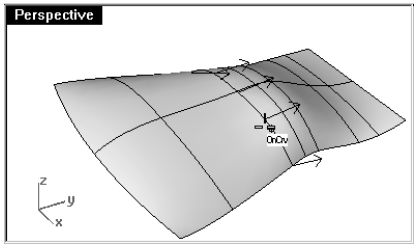
1 Start the **EndBulge** command *(Edit menu: Adjust End Bulge)*.

2 At the **Select curve or surface edge to adjust** prompt, pick the edge of the red surface.

3 At the **Point to edit** prompt, pick a point on the edge at which the actual adjustment will be controlled.



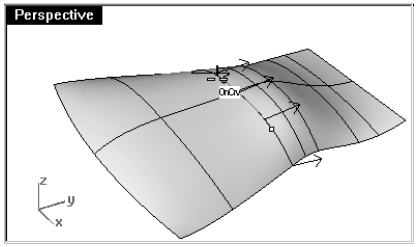
4 At the **Start of range to edit** prompt, pick a point along the common edges to define the region to be adjusted.



Notes:

Adjust Surface End Bulge

5 At the **End of range to edit** prompt, pick another point to define the region to be adjusted.

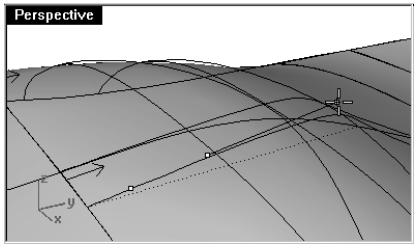


The influence of the adjustment will fade to zero at each end of the region you define. Construction geometry may be useful here for snapping an exact region if necessary. If the whole edge is to be adjusted equally, simply press **Enter**.

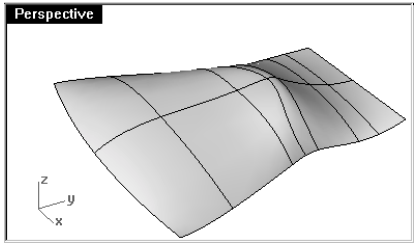
Rhino shows three sets of points on each curve, of which you are allowed to manipulate only two. Of these two, notice that Rhino also moves the point that is not being directly manipulated in order to maintain the continuity. If maintaining the G2 curvature-matching condition at the edge is not needed, use the PreserveCurvature option to turn off one of the two points available for editing. Only G1 will be preserved.

6 At the **Select point to move** (PreserveCurvature=*Yes*) prompt, select a point.

7 At the **Pick new point location** (PreserveCurvature=*Yes*) prompt, drag the point and click.



8 Press **Enter** to end the command.



Notes:

Commands that use continuity

Rhino has several commands that that can build surfaces using the edges of other surfaces as input curves. They can build the surfaces with G1 or G2 continuity to those neighboring surfaces. The commands are:

- NetworkSrf
- Sweep2
- Patch (G1 only)
- Loft (G1 only)
- Blend (G1 or G2)

The following exercises will provide a quick overview of these commands.

Exercise 10—Continuity Commands

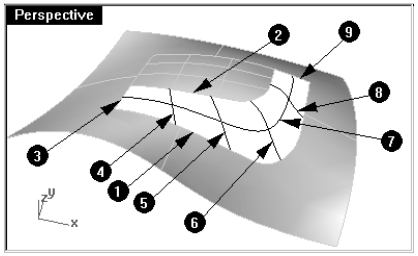
To create a surface from a network of curves:

1 **Open** the model **Continuity Commands.3dm**.

On the Surfaces layer there are two joined surfaces which have been trimmed leaving a gap. This gap needs to be closed up with continuity to the surrounding surfaces.

2 Turn on the **Network** layer.

There are several curves already in place which define the required cross sections of the surface.

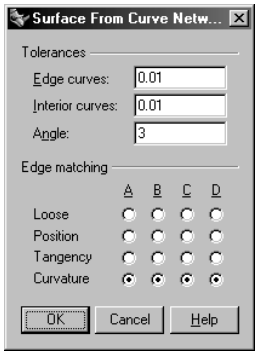


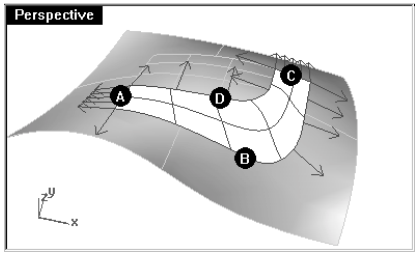
Notes:

3 Use the **NetworkSrf** command *(Surface menu: Curve Network)* to close the hole with an untrimmed surface using the curves and the edges of the surfaces as input curves.

The **NetworkSrf** dialog box allows you to specify the desired continuity on edge curves which have been selected.

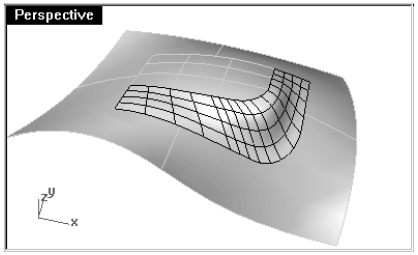
Note that there is a maximum of four edge curves as input. You can also specify the tolerances or maximum deviation of the surface from the input curves. By default the edge tolerances are the same as the model's Absolute Tolerance setting. The interior curves' tolerance is set 10 times looser than that by default.



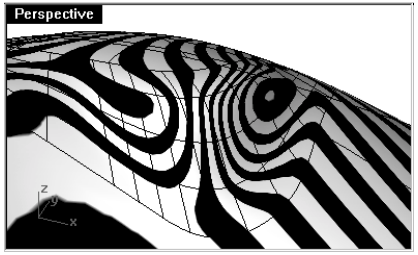


4 Change the **Interior curves** settings to **0.01**. Choose **Curvature** continuity for all the edges.

The surface that is created has curvature continuity on all four edges.



5 Check the resulting surface with **Zebra** analysis.



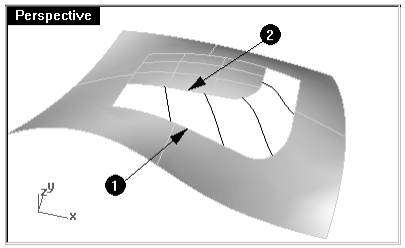
Notes:

Surface from Curve Network

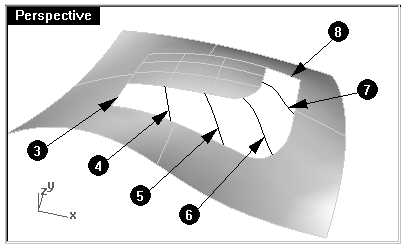
To make the surface with a two-rail sweep:

1 Use the **OneLayerOn** command to open the **Surfaces** layer by itself again and then left click in the layers panel of the status bar and select the **Sweep2** layer.

2 Start the **Sweep2** command *(Surface menu: Sweep 2 Rails)* and select the long surface edges as the rails.

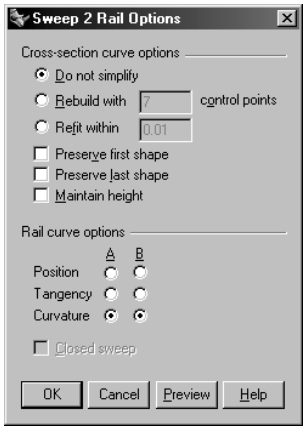


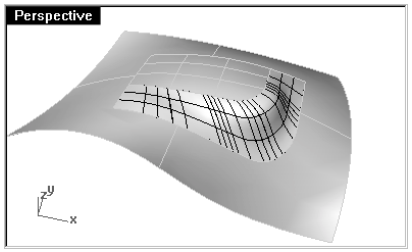
3 Select one short edge, the cross-section curves and the other short edge as profiles.



Since the rails are surface edges, the display labels the edges, and the **Sweep 2 Rails Options** dialog box gives the option of maintaining continuity at these edges.

4 Choose **Curvature** for both **Rail curve options**.

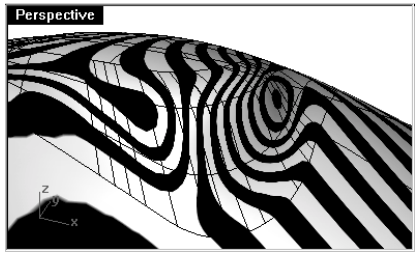




Notes:

Sweep along 2 Rails

5 Check the resulting untrimmed surface with **Zebra** analysis.



To make a patch surface:

The **Patch** command builds a trimmed surface, if the bounding curves form a closed loop, and can match continuity to G1 if the bounding curves are edges.

1 Turn on the **Surfaces**, and **Patch** layers.

Turn all other layers off.

2 Start the **Patch** command *(Surface menu: Patch)*.

3 Select the edge curves and the interior curves, and then press **Enter**.

Notes:

Patch

Notes:

4 In the **Patch Options** dialog box, set the following options

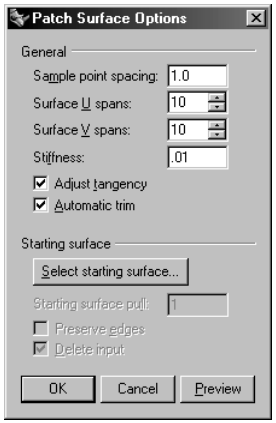
Set **Sample point spacing** to **1.0**

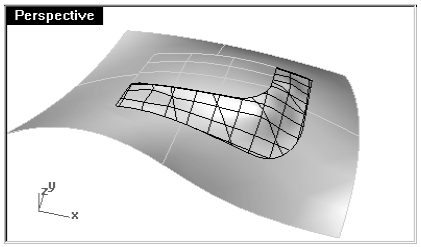
Set **Stiffness** to **.01**

Set **Surface U** and **V spans** to **10**

Check **Adjust tangency** and **Automatic trim**, then click **OK**.

The finished surface does not appear to be very smooth. There are a number of settings available for adjusting the surface accuracy. We will make some changes and repeat the command.



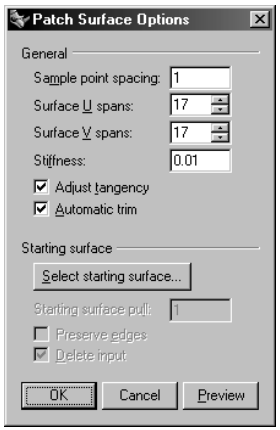


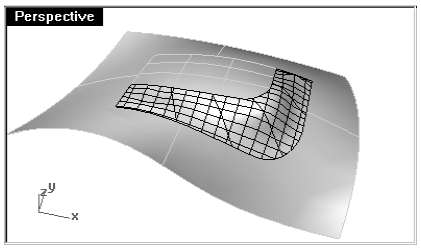
5 **Undo** the previous operation.

6 Use the **Patch** command and select the same edges and curves.

7 In the **Patch Options** dialog box, change the **Surface U** and **V spans** to **17,** then click **OK**.

The finished surface appears has more isocurves but isn't much smoother.



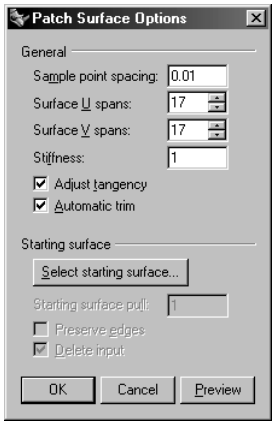


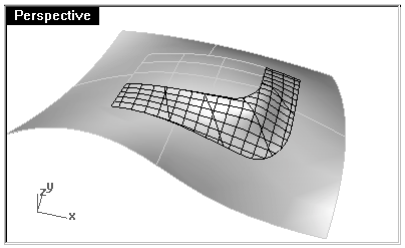
8 **Undo** the previous operation.

9 Use the **Patch** command and select the same edges and curves.

10 In the **Patch Options** dialog box, change the **Sample point spacing** to **.01**, the **Stiffness** to **1.0**, then click **OK**.

The finished surface appears smoother.



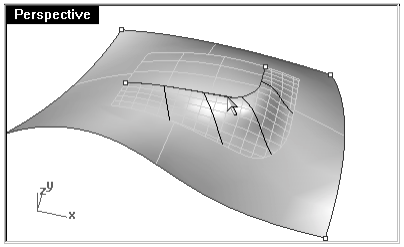


11 **Join** the surfaces.

12 Use the **ShowEdges** command *(Analyze menu: Edge Tools > Show Edges)* to display the naked (unjoined) edges.

There is a naked edge between the patch and the polysurface.

You can join the naked edges for meshing or rendering purposes.



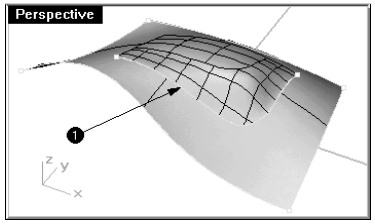
Notes:

Why can't I join the edges using Join 2 Naked Edges?

13 Undo the patch surface and remake it with more isocurves.

14 Continue to work with this until it joins without naked edges.

15 Check the results with **Zebra** analysis.



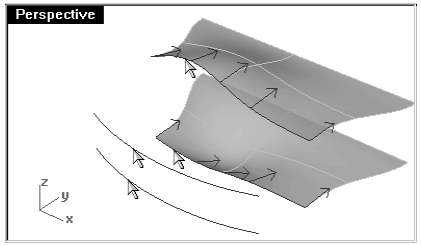
To make a lofted surface:

The **Loft** command also has built in options for surface continuity.

1 Open the model **Loft and Blend.3dm**.

2 Start the **Loft** command *(Surface menu: Loft)*.

3 At the **Select curves to loft** (Point) prompt, select the top edge curve, the two curves, and then the bottom edge curve.



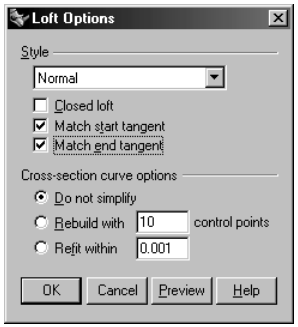
4 Press **Enter** when done.

Notes:

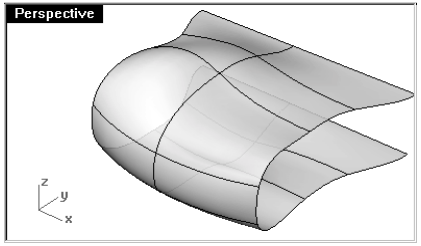
Loft

5 In the **Loft Options** dialog box under **Style**, select **Normal**

Check **Match start tangent**, **Match end tangent**, and **Do not simplify**.



The new surface has G1 continuity to the original surfaces.



To make a surface blend:

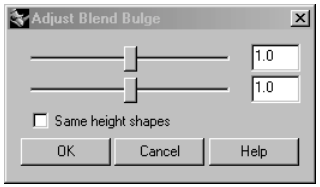
The last command can control continuity with adjoining surfaces is **BlendSrf**.

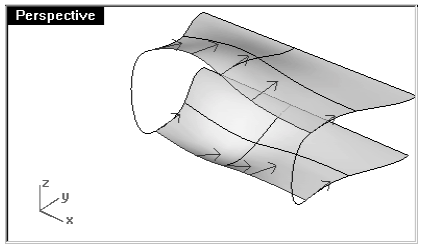
1 **Undo** the loft.

2 Start the **BlendSrf** command *(Surface menu: Blend Surface)*, in the command line options, set **Continuity=*curvature***.

3 Select an edge and press **Enter**, then select the other edge and press **Enter**.

The curve edges at each are highlighted and the **Blend Bulge** dialog box opens.





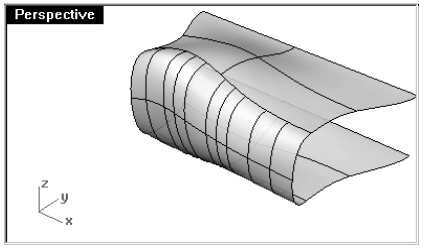
Notes:

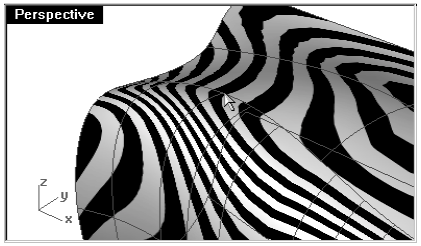
Blend Surface

There is an option to add more sections when the dialog box is displayed.

4 Adjust the bulge if desired, then click **OK**.

5 Check the results with **Zebra** analysis.





Additional surfacing techniques

There are several methods for making surface transitions. In this exercise we will discuss a variety of ways to fill holes and make transitions using the **NetworkSrf**, **Loft**, **Sweep1, Sweep2**, **Blend**, **Fillet** and **Patch** commands.

Fillets and Corners

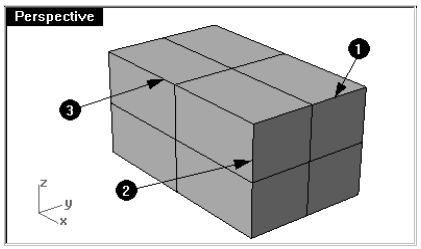
While Rhino has automated functions for making fillets, there are several situations that take manual techniques. In this section, we will discuss making corners with different fillet radii, variable radius fillets and blends, and fillet transitions.

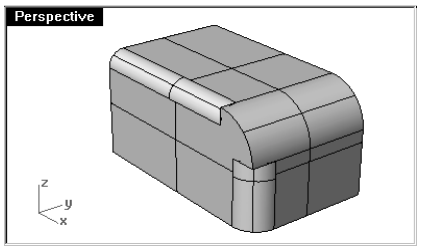
Exercise 11—Fillets and Blends

To make a corner fillet with 3 different radii and a curve network:

1 **Open** the model **Corner Fillet.3dm**.

2 Use the **FilletEdge** command *(Solid menu: Fillet Edge)* to fillet edge (1) with a radius of **5**, edge (2) with a radius of **3**, and edge (3) with a radius of **2**.

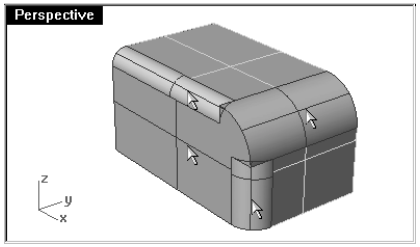




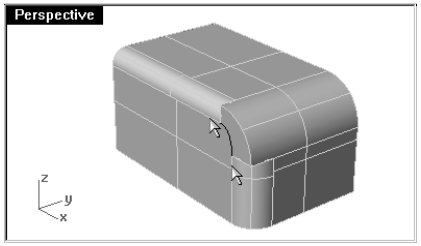
Notes:

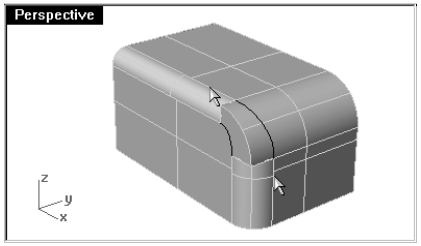
Fillet Edge

3 Start the **ExtractSrf** command *(Solid menu: Extract Surface)*, then select the 3 fillets and the front surface, the press **Enter** to end the command.



4 Use the **Blend** command *(Curve menu: Blend Curves)*, to create curves between the edge curves of the smaller fillet surfaces.

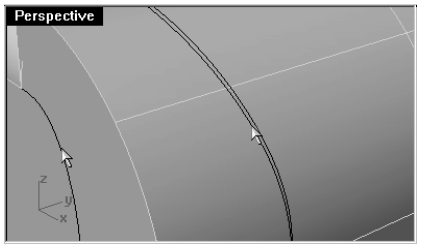


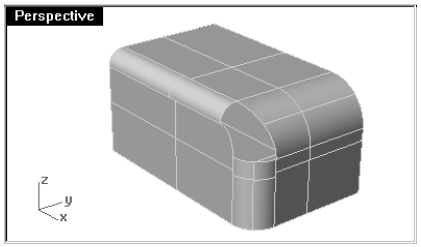


Note: The blend curves will not actually touch the fillet surface precisely. The blend curve is not an arc like the fillet surface cross-section. You may have to pull the curve to the surface before trimming or use the **Split** command.

5 Use the **Pull** command *(Curve menu: Curve from objects > Pullback)* to pull the right-hand blend curve to the fillet surface.

6 Use the **Trim** command to trim the surfaces with the blend and the pull curve.



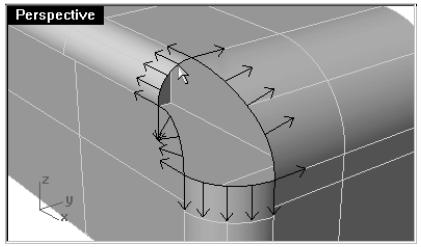


7 Use the **NetworkSrf** command *(Surface menu: Curve Network)* to fill the hole.

Notes:

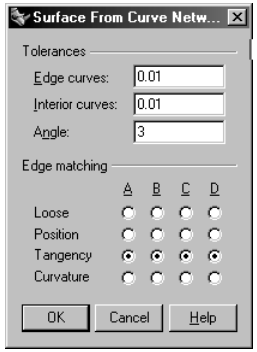
Extract Surface

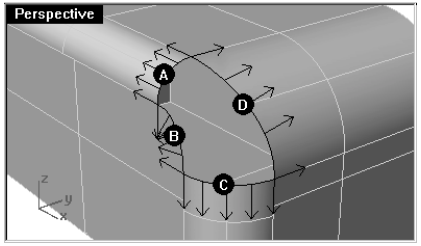
8 At the **Select curves in network** (NoAutoSort) prompt, select the edge curves.

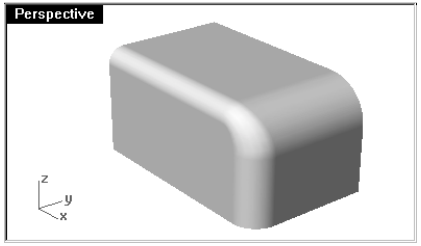


9 At the **Select curves in network** (NoAutoSort) prompt, press **Enter**.

10 In the **Surface From Curve Network** dialog box, select **Tangency** for all four edges.







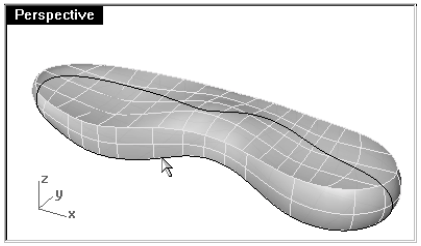
11 **Join** the surfaces and check the polysurface for naked edges.

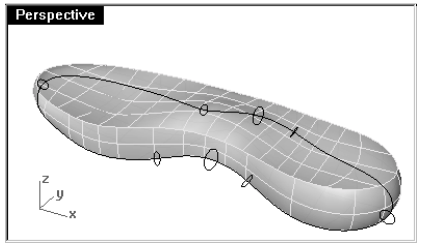
Notes:

To make a variable radius fillet:

1 **Open** the model **Sandal Sole.3dm**.

2 Use the **Circle** command with the **AroundCurve** option to create circles of different radius around the bottom edge of the sole.



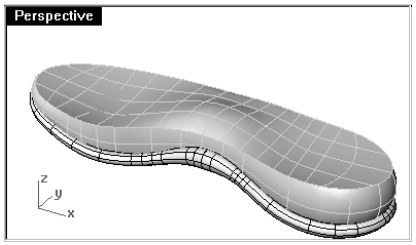


3 Use the **SelLaye**r command *(Edit menu: Select Objects > By Layer...)* to select the curve and the circles.

4 Start the **Sweep1** command *(Surface menu: Sweep 1 Rail)* to make a variable radius pipe around the edge.

5 In the **Sweep 1 Rail Options** dialog box, check **Rebuild with 8 control points** and **Closed sweep**, and then click **OK**.

If you do not rebuild the surface, it can become quite complex. Another option to simplify the swept surface is to align the seam of each circle to the same knot point on each cross-section.



Notes:

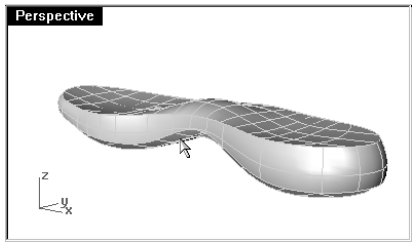
Circle: Around Curve

Select Layers

Sweep along 1 Rail

6 Unlock the **Shoe Bottom** layer.

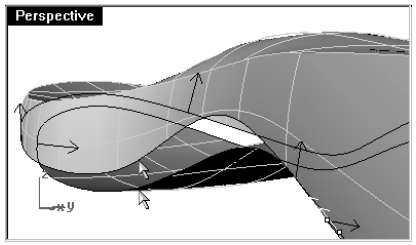
7 **Trim** the sidewall and the bottom with the swept surface.

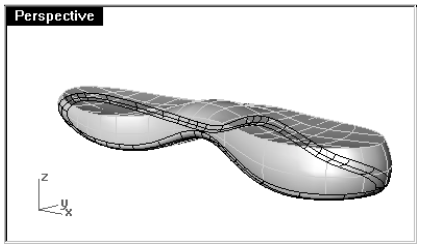


8 Turn off the **Curve** Layer and change to the **Fillet** layer.

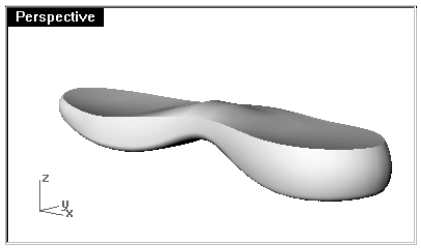
Note: You may have to merge the edges *(Analyze menu: Edge Tools > Merge Edge)* of the trimmed surfaces before you blend. It helps to hide the other surfaces while you merge the edges.

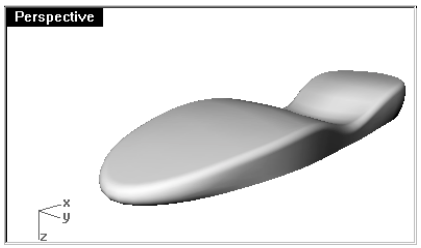
9 Use the **BlendSrf** command *(Surface menu: Blend Surface)* to make the variable fillet.





10 **Join** the surfaces.





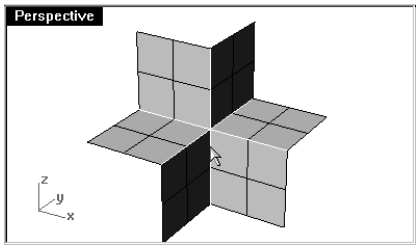
Notes:

Merge Edge

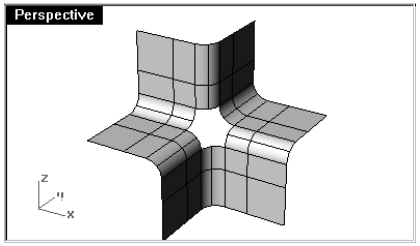
Blend Surface

To make a six-way fillet using a patch:

1 **Open** the model **Fillet Edge.3dm**.



