

Engineering Sketch Pad (ESP)



Training Session 7 Sketcher Fundamentals

John F. Dannenhoffer, III

jfdannen@syr.edu
Syracuse University

Bob Haimes

haimes@mit.edu
Massachusetts Institute of Technology
updated for v1.22

- Purpose of Sketches
- Sketching Segments
- Sketching methods
 - programmatically
 - interactively
- Homework Exercises

- Method for generating a SheetBody, WireBody, or NodeBody
- Sketches are used a basis of grown Bodys
 - EXTRUDE, REVOLVE, RULE, and BLEND

- LINSEG — straight line segment
- CIRARC — circular arc
- ARC — alternative way of specifying a circular arc
- BEZIER — Bezier curve
- SPLINE — cubic spline

- Programmatically
 - can generate Sketch in 3D
 - user does all required math
 - is very robust
- Interactively
 - can generate Sketch only in 2D
 - required math is done by solving constraints
 - is somewhat fragile

- Begin with a **SKBEG** statement, which provides an initial point
- Add **LINSEG**, **CIRARC**, **BEZIER**, or **SPLINE** Segments
 - for the **BEZIER** and **SPLINE** statements, one curve is created from the point before these statement, using all the **BEZIER** or **SPLINE** statements
 - an **SSLOPE** statement before the first and/or after the last **SPLINE** statement can be used to specify the slope at the beginning or end
 - to have two adjacent curves, put a zero-length **LINSEG** between them
- Ends with a **SKEND** statement
 - if there are no Segments, a **NodeBody** is created
 - if the last Segment does not end at the point specified in the **SKBEG** statement, a **WireBody** is created
 - if the Sketch is closed, a **SheetBody** is created (unless the **wireonly** flag on the **SKEND** statement is non-zero)



```
# sketch
```

```
DESPMTR L 2.0
DESPMTR H 1.0
DESPMTR Z 3.0
```

```
SET s2 1/sqrt(2)
```

```
SKBEG 1.0 2.0 Z
LINSEG 1.0+L 2.0 Z
CIRARC 1.0+L-(1-s2)*H 2.0+s2*H Z \
1.0+L-H 2.0+H Z
LINSEG 1.0 2.0+H Z
LINSEG 1.0 2.0 Z
```

```
SKEND
```

```
END
```

- 1 Define the Design Parameters
- 2 Create an empty Sketch
- 3 Draw the Segments
- 4 Constrain the Sketch
- 5 Solve the Sketch



Creating a Sketch

Step 1: Define the Design Parameters

- Press **Design Parameters** in the Tree window to create each of the Design Parameters
- Most Design Parameters are a scalar, so that they have only 1 row and 1 column
- Enter nominal value(s) in the box(es) that appears
- Press **OK** to proceed
- Repeat as needed



Interactive Sketcher Example (1)

Define the Design Parameters

```
DESPMTR  length  4.0  # length
DESPMTR  height  2.0  # height
DESPMTR  rad     1.0  # radius of cutout
```



Creating a Sketch

Step 2: Create an Empty Sketch

- Press **Branches** in the Tree window to create a **SKBEG** Branch
 - coordinates should be specified at one point on the boundary of the Sketch
 - coordinates can be defined in terms of a Design Parameter
- A **SKEND** is automatically created for you
- The Sketcher is entered automatically



Interactive Sketcher Example (2)

Create an Empty Sketch

The screenshot shows the ESP Engineering Sketch Pad interface. The main workspace contains a yellow coordinate grid with a blue line segment starting from the origin and extending into the first quadrant. The left sidebar contains a menu with options: Design Parameters, Local Variables, Branches, Display, Axes, DisplayType, and DisplayFilter. The bottom panel shows a command prompt with the following text:

```
ndof=2  ncon=2
Valid commands are:
'1'  add lineeg
'c'  add cirarc
's'  add spline
'b'  add bezier
'g'  add zero-length segment
'o'  complete (open) sketch
```

Below the command prompt, a status message reads: "ESP has been initialized and is attached to 'serveCSM'. './data/basic/sketch7s.csm' has been loaded. Branch (type=skbeg) has been added ==> Re-build is needed <==>>>>".

