# True*Grid*® Training Manual
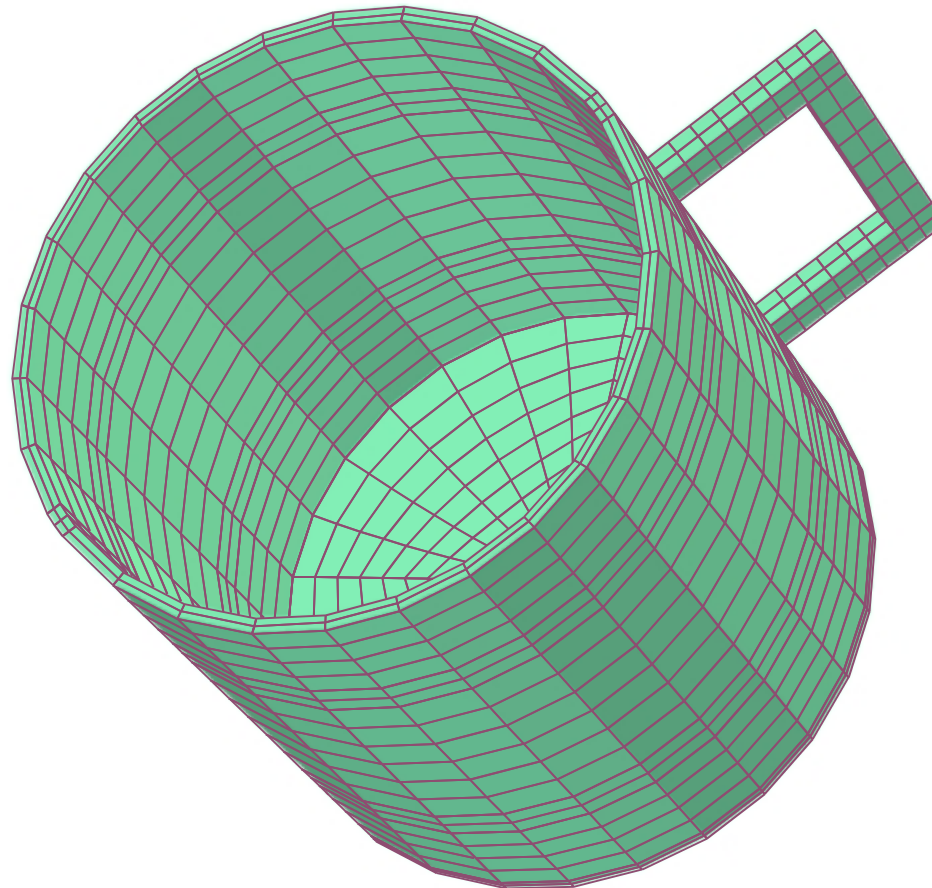
block 1 3 5 7 9 11 13 15;
1 3 5 7 9 11 13 15;
1 3 5 7 9 11 13;
-2.1 -2 -.6 -.1 .1 .6 2 2.1
-2.1 -2 -.6 .6 2 2.1 3.1 3.4
0 .1 1 1.3 3.1 3.4 4.3
dei 1 3 0 6 8; 1 3 0 4 6;;
dei 2 7; 2 5; 2 7;
dei 1 4 0 5 8; 6 8;;
dei 4 5;6 8; 1 3 0 6 7;
dei 4 5; 6 7; 4 5;
sd 1 cy 0 0 0 0 0 1 2
sd 2 cy 0 0 0 0 0 1 2.1
sfi -1 -8; -1 -6;;sd 2
sfi -2 -7; -2 -5;;sd 1
sd 3 plan 0 0 0 1 1 0
sfi 1 2; -4; 1 7;sd 3
sfi -3; 5 6; 1 7;sd 3
pb 7 4 1 8 4 7 xy 2 2
pb 6 5 1 6 6 7 xy 2 2
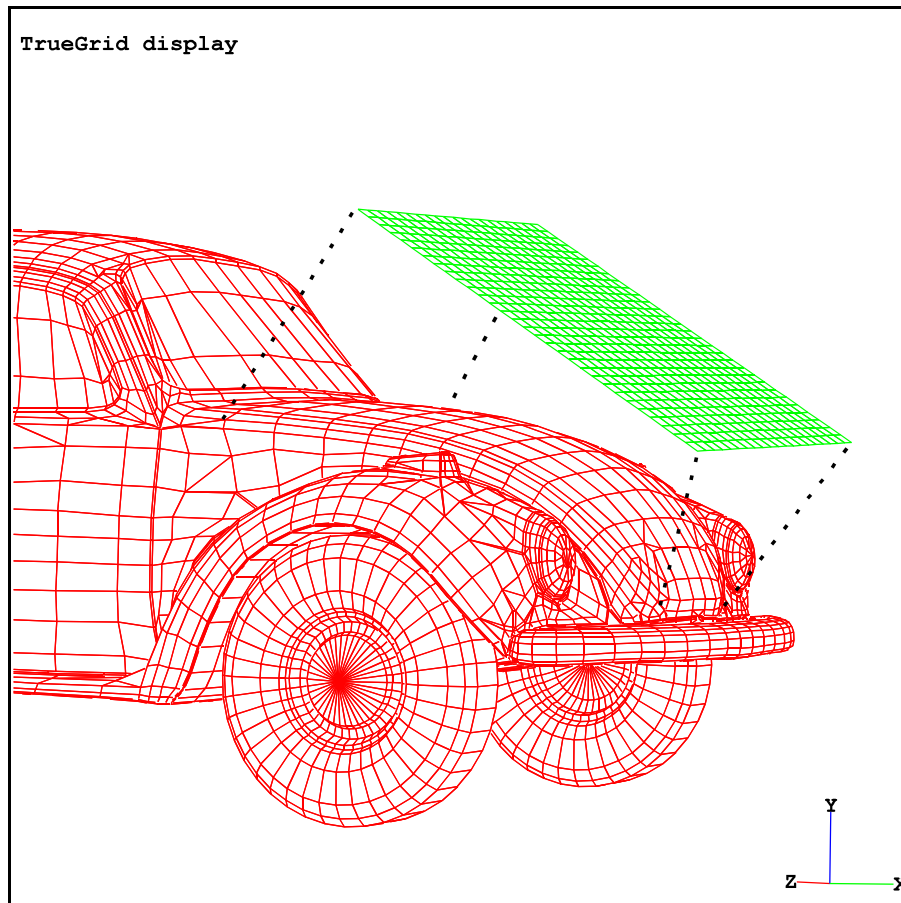curd 1 lp3 2 -2 0 2 -2 5 ;;
curs 6 1 1 6 1 7 1
curs 6 2 1 6 2 7 1

curs 8 3 1 8 3 7 1
curs 7 3 1 7 3 7 1
tri 1 2; -3; 1 7;
  v 0.204784e-01
-0.527519e-01 -2.15000
  tf rt -0.204784e-01
0.527519e-01 2.15000
  rt 0.846535 0.551037
2.15000
  rt -0.518763 0.919765
2.15000;
pb 3 2 1 3 2 7 xy
-1.370804e+00
-1.456330e+00
pb 3 1 1 3 1 7 xy
-1.459775e+00
-1.509655e+00
mseq i 0 5 1 0 1 5 0
mseq j 0 5 5 5 0 4 0
mseq k 0 2 0 4 0 2
endpart
merge
stp .001

**True*Grid*®** Training Manual

# Table Of Contents

# True*Grid*® implements the powerful projection method.

Before projection

After projection
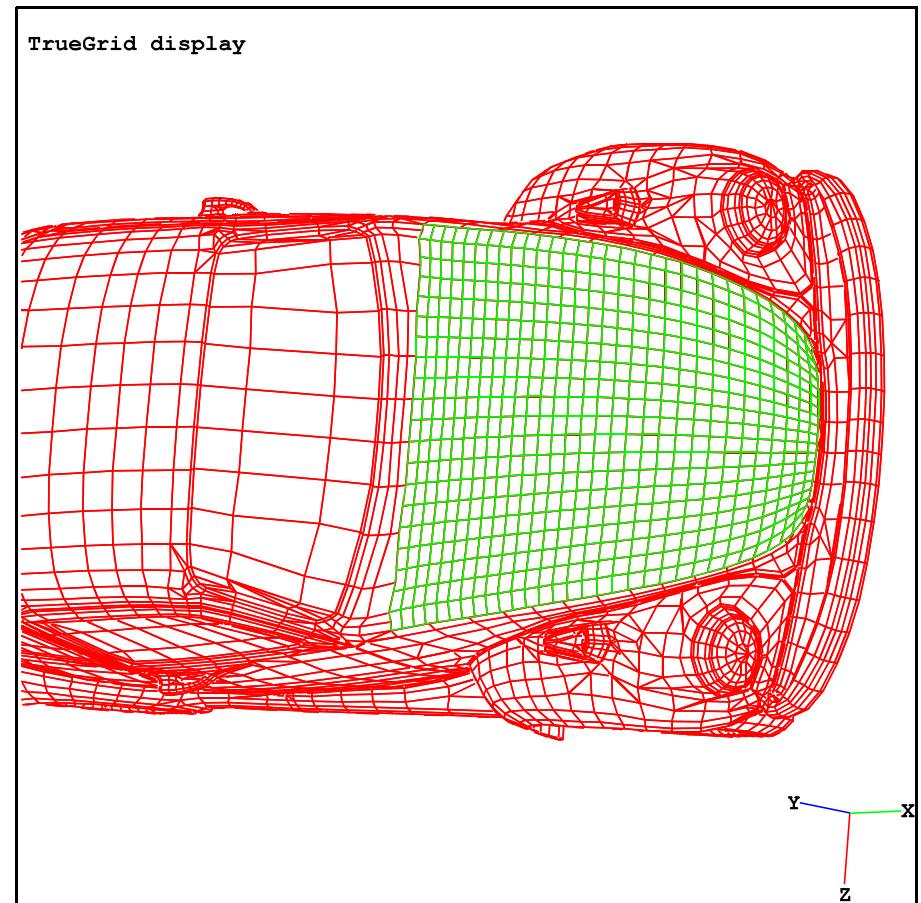
## TrueGrid can be executed by switching between the interactive or batch modes.

| Interactive mode | | Batch mode |

**Execute the selected or typed commands on the screen interactively.**

**TG records commands and parameters in the tsave file.**

**Execute the command file.**
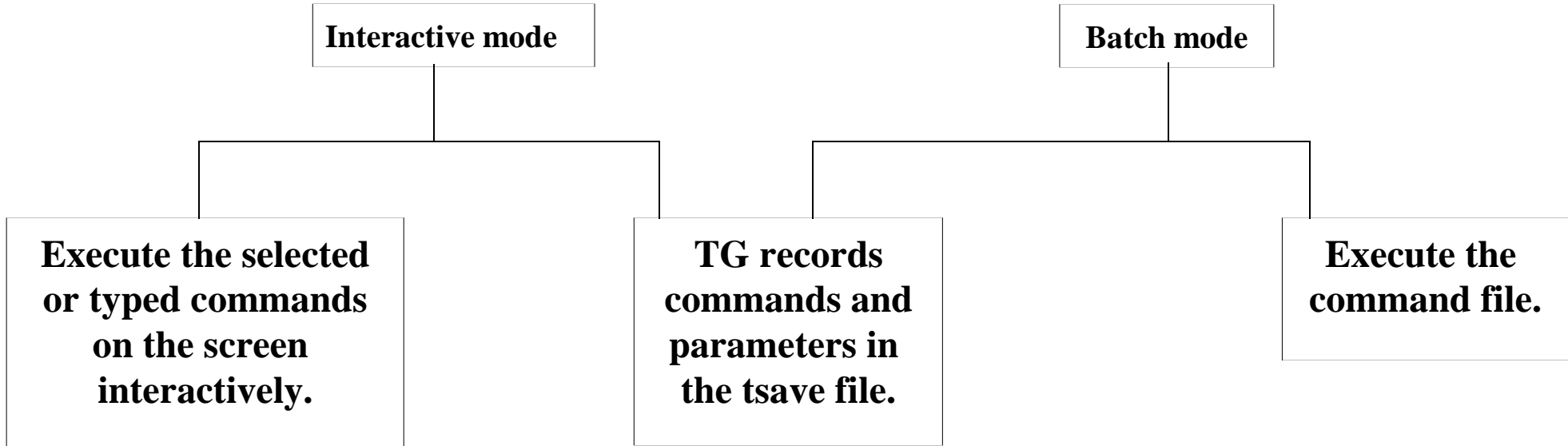
**The tsave file can be renamed, edited, and run as a command file.**

**Resume**

**Interactive**       **Batch**

**Interrupt**
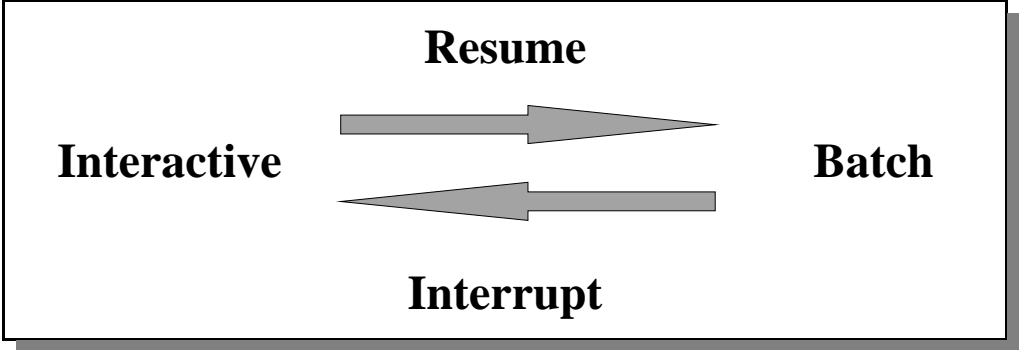
## Type the execution line under the UNIX OS.

**TG   i = comd   s = csave   o = model   len = size   -font name   -display hostname:0.0**

| | |
|---|---|
| **i = comd** | Initial command file name |
| **s = csave** | Session file name which defaults to tsave. |
| | Recommend renaming the tsave file after TrueGrid stops. |
| **o = model** | Output file name |
| **len = size** | Memory size in Megabytes which defaults to 20 MB. |
| **-font name** | Font selection for X windows only. |
| **-display hostname:0.0** | Remote execution for X windows. |

## Execution under WINDOWS

After **True*Grid*®** is installed, run the controls program
from the program menu or double click on the icon and
make the required selections (see the window  on the right).
Run **True*Grid*®** by double clicking on the icon or using
the program  menu. Every command file ending with .tg
will have the  icon which is shown on the right. Double
click on the icon to run **True*Grid*®** with the command input file.
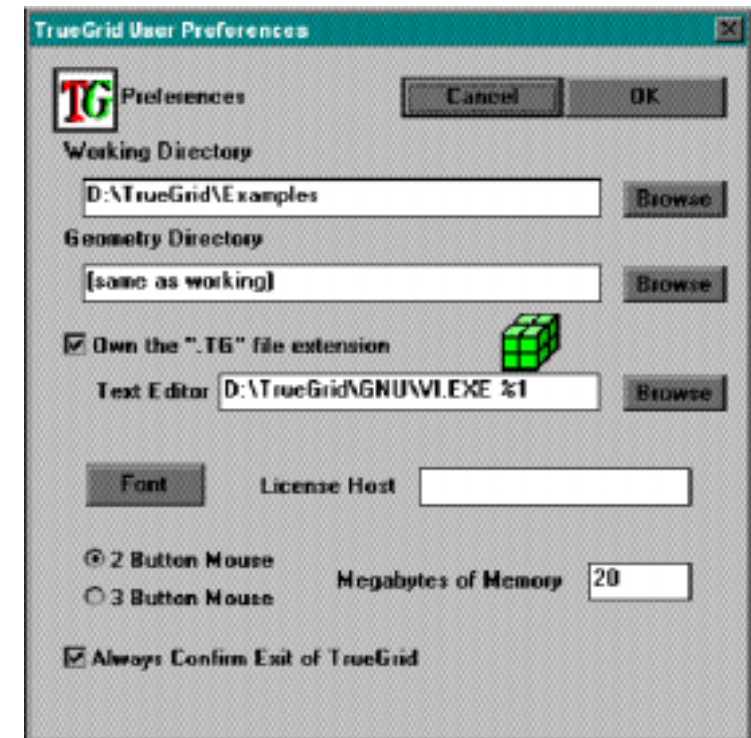
# TrueGrid generates a mesh by projecting a block mesh of your choice of refinement onto any geometry.

| Computational Objects | | | Physical Objects |
|---|---|---|---|

Vertices     **attach** →    Points

Edges     **attach** →    Curves

Vertices     **project** →    Intersection of 3 Surfaces

Edges     **project** →    Intersection of 2 Surfaces

Faces     **project** →    Surfaces

point and click →

operations

K    J    I

Z    Y    X
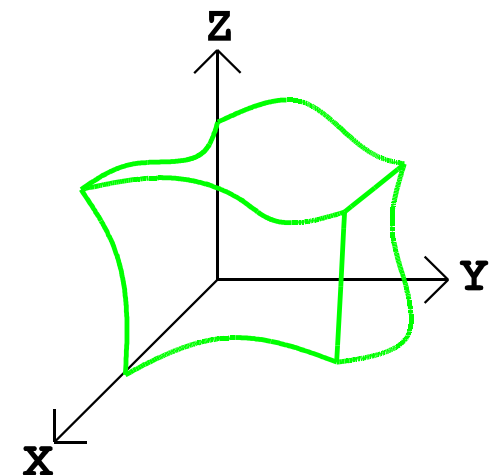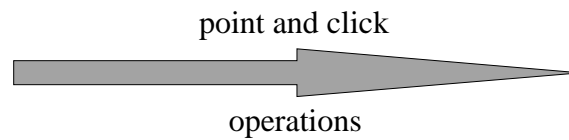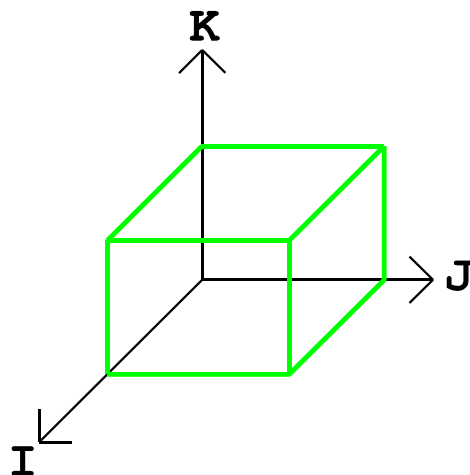
# A mesh may be generated interactively following this recipe.

1. Execute **True*Grid*®**

2. Enter Control Phase
      Input title (a brief description of the structure or fluid)
      Select output format in terms of the analytical codes
      Select material type and properties (keep consistent units)
      Select properties of sliding interfaces and symmetry planes
      Define cross sectional properties
      Import geometry (if needed)

3. Enter Part Phase as many times as needed
      Build a part from a single block or multiple blocks - bricks, shells, and beams
      Select number of nodes and nodal distribution
      Generate geometry where needed
      Identify parts of the mesh to be formed to the geometry
      Check the quality of the mesh
      Select boundary conditions

4. Enter Merge Phase
      Merge parts into one integrated structure
      Check the quality of the mesh
      Generate beam and special elements
      Write output file

# Many options are provided in the main menu in each phase.

## Control Phase
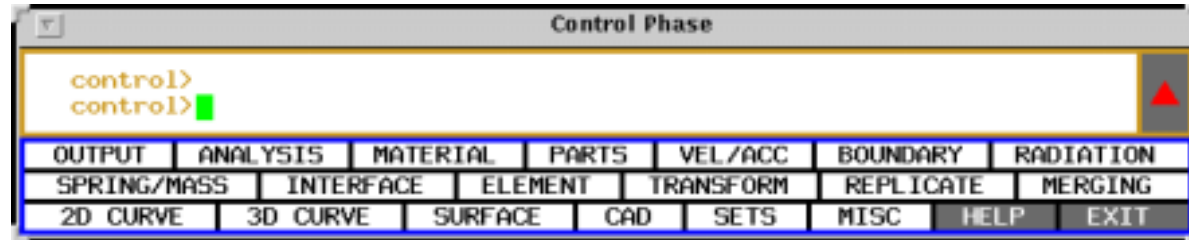


## Part Phase
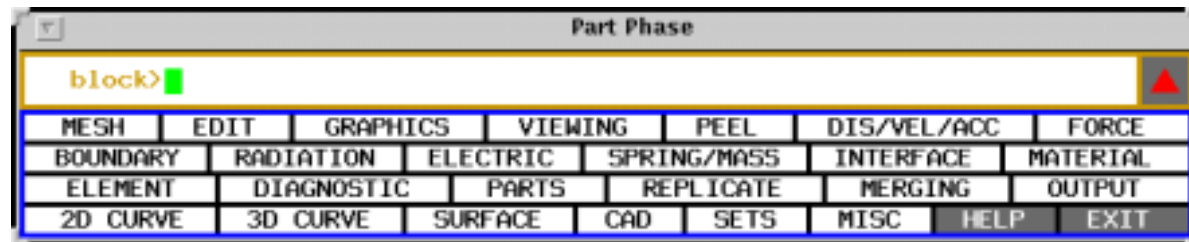


## Merge Phase



**Meshes can be generated in the Part Phase only.**

**Geometry can be generated in all three phases.**

# Mouse buttons and special keys.

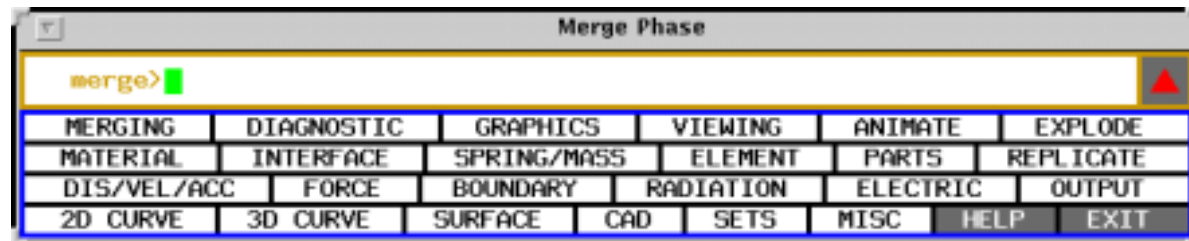| | |
|---|---|
| **LB** | To select options and to enter parameters (text in the text window). |
| **MB** | To move 3D objects in the picture and execute commands (paste text in the text window). |
| **RB** | To create additional windows and write Postscript (physical window only). |
| **CT+r** | Same as remove in the display list panel. |
| **CT+s** | Same as show only in the display list panel. |
| **CT+u** | Erase the text string (text window only). |
| **CT+v** | To display the hidden command option names (dialogues only). |
| **CT+z** | Recreate a dialogue box from highlighted text (text window only). |
| **F1** | To enter selected mesh into the dialogue box. |
| **F2** | To clear mesh selection. |
| **F3** | To display command history in the text window. |
| **F4** | To freeze the current window configuration. |
| **F5** | To select beginning vertex of a mesh. |
| **F6** | To select the ending vertex of a mesh. |
| **F7** | To extract coordinates for a selected vertex. |
| **F8** | To type the selection label into the text window or dialogue. |

# The text window is for typing in commands and parameters.

To close window (and kill TG)    Iconify    Maximize window size

| − | Text Window | • | ▭ |

- Click LB on △ to remove menu window.

- Click RB inside the window or hit enter to bring menu window back..

- Text is printed in this window.

- Input commands, options, and parameters.

△

Option     Main menu window

HELP | EXIT
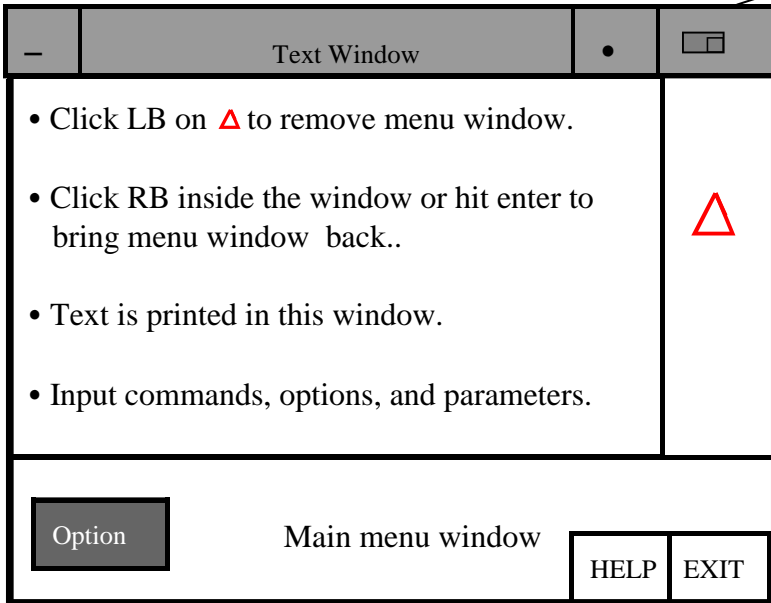
Click LB at an option key to
bring up the submenu.

| Dialogue Box |

- ■ Input parameters at solid green box.

- ■ Enter to turn the green box red.

- > means must choose one exclusively.

- o means optional.

QUIT | EXEC | EXEC/QUIT
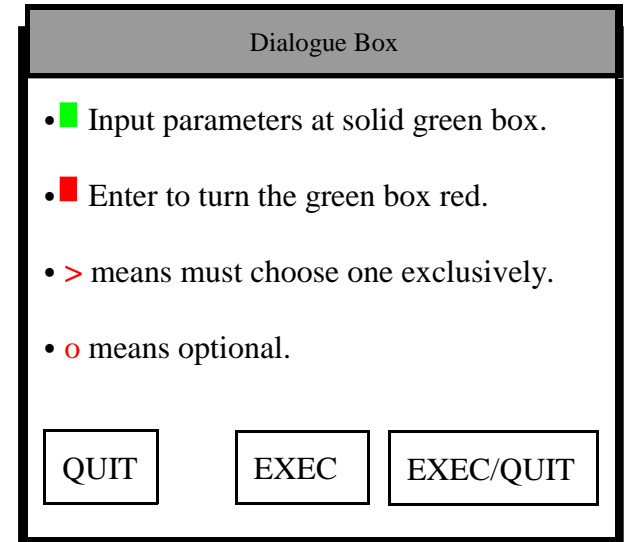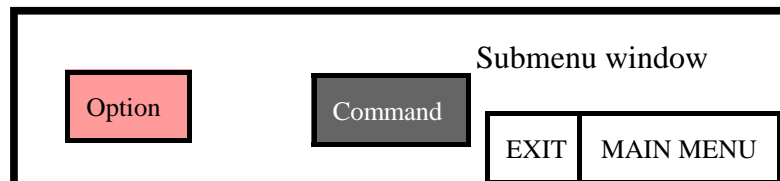
Click LB or MB at an option
to bring up the dialogue box.

Submenu window

Option | Command

EXIT | MAIN MENU

## Commands can be typed directly into the text window.

Stack the input commands and parameters on any number of 80 character lines of input.

Begin a Single-line comment with a " c ".

Place multiple line comments within a pair of upper case brackets { }.

Click the Esc key to abort any input sequence in the text window.

FORTRAN like IF... ELSEIF ... ELSE ... ENDIF statements.
```
    if(%len.le.0.0)then
        echo error - length must be positive
        end
    elseif(%len.lt.1.1)then
        block 1 4;1 4;1 3 6;0 %len;0 %len;0 1 2;
    else
        para i1 [max(%len/2,sqrt(%len*%len+3.5*%len-1)+1];
        block 1 %i1;1 %i1;1 3 6;0 %len;0 %len;0 1 2;
    endif
```

Include commands from files.

### Text window may be use to acquire information.

Cut and paste with the mouse into the text and dialogue windows.

Commands from dialogues are shown in the text window.

Use Fortran expressions in square brackets. `sd 1 sp 0 0 0 [%len*sqrt(2)]`

Define parameters and refer to them.. `para a 1.3 b 2.5 d [%a/sqrt(%b)];`

List values and terminate with a semicolon `ld 1 lp2 1 1 1.2 3 1.4 3 1.6 2;`

Extract coordinates of the selected vertices and compute the distance between these vertices using the distance command. `distance 0 0 0 %len %len 0`

Calculate an angle from 3 points in the picture. `subang 1 1 0 0 0 0 1 1 1`

Calculate cross products and inner (dot) products of vectors. `crprod 1 1 0 1 1 1`

Can be used for calculation like a desk top calculator. `dc 12.5 + 1.3 * 5.4/3`

Many commands with the info suffix. `painfo`

## The comprehensive help package is available in all three phases.

**To access the help window:**

In any menu, click on the   **HELP**   to activate the help window.

