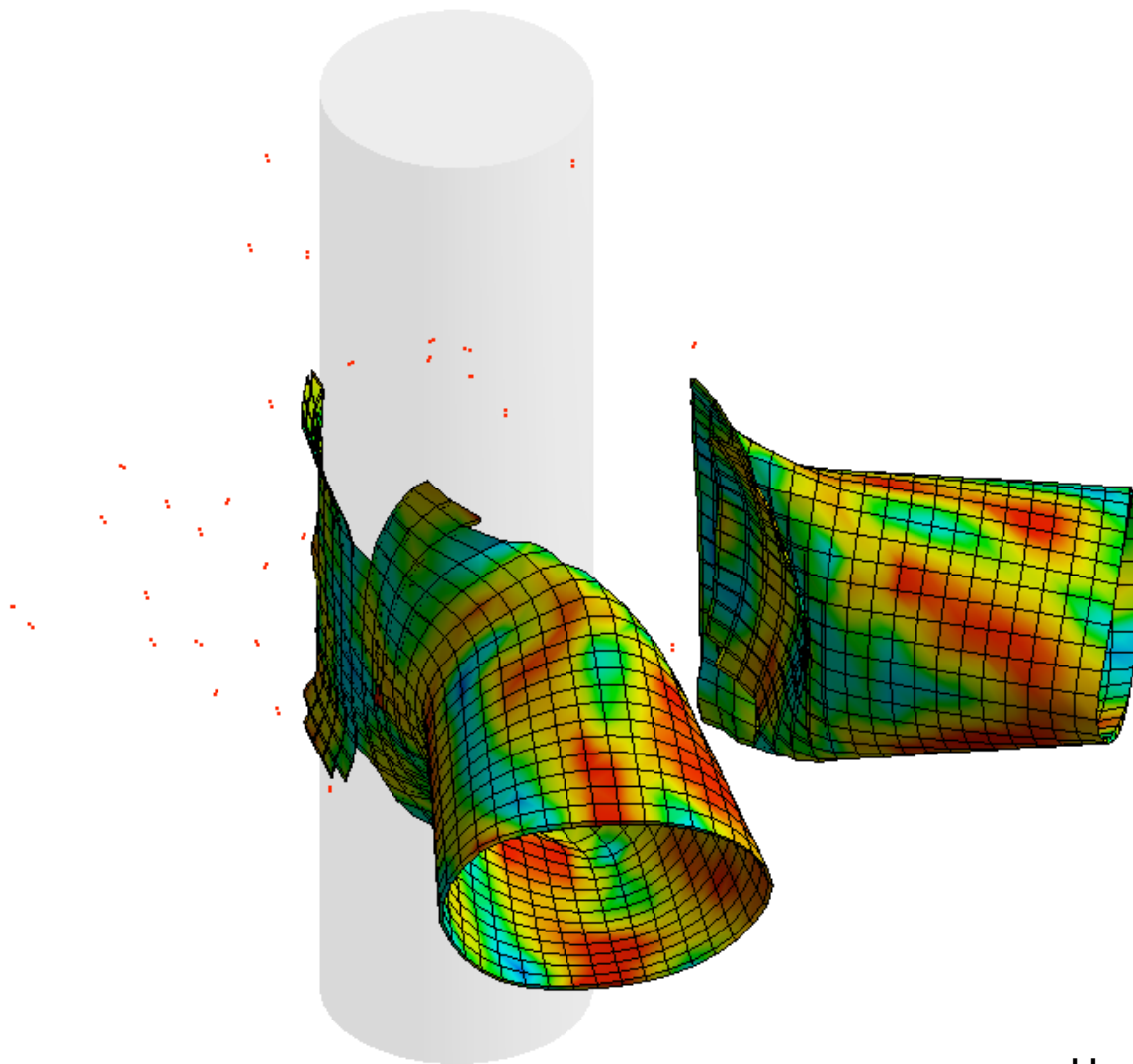# Finite Element Simulations

with ANSYS® Workbench 17

Theory, Applications, Case Studies

Huei-Huang Lee

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Chapter 2

Sketching

A complex 3D geometry can be viewed as a series of adding/removing material from simple solid bodies. Each solid body is often created by first drawing a 2D sketch, and then using the sketch to generate a 3D solid body with tools such as **Extrude**, **Revolve**, **Sweep**, **Skin/Loft**, etc.

Purpose of This Chapter

This chapter provides exercises for the students so that they can be acquainted with sketching using **DesignModeler**. Profiles of several mechanical parts are sketched in this chapter. Each sketch is then used to generate a 3D model using either **Extrude** or **Revolve**. The use of these 3D tools is so trivial that we may focus on 2D sketching techniques.

About Each Section

Each mechanical part will be completed in a section. Section 2.1 sketches a cross section of W16x50; the cross section is then extruded to generate a 3D beam. Section 2.2 sketches a triangular plate; the sketch is then extruded to generate a 3D solid model. Section 2.3 does not provide a hands-on case. Rather, it overviews the sketching tools in a systematic way, attempting to complement what was missed in the first two sections. Sections 2.4, 2.5, and 2.6 provide three additional exercises, in which we'll purposely leave out some steps for the students to figure out the details.
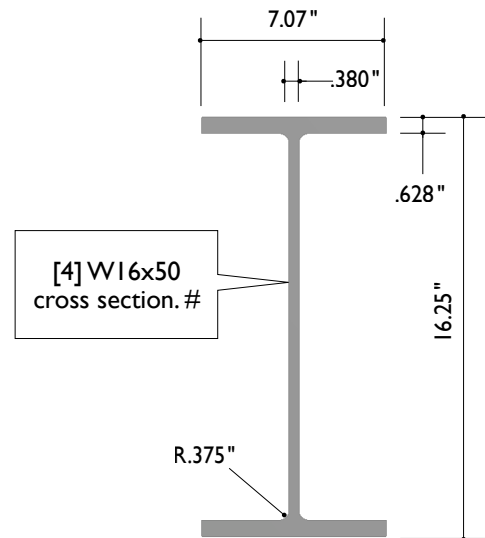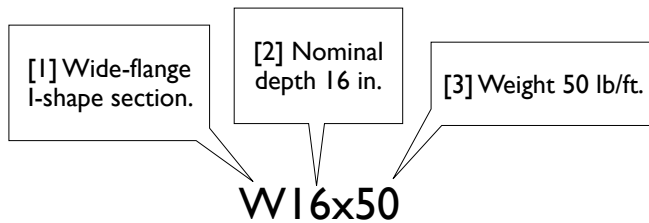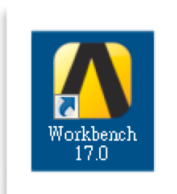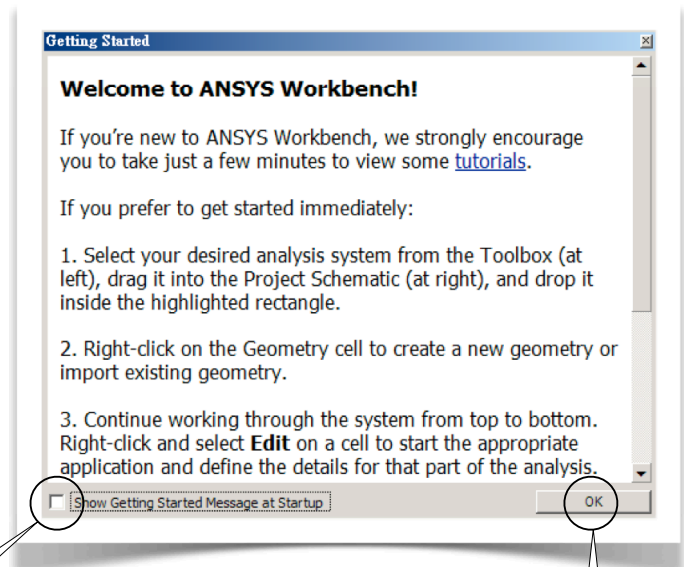
Section 2.1

W16x50 Beam
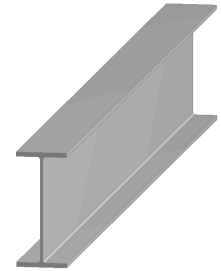
2.1-1 About the W16x50 Beam

In this section, we will create a W16x50 [1-4] steel beam. The beam has a length of 10 ft.

[1] Wide-flange I-shape section.

[2] Nominal depth 16 in.

[3] Weight 50 lb/ft.

W16x50

7.07"

.380"

.628"

[4] W16x50 cross section. #

16.25"

R.375"

2.1-2 Start Up DesignModeler

Workbench 17.0

[1] Double click to launch **Workbench**.

Getting Started

Welcome to ANSYS Workbench!

If you're new to ANSYS Workbench, we strongly encourage you to take just a few minutes to view some tutorials.

If you prefer to get started immediately:

1. Select your desired analysis system from the Toolbox (at left), drag it into the Project Schematic (at right), and drop it inside the highlighted rectangle.

2. Right-click on the Geometry cell to create a new geometry or import existing geometry.

3. Continue working through the system from top to bottom. Right-click and select **Edit** on a cell to start the appropriate application and define the details for that part of the analysis.

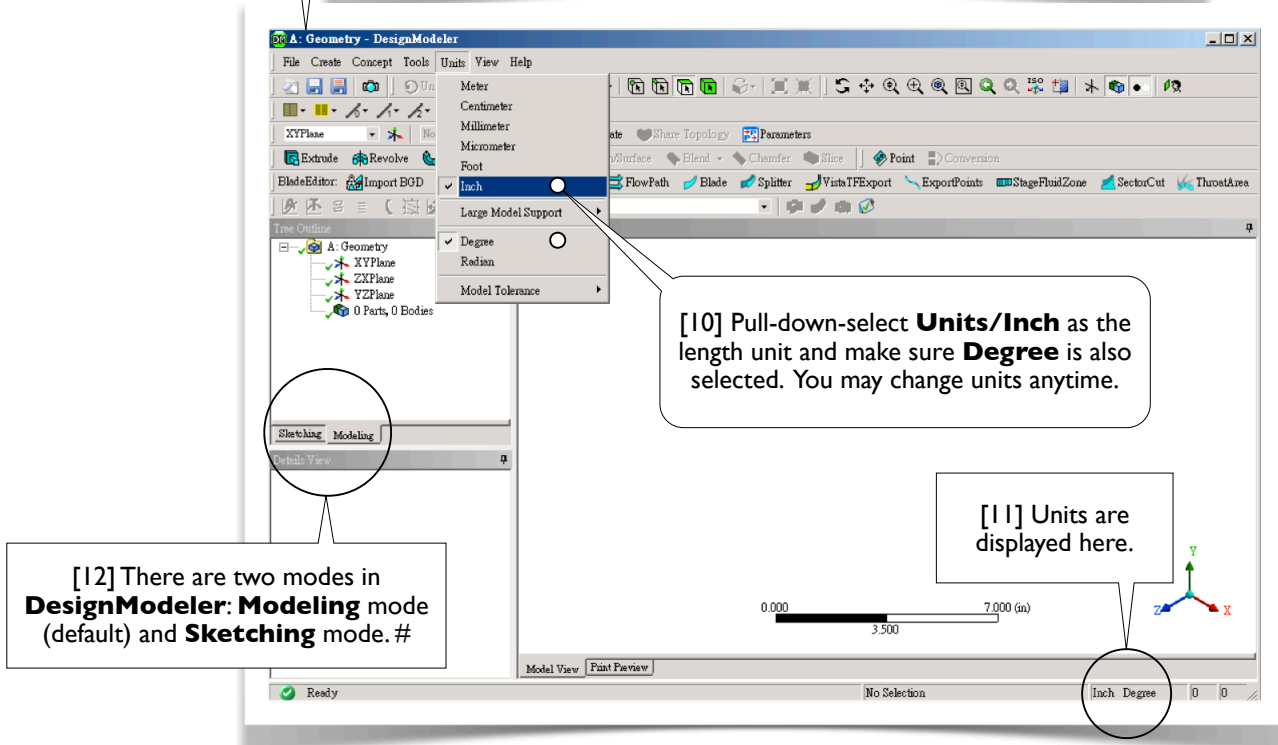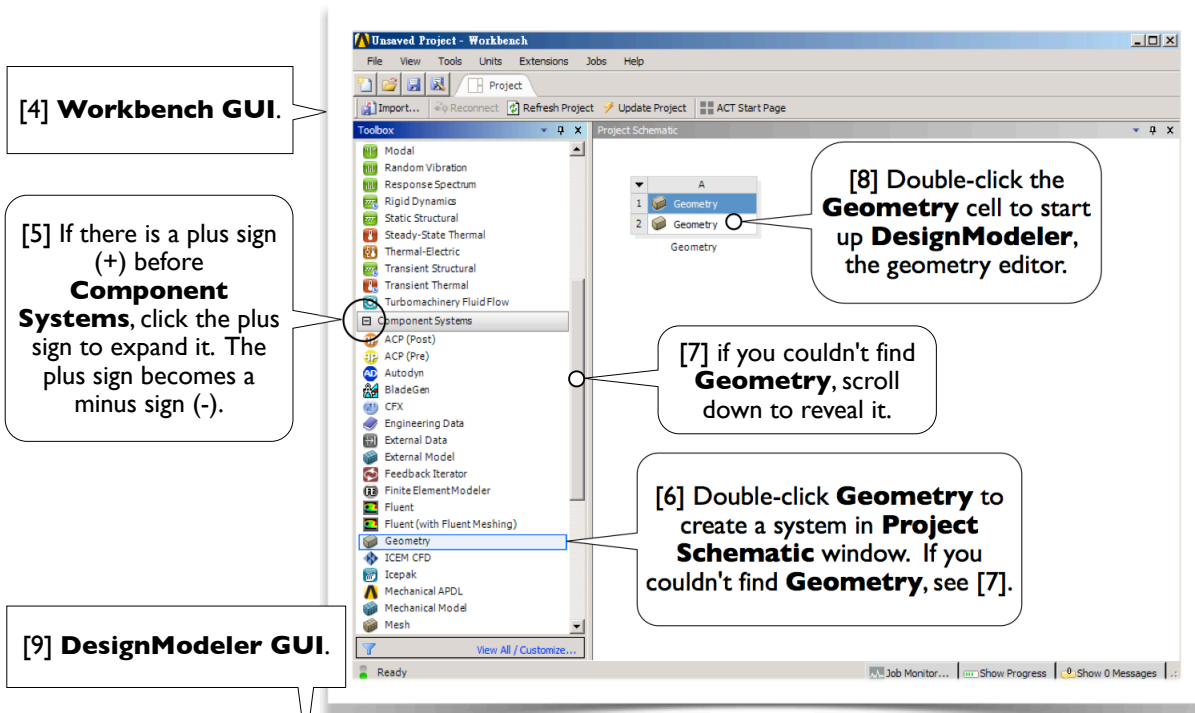☐ Show Getting Started Message at Startup   OK

[2] If a **Getting Started** message window appears, uncheck this box so that it won't appear next time at startup.

[3] Click **OK** to dismiss this window.

[4] **Workbench GUI**.

[5] If there is a plus sign (+) before **Component Systems**, click the plus sign to expand it. The plus sign becomes a minus sign (-).

[8] Double-click the **Geometry** cell to start up **DesignModeler**, the geometry editor.

[7] if you couldn't find **Geometry**, scroll down to reveal it.

[6] Double-click **Geometry** to create a system in **Project Schematic** window. If you couldn't find **Geometry**, see [7].

[9] **DesignModeler GUI**.

[10] Pull-down-select **Units/Inch** as the length unit and make sure **Degree** is also selected. You may change units anytime.

[11] Units are displayed here.

[12] There are two modes in **DesignModeler**: **Modeling** mode (default) and **Sketching** mode. #

About Textboxes

In this book, a round-cornered textbox (e.g., [1-3, 5-8, 10]) is used to indicate that mouse or keyboard ACTIONS are needed in that step. A sharp-cornered textbox (e.g., [4, 9, 11-12]) is used for commentary only; no mouse or keyboard actions are needed in that step.

2.1-3 Draw a Rectangle on **XYPlane**

[1] Current **sketching plane** is displayed here. **XYPlane** is the default sketching plane.

[3] This is the **global coordinates system**. **Workbench** uses red, green, and blue (RGB) arrows to indicate X, Y, and Z directions, respectively.

[2] Click the **Sketching** mode.

[7] As soon as you begin to draw, a sketch (with default name **Sketch1**) is created on the sketching plane.

[6] Draw a rectangle roughly like this by clicking a corner and then dragging to the diagonally opposite corner

[4] Click **Look At** so that you look at the sketching plane, **XYPlane**.

[5] Click the **Rectangle** tool.

[12] Right-click anywhere on the graphic window to open a context menu, and choose **Select new symmetry axis**.

- ○ Select new symmetry axis
- Selection Filter   ▶
- ○ Isometric View
- ISO Set
- ISO Restore Default
- ⊕ Zoom to Fit (F7)
- Cursor Mode   ▶
- View   ▶
- ◐ Look At
- ✕ Delete
- ⚡ Generate (F5)

[8] Click the **Constraints** toolbox. We want to impose symmetry constraints.

[10] Click the **Symmetry** tool.

[9] If the **Symmetry** tool is not visible, click to scroll down until you see the tool.

[13] Click the horizontal axis and then the two horizontal lines to make the lines symmetric about the horizontal axis.

[11] Click the vertical axis and then the two vertical lines to make the lines symmetric about the vertical axis.

[20] Click **Zoom to Fit**. #

[16] Click this line, move the mouse upward, and click to create H1.

[14] Click the **Dimensions** toolbox.

[17] Click this line, move the mouse rightward, and click again to create V2.

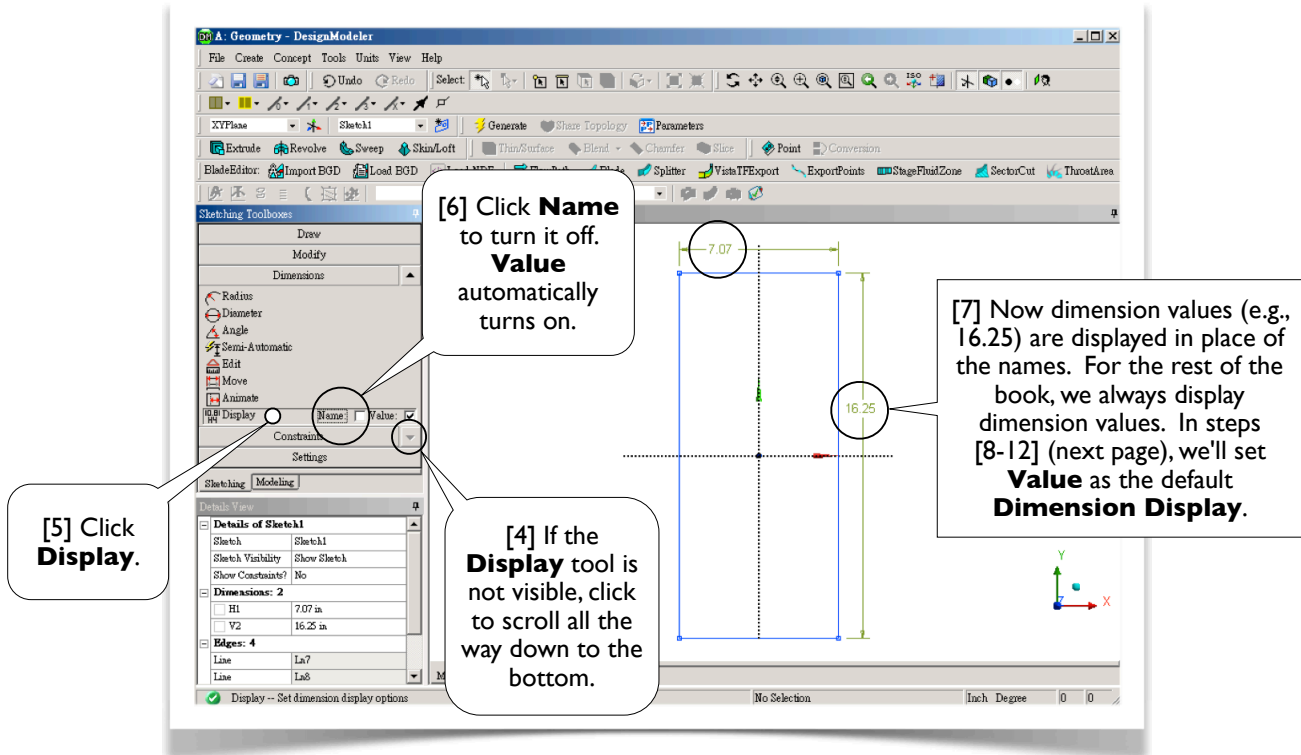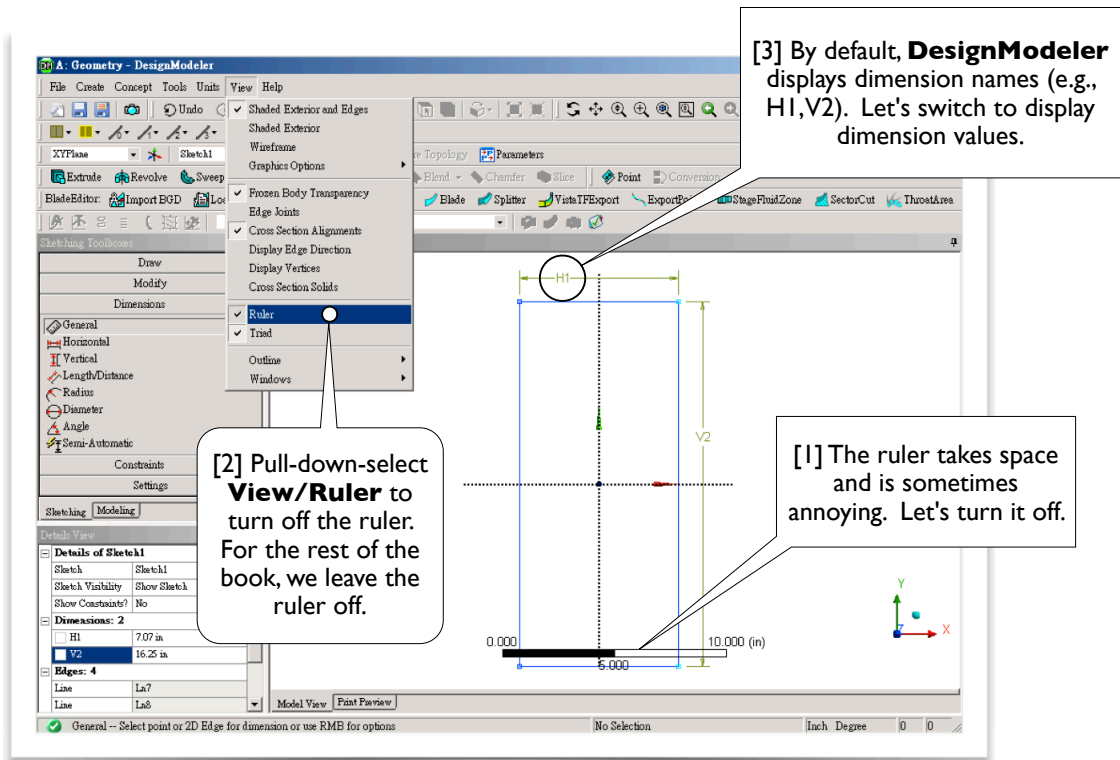[15] **General** is the default tool.