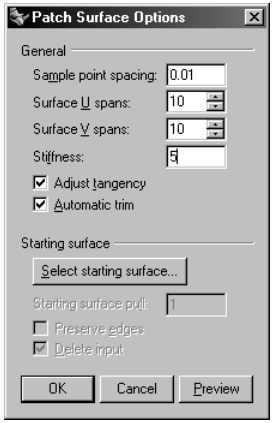
2 Use the **FilletEdge** command *(Solid menu: Fillet Edge)*, with **Radius=*1***, to fillet all the joined edges at the same time.

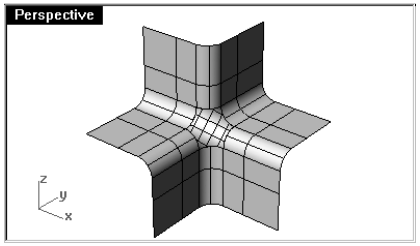


3 Use the **Patch** command *(Surface menu: Patch)* to fill in the opening at the center.

4 Select all six edges to define the patch.

5 In the **Patch Options** dialog box, check **Adjust Tangency** and **Automatic Trim**. Change the **Surface U** and **V Spans** to **10**, and the **Stiffness** to **10**.





Notes:

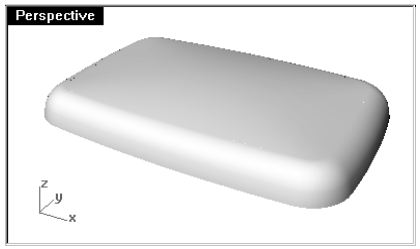
*When the area to fill has more than four edges, the **Patch** command works better than the **NetworkSrf** command.*

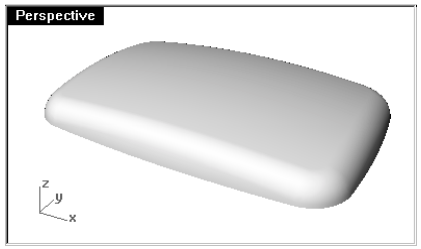
Patch

To make a rectangular shape with a curved top and soft corners:

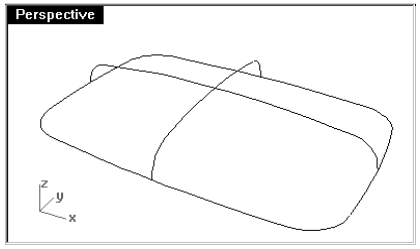
There are several ways to approach making a soft top like the illustration below. Often, the curves you start with are made up of a series of arcs.

In this exercise we explore two different methods to make the surfaces using the same underlying curves.



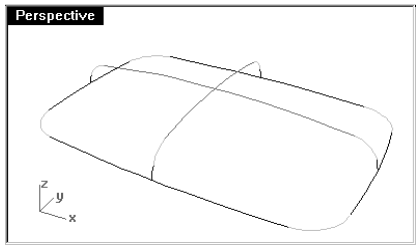


1 **Open** the model **Soft Corners.3dm**.



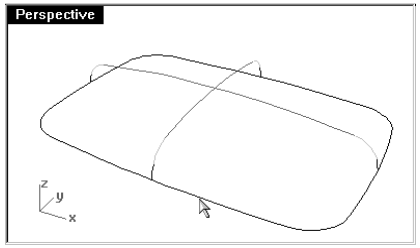
2 Change to the **02 Separate Curves** layer and turn the **Original** layer off.

Notice that the curves are separate arcs that meet at the ends, but are not joined. In this case the arcs have tangent continuity.



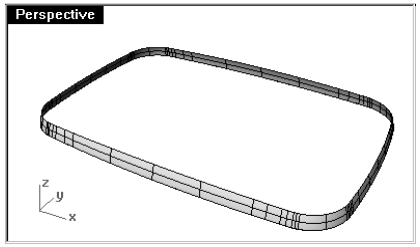
Notes:

3 Use the **Join** command *(Edit menu: Join)* to join the arcs that form the base rectangular shape.



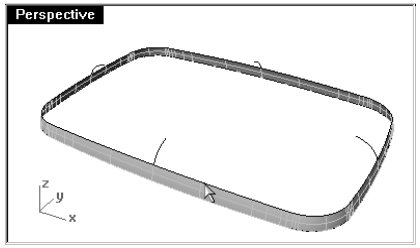
4 Change to the **03 Sweeps** layer.

5 Use the **Sweep1** command *(Surface menu: Sweep 1 Rail)* to make the first surface.



6 Use the **Sweep1** command *(Surface menu: Sweep 1 Rail)* to make the second surface.

7 At the **Select Rail** prompt, pick the top edge of the surface you just created, then select the cross-sections in order, and press **Enter**.

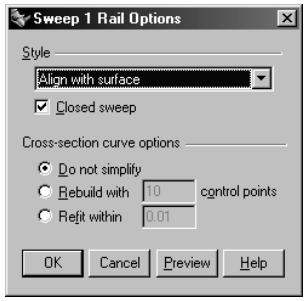


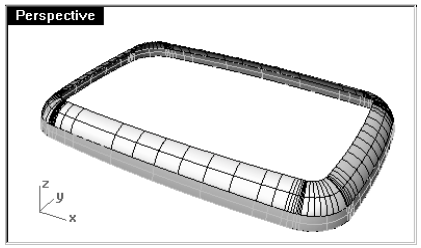
Notes:

Sweep along 1 Rail

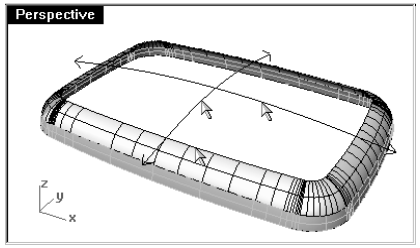
8 In the **Sweep 1 Rail** Options dialog box, change the **Style** to **Align with surface**, then click **OK**.

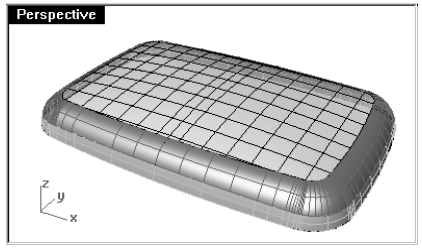
This will insure tangent continuity with the first surface.

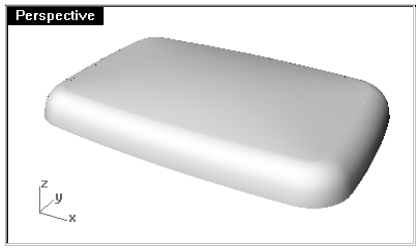




9 Use the **Patch** command *(Surface menu: Patch)* to fill in the opening at the center.







To make a rectangular shape with a curved top and soft corners (Part 2):

In this exercise you will start by making new curves.

1 Change to the **02 Separate Curves** layer and turn the **03 Sweeps** layer off.

2 Use the **Extend** command with the **Arc** option *(Curve menu: Extend Curve > By Arc)* to extend each of the curves as shown below.

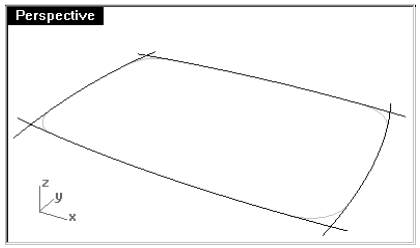
3 At the **Center of arc extension** prompt, snap to the center of the same arc.

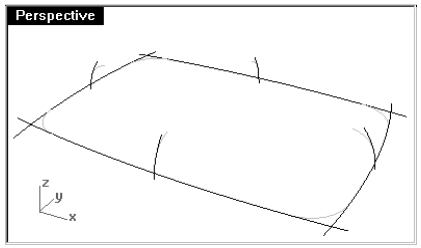
Notes:

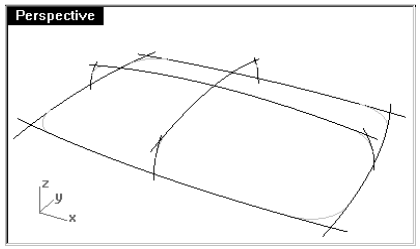
Patch

4 At the End of extension prompt, pick a point.

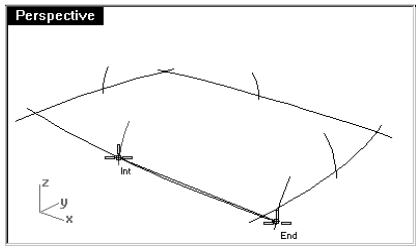
It is important to extend both ends of each arc.

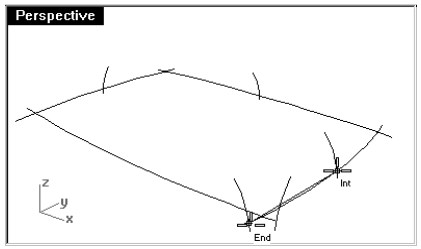


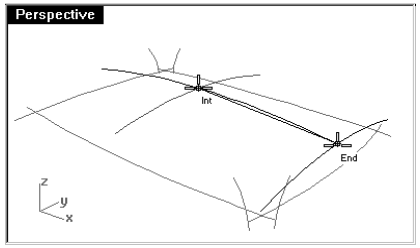


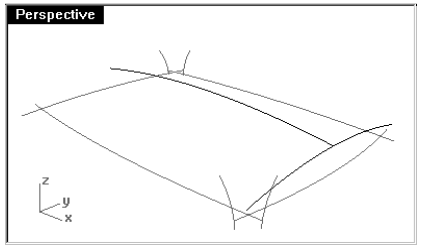


5 **Move** the curves from their intersection with the other curve to the end of the base curve as shown below.







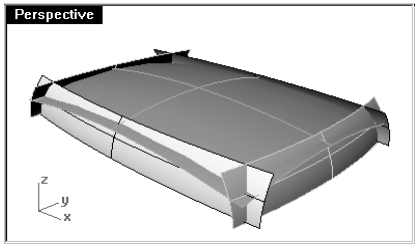


Notes:

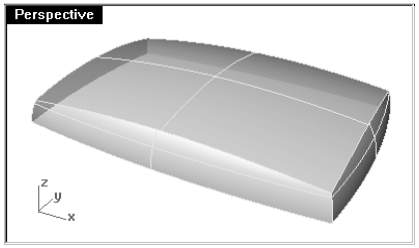
6 Change to the **04 Surfaces** layer.

7 Use the **Sweep1** command *(Surface menu: Sweep 1 Rail)* to make the five surfaces.

The surfaces will intersect each other.

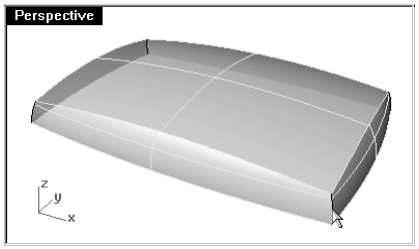


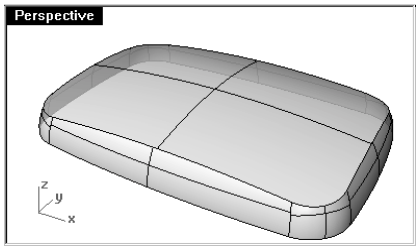
8 Use the **Trim** command *(Edit menu: Trim)* to trim the ends of the surfaces.



9 Use the **Join** command *(Edit menu: Join)* to join the surfaces.

10 Use the **FilletEdge** command *(Solid menu: Fillet Edge)* to fillet the four vertical edges with a **15mm** radius.

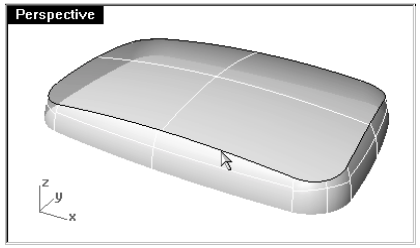


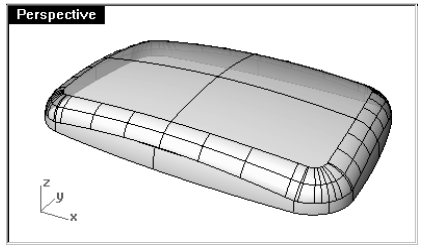


Notes:

Sweep along 1 Rail

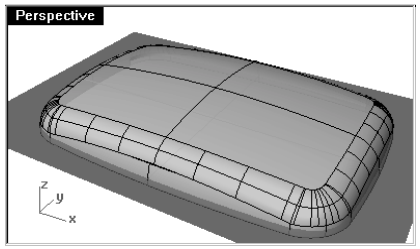
11 Use the **FilletEdge** command *(Solid menu: Fillet Edge)* to fillet the top edges with a **10mm** radius.

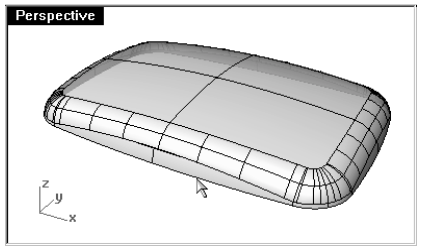




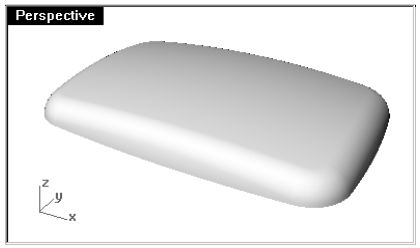
12 Use the **CutPlane** command *(Surface menu: Plane > Cutting Plane)* to make a cutting plane at the origin in the z-axis.

13 Use the cutting plane to trim the bottom of the polysurface.





The resulting surface is very clean and smooth with no hard edges.



Notes:

6 Advanced Surfacing Techniques

In this chapter you will learn to make soft domed button shapes, creased surfaces, and how to use curve fairing techniques.

Dome-shaped buttons

To model a product like a cell phone case, we need soft domed buttons: the button edges have to conform to a compound-curved button face. In the following exercise we will discuss several methods to make dome-shaped buttons.

Exercise 12—Soft Domed Buttons

1 **Open** the model **Button Domes.3dm**.

The key to this exercise is defining a custom construction plane that represents the closest plane through the area of the surface that you want to match. Once you get the construction plane established, there is a variety of approaches available for building the surface.

There are several ways to define a construction plane. In this exercise we will discus three methods: construction plane through three points, construction plane perpendicular to a curve, and fit a plane.

Notes:

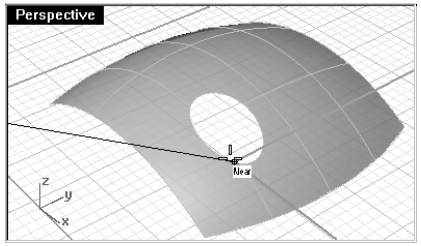
2 Use **OneLayerOn** to turn on the **Surfaces to Match** layer to see the surface that determines the cut of the button.

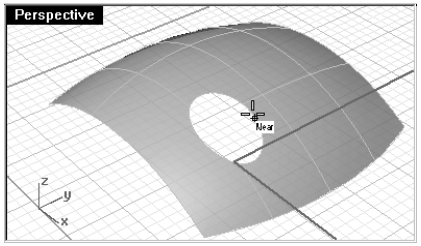
To create a custom construction plane using three points method:

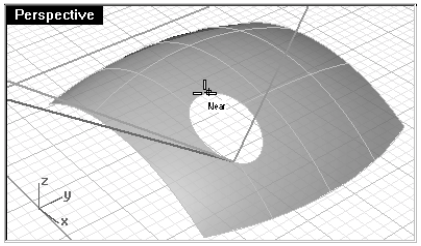
1 Start the **CPlane** command with the **3Point** option *(View menu: Set CPlane > 3 Points)*.

2 In the **Perspective** viewport, using the **Near** object snap, pick three points on the edge of the trimmed hole.

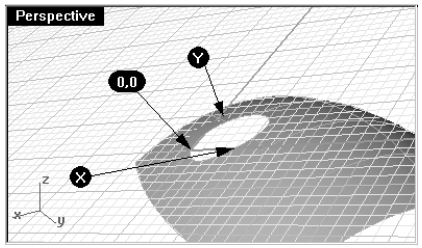
The construction plane now goes through the three points.







3 Rotate the **Perspective** viewport to see the grid aligned with the surface.



To create a custom construction plane perpendicular to a curve:

With a line normal to a surface and a construction plane perpendicular to that normal line, you can define a tangent construction plane at any given point on the surface.

1 Start the **CPlane** command with the **Previous** option *(View menu: Set CPlane > Previous)*.

2 Use the **Line** command with the **Normal** option *(Curve menu: Line > Normal to Surface)* to draw a line normal to the surface at a point near the edge of the trimmed hole.

3 Start the **CPlane** command with the **Curve** option *(View menu: Set CPlane > Perpendicular to Curve)*

4 At the **Select curve to orient CPlane to** prompt, pick the normal.

Notes:

Set CPlane: 3 Points

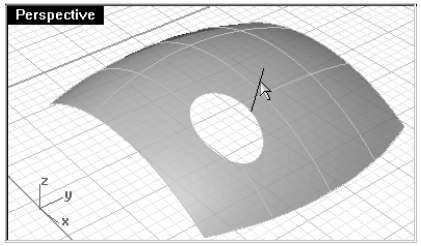
Set CPlane: Previous

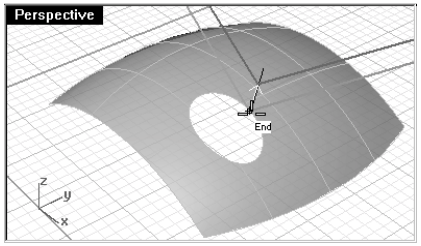
Surface Normal

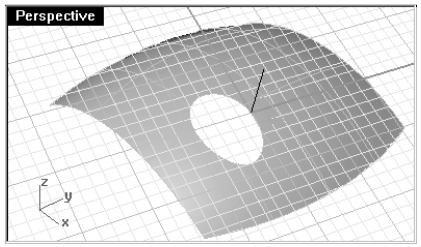
Set CPlane: Perpendicular to Curve

5 At the **CPlane origin** prompt, use the **End** object snap and pick the end of the normal where it intersects the surface.

The construction plane is set perpendicular to the normal line.







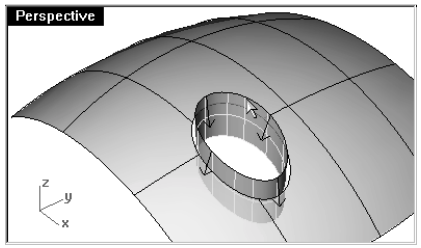
To create a construction plane fit through points:

Using the PlaneThroughPt command to create a surface through a sample of extracted point objects will generate a plane that best fits the points. The **CPlane** command with the **Object** option places a construction plane with its origin on the center of the plane. This is a good choice in the case of the button in this file. There are several curves from which the points can be extracted the edge of the button itself, or from the trimmed hole in the surrounding surface.

1 Start the **CPlane** command with the **Previous** option *(View menu: Set CPlane > Previous)*.

2 Turn on the **Surfaces** layer.

3 Use the **DupEdge** command *(Curve menu: Curve From Objects > Duplicate Edge)* to duplicate the top edge of the button.

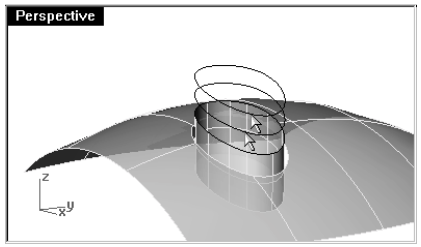


Notes:

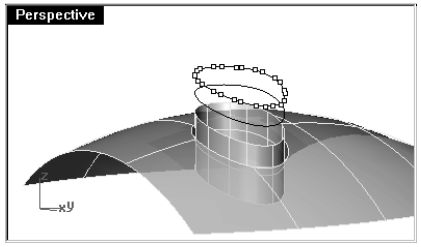
Duplicate Edge

4 **Copy** the duplicated curve vertically twice.

The vertical position of these curves will determine the shape of the curved edge of the button.

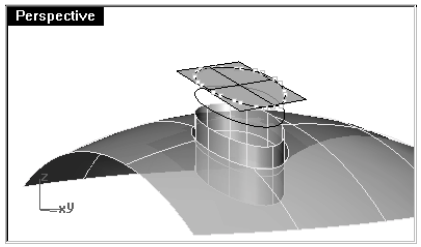


5 Use the **ExtractPt** command *(Curve menu: Curve From Objects > Extract Points)* on the top curve.



6 Use the **PlaneThroughPt** command *(Surface menu: Plane > Through Points)* with the extracted points that are already selected, then hide the points.

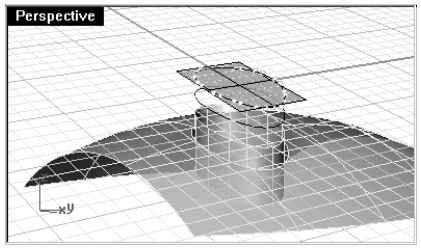
A plane is fitted through the points.



Notes:

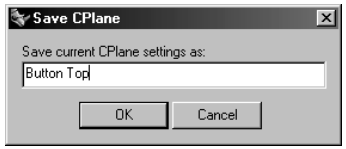
Extract Points

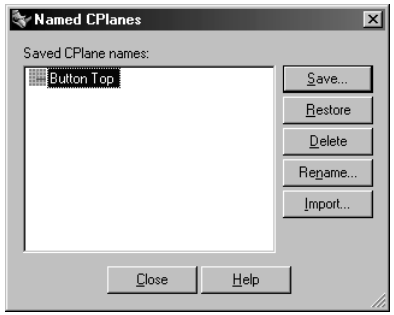
7 Use the **CPlane** command with the **Object** option *(View menu: Set CPlane > To Object)* to align the construction plane with the plane.



8 From the **View** menu, click **Named CPlanes**, then click **Save** to save and name the custom construction plane.

9 In the **Name of CPlane** dialog box, type **Button Top** and click **OK**.





To loft the button:

1 Use **Loft** to make the button.

2 At the **Select curves to loft** prompt, select the curves.

3 At the **Select curves to loft** (Point) prompt, type **P** and press **Enter**.

4 At the **End of lofted surface** prompt, type **0** (zero) and press **Enter**.

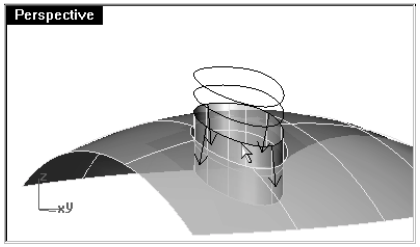
The loft will end at a point in the middle of the plane, which is the origin of the construction plane.

Notes:

Set CPlane: To Object

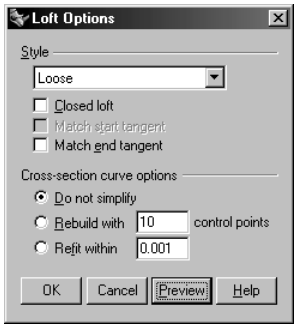
Save CPlane

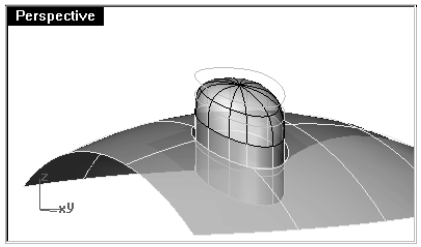
5 At the **Matching seams and directions...** prompt, press **Enter**.



6 In the **Loft Options** dialog box, under **Style**, choose **Loose**.

With the **Loose** option, the control points of the input curves become the control points of the resulting surface, as opposed to the **Normal** option, in which the lofted surface is interpolated through the curves.





7 Turn on control points on the lofted surface.

8 Select the next ring of points out from the center.

Select one point and use **SelV** or **SelU** to select the whole ring of points.

9 Use the **SetPt** command *(Transform menu: Set Points)* to set the points to the same Z-elevation as the point in the center.

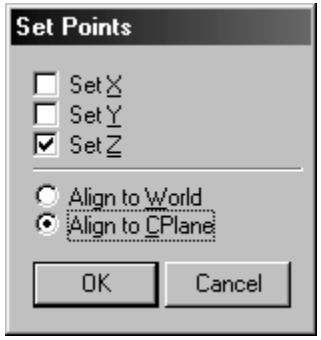
Remember, this elevation is relative to the current construction plane.

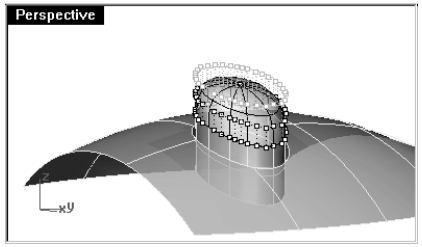
10 In the **Set Points** dialog box, check the **Z** box only and **Align to CPlane** option.

Notes:

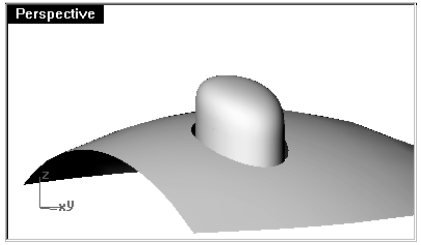
Set Points

11 At the **Location of points** prompt, type in **0** and press **Enter**.



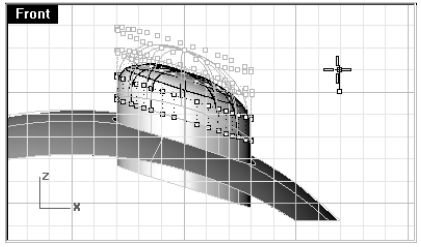


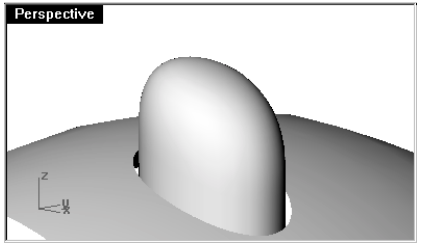
Aligning the row of points with the central point makes a smooth top on the button.



12 In the **Perspective** viewport, use the **SetView CPlane Top** command *(View menu: Set Camera > CPlane Top)* to set the construction plane back to the default position.

Once the surface is made you can adjust it by selecting rings of points with elevator mode, or in another orthogonal view, move the points up and down to alter the shape. Remember to move the middle point and the next ring of points together so they do not go out of plane with one another.





To use a patch surface to make the button:

1 Use the **DupEdge** command to duplicate the top edge of the surface.

2 **Move** the duplicated curve in the Z-direction a small amount.