Step 3: Draw the Segments (1)

- Start drawing the Sketch at the point defined in the **SKBEG** Branch
 - **X** and **Y** Constraints are automatically generated at the initial point
 - these constraints cannot be deleted
- Draw the Segments by proceeding counter-clockwise around the Sketch (which is consistent with the right-hand rule pointing out of the screen)
- Line between previous point and cursor shows proposed position of next Segment
 - blue is default color
 - if drawn in orange, a vertical (V) or horizontal constraint (H) will be added automatically

Step 3: Draw the Segments (2)

- Supported Segment types include:
 - (straight) line Segment
 - **l** or **L** or mouse click
 - (circular) arc Segment
 - **c** or **C**
 - Segment turns red until you press the mouse button to set its approximate radius
 - cubic spline
 - **s** or **S**
 - cubic splines are shown only as straight line Segments in the Sketcher
 - Bezier curve control points
 - **b** or **B**
 - ...

Step 3: Draw the Segments (3)

- Supported Segment types include:
 - zero-length Segment
 - **z** or **Z**
 - constraints automatically set
 - leave Sketch open (and switch mode to “Constraining...”)
 - **o** or **O**
- When Sketch is closed, its interior is filled with gray (and the mode is switched to “Constraining...”)
- Pressing the **Undo** button will remove the last Segment



Interactive Sketcher Example (3a)

Draw the Segments

- Line horizontally to the right (orange)
- Line up and to the right (blue)
- Line up and to the left (blue)
- Circle down and to the left (concave)
- Line horizontally to the left (orange)
- Line back to the beginning (target circle lights up)



Interactive Sketcher Example (3b)

Draw the Segments

The screenshot shows the ESP Engineering Sketch Pad interface. The main workspace displays a 2D sketch of a mechanical part, a shaded polygon with a curved top edge. The sketch is overlaid on a coordinate system with yellow axes. The left sidebar contains a tree view with the following items:

- File Sketch StepThru Help
- Constraints Undo
- H L R B T + -
- + Design Parameters
- + Local Variables
- Branches
 - + Brch_00001 skbeg
 - Brch_00013 skend
- Display Viz Ged
- + Body 8 Viz Ged
- Axes Viz Ged
- DisplayType
- DisplayFilter

The bottom panel shows the command console with the following text:

```
ndof=13 ncon=4
Valid constraints at points
'a' (fix x) 'y' (fix y)
'p' (perp) 't' (tangent)
'a' (angle) 'd' (depth)
'w' (width)
Valid constraints on segments
'h' (horiz) 'v' (vertical)
'i' (incline) 'l' (length)
Valid constraints on cirarcs

ESP has been initialized and is attached to 'serveCSM'
'../data/basic/sketch7b.csm' has been loaded
```

Step 4: Constrain the Sketch (1)

- As many constraints (**ncon**) must be defined as there are degrees of freedom (**ndof**) in the Sketch
 - these values are listed in the Key window
 - the fill turns to light green when they match (**ncon=ndof**)
 - having them match is necessary, but not sufficient, for a Sketch to be properly constrained

Step 4: Constrain the Sketch (2)

- Constraints that can be applied to Segments:
 - set the Segment's length
 - **l** or **L**
 - make the Segment horizontal ($y_{\text{beg}} = y_{\text{end}}$)
 - **h** or **H**
 - might be automatically created if Segment was orange when created
 - make the Segment vertical ($x_{\text{beg}} = x_{\text{end}}$)
 - **v** or **V**
 - might be automatically created if Segment was orange when created
 - set the inclination in degrees (measured counter-clockwise from the right horizontal)
 - **i** or **I**

Step 4: Constrain the Sketch (3)