[18] All the lines turn to blue color. Colors are used to indicate **constraint status**. The blue color means the geometric entities are well-defined (fixed in the space).
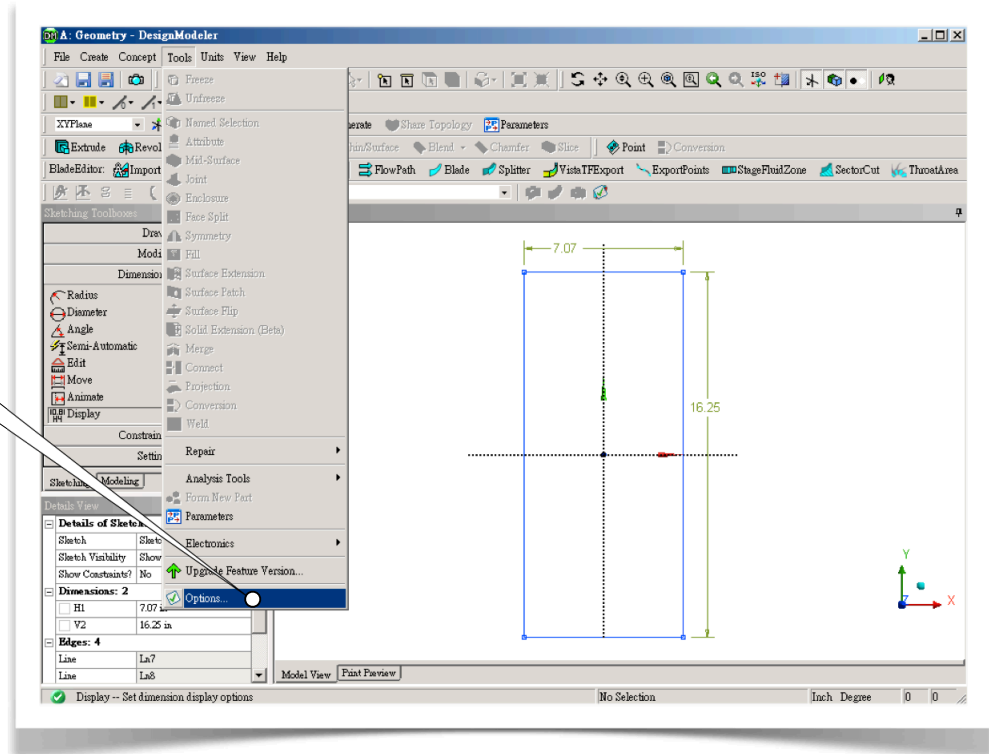
[19] In **Details View**, type 7.07 (in) for H1 and 16.25 (in) for V2.

2.1-4 Set Up Sketching Options

[3] By default, **DesignModeler** displays dimension names (e.g., H1,V2). Let's switch to display dimension values.

[2] Pull-down-select **View/Ruler** to turn off the ruler. For the rest of the book, we leave the ruler off.

[1] The ruler takes space and is sometimes annoying. Let's turn it off.

[6] Click **Name** to turn it off. **Value** automatically turns on.

[7] Now dimension values (e.g., 16.25) are displayed in place of the names. For the rest of the book, we always display dimension values. In steps [8-12] (next page), we'll set **Value** as the default **Dimension Display**.

[5] Click **Display**.

[4] If the **Display** tool is not visible, click to scroll all the way down to the bottom.
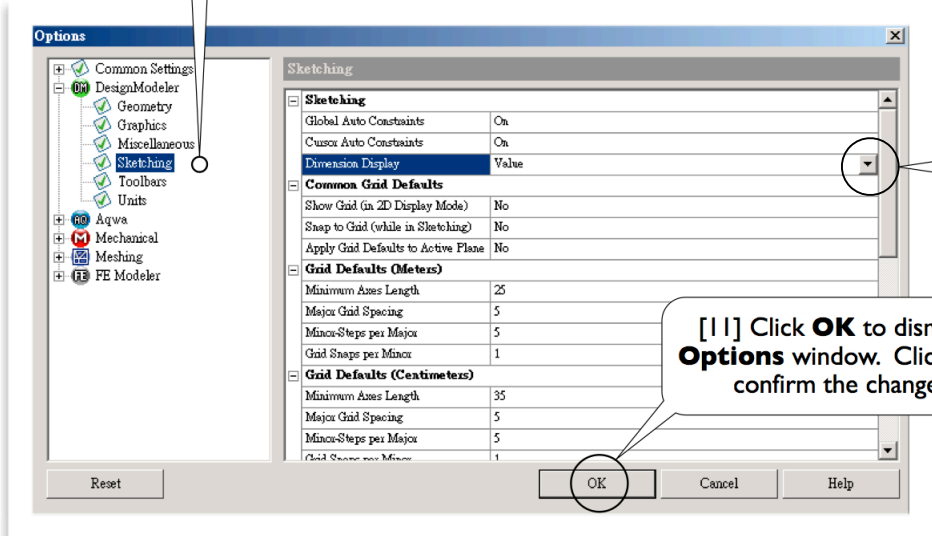
[8] Pull-down-select **Tools/Options...**

[9] Select **Sketching**.

[10] Select **Value** as the default **Dimension Display**.

[11] Click **OK** to dismiss the **Options** window. Click **Yes** to confirm the changes. #

Background Color of the Graphic Area

In this book, for better readability, the background color of the graphic area is always shown in white. If your background color is not white and you want to change it to white, pull-down-select **Tools/Options** in **Workbench GUI** (not **DesignModeler GUI**; see 2.1-2[4], page 57) and click **Appearance**.

2.1-5 Draw a Polyline

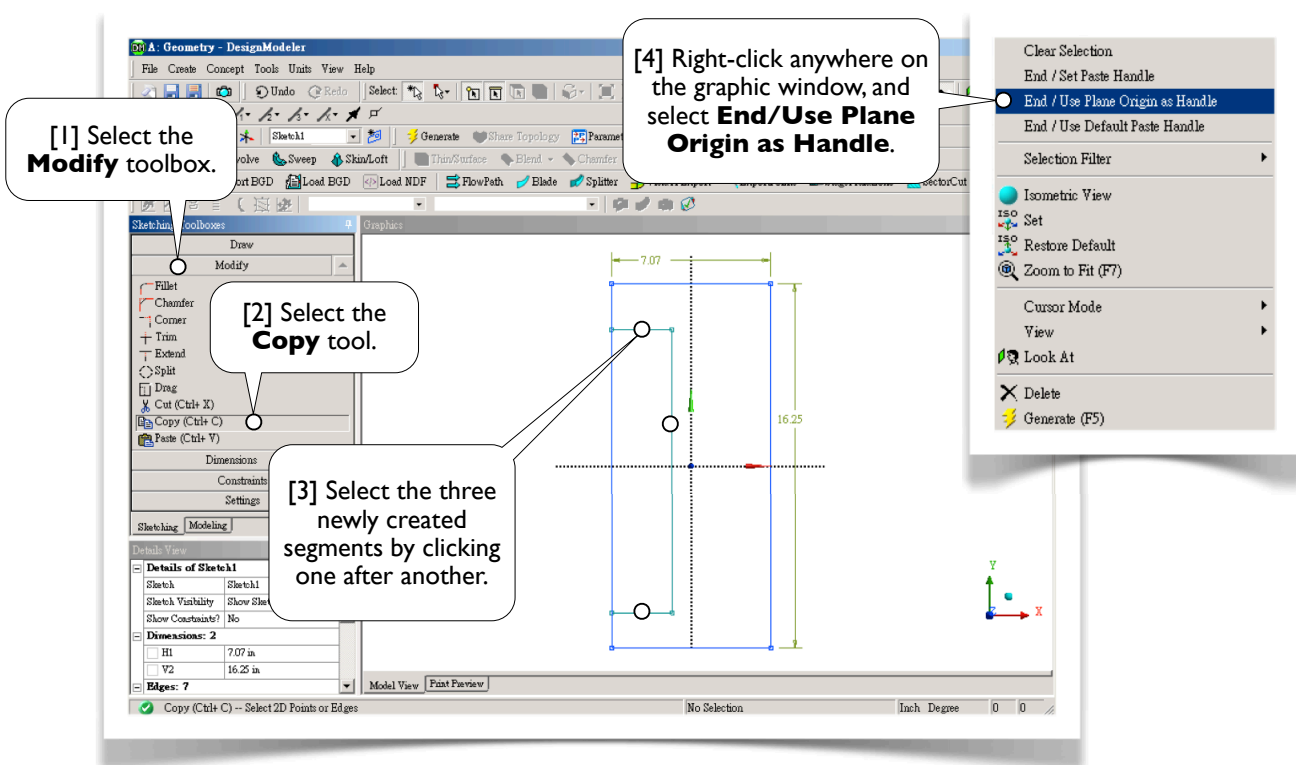[7] Right-click anywhere on the graphic window to open a context menu, and select **Open End** to end the **Polyline** tool. #

[1] Select the **Draw** toolbox.

[2] Select the **Polyline** tool.

[3] Click roughly here to start a polyline. Before clicking, make sure a **C** (coincident) appears.

[4] Click the second point roughly here. Before clicking, make sure a **C** and an **H** (horizontal) appear.

[6] Click the fourth point roughly here. Before clicking, make sure an **H** and a **C** appear.

[5] Click the third point roughly here. Before clicking, make sure a **V** (vertical) appears.

2.1-6 Copy the Polyline

[4] Right-click anywhere on the graphic window, and select **End/Use Plane Origin as Handle**.

[1] Select the **Modify** toolbox.

[2] Select the **Copy** tool.

[3] Select the three newly created segments by clicking one after another.

Sketching Toolboxes

Draw

Modify

- Fillet
- Chamfer
- Corner
- Trim
- Extend
- Split
- Drag
- Cut (Ctrl+ X)
- Copy (Ctrl+ C)
- Paste (Ctrl+ V)   r = 90 °   f = 2
- Move

Dimensions

Constraints

Settings

Sketching   Modeling

[5] The **Paste** tool is automatically selected.

Rotate by r
Rotate by -r
Flip Horizontal
Flip Vertical
Scale by factor f
Scale by factor 1/f
Paste at Plane Origin
Change Paste Handle

End
Cut (Ctrl+ X)
Copy (Ctrl+ C)

Selection Filter

Isometric View
Set
Restore Default
Zoom to Fit (F7)

Cursor Mode
View
Look At

Generate (F5)

[6] Right-click-select **Flip Horizontal**.

[7] Right-click-select **Paste at Plane Origin**.

[8] Right-click-select **End** to end the **Paste** tool. An alternative way (a more convenient way) is to press **ESC** to end a tool. #

7.07

16.25

2.1-7 Basic Mouse Operations in Sketching Mode

Now, try these basic mouse operations in sketching mode [1-6]. Press **ESC** to deselect all entities. After trying any of [4-6], click **Zoom to Fit** (2.1-3[20], page 59) or **Look At** (2.1-3[4], page 58) to go back to the fitting view.
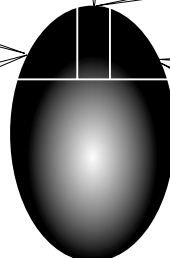
[1] **Click**: add a sketching entity to the selection set. Click a selected entity to remove it from the selection set.

[6] **Middle-click-drag**: rotate.
Shift-middle-click-drag: zoom.
Control-middle-click-drag: pan. #

[5] **Scroll-wheel**: zoom in/out.
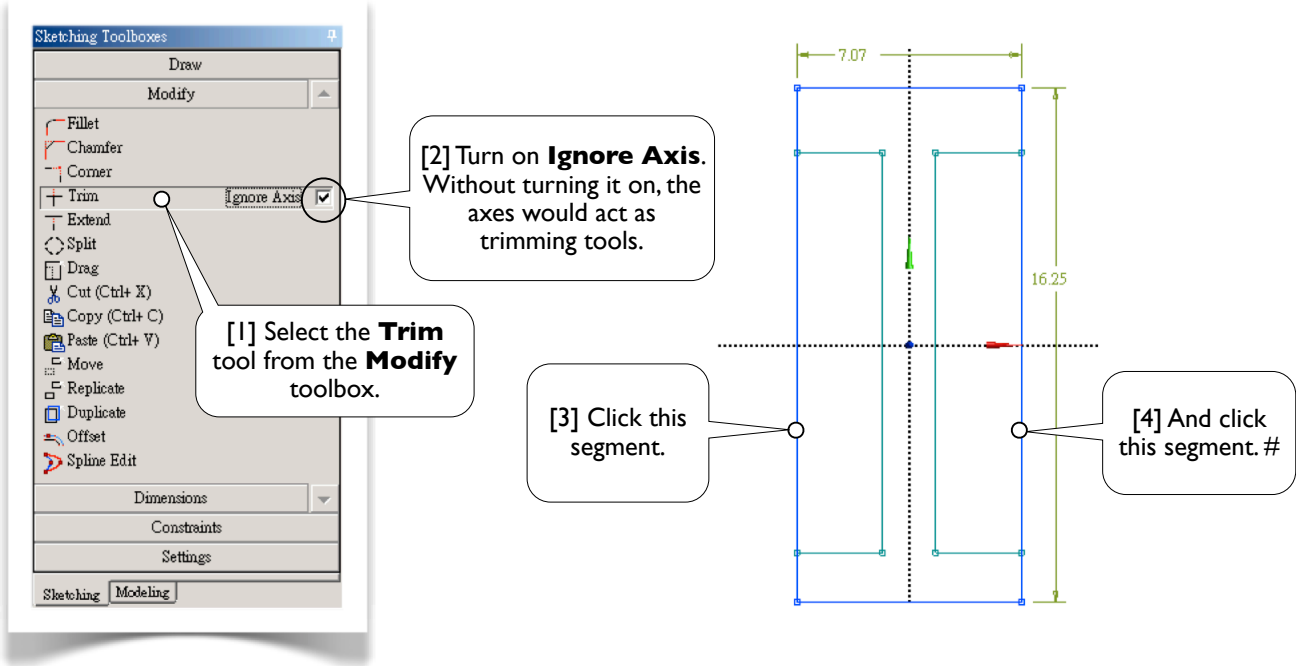
[4] **Right-click-drag**: box zoom.
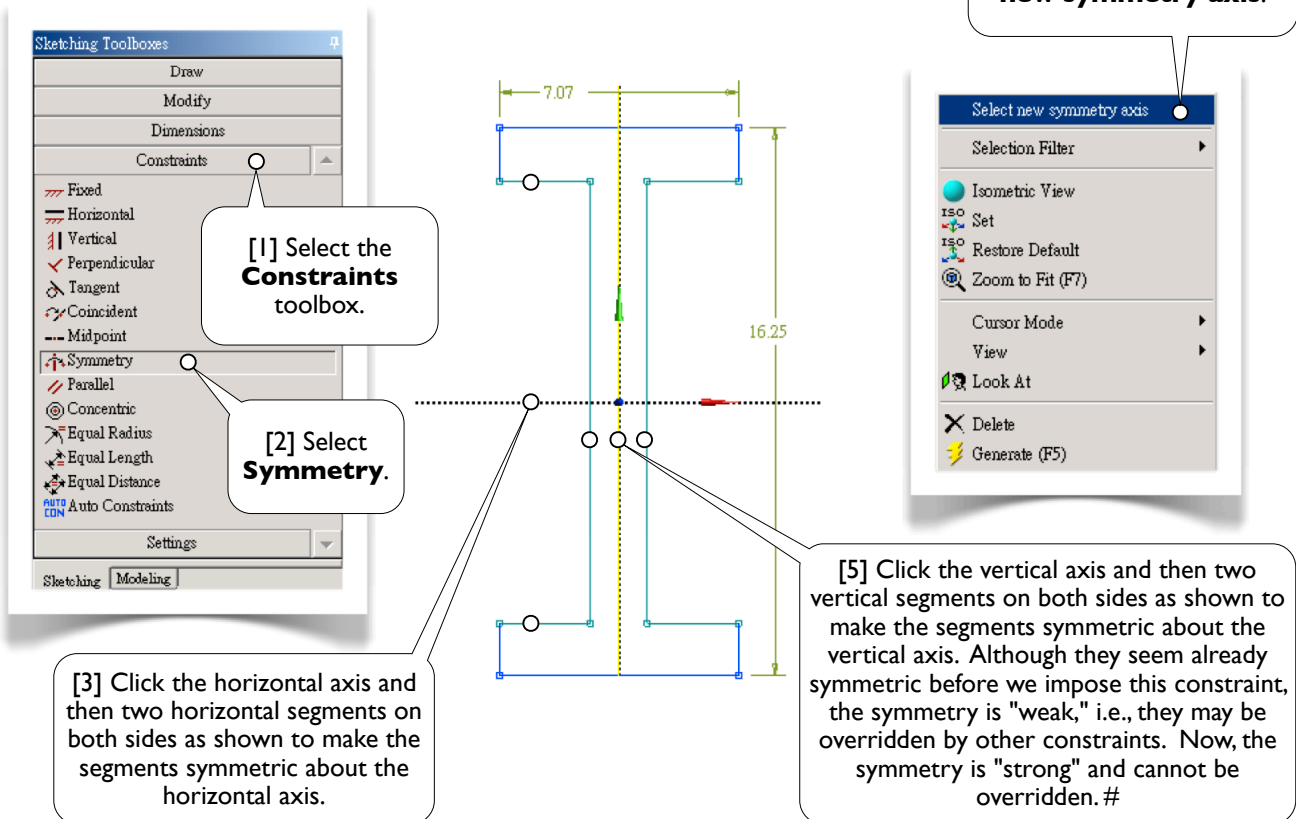
[2] **Click-Sweep**: continuous selection.

[3] **Right-click**: open a context menu.
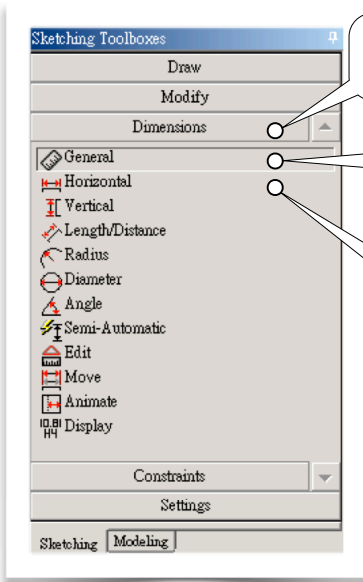
2.1-8 Trim Away Unwanted Segments

[2] Turn on **Ignore Axis**. Without turning it on, the axes would act as trimming tools.

[1] Select the **Trim** tool from the **Modify** toolbox.

[3] Click this segment.

[4] And click this segment. #

2.1-9 Impose Symmetry Constraints

[4] Right-click-select **Select new symmetry axis**.

[1] Select the **Constraints** toolbox.

[2] Select **Symmetry**.

[3] Click the horizontal axis and then two horizontal segments on both sides as shown to make the segments symmetric about the horizontal axis.

[5] Click the vertical axis and then two vertical segments on both sides as shown to make the segments symmetric about the vertical axis. Although they seem already symmetric before we impose this constraint, the symmetry is "weak," i.e., they may be overridden by other constraints. Now, the symmetry is "strong" and cannot be overridden. #

2.1-10 Specify Dimensions

Sketching Toolboxes

Draw

Modify

Dimensions

General

Horizontal

Vertical

Length/Distance

Radius

Diameter

Angle

Semi-Automatic

Edit

Move

Animate

Display

Constraints
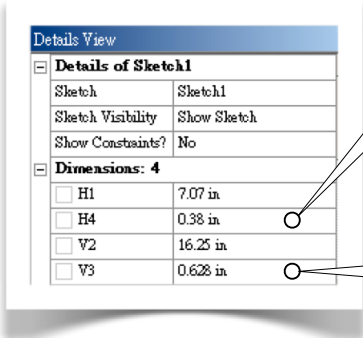
Settings

Sketching | Modeling

[1] Select the **Dimensions** toolbox.