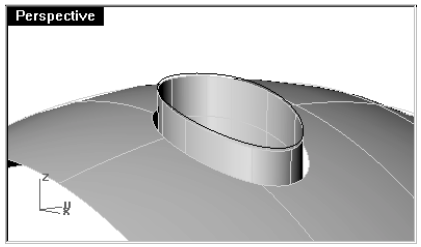
Notes:

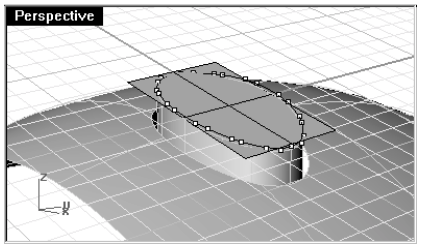
Set CPlane: World Top

3 Use the **ExtractPt** command on the curve.

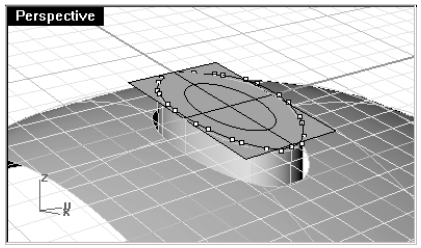
4 Use the **PlaneThroughPt** command with the extracted points that are already selected, then hide the points.

5 Use the **CPlane** command with the **Object** option to set the construction plane to the planar surface.

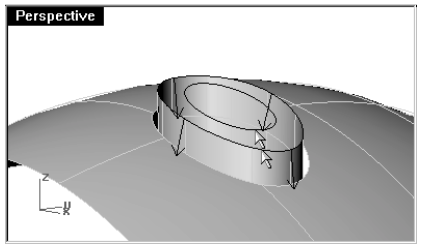




6 Make a circle or ellipse centered on the origin of the custom construction plane.



7 Use the **Patch** command, selecting the top edge of the button and the ellipse or circle.

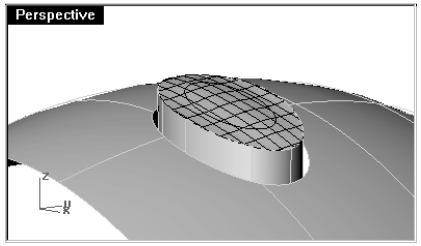


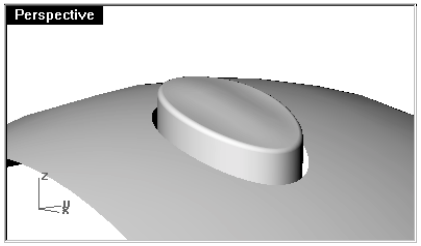
Notes:

Patch

8 In the **Patch options** dialog box, set the point sampling small enough to get a good join at the edge, and uncheck the adjust tangency setting.

The size and vertical position of the circle/ellipse will affect the shape of the surface.



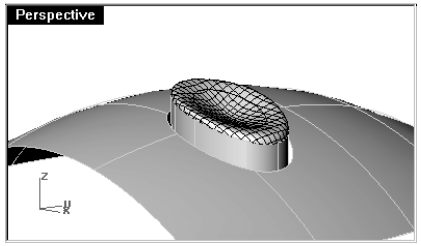


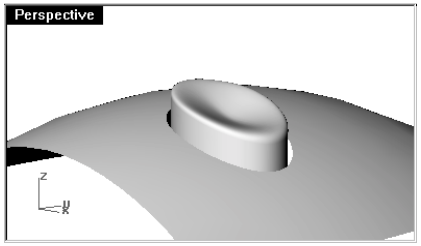
9 **Join** the surfaces and use the **FilletEdge** command to soften the edge.

10 **Undo** back to before the **Patch**, move the ellipse down, and repeat the command.

11 In the **Patch options** dialog box, check the adjust tangency setting.

The surface is tangent to the edge and concave on the top.





To use a rail revolve surface to make the button:

1 Use the **DupEdge** command to duplicate the top edge of the surface.

2 **Move** the duplicated curve in the Z-direction a small amount.

3 Use the **ExtractPt** command on the curve.

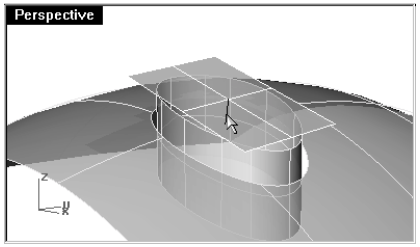
4 Use the **PlaneThroughPt** command with the extracted points that are already selected, then hide the points.

5 Use **CPlane** command with the **Object** option to set the construction plane to the planar surface.

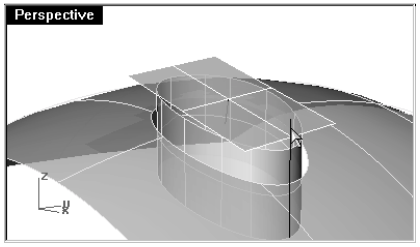
Notes:

Notes:

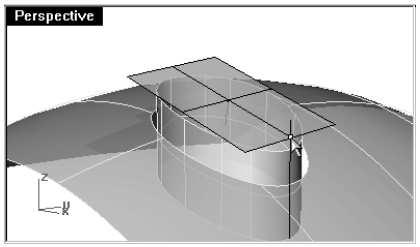
6 Use the **Line** command with the **Normal** option *(Curve menu: Line > Normal to Surface)* to draw a line normal to the surface down from the center of the plane to use as an axis.



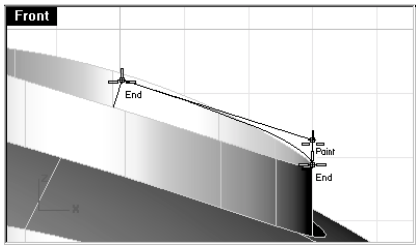
7 Use the **Extend** command *(Curve menu: Extend Curve > By Line)* to extend the edge at the seam through the rectangular surface.



8 Use the **Intersect** command *(Curve menu: Curve From Objects > Intersection)* to find the intersection between the extended line and the rectangular surface.



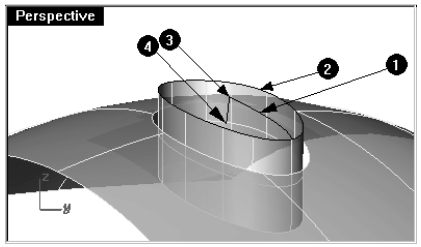
9 Use the **Curve** command to draw a curve from the end of the normal line, using the intersection point as the middle control point, to the end of the seam to use as a profile curve.

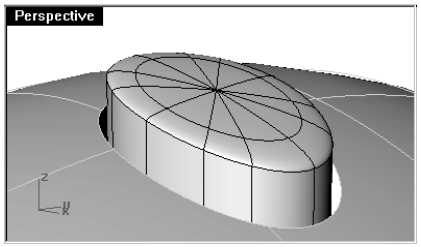


10 Start the **RailRevolve** command *(Surface menu: Rail Revolve)*.

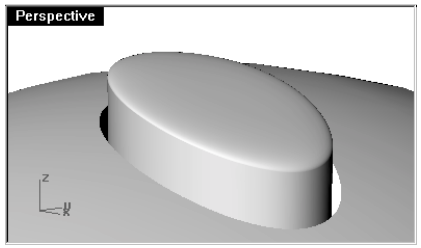
11 At the **Select profile curve** (ScaleHeight) prompt, type **S** and press **Enter**.

12 Select the profile curve (1), the top edge of the surface (2) as the path curve, and the ends of the normal (3 and 4) as the axis for the revolve.

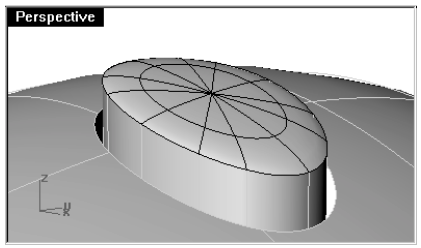


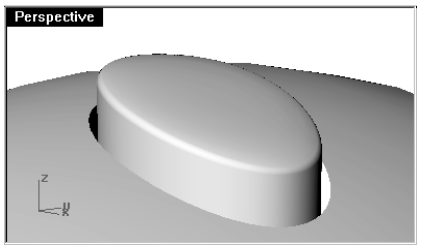


13 Use the **MatchSrf** command to match the two surfaces to tangent continuity.



Another option would be to not bother to make the profile curve tangent. With this method you would fillet the edge to soften it.





Notes:

Rail Revolve

Match Surface

Creased surfaces

Often a surface needs to be built with a crease in it which begins with an angle and diminishes to zero angle at the other end. The following exercise covers two possible situations.

Exercise 13—Surfaces with a crease

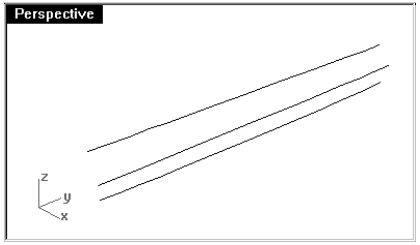
The key to following exercise is to get two surfaces that match with different continuity at each end. At one end we will match the surface with a 10 degree angle and at the other end we will match the surface with curvature continuity. To accomplish this we will create a dummy surface at the correct angles and use this to match the lower edge of the upper surface.

1 **Open** the model **Crease 01.3dm**.

2 Turn on the **Curve** and **Loft** layers.

3 Make the **Loft** layer current.

4 Use the **Loft** command to make a surface from the three curves on the **Loft** layer.

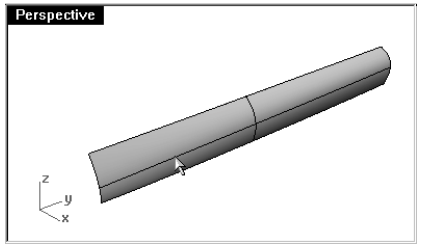


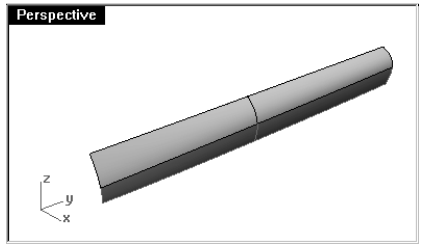
We are going to make a surface that includes all the curves but has a crease along the middle curve.

Notes:

Loft

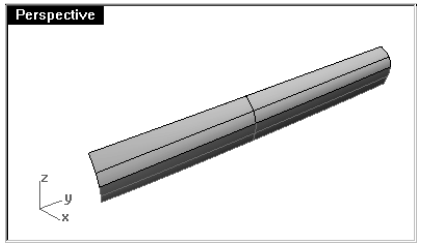
5 Use the middle curve to **Split** the resulting surface into two pieces.





6 Use the **ShrinkTrimmedSrf** command *(Surface menu: Surface Edit Tools > Shrink Trimmed Surface)* on both surfaces.

The surfaces are now untrimmed.



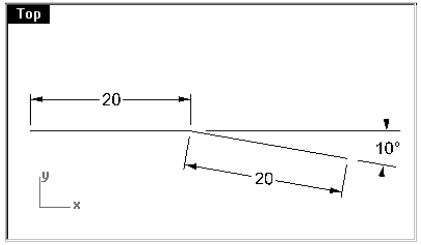
7 Hide the lower surface.

To create the dummy surface:

We will change the top surface by matching it to a dummy surface that we will create. The dummy surface will be made from one or more line segments along the bottom edge of the top surface that are set at varying angles to it. To get a line that is not tangent but at a given angle from tangent, two line segments are needed. They are touching at their ends but are at an angle from each other.

1 Change to the **Dummy Curve** layer.

2 In the **Top** viewport, use the **Polyline** command to make the first segment **20** units long and parallel to the x-axis.



Notes:

Shrink Trimmed Surface

3 Make the next segment 20 units long and at a 10 degree angle from the x axis.

The crease will have a maximum angle of 10 degrees.

4 Start the **OrientCrvToEdge** command *(Transform menu: Orient > Curve To Edge)*.

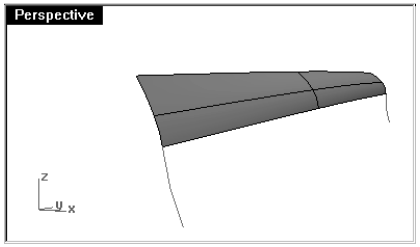
5 At the **Select curve to orient** prompt, in the **Front** viewport, select the left end of the polyline.

The orientation of the curve is relative to the construction plane where the curve is picked.

The command uses the active construction plane's z-direction as the reference for determining the alignment of the curve to the surface normal at the target edge. The end closest to the end picked will be the end touching the edge.

6 At the **Select target surface edge** prompt, select the bottom edge of the surface.

7 At the **Pick target edge point** prompt, snap to the endpoint.



8 At the **Pick target edge point** prompt, snap to the other endpoint.

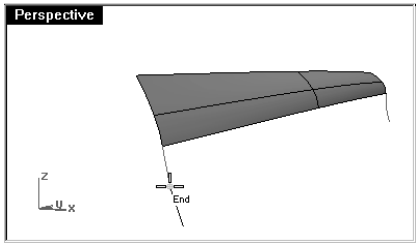
9 At the **Pick target edge point** prompt, press **Enter**.

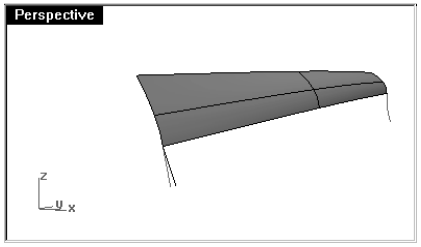
The result should look like the image above. If the result looks different (the curve angles the wrong way), flip the surface normals on the target surface and place the polylines again.

The upper segment of polyline is tangent to the surface, and the lower segment is at 10 degrees from tangent.

10 **Explode** the polylines.

11 **Move** the 10-degree segment of the polyline at the right side of the surface by its upper end to coincide with the upper end of the tangent segment.



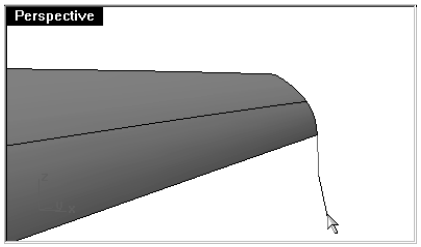


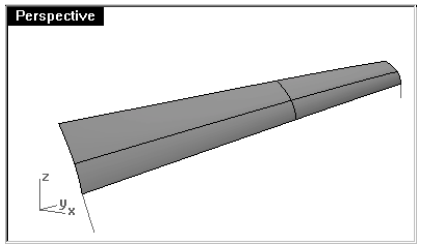
Notes:

Orient Curve to Edge

12 **Delete** the tangent segment on the left.

13 **Delete** the 10-degree segment of the polyline at the right side of the surface.





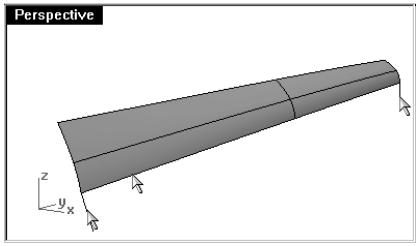
14 Make the **Dummy Surface** layer current.

15 Use the **Sweep1** command *(Surface menu: Sweep 1 Rail)* to create the dummy surface.

Sweep 1 Rail

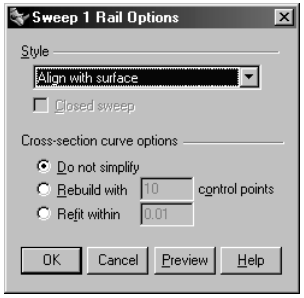
16 Select the lower edge of the upper surface as the rail and the two line segments as cross-section curves.

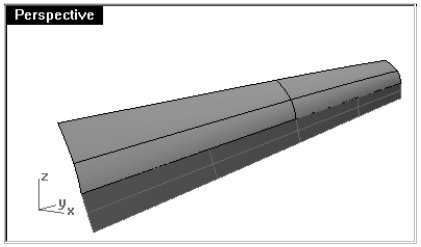
Make sure to use the surface edge and not the original input curve as the rail for the sweep.



17 In the **Sweep 1 Rail Options** dialog box, under **Style**, choose **Align with surface**.

This option causes the cross-section curves to maintain their orientation relative to the surface edge. A tangent curve (2) will be swept along the edge holding tangency all along unless another shape curve (3) with a different orientation is encountered, in which case there will be a smooth transition from one to the next.



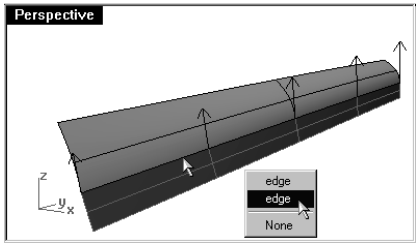


Notes:

To match the surface to the dummy surface:

1 Use the **MatchSrf** command to match the upper surface to the dummy surface.

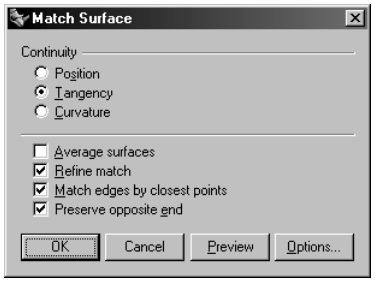
2 At the **Select surface to change - select near edge** prompt, select the lower edge of the upper surface.

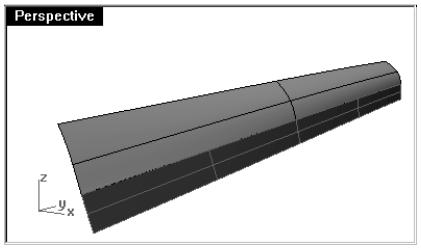


3 At the **Select target surface - select near edge** prompt, select the upper edge of the dummy surface.

4 In the **Match Surface** dialog box, choose **Tangency** and check **Match edges by closest point**.

This will keep distortion to a minimum.



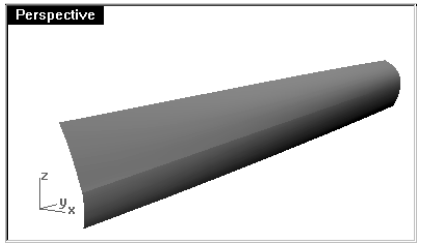


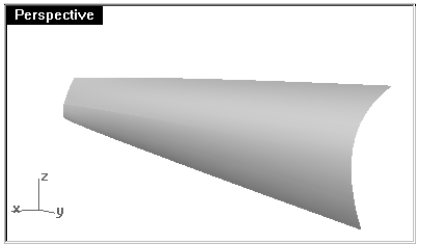
5 Show the lower (red) surface and hide the (blue) dummy surface.

Notes:

6 **Join** the lower surface with the upper surface.

The crease fades smoothly from one end to the other of the polysurface. If more control is needed over the angles of the crease, more segments can be placed to create the dummy surface.





Because the surfaces are untrimmed, you have the option to merge the surfaces back into one surface.

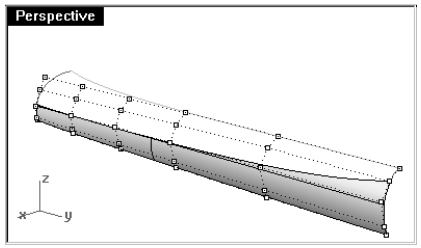
Exercise 14—Surfaces with a crease (Part 2)

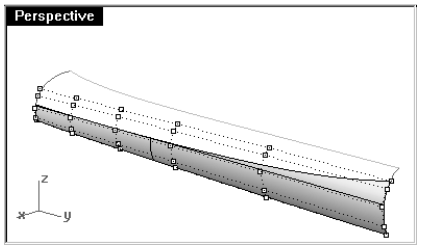
In this exercise there is no convenient relationship between the crease curve and the surface. While similar to the other example, the upper surface is made with a two rail sweep.

To create a crease with trimmed surfaces:

1 **Open** the model **Crease 02.3dm**.

2 Use the **ShrinkTrimmedSrf** command *(Surface menu: Surface Edit Tools > Shrink Trimmed Surface)* on the surface.



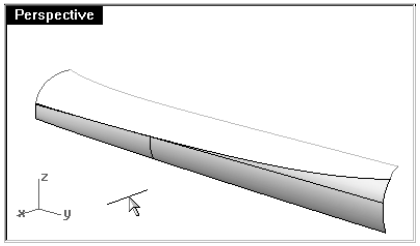


3 Use the **RebuildEdges** command *(Analyze menu: Edge Tools > Rebuild Edges)* to rebuild the edges of the surface to a 0.001 tolerance.

Notes:

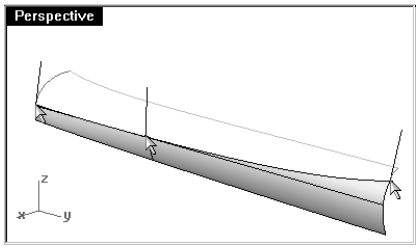
4 Use the **Line** command *(Curve menu: Line > Single Line)* to draw a single line anywhere in the viewport.

We will use this line to make a dummy surface.



4 Use the **OrientCrvToEdge** command *(Transform menu: Orient > Curve to Edge)* to move the curve for the dummy surface to the upper edge of the lower surface.

5 Place a line at each end of the edge and somewhere in the middle of the edge.

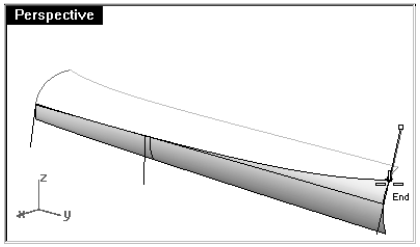


If the line flips over at either end, place it as close to the end as you can and move it later.

The line is tangent to the surface.

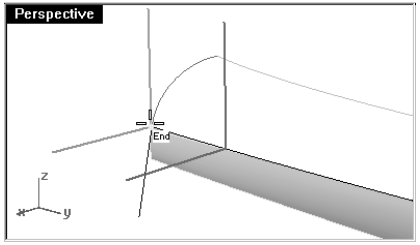
Notes:

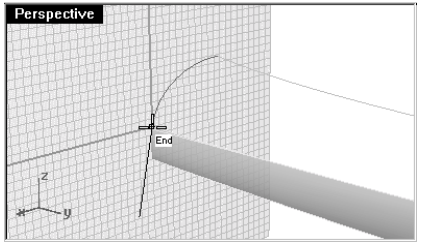
6 **Move** each line segment by moving its upper end to the lower end of the same segment.



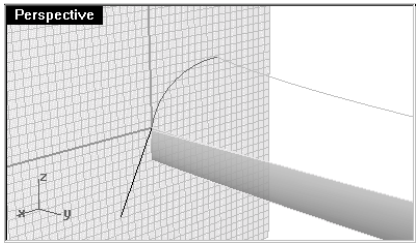
To use a custom construction plane to rotate a curve:

1 Use the **CPlane** command *(View menu: Set CPlane > Perpendicular to Curve)* to set the construction plane to align with the line at the left of the surface.

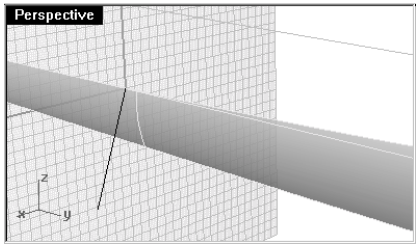




2 Use the **Rotate** command *(Transform menu: Rotate)* to rotate the line -15 degrees (counterclockwise).



3 Repeat these steps for the line in the middle of the surface.

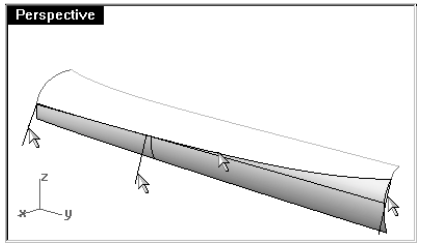


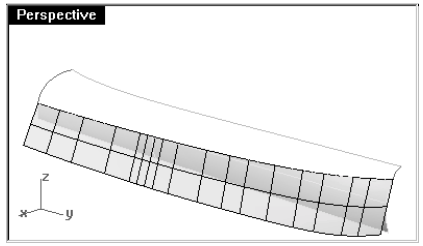
Notes:

To make the dummy surface:

1 Use the **Sweep1** command to create the dummy surface.

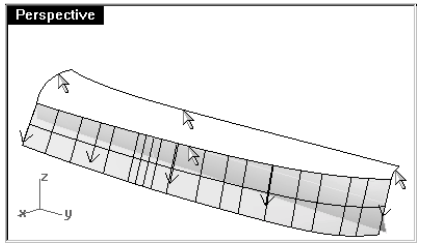
2 Select the upper edge of the lower surface as the rail and the three line segments as cross-section curves. Use the **Align with surface** style for the sweep.





3 Use the **Sweep2** command to make the upper surface.

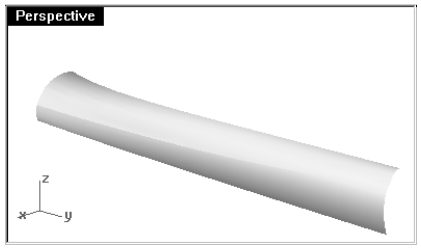
Choose the upper edge of the dummy surface as a rail and the long curve at the top as the other rail. Choose the curves at both ends as the cross-section curves.



4 In the **Sweep 2 Rails Options** dialog box, for the **Rail continuity** of edge **A**, choose **Tangency**.

5 **Hide** the dummy surface.

6 **Join** the lower surface with the upper surface.



Notes:

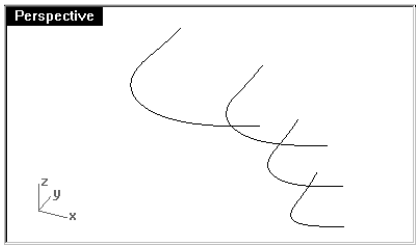
Curve fairing to control surface shapes

Fairing is a technique to simplify curves while improving their curvature graphs and keeping their shape within tolerance. It is especially important to fair curves that are generated from digitized data, intersections, extracted isocurves, or curves from two views.

Generally curves that are single-span curves work better for this process. A single span curve is a curve that has one more control point than the degree. Examples are a degree 3 curve with 4 control points, a degree 5 curve with 6 control points, or a degree 7 curve with 8 control points.

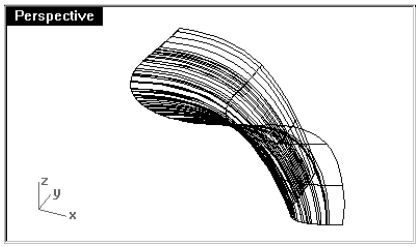
To make a surface with fair curves:

1 **Open** the model **Fair Curves.3dm**.



2 Select the curves and use the **Loft** command *(Surface menu: Loft)* to make a surface.

The surface is very complex. It has too many isocurves for the shape, because the control point structures of the curves are very different.