- Constraints that can be applied to circular arcs:
 - acute radius (positive if convex when drawing counter-clockwise)
 - **r** or **R**
 - *X*-coordinate at arc center
 - **x** or **X**
 - *Y*-coordinate at arc center
 - **y** or **Y**
 - sweep angle in degrees (positive if convex when drawing counter-clockwise)
 - **s** or **S**

Step 4: Constrain the Sketch (4)

- Constraints that can be applied to points:
 - specify X -coordinate
 - **x** or **X**
 - specify Y -coordinate
 - **y** or **Y**
 - adjacent Segments are perpendicular
 - **p** or **P**
 - adjacent Segment are tangent (parallel)
 - **t** or **T**
 - turning angle between adjacent Segments in degrees (positive if turning to the left)
 - **a** or **A**

Step 4: Constrain the Sketch (5)

- Constraints that can be applied to a pair of points:
 - specify width ($x_{\text{end}} - x_{\text{beg}}$) between two points
 - **w** or **W**
 - if first point is toward the left, a positive value should be specified
 - if first point is toward the right, a negative value should be specified
 - specify depth ($y_{\text{end}} - y_{\text{beg}}$) between two points
 - **d** or **D**
 - if first point is toward the bottom, a positive value should be specified
 - if first point is toward the top, a negative value should be specified

Step 4: Constrain the Sketch (6)

- Other options:
 - remove Constraints
 - <
 - if more than one constraint is present, you are asked which constraint to remove
 - inquire about constraints at current point or Segment
 - ?
- Pressing the **Undo** button will remove/restore the last constraint

Step 4: Constrain the Sketch (7)

- Special shortcuts
 - `::L[i]` is the length of the Segment `i`
 - `::I[i]` is the inclination of Segment `i` (in degrees)
 - `::R[i]` is the radius of CIRARC Segment `i`
 - `::S[i]` is the sweep of CIRARC Segment `i` (in degrees)
- Segment numbers can be determined by pressing `?` near the center of a Segment

Step 4: Constrain the Sketch (8)

- If you need help during the constraint process
 - Press the yellow **Constraining...** button
- Redundant constraints are shown in red
 - Use the < key to remove a redundant constraint
- Suggested new constraints are shown in green
 - Add the constraint using a key that matches the hint



Interactive Sketcher Example (4a)

Constrain the Sketch — Result of pressing **Constraining...**

The screenshot shows the ESP Engineering Sketch Pad interface. The main workspace displays a grey-shaded sketch of a shape with several constraints applied, indicated by green labels: 'XY' at the top corners, 'HL' (horizontal) on the top-right edge, 'VL' (vertical) on the right edge, 'L' (length) on the top horizontal edge, 'R' (radius) on the curved bottom edge, and 'I' (isocline) on the bottom horizontal edge. The left sidebar shows the 'Constraining...' menu and a tree view of the sketch's structure, including 'Design Parameters', 'Local Variables', 'Branches', and 'Body 8'. The bottom panel contains a list of valid constraints and their parameters, and a status message indicating that ESP has been initialized and attached to 'serveCSM'.

File Sketch SnapThru Help
Constraining Undo
H L R B T + -

- + Design Parameters
- + Local Variables
- Branches
 - + Brch_000001 skbg
 - Brch_000013 sknd
- Display Vltz Gcd
- + Body 8 Vltz Gcd
- Axes Vltz
- DisplayType
- DisplayFilter

ndof=13 ncon=4
Valid constraints at points
'a' (fix x) 'y' (fix y)
'p' (perp) 't' (tangent)
'a' (angle) 'd' (depth)
'w' (width) 'd' (depth)
Valid constraints on segments
'h' (horiz) 'v' (vertical)
'i' (isocline) 'l' (length)
Valid constraints on cirarcs

ESP has been initialized and is attached to 'serveCSM'
"../data/basic/sketch7b.csm" has been loaded
Add one of the constraints in green.
Note: others may be possible as well.

The screenshot shows the ESP Engineering Sketch Pad interface. The main workspace displays a grey-shaded sketch of a shape with a curved top edge. The shape is defined by several points and segments. Labels indicate constraints: $R = -rad$ for the curved segment and $L = length$ for the bottom horizontal segment. The right vertical side is labeled $L = height$. The sketch is overlaid on a coordinate system with yellow axes.