[2] **General** is the default tool.

[5] Select **Horizontal**.

[3] Click this vertical segment and move leftward to create a dimension (in details view [4], the name is V3).

Details View

Details of Sketch1	
Sketch	Sketch1
Sketch Visibility	Show Sketch
Show Constraints?	No
Dimensions: 4	
H1	7.07 in
H4	0.38 in
V2	16.25 in
V3	0.628 in

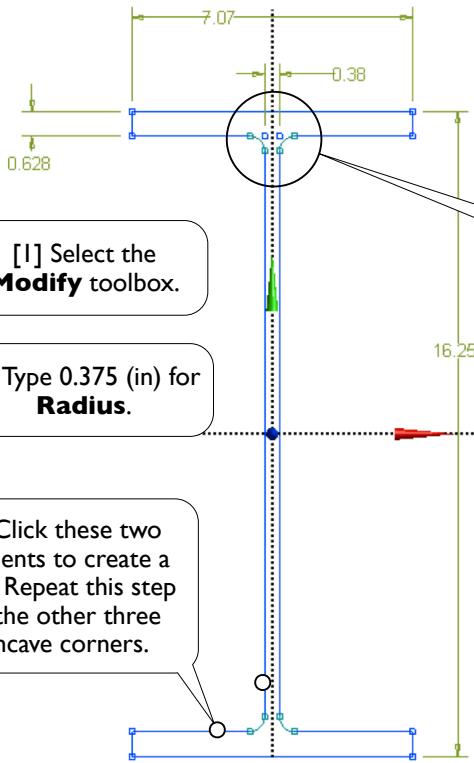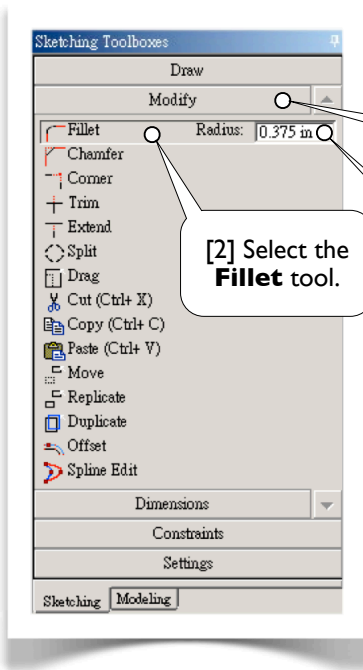[7] In **Details View**, type 0.38 (in) for H4.

[4] In **Details View**, type 0.628 (in) for V3.

[6] Click these two vertical segments one after the other and move upward to create a horizontal dimension (H4).
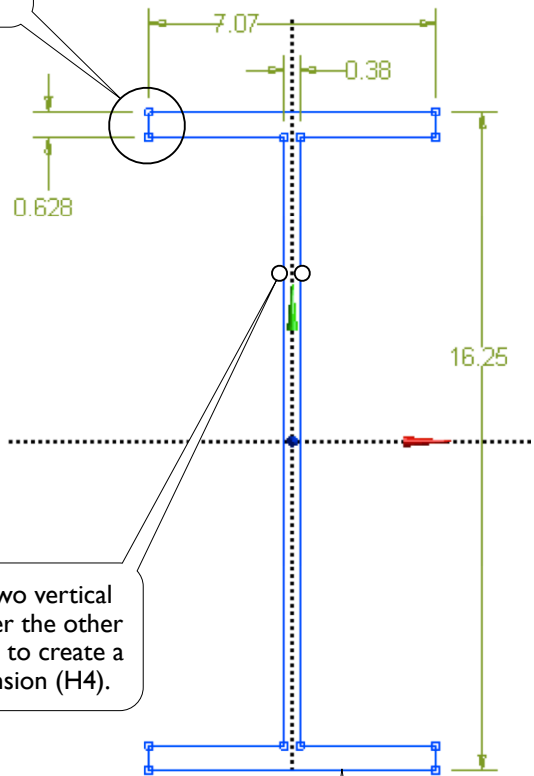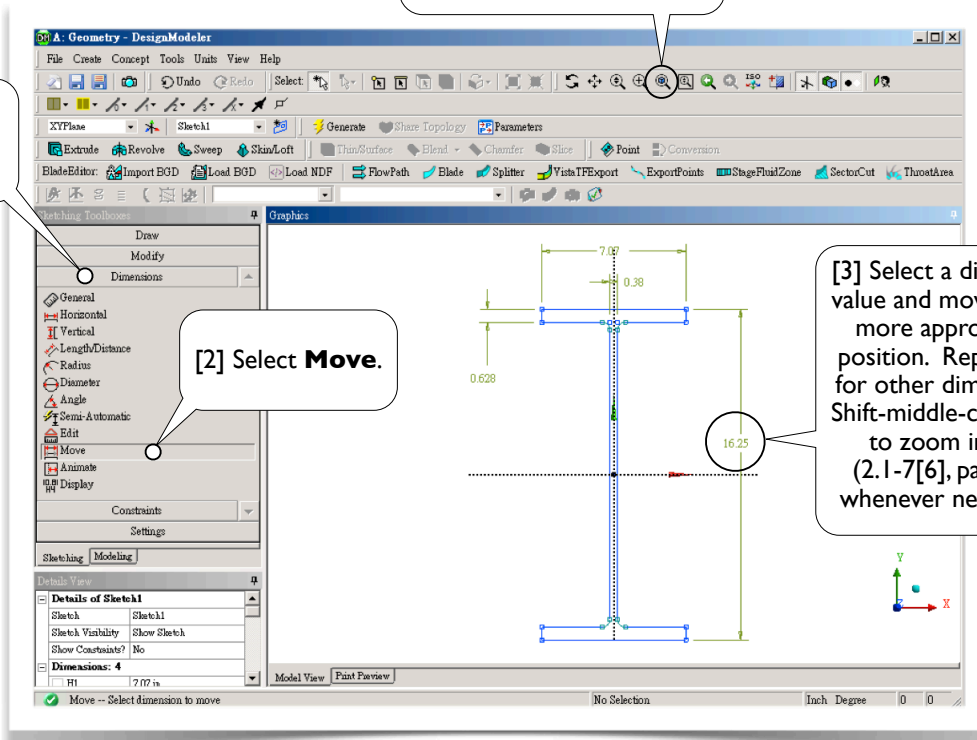
[8] All the sketching entities are blue-colored, meaning that they are well-defined (fixed in the space). #

2.1-11 Add Fillets

Sketching Toolboxes

Draw

Modify

Fillet   Radius: 0.375 in
Chamfer
Corner
Trim
Extend
Split
Drag
Cut (Ctrl+ X)
Copy (Ctrl+ C)
Paste (Ctrl+ V)
Move
Replicate
Duplicate
Offset
Spline Edit

Dimensions
Constraints
Settings

Sketching | Modeling

7.07

0.38

0.628

16.25

[1] Select the **Modify** toolbox.

[2] Select the **Fillet** tool.

[3] Type 0.375 (in) for **Radius**.

[4] Click these two segments to create a fillet. Repeat this step for the other three concave corners.

[5] The greenish-blue color of the fillets indicates that these fillets are under-constrained. The radius specified in [3] is a "weak" dimension (may be overridden by other constraints). We could specify a **Radius** dimension (in the **Dimensions** toolbox) to turn the fillets blue. However, we decide to ignore the color. We want to demonstrate that an under-constrained sketch can still be used. Remember, however, it is a good practice to make all entities blue-colored. #

2.1-12 Move Dimensions

[4] Click **Zoom to Fit**. #

[1] Select the **Dimensions** toolbox.

A: Geometry - DesignModeler

File Create Concept Tools Units View Help

Undo Redo Select:

XYPlane   Sketch1   Generate Share Topology Parameters

Extrude Revolve Sweep Skin/Loft   Thin/Surface Blend Chamfer Slice   Point Conversion

BladeEditor: Import BGD Load BGD Load NDF   FlowPath Blade Splitter VistaTFExport ExportPoints StageFluidZone SectorCut ThroatArea

Sketching Toolboxes

Draw

Modify

Dimensions

General
Horizontal
Vertical
Length/Distance
Radius
Diameter
Angle
Semi-Automatic
Edit
Move
Animate
Display

Constraints
Settings

Sketching | Modeling

Details View

Details of Sketch1
Sketch   Sketch1
Sketch Visibility   Show Sketch
Show Constraints? No
Dimensions: 4
H1   7.07 in

Graphics

7.07

0.38

0.628

16.25

Move -- Select dimension to move   No Selection   Inch Degree   0   0

[2] Select **Move**.

[3] Select a dimension value and move it to a more appropriate position. Repeat this for other dimensions. Shift-middle-click-drag to zoom in/out (2.1-7[6], page 63) whenever necessary.

Model View | Print Preview

2.1-13 Generate a 3D Solid Body

[3] Remember that the active sketch is shown here (2.1-3[7], page 58).

[8] Click **Generate**.

[1] Click the little cyan sphere to rotate the view to an isometric view, which is a convenient 3D view.

[4] Click **Extrude**.
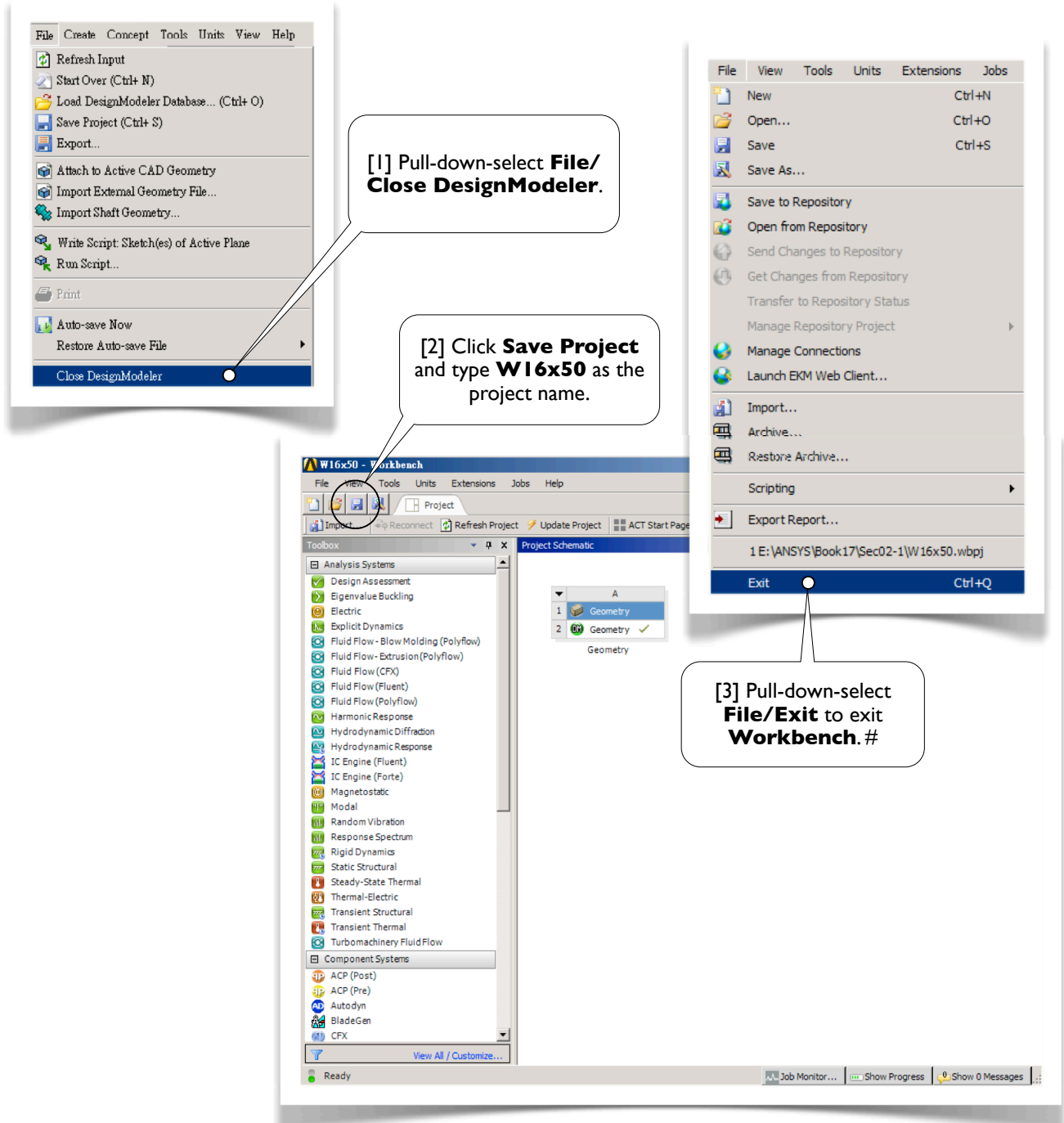
[5] It automatically switches to the **Modeling** mode.

[6] Click **Apply**. By default, the active sketch (see [3]) is selected as **Geometry**.

[7] Type 120 (in) for **Depth**.

[2] The view rotates to an isometric view.

[9] Click **Display Plane** to turn off the display of sketching plane.

[10] Click **Zoom to Fit**. Feel free to use this tool any time.

[11] Click all plus signs (+) to expand the **model tree** and browse its structure. #

2.1-14 Save Project and Exit Workbench

[1] Pull-down-select **File/ Close DesignModeler**.

[2] Click **Save Project** and type **W16x50** as the project name.

[3] Pull-down-select **File/Exit** to exit **Workbench**. #

Supporting Files

To download the finished project files or view the demo videos, please visit the SDC Publications website. See the inside front cover for details.

Section 2.2

Triangular Plate

2.2-1 About the Triangular Plate

The triangular plate [1, 2], with a thickness of 10 mm, is made to withstand tensile forces on three side faces [3].

In this section, we'll sketch a profile of the plate on **XYPlane** and then extrude a thickness of 10 mm along *Z*-axis to generate a 3D solid body.

In Section 3.1, we will use this sketch again to generate a 2D solid model, which is then used for a static structural simulation to assess the stress under design loads.

The 2D solid model will be used again in Section 8.2 to demonstrate a design optimization procedure.

[3] Tensile forces are applied on the three side faces. #

[2] The radius of the fillets is 10 mm.

40 mm

[1] The plate has three planes of symmetry.

30 mm

300 mm

2.2-2 Start up DesignModeler

[1] Double-click to launch **Workbench**.

[3] Double-click to start up **DesignModeler**.

[2] Double-click to create a **Geometry** system (2.1-2[5-7], page 57).

[4] Pull-down-select **Units/Millimeter**.

[7] Click **Look At** to look at **XYPlane**. #

[5] The length unit and the angle unit are shown here.

[6] Select **Sketching** mode.

2.2-3 Draw a Triangle on XYPlane

[1] Select **Polyline**.

[3] Click the second point roughly here. Before clicking, make sure a **V** (vertical) appears.

[5] Right-click-select **Closed End** to close the polyline and end the tool. #

[2] Click roughly here to start a polyline.

[4] Click the third point roughly here. Before clicking, make sure a **C** (coincident) appears. **Auto Constraints** is a useful feature of **DesignModeler** (see 2.3-5, page 83).

2.2-4 Make the Triangle Regular

[2] Click this and the vertical segments to make their lengths equal.

[1] From the **Constraints** toolbox, select the **Equal Length** tool.

[3] Click this and the vertical segments to make their lengths equal. #

2.2-5 2D Graphics Controls

Tools for 2D graphics controls are available in the **Display Toolbar** [1-9]. Click the tools in [3-5] to switch them on/off. Feel free to use these tools any time. Try to click each tool now. They don't modify the model. Note that other ways to **Pan**, **Zoom**, and **Box Zoom** are given in 2.1-7 (page 63) and 2.3-4 (page 82).

[3] When on, **Pan** allows you to click-and-drag on the graphic area to move the sketch.

[2] **Zoom to Fit** fits the entire sketch in the graphic area.

[7] Click **Next View** to go to next view.

[1] **Look At** rotates the view so that you look at the sketch.

[5] When on, **Zoom** allows you to click-and-drag on the graphic area to zoom in/out.

[4] When on, **Box Zoom** allows you to click-and-drag a box on the graphic area to enlarge that portion of the graphics.

[6] Click **Previous View** to go to previous view.

[8] Click **Undo** to undo what you've just done. Multiple undo is allowed. This tool is available only in **Sketching** mode.

[9] Click **Redo** to redo what you've just undone. This tool is available only in **Sketching** mode. #

2.2-6 Specify Dimensions

Sketching Toolboxes

Draw

Modify

Dimensions   ○

∿ General
⊢⊣ Horizontal   ○
𝕀 Vertical
↗ Length/Distance
⌒ Radius
⊖ Diameter
⌔ Angle
⚡ Semi-Automatic
≙ Edit
⊢⊣ Move   ○
⊢⊣ Animate
⊞⊞ Display

Constraints

Settings

Sketching | Modeling

Details View

⊟ **Details of Sketch1**	
Sketch	Sketch1
Sketch Visibility	Show Sketch
Show Constraints?	No
⊟ **Dimensions: 2**	
☐ H1	300 mm ○
☐ H2	200 mm ○

[4] In **Details View**, type 300 (mm) and 200 (mm) for the dimensions just created. Click **Zoom to Fit** (2.2-5[2], last page).

[1] From the **Dimension** toolbox, select **Horizontal**.

[5] Select **Move** and move the dimensions to appropriate positions (2.1-12[2-3], page 66). #

[3] Click the vertex on the left and the vertical axis, and then move the mouse downward to create this dimension. All the segments turn blue, indicating they are well defined now. (The value 200 is typed in step [4].)

[2] Click the vertex on the left (before clicking, make sure that the cursor turns to a point) and the vertical line on the right, and then move the mouse downward to create this dimension. (The value 300 is typed in step [4].)

200

300

2.2-7 Draw an Arc

Sketching Toolboxes

Draw   ○

↘ Line
⟋ Tangent Line
⟋ Line by 2 Tangents
⋀ Polyline
⬠ Polygon
▭ Rectangle
▱ Rectangle by 3 Points
⬭ Oval
◯ Circle
◯ Circle by 3 Tangents
↱ Arc by Tangent
⌒ Arc by 3 Points
⌢ Arc by Center   ○
⬭ Ellipse
⟩ Spline
∗ Construction Point
⚙ Construction Point at Intersecti

Modify

Dimensions

Constraints

Settings

Sketching | Modeling

[3] Click the second point roughly here. Before clicking, make sure a **C** (coincident) constraint appears.

[2] Click this vertex as the arc center. Before clicking, make sure a **P** (point) constraint appears.

[4] Click the third point here. Before clicking, make sure a **C** (coincident) constraint appears. #

[1] From the **Draw** toolbox, select **Arc by Center**.

200

300

2.2-8 Replicate the Arc

[4] Select this vertex as paste handle. Before clicking, make sure a **P** (point) appears.

Sketching Toolboxes

Draw

Modify ○

- Fillet
- Chamfer
- Corner
- Trim
- Extend
- Split
- Drag
- Cut (Ctrl+ X)
- Copy (Ctrl+ C)
- Paste (Ctrl+ V)
- Move
- Replicate r = 120 °   f = 2
- Duplicate
- Offset
- Spline Edit

Dimensions
Constraints
Settings

Sketching | Modeling

[1] From **Modify** toolbox, select **Replicate**. Type 120 (degrees) for **r** (rotate). **Replicate** is equivalent to **Copy**+**Paste** (2.1-6[2, 5], pages 62, 63)

[3] Right-click-select **End/Set Paste Handle**.

[2] Select the arc.

Clear Selection
End / Set Paste Handle   ○
End / Use Plane Origin as Handle
End / Use Default Paste Handle
Selection Filter   ▶
Isometric View
Set
X Delete
Generate (F5)

[8] **Selection Filter** is also available in the context menu.

—200.000—
—300.000—

Rotate by r   ○
Rotate by -r
Flip Horizontal
Flip Vertical
Scale by factor f
Scale by factor 1/f
Paste at Plane Origin
Change Paste Handle
End
Selection Filter   ▶
Ison
Set
Res
Zoo
Cur
Viev
Look At
Generate (F5)

[5, 9] Right-click-select **Rotate by r** from the context menu.

[6] Click this vertex to paste the arc. Before clicking, make sure a **P** appears. If you have difficulty making **P** appear, see [7, 8].

[7] Whenever you have difficulty making **P** appear, click **Selection Filter: Points** in the toolbar. **Selection Filter** is also available in the context menu, (see [8]).

—200—
—300—
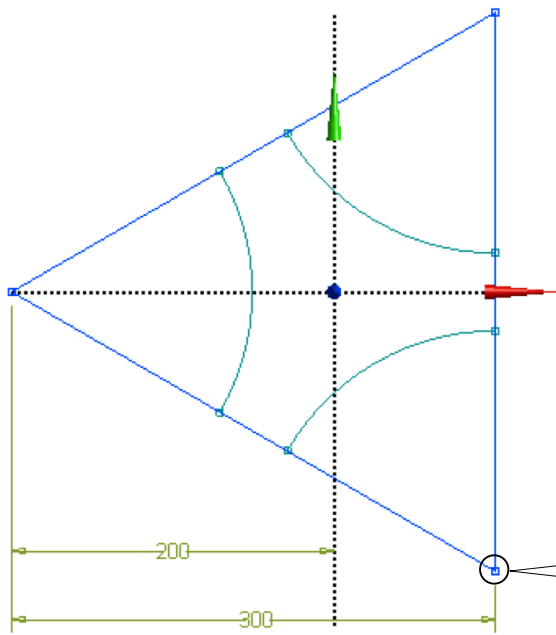
[10] Select this vertex to paste the arc. Before clicking, make sure a **P** appears.