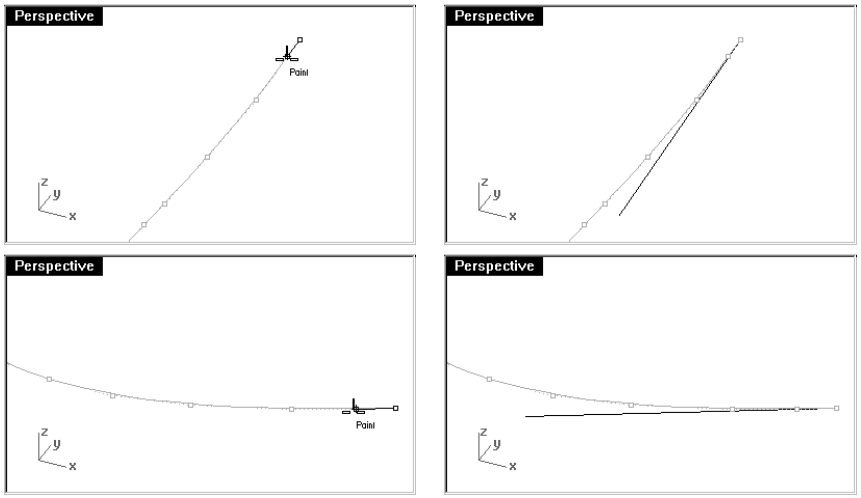
3 **Undo** the loft.

4 Change to the **Tangency Direction** layer and turn on the control points on the original curves.

Notes:

Loft

5 To maintain the tangency direction of the originals, make a line tangent to the originals from the end points and coming back towards the curve, any length. Use the Tab lock and snap to the second point to extend the line.

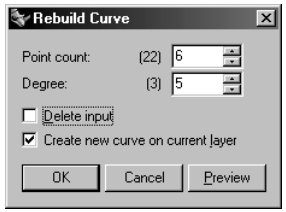


6 Change to **Rebuilt Curves** layer, and **Lock** the **Tangency Direction** layer

7 Use the **Rebuild** command *(Edit menu: Rebuild)* to rebuild the curves.

Note: Although there is a **Rebuild** option in the **Loft** command, rebuilding the curves before lofting them gives you control over the degree of the curves as well as the number of control points.

8 In the **Rebuild Curve** dialog box, change the **Degree** to **5** and the **Point Count** to **6** points. Uncheck **Delete input**, check **Current layer**.



Click the **Preview** button. Notice how much the curves deviate from the originals.

Notes:

Rebuild

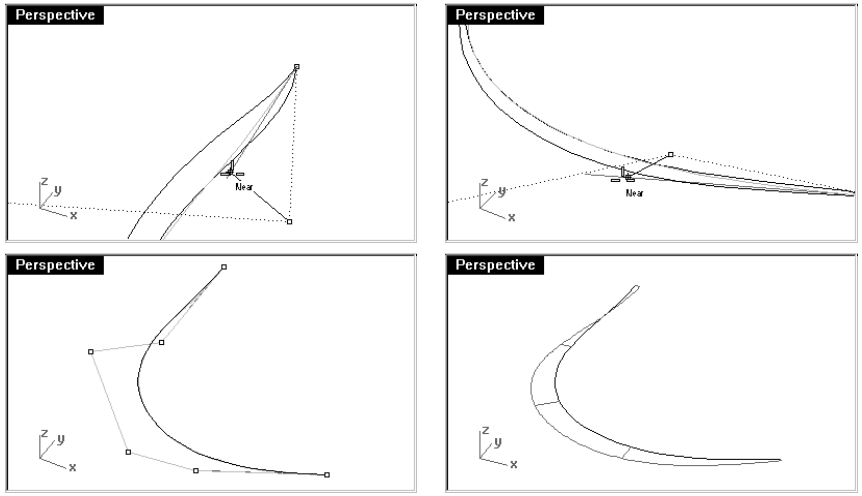
Note: This makes the curves into single-span curves. Single-span curves are Bézier curves. A single-span curve is a curve that has degree +1 control points. While this is not necessary to get high quality surfaces, it produces predictable results.

9 **Lock** the **Original Curves** layer.

10 Select one curve, turn on the points and the curvature graph.

11 Fair the curve by adjusting points until it matches the original curve closely enough.

Start by moving the second point of the rebuilt curve onto the tangent line. Use the **Near** object snap to drag along the tangent line.



12 Check the curvature graph to make sure the curve has smooth transitions.

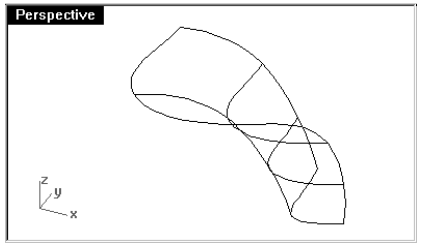
The curves are fair when the points are adjusted so the rebuilt curves match the original locked curves closely, with good graphs.

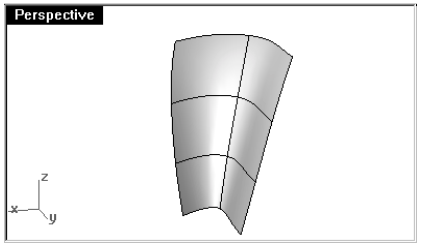
13 Fair the other curves the same way.

Notes:

14 **Loft** the new curves.

Note the shape and quality of the surface. It has very few isocurves but it has close to the same shape as the first surface.





Notes:

7 Use Background Bitmaps

This exercise describes the steps in creating a case for a handset, using bitmaps as templates. In this exercise we will focus on making curves from bitmaps images and using fairing techniques on the curves before making the surfaces.

We will begin by taking scanned sketches and placing them in three different viewports. The three hand-drawn images need to be placed in their respective viewports and scaled appropriately so that they match each other.

You can align images more easily if they have been aligned and cropped so that they share the same length in pixels. It helps to darken and slightly reduce the contrast of images that have a lot of bright white in them. This allows a greater range of colors to be seen against them when tracing them in Rhino.

Exercise 15—Handset

1. **Open** the model **Handset.3dm**.
2. From the **Tools** menu, click T**oolbar Layout**.
3. In the **Toolbars** dialog box, check **Background Bitmap** to open the toolbar, then close the dialog box.

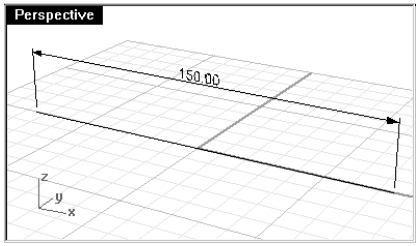
   Use the toolbar buttons for the next part of the exercise.

Notes:

To place background bitmaps:

We will begin by making reference geometry to help in placing the bitmaps.

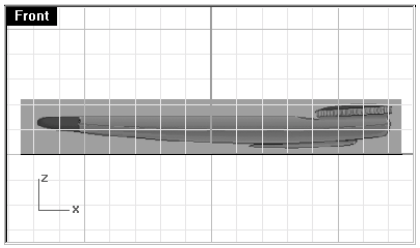
1 Make a horizontal line, from both sides of the origin of the **Top** viewport, 150 mm long.



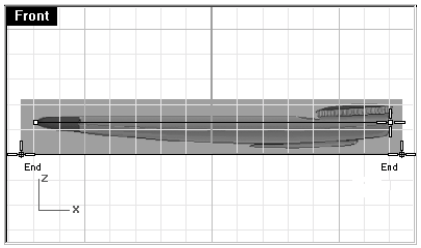
2 Toggle the grid off in the viewports that you are using to place the bitmaps by pressing the **F7** key.

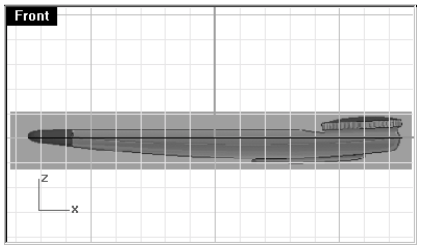
This will make it much easier to see the bitmap. The grid is displayed in the illustrations for reference only.

3 In the **Front** viewport, use the **BackgroundBitmap Place** command *(View menu: Background Bitmap > Place)* to place the **HandsetElevation.bmp**.



4 Use the **BackgroundBitmap Align** command *(View menu: Background Bitmap > Align)* to align the ends of the handset to the line.





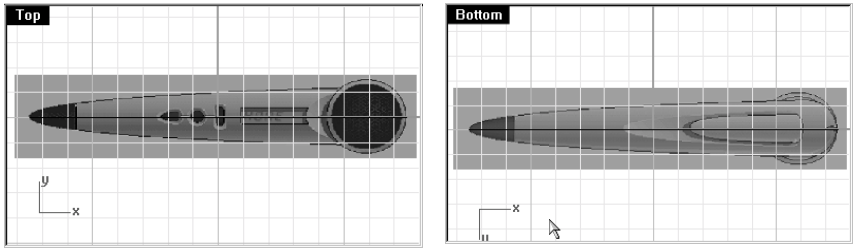
Notes:

Place Background Bitmap

Align Background Bitmap

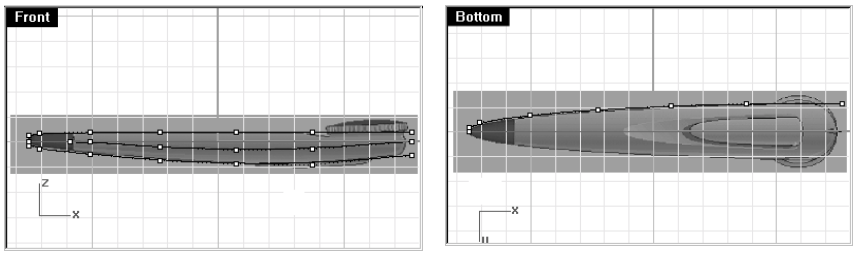
5 Change the **Right** viewport to a **Bottom** view.

6 Use the same technique to place and align the **HandsetTop.bmp** and **HandsetBottom.bmp** in the respective viewports.



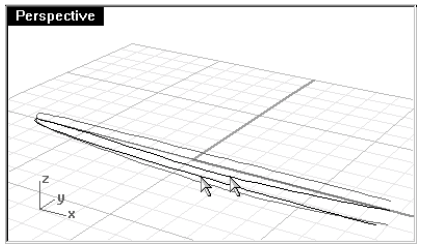
To build the case:

1 In the **Front** and **Bottom** viewports, trace the curves you need to define the form of the case. Since the bottom view of the object is symmetrical you can make one curve.



The front view curves describing the top and bottom edges of the case should extend on the right past the form in the background image approximately the same amount as the corresponding top view curves do. You can draw them too long and trim both top view and both front view edge curves off with a single cutting plane. Now draw the curve in the **Front** viewport that defines the parting line separating the top and bottom halves of the case. This curve is the front view of the plan view's edge curves. It should be extended to the right the same distance as the other edge curves.

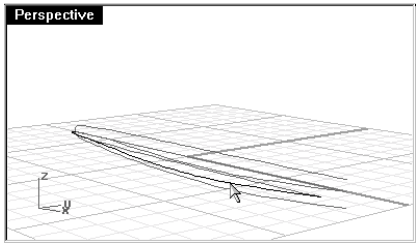
2 In the **Bottom** viewport, select the parting line curve and the outline curve.



Notes:

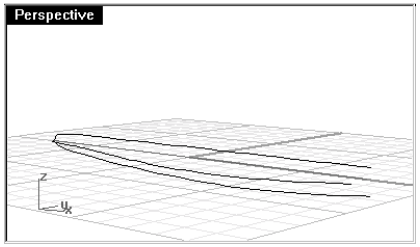
3 Use the **Crv2View** command *(Curve menu: From Two Views)* to create a curve based on the selected curves.

A 3-D curve is created.



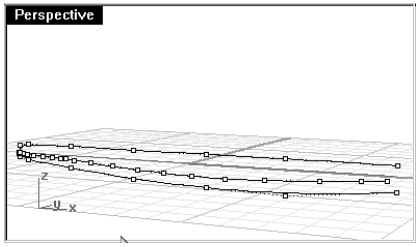
4 **Hide** or **Lock** the two original curves.

Now there are three curves.



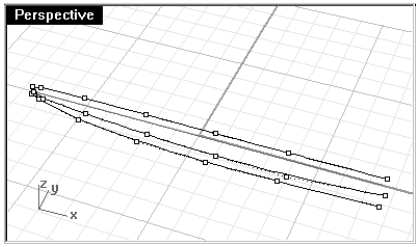
5 Turn on the control points for the curves.

Note the number of control points and the spacing. This is an example of curves that need to be faired before you can create a good surface from them.



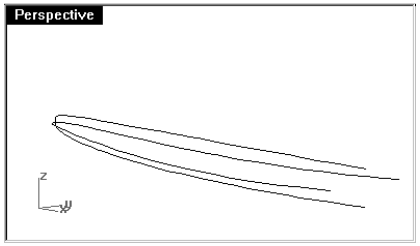
Notes:

6 Fair the curves, using the same technique as in the previous exercise.



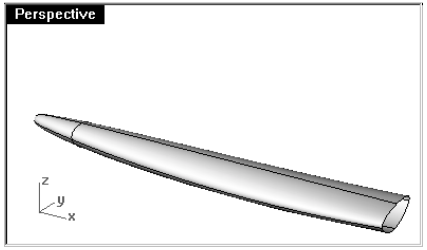
7 **Mirror** the 3-D curve for the other side.

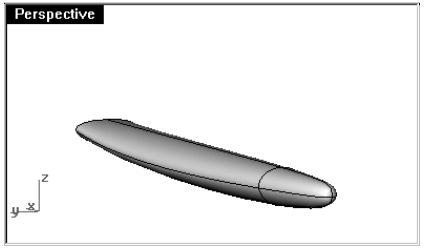
The macros **! Mirror 0 1,0,0** and **! Mirror 0 0,1,0** are very useful for accomplishing this quickly if they are assigned to a command alias and if the geometry is symmetrical about the x or y axis.



8 **Loft** the faired curves.

Note the quality of the surface and how few isocurves there are.





Notes:

8 An Approach to Modeling

A common question that occurs when modeling, is “Where do I start?” In this section we will discuss various approaches to the modeling process.

There are two things to consider before your begin modeling: if reflections, fluid flow, air flow, or the ability to edit using control points are important in the finished model, you will want to begin your models with geometry that consists of cubic (degree 3) or quintic (degree 5) curves. If these are not important, you can use a combination of linear (degree 1), quadratic (degree 2), cubic or quintic curves.

Start with simple shapes, the details can be added later. Begin by creating layers for the different parts. This will help separate the parts for visualization, and help with matching the parts as you go.

We will review different products to try to determine which kind of surfaces are most important and some approaches to modeling the product.

Exercise 16—Cutout

This exercise shows an approach to making a cutout surface which blends smoothly and seamlessly into an existing curved surface. The new surface has an arbitrary relationship to the existing surface so the general strategy can be used in other cases.

1 **Open** the model **Scoop.3dm**.

Notes:

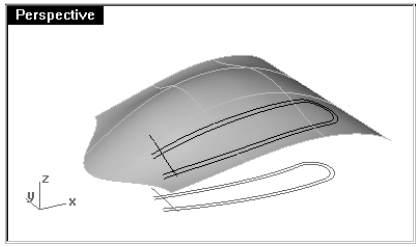
2 Make the **Cut-out Curves** layer current, turn on the **Original Surface** layer, turn off the **Completed Scoop** layer.

3 In the **Top** viewport, select the curves.

4 Start the Project command *(Curve menu: From Objects > Project)*.

5 At the **Select surfaces or polysurfaces to project onto** prompt, select the surface.

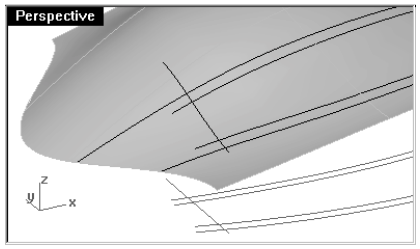
The curves will be copied to the surface.



6 Start the **ExtendCrvOnSrf** command *(Curve menu: Extend > Curve On Surface)*.

7 At the **Select curve to extend** prompt, select the outer curve on the surface.

8 At the **Select surface that curve is on** prompt, select the surface.
The ends of the curve are extended to the edge of the surface.

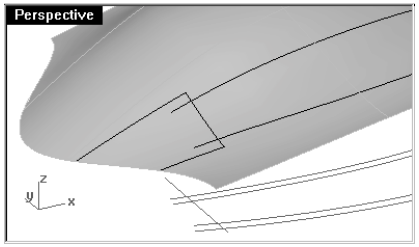


Notes:

Project

Extend Curve On Surface

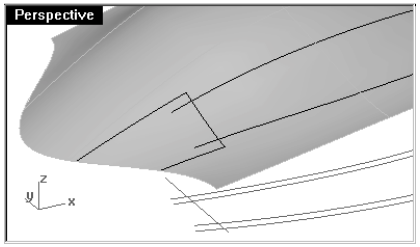
9 Use the **Trim** command *(Edit menu: Trim)* to trim the curves with each other.

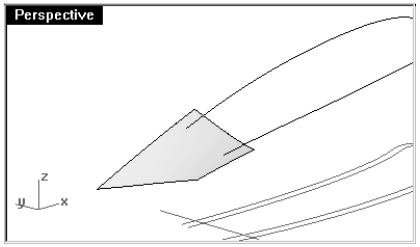


10 **Join** the three small curves into one.

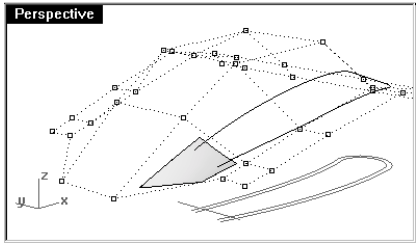
11 **Duplicate** the surface and hide the duplicate.

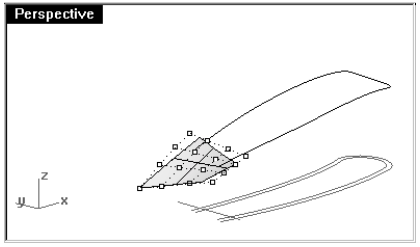
12 Use the joined curve to trim away the part of the surface which is outside the curve. This leaves a small trapezoidal surface. This surface is a dummy used to match a new surface to and will be deleted later.





13 Use the **ShrinkTrimmedSrf** command *(Surface menu: Edit Tools > Shrink Trimmed Surface)* to make this surface easier to use.





Notes:

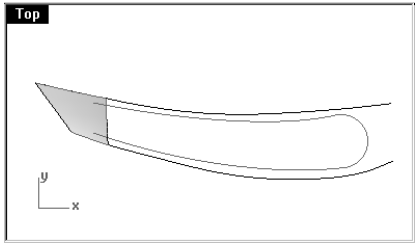
To make the bottom of the cutout:

Next we will make a surface for the bottom of the cutout. The cutout is round at one end, but we will build a rectangular surface and trim it to be round at one end. This approach allows for a much lighter, more easily controlled surface.

1 Make one curve first with as few points as possible.

Look at from various views while you work. Five or six points should be enough in the curve.

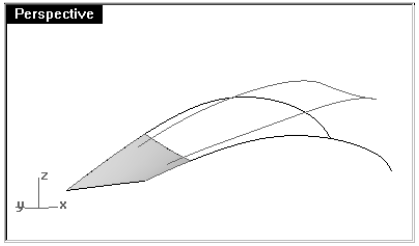
Use the curvature graph to get a nice fair curve.



2 Copy the curve to the other edge.

3 Adjust the curves by moving the control points until they look the way you want.

The curves should be as wide as the dummy surface. Make sure the curves extend past the end of the cutout curve in the **Top** viewport.



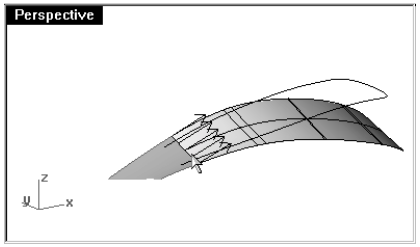
4 Use the **Match** command *(Curve menu: Edit Tools > Match)* to match the curves with curvature continuity to the edges of the dummy surface.

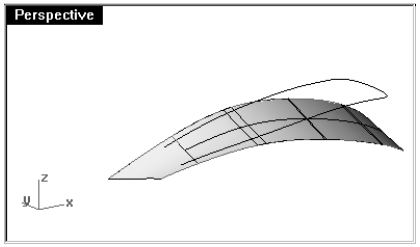
If matching makes the curve distort too much add a knot and try again. EndBulge and further point editing may be needed.

5 Use the **Loft** command *(Surface menu: Loft)* to create the surface between the two curves.

Notes:

6 Use the **MatchSrf** command *(Surface menu: Edit Tools > Match)* to match the lofted surface to the edge of the dummy surface.





If the lofted surface distorts too much, undo and restart the **MatchSrf** command.

7 In the **Match Surface** dialog box, click **Options**.

8 In the **Match Surface Options** dialog box, click **Preserve isocurve direction**.

This time the match should not distort the surface.

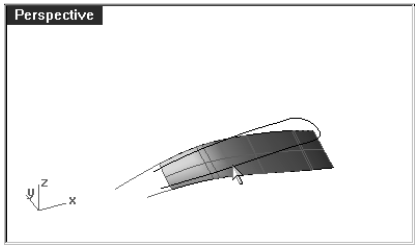
9 Use the **ChangeLayer** command to move the dummy surface to the **Dummy Surface** layer.

To make the sides of the cutout:

To make the sides of the cutout, we will extrude the projected outline with 10 degrees of draft and trim it with the lofted surface.

1 Select the projected curve.

2 Use the **Rebuild** command *(Curve menu: Edit Tools > Rebuild)* to rebuild the curve with as few points as you can, while still maintaining the curvature of the original curve.



3 Use the **Extrude** command *(Surface menu: Extrude > Straight)* to extrude the rebuilt curve.

4 At the **Extrusion distance** (Direction BothSides Tapered) prompt, type **T** and press **Enter**.

5 At the **Draft angle <0 >** prompt, type **–10** and press **Enter**.

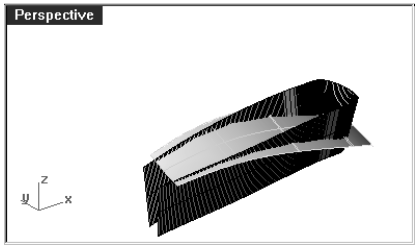
Notes:

Rebuild

Extrude

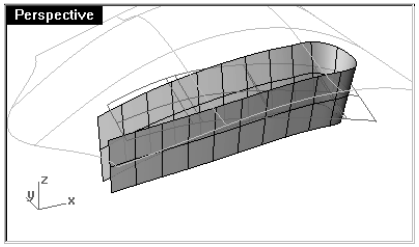
6 At the **Extrusion distance** (Direction Corner=*round*) prompt, pull the surface until it fully intersects with the bottom surface and pick.

The extruded surface is a very dense surface.



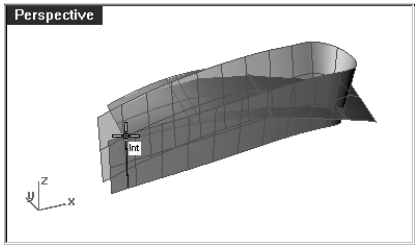
7 Use the **Rebuild** command *(Surface menu: Edit Tools > Rebuild)* to rebuild the surface.

Fifty to seventy points in the V-direction and 4 points in the U-direction should be enough.



8 Trim the lofted surface with the extrusion to create the floor of the cutout.

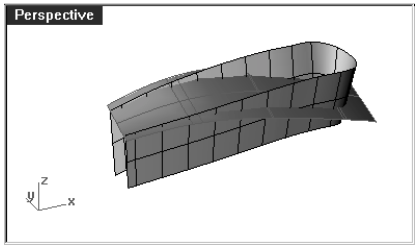
9 Use the **Split** command *(Edit menu: Split)* with the **Isocurve** option to split the ends of the extruded surface at the intersection with the original projected curve on both sides.



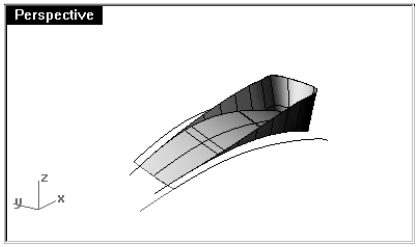
Notes:

Rebuild Surface

10 Delete the ends that are split.



11 Trim the sides of the extruded surface with the floor of the cutout.



To create the fillets:

Now the surfaces are ready to be filleted.

1 **Show** the main surface.

2 Use the **FilletSrf** command *(Surface menu: Fillet Surface)* to make the fillets between the bottom surface and the sides.

Fillet Surface

3 At the **Select first surface to fillet** (Radius=*1* Extend=*Yes* Trim=*Yes*) prompt, type **5** and press **Enter**.

4 At the **Select first surface to fillet** (Radius=*5* Extend=*Yes* Trim=*Yes*) prompt, click **Extend** to change the setting to **No**.

5 At the **Select first surface to fillet** (Radius=*5* Extend=*No* Trim=*Yes*) click **Trim**.

6 At the **Trim <Yes >** (Yes No Split) prompt, click **No**.

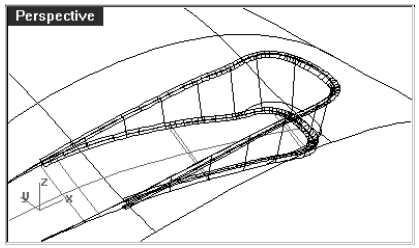
7 At **Select first surface to fillet** (Radius=*5* Extend=*No* Trim=*No*) prompt, pick the bottom surface.

8 At the **Select second surface to fillet** (Radius=*5* Extend=*No* Trim=*No*) prompt, pick the side surface near the same spot.

Notes:

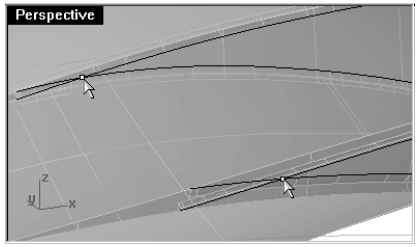
9 Repeat this for the side surface and the original surface.

The two fillets cross each other. We will trim them both back to their intersection points.



10 Use the **DupEdge** command *(Curve menu: From Objects > Duplicate Edge)* to duplicate the upper edge of the lower fillet and the lower edge of the upper fillet.

11 Use the **Intersect** command *(Curve menu: From Objects > Intersection)* to find the intersections between the duplicated curves for the fillet edges on the side surfaces.