Then click on an   **option**   for the pop up help window.

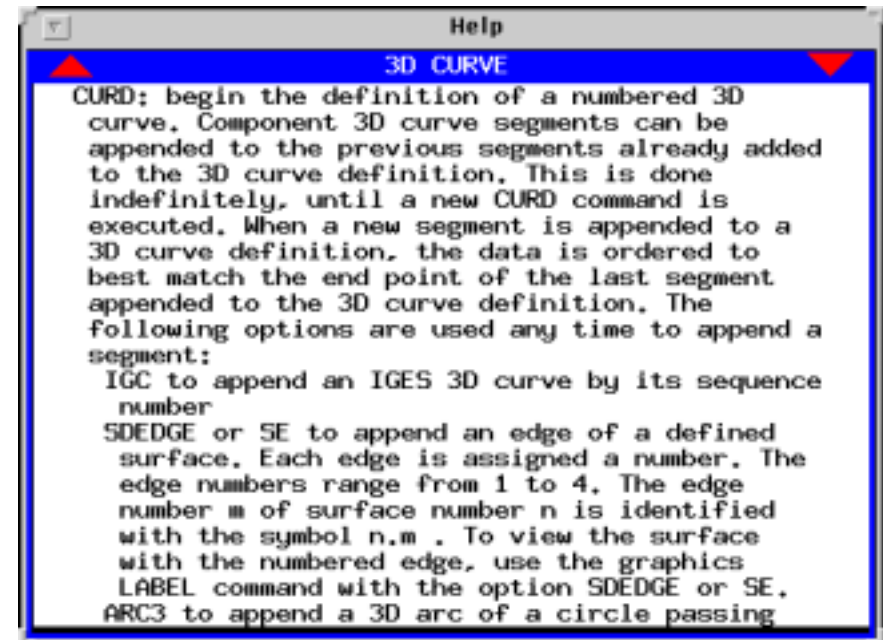Alternatively, type the help command.

**Scrolling in the help window:**

Click **LB** or page key to scroll by page.

Click **MB** or arrow key to scroll by line.

Click **LB** on   **HELP**   to close the help window, or

click **LB** on the **-** in the border of the help  window.

Help

**3D CURVE**

CURD: begin the definition of a numbered 3D
curve. Component 3D curve segments can be
appended to the previous segments already added
to the 3D curve definition. This is done
indefinitely, until a new CURD command is
executed. When a new segment is appended to a
3D curve definition, the data is ordered to
best match the end point of the last segment
appended to the 3D curve definition. The
following options are used any time to append a
segment:
 IGC to append an IGES 3D curve by its sequence
  number
 SDEDGE or SE to append an edge of a defined
  surface. Each edge is assigned a number. The
  edge numbers range from 1 to 4. The edge
  number m of surface number n is identified
  with the symbol n.m . To view the surface
  with the numbered edge, use the graphics
  LABEL command with the option SDEDGE or SE.
 ARC3 to append a 3D arc of a circle passing

## Dialogue box prompts you with the required parameters.

The option turns yellow when it is clicked. One more click turns it off.

If execution is issued before entering all parameters, the first incomplete line is highlighted in blue.

Click **MB** on   **EXEC/QUIT**   or   **EXEC**   to execute right away and force a redraw.

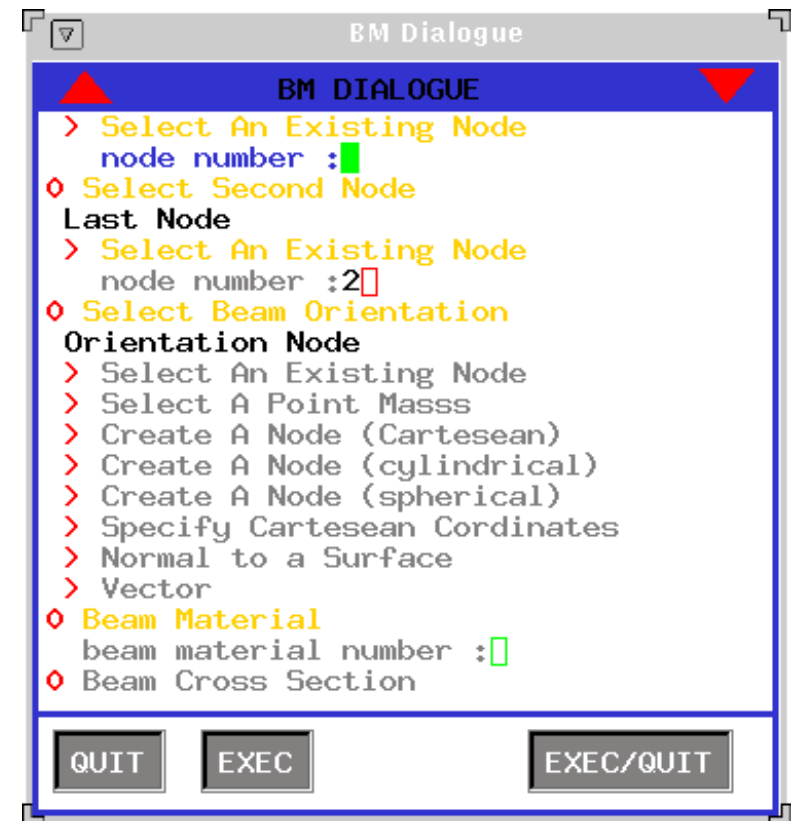Click **LB** on   **EXEC/QUIT**   or   **EXEC**   to enter the

command for execution but with no redraw event.

When the **MB** is left inside the   **EXEC**   after execution, then

the   **EXEC**   turns red to flag against duplicate execution.  Just

move the mouse off of the button and it will return to its original

color.

# Create a mesh starting in the Control or Merge phase.

**Method 1:**

Type the following command into the text window.

> **Block  1 11; 1 11; 1 11;  -1 1;  -1 1; -1 1;**

**Method 2:**

Select the dialogue box by clicking the **LB** on  **PARTS**  >  **BLOCK**  .
Then fill in the parameters.

BLOCK DIALOGUE

**Specify An Index Progression**
  **i-list : 1 11**
  **j-list : 1 11**
  **k-list : 1 11**
**List the x,y,z Coordinates**
  **x-list : -1 1**
  **y-list : -1 1**
  **z-list : -1 1**

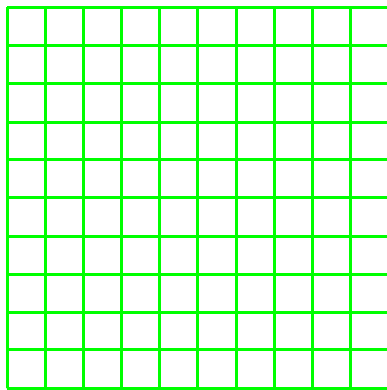QUIT    EXEC          EXEC/QUIT

# Mesh in the Physical and Computational windows.

Perspective is on by default. The front face appears to be larger than the back face for both the physical mesh on the left and the computational mesh on the right.
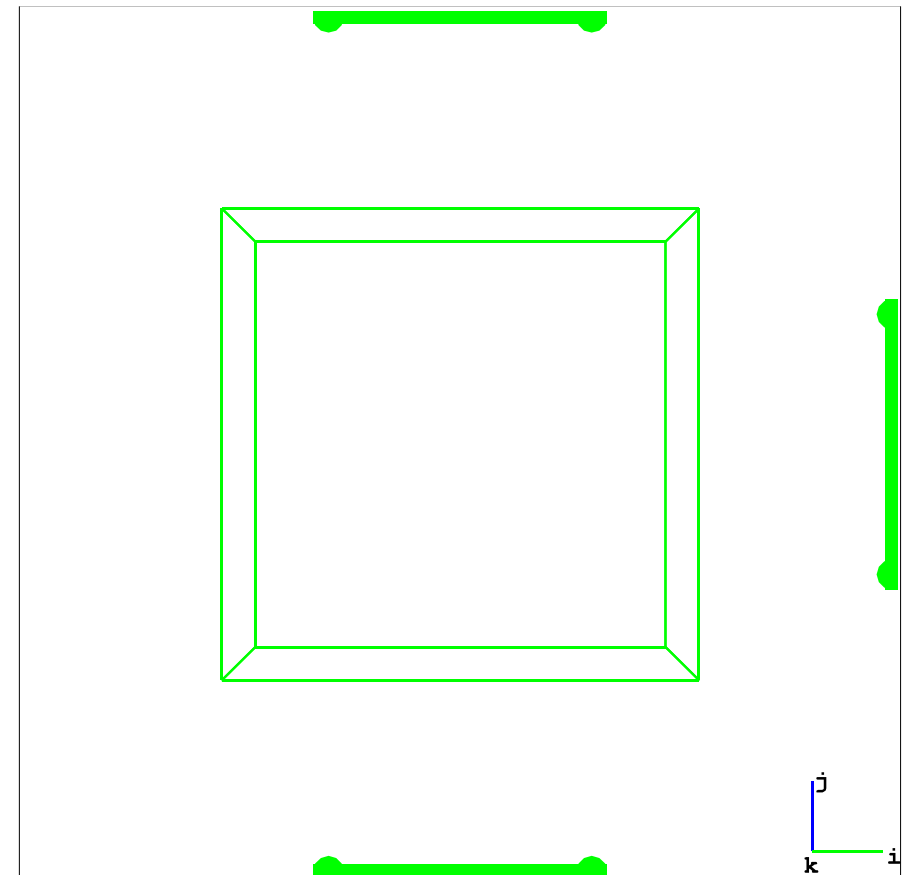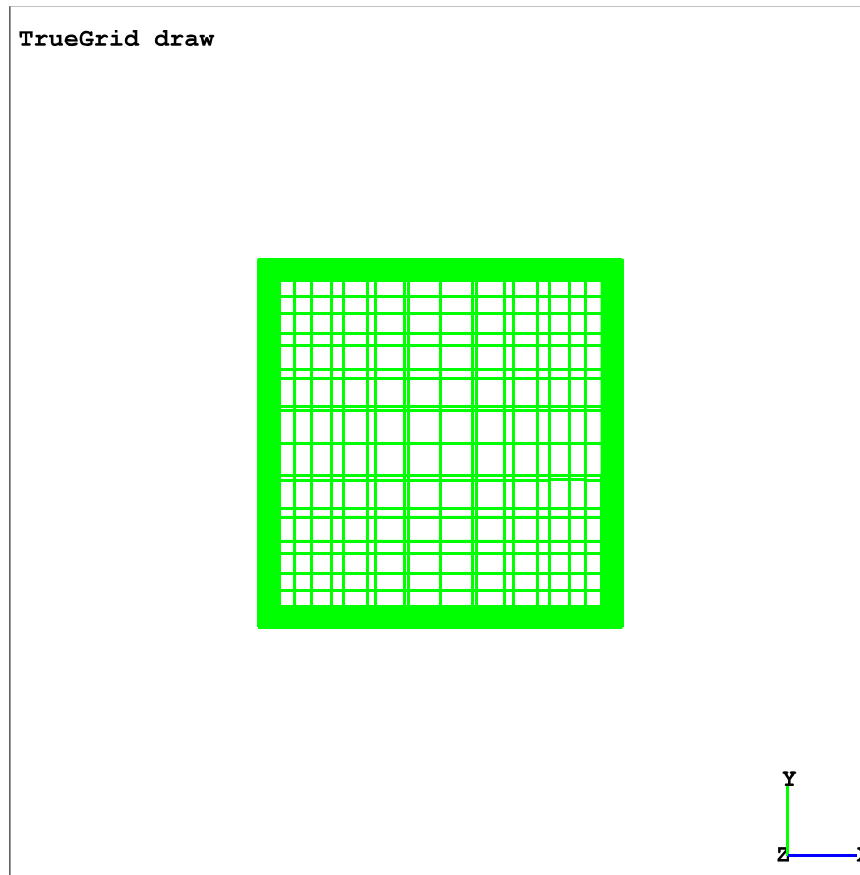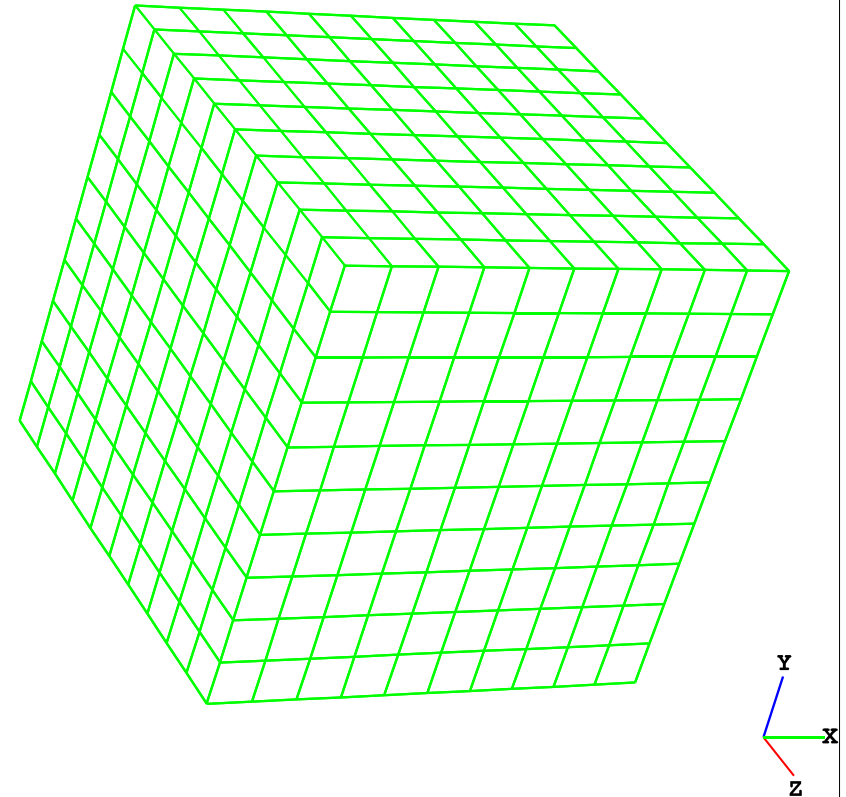
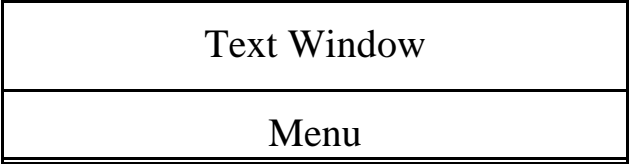# Cent and Rest fit the entire mesh in the screen.

`TrueGrid display`

`TrueGrid display`

Y
Z   X

Y
X
Z

To activate the grid,

Click on | **GRAPHICS** | > | **GRID** |

Select on or off in the Dialogue.

| **Rest** | Displays the geometry and block lining up the global coordinates (geometry with the screen coordinates.)
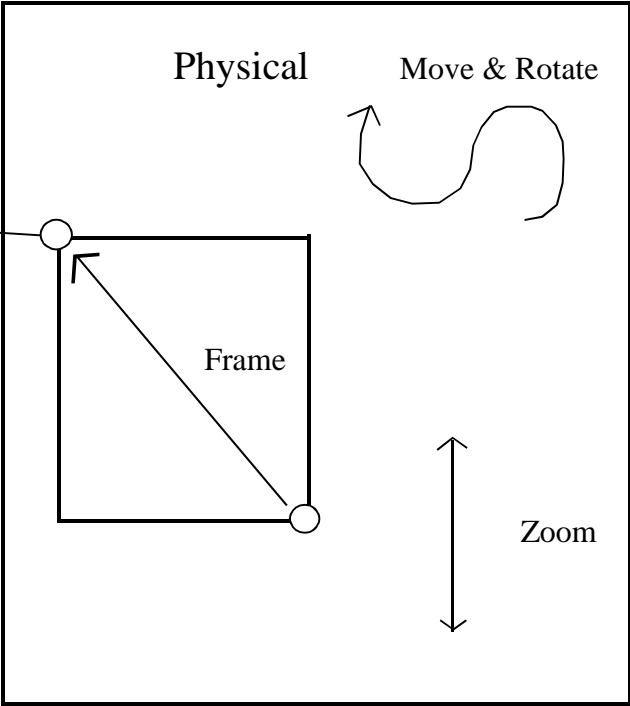
## Environment window has display screen control.

Text Window

Menu

Computational

The Computational
is independent of
the Physical display.
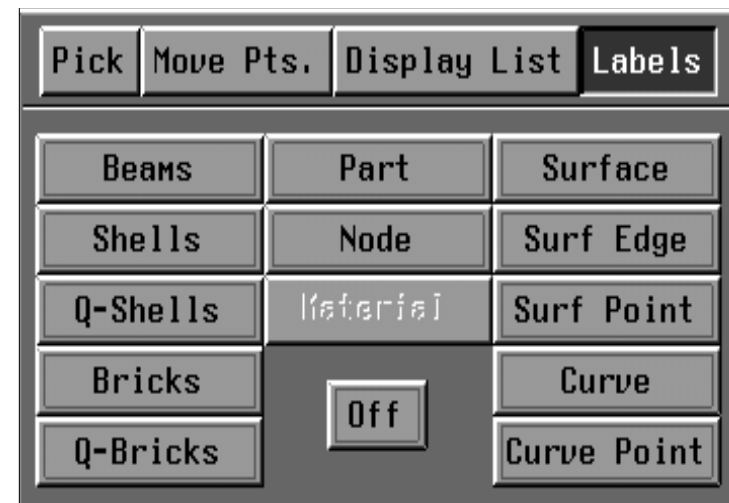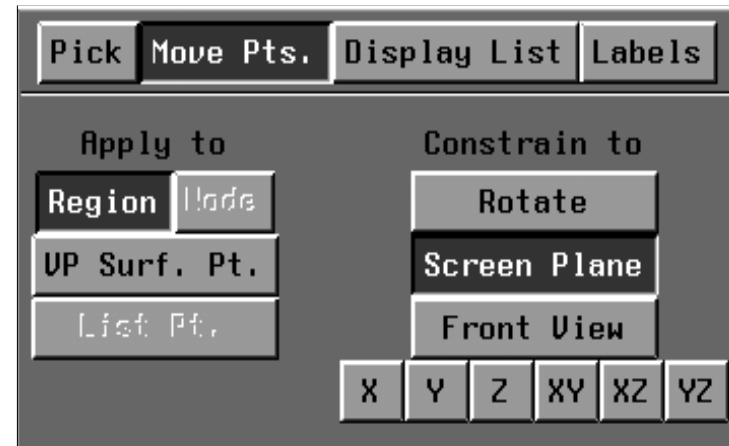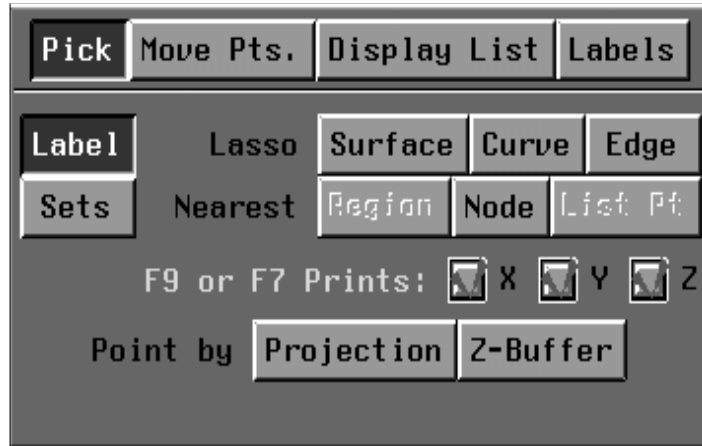
Physical          Move & Rotate

Use SHIFT + **MB**
to rotate large angles
when zoomed in.

Drag the
mouse
out of the
window to kill
the Frame action.

Frame

Zoom



Select the type of motion control from the Environment window with the **LB**. Move the mouse into the Physical or Computational window. Then click and drag the **MB** to change the picture. Release the **MB** for a full redraw of the picture.

# Environment provides multiple-layer-panel for display, edit, and label features.

Panel 1 (Pick):

| Pick | Move Pts. | Display List | Labels |

Label    Lasso    Surface    Curve    Edge
Sets    Nearest    Region    Node    List Pt.

F9 or F7 Prints: ☑ X ☑ Y ☑ Z

Point by   Projection   Z-Buffer

Panel 2 (Move Pts.):

| Pick | Move Pts. | Display List | Labels |

Apply to        Constrain to

Region   Node        Rotate
VP Surf. Pt.     Screen Plane
List Pt.        Front View

X   Y   Z   XY   XZ   YZ

Panel 3 (Display List):

| Pick | Move Pts. | Display List | Labels |

Apply Action to:      Action:

Surface   Material     Add   Show Only
Curve   Part     Remove   Show All
Point   Region        Show None

Panel 4 (Labels):

| Pick | Move Pts. | Display List | Labels |

Beams    Part    Surface
Shells    Node    Surf Edge
Q-Shells    Material    Surf Point
Bricks        Curve
Q-Bricks   Off   Curve Point

# Display List Control Commands

| Menu | | Surface | 3D Curve | Parts | Material | Interface | Cad | Cad |
|---|---|---|---|---|---|---|---|---|
| **Type** | | **Surfaces (sd)** | **3Dcurves (cd)** | **Parts (p)** | **Materials (m)** | **Boundaries (bb)** | **Groups (grp)** | **Levels (lv)** |
| **Display 1** | **(d\*)** | dsd # | dcd # | dp # | dm # | dbb # | dgrp # | dlv # |
| **Add 1** | **(a\*)** | asd # | acd # | ap # | am # | abb # | agrp # | alv # |
| **Remove1** | **(r\*)** | rsd # | rcd # | rp # | rm # | rbb # | rgrp # | dlv # |
| **Display Many** | **(d\*s)** | dsds list ; | dcds list ; | dps list ; | dms list ; | dbbs list ; | dgrps list ; | dlvs list ; |
| **Add Many** | **(a\*s)** | asds list ; | acds list ; | aps list ; | ams list ; | abbs list ; | --- | --- |
| **Remove Many** | **(r\*s)** | rsds list ; | rcds list ; | rps list ; | rms list ; | rbbs list ; | --- | --- |
| **Display All** | **(da\*)** | dasd | dacd | dap | dam | dabb | --- | --- |
| **Remove All** | **(ra\*)** | rasd | racd | rap | ram | rabb | --- | --- |

A list can include a sequence where only the first and last numbers of the sequence are give and separated by a " : ". For example:

**dsds 2 14 19:29 32 97 63:69;**

The display list panel in the environment window has buttons for some of the commands in the picture to the right.
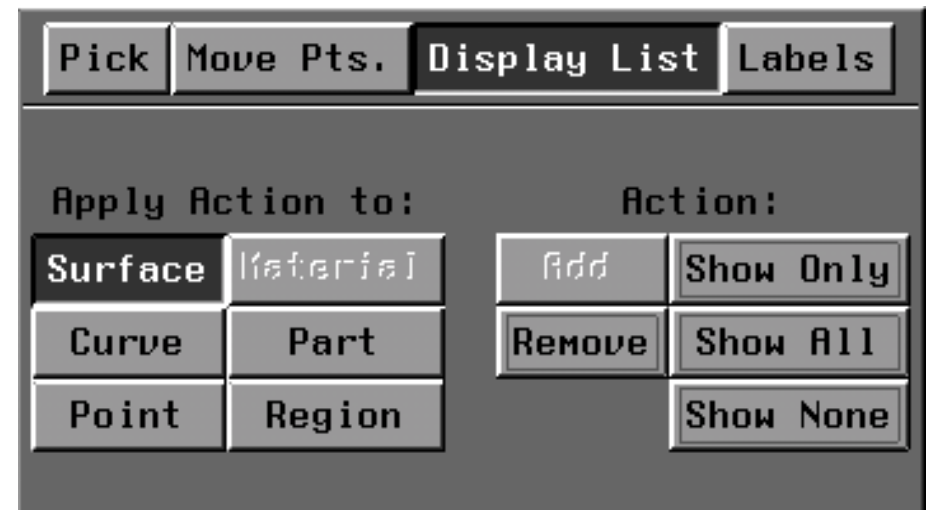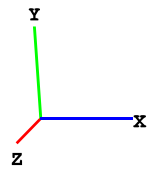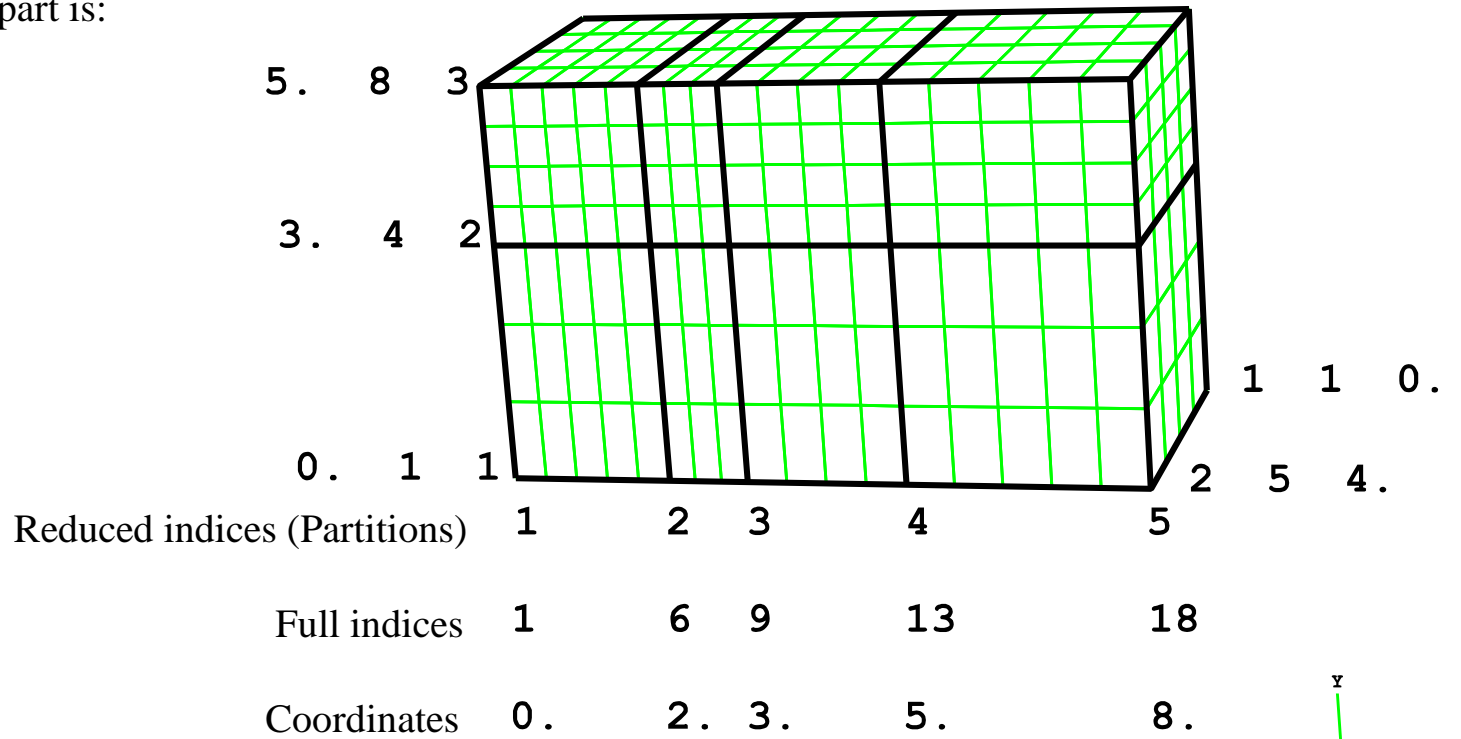
# Physical Window Showing Indices and Coordinates

The command that created this part is:

**block**   1   6   9   13   18;
            1   4   8;
            1   5;
            0.  2.  3.   5.   8.
            0.  3.  5.
            0.  4.

5.  8  3

3.  4  2

0.  1  1

1  1  0.

2  5  4.

Reduced indices (Partitions)   1       2   3       4           5

Full indices   1       6   9       13          18

Coordinates   0.      2.  3.      5.          8.