Rotate by r
Rotate by -r
Flip Horizontal
Flip Vertical
Scale by factor f
Scale by factor 1/f
Paste at Plane Origin
Change Paste Handle
End
Selection Filter
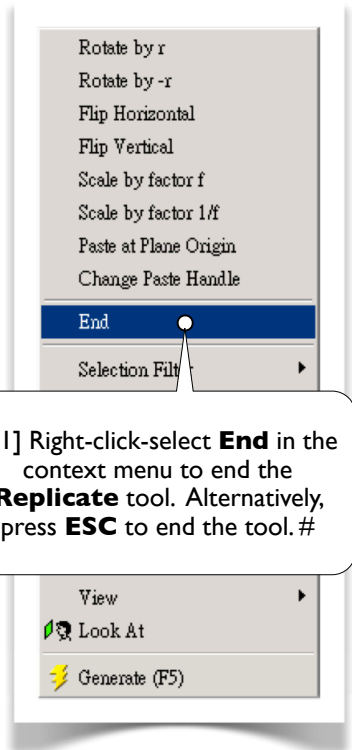
[11] Right-click-select **End** in the context menu to end the **Replicate** tool. Alternatively, press **ESC** to end the tool. #

View
Look At
Generate (F5)

We chose to manually set the paste handle at a vertex [4] (last page) because we want to demonstrate the use of **Set Paste Handle** [3] (last page). In this case, select **Use Plane Origin as Handle**, **Rotate by r**, and then **Paste at Plane Origin** have the same effect (similar to the steps in 2.1-6[4, 7], pages 62, 63).

2.2-9 Trim Away Unwanted Segments

Sketching Toolboxes
Draw
Modify
Fillet
Chamfer
Corner
Trim   Ignore Axis ☑
Extend
Split
Drag
Cut (Ctrl+ X)
Copy (Ctrl+ C)
Paste (Ctrl+ V)
Move
Replicate
Duplicate
Offset
Spline Edit
Dimensions
Constraints
Settings
Sketching Modeling
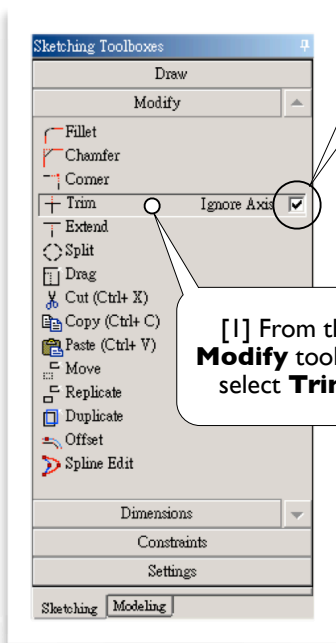
[2] Turn on **Ignore Axis** (2.1-8[2], page 64).

[3] Click to trim away these 6 segments. #

[1] From the **Modify** toolbox, select **Trim**.

200
300
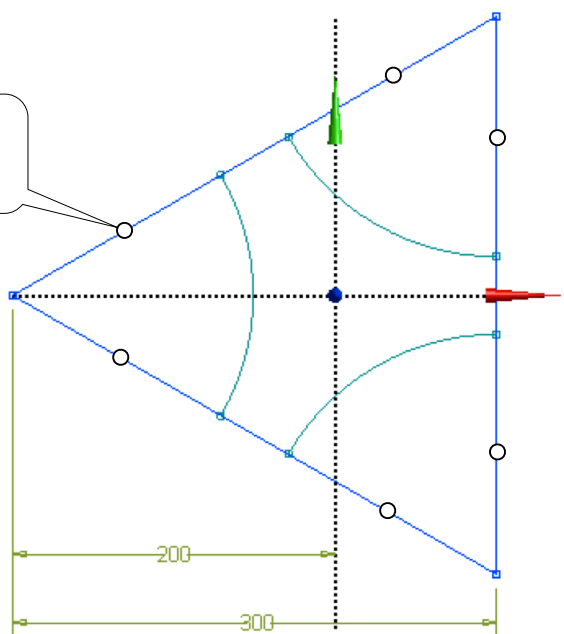
2.2-10 Impose Constraints

[2] Select this segment and the vertical segment to make their lengths equal.

[5] Select the horizontal axis as the line of symmetry.

[4] Select **Symmetry**.

[3] Select this segment and the vertical segment to make their lengths equal.

[6] Select the lower and upper arcs to make them symmetric. #

[1] From the **Constraints** toolbox, select **Equal Length**.

200

300

Constraint Status

The three straight lines turn blue, indicating they are well-defined, while the three arcs remain greenish-blue, indicating they are not well-defined yet (under-constrained). Other color codes are: black for fixed, red for over-constrained, and gray for inconsistency.

2.2-11 Specify Dimension for Side Edges

Details View

Details of Sketch1	
Sketch	Sketch1
Sketch Visibility	Show Sketch
Show Constraints?	No
Dimensions: 3	
H1	300 mm
H2	200 mm
V3	40 mm

[1] Select the **Dimension** toolbox and leave **General** as the default tool.

40

[3] Type 40 (mm) for the new dimension. #

200

300

[2] Click the vertical segment and move the mouse rightward to create this dimension. All the entities turn to blue now. (The value 40 is typed in [3].)

2.2-12 Create Offset

Sketching Toolboxes

| Draw |
| Modify ○ |

- Fillet
- Chamfer
- Corner
- Trim
- Extend
- Split
- Drag
- Cut (Ctrl+ X)
- Copy (Ctrl+ C)
- Paste (Ctrl+ V)
- Move
- Replicate
- Duplicate
- Offset
- Spline Edit

| Dimensions |
| Constraints |
| Settings |

Sketching Modeling

[1] From the **Modify** toolbox, select **Offset**.

[2] Sweep-select all the segments (sweep each segment while holding your left mouse button down, see 2.1-7[2], page 63). Sweep-select is also called *paint-select*. (Also see [3].)

40

200

300

Select: Single Select Box Select

[3] Another way to select multiple entities is to switch **Select Mode** to **Box Select**, and then left-click-drag a box to select all entities inside the box.

[4] Right-click-select **End selection/Place Offset** in the context menu.

Clear Selection
End selection / Place offset
Selection Filter
Isometric View
Set
Restore Default
Zoom to Fit (F7)
Cursor Mode
View
Look At
Delete
Generate (F5)

[5] Click roughly here to place the offset.

[6] Right-click-select **End** in the context menu, or press **ESC**, to close the **Offset** tool.

Clear Selection
End
Selection Filter
Isometric View
Set
Restore Default
Zoom to Fit (F7)
Cursor Mode
View
Look At
Generate (F5)

40

200

300

Sketching Toolboxes

Draw
Modify
Dimensions

General
Horizontal
Vertical
Length/Distance
Radius

[7] From the **Dimension** toolbox, select **Horizontal**.

Animate
Display

Constraints
Settings

Sketching | Modeling

Details View

Details of Sketch1

Sketch	Sketch1
Sketch Visibility	Show Sketch
Show Constraints?	No

Dimensions: 4

H1	300 mm
H2	200 mm
H4	30 mm
V3	40 mm

[9] Type 30 (mm) for the new dimension.

[10] If you see something like this, never mind; there is nothing wrong with it. #

[8] Create this dimension by clicking the two arcs on the left and move downward. Note that all the entities turn to blue now.

2.2-13 Create Fillets

[2] Click these two segments to create a fillet. Repeat this step to create the other two fillets. The fillets are in greenish-blue color, indicating they are weakly defined (see [3]).

[1] In the **Modify** toolbox, select **Fillet**. Type 10 (mm) for **Radius**.

Sketching Toolboxes

Draw
Modify

Fillet   Radius: 10 mm
Chamfer
Corner
Trim
Extend
Split
Drag
Cut (Ctrl+ X)
Copy (Ctrl+ C)
Paste (Ctrl+ V)
Move
Replicate
Duplicate
Offset
Spline Edit

[3] Dimensions specified in a toolbox are "weak," meaning they may be overridden by other constraints or dimensions (also see 2.1-11[5], page 66).

Dimensions
Constraints
Settings

Sketching | Modeling

Sketching Toolboxes

Draw

Modify

Dimensions ○

- General
- Horizontal
- Vertical
- Length/Distance
- Radius ○
- Diameter
- Angle
- Semi-Automatic
- Edit
- Move
- Animate
- Display

Constraints

Settings

Sketching | Modeling

[5] Click one of the fillets to create this dimension. This turns a "weak" dimension to a "strong" one. Now, all the fillets are blue-colored. #

[4] From the **Dimension** toolbox, select **Radius**.

R10

40

30

200

300

2.2-14 Extrude to Create 3D Solid

[5] Click **Display Plane** to turn off the display of sketching plane.

[2] Click **Extrude**.

[4] Click **Generate**.

[6] Click **Zoom to Fit**.
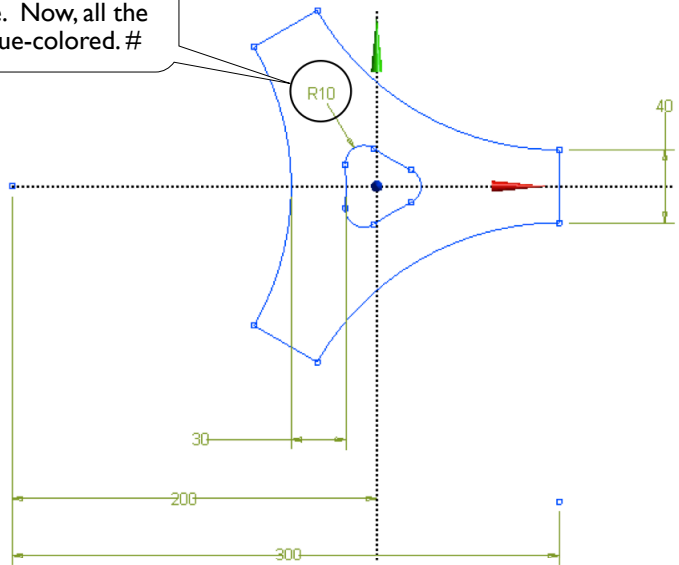
[1] Click the little cyan for an isometric view.

A: Geometry - Design

File Create Concept

XYPlane   Sketch1   Generate

Extrude Revolve Sweep Skin/Loft Thin/Surface Point Conversion

BladeEditor Import BGD Load BGD Load NDF FlowPath StageFluidZone SectorCut ThroatArea

Tree Outline

- A: Geometry
  - XYPlane
  - ZXPlane
  - YZPlane
  - Extrude1
    - Sketch1
  - 1 Part, 1 Body
    - Solid

Sketching | Modeling

[7] Click all plus signs (+) to expand and browse the **model tree**. #

Details View

Details of Extrude1	
Extrude	Extrude1
Geometry	Sketch1 ○
Operation	Add Material
Direction Vector	None (Normal)
Direction	Normal
Extent Type	Fixed
FD1, Depth (>0)	10 mm ○
As Thin/Surface?	No
Merge Topology?	Yes
Geometry Selection: 1	
Sketch	Sketch1

Ready   Millimeter Degree 0   0

[3] Type 10 (mm) for **Depth**. Note that **Sketch1** is automatically entered as **Geometry**.

2.2-15 Save the Project and Exit Workbench

[1] Click **Save Project**. Type **Triplate** as project name.

[2] In **Workbench GUI**, pull-down-select **File/Exit** to exit **Workbench**. #

Section 2.3

More Details
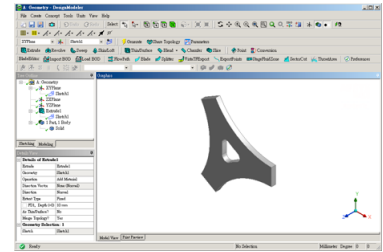
2.3-1 DesignModeler GUI

DesignModeler GUI consists of several areas [1-7]. On the top are **pull-down menus** and **toolbars** [1]; on the bottom is a **status bar** [7]. In-between are several **window panes**. **Separators** [8] between window panes can be dragged to resize the window panes. You even can make a window pane "float" by dragging or double-clicking its title bar. To return to its original position, simply double-click its title bar again.

    Tree Outline [3] shares the same area with **Sketching Toolboxes** [4]. To switch between **Modeling** mode and **Sketching** mode, simply click a **mode tab** [2]. **Details View** [6] shows the detail information of the objects highlighted in **Tree Outline** [3] or **Graphics Window** [5]; the former displays a **Model Tree** (discussed next page) while the latter displays the geometric model. Note that we focus on 2D functions of **DesignModeler** in this chapter and will discuss 3D functions in Chapter 4.

[1] **Pull-down menus** and **toolbars**.

[4] **Sketching Toolboxes**, in **Sketching** mode.

[3] **Tree Outline**, in **Modeling** mode.

[5] **Graphics window**.

[2] **Mode tabs**.

[8] **Separators** allow you to resize window panes. #

[6] **Details View**.

[7] **Status bar**.
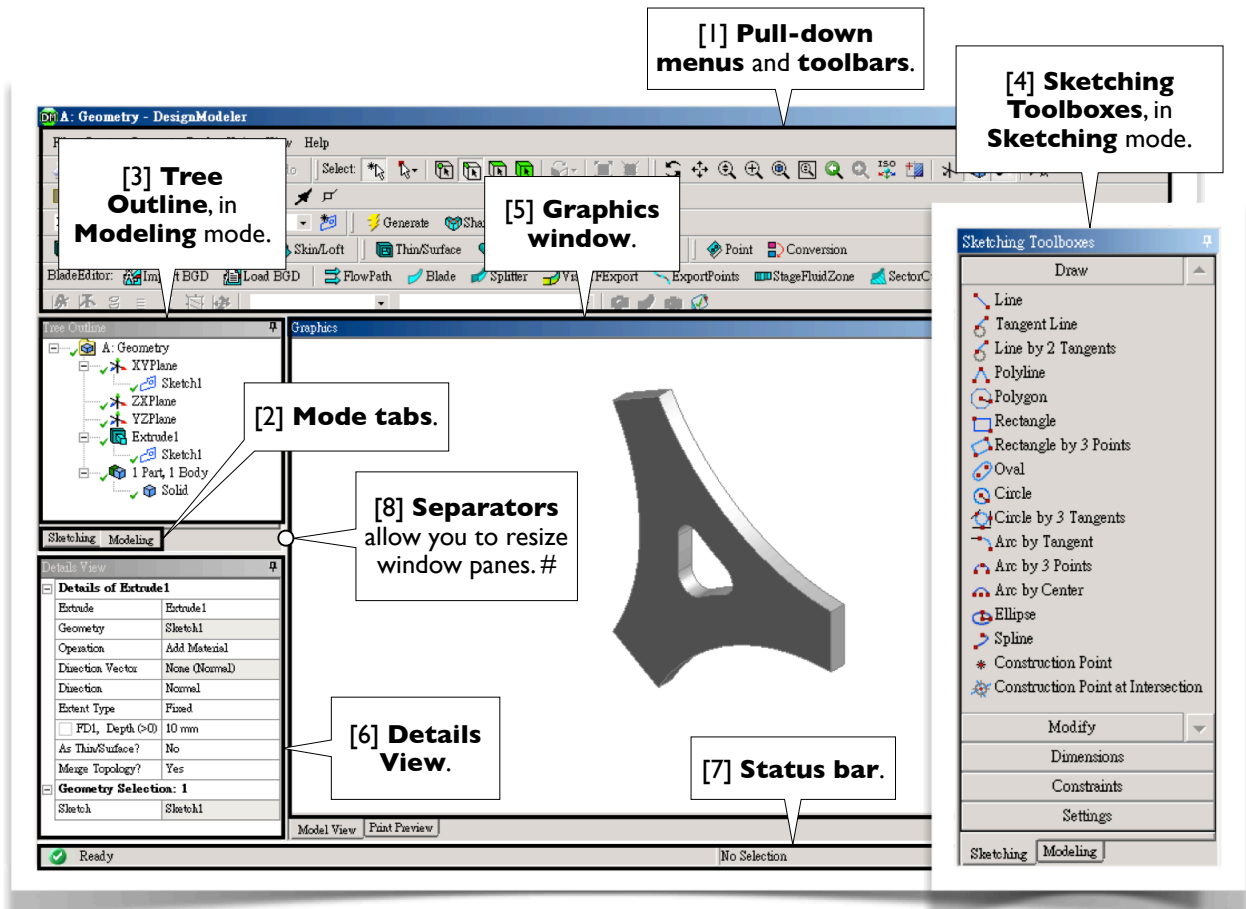
Model Tree

Tree Outline [3] contains an outline of a **model tree**, the data structure of the geometric model. Each *branch* of the tree is called an *object*, which may contain one or more objects. At the bottom of the model tree is a **part** branch, which is the only object that will be exported to **Mechanical** for simulations. By right-clicking an object and selecting a tool from the *context menu*, you can operate on the object, such as delete, rename, duplicate, etc.

The order of the objects is relevant. **DesignModeler** renders the geometry according to the order of objects in the model tree. New objects are normally added one after another. If you want to insert a new object BEFORE an existing object, right-click the existing object and select **Insert/...** from the context menu. After insertion, **DesignModeler** will re-render the geometry.

2.3-2 Sketching Planes

A sketch must be created on a *sketching plane*, or simply called a *plane*; each plane may contain multiple sketches. In the beginning of a **DesignModeler** session, three planes are automatically created: **XYPlane**, **YZPlane**, and **ZXPlane**. The currently active plane is shown on the toolbar [1]. You can create as many new planes as needed [2]. There are several ways to create a new plane [3]. In this chapter, since we always create sketches on **XYPlane**, we will not discuss how to create sketching planes now and will discuss it in Chapter 4.

[1] Currently active plane.

[2] To create a new plane, click **New Plane**.

[3] There are several ways of creating a new plane. #
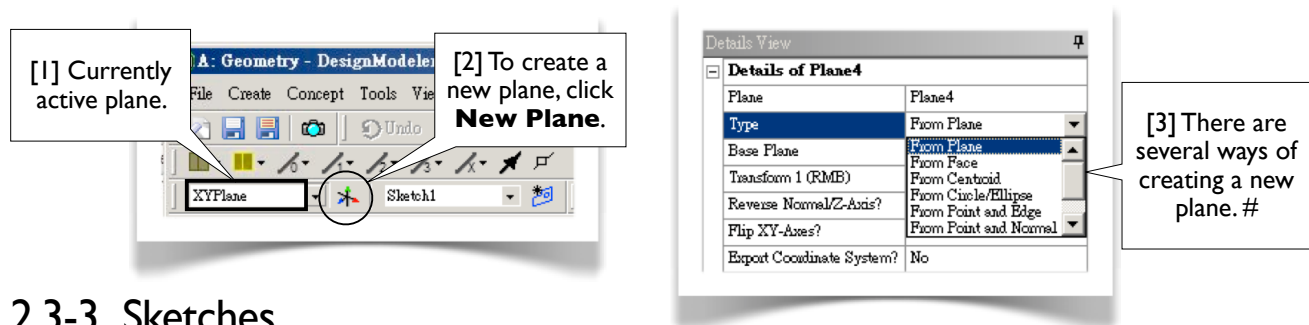
2.3-3 Sketches

A sketch consists of *points* and *edges*; edges may be straight lines or curves. Dimensions and constraints may be imposed on points and edges. As mentioned (2.3-2), multiple sketches may be created on a plane. To create a new sketch on a plane on which there are yet no sketches, you simply switch to **Sketching** mode and draw any geometric entities on it. Later, if you want to add a new sketch on that plane, you have to click **New Sketch** [1]. Exactly one plane and one sketch is active at a time [2-5]; newly created points and edges are added to the active sketch, and newly created sketches are added to the active plane. In this chapter, we almost exclusively work with a single sketch; the only exception is Section 2.6, in which a second sketch is used (2.6-4[1, 2], page 105). When a new sketch is created, it becomes the active sketch. More on creating sketches will be discussed in Chapter 4.

[2] Currently active plane.

[3] Currently active sketch.

[1] To create a new sketch on the active sketching plane, click **New Sketch**.

[4] Active sketching plane can be switched using the pull-down list, or by clicking in **Tree Outline**.

[5] Active sketch can be switched using the pull-down list, or by clicking in **Tree Outline**. #
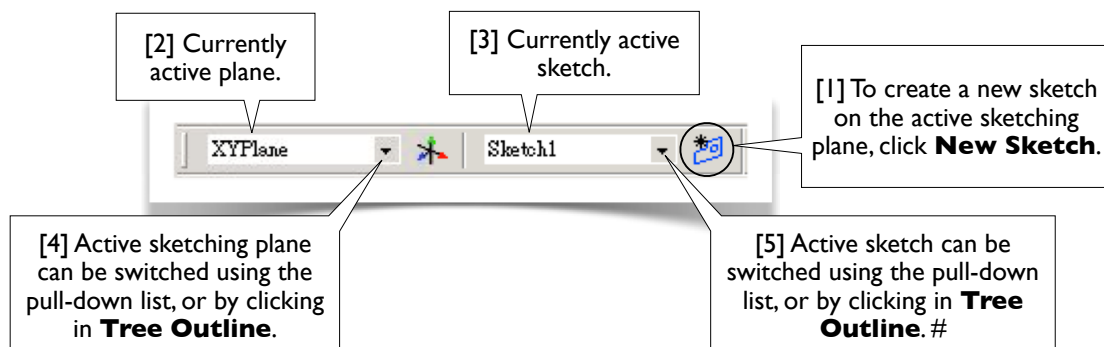
2.3-4 Sketching Toolboxes

When you switch to **Sketching** mode by clicking a mode tab (2.3-1[2], page 80), you see **Sketching Toolboxes** (2.3-1[4], page 80).   There are five **Sketching Toolboxes**: **Draw**, **Modify**, **Dimensions**, **Constraints**, and **Settings** [1-5]. Most of the tools in the toolboxes are self-explained. The best way to learn these tools is to try them out individually. During the tryout, whenever you want to clean up the graphics window, pull-down-select **File/Start Over**. These sketching tools will be explained, starting from 2.3-6 (next page) until the end of this section.