12 Select the duplicated curves and the intersection points.

13 Use the **Invert** command *(Edit menu: Select Objects > Invert)* to invert the selection.

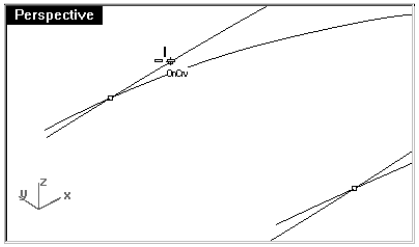
14 Use the **Hide** command *(Edit menu: Visibility > Hide)* to hide the selected geometry.

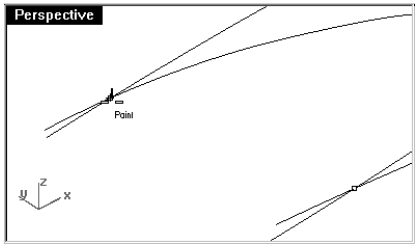
Notes:

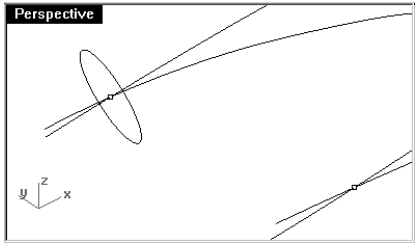
Duplicate Edge

Hide: Invert

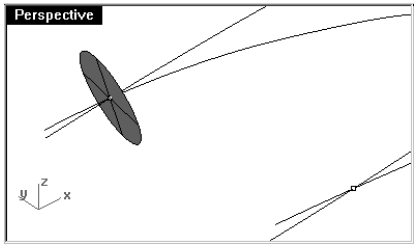
15 Use the **Circle** command with **AroundCurve** option *(Curve menu: Circle > Center, Radius)* to create a curve at the point, use the **OnCrv** object snap to select one of the curves.



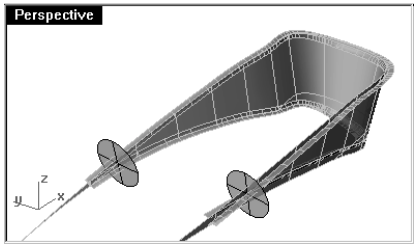




16 Use the **PlanarSrf** command *(Surface menu: From Planar Curves)* to create a circular surface at the intersection point.



17 Repeat these steps for the other intersection.

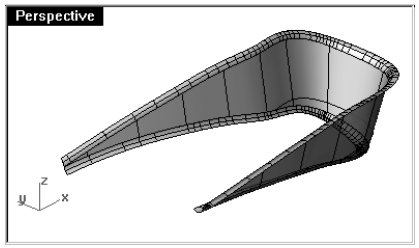


Notes:

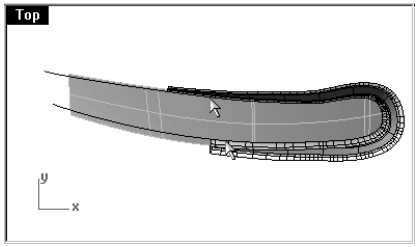
Circle: Around Curve

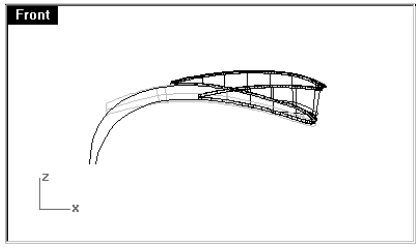
18 **Trim** the fillets to the surfaces.

19 **Trim** the sides to the fillets.

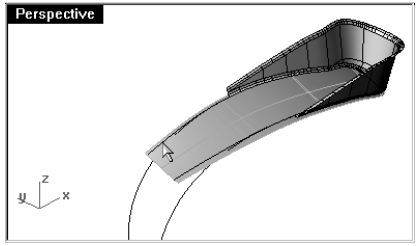


20 In the **Top** viewport, use the **Extend** command with the **Type=*Smooth*** option to extend the bottom ends of the fillet curve to the ends of the cutout surface.

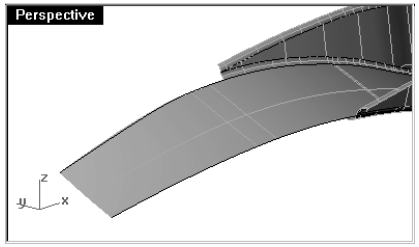




21 Use the **Project** command to project the extended curve onto the original surface.



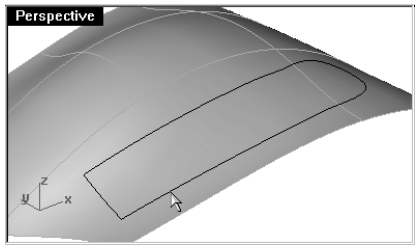
22 Use the extended curve to trim the bottom surface.



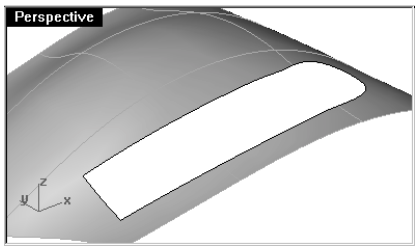
Notes:

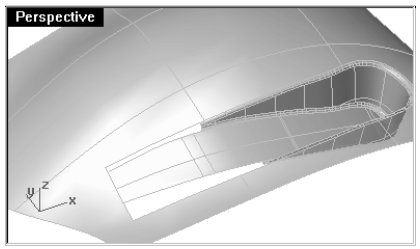
23 Repeat steps 19 and 20 for the curves at the top of the upper fillet.

24 Duplicate the edge of the dummy surface and trim the curves to make a closed loop.

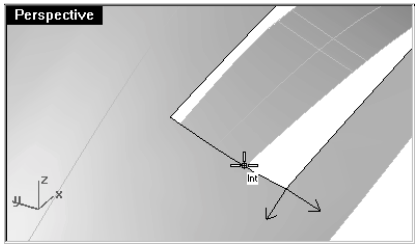


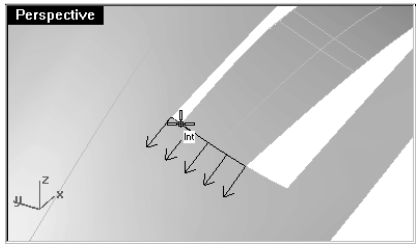
25 Use the projected curve and the edge of the dummy surface to trim the cutout from the original surface.



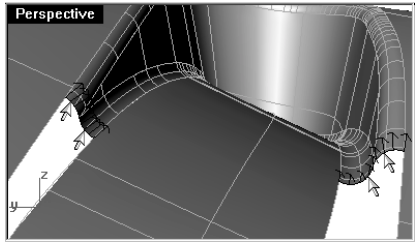


26 Use the **SplitEdge** command *(Analyze menu: Edge Tools > Split Edge)* to separate the short edges on the original surface into three separate parts.





27 Duplicate the edge curves at the trimmed edges of the fillets and join them.



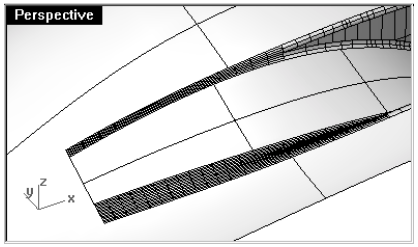
Notes:

Split Edge

Merge Edge

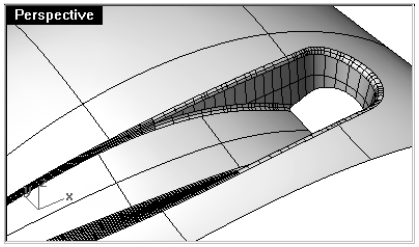
28 Use the **Sweep2** command with **Rail continuity=*Tangency*** or the **NetworkSrf** command to create the last two surfaces.

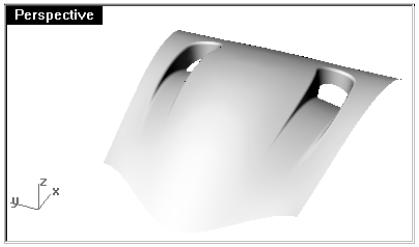
The surfaces start with the s-shaped curves that you duplicated and end with a flat line at the split edge.



29 **Join** the cutout surfaces and then trim a hole at the bottom.

30 **Mirror** and **Trim** to get the other scoop.





Notes:

9 Use 2-D Drawings

Use 2-D drawings as part of a model

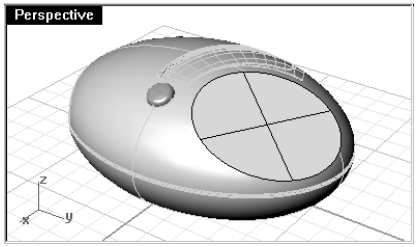
Often you are asked to take an existing design from a 2-D graphics package and include it as part of a Rhino model. One of the tasks to complete will include moving and positioning the graphic onto the model.

In the following exercise we will use a logo design created in Adobe Illustrator to make a 3-D logo on a model.

Exercise 17—Importing an Adobe Illustrator file

In this exercise we will make a custom construction plane, import an Illustrator file, and place a logo on some surfaces.

1 **Open** the model **Air Cleaner.3dm**.



To import a file:

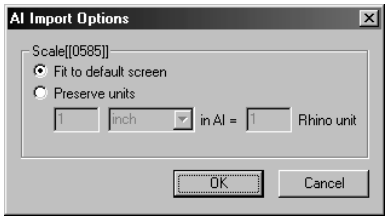
1 Start the **Import** command *(File menu: Import)*.

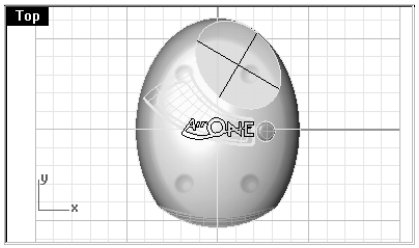
2 Change the **Files of type** to Adobe Illustrator (*.ai), and choose the **AirOne_Logo.ai** to import.

Notes:

3 In the **AI Import Options** dialog box, click **OK**.

The logo is selected and located on the Top construction plane.





4 Start the **Layer** command.

5 Make a new layer named **Logo1** and turn off the new layer.

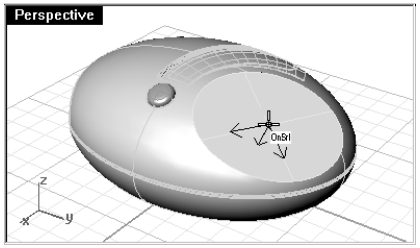
6 Right click on the **Logo1** layer, then click **Copy Objects to Layer** to make a copy of the logo on the new layer.

To create the custom construction plane:

1 Select the flat disc shaped surface.

It is important to know normal direction and the U- and V-directions of the surface.

2 Start the **Dir** command *(Analyze menu: Direction)*.



3 At the **Press Enter when done** (UReverse VReverse SwapUV Flip) prompt, click on the surface to flip the normal direction.

Put your cursor over the surface and observe the red and green direction arrows.

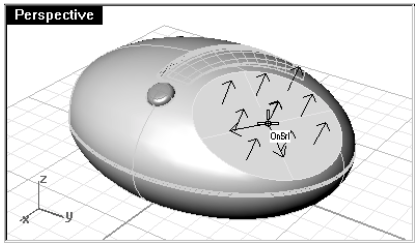
4 At the **Press Enter when done** (UReverse VReverse SwapUV Flip) prompt, click **UReverse** or **VReverse** to change the direction of U and V (surface "x" and "y" directions).

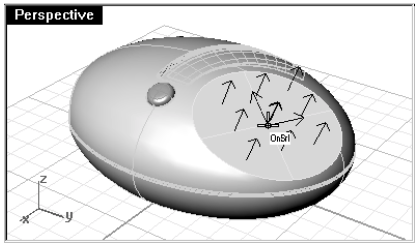
5 At the **Press Enter when done** (UReverse VReverse SwapUV Flip) prompt, press **Enter**.

The direction of U, V, and the normal have been changed.

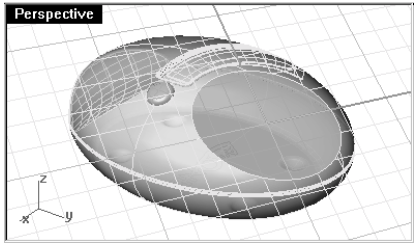
Notes:

Direction





6 Use the **CPlaneToObject** command *(View menu: Set CPlane > To Object)* to realign the **Perspective** viewport construction plane to the surface.



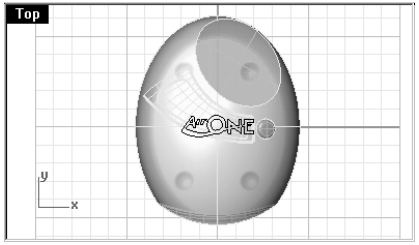
To move the logo to the custom construction plane:

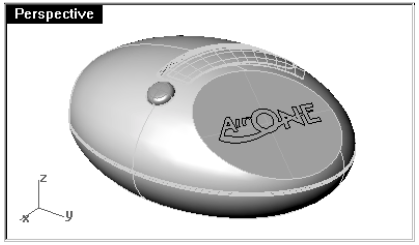
The command we will use to move the logo to the flat disk shaped surface uses the position of the object relative to a construction plane. Make sure **Top** is the active viewport and the logo is selected.

1 Start the **RemapCPlane** command *(Transform menu: Orient > Remap To CPlane)*.

2 At the **Click on CPlane to map to** (Copy) prompt, click in the **Perspective** viewport.

The logo is positioned in the same relative position on the custom construction plane.



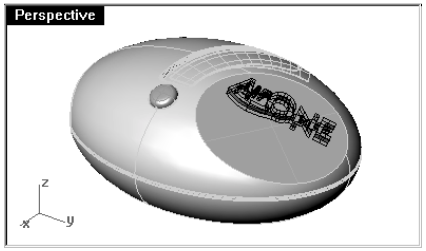


Notes:

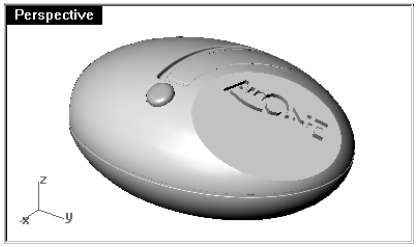
Remap To CPlane

3 Rotate or move the logo to a new position.

4 Use the **Extrude** command *(Solid menu: Extrude Planar Curve)* with the **BothSides** option to make the text 3-D. The extrusion distance should be 2 mm.



5 Use the **BooleanDifference** command *(Solid menu: > Difference)* to recess the text into the surface.



To place the logo on an irregularly shaped surface:

In this part of the exercise, we will import another logo and position it on the cutout surface.

1 Select the purple cutout surface.

2 Use the **Invert** command *(Edit menu: Select > Invert)* to invert the selection set.

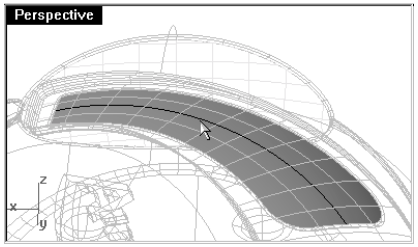
3 Use the **Hide** command *(Edit menu: Visibility > Hide)* to hide everything but the cutout surface.

Notes:

Invert Hide

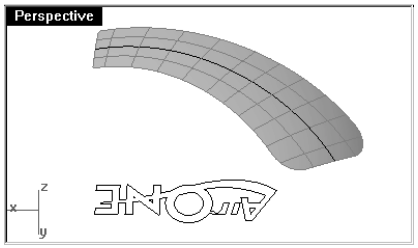
4 Use the **ExtractIsocurve** command *(Curve menu: From Object > Extract Isocurve)* to extract a lengthwise isocurve on the cutout surface.

We will use this curve to align the logo.

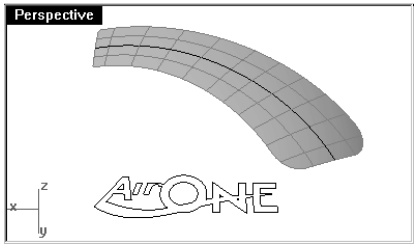


5 Use the **Length** command *(Analyze menu: Length)* to check the length of the extracted isocurve.

6 Turn on the **Logo1** layer.



7 In the **Perspective** viewport, **Rotate** the logo **180** degrees about the **0,0** point.

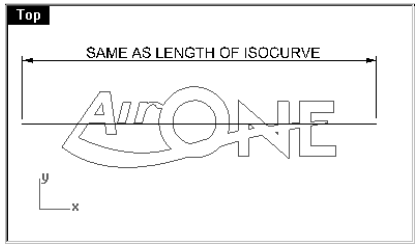


Notes:

Extract Isocurve

8 Use the **Line** command with the **BothSides** option to draw a line from **0,0** that is the same length as the extracted isocurve.

The line should be oriented so that it goes through the center of the logo.



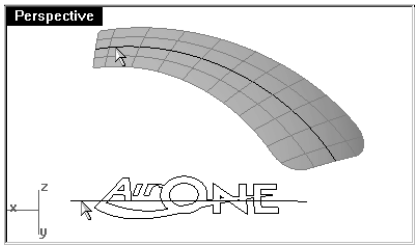
9 Window select the logo, not the line.

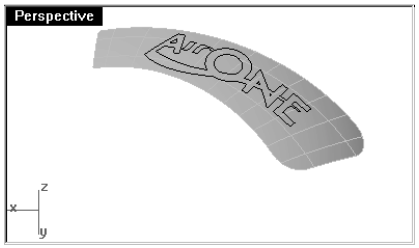
10 Start the **Flow** command *(Transform menu: Flow along Curve)*.

11 At the **Original backbone curve - select near end** (Line Copy) prompt, select the line.

12 At the **New backbone curve - select near end** (Line Copy) select the extracted isocurve.

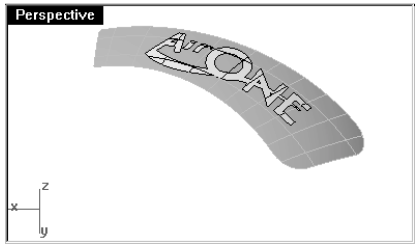
The logo follows the curve.





To raise the logo lettering

1 In the **Perspective** or **Top** viewport, use the **Split** command *(Edit menu: Split)* to split the surface with the logo curves.



Notes:

Flow along Curve

2 Select the logo surfaces.

Do not pick the parts of the surfaces that are inside the letters (A, O, and N).

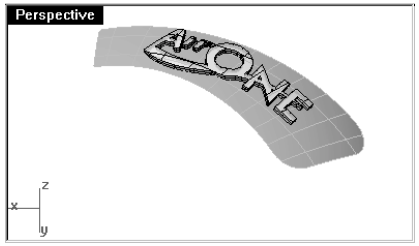
3 Start the **OffsetSrf** command *(Surface menu: Offset Surface)*.

4 At the **Offset distance <1 >** (Flip Solid Loose Tolerance) prompt, move your cursor over the logo surface. If the normal is pointing down, click on the surface to flip it.

5 At the **Offset distance <1 >** (Flip Solid Loose Tolerance) prompt, click **Solid** to activate the solid option.

6 At the **Offset distance <1 >** (Flip Loose Tolerance) prompt, type **1** and press **Enter**.

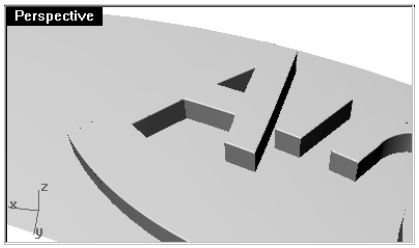
The logo is offset with the sides filled in.

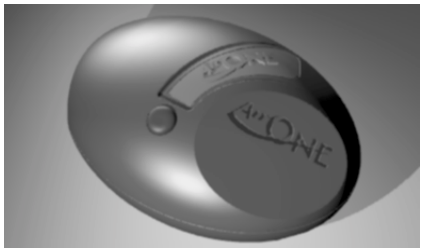


7 Use the **ExtractSrf** command *(Solid menu: Extract Surface)* to separate the bottom surfaces from the logo and delete them.

8 Use the **Join** command *(Edit menu: Join)* to join the logo with the cutout surface.

9 Use the **FilletEdge** command *(Solid menu: Fillet Edge)* with a .01 radius to soften the top edges of the logo.





Notes:

Offset Surface

Make a model from a 2-D drawing

One of the more difficult modeling tasks in modeling is to interpret a set of 2-D views into a 3-D model. Very often the drawings are precise in some areas and inexact in areas where complex surface transitions must take place in three dimensions.

It is best to consult directly with the designer to clarify difficult areas, but this is not always possible. Usually there are discrepancies between the views.

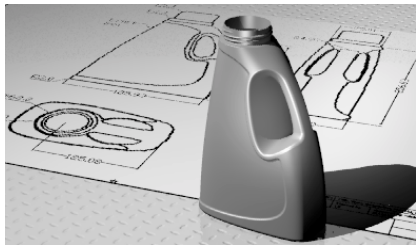
If there is no physical model available as reference, some decisions must be made along the way about the best way to interpret the sketch or drawing. For example, you will have to consider which view to consider the most accurate for a given feature.

In the following exercise we will explore some strategies to create a blow-molded plastic bottle from a set of 2-D drawings. In this exercise we have a control drawing showing three views of the bottle. It is roughly dimensioned, but we need to hold to the designer's curves wherever possible.

We will only have time to finish the first stage of this model in class. We will complete the bottle surfaces, but the details will be left out. Included in the models folder is a finished bottle for your review.

Exercise 18—Making a detergent bottle

1 **Open** the model **Detergent Bottle.3dm.**



2 In the **Top** viewport, window select the objects that make the top view (lower left) including the dimensions of the 2-D drawing.

3 Use the **Group** command to group the selected objects *(Edit menu: Group)*.

4 Repeat the previous steps to group the objects for the front view (upper left) and the right view (upper right).

Each of the views is a separate group of objects.

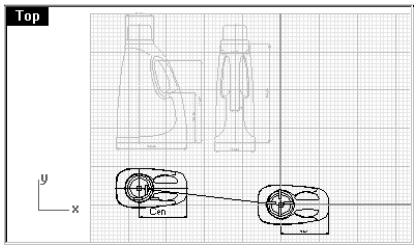
Notes:

To orient the views:

1 Select the top view group.

2 Use the **ChangeLayer** command *(Edit menu: Layers > Change Object Layer)* to change the layer to the **3D Template Top** layer.

3 In the **Top** viewport, use the **Move** command to move the center of the circles to **0,0**.



4 Select the front view group.

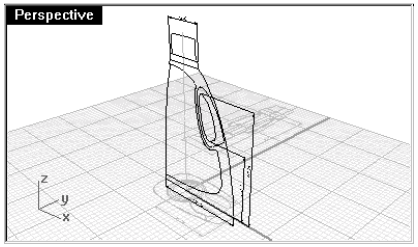
5 Use the **ChangeLayer** command to change the layer to the **3D Template Front** layer.

6 In the **Top** viewport, use the **Move** command to move the intersection of the centerline and the horizontal line at the bottom to **0,0**.

7 Start the **RemapCPlane** command *(Transform menu: Orient > Remap to CPlane)*.

8 At the **Click on CPlane to map to** (Copy) prompt, click in the **Front** viewport.

The view is oriented in 3-D space.



9 In the **Top** or **Perspective** viewport, select the right view group.

10 Use the **ChangeLayer** command to change the layer to the **3D Template Right** layer.

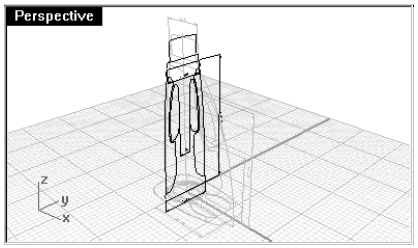
11 In the **Top** viewport, use the **Move** command to move the intersection of the centerline and the horizontal line at the bottom to **0,0**.

12 From the **Transform** menu: **Orient**, then click **Remap to CPlane**.

Notes:

13 At the **Click on CPlane to map to** (Copy) prompt, click in the **Right** viewport.

The view is oriented in 3-D space.



Frequently 2-D curves for design control drawings will not be as carefully constructed as would you like for making accurate geometry. Before building 3-D geometry from the 2-D curves, check the curves and correct any errors that can be found.

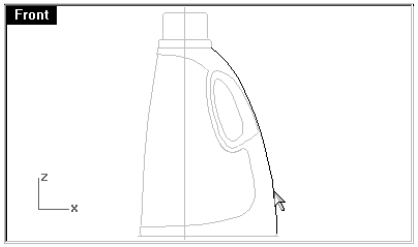
To create the 3-D curves for the front view:

1 Change to the **3d Curves** layer, turn off all layers except **3d Template Front** layer.

2 Use the **Duplicate** command (the right-click button you made in a previous exercise) to copy the curve on the right.

3 Use the **ChangeLayer** command to change the duplicated curve to the **3D Curves** layer.

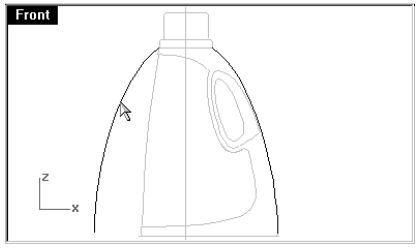
4 **Lock** the **3d Template Front** layer.



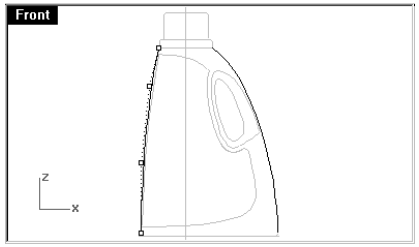
Notes:

5 Use the **Mirror** command *(Transform menu: Mirror)* to mirror the curve (1) around the origin.

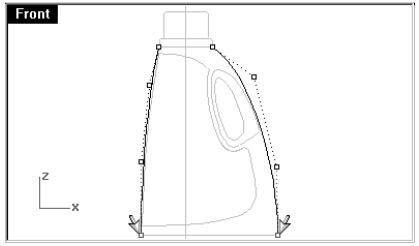
This curve will be used to make a new curve for the left side of the bottle. The left hand profile curve in the front view is actually unknown because the walls of the bottle are inset by 2mm.



6 Turn on points for this curve, and adjust it to create the new curve for the left side.



7 Turn on points for the right hand curve and select the bottom points on both curves.

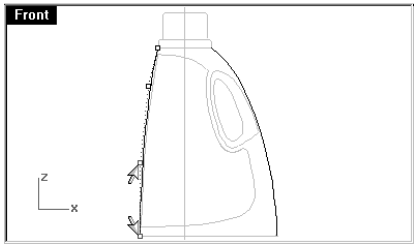


8 Use the **SetPt** command *(Transform menu: Set Points)* to set the world z-coordinate of the points to **0**.

This will make a sharp corner at the bottom. The fillet will be added to the surface later.