The left sidebar shows a tree view with the following items:

- Design Parameters
- Local Variables
- Branches
 - Brch_00001 skbg
 - Brch_00021 skend
- Display
 - Body 8 Viz Red
 - Axes Viz Red
 - DisplayType
 - DisplayFilter

The bottom status area contains the following text:

```

ndof=13  ncon=12
Valid constraints at points
'a' (fix x)  'y' (fix y)
'p' (perp)  't' (tangent)
'a' (angle)  'd' (depth)
Valid constraints on segments
'h' (horiz)  'v' (vertical)
'i' (incline)  'l' (length)
Valid constraints on circles
    
```

Below the constraint list, a message states: "ESP has been initialized and is attached to 'serveCSM'" and ".../data/basic/sketch7c.csm" has been loaded. It also includes instructions: "Add one of the constraints in green. Note: others may be possible as well."

The screenshot shows the ESP Engineering Sketch Pad interface. The main workspace displays a green-shaded sketch of a shape with a curved top. The shape is defined by a horizontal bottom edge of length L , a vertical right edge of height L , and a curved top edge with radius $R = -rad$. The top edge is divided into three segments: a horizontal segment of length $L = (width - 2 * rad) / 2$, a curved segment, and another horizontal segment. The sketch is constrained to a coordinate system with yellow axes. The left sidebar shows the design tree with 'Body 8' selected. The bottom panel displays the following text:

```

ndof=13  ncon=13
Valid constraints at points
'a' (fix x) 'y' (fix y)
'p' (perp) 't' (tangent)
'a' (angle) 'd' (depth)
Valid constraints on segments
'h' (horiz) 'v' (vertical)
'i' (isoline) 'l' (length)
Valid constraints on circles
    
```

Below the text, a message states: "ESP has been initialized and is attached to 'serveCSM'" and ".../data/basic/sketch7c.csm" has been loaded. A note follows: "Add one of the constraints in green. Note: others may be possible as well."



Creating a Sketch

Step 5: Solve the Sketch

- Press **Press to Solve**
 - if successful, Sketch will change on screen
 - if unsuccessful, read about error in Messages window to help you diagnose the problem
- Press **Sketch**→**Save** to return to normal (non-Sketching) mode
- Press **Press to Re-build** to see the completed Sketch



Interactive Sketcher Example (5a)

Solve the Sketch

The screenshot shows the ESP Engineering Sketch Pad interface. The main workspace displays a green-filled sketch of a shape with a semi-circular cutout. The sketch is defined by several points and lines: a vertical line segment from point M to point N, a horizontal line segment from M to H, a horizontal line segment from H to Y, a curved segment from Y to R, a horizontal line segment from R to V, a vertical line segment from V to N, and a horizontal line segment from N to H. The semi-circular cutout is centered at point R. The software interface includes a menu bar (File, Sketch, StepThru, Help), a toolbar (Up to date, Undo, H, L, R, B, T, +, -), a left sidebar with a tree view (Design Parameters, Local Variables, Branches, Display, Body 8, Axes, Display Type, Display Filter), and a bottom console window showing the following text:

```
ndof=13 ncos=13  
ESP has been initialized and is attached to 'serveCSM'  
"../data/basic/sketch7d.csm" has been loaded
```

ESP Engineering Sketch Pad V.10.1

file:///Users/jdannen/Projects/OpenCSM/ESP/ESP-localhost7681.html

125%

File Sketch StepThru Help

Constraining Undo

H L R B T + -

- + Design Parameters
- + Local Variables
- Branches
 - + Brch_000001 skbeg
 - Brch_000021 skend
- Display
 - + Body 8 Viz Red
 - Axes Viz Red
 - DisplayType
 - DisplayFilter

ndof=13 ncon=12

Valid constraints at points

'a' (fix x)	'y' (fix y)
'p' (perp)	't' (tangent)
'a' (angle)	'd' (depth)

Valid constraints on segments

'h' (horiz)	'v' (vertical)
'i' (isoline)	'l' (length)

Valid constraints on cirarcs

ESP has been initialized and is attached to 'serveCSM'

"../data/basic/sketch7e.csm" has been loaded

Delete one of the constraints in red (using < key)

Note: others may be possible as well.