   Before we discuss these sketching tools, let's emphasize again some important tips about sketching.

Pan, Zoom, and Box Zoom

Besides **Pan** tool (2.2-5[3], page 71), a sketch can also be panned by dragging your mouse while holding down both the control key and the middle mouse button (2.1-7[6], page 63). Besides **Zoom** tool (2.2-5[5], page 71) a sketch can also be zoomed in/out by simply rolling your mouse wheel (2.1-7[5], page 63); the cursor position is the "zoom center." Besides **Box Zoom** tool (2.2-5[4], page 71), box zoom can also be done by dragging a rectangle in the graphics window using the right mouse button (2.1-7[4], page 63).   When you get used to these mouse shortcuts, you usually don't need **Pan**, **Zoom**, and **Box Zoom** tools (2.2-5[3, 4, 5], page 71).

Context Menu

While most of the operations can be done by commands in pull-down menus or toolbars, many operations either require or are more efficient using a context menu. The context menu can be popped-up by right-clicking an entity in the graphics window or an object in the model tree. Try to explore whatever is available in the context menu.

Status Bar

The status bar (2.3-1[7], page 80) contains instructions on each operation. Look at the instructions whenever helpful. When a draw tool is in use, the coordinates of your mouse pointer are shown in the status bar.

[1] **Draw** toolbox.

[2] **Modify** toolbox.

[3] **Dimensions** toolbox.

[4] **Constraints** toolbox.

[5] **Settings** toolbox. #
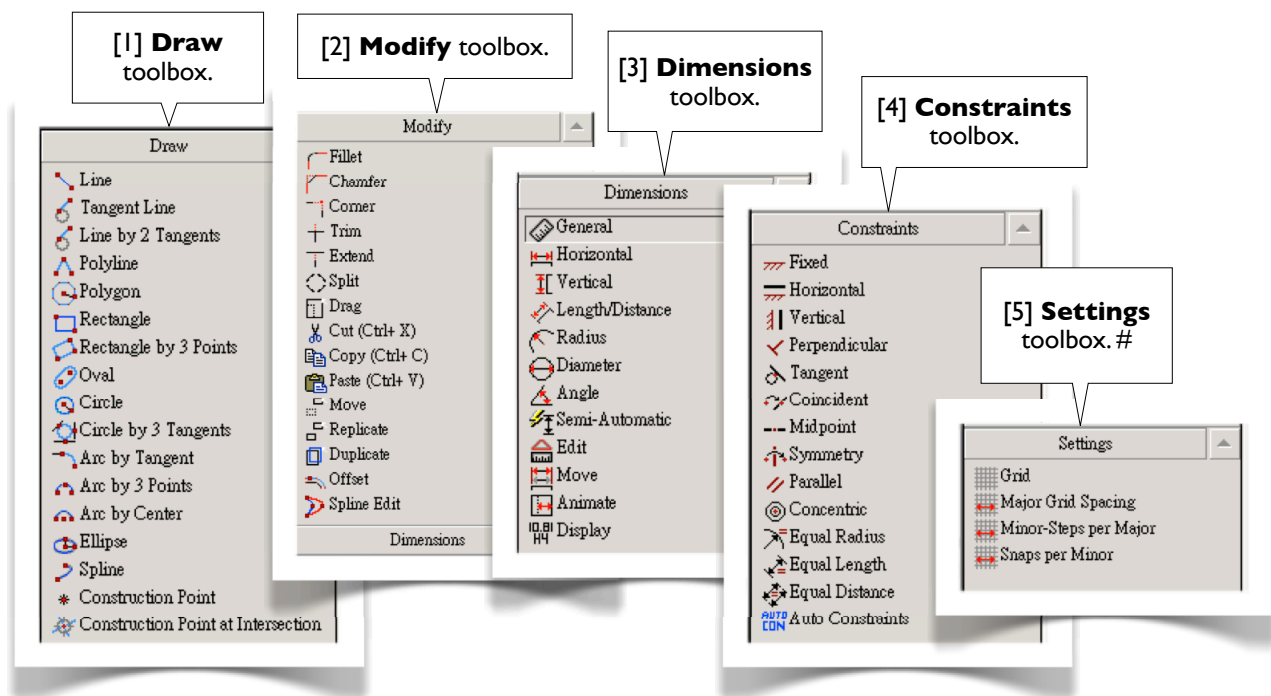
2.3-5 Auto Constraints[Refs 1, 2]

By default, **DesignModeler** is in **Auto Constraints** mode, both globally and locally. **DesignModeler** attempts to detect the user's intentions and tries to automatically impose constraints on sketching entities. The following cursor symbols indicate the kind of constraints that are applied:

C   - The cursor is coincident with a line.
P   - The cursor is coincident with a point.
T   - The cursor is a tangent point.
⊥   - The cursor is a perpendicular foot.
H   - The line is horizontal.
V   - The line is vertical.
//   - The line is parallel to another line.
R   - The radius is equal to another radius.

Both **Global** and **Cursor** modes are based on all entities of the active plane (not just the active sketch). The difference is that **Cursor** mode only examines the entities nearby the cursor, while **Global** mode examines all the entities in the active plane.
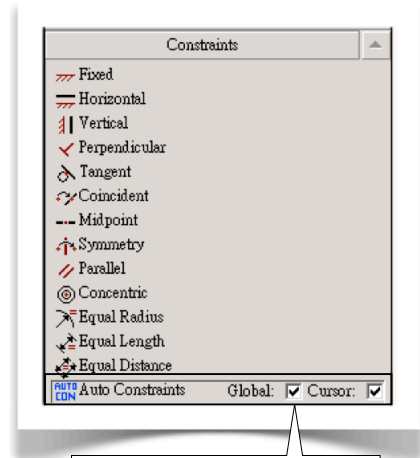
[1] By default, **DesignModeler** is in **Auto Constraints** mode, both globally and locally. #

2.3-6 Draw Tools[Ref 3] [1]

[1] **Draw** toolbox.

Line

Draws a line by two clicks.

Tangent Line

Click a point on a curve (e.g., circle, arc, ellipse, or spline) to create a line tangent to the curve at that point.

Line by 2 Tangents

Click two curves to create a line tangent to these two curves. Click a curve and a point to create a line tangent to the curve and connecting to the point.

Polyline

A polyline consists of multiple straight lines. A polyline must be completed by choosing either **Open End** or **Closed End** from the context menu [2].

Polygon

Draws a regular polygon. The first click defines the center and the second click defines the radius of the circumscribing circle.
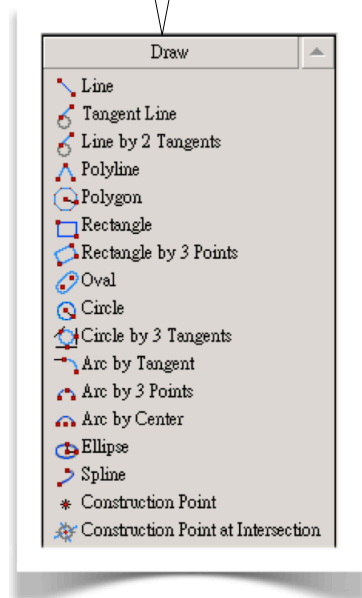
Rectangle by 3 Points

The first two points define one side and the third point defines the other side.

Oval

The first two clicks define two centers, and the third click defines the radius.

Circle

The first click defines the center, and the second click defines the radius.

Circle by 3 Tangents

Select three edges (lines or curves) to create a circle tangent to these three edges.

Arc by Tangent

Click a point (usually an end point) on an edge to create an arc starting from that point and tangent to that edge; click a second point to define the other end and the radius of the arc.

Arc by 3 Points

The first two clicks define the two ends of the arc, and the third click defines a point in-between the ends.

Arc by Center

The first click defines the center, and two additional clicks define two ends.

Ellipse

The first click defines the center, the second click defines the major radius, and the third click defines the minor radius.

Spline

A spline is either rigid or flexible. A flexible spline can be edited or changed by imposing constraints, while a rigid spline cannot. After defining the last point, you must specify an ending condition [3]: either open end or closed end; either with fit points or without fit points.

Construction Point at Intersection

Select two edges, a construction point will be created at the intersection.

[2] A polyline must be completed by choosing either **Open End** or **Closed End** from the context menu.
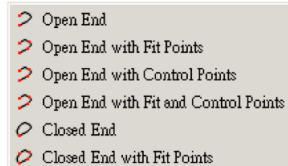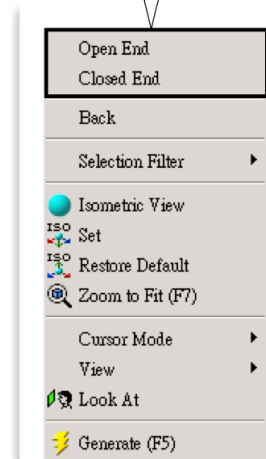
[3] A spline must be complete by specifying an ending condition from the context menu. #

How to delete edges?

To delete edges, select them and choose **Delete** or **Cut** from the context menu. Multiple selection methods (e.g., control-selection or sweep-selection) can be used to select edges. To clean up the graphics window entirely, pull-down-select **File/ Start Over**. A general way of deleting any sketching entities (edges, dimensions, or constraints) is to right-click the entity in **Details View** and issue **Delete**. See 2.3-8[6, 7] (page 88) and 2.3-9[3, 4] (page 89).

How to abort a tool?

Simply press **ESC**.

2.3-7 Modify Tools[Ref 4] [1]

Fillet

Select two edges or a vertex to create a fillet. The radius of the fillet can be specified in the toolbox [2]. Note that this radius value is a weak dimension; i.e., it can be changed by other dimensions or constraints.

Chamfer

Select two edges or a vertex to create an equal-length chamfer. The sizes of the chamfer can be specified in the toolbox.

Corner

Select two edges, and the edges will be trimmed or extended up to the intersection point and form a sharp corner. The clicking points decide which sides to be trimmed.

Trim

Select an edge, and the portion of the edge will be removed up to its intersection with another edge, axis, or point.

Extend

Select an edge, and the edge will be extended up to an edge or axis.

Split

This tool splits an edge into several segments depending on the options from the context menu [3]. **Split Edge at Selection**: Click an edge, and the edge will be split at the clicking point. **Split Edges at Point**: Click a point, and all the edges passing through that point will be split at that point. **Split Edge at All Points**: Click an edge, the edge will be split at all points on the edge. **Split Edge into n Equal Segments**: Click an edge and specify a value *n*, and the edge will be split equally into *n* segments.

Drag

Drags a point or an edge to a new position. All the constraints and dimensions are preserved.

Copy

Copies the selected entities to a "clipboard." A **Paste Handle** must be specified using one of the methods in the context menu [4]. After completing this tool, **Paste** tool is automatically activated.

[1] **Modify** toolbox.

Modify
- Fillet
- Chamfer
- Corner
- Trim
- Extend
- Split
- Drag
- Cut
- Copy
- Paste
- Move
- Replicate
- Duplicate
- Offset
- Spline Edit
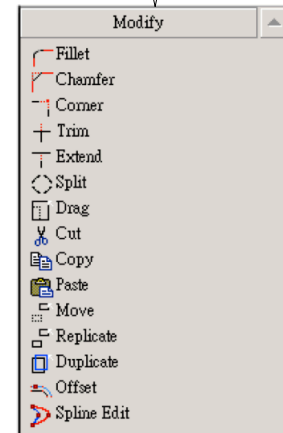
[2] Radii of fillets can be suggested; it is a "weak" dimension.

Modify
- Fillet   Radius: 2.5 mm
- Chamfer
- Corner
- Trim
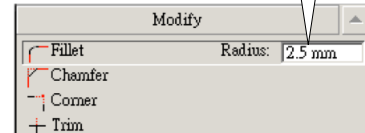
[3] Options of **Split** in the context menu.

✓ Split Edge at Selection
Split Edges at Point
Split Edge at All Points
Split Edge into n Equal Segments
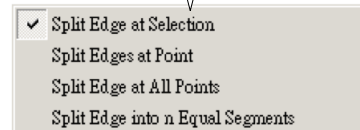
[4] Options of **Copy** in the context menu.

Clear Selection
End / Set Paste Handle
End / Use Plane Origin as Handle
End / Use Default Paste Handle
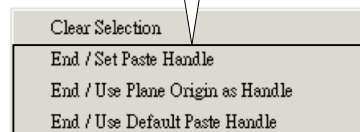
Cut

Similar to **Copy**, except that the copied entities are removed.

Paste

Pastes the entities in the "clipboard" to the graphics window. The click defines the point at which the **Paste Handle** positions. Many options can be chosen from the context menu [5], where the rotating angle r and the scaling factor f can be specified in the toolbox.

Move

Equivalent to a **Cut** followed by a **Paste**. (The original is removed.)

Replicate

Equivalent to a **Copy** followed by a **Paste**. (The original is preserved.)

Duplicate

Similar to **Replicate**. However, **Duplicate** copies entities to the same position in the active plane. **Duplicate** can be used to copy features of a solid body or plane boundaries.

Offset

Creates a set of edges that are offset by a distance from an existing set of edges.

Spline Edit

Used to modify flexible splines. You can insert, delete, drag the fit points, etc [6]. For details, see the reference[Ref 4].

2.3-8 Dimensions Tools[Ref 5] [1]

General

Allows creation of any of the dimension types, depending on what edge and context-menu options are selected. If the selected edge is a straight line, the default dimension is its length [2]. If the selected edge is a circle or arc, the default dimension is its radius [3].

[5] Options of **Paste** in the context menu.

Rotate by r Degrees
Rotate by -r Degrees
Flip Horizontal
Flip Vertical
Scale by factor f
Scale by factor 1/f
Paste at Plane Origin
Change Paste Handle

[6] Option of **Spline Edit** in the context menu. #

Select New Spline

Re-fit Spline
Create Missing Fit Points
Delete New Fit Points
Create Missing Control Points

Drag Fit Point
Drag Control Point

Insert Fit Point
Delete Fit Point

[1] **Dimension** toolbox.

Dimensions
General
Horizontal
Vertical
Length/Distance
Radius
Diameter
Angle
Semi-Automatic
Edit
Move
Animate
Display

Horizontal

Select two points to specify a horizontal dimension. If you select an edge (instead of a point), the end point near the click will be picked.

Vertical

Similar to **Horizontal**.

Length/Distance

Select two points to specify a distance dimension. You also can select a point and a line to specify the distance between the point and the line.

Radius

Select a circle or arc to specify a radius dimension. If you select an ellipse, the major (or minor) radius will be specified.

Diameter

Select a circle or arc to specify a diameter dimension.

Angle

Select two lines to specify an angle. By varying the selection order and location, you can control which angle you are dimensioning. The end of the lines that you select will be the direction of the hands, and the angle is measured counterclockwise from the first selected hand to the second. Before you click to locate the dimension, if the angle is not what you want, repeatedly choose **Alternate Angle** from the context menu until a correct angle is selected [4].

Semi-Automatic

This tool displays a series of dimensions automatically to help you fully dimension the sketch.

Edit

Click a dimension and this tool allows you to change its name or values.

Move

Click a dimension and move it to a new position.

Animate

Click a dimension to show the animated effects.

Display

Allows you to decide whether to display dimension names, values, or both. In this book, we always choose to display dimension values [5] rather than dimension names.

[2] Options of **General** in the context menu if you select a line.

Horizontal
Vertical
Length/Distance
Angle
Select Pair

[3] Options of **General** in the context menu if you select a circle or arc.

Radius
Diameter
Select Pair

[4] Repeatedly choose **Alternate Angle** from the context menu until the correct angle is selected.

Alternate Angle
Do Not Move with geometry
Edit Name/Value

Dimensions

General
Horizontal
Vertical
Length/Distance
Radius
Diameter
Angle
Semi-Automatic
Edit
Move
Animate
Display   Name: ☐ Value: ☑
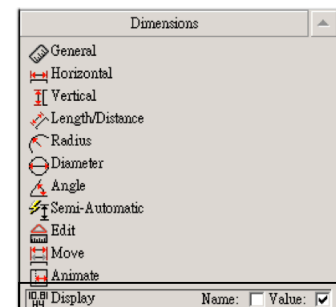
[5] In this book, we always display dimension values.

How to delete dimensions?

To delete a dimension, select the dimension in **Details View**, and choose **Delete** from the context menu [6]. You can delete ALL dimensions by right-clicking **Dimensions** in **Details View** [7].

[7] You can delete all dimensions by right-clicking **Dimensions**. #

[6] You can delete a dimension by right-clicking it in **Details View**.
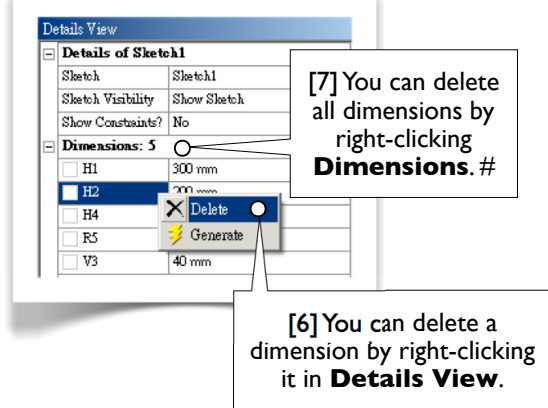
2.3-9　Constraints Tools[Ref 6] [1]

Fixed

Applies on an edge to make it fully constrained if **Fix Endpoints** is selected [2].　If **Fix Endpoints** is not selected, then the edge's endpoints can be changed, but not the edge's position and slope.

Horizontal

Applies to a line to make it horizontal.

Vertical

Applies to a line to make it vertical.

Perpendicular

Applies to two edges to make them perpendicular to each other.

Tangent

Applies to two edges, one of which must be a curve, to make them tangent to each other.

Coincident

Select two points to make them coincident.　Or, select a point and an edge to make the edge or its extension pass through the point. There are other possibilities, depending on how you select the entities.

Midpoint

Select a line and a point to make the midpoint of the line coincide with the point.

Symmetry

Select a line or an axis, as the line of symmetry, and then select two entities to make them symmetric about the line of symmetry.

[1] **Constraints** toolbox.
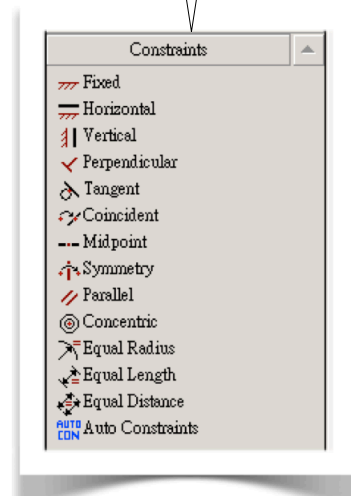
[2] If **Fix Endpoints** is selected, the edge will be fully constrained.
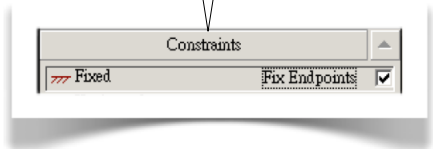
Parallel

Applies to two lines to make them parallel to each other.

Concentric

Applies to two curves, which may be circle, arc, or ellipse, to make their centers coincident.

Equal Radius

Applies to two curves, which must be circle or arc, to make their radii equal.

Equal Length

Applies to two lines to make their lengths equal.

Equal Distance

Applies to two distances to make them equal. A distance can be defined by selecting two points, two parallel lines, or one point and one line.

Auto Constraints

Allows you to turn on/off **Auto Constraints** (2.3-5, page 83).

How to delete constraints?

By default, constraints are not displayed in **Details View**. To display constraints, select **Yes** for **Show Constraints?** in **Details View** [3]. To delete a constraint, right-click the constraint and issue **Delete** [4].

---

[3] Select **Yes** for **Show Constraints?** in **Details View**.

[4] Right-click a constraint and issue **Delete**. #
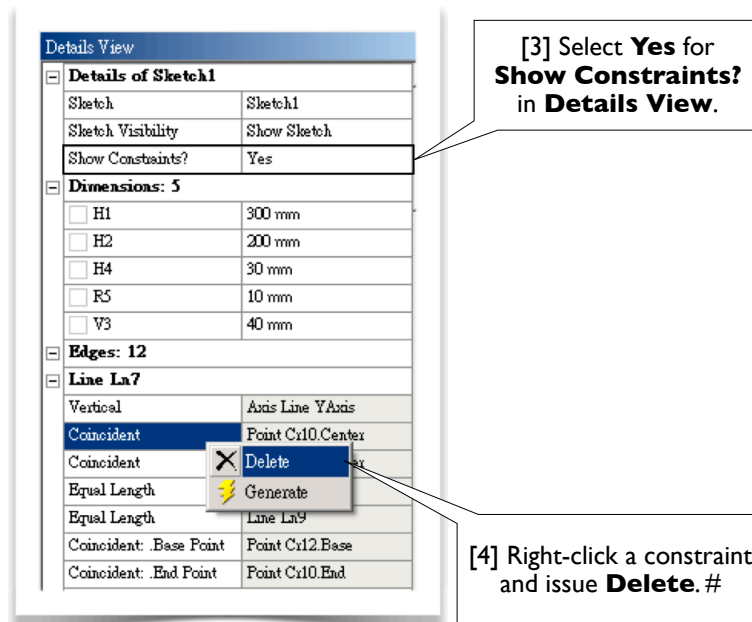
2.3-10 Settings Tools[Ref 7] [1]

Grid

Allows you to turn on/off grid visibility and snap capability [2, 3]. The grid is not required to enable snapping.