Notes:

9 Select the two points closest to the bottom on the left hand curve.



10 Use the **SetPt** command to align the upper point in the X direction to the lower point.

11 Repeat this step for the right hand curve.

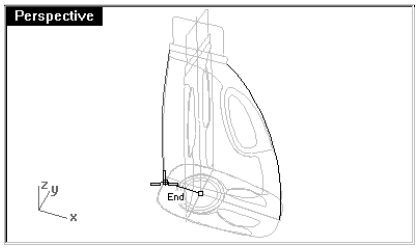
This ensures that the curves will be tangent to a vertical at the lower endpoint.

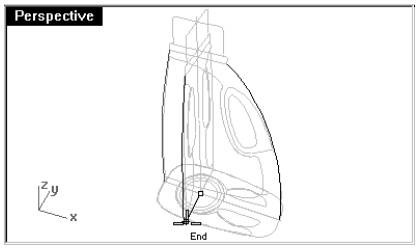
To create the 3-D curves for the right view:

1 Turn off the **3d Template Front** layer and turn on the **3d Template Right** Layer.

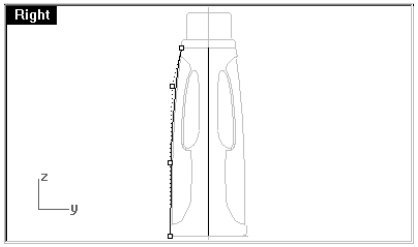
2 Select the curve at the left, front of the bottle.

3 In the **Top** viewport, use the **Rotate** command *(Transform menu: Rotate)* with the **Copy** option to rotate the curve around the origin, by 90 degrees.





4 Turn on the points for this curve, and adjust it.



5 Use the **SetPt** command to set the world z-coordinate of the last point to **0**.

6 Select the two points closest to the bottom on the new curve.

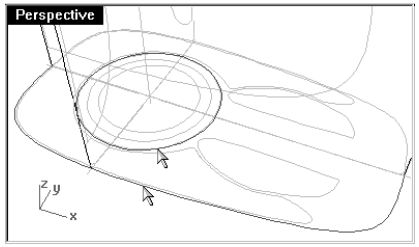
7 Use the **SetPt** command to align the points in the World Y direction.

Notes:

To create the 3-D curves for the top view:

1 Turn off the **3d Template Right** layer and turn on the **3d Template Top** Layer.

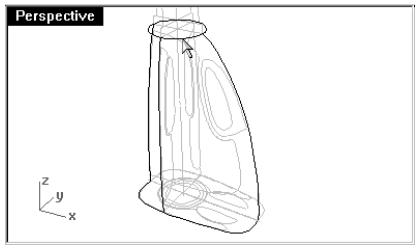
2 Use the **Duplicate** command to duplicate the boundary curve and the largest circle.



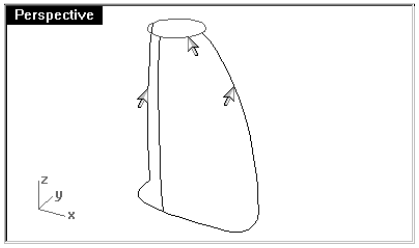
3 Use the **ChangeLayer** command to change the duplicated curve to the **3D Curves** layer.

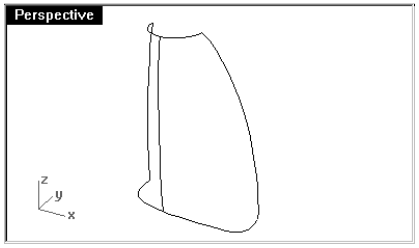
4 **Lock** the **3d Template Top** layer.

5 Use the **SetPt** command to move the duplicated circle to the same z-elevation as the top of the curves.



6 Use the **Split** command to split the circle at the top into an arc using the curves at the left and right as cutting edges.





To make a surface for the bottle with a sweep:

From the drawing these are the only curves we have available to define the shape, so we will use these curves directly to create the surface.

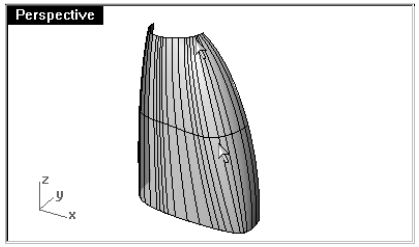
1 Change to the **Surfaces Sweep2** layer.

Notes:

2 Select the curves and use the **Sweep2** command *(Surface menu: Sweep 2 Rails)* to make a surface.

3 In the **Sweep 2 Rails Options** dialog box, click **OK**.

The surface has an unacceptable pinch near the top and bulge around the back of the surface.



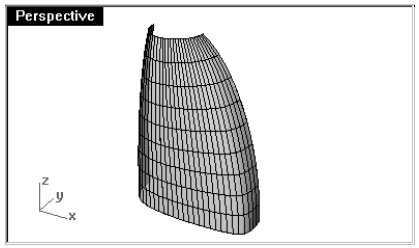
To make a surface for the bottle from a network of curves:

1 **Undo** the previous operation.

2 Change to the **Surfaces NetworkSrf** layer.

3 Select the curves and use the **NetworkSrf** command *(Surface menu: Curve Network)* to make the surface again.

It is better, but it still has a slightly pinched area at the back near the top.



To eliminate this defect, an additional curve needs to be created.

4 **Undo** the previous operation.

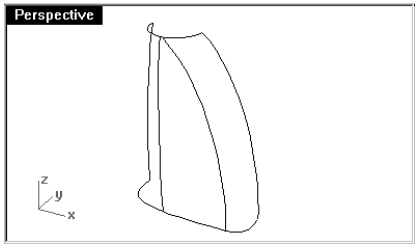
To make the surfaces for the bottle from the edge curves:

The area causing the most problems in the earlier attempts was the transition along the back, where the handle will be, as it goes from a rounded rectangular shape to an arc at the top. We will add an additional curve and make the surface from several surfaces.

1 Change to the **Surfaces EdgeSrf** layer.

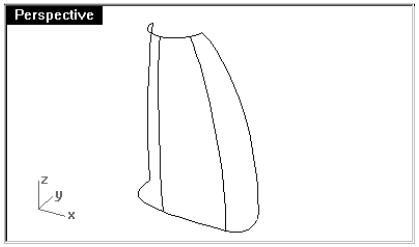
Notes:

2 **Copy** the back profile curve and place it using the **Knot** object snap on the knot just on the flat side of the base curve, near the corner.

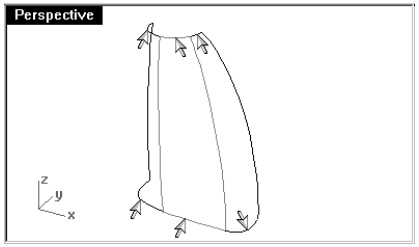


3 Drag the top point of this curve to the top circle approximately one-third of the way between the back profile curve and the side profile curve.

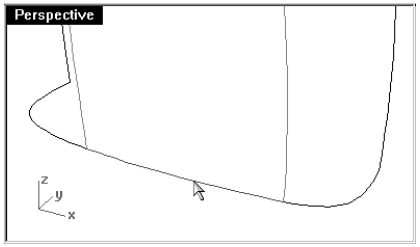
This gives a little more control over the surface, especially at the top edge.

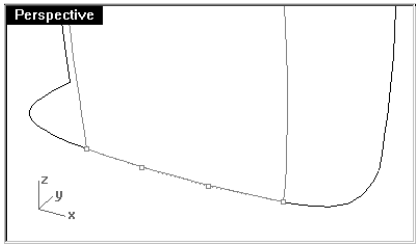


4 **Split** the top circle and the base curve with the vertical curves.



5 **Rebuild** *(Edit menu: Rebuild)* the middle base curve to degree 3 with 4 points.

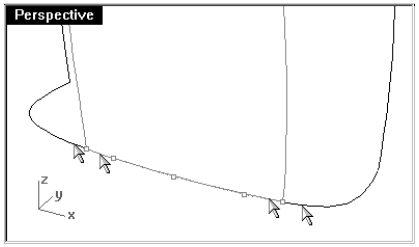




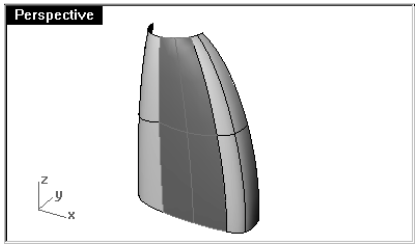
Notes:

Knot

6 Use the **Match** command *(Curve menu: : Curve Edit Tools > Match) to* match it to the other curves.

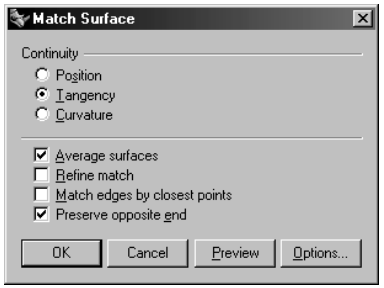


7 Use the **EdgeSrf** command *(Surface menu: Edge Curves)* to make the 3 surfaces.



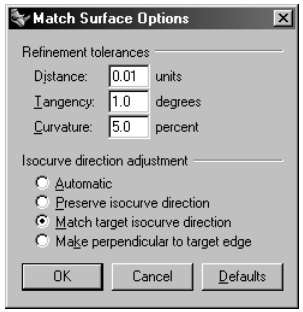
8 Use the **MatchSrf** command *(Surface menu: Surface Edit Tools > Match)* to match the surfaces at their edges for tangency.

9 In the **Match Surface** dialog box, check **Average Surfaces**, **Preserve opposite end**, and **Tangency**.

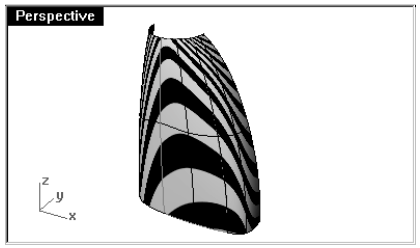


Notes:

10 In the **Match Surface Options** dialog box, experiment with the **Isocurve direction adjustments** and preview until you get the best surface.

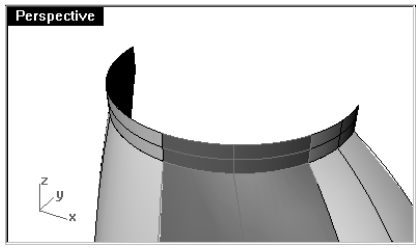


11 Use **Zebra** analysis *(Analyze menu: Analyze Surface > Zebra)* to evaluate the results.



When the surfaces are all matched, the top edges are likely to have come off the circle very slightly.

12 To restore these, extrude the top input curves up a short distance and use the **MatchSrf** command to match the top edges of the surfaces to the extrusions using **Position** only.

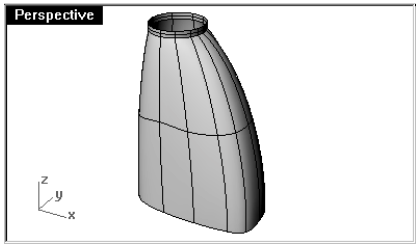


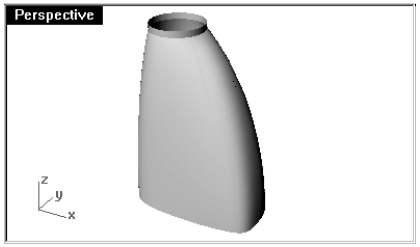
13 Select the surfaces and use the **Mirror** command to copy the surfaces for the other side of the bottle.

14 Use the **MatchSrf** command to match the edges for tangency.

Notes:

15 **Join** the surfaces together.





16 Check for naked edges.

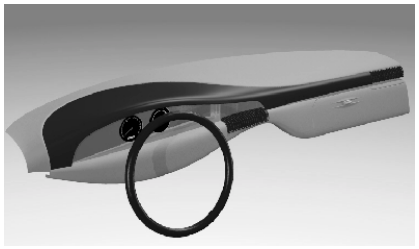
On your own:

Make the inset surface and the handle. Fillet the edges where indicated in the 2-D drawing. Included in the model directory is a finished bottle for your review.

Notes:

10 Sculpting

Designers can build a relatively undefined surface and then use a variety of transform and analysis tools to sculpt a surface in 3-D space in an intuitive and direct manner.



Curves can be placed approximately. The curves should be edited copies of a single original if possible. This ensures that they will be compatible when lofted, and create the simplest, most easily edited surface.

In the following exercise four curves have been created for you to use.

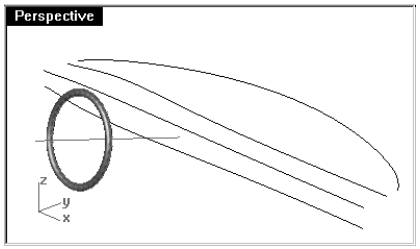
Notes:

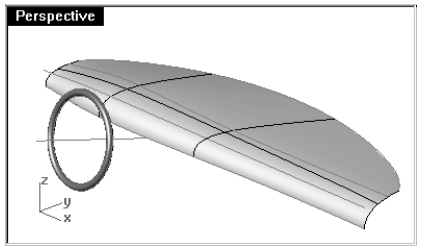
Exercise 19—Dashboard

1 Open the model **Dash.3dm**.

2 **Loft** the four curves together with the Loose option from the dropdown list. Using Loose creates the simplest possible geometry and is essential to creating a surface with this technique.

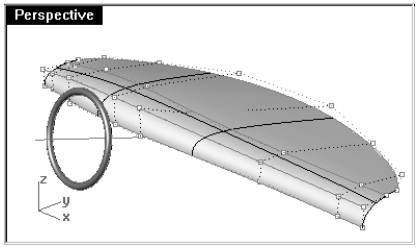
The surface will not touch the interior curves of the loft with this option, but it should be very smooth and clean looking.





3 Turn on points.

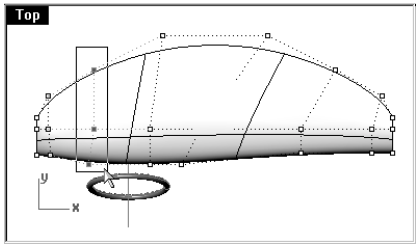
If you also turn on points for the input curves you will see that the point structure of the surface exactly matches that of the four curves.

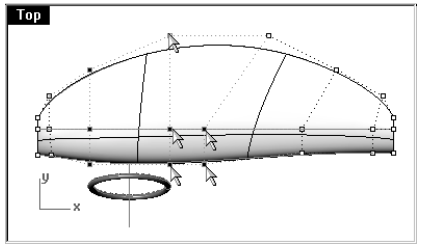


There is a steering wheel on a locked layer to help you get a sense of scale and positioning of any elements you might wish to add.

4 Turn off the **Curve** layer.

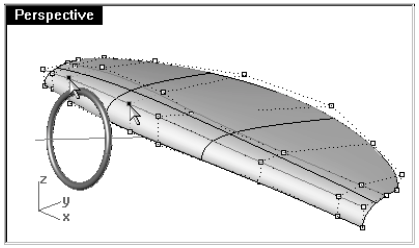
5 Turn on the points for the surface, use the **SetPt** command *(Transform menu: Set Points)* to align the groups of points in the x direction.





Notes:

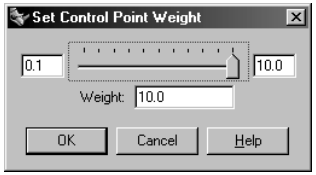
6 Select the points nearest the top edge of the steering wheel.



7 Start the **Weight** command *(Edit menu: Control Points > Edit Weight)*.

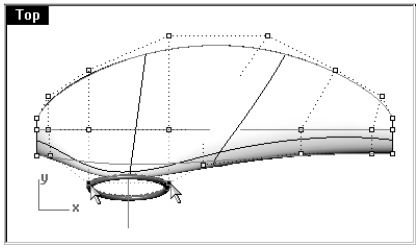
8 In the **Set Control Point Weight** dialog box, move the slider to the right.

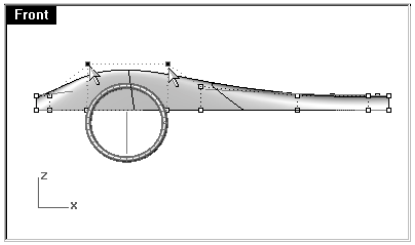
Changing the weight of some of the points gives you more or less local control over the surface nearest the points.



9 Use the **Nudge** keys to move the points in the **Top** and the **Front** viewports.

Notice the sharpness of the bulge closest to the points where weight was changed.

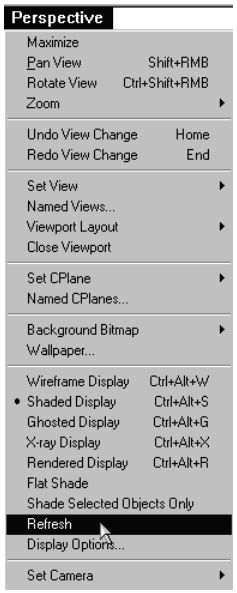


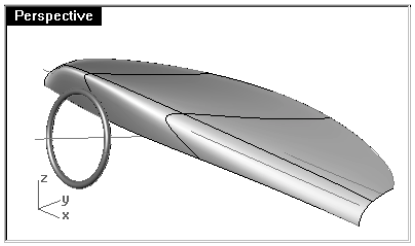


Notes:

Edit Control Point Weight

If the surface starts to look chunky, use the **Refresh** option from the **Viewport** menu. To activate the **Viewport** menu, right-click the viewport title. The **RefreshShade** command replaces the render meshes on the selected objects.

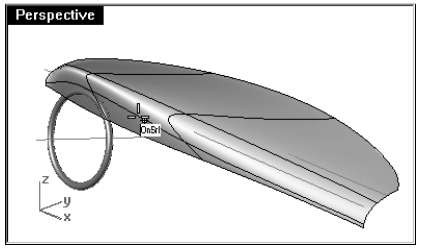




10 To get more localized control over the surface knots use the **InsertKnot** command *(Edit menu: Control Points > Insert Knot)* to add a row of points in the V-direction about half way between the bottom and the next row of points.

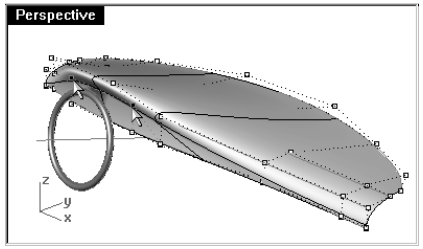
Knots can be added in the U- or V-direction or both with the **InsertKnot** command.

Wherever possible try to place new knots midway between the existing knot lines which are highlighted during the command.



Notes:

11 **Nudge** these points a little to make a slight indention.



Keep the surface as simple as possible throughout. Add knots sparingly and only when needed; that is, make sure the big curves in the surface are satisfactory before adding knots to contend with the more local ones. Once knots are added it is much more work to edit and fair the long sweeping parts of the curves than with fewer knots.

When you are satisfied with the overall shape of the surface, you can add details to make a more finished object.

The surface can be offset and trimmed as in the first illustration.

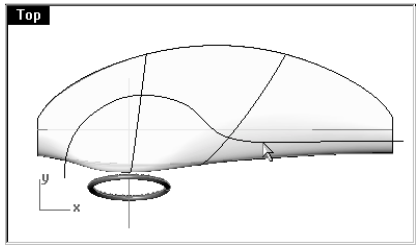
Best results are obtained when the surface has at least degree 3 in both directions. This can be checked with Object Properties.

Note that offsetting surfaces generally results in a surface of one step lower in internal continuity. Surfaces that are only G1 internally may result in surfaces that have G0 continuity; that is, they may have a kink in them. Although Rhino allows these surfaces, this can lead to problems downstream. For this reason, if you intend to offset surfaces, it is best where possible to create the initial surface from degree 3 or higher curves. These surfaces have at least G2 continuity so that offsetting them will result in at least G1 continuous surfaces. Changing the degree of a surface that has been created from degree 2 curves to at least degree 3 in both directions is not sufficient to ensure a G2 surface. Simply changing the degree after the fact does not improve internal continuity.

To make the offset surface:

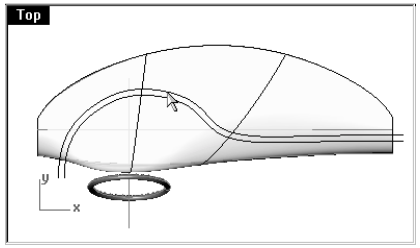
1 Change to the **Cutting Curves** layer.

2 Draw a curve that represents where you want to split the surface.

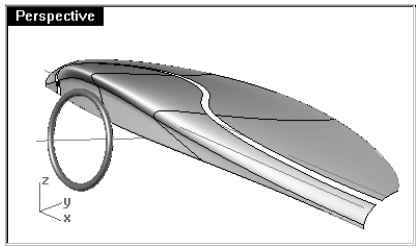


Notes:

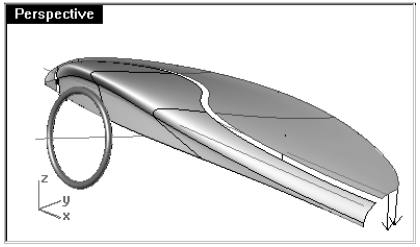
3 Use the **Offset** command *(Curve menu: Offset Curve)* to make a duplicate of the curve.

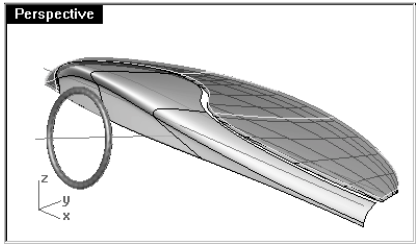


4 Use the **Trim** command *(Edit menu: Trim)* to trim the surface between the curves.

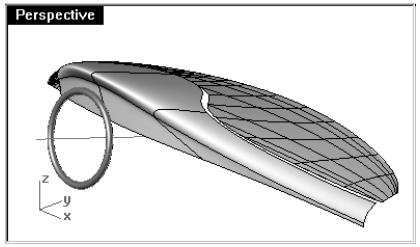


5 Use the **OffsetSrf** command *(Surface menu: Offset Surface)* to offset the surface.



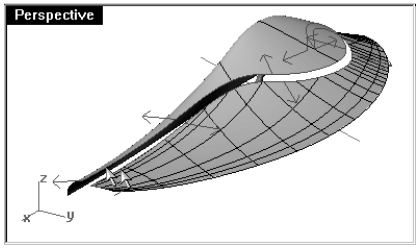


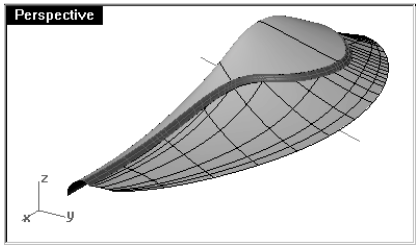
6 **Delete** the original surface.



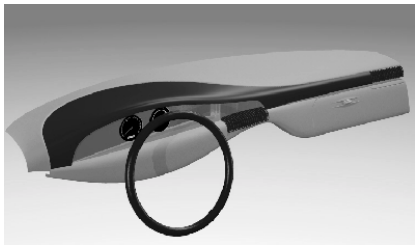
Notes:

7 Use the **BlendSrf** command *(Surface menu: Blend Surface)* to blend between the two surfaces.





8 Add details if time allows.



Notes:

11 Troubleshooting

Some Rhino operations can make “bad objects” under certain circumstances. Bad objects may cause failure of commands, shade and render badly, and export incorrectly.

It is good practice to use the **Check** *(Analyze menu: Diagnostics > Check)* or **SelBadObjects** *(Analyze menu: Diagnostics > Select Bad Objects)* commands frequently during modeling. If errors can be caught right away the objects can often be fixed more easily than if the bad part is used to make other objects.

If the goal is to create a rendering or a polygon mesh object, some errors can safely be ignored so long as they do not get in the way of building the model itself in later stages.

For objects which must be exported as NURBS to other applications such as engineering or manufacturing, it is best to eliminate all errors if possible.

The troubleshooting tools are used mostly for repairing files imported from other programs.

General strategy

The troubleshooting steps will be the same, whether or not the file was created in Rhino or another application. Over time, you will discover patterns of problems and develop procedures to fix them.

Although the techniques used vary greatly depending on the individual file, we will focus on a general strategy for repairing problem files

Start with a clean file

When possible, spending a little time in the originating application to export a “clean” file will save a great deal of clean up work later. Unfortunately, this is not always an option.

Notes:

Guidelines for Repairing Files:

1 **Open** the file.

2 **Hide** or delete extra data.

Use the **SelDup** command *(Edit menu: Select Objects > Duplicate Objects)* to find duplicate entities and delete them or move them to a “duplicate” layer in case you need them later.

3 **Hide** curves and points.

Use the **SelSrf** command *(Edit menu: Select Objects > Surfaces)* to select all the surfaces or the **SelPolysrf** command *(Edit menu: Select Objects > Polysurfaces)* to select all the polysurfaces, **Invert** *(Edit menu: Select Objects > Invert)* the selection, and move the selected items to another layer and turn it off. This will leave only surfaces or polysurfaces on the screen.

4 Check for bad surfaces.

The **Check** and **SelBadObjects** commands will determine if some of the surfaces in the model have problems in their data structures. Move these surfaces to a “bad surfaces” layer for later clean up. If the bad object is a polysurface, explode the polysurface and use the **SelBadObjects** command again.

5 Use **ShadedViewport** and visually inspect the model.

Does it look like you expected it would? Are there obviously missing surfaces? Do surfaces extend beyond where they should? The trimming curves needed to fix them may be on the “duplicate” layer.

6 Look at the **Absolute tolerance** setting in the **Document Properties** dialog box on the **Units** page.

Is it reasonable? Free-form surface modeling requires an intelligent compromise in modeling tolerance. Curves are fitted to neighboring curves within the specified modeling tolerance. The tighter the tolerance, the more complex these curves become and system performance suffers. There is no point in calculating high density curve fitting to tolerance values that are not supported by your down-stream manufacturing processes or by the precision of the input data.

7 **Join** *(Edit menu: Join)* the surfaces.

When joining, edges are joined if they fit within the specified modeling tolerance. If they are outside the tolerance, they are not joined. Joining does not alter the geometry. It only tags the edges as being close enough to be treated as coincident, then one edge is discarded.

Look at the results on the command line. Did you get as many polysurfaces as you thought you would? Sometimes there are double surfaces after importing an IGES file. Usually, one will be complete and the second one will be missing interior trims. When the **Join** happens, you have no control over which of the two surfaces it will select. If you suspect this has occurred, try joining two naked edges. If there is no nearby naked edge where one should be, **Undo** the join, and select for duplicate surfaces. Delete the less complete surfaces and try the **Join** again.