# The Computational window shows the topology of the multi-block part.

The buttons on the I, J, and K index bars are tied to the corners of the Physical and Computational meshes.

The primary use of the buttons along the index bars is as an easy and unambiguous method of selecting parts of the mesh. There are many ways to select parts of the mesh to attach, project, and assign properties.

Click on a button to toggle it on and off.

When a solid region between two buttons is selected, the solid bar between the buttons turns red. A click and drag mouse action from one button to the other toggles the selection.

Corners, edges, faces, and solids of the mesh can be selected with this technique. Each type of object is color coded.

<div style="border:1px solid">
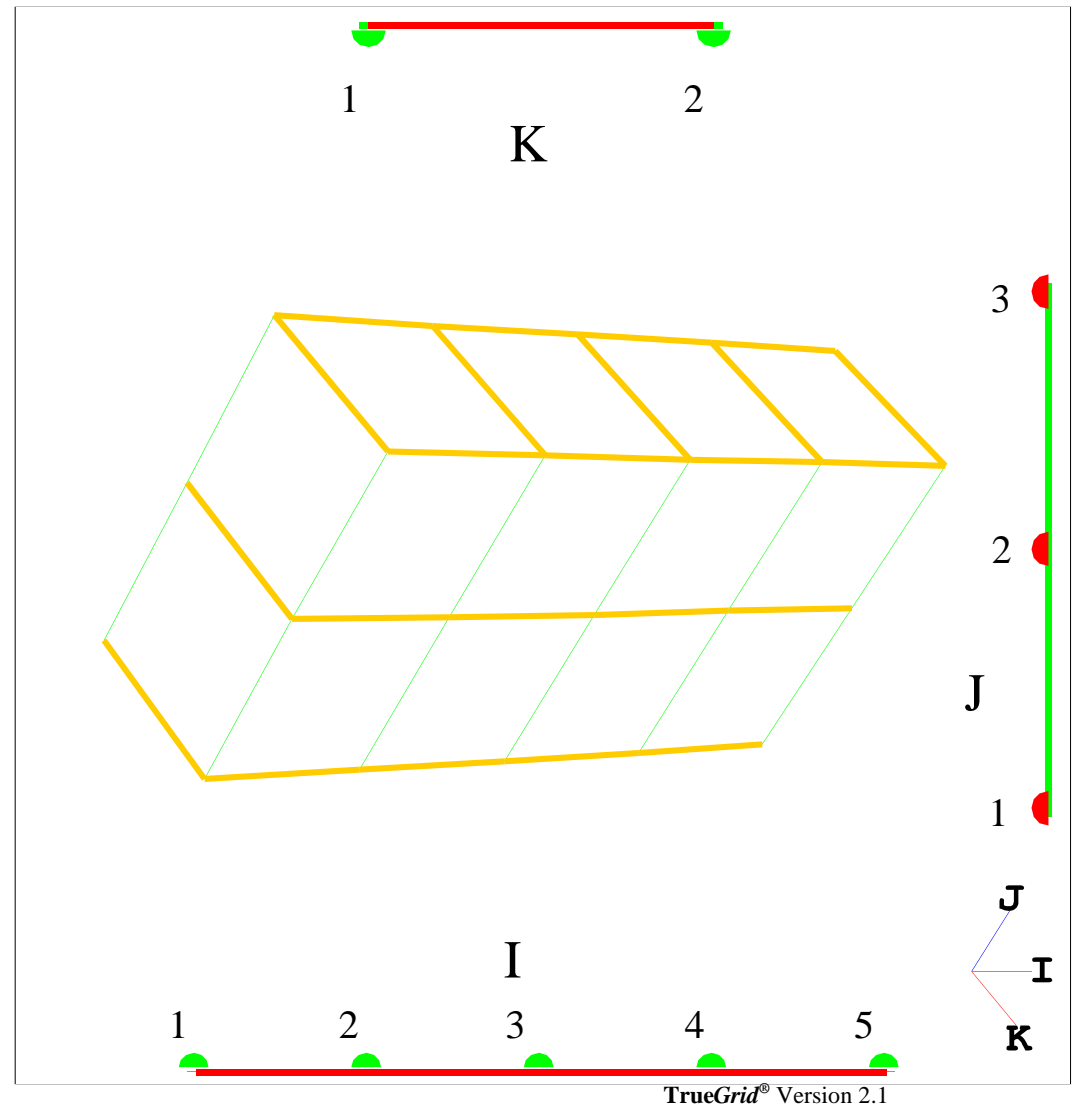
# Select mesh objects by "click" and "click-and drag".

</div>

Click **LB** on a point of the index bars.

Click **LB** on a vertex of the Computational mesh.

Click-and-drag **LB** from one point on an index bar to the other point.

Click-and-drag **LB** from one vertex in the Computational mesh to other.

Point the mouse at a vertex in the Physical mesh and press **F5**.

Point the mouse at another vertex in the Physical mesh and press **F6**.

Select Region in the pick panel and click on a vertex in the Physical window.

Select Region in the pick panel and click-and-drag from one vertex in the Physical window to another.

Click **F2** to clear all mesh selection.

# The projection function constrains the mesh to the geometry.

Simple block mesh projected on a cylindrical surface.

**Block** 1 11; 1 11; 1 11; -2 2 -2 2 -2 2
**Sfi** -1 -2;-1 -2;;sd 1

Before projection                                                                      After projection

```
TrueGrid display

                    ←——  SURFACE




MESH ——→




                              z  Y

                                   x
```
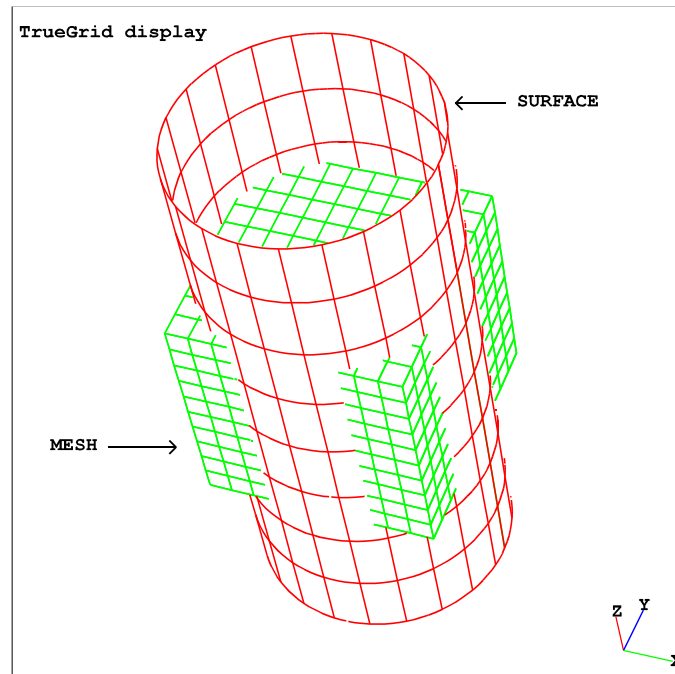
```
STEPS

1. Select mesh region

2. Select surface

3. Project
```

```
TrueGrid display




      FINAL
      MESH——→
      (MODEL)




                        z  Y

                           x
```
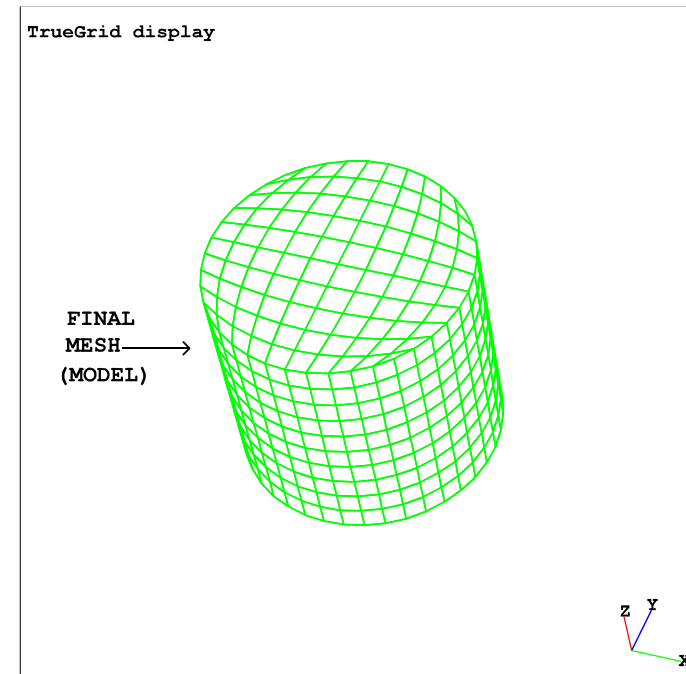
Use the **sf** or the **sfi** command under the mesh menu to constrain parts of the mesh to a surface. Alternatively, use the **project** button in the environment window. There are several ways to make selections.

## The attach function positions the mesh before projection.

A vertex attached to a surface point and an edge attached to a curve.

**Pb** 2 2 2 2 2 2 xyz 2.543 2.112 1.989
**Curs** 1 1 1 1 1 2 5

Before attach                                                                      After attach
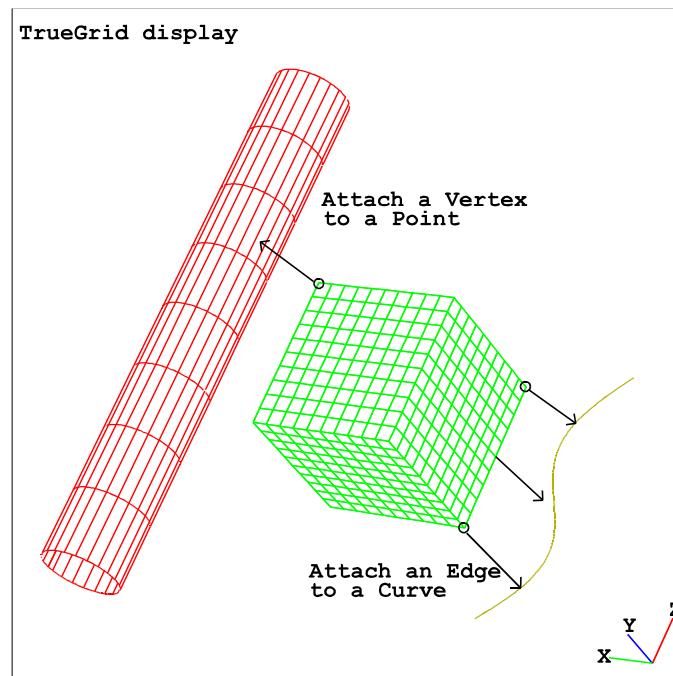


```
TrueGrid display


                Attach a Vertex
                to a Point




                              STEPS
                      1. Select mesh region

                      2. Select geometry

                      3. Attach
   Attach an Edge
   to a Curve
                              Z
                          Y
                      X
```
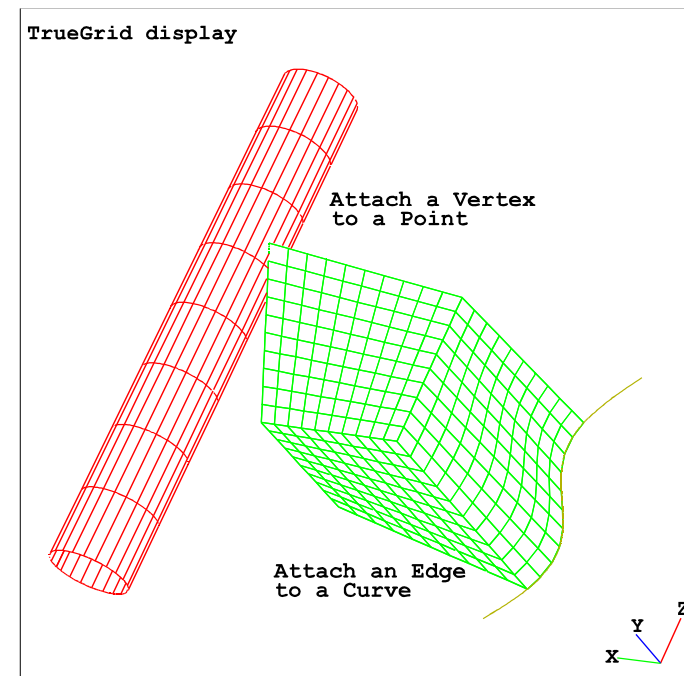
Use the **pb**, **mb**, **mbi**, **tr**, **tri**, **pbs**, **q**, **cur**, **curs**, **cure**, **curf**, and **edge** commands in the mesh menu to initialize parts of the mesh. Alternatively, use the **attach** button in the environment window. There are many ways to select geometry.

# Coincident Coordinates

Move a vertex to another vertex.

```
1.Select Vertex

2.Pick by node

3.Select node

4.Click on attach
```
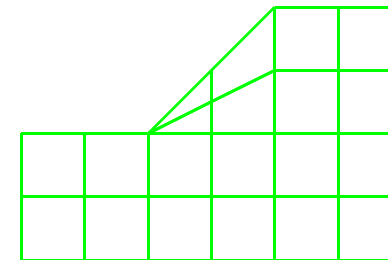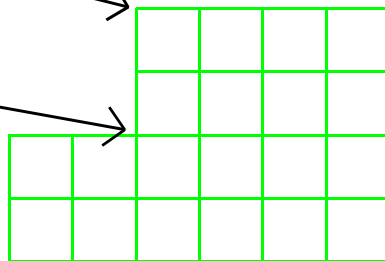
Aligning a vertex with another vertex.

```
1.Select vertex

2.Pick by node

3.Pick coordinate type
  (For example - x only)

4.Select node

5.Click on attach
```
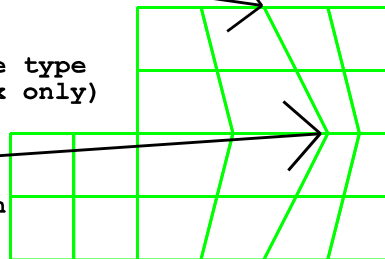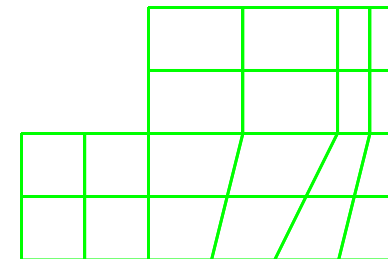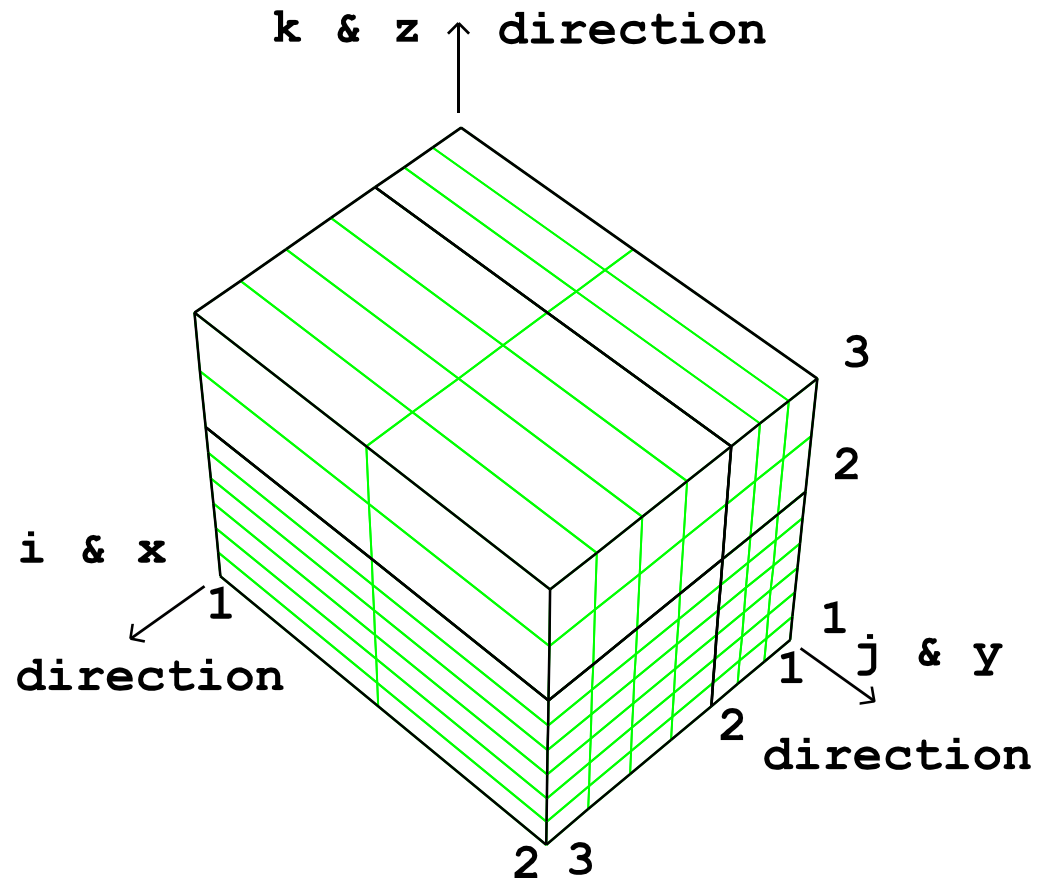
$\longrightarrow$ **X**                                                                    $\longrightarrow$ **X**

# Block Command Explanation

Command syntax:

> **Block**     **i-list ;**
> **j-list ;**
> **k-list ;**
> **x-list**
> **y-list**
> **z-list**

For Example:

> **Block**     **1  4  8 ;**
> **1  3 ;**
> **1  7  9 ;**
> **0  .5  1.5**
> **-1  1**
> **.3  1.3  2**

**k & z ↑ direction**

**i & x**

**1**

**direction**

**3**

**2**

**1**

**1 j & y**

**2**

**direction**

**2 3**

The **i-list** contains the node numbers of the block in the i-direction. In the example, there are 2 blocks in the i-direction. The nodes starting at 1 and ending at 4 (i.e. 3 elements thick) forms the first block. Nodes 4 to 8 (i.e. 4 elements) form the second block. The **x-list** assign the x-coordinates to the faces (or partitions) in the block in the i-direction. There must be as many x-coordinates in the **x-list** as there are i-indices in the **i-list** so that each i-partition has an x-coordinate. There is a similar interpretation for the **j-list** and the **y-list**, and the **k-list** and the **z-list**. The **partmode** selects a simpler version of the block command, if no shells are needed.

## Block Command Explanation (cont.)

When negative integers are used in the **i** , **j** , or **k-lists** , then the faces of the blocks corresponding to the negative numbers become shells.

For example:

    **Block**      **-1 4 -8 ;**
                  **-1 -3 ;**
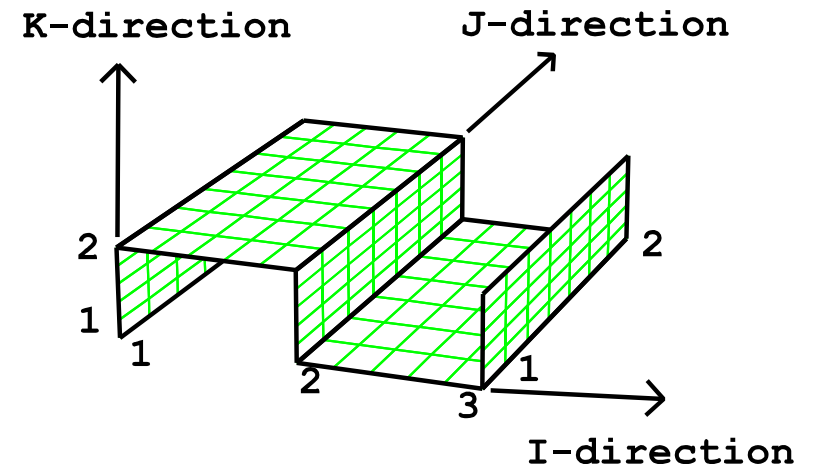                  **-1  7  9 ;**
                  **0  .5  1.5**
                  **-1  1**
                  **.3  1.3  2**
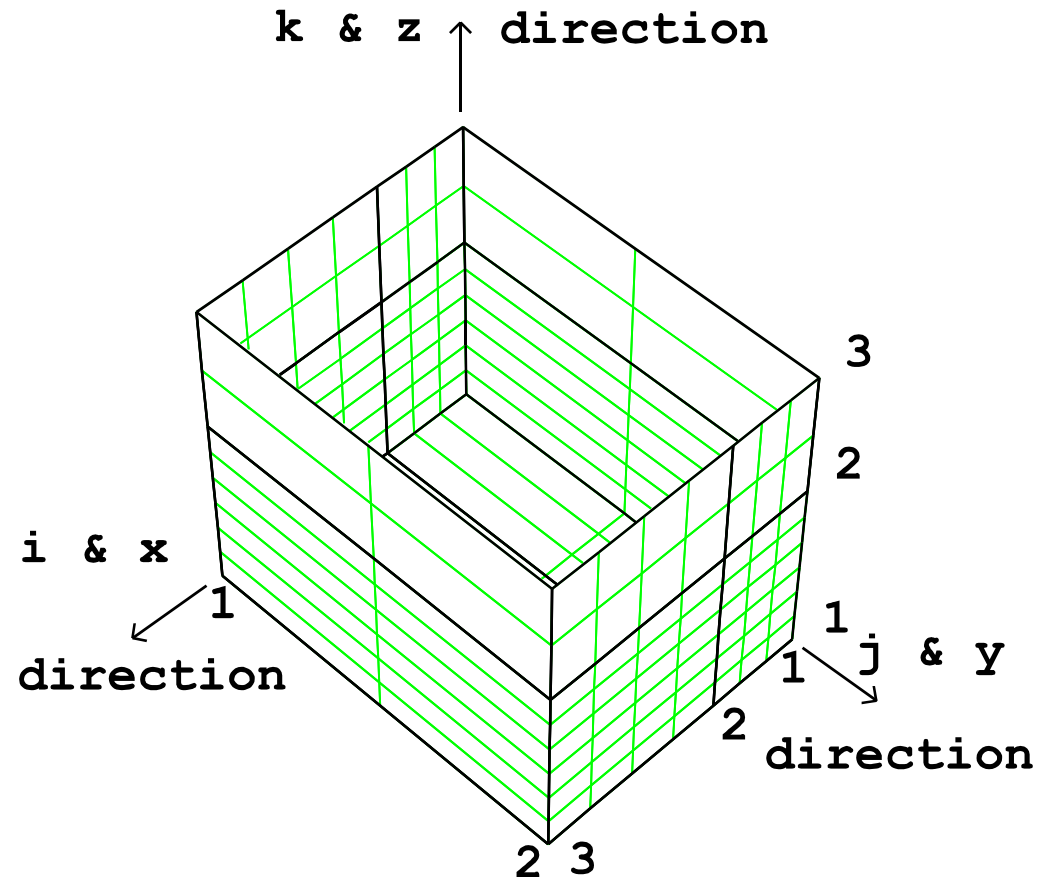


This example produces two shells faces in the i-direction , 2 shells faces in the j-direction , and 1 shell face in the k-direction to form a five-sided box with a bottom. There is a face corresponding to each negative number in the index **i**, **j**, and **k-lists**.

# Block Command Exercises

**K-direction**

2

1

**J-direction**

1

2

3

2

3    1

**I-direction**
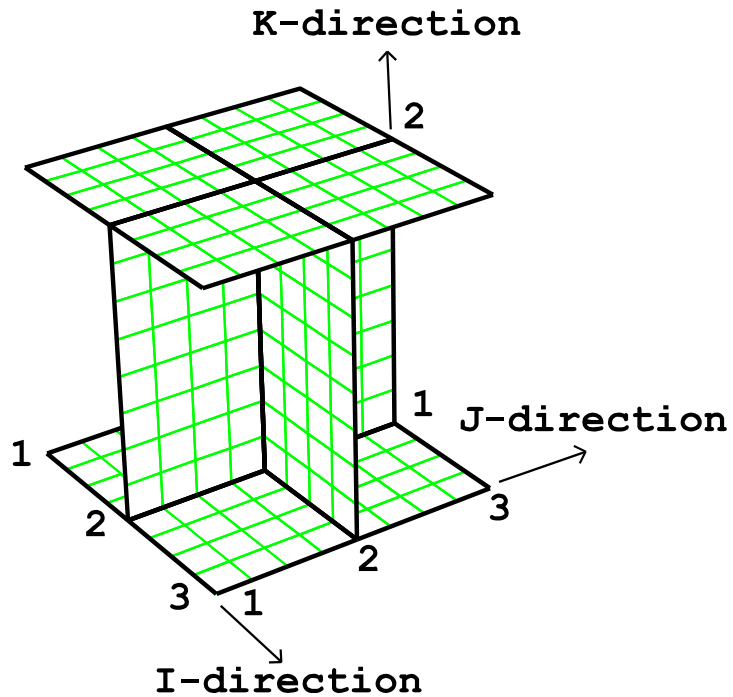
**Block**
1 -5 9; 1 -5 9; -1 -9;
1 2 3; 1 2 3; 1 3;
endpart

**K-direction**          **J-direction**

2

1

1

2

2        1

3

**I-direction**

**Block**
-1 -6 -11; 1 8; -1 -6;
0 2 4 0 5 0 1
**dei** 1 2 ; ; -1;
**dei** 2 3 ; ; -2;
endpart

## Block Commands Exercises (cont)

**J-Direction**

**K-Direction**

2

1

**I-Direction**

1  2  3  4

1

2

3

4
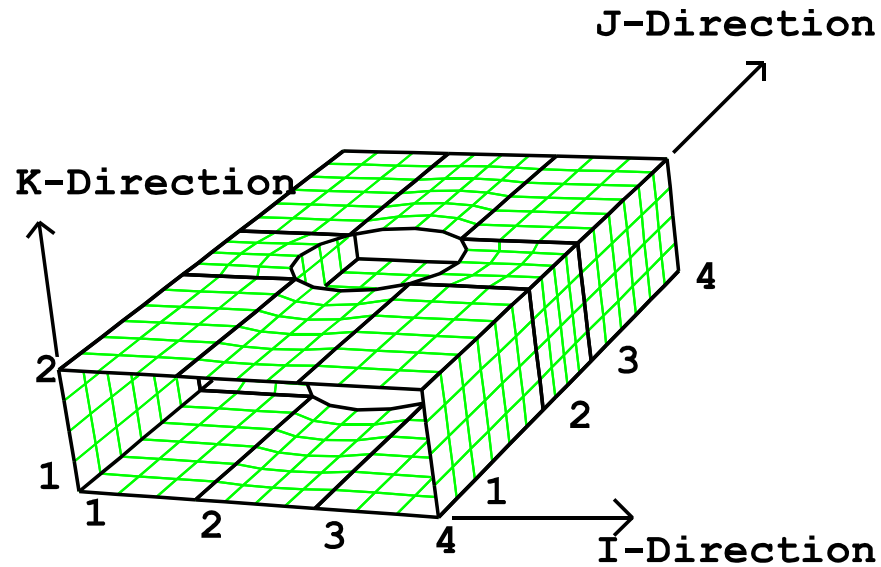
**Block**
-1 4 8 -11; 1 7 11 17; -1 -5;
0 1 2 3; 0 2 3 5 0 1
**sd** 1 cy 1.5 2.5 0  0  0 1 .7
**dei** 2 3; 2 3; ;
**sfi** -2 -3; -2 -3; 1 2; sd 1
endpart

**K-direction**

2

1

2

3

4  1  2  3  4

**I-direction**

**J-direction**
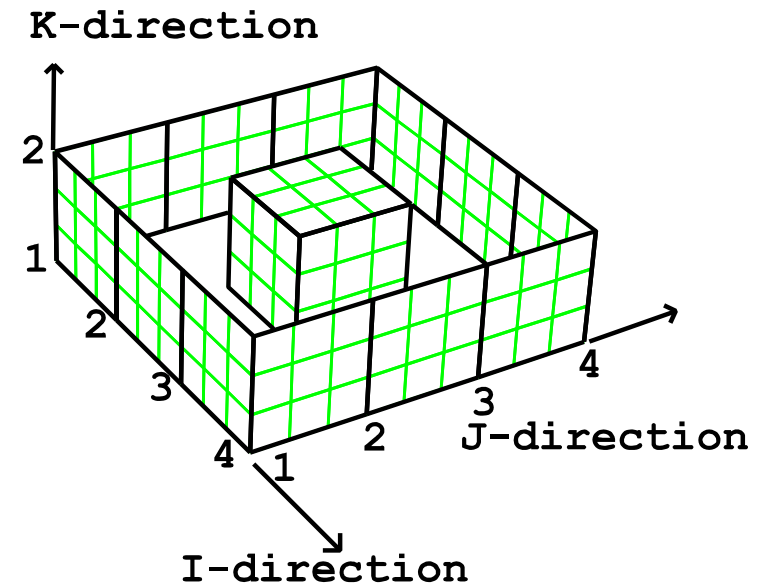
**Block**
-1 4 7 -10; -1 4 7 -10; 1 4;
 1 2 3 4; 1 2 3 4; 1 2;
endpart