Major Grid Spacing

Allows you to specify **Major Grip Spacing** [4, 5] if **Show in 2D** is turned on.

Minor-Steps per Major

Allows you to specify **Minor-Steps per Major** [6, 7] if **Show in 2D** is turned on.

Snaps per Minor

Allows you to specify **Snaps per Minor** [8] if **Snap** is turned on.

[1] **Settings** toolbox.

[2] Check here to turn on **Show in 2D**.

[3] Check here to turn on **Snap**.

[4] If **Show in 2D** is turned on, specify **Major Grid Spacing** here.

[5] **Major Grid Spacing** = 10 mm.

[6] If **Show in 2D** is turned on, specify **Minor-Steps per Major** here.

[7] **Minor-Steps per Major** = 2.

[8] If **Snap** is turned on, specify **Snaps per Minor** here. #

40 mm
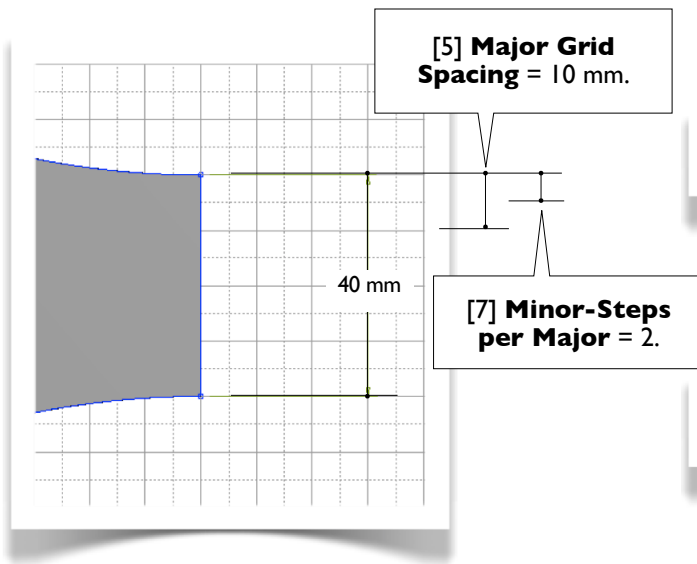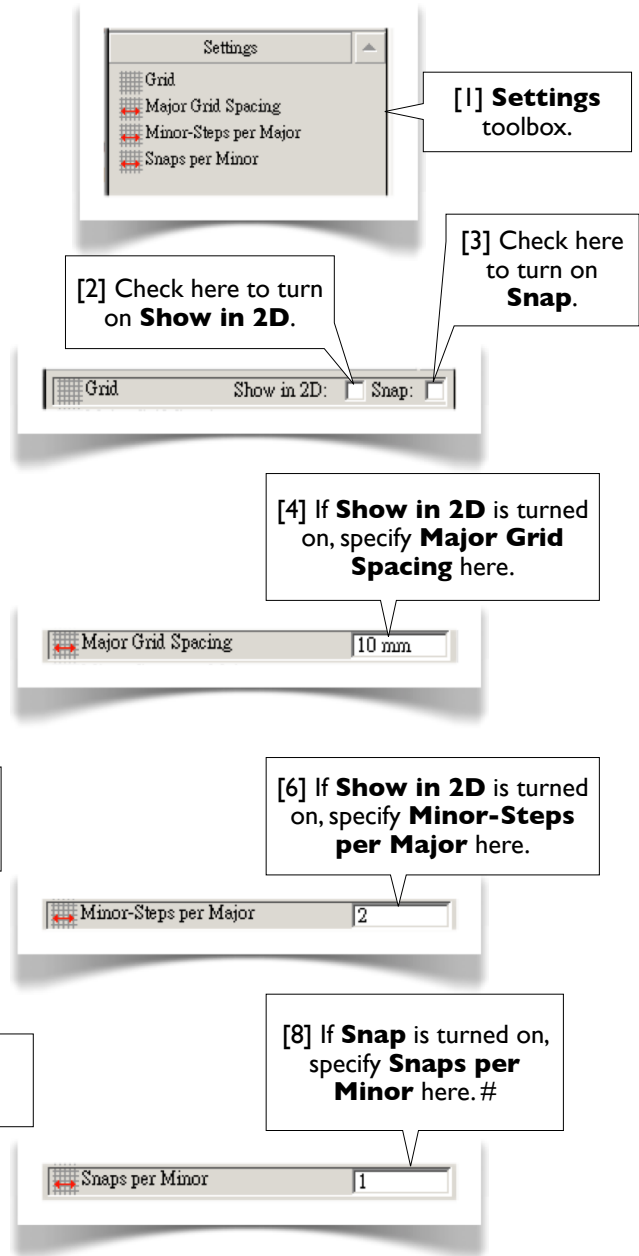
References

1.   ANSYS Documentation//DesignModeler User's Guide//2D Sketching//Auto Constraints
2.   ANSYS Documentation//DesignModeler User's Guide//2D Sketching//Constraints Toolbox//Auto Constraints
3.   ANSYS Documentation//DesignModeler User's Guide//2D Sketching//Draw Toolbox
4.   ANSYS Documentation//DesignModeler User's Guide//2D Sketching//Modify Toolbox
5.   ANSYS Documentation//DesignModeler User's Guide//2D Sketching//Dimensions Toolbox
6.   ANSYS Documentation//DesignModeler User's Guide//2D Sketching//Constraints Toolbox
7.   ANSYS Documentation//DesignModeler User's Guide//2D Sketching//Settings Toolbox

Section 2.4

M20x2.5 Threaded Bolt
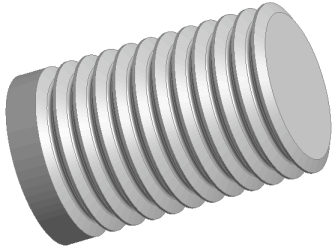
2.4-1 About the M20x2.5 Threaded Bolt[Refs 1, 2]

In this section, we'll create a sketch, revolving the sketch 360° to generate a 3D solid body, a body representing a portion of an M20x2.5 threaded bolt [1-6]. We will use this sketch in Section 3.2 again to generate a 2D solid body, which is then used for a static structural simulation.

[2] Metric system.

[3] Major diameter d = 20 mm.

[4] Pitch p = 2.5 mm.

[6] Calculation of detail sizes. #

$$H = (\sqrt{3}/2)p = 2.165 \text{ mm}$$
$$d_1 = d - (5/8)H \times 2 = 17.294 \text{ mm}$$

M20x2.5

[5] Thread standards in metric system.

d

d_1

p

$11 \times p = 27.5$

32

$\frac{H}{4}$

H

$\frac{H}{8}$

p

External threads (bolt)

60°

Internal threads (nut)

[1] The threaded bolt created in this exercise.

Minor diameter of internal thread d_1

Major diameter d
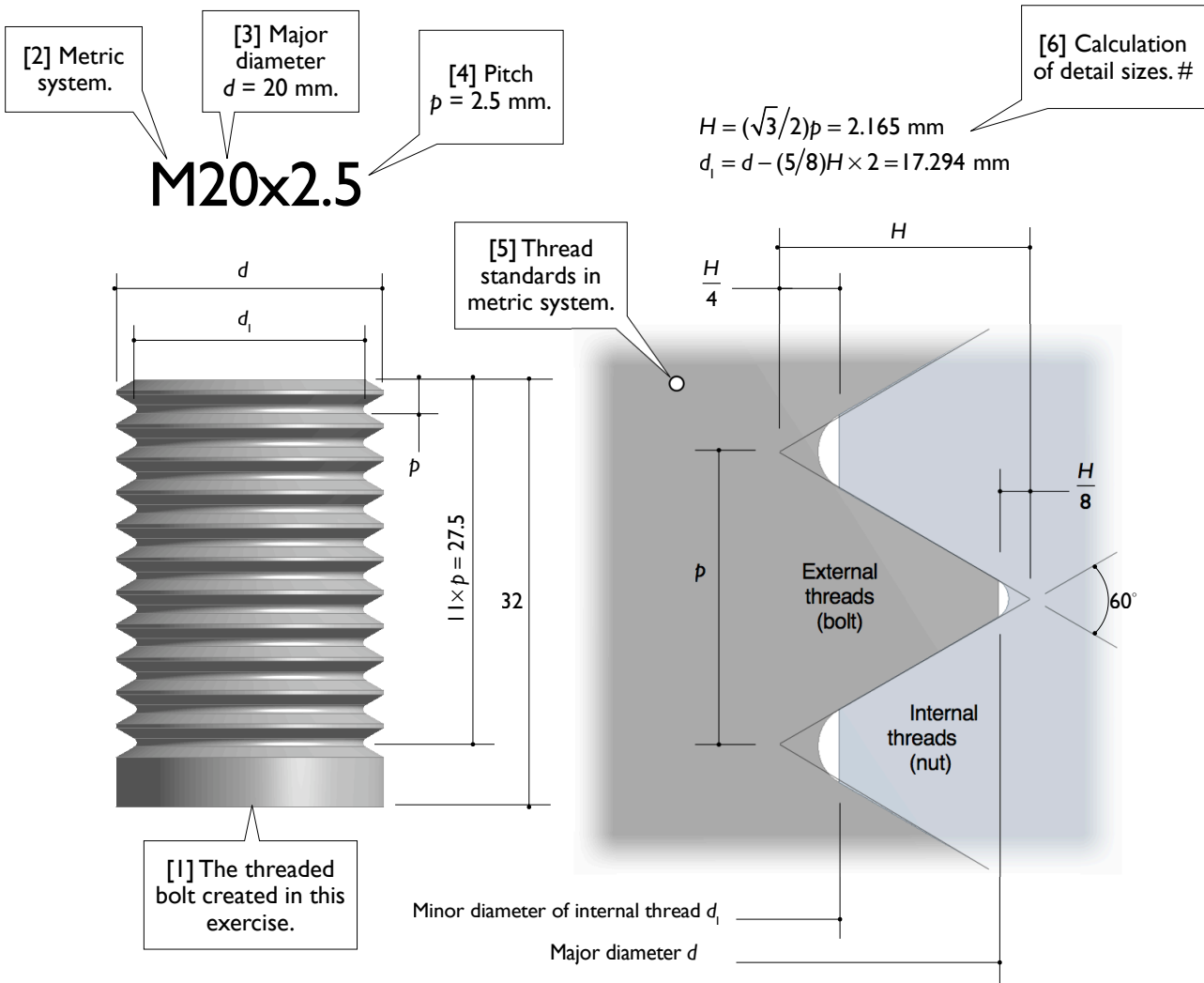
2.4-2 Draw a Horizontal Line

Launch **Workbench** and create a **Geometry** system. Save the project as **Threads**. Start up **DesignModeler**. Select **Millimeter** as the length unit.

On **XYPlane**, draw a horizontal line. Specify the dimensions (8.647 mm and 27.5 mm) as shown [1].

[1] Draw a horizontal line with dimensions like this. #
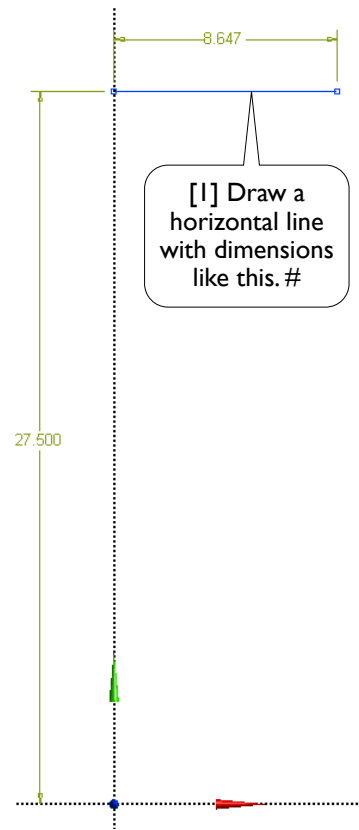
2.4-3 Draw a Polyline

Draw a polyline of 3 segments and specify dimensions (30°, 60°, 60°, 0.541 mm, and 2.165 mm) as shown [1-2]. To specify angle dimensions, please see **Angle**, 2.3-8, page 87.

[1] This is the line drawn in 2.4-2[1].

[2] Draw a polyline of 3 segments. #
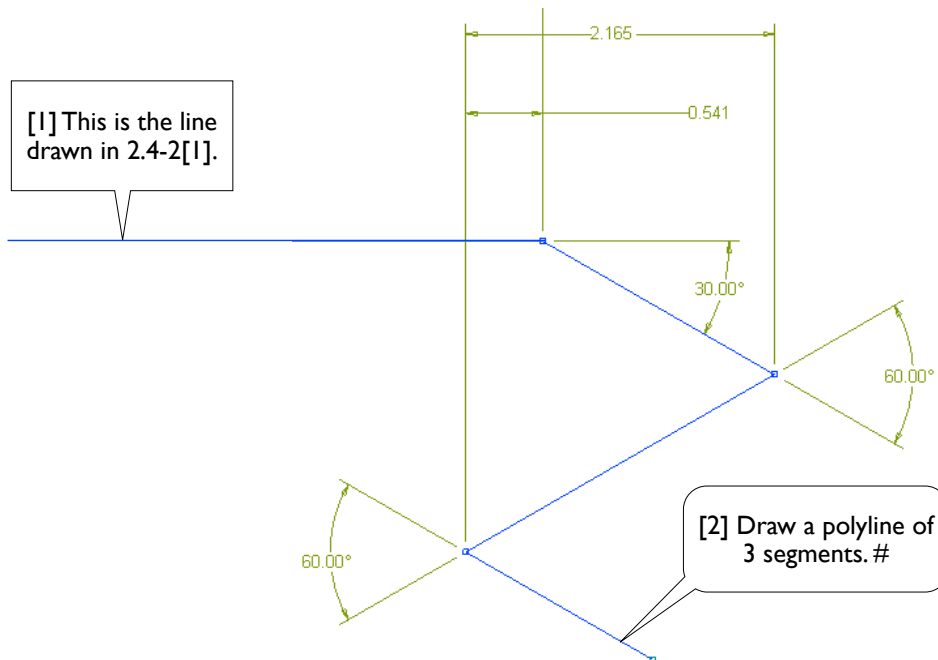
2.4-4 Draw Fillets

Draw a vertical line and specify its position [1].
Create a fillet and specify its position [2-3].

2.165

0.541

[1] Draw a vertical
line and specify its
position (0.271 mm).

30.00°

[2] Create a fillet (also
see [3]) and specify its
position (0.541 mm).

60.00°

0.541

[3] Before creating fillets,
specify an approximate
radius value, say 0.5 mm. #

0.271

60.00°

Modify

Fillet   Radius: 0.5 mm

2.4-5 Trim Away Unwanted Segments

2.165

0.541

30.00°

60.00°

0.541

0.271

60.00°

[1] Trim away these
three segments.

2.165

0.541

30.00°

60.00°

0.541

0.271

[2] The sketch after
trimming. #

2.4-6 Replicate 10 Times

Select the **Replicate** tool and select all segments except the horizontal line (totaling 4 segments), and replicate 10 times. Set the **Paste Handle** as shown [1]. You may need to use **Selection Filter: Points** [2] (also see 2.2-8[7-8], page 73).
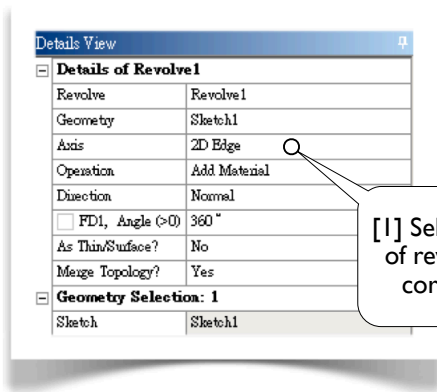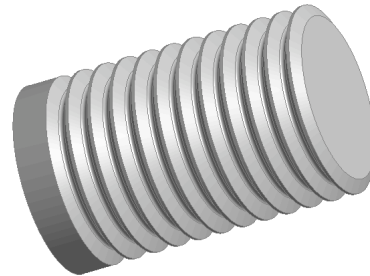
[2] **Selection Filter: Points**. #

[1] Set **Paste Handle** at this point (also see [2]).

8.647

2.165

0.541

0.271

30.00°   60.00°

27.500
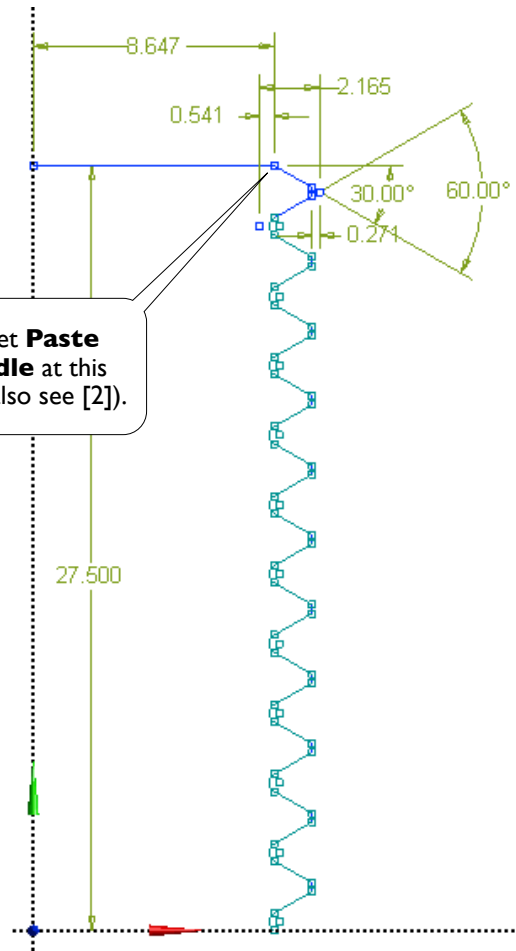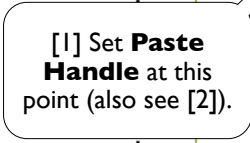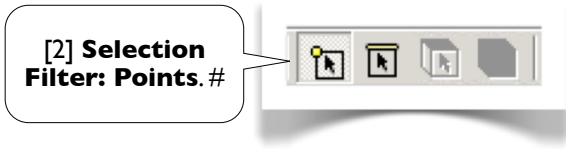
2.4-7 Complete the Sketch

Follow steps [1-5] to complete the sketch.

8.647

2.165

0.541

0.271

30.00°   60.00°

[2] Draw this vertical line, which passes through the origin.

27.500

[5] Draw this horizontal line. #

[1] Create this segment, using **Replicate**.

[3] Specify this dimension (4.5 mm).

4.500

[4] Draw this vertical line. You may need to trim away extra length later after the next step.
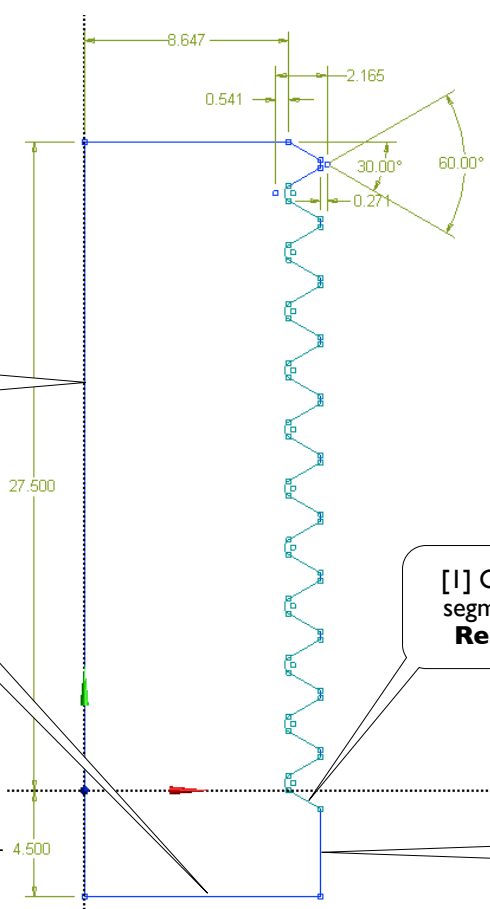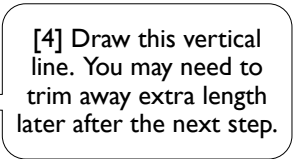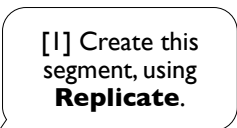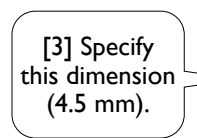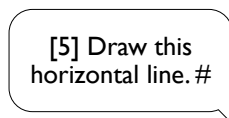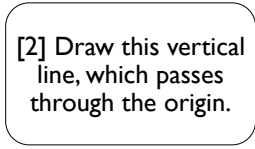
2.4-8 Revolve to Create 3D Solid

Click **Revolve** to generate a solid of revolution. Select the Y-axis as the axis of revolution [1]. Remember to click **Generate**.

   Save the project and exit from **Workbench**. We will resume this project in Section 3.2.