Removing P on top-left and redefining a length

The screenshot shows the ESP Engineering Sketch Pad interface. The main workspace displays a green sketch of a shape with several constraints. A label "segment 5" with an arrow points to the top-left horizontal edge. The top-right edge is labeled "L=:L[5]". The sketch is positioned on a coordinate system with yellow axes. The left sidebar shows the design tree with "Body 8" selected. The bottom panel displays the following text:

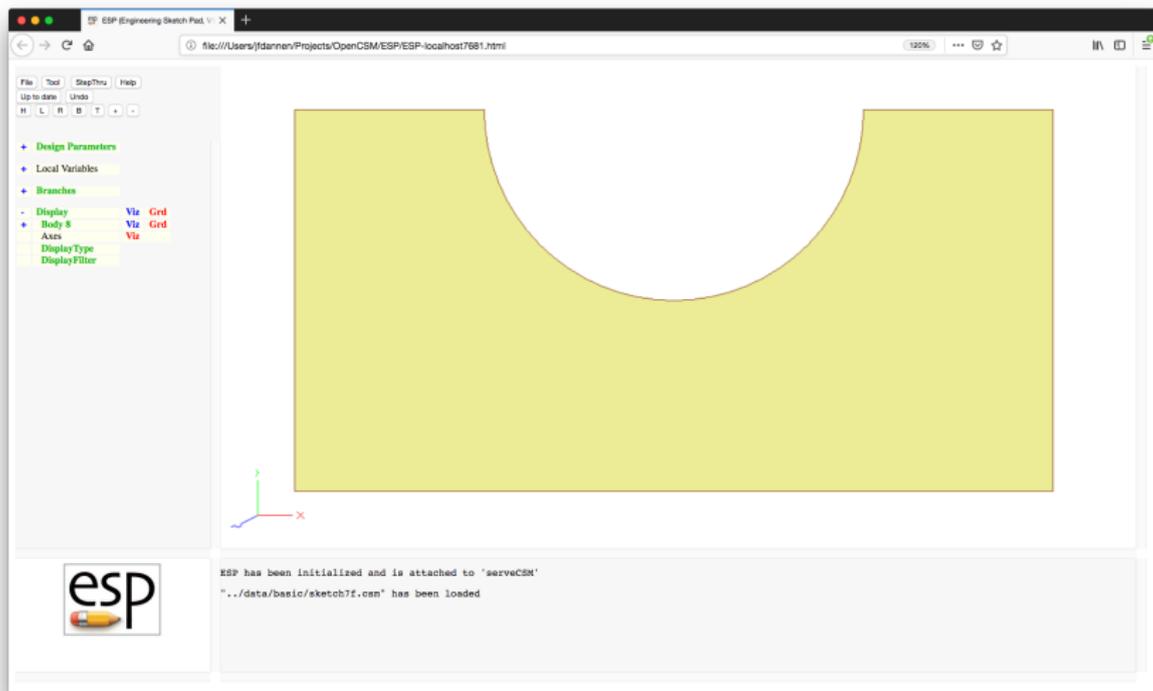
```

ndof=13 ncon=13
Valid constraints at points
'a' (fix x) 'y' (fix y)
'p' (perp) 't' (tangent)
'a' (angle) 'd' (depth)
'w' (width)
Valid constraints on segments
'h' (horiz) 'v' (vertical)
'i' (incline) 'l' (length)
Valid constraints on cirarcs
    
```

Below the design tree, a message states: "ESP has been initialized and is attached to 'serveCSM'" and ".../data/basic/sketch7f.csm" has been loaded.