# Block Commands Exercises (cont)



**K-direction**

**J-direction**

**K-direction**

2

5

4

1

1                2

4                5

1

2

**I-direction**

**K-direction**

2

**J-direction**

1

1

2

1

2                3

3      3

**I-direction**
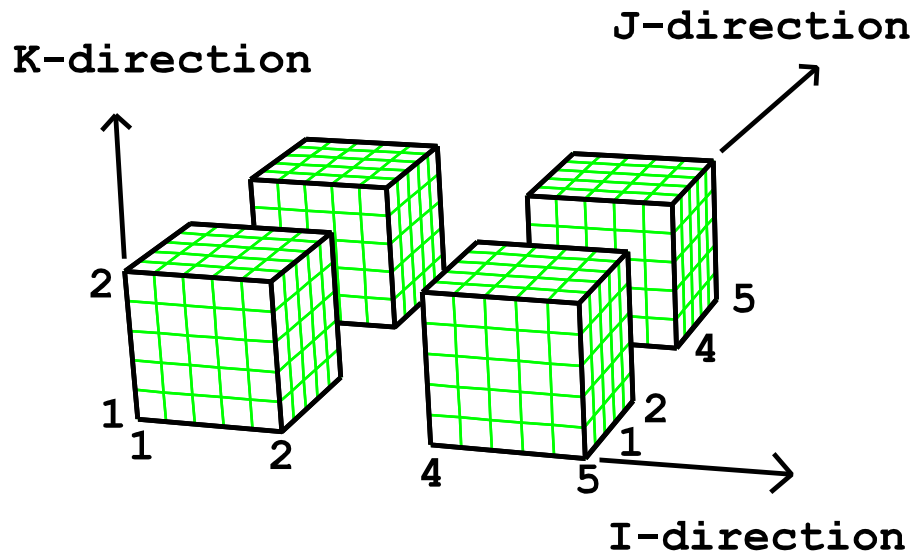
**Block**
1 6 0 7 12; 1 6 0 7 12; 1 6;
1 2 0 3 4; 1 2 0 3 4; 1 2 ;
endpart
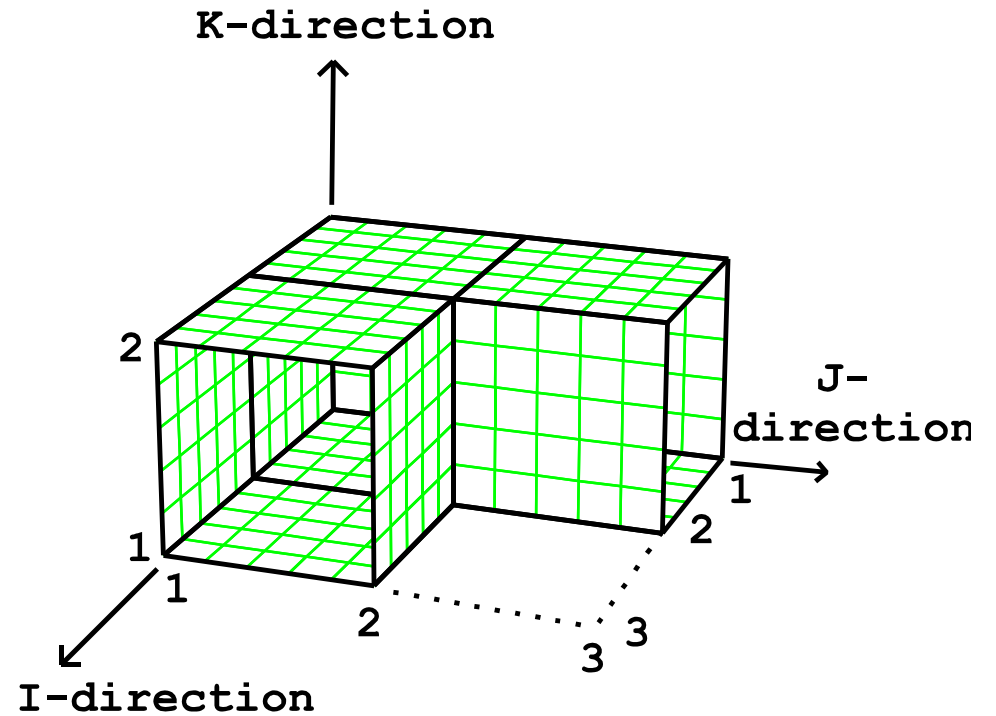
**Block**
-1 -6 11; -1 -6 11; -1 -6;
0 1 2; 0 1 2; 0 1;
**dei** 2 3; 2 3; -1 0 -2;
**dei** -2; 1 2; 1 2;
**dei** 1 2; -2 ; 1 2;
endpart

# Butterfly Technique

The butterfly topology is used to create a good mesh of a curved object using quad or hex elements.
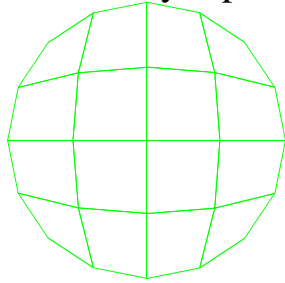
Simple Block Topology                    Simple Wedge Topology                    Butterfly Topology
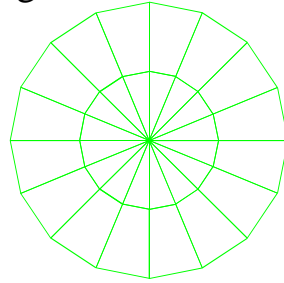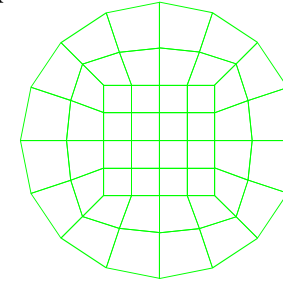
Computational Mesh
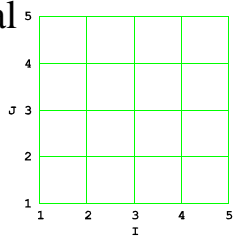
Initial Part

$X_1=X_2$, $X_4=X_5$, $Y_1=Y_2$, $Y_4=Y_5$
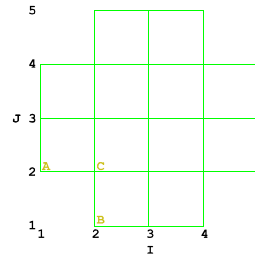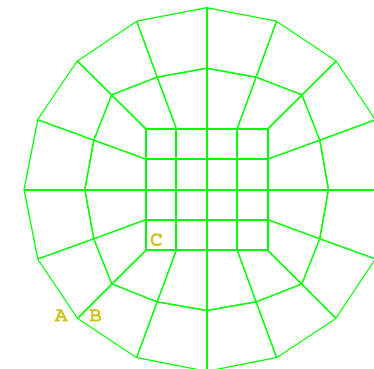
Delete Corner Blocks

Cylinder of Projection

After Projections

Physical Mesh

# Parts of a structure may be generated separately and then merged to build a connected model.

This is an exercise to build a two part model with an interface of matching nodes. The interface in both parts require the same constraints to match.

Initiate a block for part 1 and generate a cylinder and a sphere:

> **Block 1 11; 1 11; 1 11; -1 1; -1 1; -1 1;**
>
> **sd 1 cy 0 0 0 0 0 1 1.1   c   cylinder: 1**
>
> **sd 2 sp 0 0 2.5 1.5        c   sphere: 2**

Project parts of the block onto the geometry:

> **sfi -1 -2; -1 -2;; sd 1   c   project to the cylinder**
>
> **sfi ;; -2; sd 2              c   project to the sphere**
>
> **endpart**
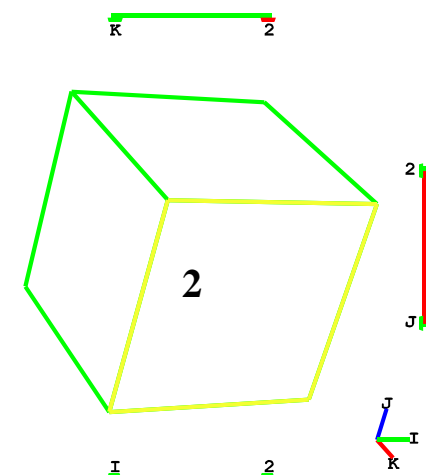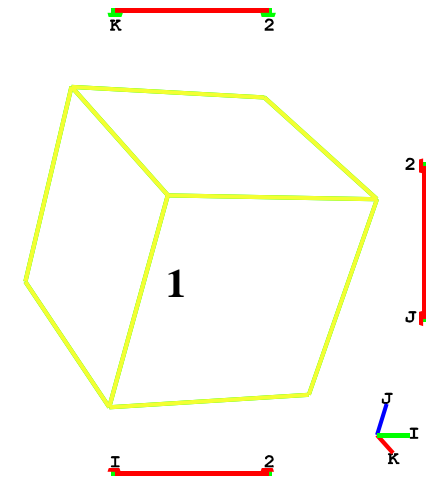
## Parts of a Structure may be generated separately; and then merged to build a connected model (cont.).

Initiate a block for part 2 and project:

**Block 1 11; 1 11; 1 11; -1 1; -1 1; 1.5 3.5;**

**sfi -1 -2; -1 -2; -1 -2; sd 2   c project to the sphere: 1**

**sfi -1 0 -2;; -1; sd 1    c   project edges to cylinder: 2**

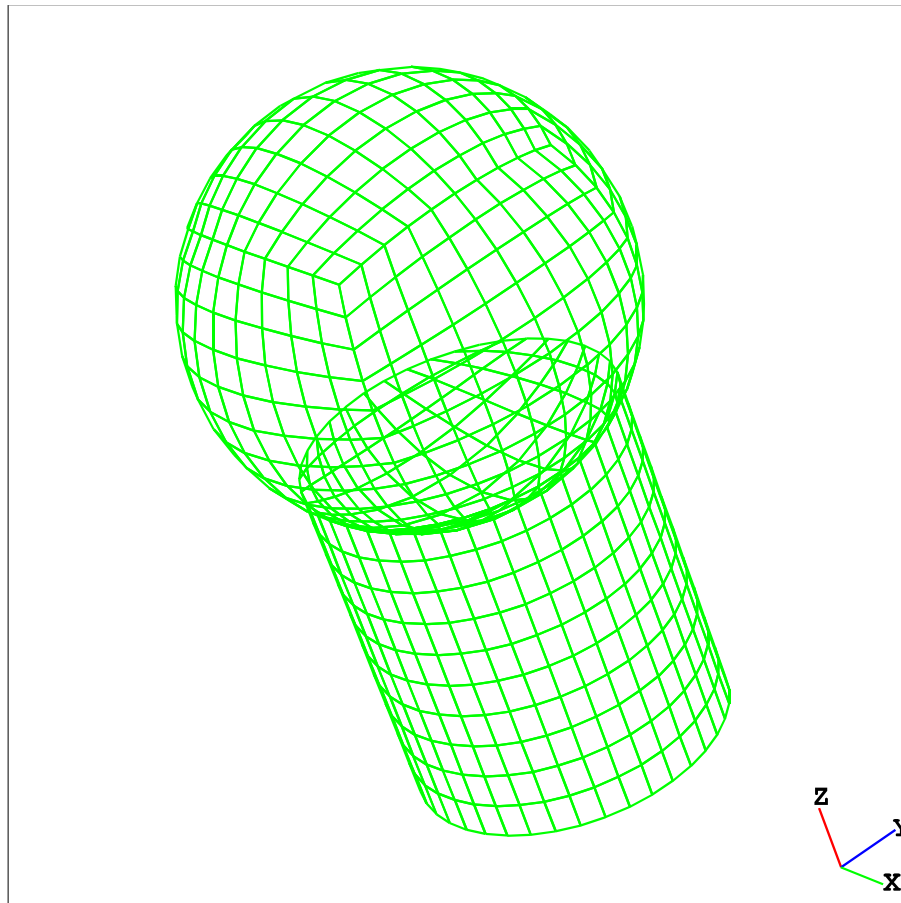**sfi ; -1 0 -2; -1; sd 1   c   project edges to cylinder: 3**

**endpart**
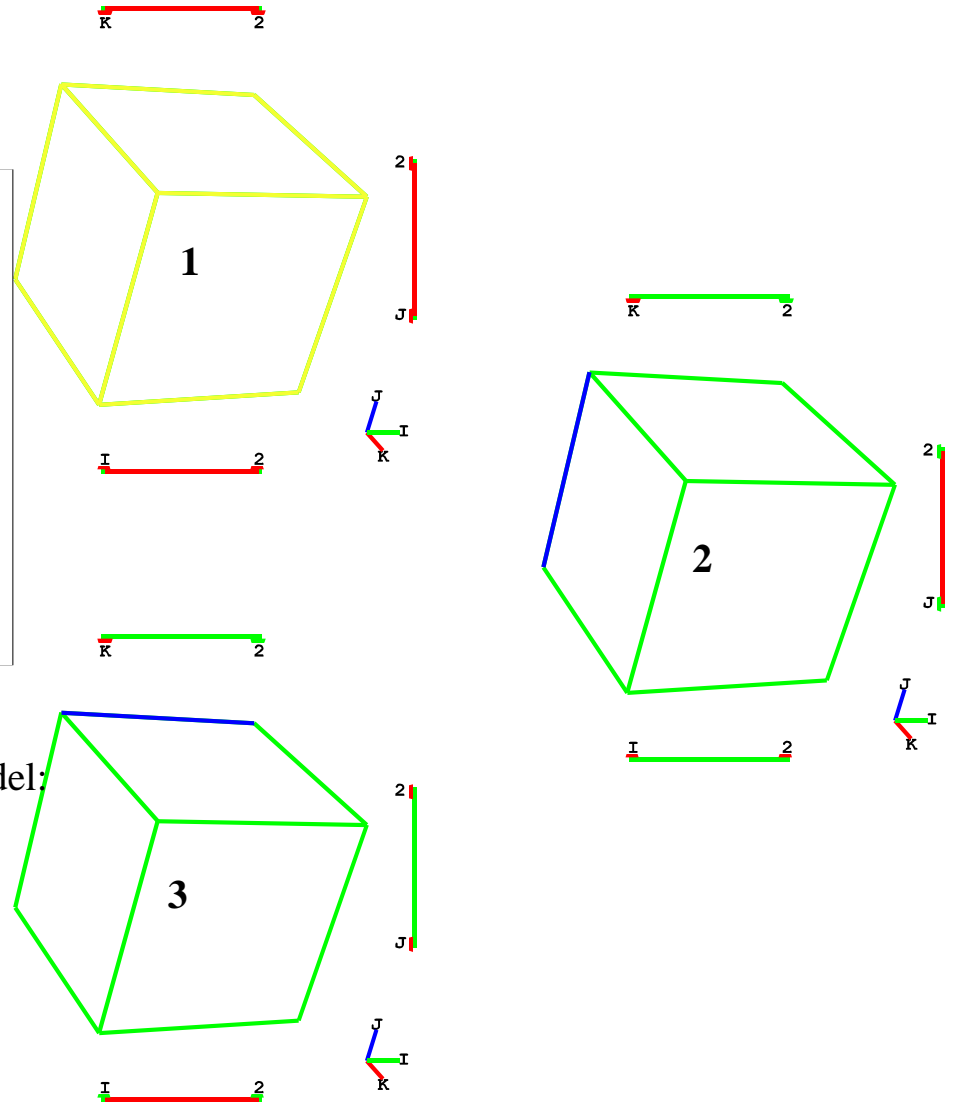
Merge the two parts together to form one connected model:
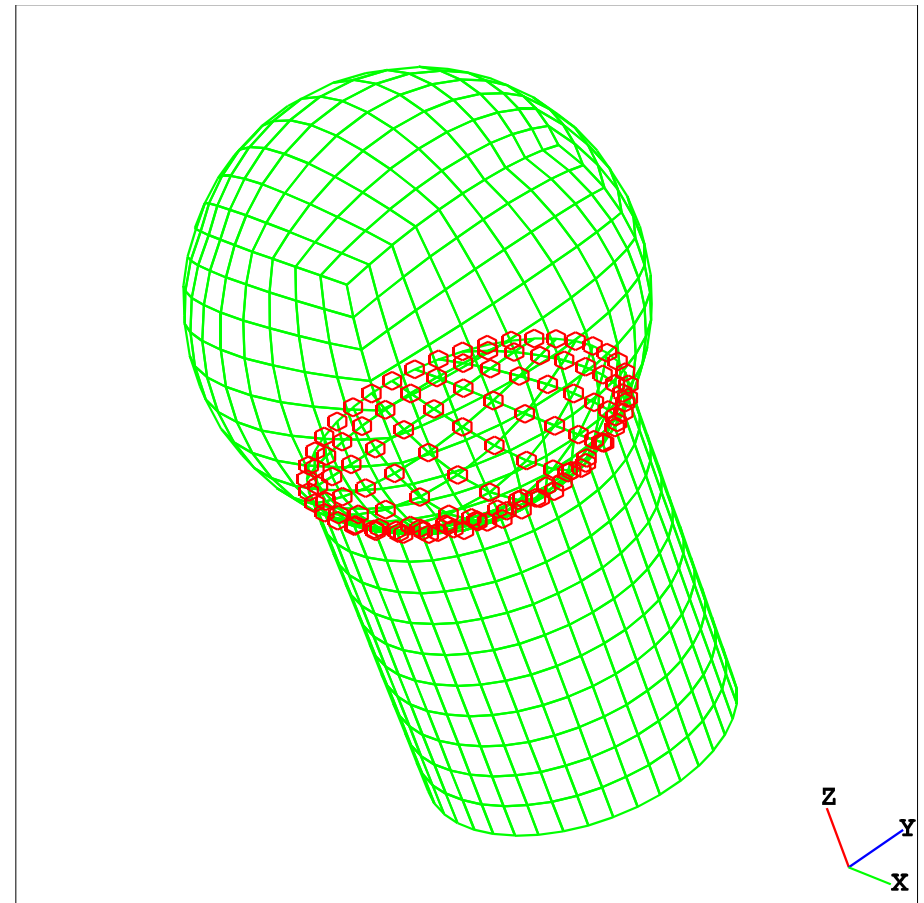
**merge stp 0.0001**

**rx -45 ry -45 labels tol 1 2**

# The merged nodes are marked by circles.

Before Merging                                                    After Merging

# Projection to 1 Surface

A typical surface is defined with three coordinate functions X, Y, and Z depending on a pair of parametric coordinates U and V. For example, a cylinder of radius ⍴ can be defined by the three functions

$$X(u,v) = \rho\cos(u)$$
$$Y(u,v) = \rho\sin(u) \quad \text{where} \quad \begin{array}{l} u \in [0,360) \\ v \in [-1,1] \end{array}$$
$$Z(u,v) = v$$

**Parametric Domain**

$$X(u,v)$$
$$Y(u,v)$$
$$Z(u,v)$$



The projection to a surface takes advantage of the differentiability of the surface. Each surface is approximated by an array of polygons. These polygons are used to display the surface. When a node is to be projected to such a surface, the initial 3D coordinates of the node are used to search the coordinates of the surface approximation. Each surface has a complex data structure to optimize this search. The point on the surface approximation which is closest to the node is then mapped back to the parametric coordinates of the surface.

**Surface**
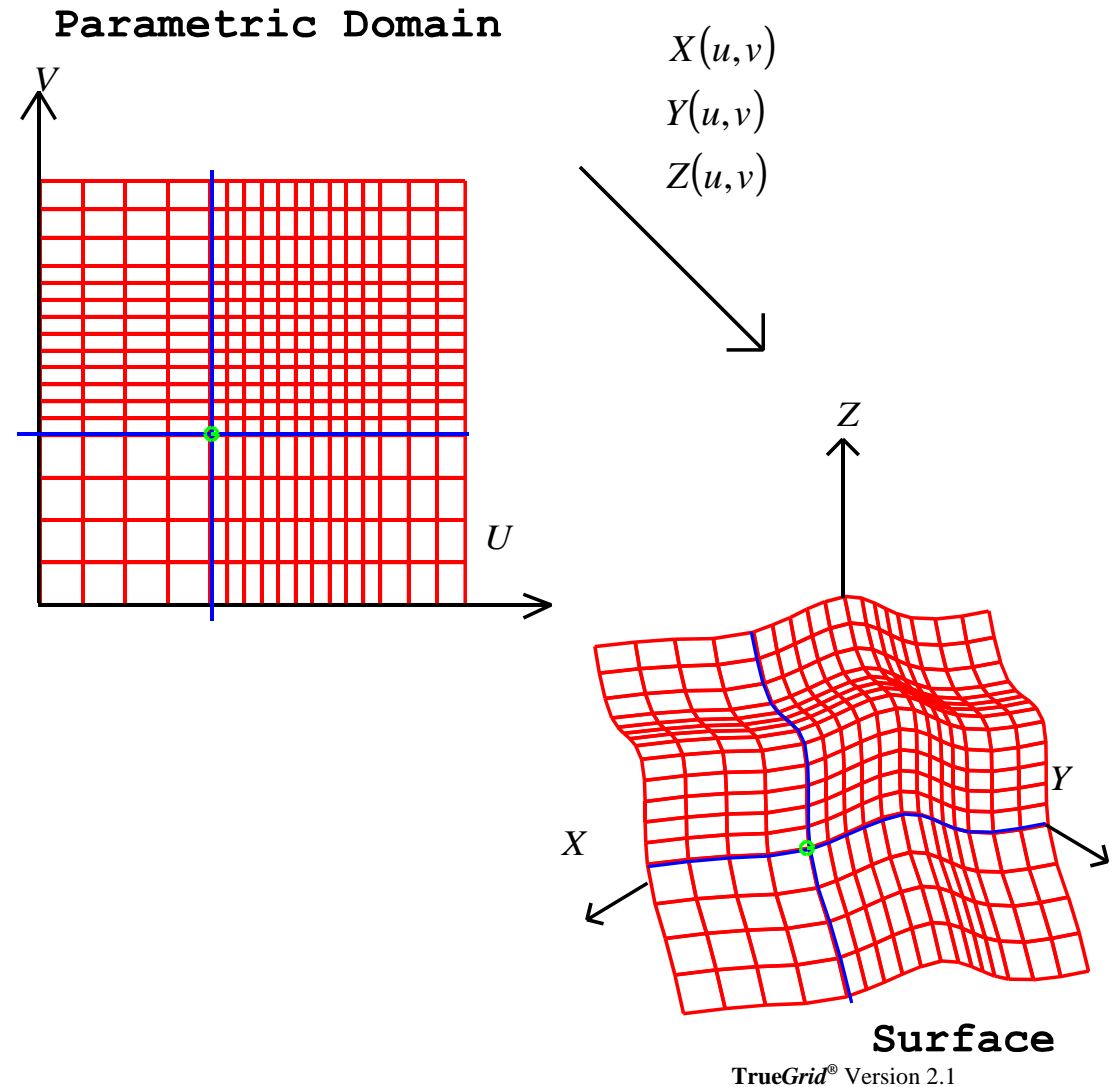
These parametric coordinates are refined with an iterative Newton method. If we let the parametric coordinates $(u_i, v_j)$ be the results of the ith iteration, then we can write the method in a standard Newton form. We use the following notations:

where $\left( X_i, Y_i, Z_i \right) = \left( X(u_i, v_i), Y(u_i, v_i), Z(u_i, v_i) \right)$

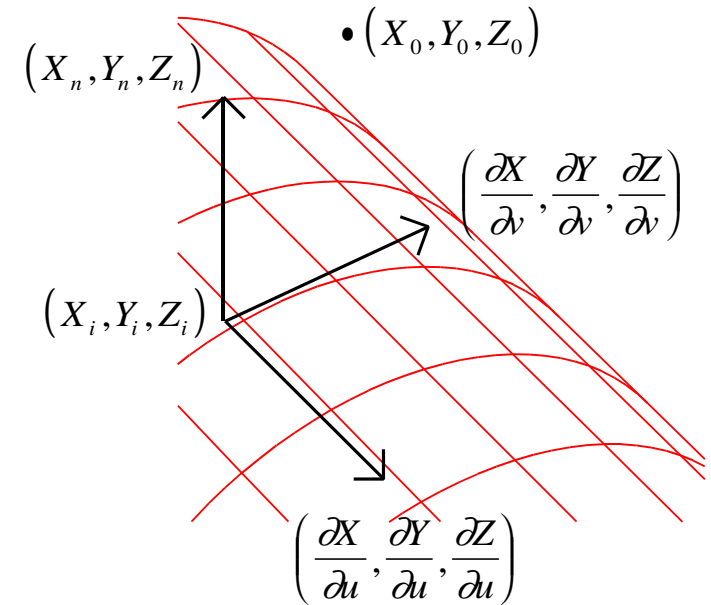$\left( X_0, Y_0, Z_0 \right)$ is the position of the node to be projected

$\left( X_n, Y_n, Z_n \right)$ is the surface normal

If we define the matrix

$$M = \begin{bmatrix} Xn & Yn & Zn \\ \dfrac{\partial X}{\partial u} & \dfrac{\partial Y}{\partial u} & \dfrac{\partial Z}{\partial u} \\ \dfrac{\partial X}{\partial v} & \dfrac{\partial Y}{\partial v} & \dfrac{\partial Z}{\partial v} \end{bmatrix}$$
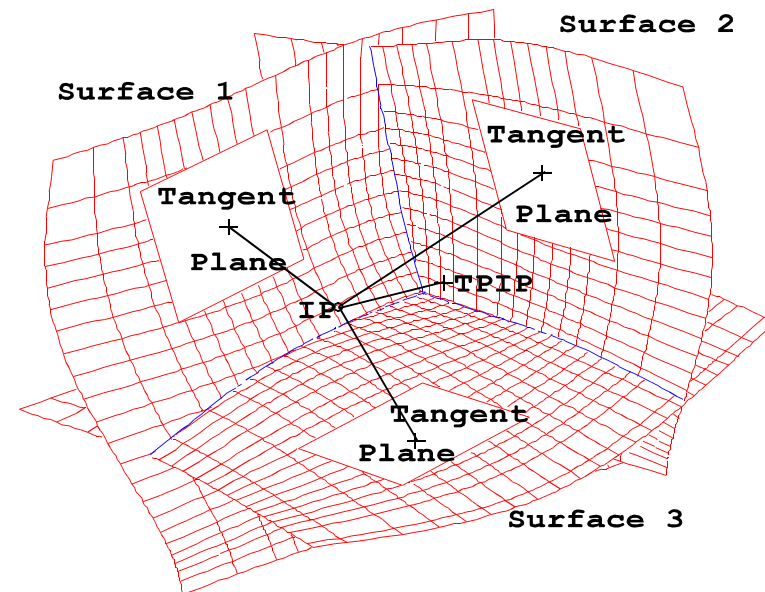
then the Newton method used is

$$\begin{bmatrix} * \\ u_{i+1} \\ v_{i+1} \end{bmatrix} = \begin{bmatrix} * \\ u_i \\ v_i \end{bmatrix} + M^{-1} * \begin{bmatrix} X_0 - X_i \\ Y_0 - Y_i \\ Z_0 - Z_i \end{bmatrix}$$

The initial search to the closest point on the surface approximation is fast and yields about 3.5 digits of accuracy. The Newton method on the actual surface takes an additional 4 iterations to yield full machine accuracy. This method has been adapted to many surface types including trimmed and non-smooth surfaces. Use the **accuracy** command with a number greater than 2 to activate the Newton method.
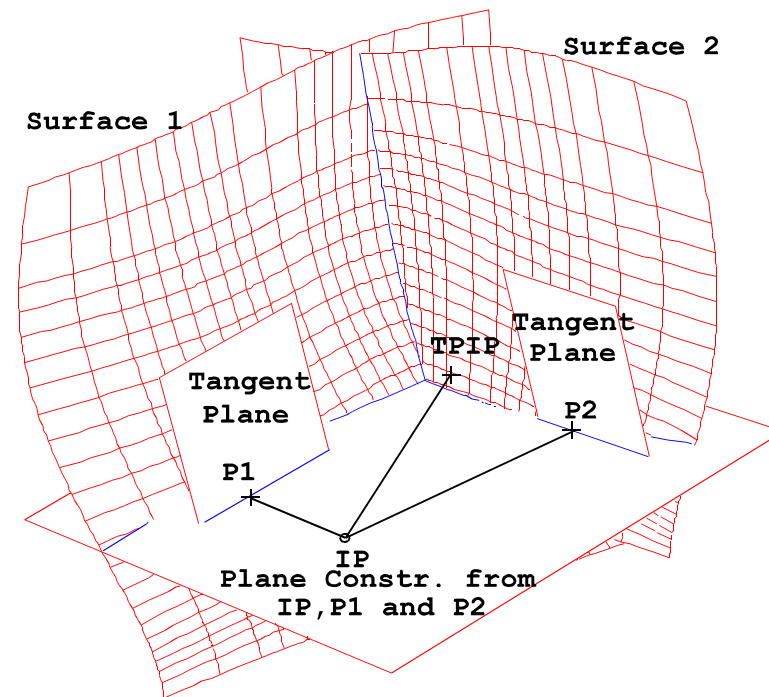
# Projection to 3 Intersecting Surfaces

Project onto the intersection of 3 **Surfaces** uses the projection onto 1 surface for each of the 3 surfaces. The resulting **Tangent Planes** are intersected. The node at **IP** is moved to this intersection point **TPIP** and the process is repeated. Convergence to the desired point of intersection occurs if the initial point **IP** is closed. This is a relative issue based on the curvature of the surfaces. When the surfaces are flat, the initial point **IP** can be almost anything. Many features in **True*Grid*®** make it easy to move control points of the mesh so that they are close to the desired points of intersection of the 3 surfaces.