Notes:

Select Duplicates

Select Bad Objects

8 Check for naked edges.

Naked edges are surface edges that aren't joined to another surface. During the join process, the two edges were farther apart than the specified modeling tolerance. This may be from sloppy initial modeling, a misleading tolerance setting in the imported IGES file, or duplicate surfaces. If there are too many naked edges showing when you run the **ShowEdges** command *(Analyze menu: Edge Tools > Show Edges)*, consider undoing the **Join** and relaxing the absolute tolerance. It is likely that the original modeling was done to a more relaxed tolerance and then exported to a tighter tolerance.

Note: You can not improve the tolerance fitting between surfaces without substantial remodeling.

9 **Join** naked edges or remodel.

The joining of naked edges can be a mixed blessing. It is a trade off and may cause problems down-stream. If your reason for joining the edges is for later import into a solid modeler as a solid, or a meshing operation like making an STL file, using the **JoinEdge** command *(Analyze menu: Edge Tools > Join 2 Naked Edges)* will not generally cause any problems. If you will be cutting sections and most other "curve harvesting" operations, the sections will have gaps as they cross edges that were joined outside of tolerance. The gap to be spanned is displayed prior to joining. If the gap is less than twice your tolerance setting, you can proceed without worry. If the gap is too wide, consider editing or rebuilding the surfaces to reduce the gap. **Join** and **JoinEdge** do not alter the surface geometry. They only tag edges as being coincident within the specified tolerance.

10 Repair the bad surfaces

It's best to repair one bad surface at a time, and **Join** them into the polysurface as you go. In order of least destructive method to most radical, the problems that caused them to fail **Check** can be repaired by the following:

- Rebuild edges
- Detach trim curves and re-trim
- Rebuild surfaces (surfaces change shape)
- Replace surfaces - harvest edges from surrounding surfaces, cut sections through bad surfaces and build replacement surfaces from the collected curves.

If a surface fails **Check** reporting that a *tedge* (trim edge) is not G1, this minor error can be ignored, or the multiple span surface can be split at the knots.

Notes:

Show Naked Edges

Join 2 Naked Edges

11 Check for bad objects

Sometimes joining surfaces that pass check can result in a polysurface that fails check. Generally this is caused by tiny segments in the edge or trimming curves that are shorter than the modeling tolerance. Extract the adjoining surfaces, check them, use the **MergeEdge** command *(Analyze menu: Edge Tools > Merge Edge)* to eliminate these tiny segments, and join them back in. You are finished when you have a closed polysurface that passes **Check** and has no naked edges. As you are joining and fixing surfaces, it is generally a good idea to run **Check** from time to time as you work.

12 **Export**

Now that the model has been cleaned up and repaired, you can export it as IGES, Parasolid, or STEP for import into your application.

Exercise 20—Troubleshooting

To try these procedures:

1 **Open** the model **Check 01.3dm**

This file has a bad object.

2 Open the file **Check 02.igs**.

This file has several problems. It is representative of commonly found problems with IGES files. After repairing the bad object and trimming it, look for other objects that don't appear to be trimmed correctly.

Notes:

Merge Edge

Check

12 Polygon Meshes from NURBS Objects

Notes:

Although Rhino is a NURBS modeler, some tools are included to create and edit polygon mesh objects.

There is no best method that works for every situation. Downstream requirements are the most important considerations when determining which technique to use for meshing. If the mesh is going to be used for rendering, you will use different mesh settings than you would use for a mesh that will be used for manufacturing (machining or prototyping).

When meshing for rendering, appearance and speed are the most important considerations. You should strive to achieve a mesh with as few polygons as possible to get the look you require. The polygon count will affect performance, but too few polygons might not give you the quality you are after in the final rendering. Generally if it looks good, then you have the right setting.

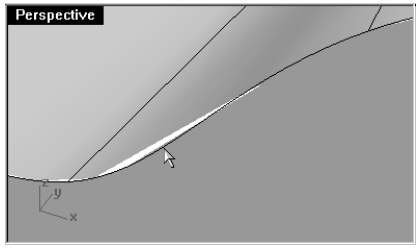
Meshing for manufacturing is an entirely different situation. You should try to achieve the smallest deviation of the mesh from the NURBS surface. The mesh is an approximation of the NURBS surface and deviation from the NURBS surface may be visible in the final manufactured part.

Exercise 21—Meshing

1 **Open** the model **Meshing.3dm**.

2 Set the **Perspective** viewport to **ShadedViewport** mode and inspect the curved edge between the surfaces.

There is a series of angular gaps where the background color shows through.



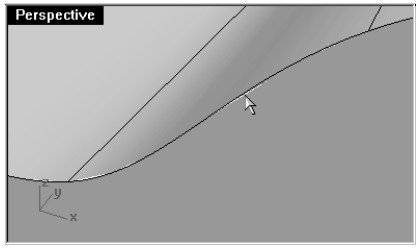
3 Press **Esc** to get back to a wireframe view.

The edges appear to be exactly coincident. The gaps you saw in the shaded view were due to the polygon mesh Rhino uses to create shaded and rendered views. The polygons are so coarse at the edges that they are clearly visible as individual facets.

4 In the **Document Properties** dialog box, on the **Mesh** page, click **Smooth & slower**.

5 Inspect the curved edge between the surfaces.

The overall rounded surface is smoother and cleaner looking but the edges still have gaps.

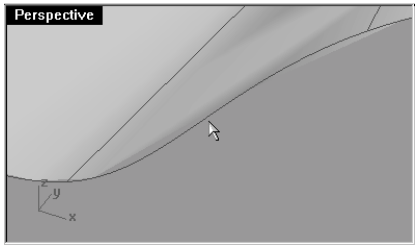


Although it is possible to use the **Custom** settings to refine the shaded mesh enough to eliminate the jagged edges, this will affect all render meshes in the model. This will increase the amount of time necessary to create meshes and may decrease the performance of shading and rendering to unacceptable levels. To eliminate the gaps without refining the mesh settings, join adjacent surfaces to each other.

Notes:

6 **Join** the three surfaces together.

The mesh is refined along each side of the joined edges so that they match exactly across the edge. This eliminates the gaps visible earlier.



Rhino saves these polygon meshes with the file in order to reduce the time needed to shade the model when it is reopened. These meshes can be very large and can increase the file size considerably.

7 From the **File** menu: **Save Small**.

This saves the file without the render meshes and the bitmap preview, to conserve disk file space.

Note: The meshes created by **Render** and shading modes on NURBS surfaces and polysurfaces are invisible in wireframe display, not editable, and cannot be separated from the NURBS object. Render meshes are controlled by settings in the **Document Properties** dialog box, on the **Mesh** page.

Creating polygon meshes

The meshes created by the **Mesh** command are visible and editable, and separate from the NURBS objects they were created from.

Rhino has two methods for controlling mesh density: **Simple Controls** or **Detailed Controls**. With **Simple Controls** a slider is used to roughly control the density and number of mesh polygons. With **Detailed Controls** you can change any of six settings and enable five check boxes to control the way the mesh is made.

The mesh is created in three steps based on the detailed criteria: initial quads, refinement, and adjustment for trim boundaries. These steps are not shown to you, it's all automatic.

Notes:

Save Small

In the following exercise we will discuss each of the six detailed controls and illustrate their influence on the model.

Maximum angle - The maximum angle between adjacent faces in the mesh. Smaller values result in slower meshing, more accurate meshes, and higher polygon count.

Maximum aspect ratio - The maximum ratio length to width of triangles/quads in the final mesh. Smaller values result in slower meshing and higher polygon count with more equilateral polygons.

Minimum edge length - Bigger values result in faster meshing, less accurate meshes and lower polygon count. Controls the minimum length of the sides of quads and triangles of the mesh.

Maximum edge length - Smaller values result in slower meshing and higher polygon count with more equally sized polygons. When **Refine** is selected, polygons are refined until all polygon edges are shorter than this value. This is also approximately the maximum edge length of the quads in the initial mesh grid.

Maximum distance, edge to surface - Smaller values result in slower meshing, more accurate meshes, and higher polygon count. When **Refine** is selected, polygons are refined until the distance from a polygon edge midpoint to the NURBS surface is smaller than this value. This is also approximately the maximum distance from polygon edge midpoints to the NURBS surface in the initial mesh grid.

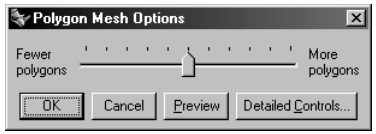
Minimum initial grid quads - Bigger values result in slower meshing, more accurate meshes and higher polygon count with more evenly distributed polygons.

To create a mesh using detailed controls:

1 Select the object.

2 Start the **Mesh** command *(Tools menu: Polygon Mesh > From NURBS Object)*.

The **Polygon Mesh Options** dialog box appears.

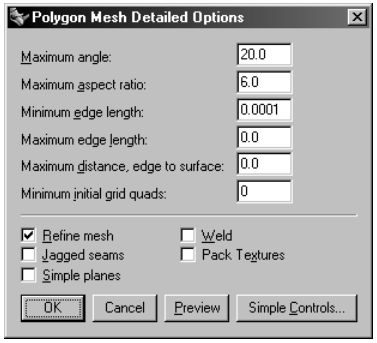


Notes:

Mesh from NURBS object

3 In the **Polygon Mesh Options** dialog box, click **Detailed Controls**.

The **Polygon Mesh Detailed Controls** dialog box appears. These settings are saved in the 3dm file or template.



4 In the **Polygon Mesh Detailed Options** dialog box set the following:

Check **Refine**.

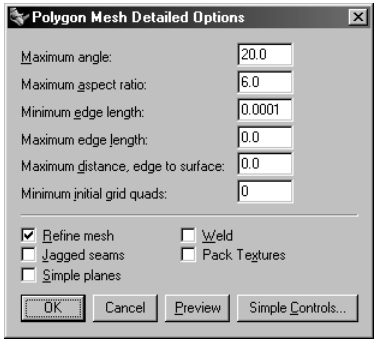
Uncheck **Jagged seams**.

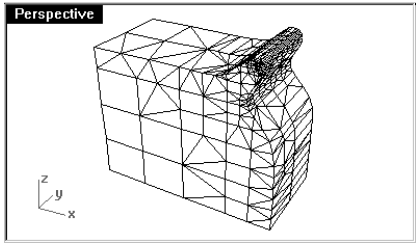
Uncheck **Simple planes**.

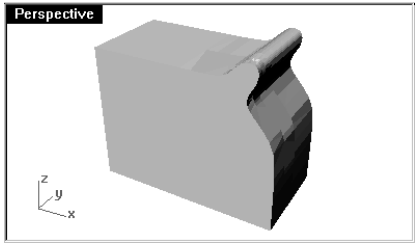
Uncheck **Weld**.

Click **OK**.

A mesh is created using the default settings.







5 **Hide** the original polysurface and use the **Flat Shade** display mode to view the output.

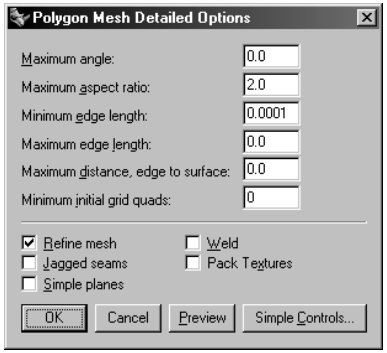
The **Flat Shade** display mode shows what the model would look like if it was output for prototyping or machining at this mesh density.

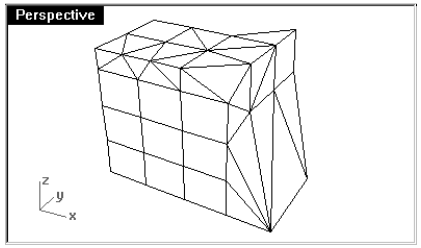
Notes:

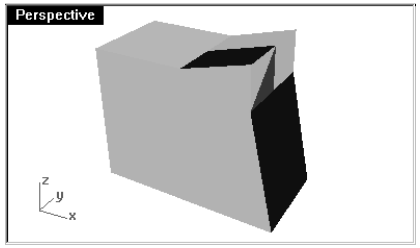
Flat Shade

6 **Undo** the previous operation, repeat the **Mesh** command, and then make the following changes in the **Polygon Mesh Detailed Controls** dialog box.

Note the changes in polygon count, the shape of the mesh, and the quality of the flat-shaded mesh.

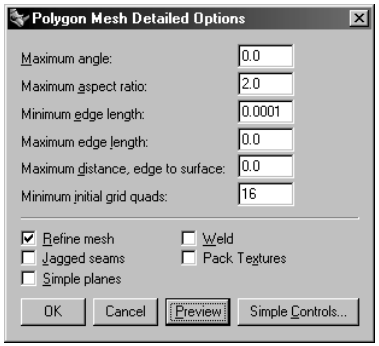


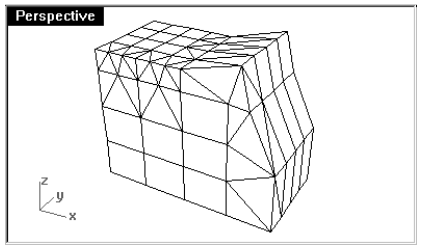


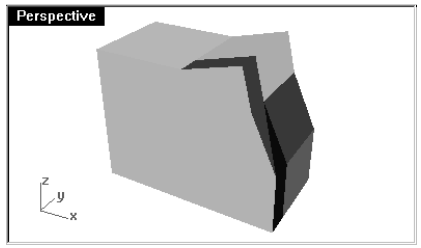


7 **Undo** the previous operation, repeat the **Mesh** command, and then make the following changes in the **Polygon Mesh Detailed Controls** dialog box.

Note the changes in polygon count, the shape of the mesh, and the quality of the flat-shaded mesh.



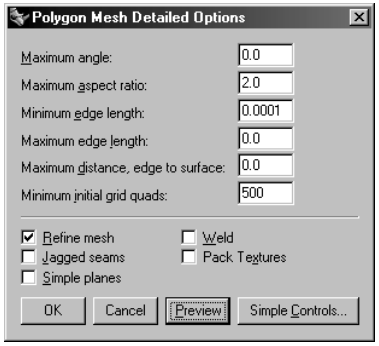


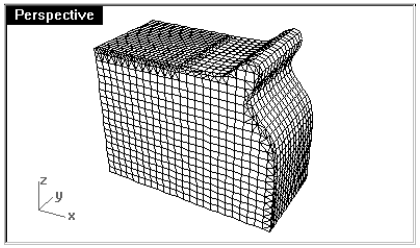


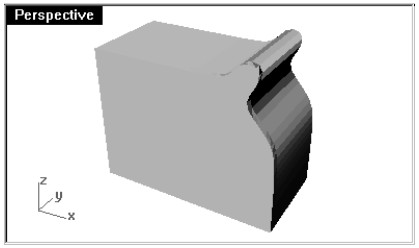
Notes:

8 **Undo** the previous operation, repeat the **Mesh** command, and then make the following changes in the **Polygon Mesh Detailed Controls** dialog box.

Note the changes in polygon count, the shape of the mesh, and the quality of the flat-shaded mesh.

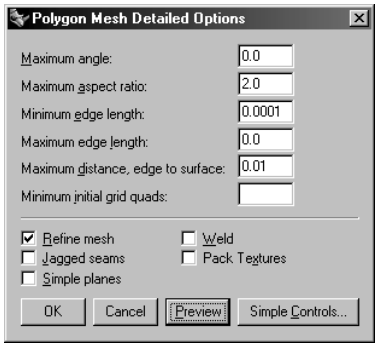


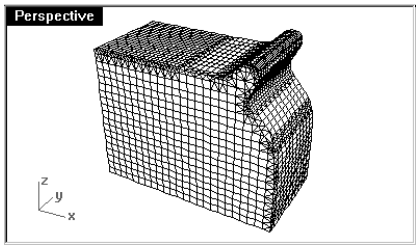


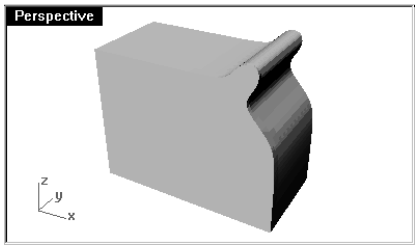


9 **Undo** the previous operation, repeat the **Mesh** command, and then make the following changes in the **Polygon Mesh Detailed Controls** dialog box.

Note the changes in polygon count, the shape of the mesh, and the quality of the flat-shaded object.







Notes:

Part Three: Rendering

13 Rendering with Rhino

With Rhino, creating design renderings of Rhino models is easy. Simply add materials, lights, and render.

There are several controls in the basic Rhino renderer that allow you to create some interesting special effects.

In the following exercise we will render with and without isocurves, adjust colors, transparency, and ambient light to create images with special effects.

Exercise 22—Rhino Rendering

1. **Open** the model **Finished Detergent Bottle.3dm**.
2. From the **Render** menu, click **Current Renderer**, then click **Rhino**.
3. From the **Render** menu, click **Properties**.

   The model has lights set up on a Lights layer that is turned off.
4. In the **Document Properties** dialog box, on the **Rhino Render** page, check **Use lights on layers that are off**.
5. Select the bottle and use the **Properties** command, on the **Material** page, to assign it a color and a glossy plastic reflective finish.
6. Select the cap and use the **Properties** command, on the **Material** page, to assign it a color and a glossy plastic reflective finish.

Notes:

7 **Render** the **Perspective** viewport.

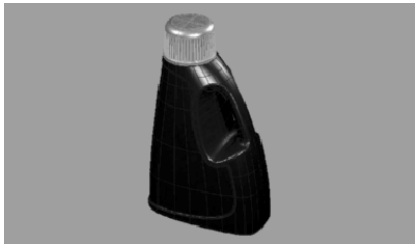
To render with isocurves displayed:

1 Start the **DocumentProperties** command.

2 In the **Document Properties** dialog box, on the **Rhino Render** page, check **Render Curves and Isocurves**.

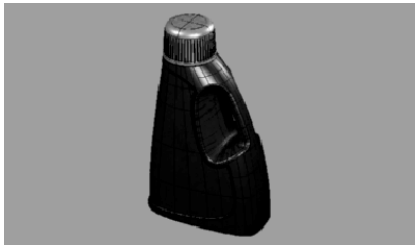
3 **Render** the **Perspective** viewport.

The wire color is the same as the layer color because the object's wire color is set to **By Layer**.



4 Use the **Properties** command, on the **Object** page, to change the color to black, then **Render** the **Perspective** viewport.

The objects are rendered with black isocurves.

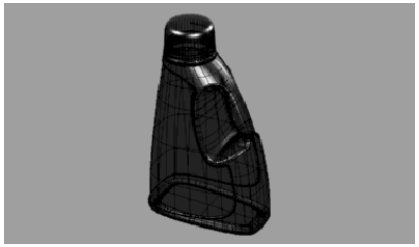


Notes:

To render a transparent material with isocurves displayed:

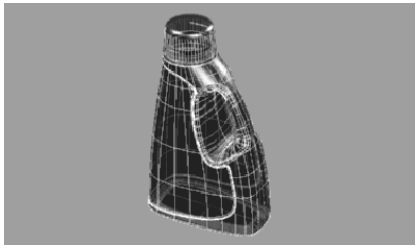
1 Use the **Properties** command, on the **Material** page, to change **Transparency** to **90**, then **Render** the **Perspective** viewport.

The objects are rendered with black isocurves and the material is transparent.



2 Use the **Properties** command, on the **Object** page, to change the **Basic** color to white, then **Render** the **Perspective** viewport.

The objects are rendered with white isocurves and the material is transparent.

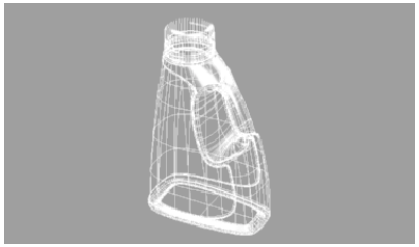


3 Use the **Properties** command, on the **Material** page, to change the **Basic** color to white.

4 Start the **DocumentProperties** command.

5 In the **Document Properties** dialog box, on the **Rhino Render** page, change the **Ambient** color to white, then **Render** the **Perspective** viewport.

The objects are rendered with white wires, but the wires on the back faces are a different tone.



6 Experiment with these adjustments to get the desired effect.

7 Turn on the Lights layer and adjust the properties of the lights for more subtle changes.

Notes:

14 Rendering with Flamingo

Notes:

With Flamingo, creating presentation images of Rhino models is easy. Simply add materials, lights, environment, and render.

With Flamingo's powerful Material Editor, you can assign any combination of color, reflectivity, transparency, highlight, multiple bitmaps, and multiple procedural patterns to one material.

In the following exercise we will add environment settings, add materials and lights, create custom materials, edit materials, add decals to objects, and render a scene.

Exercise 23—Rendering

- **Open** the model **Mug.3dm**.

To set Flamingo as the current renderer:

- From the Rhino **Render** menu, click **Current Renderer**, and then click **Flamingo Raytrace**.

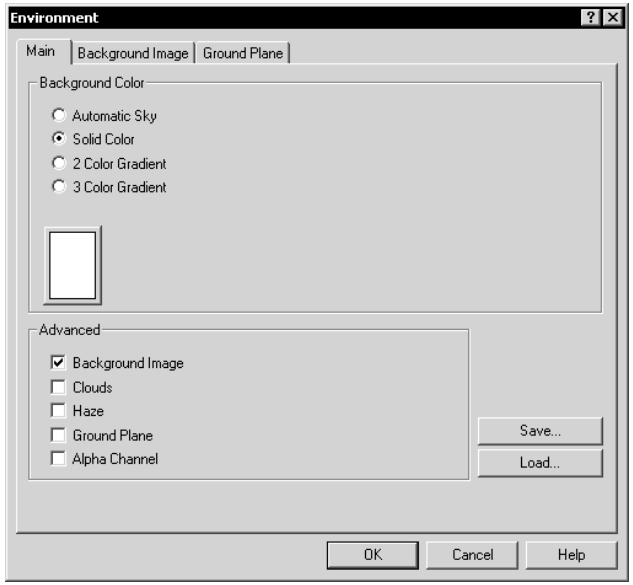
To set up the rendering properties:

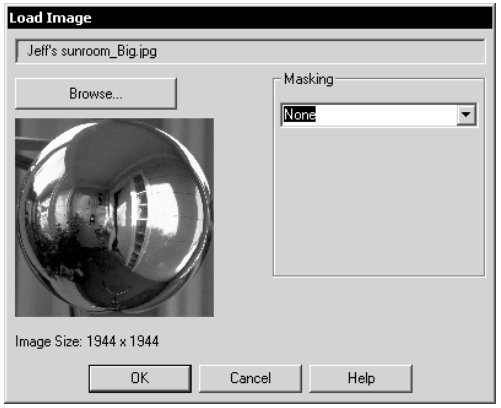
The rendering properties include environment settings, sun light, plant season, render, and ambient light settings.

1 From the **Raytrace** menu, click **Properties**.

2 In the **Document Properties** dialog box, on the **Flamingo** tab, click **Environment** to change how the background appears or to add certain special effects such as an infinite ground plane or haze.

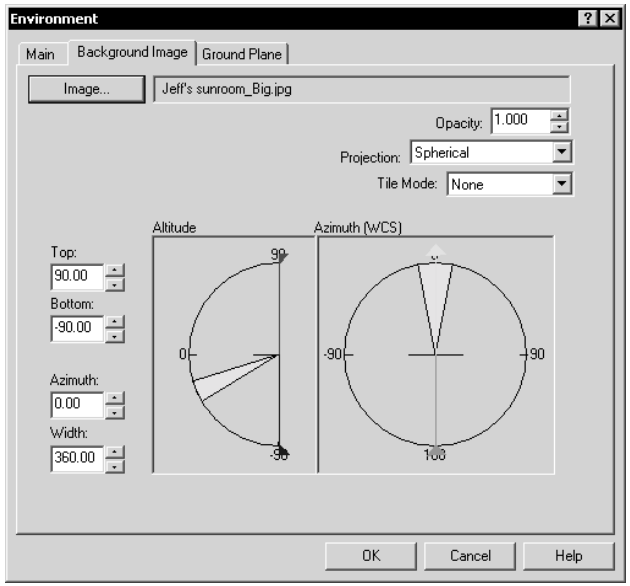
3 In the **Environment** dialog box, check **Background Image**, and select **Jeff's Sunroom_Big.jpg**.





Notes:

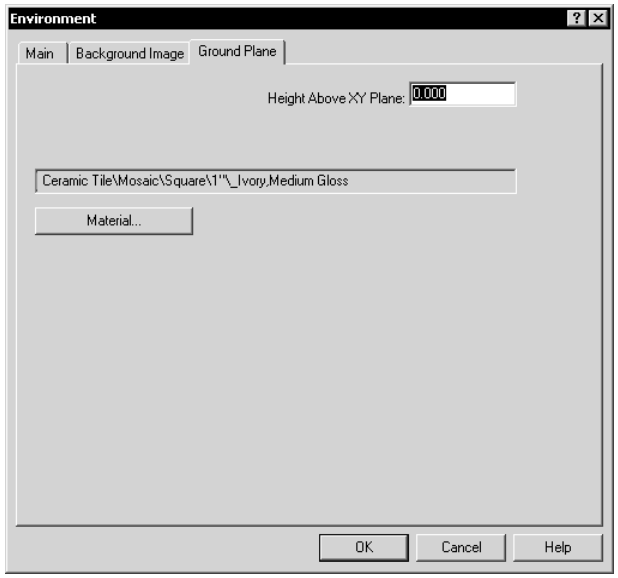
4 In the **Background Image** dialog box, change the **Projection** to **Spherical**, then click on the **Main** tab.



5 In the **Environment** dialog box, **Main** tab, check **Ground Plane**.

Notes:

6 In the **Ground Plane** tab, click **Material**, and from the Flamingo library select **Ceramic Tile, Mosaic, Square 1",_ Ivory,Medium Gloss**, then click **OK** in all of the dialog boxes.



7 From the **Raytrace** menu, click **Render** to render the **Perspective** viewport.

To assign Flamingo materials to layers:

1 Open the **Edit Layers** dialog box.

2 In the **Edit Layers** dialog box, select the **Floss Blister** layer, and click in its **Material** column.

3 In the **Material Properties** dialog box, under **Assign By**, click **Plug-in** to use Flamingo materials.

4 Click **Browse** to access the Flamingo material libraries.

5 From the **Material Library** dialog box, in the Mug library select **Blister Plastic**, and click **OK**.

6 In the **Material Properties** dialog box, click **OK**.

7 In the **Edit Layers** dialog box, click **OK**.

Notes:

Add lights

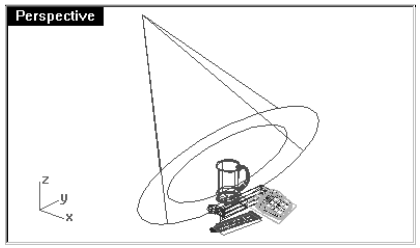
So far we have used the default lighting in Flamingo. This invisible light comes from over the viewer's left shoulder. It is enough to illuminate the model and to give you a starting point. The default light is on only if no other lights are on in the scene and it cannot be modified. In order to control the lighting, we are going to add our own lights.