esp Interactive Sketcher Example (5d)

After **Sketch** → **Save** and **Press to Re-build**





Editing an Existing Sketch

- Select one of the Branches between the SKBEG and SKEND Branches (inclusive) and press **Enter Sketcher**
- Follow directions given above

- Select each of the Branches between the **SKBEG** and **SKEND** and press **Delete Branch** for each. Then delete the **SKEND** and **SKBEG** Branches.
- Select the **SKBEG** Branch and press **Delete Branch** (to delete whole sketch at once)

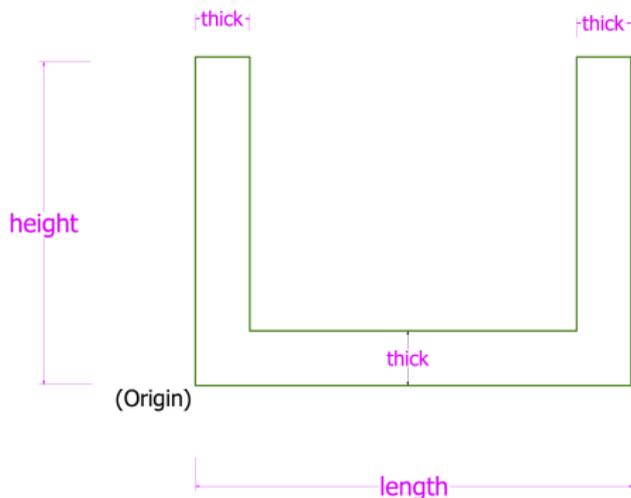
- Recenter Sketch
 - **H** button
- Move the Sketch to the left
 - **L** button or ← key
- Move the Sketch to the right
 - **R** button or → key
- Move the Sketch to the bottom
 - **B** button or ↓ key
- Move the Sketch to the top
 - **T** button or ↑ key
- Zoom in
 - **PgUp** key or + button
- Zoom out
 - **PgDn** key or - button

- Try to start the Sketch at a point with known coordinates
- Proceed around the sketch in a counter-clockwise direction
- Constrain the X -coordinate at one or more points (or arc centers)
- Constrain the Y -coordinate at one of more points (or arc centers)
- Specify the orientation of one or more Segments
 - this is sometimes done by specifying the coordinates of both ends
- Avoid redundancies, such as:
 - points at which angles are constrained and which are adjacent to Segments in which the inclination is constrained
 - dimensions specified for both a series of Segments as well as their combination

- U-shaped bracket (version 1)
- U-shaped bracket (version 2)
- oval
- bi-convex airfoil (with arcs)
- swivel base
- V-slide plate
- bi-convex airfoil (with splines)
- fuselage cross-section (with Beziers)

Example: U-bracket (version 1)

Hint: move mouse until blue line turns orange to automatically generate horizontal and vertical constraints

**Measurements**

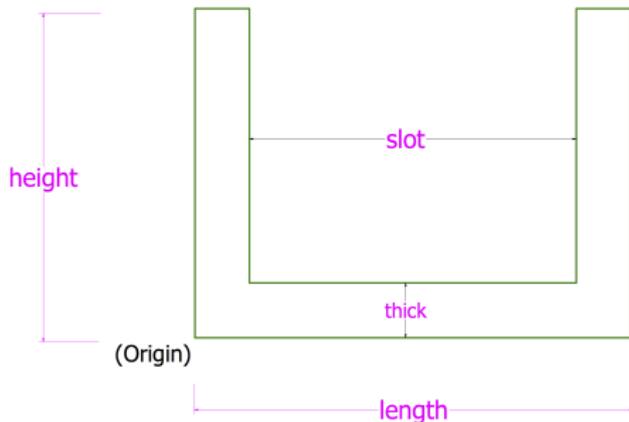
length = 4.00

height = 3.00

thick = 0.5

Example: U-bracket (version 2)

Hint: You can specify the length of a Segment to be equal to Segment 5's length with `::L[5]` (where the Segment number can be obtained with the "?" command).