# Projection to 2 Surfaces

The two **Tangent Planes** from the projection to two **Surfaces** are intersected with the plane which passes through the two points of projection **P1** and **P2** and the Initial Point **IP**. The node is moved to this point of intersection **TPIP** and the process is repeated. This is commonly the case with edge nodes that are required to be on two surfaces.



```
IP - Initial Point
TPIP - Tangent Plane Intersection Point
```

# Projection onto Multiple Surfaces

It is easy to form a composite surface. The first step is to determine which surfaces are to be combine. If you can isolate the surfaces by showing only the surfaces you want to combine, then use the **lasd** command to list all of the surfaces in the picture.

Issue a command like the following:

**sd** 25 sds 3 6;

This creates a new surface number 25 consisting of surfaces 3 and 6. Then project.

**sfi** ;;-1;sd 25

CAD models typically have thousands of surfaces. This feature helps organize the geometry. Then one can build the mesh with out regard to the boundaries of the component surfaces. Without this feature, one would be forced to use a mesh topology based on the boundaries of the surfaces instead of the right topology.
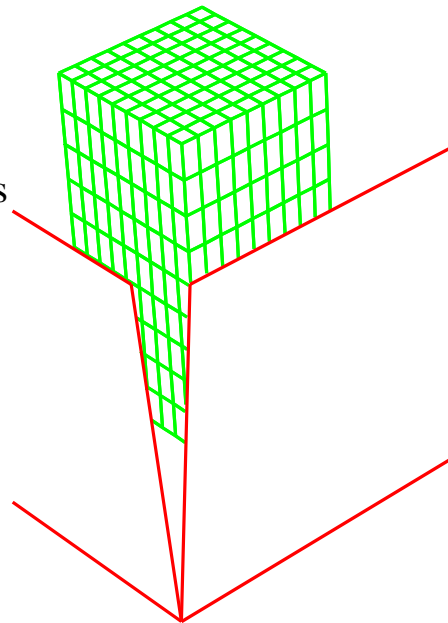
Composite surface

Mesh across composite surface
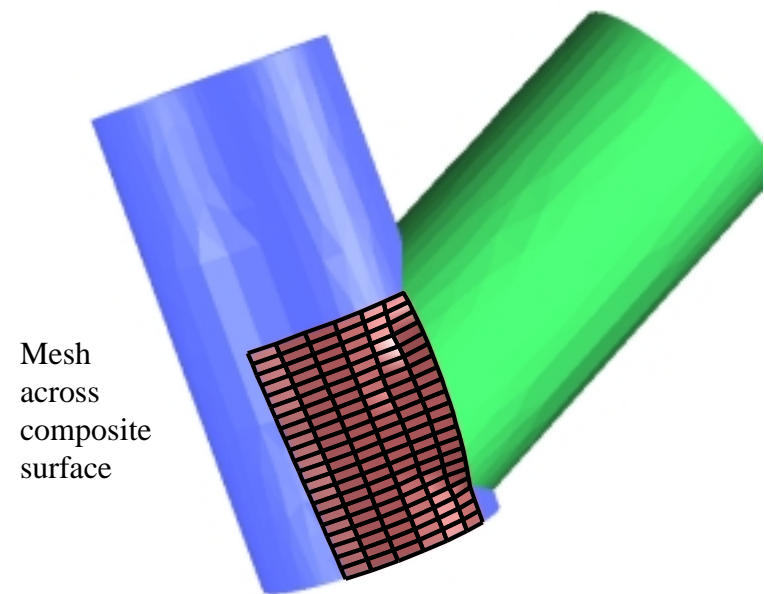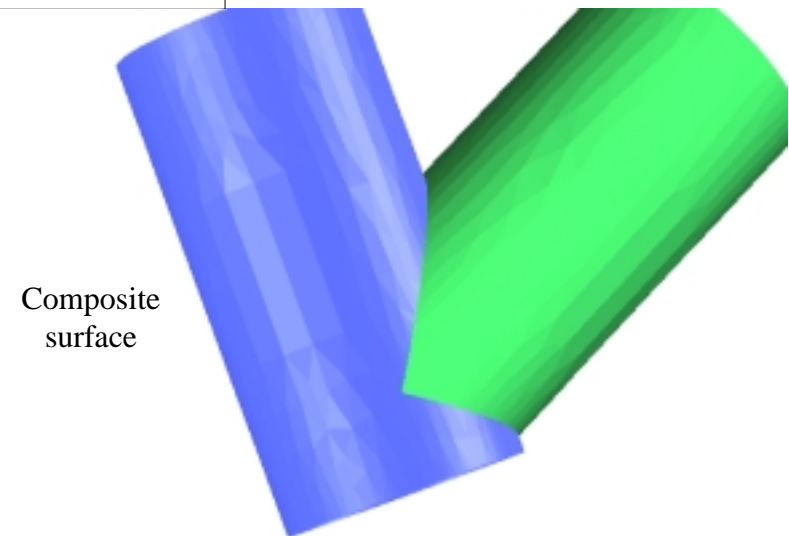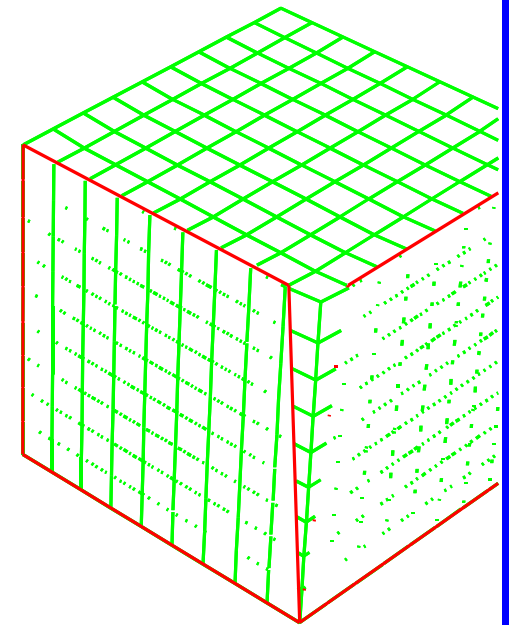
# Intersecting Surfaces With Gaps

Before

After

Geometry can be used directly from most CAD systems without clean-up. It is typical that surfaces do not meet perfectly. The intersection of surfaces automatically compensates for surfaces that do not quite intersect. This is because the algorithm intersects the tangent planes of closest points instead of intersecting the actual surfaces.

In the example to the right, the before view shows the initial position of the mesh before projections. The left face is projected to the left surface and the right face is projected to the right surface. No special care is needed as long as the gap between the two intersecting surfaces is smaller than a element.
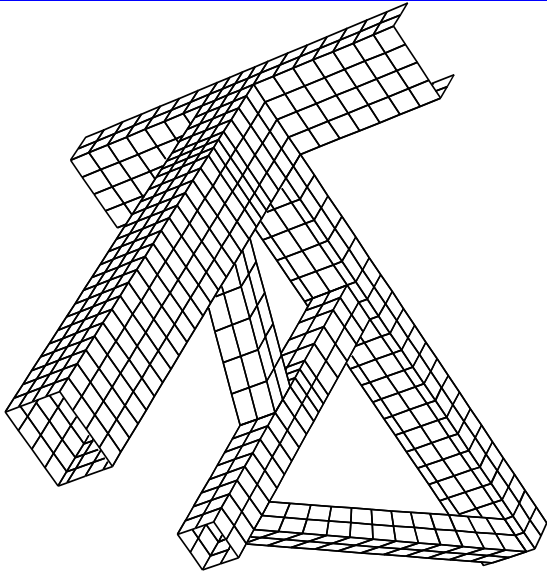
## Use Projection Only Where Needed

Many parts can be created using only a few projection commands. All faces do not need to be projected. Projection is only needed to charge the initial shape of the mesh.

The frame on the left required no projections.

The strut on the right only required projections in two small regions of the part.
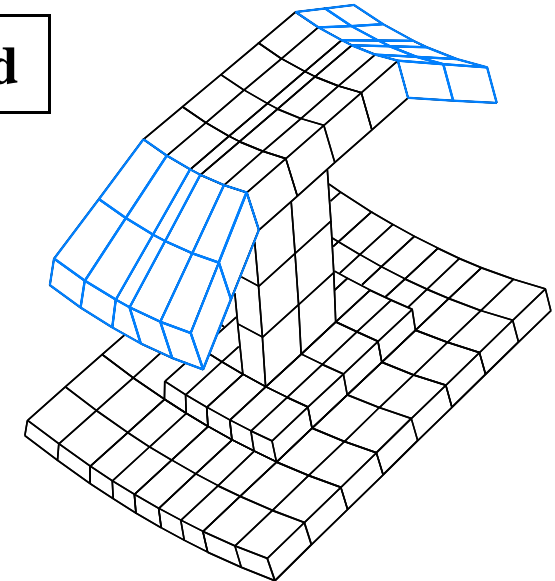
```
block 1 9 -11 -13 -17 -19 22 25 -27 -29 31;
      1 3 -15 -17 -22 -26;
      1 -8 -9 -11 -12 19;
      0 2 3 4 6 7 8 10 11 12 13
      0 1 7 8 11 13
      -4.75 -.75 -.5 .5 .75 4.75
dei 10 11; 1 -3 -4 6; 1 -2 -3 -4 -5 6;
dei 1 -3 -4 -5 -6 10; 1 -3 -4 6; 1 3 0 4 6;
dei 1 -9 0 -10; 1 -5 0 -6; 1 2 0 5 6;
dei -9 10; -3 0 -4 0 -5 -6; 1 2 0 5 6;
dei 1 9; 1 5; -2 0 -5;
dei ; 5 6; -3 0 -4;
dei 9 10;; -3 0 -4;
dei 1 2; 1 -3 -4 5; -3 -4;
dei 1 -3 -4 -5 -6 9; 1 2; -3 -4;
dei 2 3 0 4 -5 -6 9; 2 3; -3 -4;
dei 2 -3 -4 5 0 6 9; 4 5; -3 -4;
dei -3 0 -4 0 -5 0 -6; 3 4 0 5 6; 2 5;
dei -9; 3 4; 3 4;
dei -9 0 -10; 5 6; 2 5;
dei 7 8; -5 -6; -2 -5;
mbi 4 7; 5 6; 2 5;x 2
pb 4 2 4 4 2 4 xyz 11 1 .5
pb 3 2 4 3 2 4 xyz 11 0 .5
pb 3 2 3 3 2 3 xyz 11 0 -.5
pb 4 2 3 4 2 3 xyz 11 1 -.5
res 1 5 2 4 6 5 i 1
res 1 6 2 11 6 5 k 1
```

```
sd 1 cone 0 0 0 0 0 1 0    35.311
sd 2 cone 0 0 0 0 0 1 5.667 -35.311
sd 3 cone 0 0 0 0 0 1 .75   35.311
sd 4 cone 0 0 0 0 0 1 6.417 -35.311
sd 5 plan 0 0 0 0 0 1
sd 6 plan 0 0 8 0 0 1
cylinder 1 2 6 7 8 ;
         1 3 5 6 8 10 ;
         1 3 4 6 7 9 ;
         4.25 5 10 10.5 11
         0 8 13.5 16.5 22 30
         0 2 3 5 6 8
dei 2 3 ; 1 3 0 4 6 ; ;
dei 2 3 ; ; 1 3 0 4 6 ;
dei 3 4 ; 1 2 0 5 6 ; ;
dei 3 4 ; 2 5 ; 1 2 0 5 6 ;
dei 1 2 ; 1 2 0 5 6 ; ;
pb 1 2 1 2 2 6 2 0
pb 1 5 1 2 5 6 2 30
mb 2 3 1 2 3 6 2 -1.3
mb 2 4 1 2 4 6 2  1.3
sf 1 1 1 1 6 2 sd 2
sf 1 1 5 1 6 6 sd 1
sf 2 1 1 2 6 2 sd 4
```
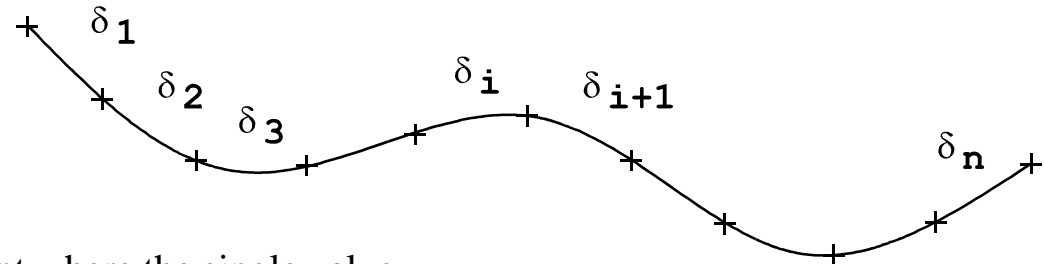
# Nodal Distributions Along Edges Only

There are 5 ways to control the distribution along an edge of the mesh.

**res** - relative spacing by a ratio

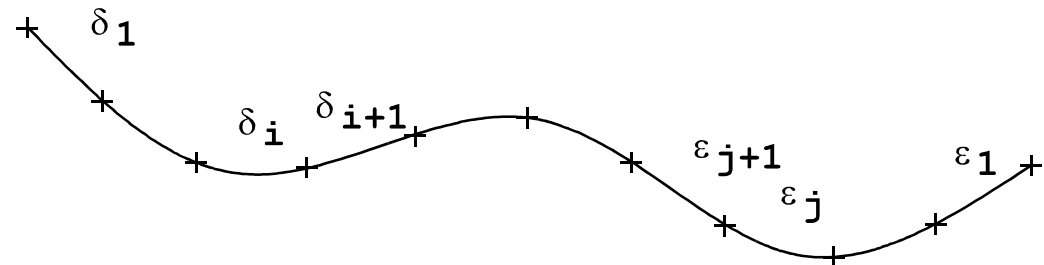$$\frac{\delta_{i+1}}{\delta_i} = \rho \text{ for all } i$$

**as** - absolute spacing by the size of the first or last element where the single value

$\rho = \dfrac{\delta_{i+1}}{\delta_i}$ is determined and true for all $i$ (i.e. only $\delta_1$ or $\delta_n$ is specified)

**drs** - double relative spacing by two ratios

$$\frac{\delta_{i+1}}{\delta_i} = \rho \text{ and } \frac{\varepsilon_{j+1}}{\varepsilon_j} = \sigma \text{ for all } i \text{ and all } j$$

**das** - double absolute spacing by the size of the first and last element where the two values

$\rho = \dfrac{\delta_{i+1}}{\delta_i}$ and $\sigma = \dfrac{\varepsilon_{j+1}}{\varepsilon_j}$ are determined and true for all $i$ and all $j$ (i.e. only $\delta_1$ and $\varepsilon_1$ are specified)

**nds** - generalized density function for nodal spacing (Use the **ndd** and **dndd** commands first)

# Notes on Interpolation

1. The default interpolation of edges, faces, and regions is linear because it is fast. This is equivalent to using the **lin** command. The default interpolation can be changed to **tfi** by using the **intyp** command.

2. Interpolation commands are used for two reasons. A partition in the mesh goes all of the way through the part. In some portions of the mesh, a partition may get in the way. If this partition is within the interior of a selected interpolation, it is as if that partition was not there.

3. The second reason to interpolate is to get a better quality mesh. Experimentation is usually needed to determine the best method for a problem.

4. Edges are the boundaries of a face and faces are the boundary of a solid. All interpolations treat the boundary of the selected region as fixed and only interpolate the interior. Sometimes the boundaries will require interpolation as well.

5. Some interpolations require a single block (**lin, tfi, tme**) with no holes. The **relax** command allows for holes. **Relax**, **esm**, and **unifm** allow for multiple blocks with coincident faces or edges  glued together with the **bb** command.

6. **Esm** was an experiment, it is difficult to use, and other methods can be just as effective in most cases. **Esmp** is used to set the nodal distribution biases for **esm**.

7. **Tfi** is not iterative (algebraic), is more expensive than **lin**, and almost as good as **tme** for orthogonality. It is more sensitive to boundary curvature.

8. Most iterative methods (**relax**, **tme**, and **esm**) are expensive. **Unifm** is very expensive. There usually is no need to do many iterations.

9. These iterative methods can be combine in sequence, with the results supper imposed on the previous.

10. Relax is good for structural problems where equal sized elements are desired.

11. **Tme** is good for CFD calculations where an orthogonal boundary layer is desired.

12. **Esm** is good when specific control of the mesh near singularities are desired.

13. **Unifm** is great. But it is slow.

14. **Tfi**, **relax**, **tme**, and **unifm** work on faces and solids. **Lin** works on edges, faces, and solids. **Esm** only works for faces.

15. Never select the step size in an iterative method to be greater than 1. It will be unstable. This step size is intended to be made smaller than 1.0 when one wants to spread the smoothing over a large area (which will require a larger number of iterations), but dampen its effect.

16. The iterative methods re-attach and re-project interior regions each iteration.

17. All methods work on non-smooth surfaces and surfaces with holes.

18. All interpolations cause the mesh to sag. **Unifm** is the exception. If the problem is two severe, split the region into two, control the nodal distribution along the new partition, and interpolate each separately.

19. **Esm** handles the meeting of 3, 4, and 5 blocks at a node. **Unifm** handles any number of blocks joined at a node.

# COMMAND HIERARCHY

**RULE 1**: Vertices, edges, faces, and volumes are automatically calculated in that order.

**RULE 2**: Commands are executed in the order according to the command type.

**RULE 3**: Commands of the same type are executed in the order they are issued.

These rules are expanded in the table below so that dependencies can be understood. This table is known as the command hierarchy. It will be necessary to understand this ordering and dependencies to build a complex model.

Position vertices  - initialize/project

    1. Initialization. There are three types of initialization.
        i) **BLOCK** and **CYLINDER** commands can contain initial coordinates of the vertices.
        ii) **BB** and **TRBB** initializes and freezes block interface nodes.
        iii) **PB**, **MB**, **PBS**, **Q**, **ILIN**, and **TR** commands initialize vertices.
    2. Specified interpolation of edges along 3D curves and faces along patches.
        (**CUR**, **CURE**, **CURF**, **CURS**, **EDGE**, **SPLINT**, **PATCH**)
    3. Project vertices to specified surfaces, (**SF**, **SSF**)

Position Edges - interpolate or attach/project

    4. Specified edge linear interpolations. (**LIN**)
    5. Default edge linear interpolations.
    6. Project edges to specified surfaces. (**SF**, **SSF**)

# COMMAND HIERARCHY (cont)

Position Face - interpolate/project

    7. Specified bi-linear interpolations of faces. (**LIN**)
    8. Default interpolation of faces.
    9. Project faces to specified surfaces. (**SF**, **SSF**, **PATCH**)
    10. Transfinite interpolation of specified faces. (**TF**)
    11. Equipotential relaxation of specified faces. (**RELAX**)
    12. Thomas-Middlecoff elliptic relaxation of specified faces.(**TME**, **ESM**, **UNIFM**)
    13. Re-interpolate and project edges and faces affected by 10, 11, and 12.

Interpolate interiors - interpolation and smoothing only

    14. Specified tri-linearly interpolation of solid regions. (**LIN**)
    15. Default interpolation of solid regions.
    16. Transfinite interpolation of solid regions. (**TF**)
    17. Equipotential relaxation of specified solid regions. (**RELAX**)
    18. Thomas-Middlecoff elliptic relaxation of specified solid regions. (**TME**, **ESM**, **UNIFM**)

Expressions - algebraic modification by coordinates and indices

    19. expressions (**X**, **Y**, **X**, **T1**, **T2**, **T3**)

# History Window

To activate the History window, click on the History button in the Environment window. This is available only in the Part Phase.

**Edit:** | Undo | History | Resume |

The history window allows you to inspect the commands affecting a selected region of the mesh.

Commands can be deactivated or re-activated.

The dialogue box for a command can be retrieved so that the arguments can be modified and the command reissued.

Regions of a command can be highlighted with one click of the mouse.

The commands can be ordered by sequence or by the command hierarchy.

Geometry references can be listed.

```
 File    View    List                                Help
Act/Deact     CMD#      CMD        Region/Progression
active          2       dei        progression 2 3; 1 3 0 4 6;
active          3       dei        progression 2 3; 1 6; 1 3 0
active          6       dei        progression 1 2; 1 2 0 5 6;
active          7       pb         region   1 2 1 2 2 6
active          8       pb         region   1 5 1 2 5 6
active          9       mb         region   2 3 1 2 3 6
active         10       mb         region   2 4 1 2 4 6
active         12       sf         region   1 1 5 1 6 6
deactivated    14       sf         region   2 1 5 2 6 6
active         16       sf         region   1 1 6 5 6 6



 Next    Previous    Act/Deactivate   Do/Undo_Highlight   Dialog
```

These features can be very useful when debugging a mesh.
They are also useful in understanding the technique used to generate the part.

# Exercise

Create a 4 block shell part like the one on the right with commands like:

**block** 1 11 21; 1 11 21; -1; -4 0 4; -4 0 4; 1;
**sd** 1 cy 0 0 0 1 0 0 4
**sfi** ; ; -1; sd 1

Select the pick panel in the Environment window. Be sure no objects have been selected in the computational window by clearing the selection with the F2 key. Then use the left mouse with a click and drag movement in the physical window to move some of the control points around. This changes the initial coordinates of the selected vertex.

Use some of the nodal distribution functions to change the way the nodes are clustered along the edges of the blocks.

Now use some of the facial interpolation functions (**lin, tf, relax, tme**) to change the way the interior face nodes are distributed. These interpolations are based on the way the nodes are distributed on the boundaries. Note that the nodes remain on the cylinder.
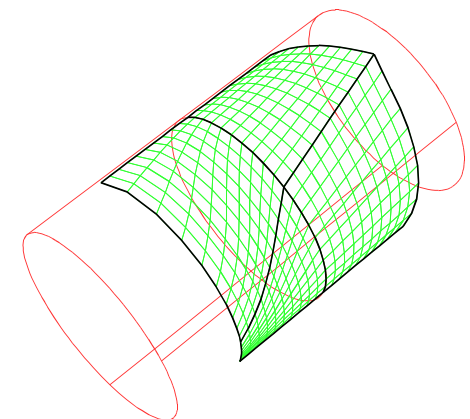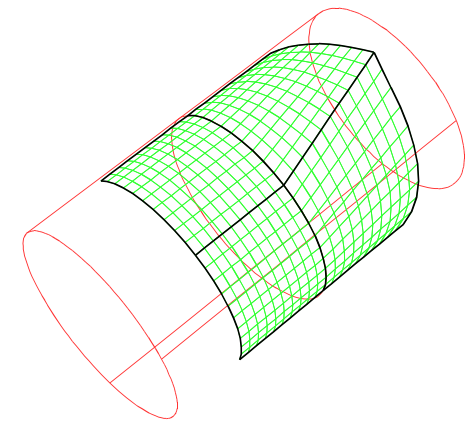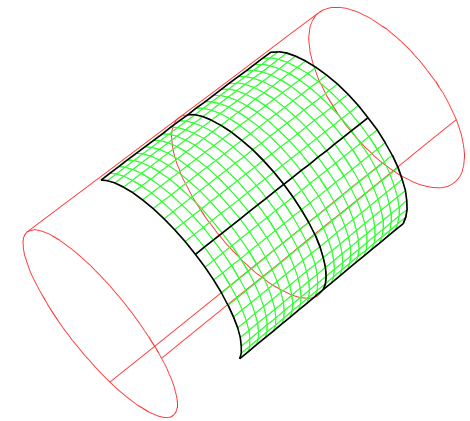
## Choices In Block Topology

There are many topological choices to consider
when designing a mesh. The mesh quality and
density are the main issues. Complexity is usually
a secondary issue. This simple fillet example shows
8 variations in the topology.