To add lights:

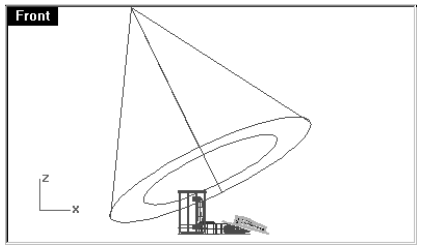
1 From the **Render** menu, click **Create Spotlight**.

2 At the prompts, draw a large spotlight that shines on the scene from the front and slightly above as shown below.

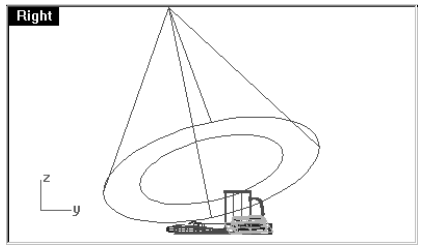
Use elevator mode, or turn on the spotlight's control points and drag them to move the light into position.



Spotlight, perspective view.



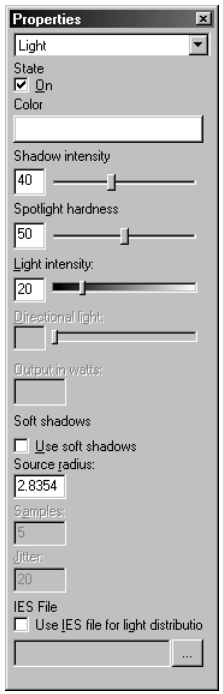
Spotlight, front view.



Spotlight, right view.

Notes:

3 Adjust the properties of the light as shown below:



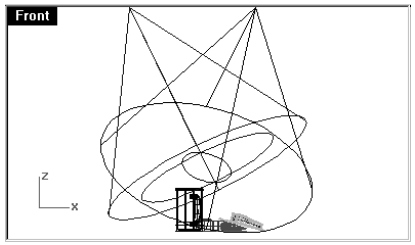
4 From the **Raytrace** menu, click **Render**.

This makes a nicer image, but two or three lights in a scene improve the rendering. We are going to add another light to create highlights on the mug.

To add a second light:

1 Select the first light.

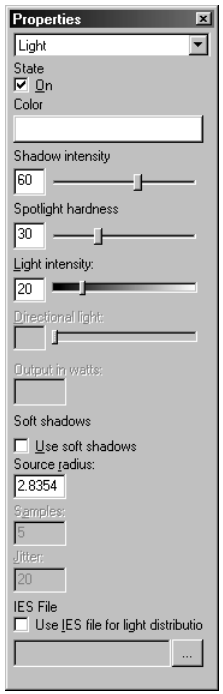
2 In the **Top** viewport, **Mirror** the light across the vertical axis.



Spotlight, front view.

Notes:

3 Adjust the properties of the light as shown below:



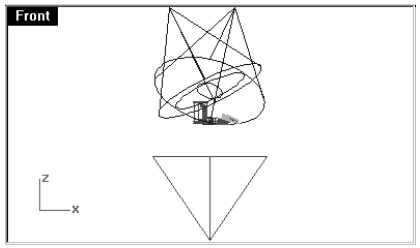
4 From the **Raytrace** menu, click **Render**.

To add a third light:

1 From the **Render** menu, click **Create Spotlight**.

2 At the prompts, draw a large spotlight that shines on the scene from the below.

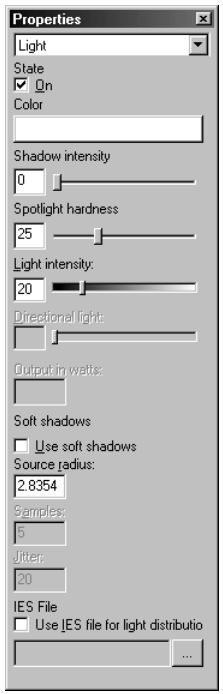
This light will be used to add a little light to the underside of the toothpaste tube and the floss packet.



Spotlight, front view.

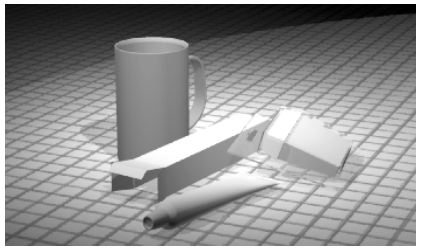
Notes:

3 Adjust the properties of the light as shown below:



It is important to turn the shadow intensity to 0 so that the light will penetrate through the ground plane.

4 From the **Raytrace** menu, click **Render**.



To make a material from scratch and assign it to a layer:

1 Open the **Edit Layers** dialog box.

2 In the **Edit Layers** dialog box, select the **Mug** layer, and click in the **Material** column.

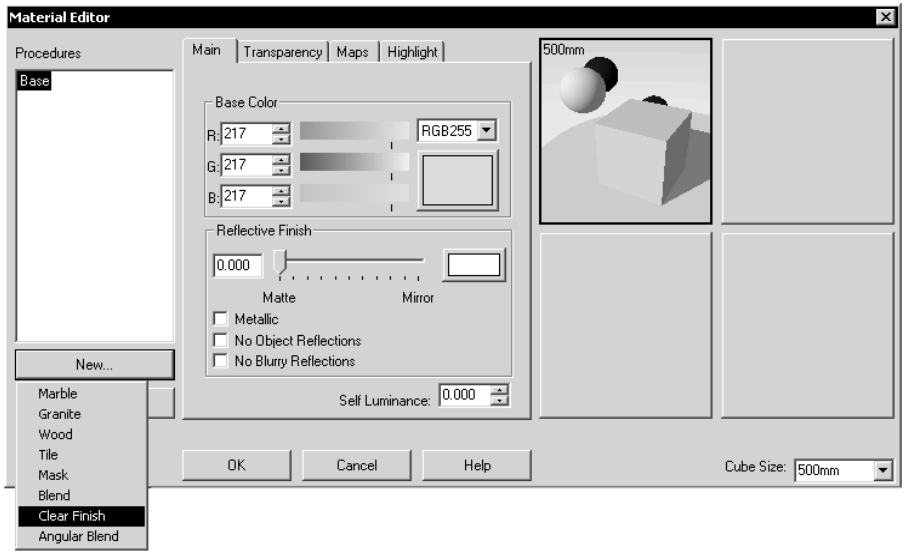
3 In the **Material Properties** dialog box, under **Assign By**, click **Plug-in** to use Flamingo.

Notes:

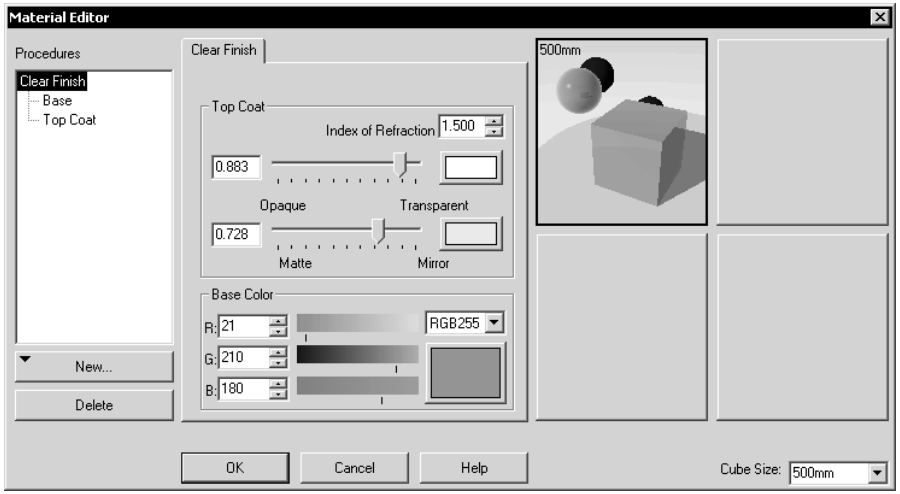
4 Click **Browse** to access the Flamingo material libraries.

5 In the **Material Library** dialog box, click **Material,** then click **New,** then click **Default Gray**.

6 In the **Material Editor** dialog box, in the **Procedures** area, click **New**, then click **Clear Finish** to give the material a multi-layer finish.

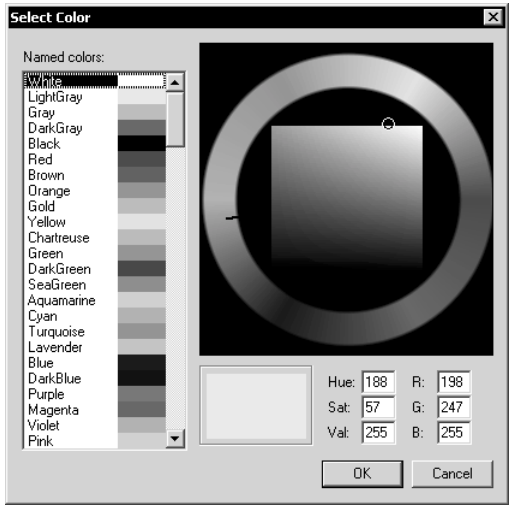


7 In the **Material Editor** dialog box, in the **Procedures** tree, select **Clear Finish**, and then change the **Base Color** to green (R=21, G=210, B=180).

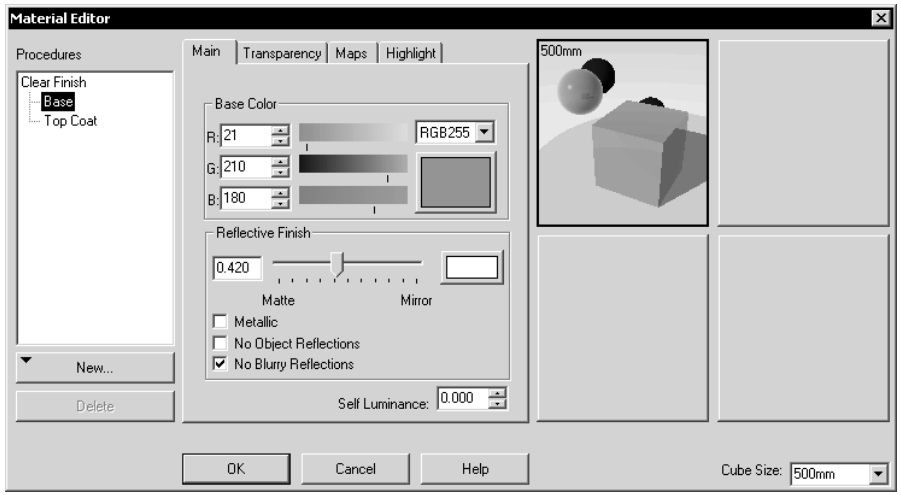


Notes:

8 Add some color to the **Top Coat Mirror** color (R=198, G=247, B=255) to add some realism.



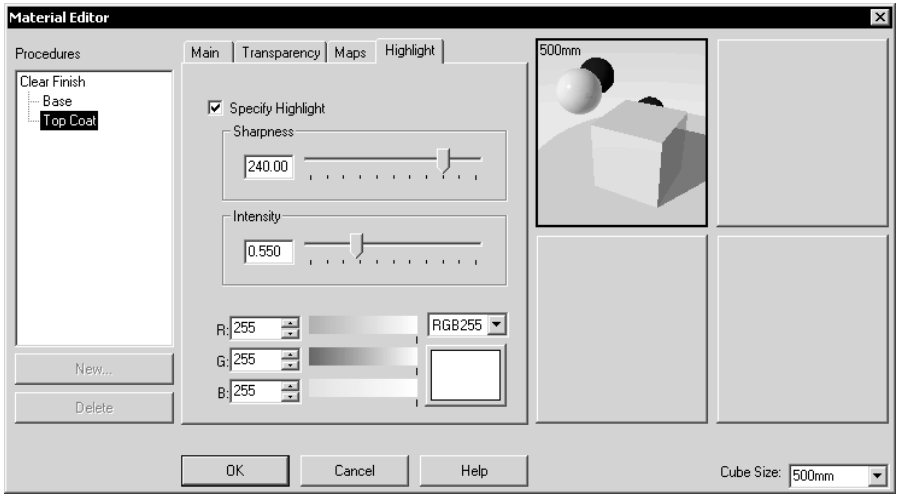
9 In the **Material Editor** dialog box, in the **Procedures** tree, highlight **Base** and move the **Reflective Finish** slider toward the middle or type in a value of **0.420**.



Notes:

10 In the **Material Editor** dialog box, in the **Procedures** tree, highlight **Top Coat**.

11 On the **Highlight** tab, check **Specify Highlight**, and change the **Sharpness** to **240** and the **Intensity** to **0.550**.



12 Save the material to the Mug Library. Name it **Green Ceramic**.

13 In the **Edit Layers** dialog box, click **OK** to close all of the dialog boxes.

14 From the **Raytrace** menu, click **Render**.

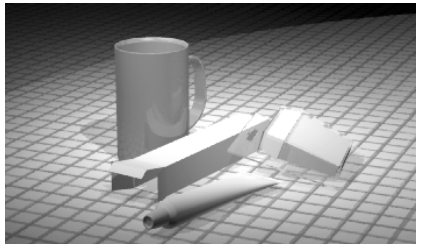


Image and bump maps

Instead of simply using color for your material you can use an image of a material. You can scan photographs and real objects like wallpaper and carpet, create patterns in a paint program, or use images from libraries of textures from other renderers, or other sources of bitmap images.

Image mapping uses bitmap images to add detail to the material. You can use images to alter many attributes of the material's surface including its color pattern and apparent three-dimensional surface quality (bump). Procedural bumps add a random roughness or knurled quality to the surface.

Notes:

To create a new material with an image map and assign it to an object:

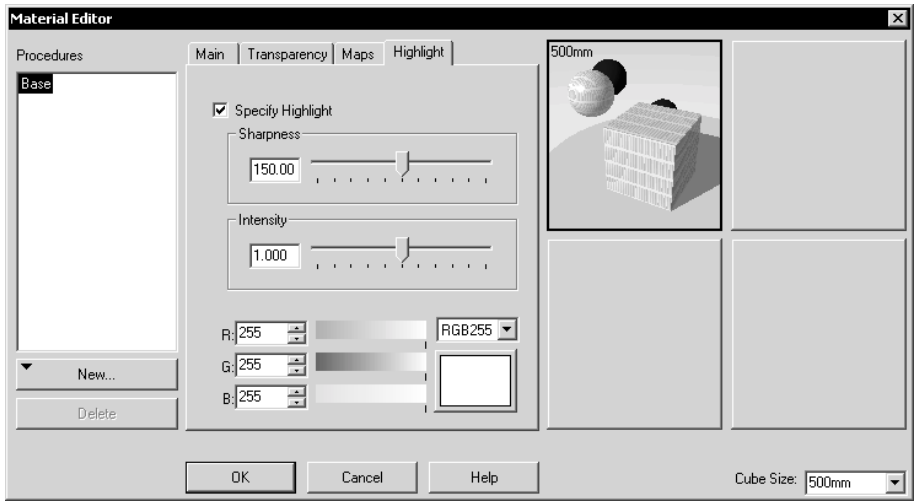
1 Select the cap on the toothpaste tube.

2 From the **Edit** menu, click **Properties**.

3 On the **Material** tab, click **Plug-in**, and then click **Browse** to access the Flamingo material libraries.

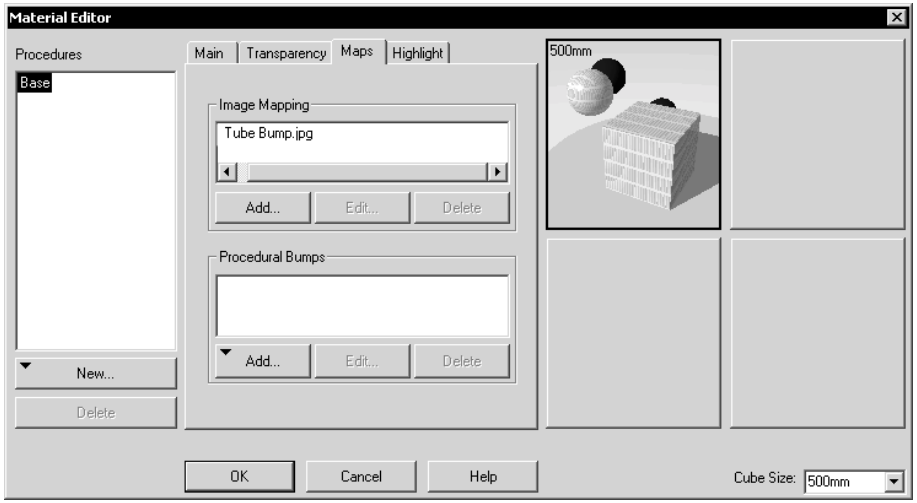
4 Select **Flamingo/Plastics, White, Smooth** to use as a template for the new material.

5 In the **Material Editor** dialog box, on the **Highlight** tab, check **Specify Highlight**, adjust the **Sharpness** and **Intensity**.



Notes:

6 In the **Material Editor** dialog box, on the **Maps** tab, under **Image Mapping**, click **Add**.



7 In the **Select Bitmap** dialog box, select **Tube Bump.jpg**.

The **Image Mapping** dialog box appears.

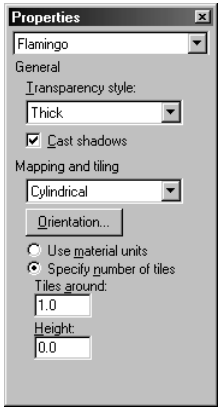
8 On the **Main** tab, click **OK**.

9 In the **Material Editor** dialog box, click **OK**.

10 In the **Save Material As** dialog box, save the material as **Toothpaste Cap** in the **Mug** material library.

11 In the **Material Library** dialog box, click **OK**.

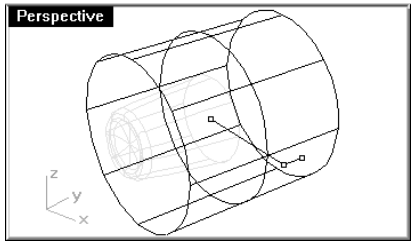
12 In the **Properties** dialog box on the **Flamingo** page, in the **Material mapping and tiling** dropdown, select **Cylindrical**, then set the number of tiles and the height.



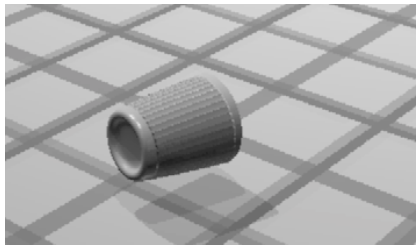
Notes:

13 On the **Flamingo** tab, click the **Orientation** button.

14 Orient the mapping cylinder to the center of the cap, then adjust the position by moving the drag points to adjust it so that it roughly aligns with the cap.



15 From the **Render** menu, click **Render**.



Decals

A decal is the method Flamingo uses to apply an image bitmap to a specific area of an object.

The decal mapping type tells Flamingo how to project the decal onto your object. The four mapping types, planar, cylindrical, spherical, and UV, are described below.

Planar

The planar mapping type is the most common mapping type. It is appropriate when mapping to flat or gently curved objects.

Cylindrical

The cylindrical mapping type is useful for placing decals onto objects that curve in one direction, such as labels on wine bottles.

The cylindrical projection maps the bitmap onto the mapping cylinder with the bitmap's vertical axis along the cylinder's axis, and the horizontal axis around the cylinder, like a wine bottle label.

Notes:

Spherical

The spherical mapping type is useful for placing images onto objects that curve in two directions. The spherical projection maps the bitmap onto the mapping sphere with the bitmap's vertical axis (height), curving from pole to pole, and the horizontal axis curving around the equator.

Initially the mapping sphere's equator is assumed to be parallel to the current construction plane, and the sphere's axis is parallel to the construction plane z-axis. Later you can modify its orientation.

UV

UV mapping stretches the image to fit the whole surface. The U- and V-directions of the surface determine which direction the map is applied. There are no controls.

UV mapping works well for organic shapes, hair, skin, and plant structures.

On some surfaces and polysurfaces, only parts of the image may appear in the rendering. UV mapping stretches the bitmap over the whole UV range of the surface. If some of that range has been trimmed away, the corresponding parts of the bitmap will not be visible.

To map a decal with planar projection:

1 Select the toothpaste box.

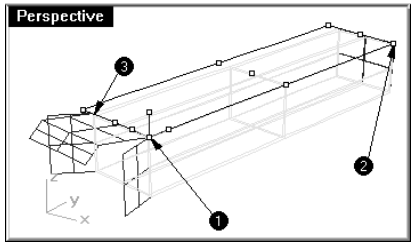
2 From the **Edit** menu, click **Object Properties**.

3 In the **Properties** dialog box, on the **Decals** page, click **Add**, select the **Minty Green-Box Upper.jpg**, then **Open**, and then click **Planar** and **OK**.

4 At the prompts, using object snaps, pick locations for the decal **Location** (1), the **Width** (2), and **Height** (3) direction of the decal.

These three points define the decal plane's location and extents. The decal plane must lie on or behind the surface of the object. The decal projects up from the decal plane. Portions of the surface that lie behind the decal plane will not show the decal.

After the decal is placed, you can click the control points on the decal control wireframe to move, rotate, or stretch the decal.



Notes:

5 Press **Enter** or right-click to set the location.

6 Continue to place bitmaps on the sides and ends of the box.

The flaps will require some additional controls.

To add a planar decal with masking:

1 Select the top end flap of the toothpaste box.

2 From the **Edit** menu, click **Object Properties**.

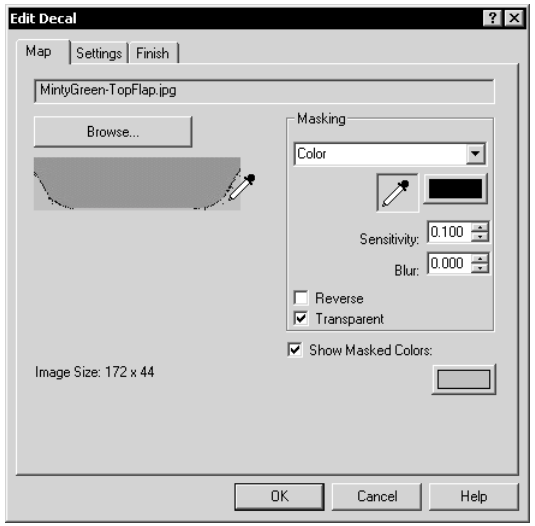
3 In the **Properties** dialog box, on the **Decals** page, click **Add**, select the **Minty Green-TopFlap.jpg**, and then click **Planar**.

Notes:

4 At the prompts, pick locations for the decal **Location**, the **Width**, and **Height** direction of the decal.

5 In the **Edit Decal** dialog box, on the **Map** tab, in the **Masking** dropdown, click **Color**.

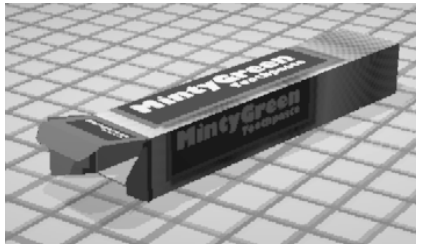
Use the dropper to select the black part of the image. Check the **Transparent** box.



The part that is black in the bitmap will appear as transparent in the rendered image.

6 Continue to place bitmaps on the sides and ends of the flaps.

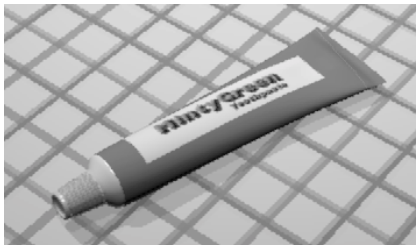
7 From the **Raytrace** menu, click **Render**.

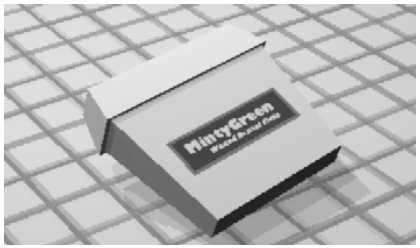


Notes:

8 Use planar mapping to put the decals on the floss container and the toothpaste tube.

The magenta rectangles were created to assist with placement of the decals.





To map a decal with cylindrical projection

The circle of the mapping cylinder is initially parallel to the current construction plane, and the cylinder's axis is parallel to the construction plane z-axis.

1 Select the mug.

2 Start the **Properties** command *(Edit menu: Object Properties...)*.

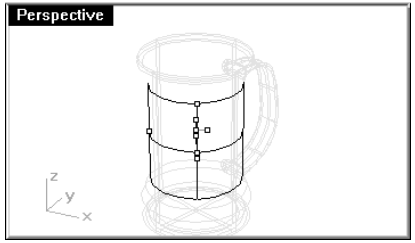
3 In the **Properties** dialog box, on the **Decals** page, click **Add**.

4 Select the **Sailboat-002.jpg**.

5 In the **Decal Mapping Style** dialog box, click **Cylindrical**.

6 At the prompts, pick locations for the **Center of cylinder** and a **Radius** or **Diameter** for the decal.

The controls then let you click the control points on the decal control wireframe to move, rotate, or stretch the decal cylinder.

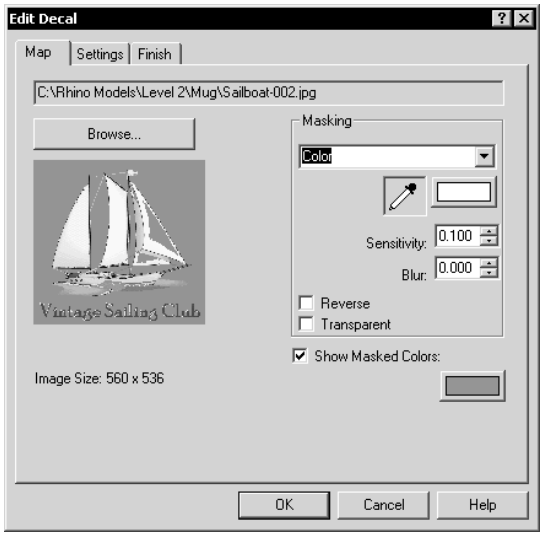


Notes:

Notes:

7 Press **Enter** or right-click to set the location.

The **Edit Decal** dialog box appears, change the decal's visual properties as indicated below.



8 From the **Raytrace** menu, click **Render**.

9 Turn on the toothbrush layers.

10 Adjust the materials settings and lighting as needed to get the desired final results.