Details View	
Details of Revolve1	
Revolve	Revolve1
Geometry	Sketch1
Axis	2D Edge
Operation	Add Material
Direction	Normal
☐ FD1, Angle (>0)	360 °
As Thin/Surface?	No
Merge Topology?	Yes
Geometry Selection: 1	
Sketch	Sketch1

[1] Select the Y-axis as the **Axis** of revolution. (Make sure you correctly select the Y-axis.)

References

1. Zahavi, E., *The Finite Element Method in Machine Design*, Prentice-Hall, 1992; Chapter 7. Threaded Fasteners.
2. Deutschman, A. D., Michels, W. J., and Wilson, C. E., *Machine Design: Theory and Practice*, Macmillan Publishing Co., Inc., 1975; Section 16-6. Standard Screw Threads.
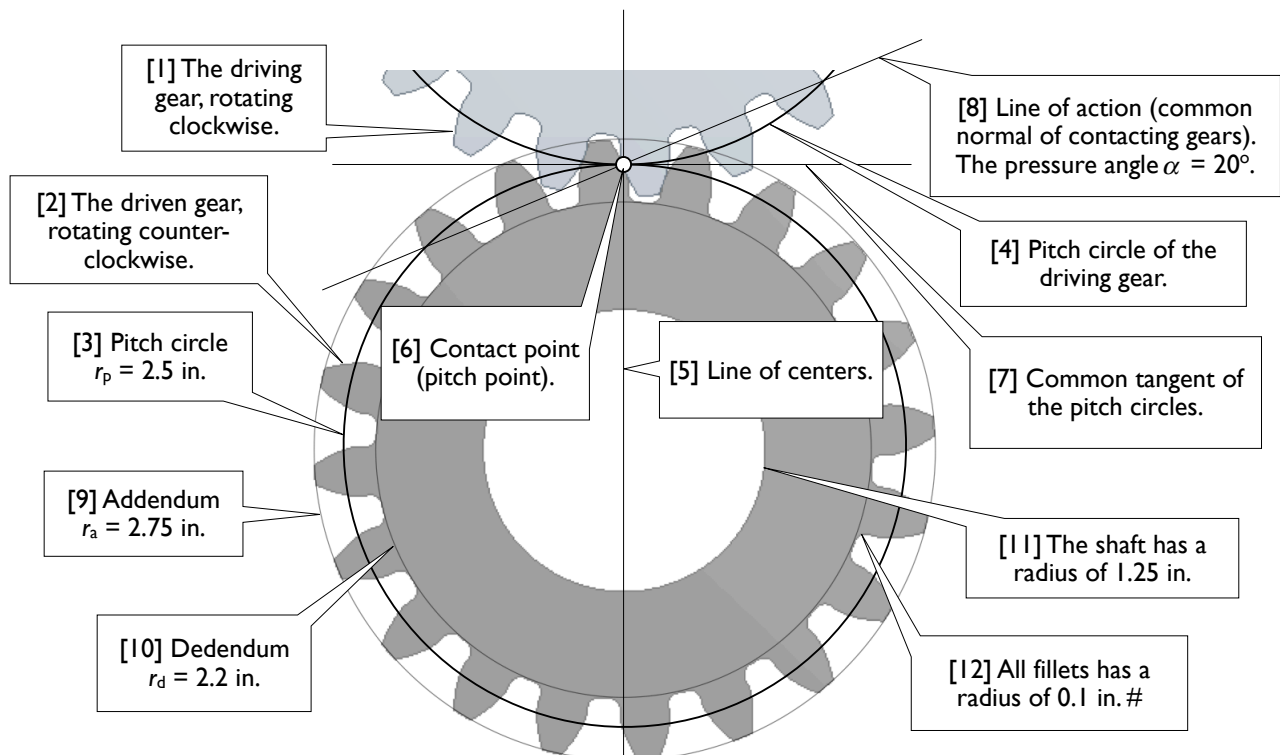
Section 2.5

Spur Gears
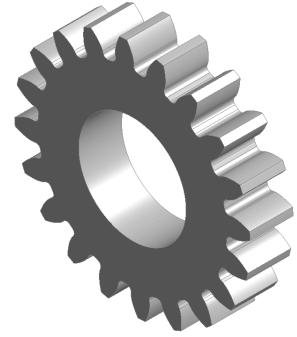
Subsections 2.5-1 and 2.5-2 detail the geometry of the spur gear used in this section. If you are not interested in these geometric details for now, you may skip them and jump directly to 2.5-3 (page 98).

2.5-1 About the Spur Gears[Refs 1, 2]

The figure below shows a pair of identical spur gears in mesh [1-4]. Spur gears have their teeth cut parallel to the axis of the shaft on which the gears are mounted, transmitting power between the parallel shafts. To maintain a constant angular velocity ratio, two meshing gears must satisfy a fundamental law of gearing: the shape of the teeth must be such that the common normal [8] at the point of contact between two teeth must always pass through a fixed point on the line of centers[Ref 1] [5]. This fixed point is called the *pitch point* [6].

The angle between the line of action [8] and the common tangent of the pitch circles [7] is known as the *pressure angle*. The parameters defining a spur gear are its pitch radius (r_p = 2.5 in) [3], pressure angle (α = 20°) [8], and number of teeth (N = 20). The teeth are cut with a radius of addendum r_a = 2.75 in [9] and a radius of dedendum r_d = 2.2 in [10]. The shaft has a radius of 1.25 in [11]. All fillets have a radius of 0.1 in [12]. The thickness of the gear is 1.0 in.

[1] The driving gear, rotating clockwise.

[2] The driven gear, rotating counter-clockwise.

[3] Pitch circle r_p = 2.5 in.

[9] Addendum r_a = 2.75 in.

[10] Dedendum r_d = 2.2 in.

[6] Contact point (pitch point).

[5] Line of centers.

[8] Line of action (common normal of contacting gears). The pressure angle α = 20°.

[4] Pitch circle of the driving gear.

[7] Common tangent of the pitch circles.

[11] The shaft has a radius of 1.25 in.

[12] All fillets has a radius of 0.1 in. #

2.5-2 About Involute Curves[Refs 1, 2]

To satisfy the fundamental law of gearing, gear profiles are usually cut to an *involute curve* [1], which may be constructed by wrapping a string (*BA*) around a *base circle* [2], and then tracing the path (*A-P-F*) of a point (*A*) on the string.

 Given the gear's pitch radius r_p and pressure angle α, we can calculated the coordinates of each point on the involute curve. For example, let's calculate the polar coordinates (r, θ) of an arbitrary point *A* [3] on the involute curve. Note that *BA* and *CP* are tangent lines of the base circle, and *F* is a foot of perpendicular.

 Since *APF* is an involute curve and $\overset{\frown}{BCDEF}$ is the base circle, by the definition of involute curve,

$$\overline{BA} = \overset{\frown}{BCDEF} \qquad (1)$$

$$\overline{CP} = \overset{\frown}{CDEF} \qquad (2)$$

In $\triangle OCP$,

$$r_b = r_p \cos\alpha \qquad (3)$$

In $\triangle OBA$,

$$r = \frac{r_b}{\cos\phi} \qquad (4)$$

Or,

$$\phi = \cos^{-1}\frac{r_b}{r} \qquad (5)$$

[3] An arbitrary point on the involute curve.

[1] Involute curve.

[4] Contact point *P* (pitch point).

[5] Line of action.

[6] Common tangent of pitch circles.

[7] Line of centers; the length *OP* is the pitch radius r_p. #

[2] Base circle.
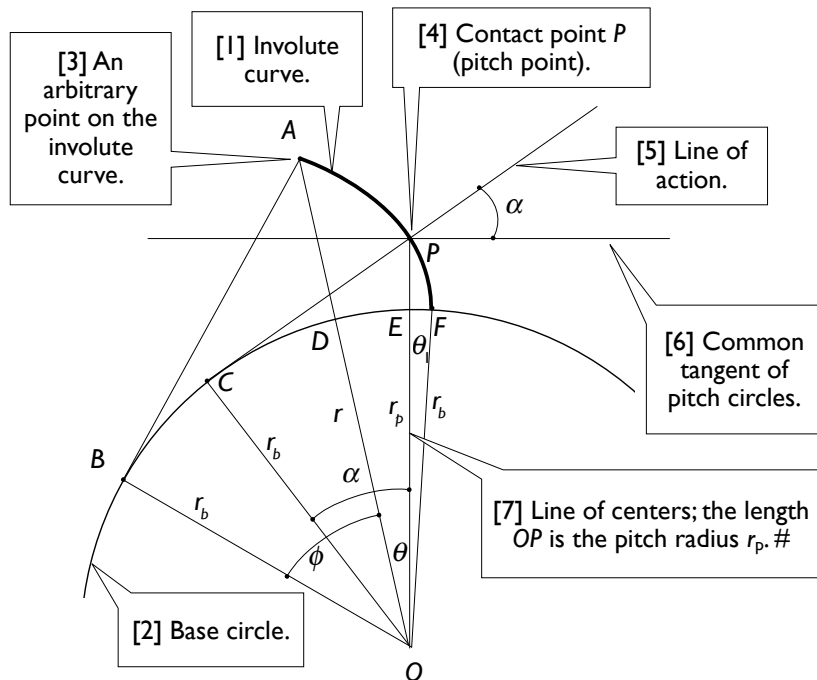
To calculate θ, we notice that

$$\overset{\frown}{DE} = \overset{\frown}{BCDEF} - \overset{\frown}{BCD} - \overset{\frown}{EF}$$

Dividing the equation with r_b and using Eq. (1),

$$\frac{\overset{\frown}{DE}}{r_b} = \frac{\overline{BA}}{r_b} - \frac{\overset{\frown}{BCD}}{r_b} - \frac{\overset{\frown}{EF}}{r_b}$$

If radian is used, then the above equation can be written as

$$\theta = (\tan\phi) - \phi - \theta_1 \qquad (6)$$

The last term θ_1 is the angle $\angle EOF$, which can be calculated by dividing Eq. (2) with r_b,

$$\frac{\overline{CP}}{r_b} = \frac{\overset{\frown}{CDEF}}{r_b}, \text{ or } \tan\alpha = \alpha + \theta_1, \text{ or}$$

$$\theta_1 = (\tan\alpha) - \alpha \qquad (7)$$

We'll show how to calculate polar coordinates (r, θ) using Eqs. (3-7). The polar coordinates then can be easily transformed to rectangular coordinates, using *O* as origin and *OP* as *y*-axis,

$$x = -r\sin\theta, \quad y = r\cos\theta \qquad (8)$$

Numerical Calculations of Coordinates

In our case, the pitch radius $r_p = 2.5$ in, and pressure angle $\alpha = 20°$; from Eqs. (3) and (7) respectively,

$$r_b = 2.5\cos 20° = 2.349232 \text{ in}$$

$$\theta_l = \tan 20° - \frac{20°}{180°}\pi = 0.01490438 \text{ (rad)}$$

The table below lists the calculated coordinates. The values in the first column (r) are chosen such that, except the pitch point ($r = 2.5$ in), the intermediate points are at the quarter points between r_b ($r = 2.349232$ in) and r_a ($r = 2.75$ in). Also note that, when using Eqs. (6) and (7), radians are used as the unit of angles; in the table below, however, degrees are used.

r in.	ϕ Eq. (5), degrees	θ Eq. (6), degrees	$x = -r\sin\theta$ in.	$y = r\cos\theta$ in.
2.349232	0.000000	-0.853958	-0.03501	2.3490
2.449424	16.444249	-0.387049	-0.01655	2.4494
2.500000	20.000000	0.000000	0.00000	2.5000
2.549616	22.867481	0.442933	0.01971	2.5495
2.649808	27.555054	1.487291	0.06878	2.6489
2.750000	31.321258	2.690287	0.12908	2.7470

2.5-3 Draw an Involute Curve

Launch **Workbench**. Create a **Geometry** system. Save the project as **Gear**. Start up **DesignModeler**. Select **Inch** as the length unit. Start to draw sketch on the **XYPlane**.

In the **Draw** toolbox, select **Construction Point**, draw 6 points and specify dimensions as shown. Note that the vertical dimensions are measured from the X-axis and the pitch point [1] is coincident with the Y-axis.

Connect these six points using the **Spline** tool in the **Draw** toolbox, leave **Flexible** option on, and finish the spline with **Open End**.

It is equally good that you draw the spline by using the **Spline** tool directly without first creating construction points. Select **Open End with Fit Points** from the context menu at the end of the **Spline** tool. After dimensioning each point, use the **Spline Edit** tool to edit the spline and select **Re-fit Spline** [2] from the context menu to smooth out the spline.

Re-fit Spline
Create Missing Fit Points
Delete New Fit Points
Create Missing Control Points

[2] Re-fit spline. #

[1] The pitch point is on the Y-axis.

0.12908
0.06878
0.01971
-0.01655
-0.03501

2.747
2.6489
2.5495
2.5
2.4494
2.349
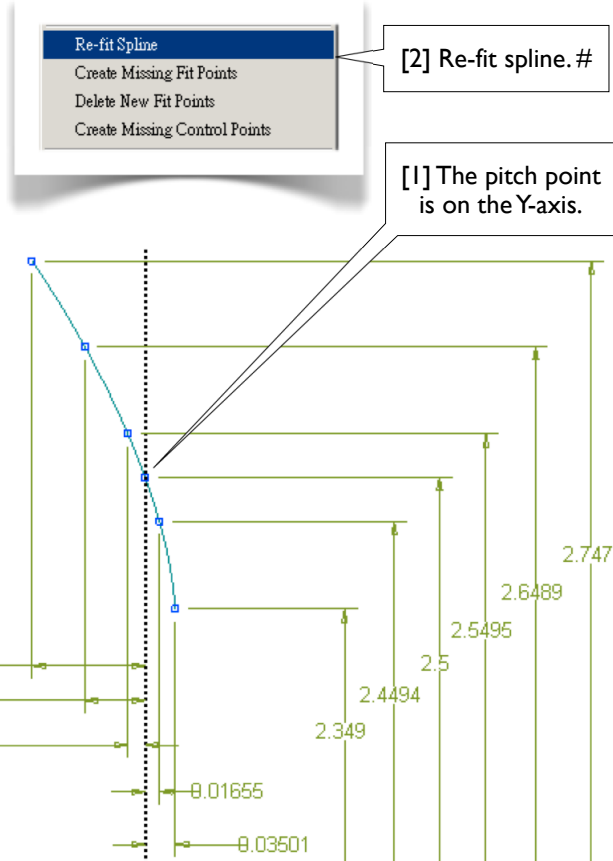
2.5-4 Draw Circles

Draw three circles using the **Circle** tool in the **Draw** toolbox [1-3]. Let the addendum circle "snap" to the outermost construction point [3]. Specify radii for the shaft circle (1.25 in) and the dedendum circle (2.2 in).

[3] Let the addendum circle "snap" to the outermost construction point. #

[2] Dedendum circle.

[1] The shaft circle.

R1.25

R2.2
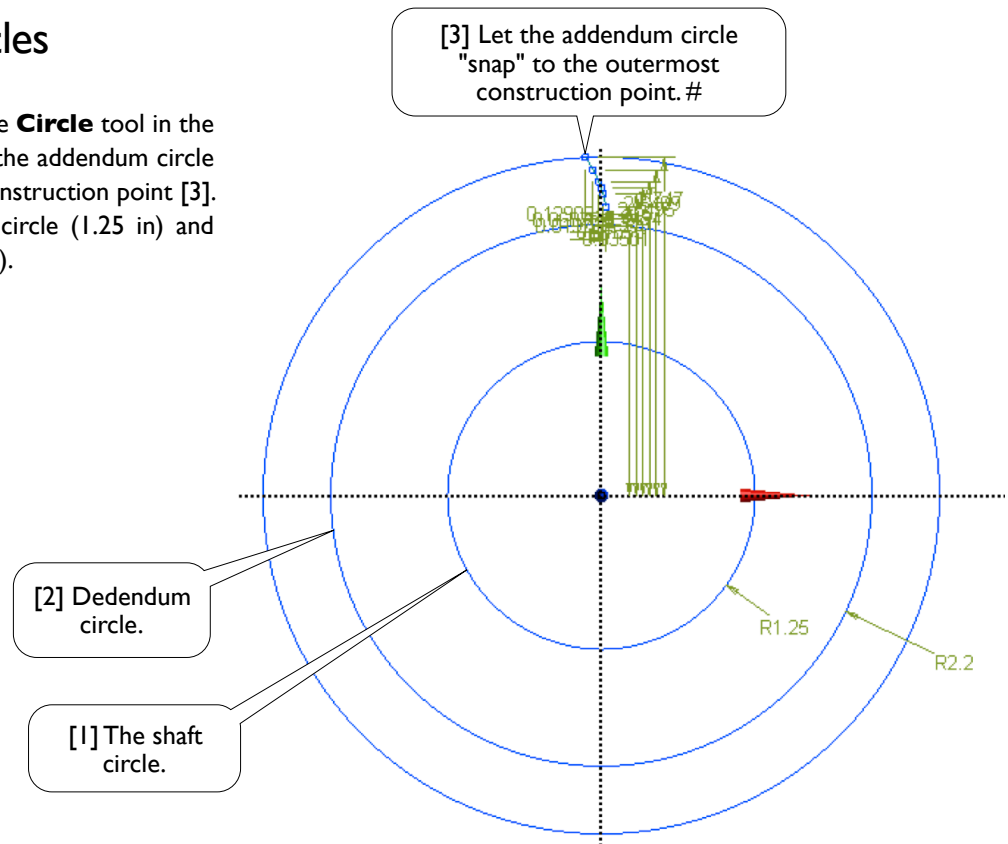
2.5-5 Complete the Tooth Profile

Draw a line from the lowest construction point to the dedendum circle, and make it perpendicular to the dedendum circle by using the **Perpendicular** tool in the **Constraints** toolbox [1-3]. When drawing the line, avoid a **V** auto-constraint (since this line is NOT vertical). Draw a fillet [4] of radius 0.1 in to complete the profile of a tooth.

Sometimes, turning off **Display Plane** may be helpful to work on the graphics window [5]. In this case, all the dimensions referring to the plane axes disappear.

[1] The lowest construction point.

[3] Make this line perpendicular to the dedendum circle.

[4] Draw a fillet of radius 0.1 in.

[2] The dedendum circle.

[5] Turn off **Display Plane** to clear up the graphics window. #
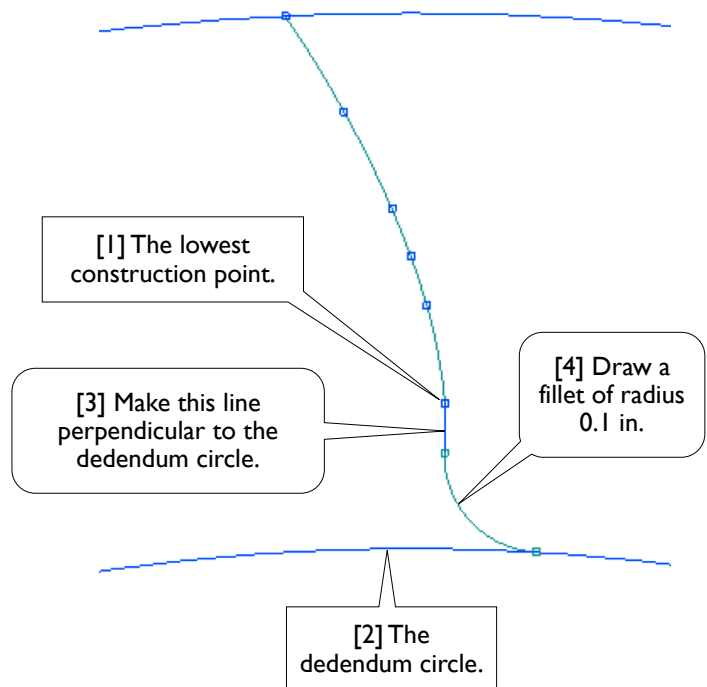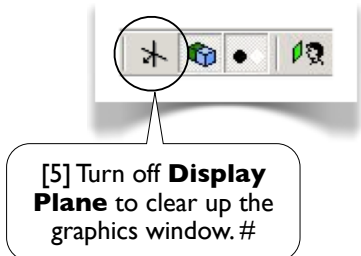
2.5-6 Replicate the Profile

Select the **Replicate** tool, type 9 (degrees) for **r**. Select the profile (3 segments), **End/ Use Plane Origin as Handle**, **Flip Horizontal**, **Rotate by r**, and **Paste at Plane Origin** [1]. End **Replicate** tool by pressing **ESC**.

Note that the gear has 20 teeth, each spanning 18 degrees. The angle between the two pitch points is 9 degrees.

[1] Replicated profile.

[2] Pitch point. #
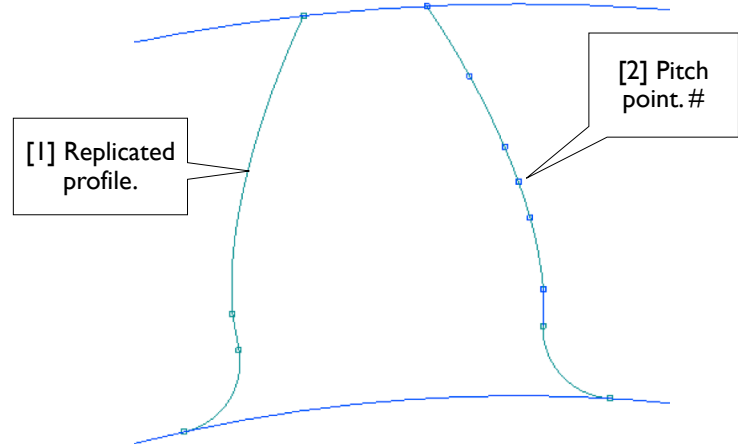
2.5-7 Replicate the Tooth 19 Times

Click **Replicate** tool again, type 18 (degrees) for **r**. Select both left and right profiles (6 segments), **End/ Use Plane Origin as Handle**, **Rotate by r**, and **Paste at Plane Origin**. Repeat the last two steps (rotate and paste) until completing a full circle (totaling 20 teeth).