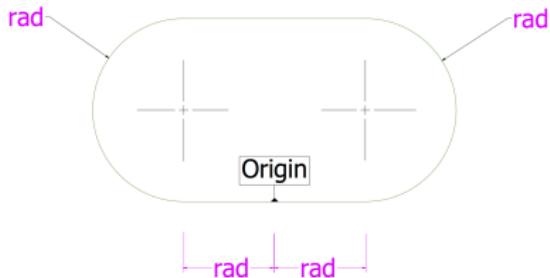
Measurements

length = 4.00
height = 3.00
thick = 0.5
slot = 2.00

Note: slot
is centered

Example: Oval

Hint: tangency constraints may be useful for this case



Measurements:
rad = 0.50

Example: Biconvex airfoil (with arcs)

Hint: the `radius()` function can be used if one knows the bounding coordinates and the “dip” (see “Help” for details)

**Measurements:**

chord = 2.00

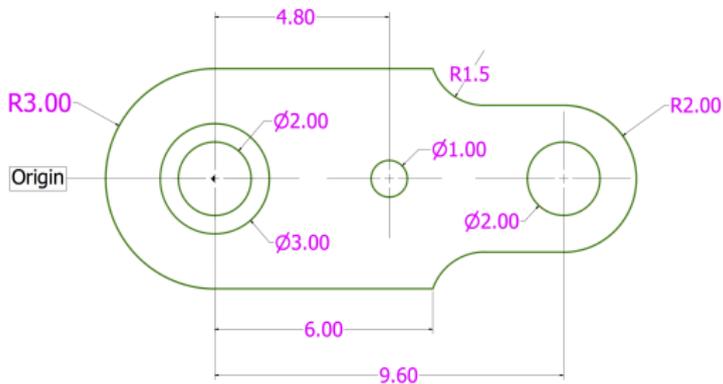
thick = 0.10

Note:

Circular Arcs

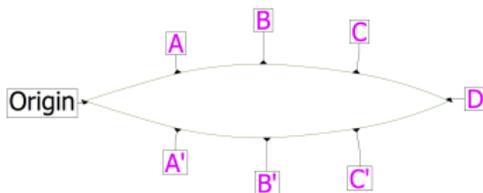
Example: Swivel Base

Hint: nested Sketches can be generated with a series of Sketches



Example: Biconvex Airfoil (with splines)

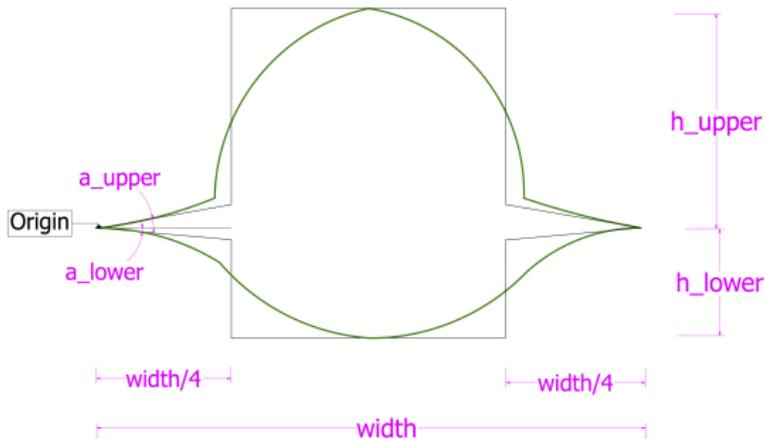
Hint: adjacent splines (with slope discontinuities) can be obtained by putting a zero-length line Segments between them



	x	y
A:	.255	.075
B:	.500	.100
C:	.745	.075
D:	1.00	0.00

Example: Fuselage X-section (with Beziers)

Hint: the Bezier control points are constrained in the same way as any other point



Measurements:

width = 5.00
 h_{upper} = 2.00
 h_{lower} = 1.00
 a_{upper} = 10°
 a_{lower} = 5°

Note:

4 Bezier Cubics