Construct the block commands used to generate these
examples. Many of these examples use more than one
part. The triangular elements are created by collapsing
an edge of a region. The transitional regions are automatically
generated between 2 parts using the bb and trbb commands,
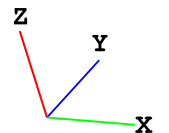respectively.
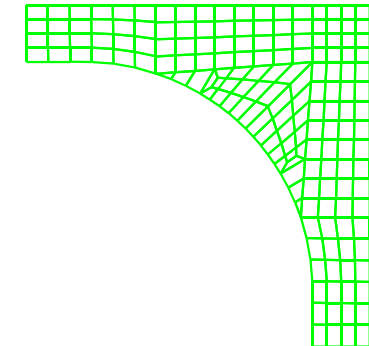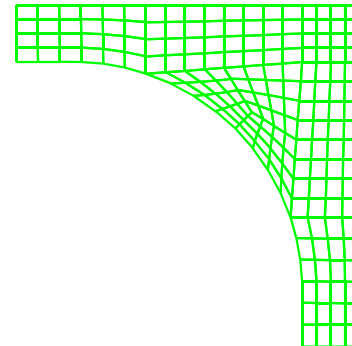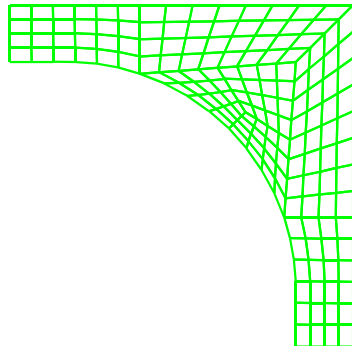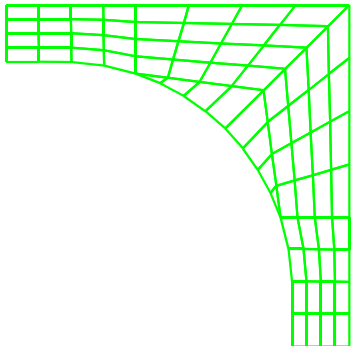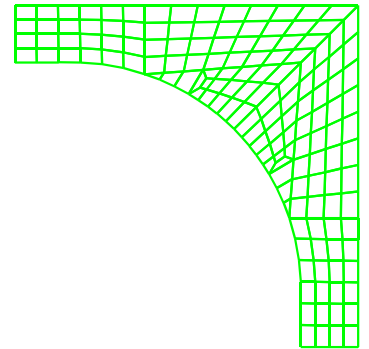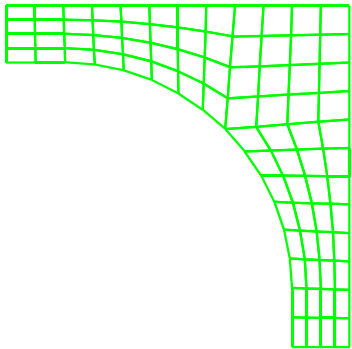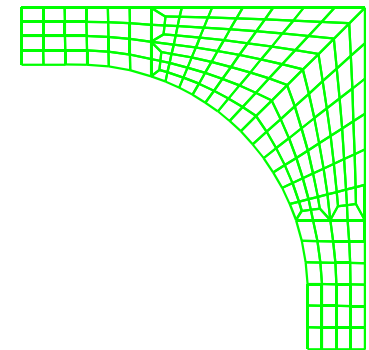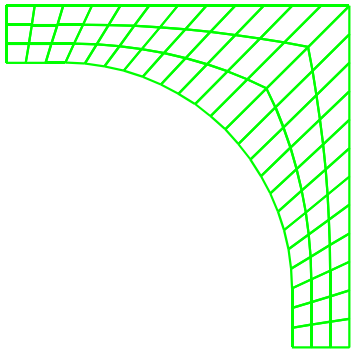
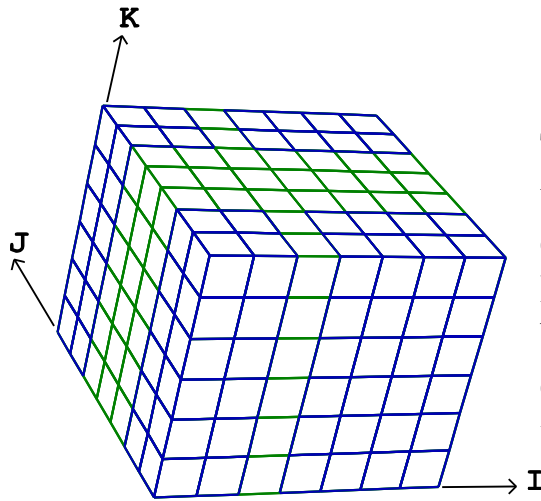# Cup with Handle Diagram
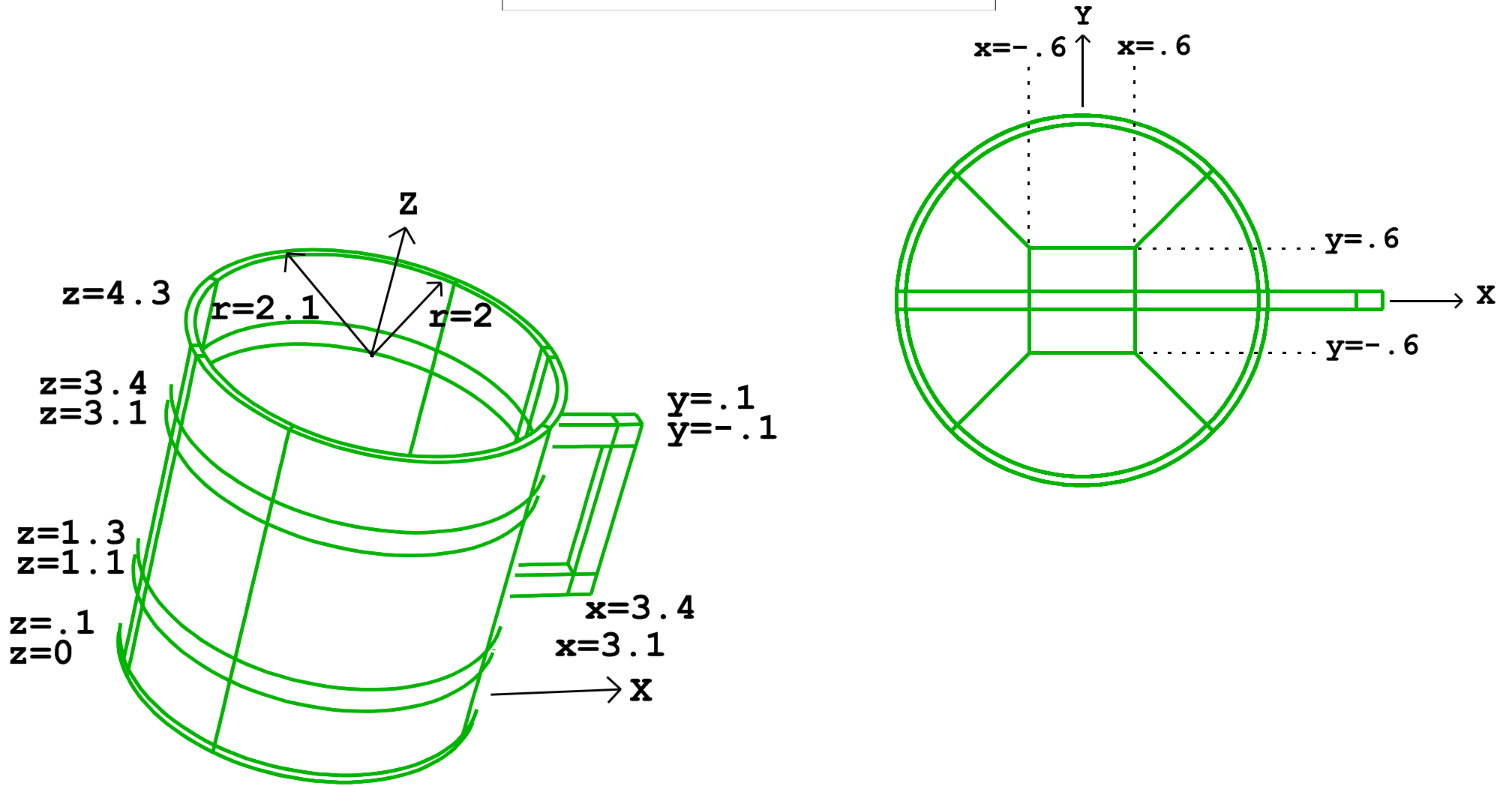
# Block Command with Regions to Delete



**Block 1  3  5  7  9  11  13  15;**

**1  3  5  7  9  11  13  15;**

**1  3  5  7  9  11  13;**

**-2.1  -2  -.6  .6  2  2.1  3.1  3.4;**

**-2.1  -2  -.6  -.1  .1  .6  2  2.1;**

**0  .1  1.1  1.3  3.1  3.4  4.3;**
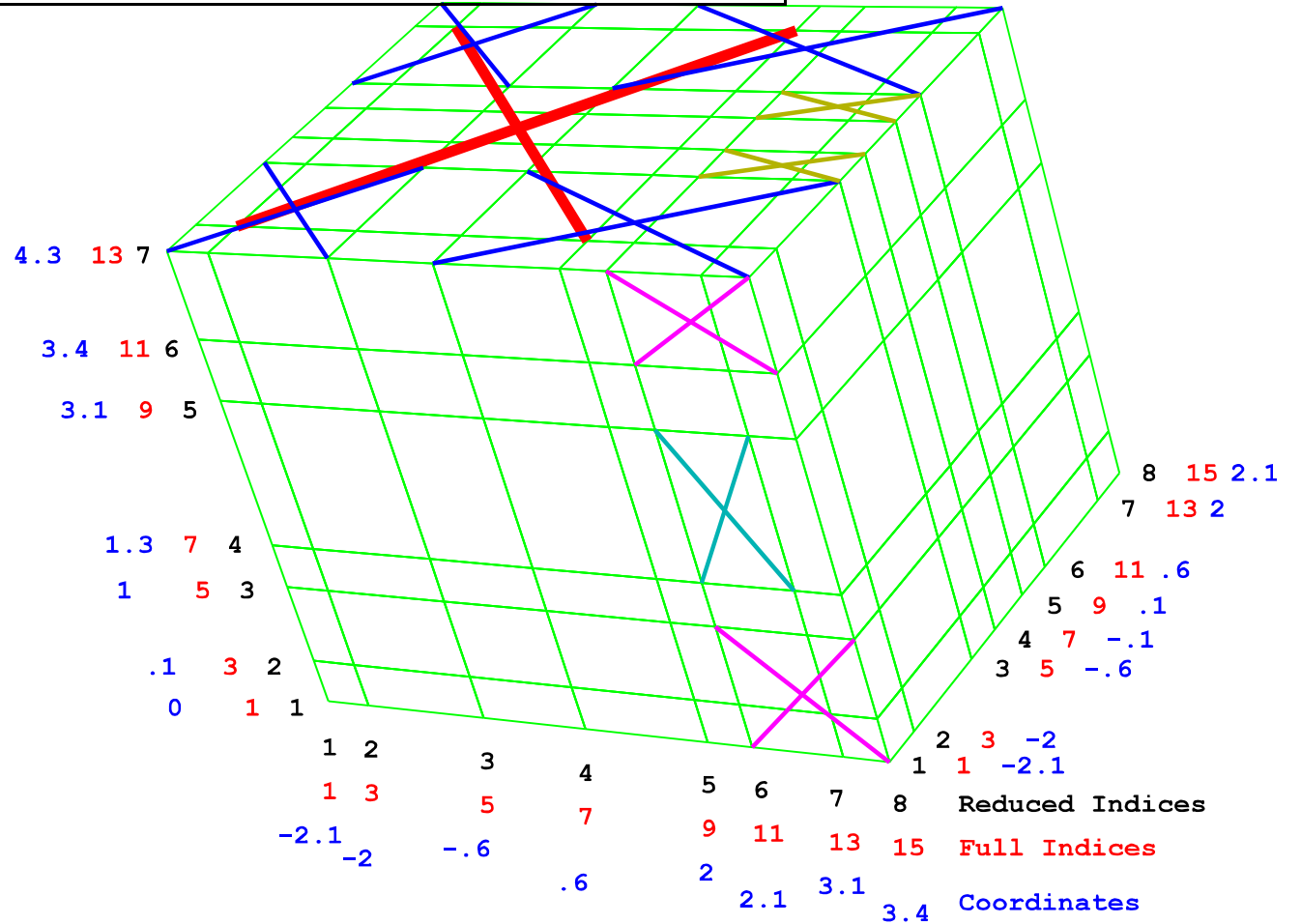
```
DELETE:   Corners
          Cavity
          Sides of Handle
          Above and Below Handle
          Handle Hole
```
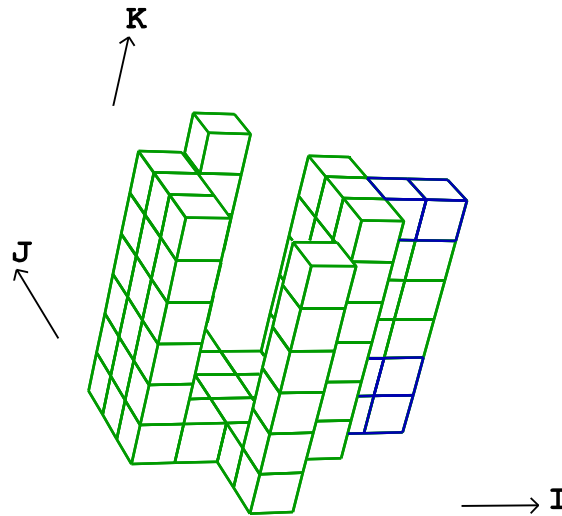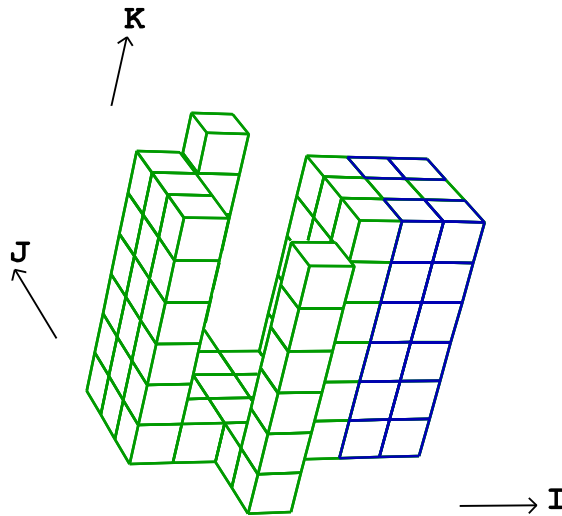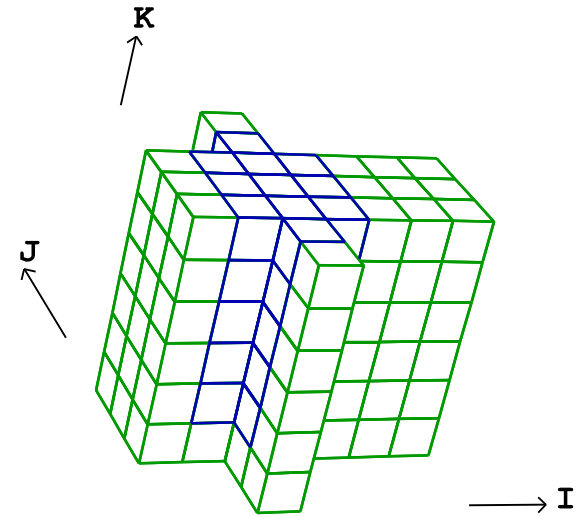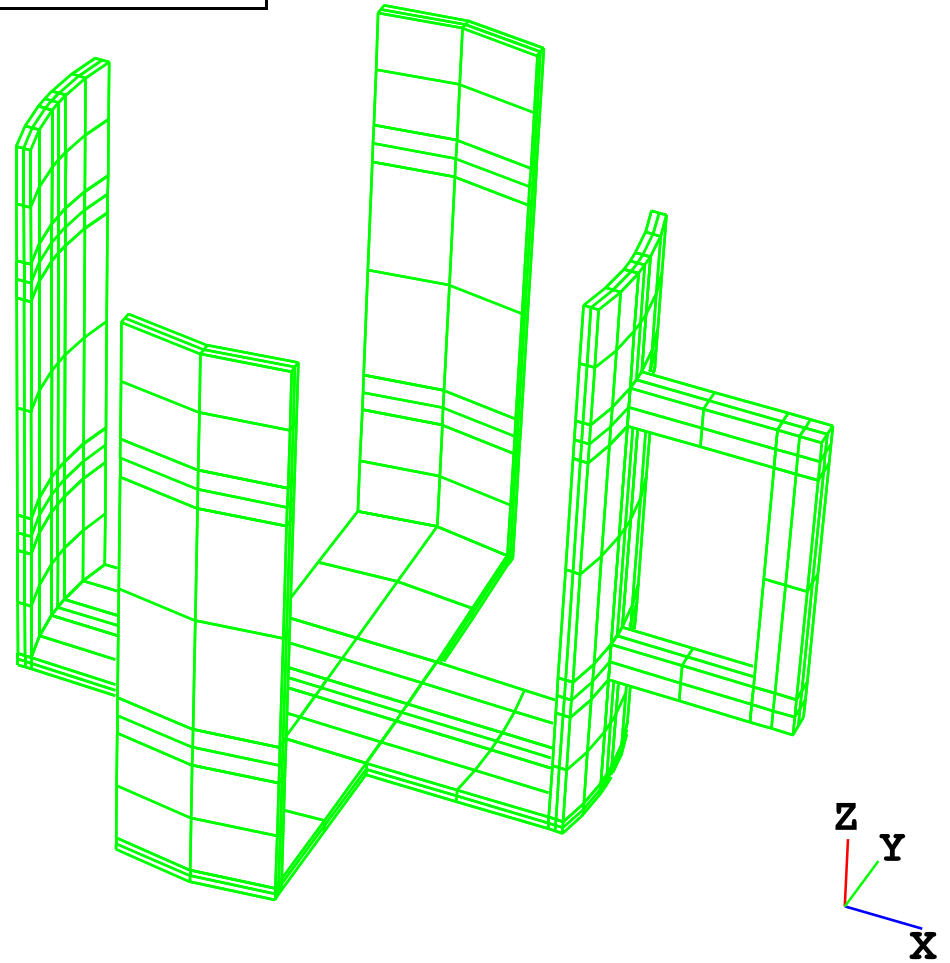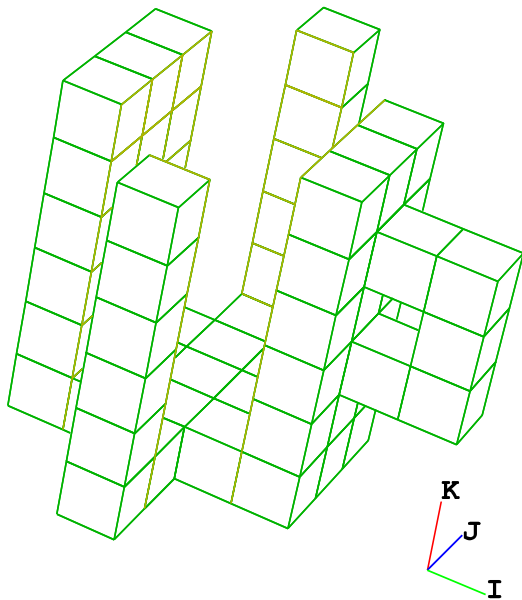
# Regions to be Deleted
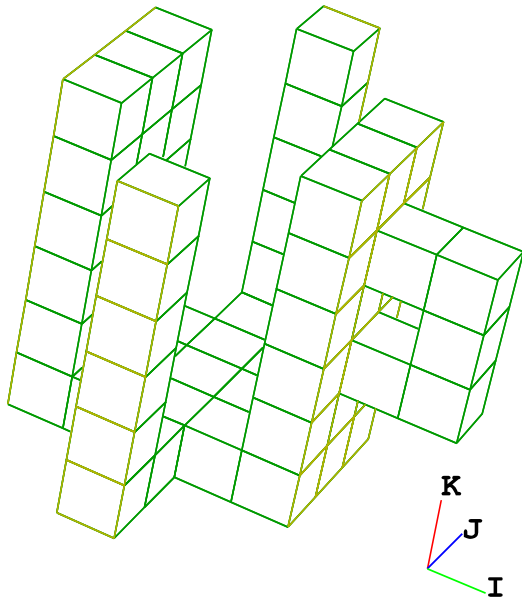
The blue regions in these pictures are the
unneeded regions to be deleted. See if you
can delete these regions using only 5 deletions.
Highlight the regions using the index
bars in the computational window. Then
click on the Delete button in the Environment
window.
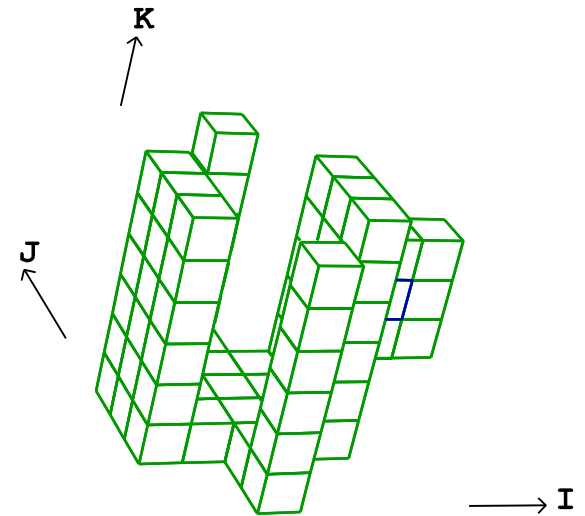
# Project to the Cylinders

The inner an outer faces are projected onto the inner and outer cylinders with two commands.

# Four ways to Close the Gaps

Construct a diagonal plane and
project two opposing faces to
that surface.

X=2, Y=−2
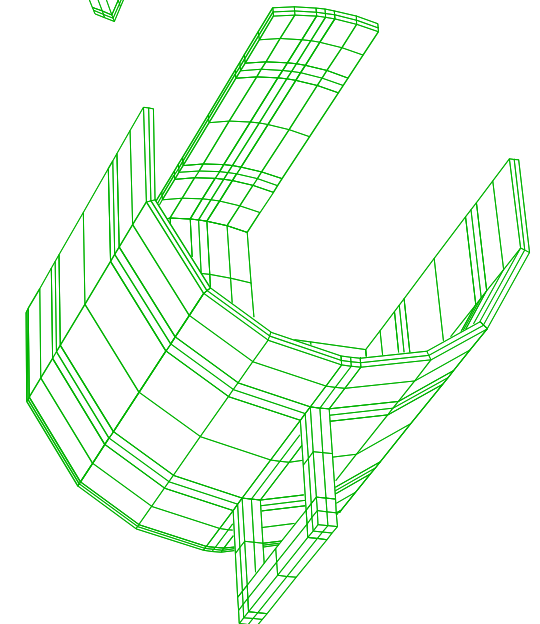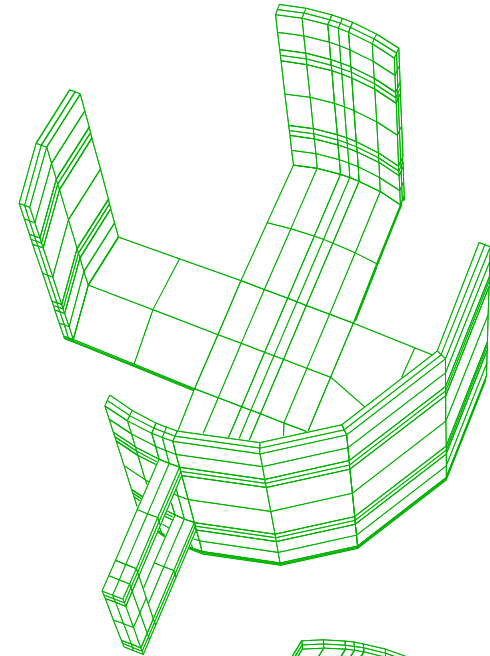
Change the initial x and y-coordinates
of two opposing faces so that both faces
are on the diagonal before the project to
the cylinders occurs. If they both start
out the same, they both end up in the
same place. Use the **PB** command for
this.
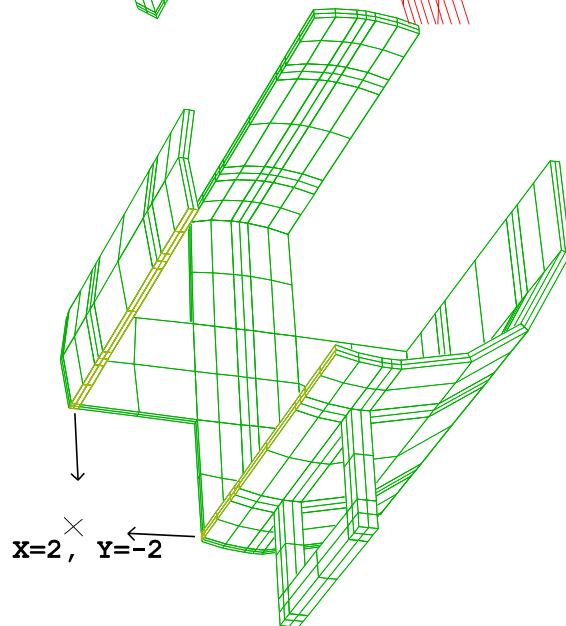
Construct a vertical line 3D curve
at one of the diagonal positions
using the **CURD** command. Then
attach the vertical edges of the
two opposing faces to this curve
This also changes the initial
position of the faces before
they are projected to the
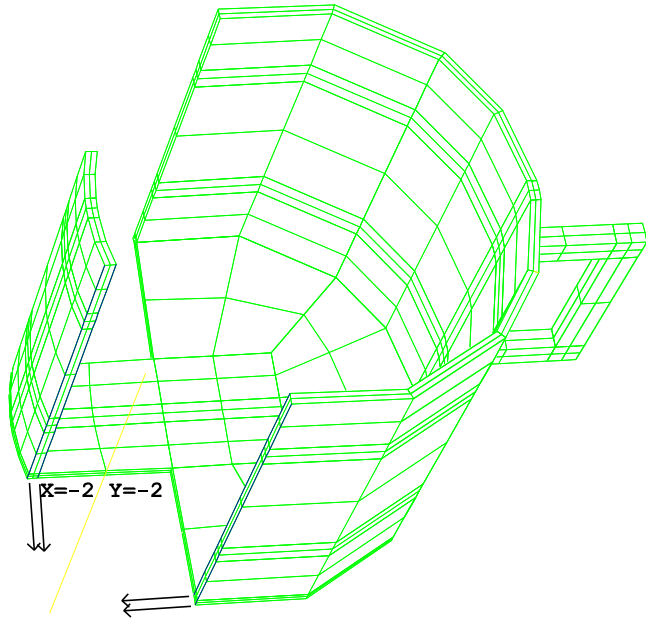cylinders. Treat both opposing
faces equally.
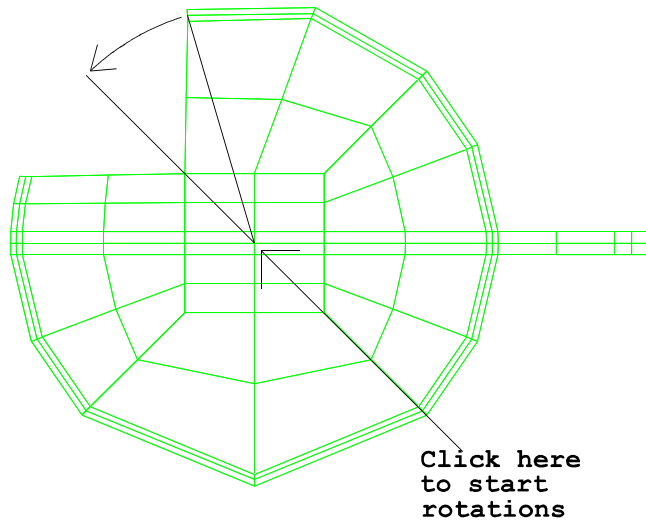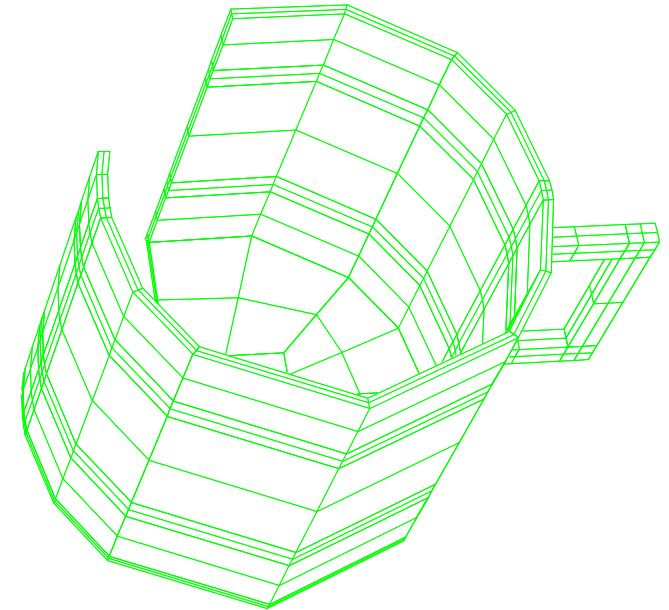
Change the initial coordinates
of a face by rotation. Select the
face, select rotation in the
environment window, set the
angle of perspective to 0,
restore the picture so that you
get the view you see here, and
then rotate. This is done by
starting the mouse at the center
and then click and drag to get
the desired rotation.