R1.25

R2.2
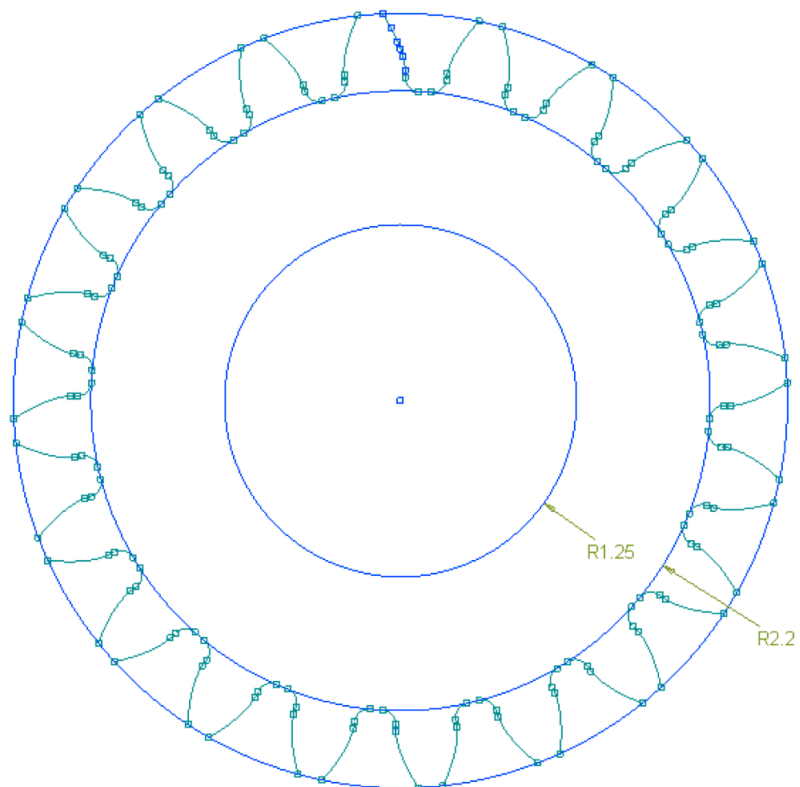
2.5-8 Trim Away Unwanted Segments

Trim away unwanted segments in the addendum circle and the dedendum circle, as shown.

R1.25

R2.2
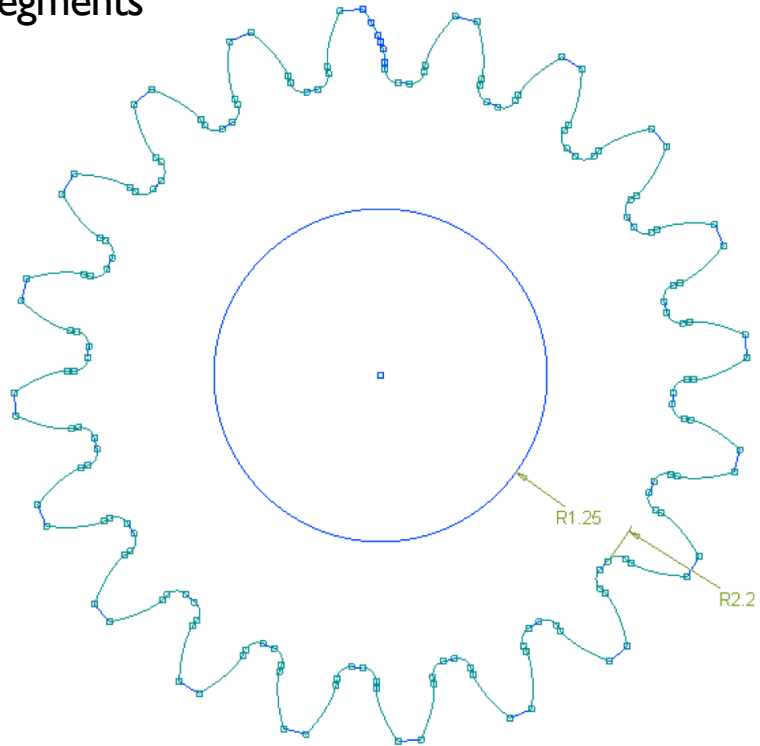
2.5-9 Extrude to Create 3D Solid

Extrude the sketch 1.0 inch to create a 3D solid. Save the project and exit from **Workbench**. We will resume this project again in Section 3.4.

It is equally good that you create a single tooth (a 3D solid body) and then duplicate it by using **Create/Pattern** in the **Modeling** mode. In this exercise, however, we use **Replicate** in **Sketching** mode because our purpose in this chapter is to practice sketching techniques.
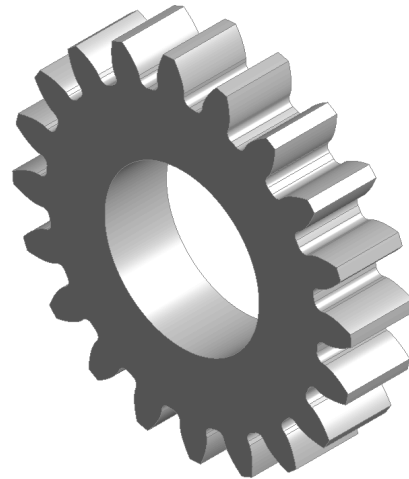
References

1.   Deutschman, A. D., Michels, W. J., and Wilson, C. E., *Machine Design: Theory and Practice*, Macmillan Publishing Co., Inc., 1975; Chapter 10. Spur Gears.
2.   Zahavi, E., *The Finite Element Method in Machine Design*, Prentice-Hall, 1992; Chapter 9. Spur Gears.
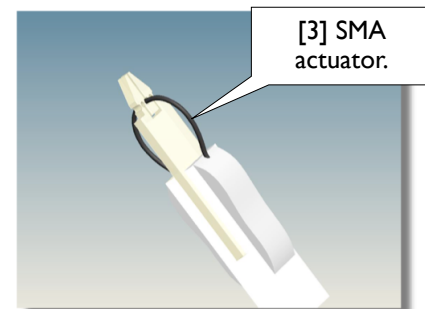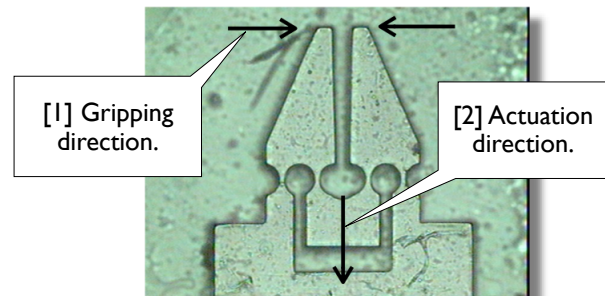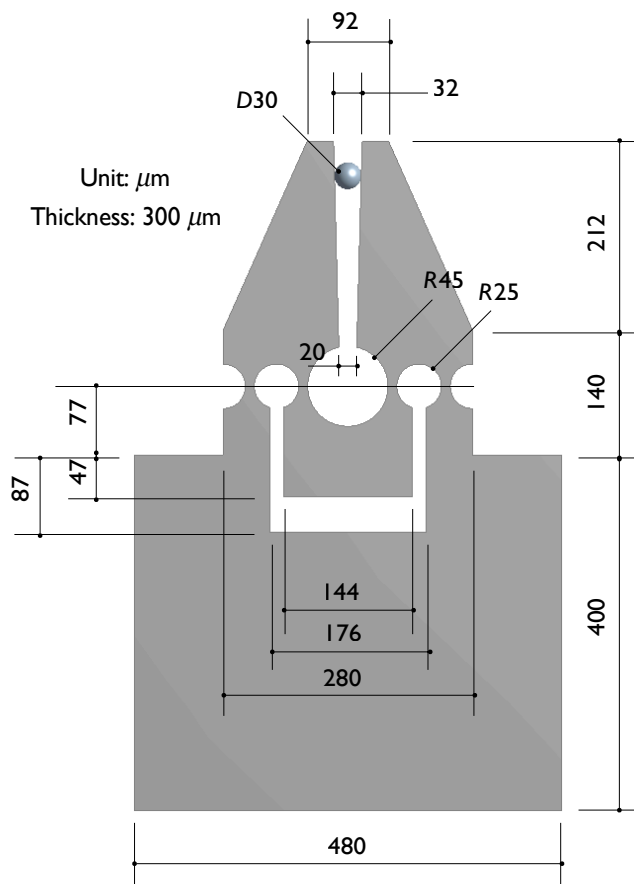
Section 2.6

Microgripper
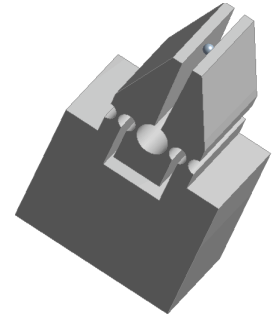
2.6-1 About the Microgripper[Refs 1, 2]

The microgripper is made of a polymer material, actuated by a shape memory alloy (SMA) actuator [1-3], its motion caused by temperature change, the temperature in turn controlled by electric current. In the lab, the microgripper is tested by gripping a steel bead of a diameter of 30 micrometers [4].
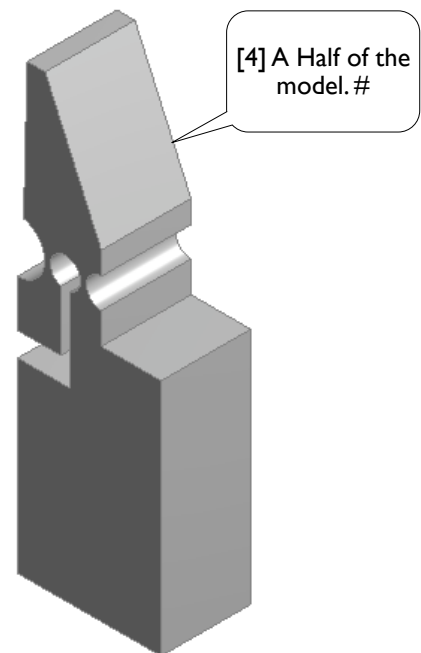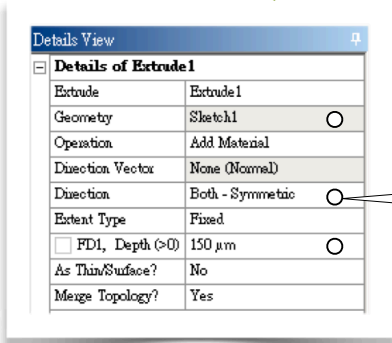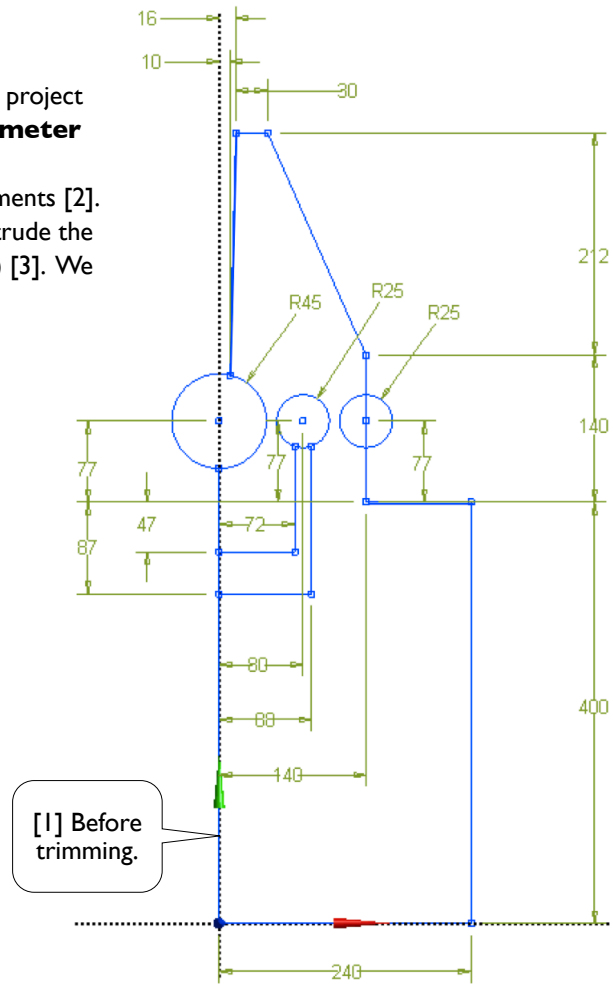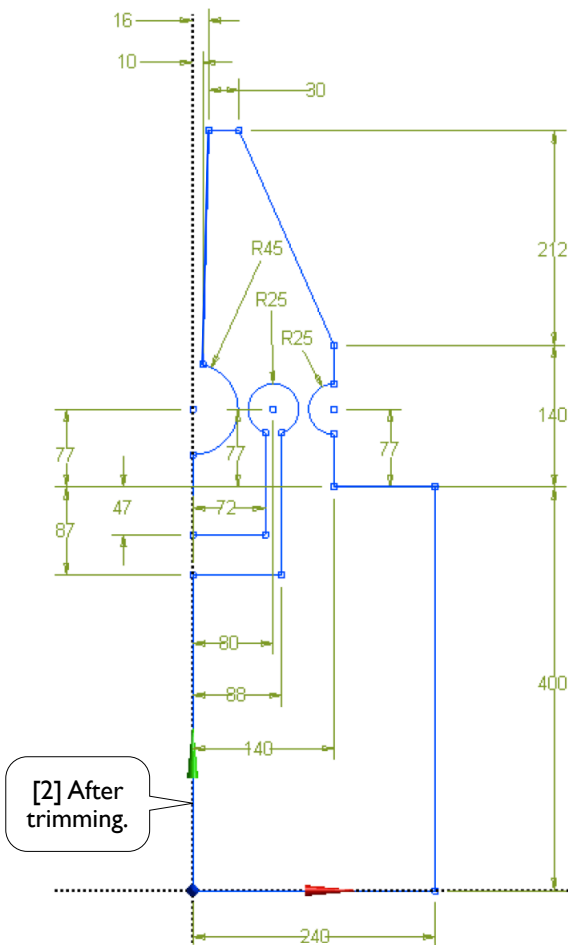
In this section, we will create a solid model for the microgripper. The model will be used for simulation in Section 13.3 to assess the gripping forces on the bead under the actuation of the SMA actuator.

Unit: μm
Thickness: 300 μm

92
32
D30
212
140
400
480
R45
R25
20
77
87
47
144
176
280

[1] Gripping direction.

[2] Actuation direction.

[3] SMA actuator.

[4] Steel bead.

2.6-2 Create Half of the Model

Launch **Workbench**. Create a **Geometry** system. Save the project as **Microgripper**. Start up **DesignModeler**. Select **Micrometer** as the length unit.

Draw a sketch on **XYPlane** [1]. Trim away unwanted segments [2]. Note that we drew half of the model, due to the symmetry. Extrude the sketch 150 μm both sides symmetrically (total depth is 300 μm) [3]. We now have a half of the gripper [4].

[1] Before trimming.

[2] After trimming.

[4] A Half of the model. #

Details View

Details of Extrude1	
Extrude	Extrude1
Geometry	Sketch1
Operation	Add Material
Direction Vector	None (Normal)
Direction	Both - Symmetric
Extent Type	Fixed
FD1, Depth (>0)	150 μm
As Thin/Surface?	No
Merge Topology?	Yes

[3] Extrude both sides symmetrically.

2.6-3 Mirror Copy the Solid Body

Create Concept Tools Units Vi

- New Plane
- Extrude
- Revolve
- Sweep
- Skin/Loft
- Thin/Surface

- Fixed Radius Blend
- Variable Radius Blend
- Vertex Blend
- Chamfer

- Pattern
- Body Operation
- Body Transformation ▶
  - Move
  - Translate
  - Rotate
  - Mirror
  - Scale
- Boolean
- Slice
- Delete ▶

- Point

- Primitives ▶

Details View

Details of Mirror1

Mirror	Mirror1
Preserve Bodies?	Yes
Mirror Plane	Not selected
Bodies	1

[3] Click this yellow area to bring up the **Apply/ Cancel** buttons.

[2] In the graphics window, select the solid body and click **Apply**.

Details View

Details of Mirror1

Mirror	Mirror1
Preserve Bodies?	Yes
Mirror Plane	YZPlane
Bodies	1

[4] In **Tree Outline**, select **YZPlane** and click **Apply**.

[1] Pull-down-select **Create/ Body Transformation/ Mirror**.

Generate

[5] Click **Generate**. #
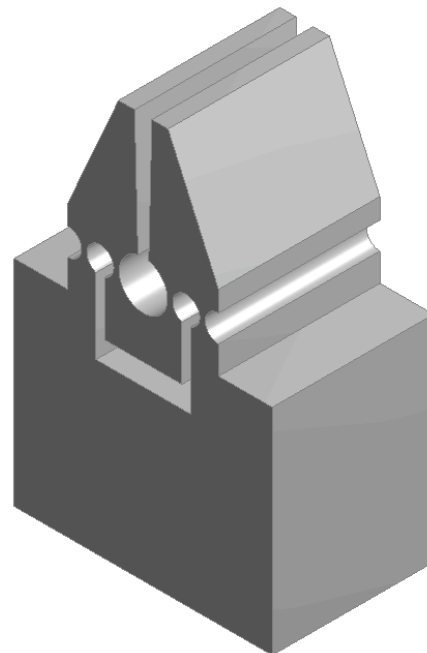
2.6-4 Create the Bead

Create a new sketch on **XYPlane** as shown in [1, 2] and draw a semicircle as shown in [3-6]. Revolve the sketch $360°$ about the Y-axis to create the bead [7]. Note that the two bodies are treated as two parts [8]. Rename the two bodies as **Gripper** and **Bead** respectively [9].

[1] Select **XYPlane**.

[2] Click **New Sketch**.

[3] The semicircle can be created by creating a full circle and then trimming it using the axis.

[6] Impose a **Tangent** constraint between the semicircle and the sloping line.

[4] Close the sketch by drawing a vertical line.

[7] **Revolve** about the Y-axis to create the steel bead.

R15

[5] Specify the radius (15 μm).

[9] Right-click to rename each body like this. #

[8] The two bodies are treated as two parts (see [9]).

Wrap Up

Close **DesignModeler**, save the project and exit **Workbench**. We will resume this project in Section 13.3.

References

1. Chang, R. J., Lin ,Y. C., Shiu, C. C., and Hsieh, Y. T., "Development of SMA-Actuated Microgripper in Micro Assembly Applications," IECON, IEEE, Taiwan, 2007.
2. Shih, P. W., *Applications of SMA on Driving Micro-gripper*, MS Thesis, NCKU, ME, Taiwan, 2005.

Section 2.7

Review

2.7-1 Keywords

Choose a letter for each keyword from the list of descriptions

1. (   ) Auto Constraints
2. (   ) Branch
3. (   ) Constraint Status
4. (   ) Context Menu
5. (   ) Edge
6. (   ) Modeling Mode
7. (   ) Model Tree

8. (   ) Object
9. (   ) Paste Handle
10. (   ) Sketching Mode
11. (   ) Sketching Plane
12. (   ) Sketch
13. (   ) Selection Filter

Answers:

1. (J)   2. (G)   3. (M)   4. (I)   5. (D)   6. (B)   7. (F)   8. (H)
9. (L)   10. (A)   11. (C)   12. (E)   13. (K)

List of Descriptions

(A) An environment under **DesignModeler**, its function to draw sketches on a plane.

(B) An environment under **DesignModeler**, its function to create 3D or 2D bodies.

(C) The plane on which a sketch is created. Each sketch must be associated with a plane; each plane may have multiple sketches on it. Usage of planes is not limited for storing sketches.

(D) In **Sketching** mode, an edge may be a (straight) line or a curve. A curve may be a circle, ellipse, arc, or spline.

(E) A sketch consists of points and edges. Dimensions and constraints may be imposed on these entities.

(F) A model tree is the structured representation of a geometry and displayed on **Tree Outline** in **DesignModeler**. A model tree consists of features and a part branch, in which their order is important. The parts are the only objects exported to **Mechanical**.

(G)   A branch is an object of a model tree and consists of one or more objects under itself.

(H)   A leaf or branch of a model tree is called an object.

(I)   The menu that pops up when you right-click your mouse. The contents of the menu depend on what you click.

(J)   While drawing in **Sketching** mode, by default, **DesignModeler** attempts to detect the user's intentions and tries to automatically impose constraints on points or edges. Detection is performed over entities on the active plane, not just active sketch. **Auto Constraints** can be switched on/off in the **Constraints** toolbox.

(K)   A selection filter filters one type of geometric entities. When a selection filter is turned on/off, the corresponding type of entities become selectable/unselectable. In **Sketching** mode, there are two selection filters, namely points and edges filters. Along with these two filters, face and body selection filters are available in **Modeling** mode.

(L)   A reference point used in a copy/paste operation. The point is defined during copying and will coincide with a specified location when pasting.

(M)   In **Sketching** mode, entities are color coded to indicate their constraint status: greenish-blue for under-constrained; blue and black for well constrained (i.e., fixed in the space); red for over-constrained; gray for inconsistent.

2.7-2 Additional Workbench Exercises

Create Models with Your Own Way

After so many exercises, you should be able to figure out many alternative ways of creating the geometric models in this chapter. Try to re-create the models in this chapter using your own way.