**Click here
to start
rotations**

X=-2 Y=-2
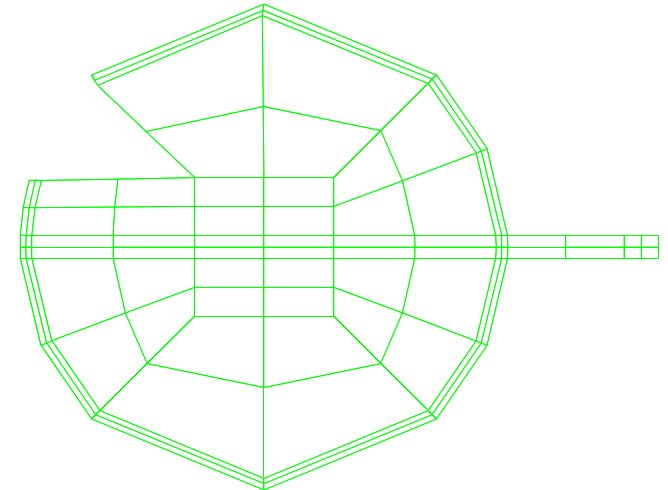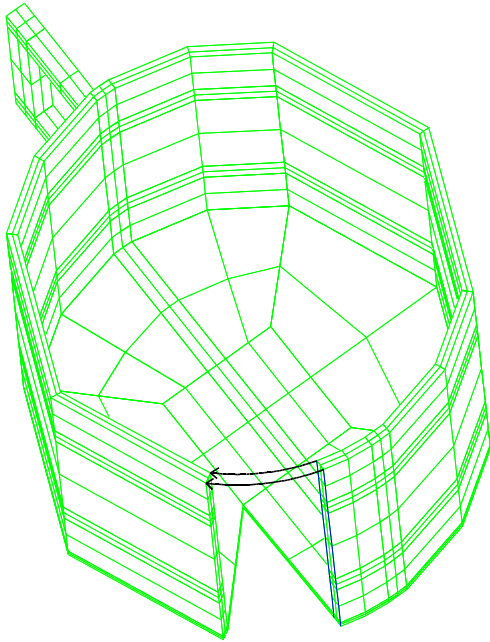
Move the remaining two edges to the same position as the opposing edges. This is done by selecting pick by node in the pick panel and deselecting the z-coordinate. Highlight one of the edges, pick a node of the opposing edge, and attach. Only the initial x and y-coordinates are changed. Do this for both edges.
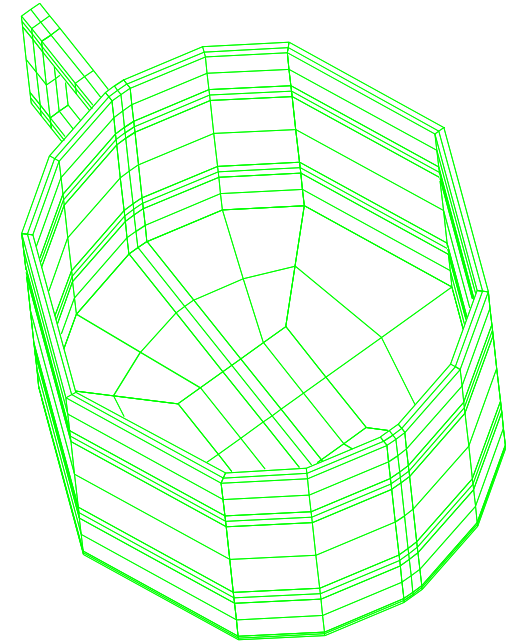
The last step is to use the **MSEQ** command to add more elements to round out the model. Take care to add matching number of elements in the regions that were folded together.
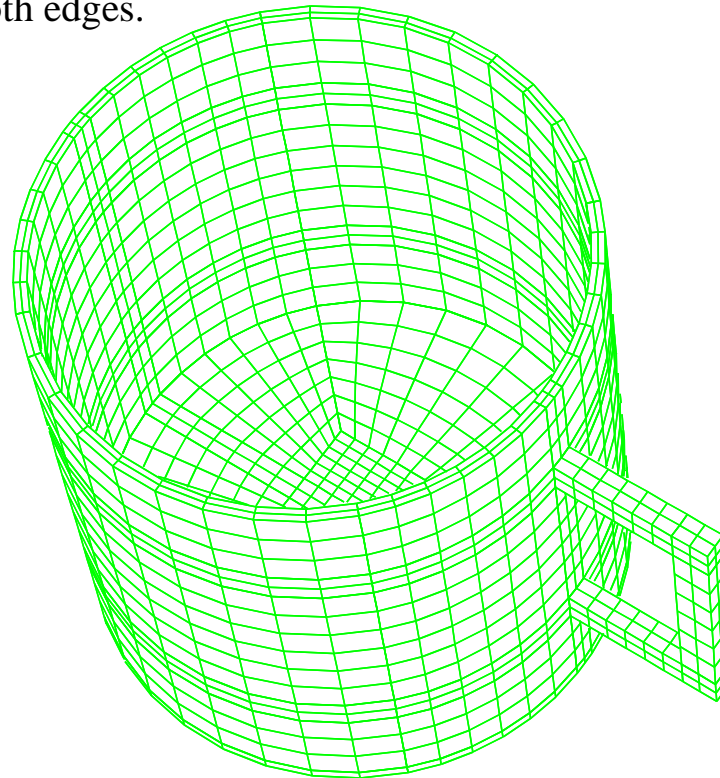
# Block Boundaries and Transitions

The **bb** (block boundary) command has many uses. It is perhaps the second most important feature. It is used to glue two parts together. This by-passes the projection to surfaces. It is used to:

1. Glue 2 parts together
2. Form a normal gap between 2 parts
3. Force periodicity in the mesh
4. Smooth the mesh within a part across disjoint regions
5. Keep disjoint regions of a part together

Each block boundary is identified by a number. A block boundary is created in two steps, using the **bb** command in both steps and in both instances, the same id number is used. The first use identifies the master side of the interface. The second use identifies the slave side that is then glued to the master side.

Care must be taken to initialize the slave side so that the mapping of the slave to the master is obvious. The vertices of the slave side can be adjusted after the **bb** command has been issued. The number of nodes on the master and slave side must be multiples of each other.
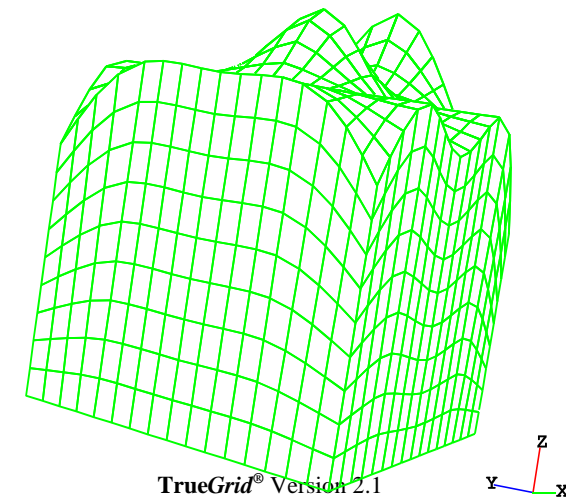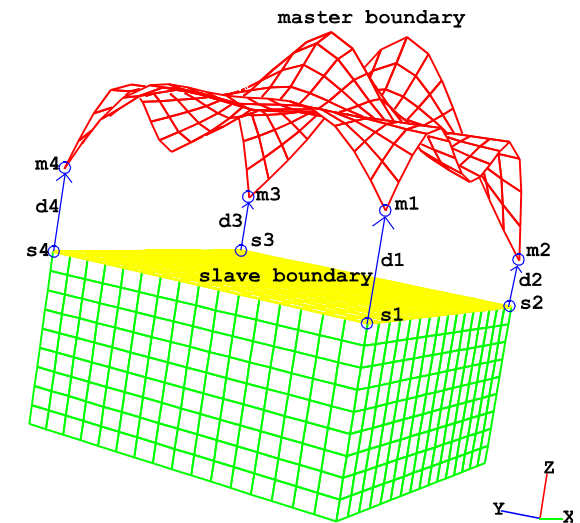
The **trbb** (transition block boundary) command is an alternative to the bb command used to select a slave side to a block boundary interface. This is valid only between parts.

The ration of elements at the interface must be selected carefully so that in one direction, the slave to master ratio is either 2:4, 4:2, 1:3, or 3:1. Anything else will cause an error. The 2:4 and 4:2 ratio means that both sides must have an even number of elements. This ratio must be satisfied for each block on the slave side.

To achieve a transition in 2 directions requires an intermediate part with transitions at both interfaces.

The transition row of elements are not generated until the part is ended. The only way to see them is to go to the merge phase.

The above limitations will be lifted (no dates).

This feature is very useful in transitioning from a coarse to a fine mesh. Care must be taken to create a good quality mesh. For best results, the interface region should be nearly planer and orthogonal.
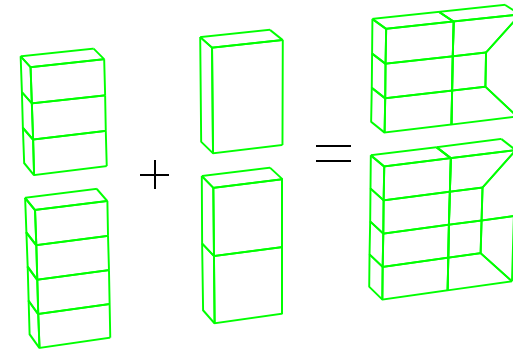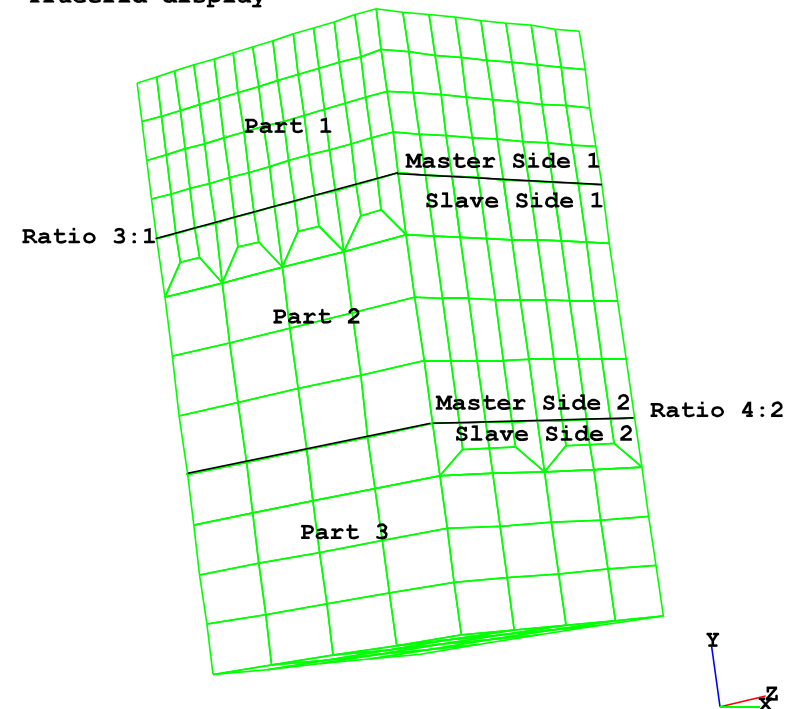
# RECIPE FOR SUCCESS

Steps below can be arranged in almost any order. If the **INSPRT** command is used, then order is important since the commands after insertion of a partition will cause the numbers referencing the partition to change. Steps performed in the **CONTROL**, **PART**, and **MERGE** phase are color coded.

1. Draw a block diagram of the topology with partitions along features

2. Break problem into parts and draw topology diagrams for each part

3. Start **True*Grid* ®** and select an output option (DYNA3D, ANSYS, MARC, AUTODYN,...)

4. Import IGES geometry and/or create geometry (IGES, IGESFILE, SD, CURD, LD)

5. Create one part at a time (BLOCK, CYLINDER)

6. Delete regions that are not needed (DE)

7. Move vertices to key positions (PB, PBS, MB, Q, TR)

8. Select faces to be attached to previously generated parts (BB, TRBB)

## RECIPE FOR SUCCESS (cont)

9. Attach edges to curves or surface edges (CURS, CUR, CURE, EDGE, SPLINT)

10. Select faces and project to desired surfaces (SF, MS, SSF, PATCH)

11. Add elements (MSEQ)

12. Select nodal distributions along edges (RES, DRS, AS, DAS, NDS)

13. Choose special interpolations or smoothings for problem faces (LIN, TF, RELAX, TME)

14. Choose special interpolations or smoothings for problem interiors (LIN, TF, RELAX, TME)

15. Assign loads/materials/ boundary conditions (PR, B, FL,...)

16. Start the next part (go back to step 5)

17. Assign material properties and select analysis options (CONTROL, *MATS and *OPTS)

18. Merge parts together and inspect them (MERGE, STP, BPTOL, PTOL, LABELS, CO, MEASURE)

19. Write the output file (WRITE)

# 8 Basic Functions in Part Phase

It is most important to understand the commands in the Mesh menu, which can be
simplified by grouping the commands by basic functions.

1. **Mesh Density** - mseq

2. **Block Deletion -** de ,dei

3. **Intialization -** pb, pbs, mb, mbi, tr, tri, q

4. **Edge Shaping -** cur, curs, cure, curf, edge, splint

5. **Interpolation** - lin, lini, ilin, ilini, tf, tfi, relax, relaxi, tme, tmei, hyr,unifm, unifi

6. **Projection -** sf, sfi, ms, patch

7. **Nodal Distributions -** res, drs, as, das, nds

8. **Equations -** dom, x, y, z, t1, t2, t3

Commands with the i suffix use index procession, but otherwise are equivalent
to the same command without the i suffix.

# True*Grid*'s IGES Filter and Its Applications

CAD/CAM systems and Solid Modelers

IGES - Initial Graphics Exchange Specification (NIST)

STEP - standard for Exchange of Product model data (NIST, ISO)

Viewpoint and STL data

IGES file format

Hierarchy of IGES geometry entities

IGES and IGESFILE commands

Numbering of surfaces and curves and multiple IGES files

USEIGES and SAVEIGES commands

IGES levels and associativity groups

Tolerances

Tangent surfaces, trimmed surfaces, and composite surfaces

How to deal with gaps and overlaps at mesh intersections

# Viewpoint Data Format

Two files with data similar to Finite Element meshes: nodal element files. Each element is associated with a surface which is named in the first field on the element definition.

Nodal coordinate file has the following format:

```
1, -3.383404, -0.583990 , 2.585073
2, -3.187954, -0.598938 , 2.572747
3, -3.186691, -0.594553 , 2.575749
4, -3.383906, -0.579564 , 2.587889
5,  4.597703, -0.602771 , 2.579074
...
```

Element connectivity file has the following format:

```
hood  7306  7302 7249 7244
body  7121  7125 7129 7116
body  7124  7307 7247 7130
hood  7301  7298 7253 7250
hood  7297  7294 7257 7254
 ...
```

# IGES Data Format

Each file contains String, Global, Directory, Parameter, and Terminator data. Pairs of directory records identify a geometric entities by the first number. The second number is a pointer into the parameter data. For example, type 128 is a NURBS surface. All geometric entities are algebraic.

```
Text messages or comments                                             S        1
1H,,1H;,, 8Hpack.igs,                                                 G        1
5HANSYS,21HREV 5.0        UP 90292,,,,,,,,,,,,13H9210 5. 6 224,,,,,,;   G        2
       128         1        0         0         0         0         0         000000001D        1
       128         0        0        12         0         0         0 SURFACE         0D        2
       126        13        0         0         0         0         0         000000001D        3
       126         0        0         6         0         0         0B-SPLINE         0D        4
...
128,        1,        1,        1,        1,        0,        0,              1P        1
            1,        0,        0,                                            1P        2
  0.000000000000E+00,   0.000000000000E+00,    1.00000000000      ,          1P        3
   1.00000000000      ,   0.000000000000E+00,   0.000000000000E+00,          1P        4
   1.00000000000      ,    1.00000000000      ,    1.00000000000      ,      1P        5
   1.00000000000      ,    1.00000000000      ,    1.00000000000      ,      1P        6
  -2.27778406141      ,   -1.31507924098      ,    3.13843157742      ,      1P        7
  12.5598045656       ,    7.25140654689      ,   -6.74905435536      ,      1P        8
   7.52332454819      ,    4.34359345309      ,   22.7490543554       ,      1P        9
  22.3609131752       ,   12.9100792410       ,   12.8615684226       ,      1P       10
  0.000000000000E+00,    1.00000000000      ,   0.000000000000E+00,          1P       11
   1.00000000000       ;                                                     1P       12
126,        1,        1,        0,        0,        1,        0,              3P       13
...
186,      737,        1,        0,        0,        0,        0;            739P     2642
S        1G        2D      740P      2642                                     T        1
```
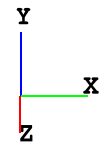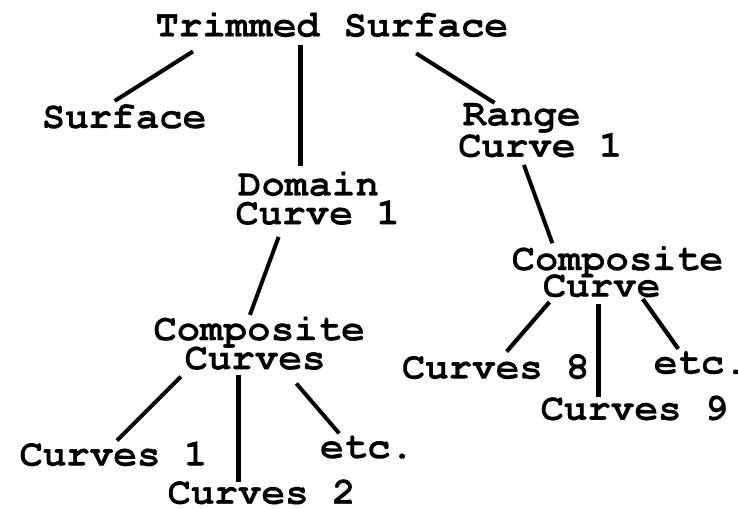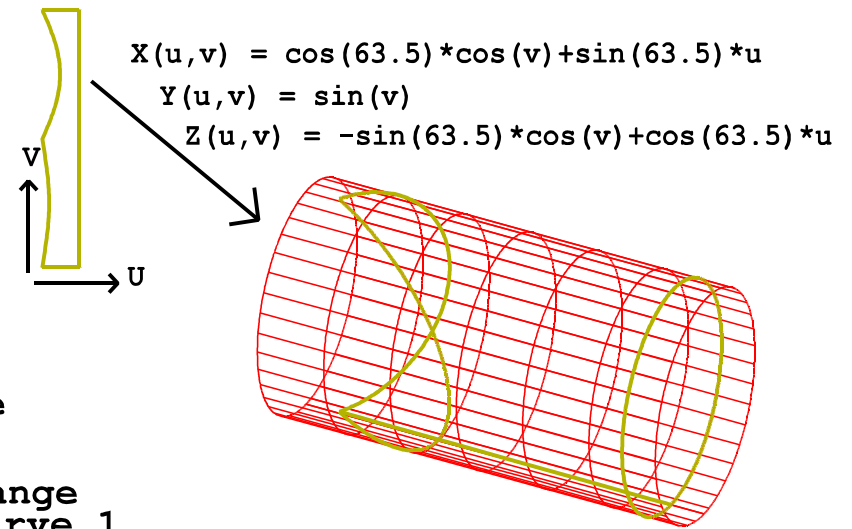
# IGES Features Supported in **True*Grid*®**

Lines
Circular arcs
Conic arcs
Parametric spline curves
NURBS curves
Composite curves
Planes including bounded
Ruled surface
Surface of revolution
Tabulated cylinder
Parametric spline surfaces
NURBS surfaces
Trimmed surfaces
Transformations
Levels
Associativity

```
Trimmed surface w/ trimming curves in Domain and Range
TrueGrid Draw
```

$$X(u,v) = \cos(63.5)*\cos(v)+\sin(63.5)*u$$
$$Y(u,v) = \sin(v)$$
$$Z(u,v) = -\sin(63.5)*\cos(v)+\cos(63.5)*u$$

V

U

```
                Trimmed Surface

        Surface                 Range
                               Curve 1
              Domain
              Curve 1
                              Composite
                                Curve
          Composite
            Curves      Curves 8 | etc.
                               Curves 9
      Curves 1 |  etc.
           Curves 2
```

Y
X
Z

# Transformation

Transformations are used to position, scale, and reflect geometric entities such as surfaces and 3D-curves and to duplicate a mesh part. Simple operators are listed in order to from complex transformations. The simple operators are:

| | |
|---|---|
| x-transformation | mx |
| y-transformation | my |
| z-transformation | mz |
| translation | v |
| x-rotation | rx |
| y-rotation | ry |
| z-rotation | rz |
| x-scale | xsca |
| y-scale | ysca |
| z-scale | zsca |
| scale | scal |
| xy-reflection | rxy |
| yz-reflection | ryz |
| zx-reflection | rzx |
| reference frame | tf $X_1$  $X_2$  $X_3$ |
| frame to frame | ftf $X_1$  $X_2$  $X_3$  $Y_1$  $Y_2$  $Y_3$ |

**Complex Transformation mx 15 rz 45 xsca 2 rx 45 ;**
**TrueGrid display**
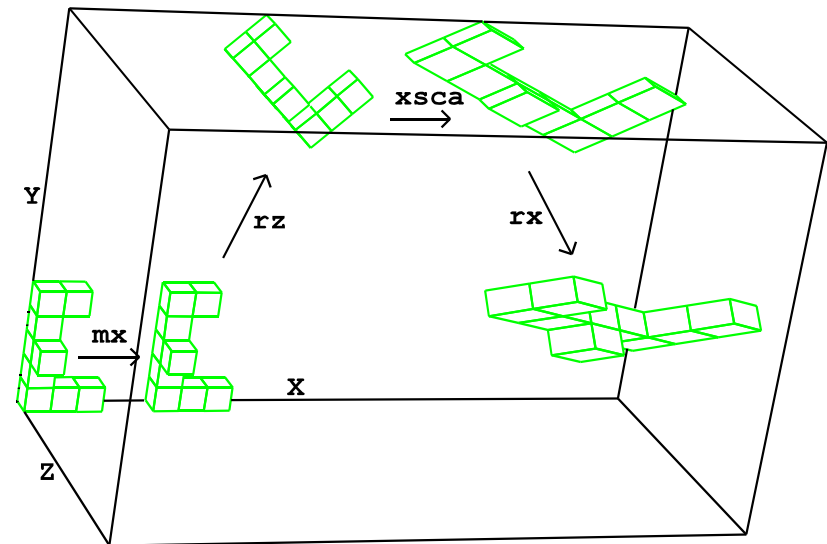
transformation mx 15   rz   45   xsca  2   rz  45

# 3D Curves

**Purpose**: 3D curves are used primarily to force a mesh edge on a geometry feature defined by a curve.

**Usage**: Only mesh edges and vertices can be attached to 3D curves (know as initialization)

### Types of 3D Curves

IGES curve
Edge of a surface
Surface contour
B-spline
NURBS spline
2D to 3D conversion
Interpolate between two curves
Surface or curve point selection
Parameterized function curve
Project a 3D curve to a surface
Project a 3D curve to a surface and smooth
Arc of a circle (3 points)
Section of a 3D curve
Copy and transform a 3D curve
Combine a set of 3D curves and transform

### Interactive 3D Curve Creation

**LP3** -        Piecewise linear curve of interactively selected points
**SPLINE** -   Cubic spline between interactively selected points
**TWSURF** - Curve automatically created at the intersection
            of two surfaces; 4 - 10 points, interactively selected,
            are needed to initialize this curve
**COEDG** -   Create curves from surface edges

The surface on the right has a non-concave boundary and an interior feature.

The mesh on the bottom left, which was projected to this surface, does not have an interior mesh line which follows the interior feature highlighted in yellow. Also, the boundaries of the mesh do not include the convex portions of the boundaries of the surface.

By attaching the boundary of the mesh to the edges of the surface and by attaching an interior line of the mesh to the 3D curve that follows the interior feature, one gets a mesh that more accurately represents the surface, as shown on the bottom right.
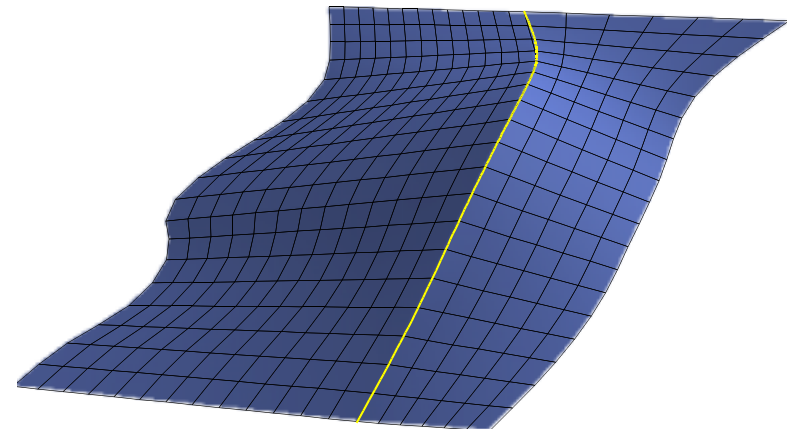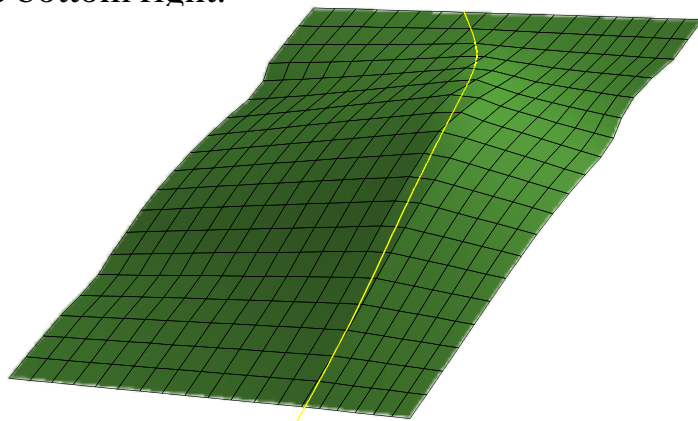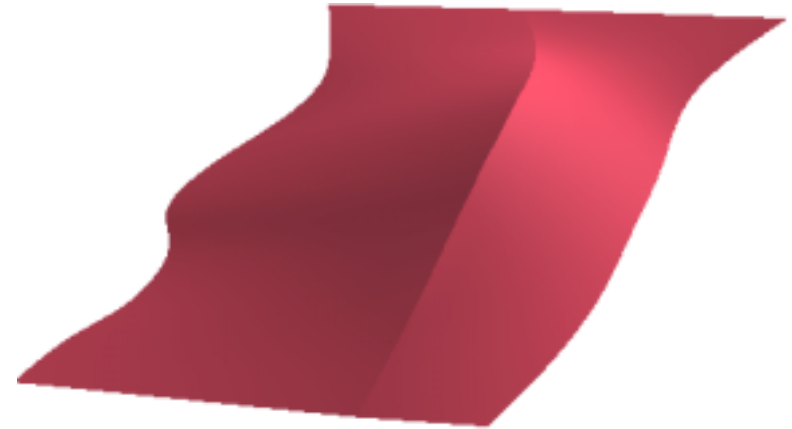
# Cubic Spline w/Natural Derivatives - 2nd Derivatives are 0 at the Endpoints

Every segment of a cubic spline is a parametric cubic polynomial. This spline passes through each of the control points. There are several options based on the properties of cubic spline. The subscript i below denotes the ith segment:

CUBIC SPLINE

Five Control Points

$$X(t) = a_i t^3 + b_i^2 + c_i t + d_i$$

$$Y(t) = e_i t^3 + f_i t^2 + g_i t + h_i$$
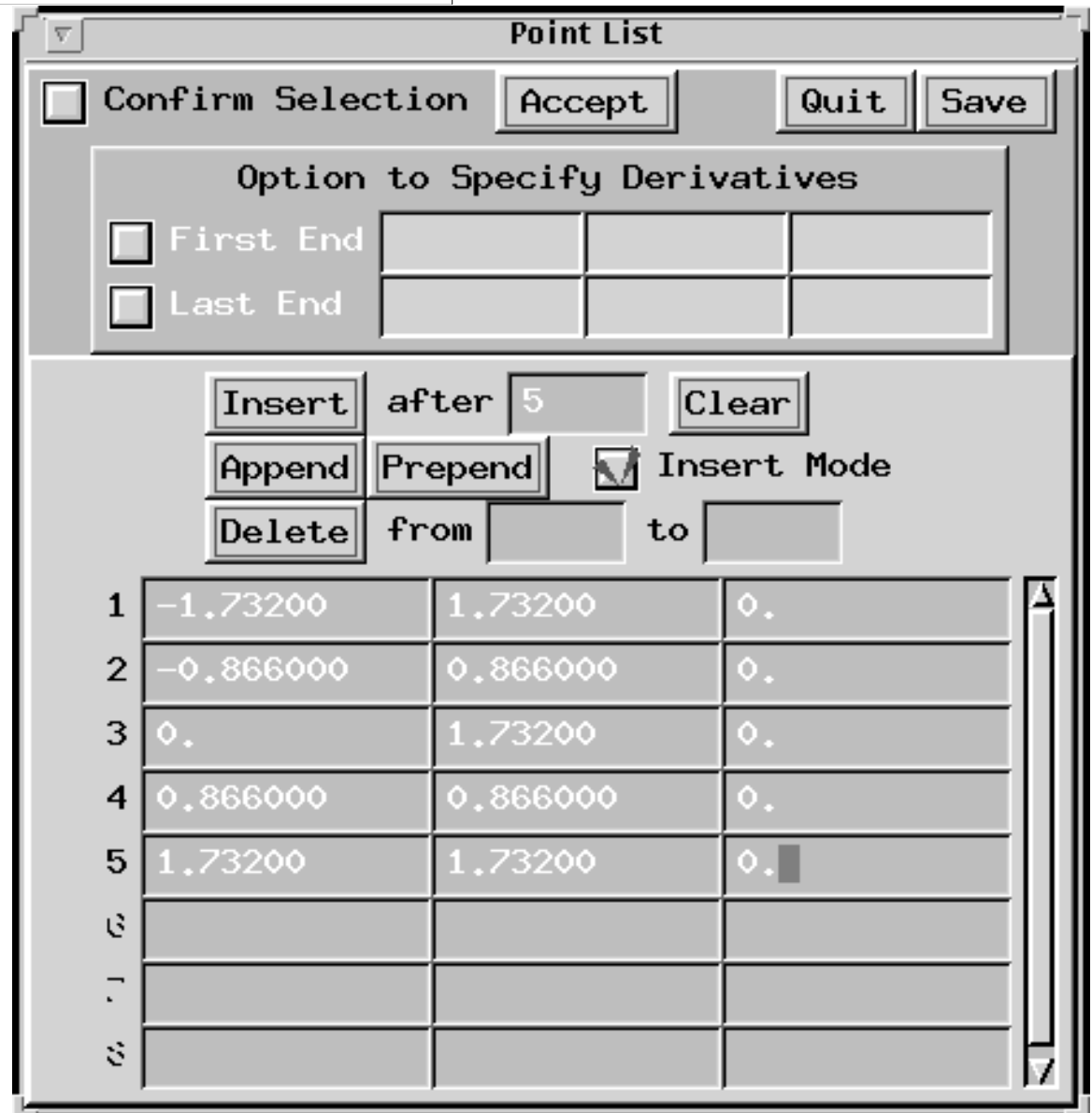
$$Z(t) = j_i t^3 + k_i t^2 + l_i t + m_i$$
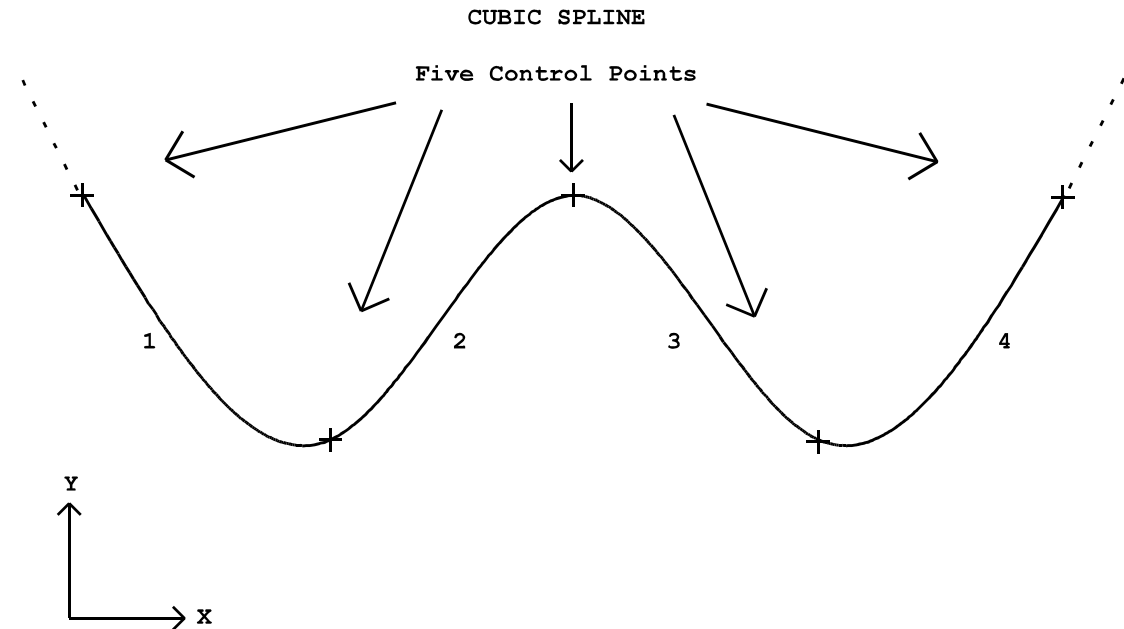
where the independent variable t is allowed to range over a short interval Suppose there are n segments in the cubic spline. This produces 12n unknowns. There are 6n constraints since the endpoints of each section passes through the control points. There are 6n-6 additional constraints imposed so that the curves has two derivatives at the interior control points. You can choose the derivative at the end points to impose the remaining 6 constraints.
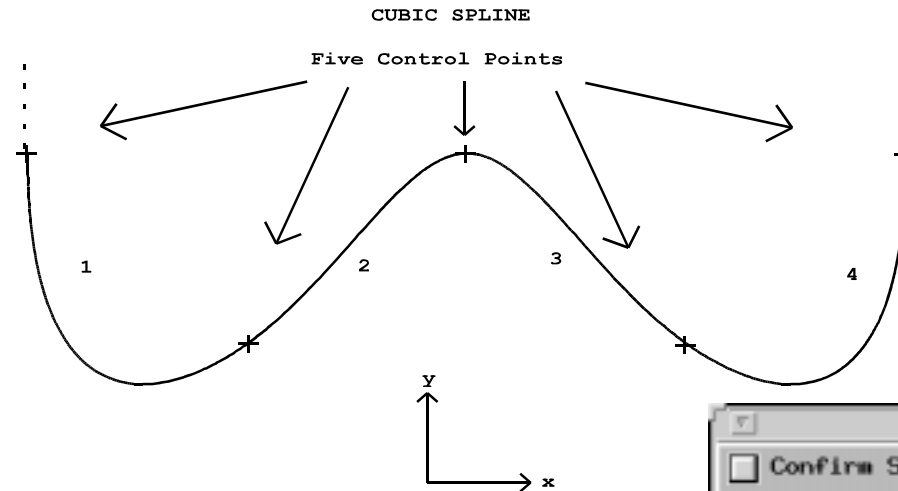
# Creating a Cubic Spline

To create a spline, choose SPLINE

from the 3DCURVES menu. You

must be in either the Merge or Part

Phase for this feature. Select points to

be entered into the table that appears.

To save the curve, click on the

SAVE button with the left mouse

button and type a curve number. Then

select the QUIT button with the left

mouse.

| ▽ | Point List | | |
|---|---|---|---|
| ☐ Confirm Selection | Accept | | Quit Save |

**Option to Specify Derivatives**

| | | | |
|---|---|---|---|
| ☐ First End | | | |
| ☐ Last End | | | |

| Insert | after | 5 | Clear |
|---|---|---|---|
| Append | Prepend | ☑ Insert Mode | |
| Delete | from | | to |

| 1 | -1.73200 | 1.73200 | 0. |
|---|---|---|---|
| 2 | -0.866000 | 0.866000 | 0. |
| 3 | 0. | 1.73200 | 0. |
| 4 | 0.866000 | 0.866000 | 0. |
| 5 | 1.73200 | 1.73200 | 0. |
| 6 | | | |
| 7 | | | |
| 8 | | | |

# Control the End Derivatives of a Cubic Spline

CUBIC SPLINE

Five Control Points

Y

x

**Point List**

Confirm Selection    Accept          Quit    Save

Option to Specify Derivatives

First End    0        −3        0
Last End    0        3        0

Insert    after  5        Clear
Append  Prepend    Insert Mode
Delete    from          to

| | | |
|---|---|---|
| 1 | −1.73200 | 1.73200 | 0. |
| 2 | −0.866000 | 0.866000 | 0. |
| 3 | 0. | 1.73200 | 0. |
| 4 | 0.866000 | 0.866000 | 0. |
| 5 | 1.73200 | 1.73200 | 0. |

Click on the box next to First End in the Point List window and

enter the three vector components of the derivative for the first

end point. To specify the derivative at the other end point, fist

select  the box next to Last End in the Point List window then

enter the vector components of the derivative.
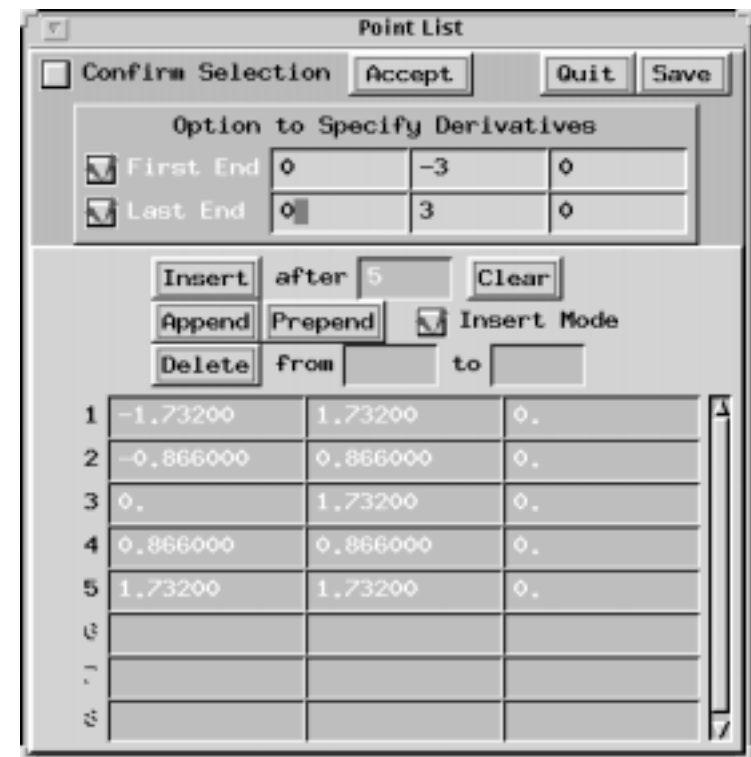
# Inserting a Cubic Spline Control Point

Before a new control point can be selected, its position
in the sequence of control points must be selected.
Insertion is done after the selected control point.
There are three ways to select the point of insertion.

Method 1 - Scroll through the control points with
the keyboard arrow keys. The mouse must be in the
Point List window. As you scroll, you will see a
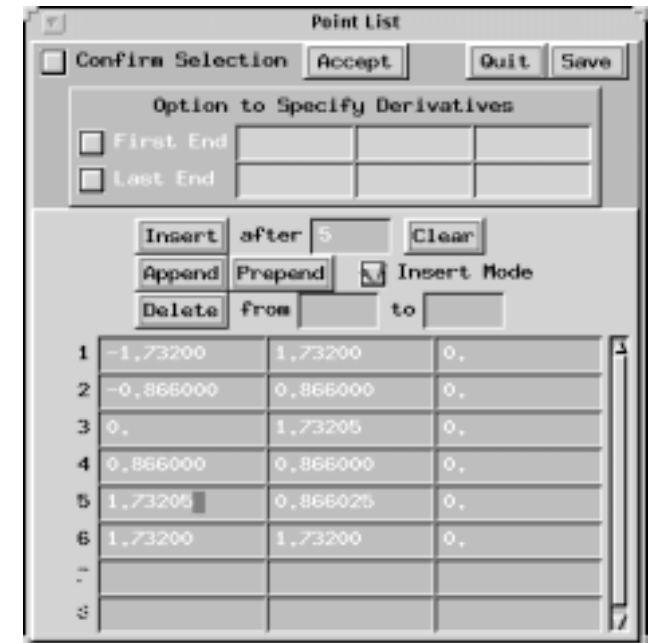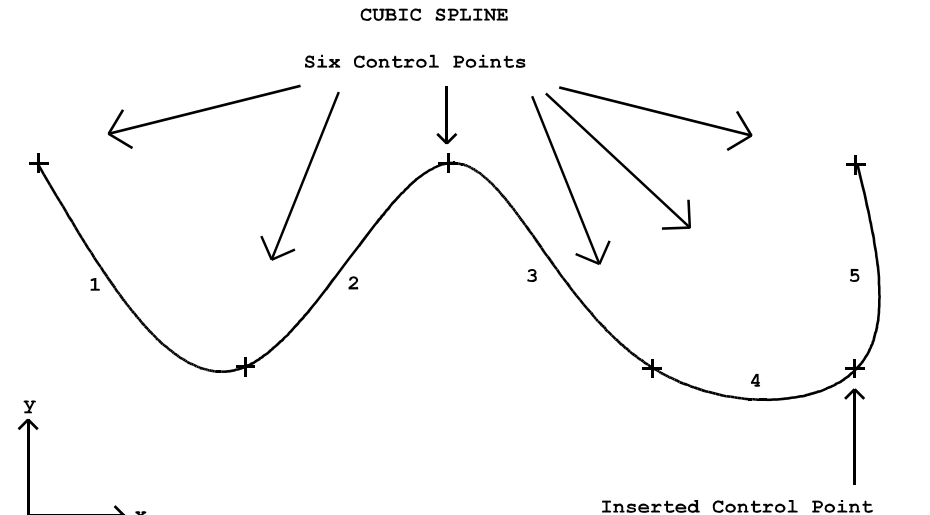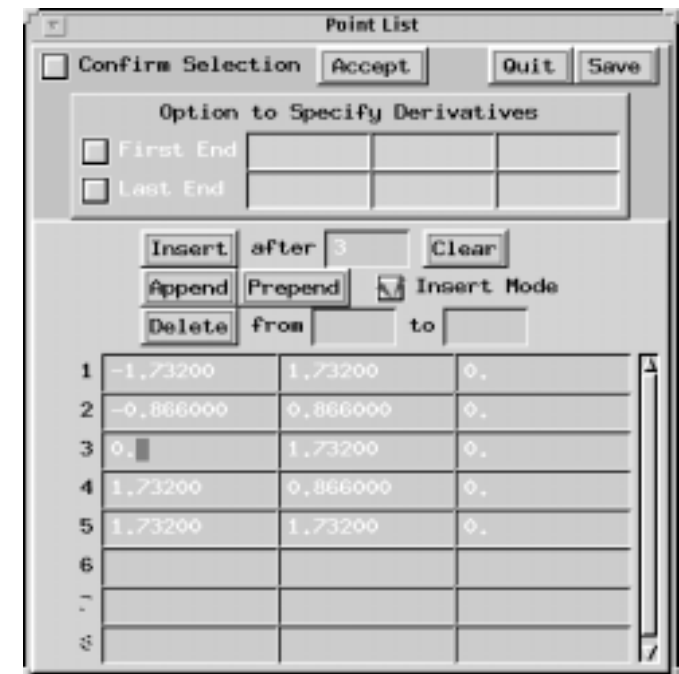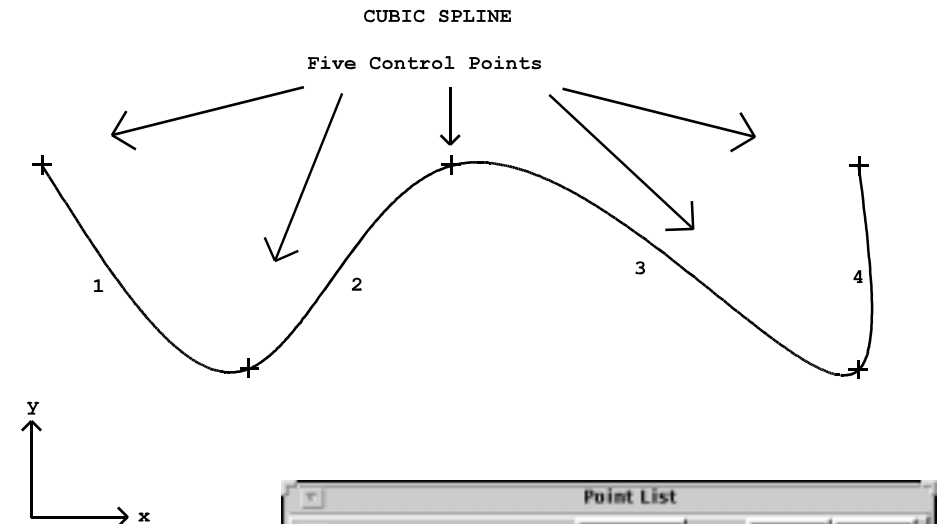small box in the picture move from one control
point to anther.

Method 2 - Click on the row of the desired control
point with the left mouse button.

Method 3 - Move the mouse close to the control point in the picture and push the F5
function key.

Method 4 - Enter the control point sequence after the Insert button. Either type the

return key or click on the   **Insert**   button.

Now select a point in the picture to add a new control point.

In this example, the fourth control point was selected and a new control point was
inserted after the fourth. Any additional after this new one until a new insertion point
is selected.

# Deleting a Cubic Spline Control Point

Before a control point can be deleted, its position in
the sequence of control points must be selected.
There are four methods to deleting control points.

Method 1- Scroll through the control points with the
keyboard arrow keys. The mouse must be in the
Point List window. As you scroll, you will see a
small box in the picture move from one control point
to another.

Method 2- Click on the row of desired control point
with the left mouse button.

Method 3- Move the mouse close to the control point in the picture and push **F5**
function key.

Method 4- Enter the sequence numbers of the control points into the **from** and
**to** boxes next to the | Delete | button.

Click on the | Delete | button.

In this example, the fourth control point was selected and deleted from the
Point List.

# Moving a Cubic Spline Control Point

Before a control point can be deleted, the Point List window must be taken
out of the insert mode and the control point must be selected. To get out
of the insert mode, click the left mouse button  on the box next to
**Insert Mode** so that the check is no longer in the box. There are
three ways to select the control point to be moved.

Method 1- Scroll through the control points with the keyboard arrow
keys. The mouse must be in the Point List window. As you scroll, you
will see small box in the picture move from one control point to another.

Method 2- Click on the row of the desired control point with the left mouse button.

Method 3- Move the mouse close to the control point in the picture and push the
F5 function key.

Select the  Move Pts.  panel. Then select  List Pt.   Then select one of
the methods under the label **Constrain to.**

With the left mouse, click and drag in the physical picture to move the control
point to a new location. In this example, the fourth control point was selected and
moved in the z-direction. Alternatively, use the
 Pick  panel options  projection  or  Z-buffer  .
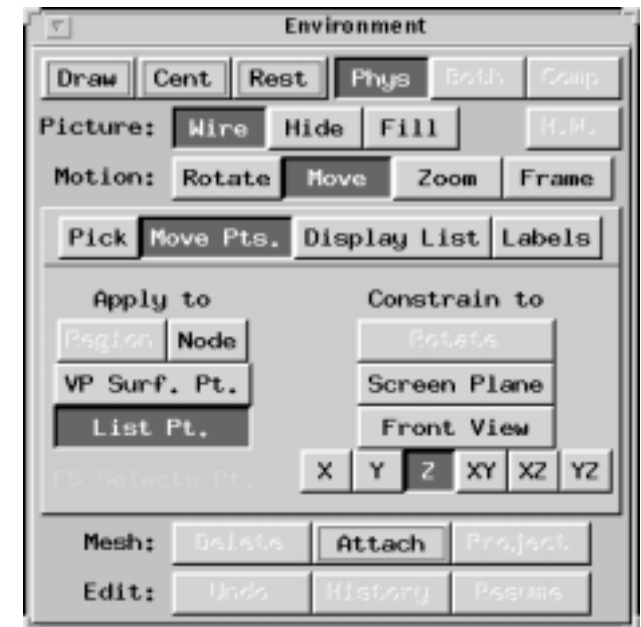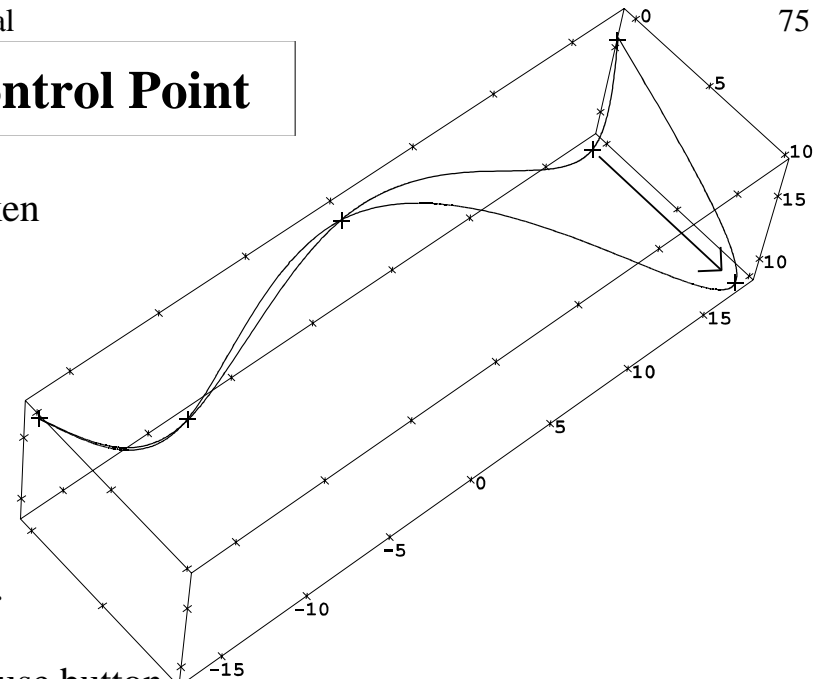
# 3D Curves Exercise

Create 2 intersecting cylinders.

> **sd** 1 cy 0 0 0 1 0 0 2 sd 2 cy 0 0 0 .3 1 0 1.5

Create a spline curve with points from a cylinder.

> 1. Hide mode graphics with sdint on for interior contour lines on
> 2. 3D Curve > SPLINE
> 3. PICK > Z-BUFFER
> 4. Select points with the left mouse button

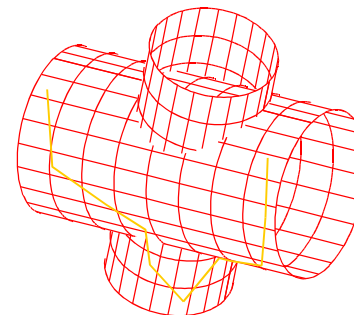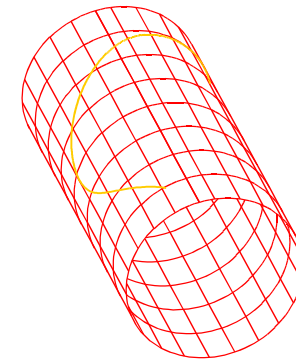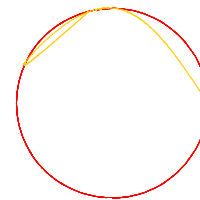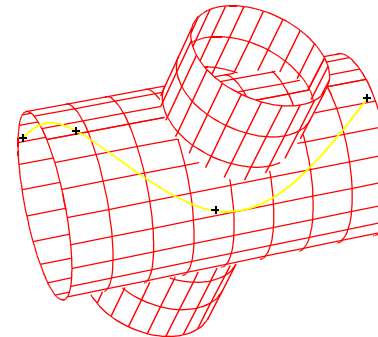Notice that the entire spline is not on the cylinder.

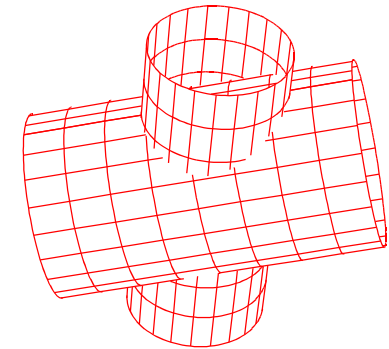> **angle** 0 dsd 1 rest ry -90

Project this curve onto the cylinder.

> **curd** 2 projcur 1 1 ;

Build a polygonal curve from surface points.

> 1. **racd** dasd rest
> 2. 3D Curve > lp3
> 3. Click the clear button
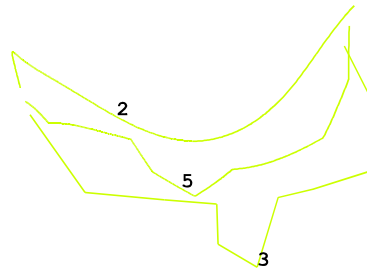> 4. Select points with the left mouse button

Form the curve at the intersection of the two cylinders.

1. **racd** rest
2. 3D Curve > **twsurf**
3. Click the clear button
4. Select points forming a crude approximation
5. Close the loop using Prepend and Accept
6. Type the two surface numbers into the window
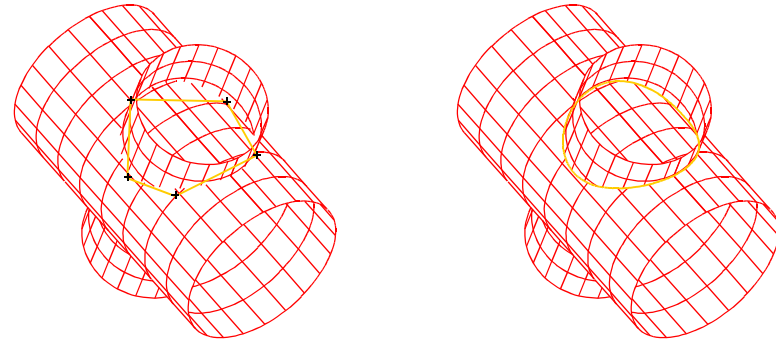
Interpolate a curve from two other curves

```
curd 5 intcur 2 3 .5 ;
```
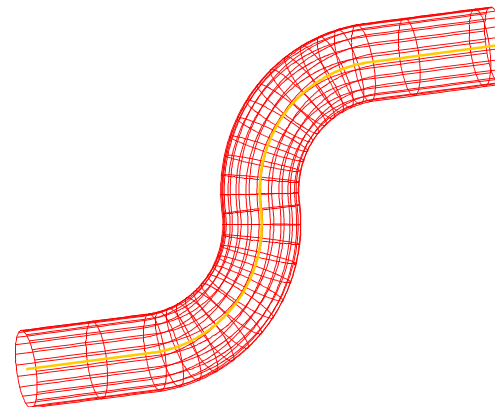
Create a composite curve with arcs.

```
curd 6  lp3 0 0 0; ;
      arc3 seqnc rt 1 0 0 rt [1+1/sqrt(2)] [1-1/sqrt(2)] 0 rt 2 1 0 ;
      arc3 seqnc rt 2 1 0 rt [3-1/sqrt(2)] [1+1/sqrt(2)] 0 rt 3 2 0 ;
      lp3 4 2 0; ;
```

Create a pipe surface about this curve.

```
sd 3 pipe 6 .3 0 .3 1;;
```

Select contours from the surface.

```
curd  7 contour 3.1.14 3.0.14;;
curd  8 contour 3.1.41 3.0.41;;
curd  9 contour 3.1.68 3.0.68;;
curd 10 contour 3.1.95 3.0.95;;
```
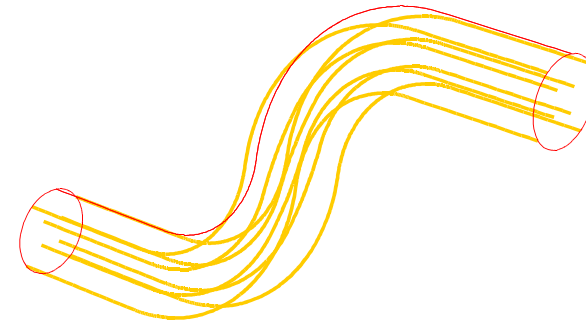
Create interpolated curves for the interior.

```
curd 11 intcur 7  9 .3 ;
curd 12 intcur 7  9 .7 ;
curd 13 intcur 8 10 .3 ;
curd 14 intcur 8 10 .7 ;
```

These curves can be used to create a butterfly part by attaching the edges to the curves and projecting to the pipe surface.
NOTE: Not all of the commands are shown here for the sake of brevity.

```
block 1 21;1 3 5 7;1 3 5 7;0 4 -.3 -.1 .1 .3 -.3 -.1 .1 .3
dei ; 1 2 0 3 4; 1 2 0 3 4;
curs 1 4 2 2 4 2  7 curs 1 3 1 2 3 1  7
curs 1 2 1 2 2 1  8 curs 1 1 2 2 1 2  8
curs 1 4 3 2 4 3 10 curs 1 3 4 2 3 4 10
curs 1 2 4 2 2 4  9 curs 1 1 3 2 1 3  9
curs 1 3 2 2 3 2 11
curs 1 2 2 2 2 2 13
curs 1 2 3 2 2 3 12
curs 1 3 3 2 3 3 14
sfi ; -1 -4; -1 -4;sd 3
```