

# FRANC3D Training Workshop: Part 6

## Crack Insertion

August - 2026

Drs. Paul “Wash” Wawrzynek, Bruce Carter,  
Tony Ingraffea and Omar Ibrahim

# Workshop Agenda

---

- Part 1: Introduction to Fatigue and Damage Tolerance
- Part 2: Introduction to Fracture Mechanics Analysis
- Part 3: Introduction to FRANC3D
- Part 4: FRANC3D User Interface
- Part 5: Finite Element (FE) Model Import
- **Part 6: Crack Insertion**
- Part 7: Static Crack Analysis & SIF Computation
- Part 8: SIFs from FE Analysis
- Part 9: Crack Growth
- Part 10: SIF History & Fatigue Life
- Part 11: Miscellaneous Topics

# Crack Insertion

---

- Process of Inserting Flaw and Meshing
- Converting FE Mesh to Model Surface Geometry
- Flaw Type Panel
- Zero Volume Crack Types
- Crack-Front Element Types
- Notch Insertion
- Void Insertion
- Flaw From Files
- Multiple Flaw Insertion
- Meshing Constrained by Underlying Geometry/Topology
- Demo & Hands On

# Process of Inserting Flaw and Meshing

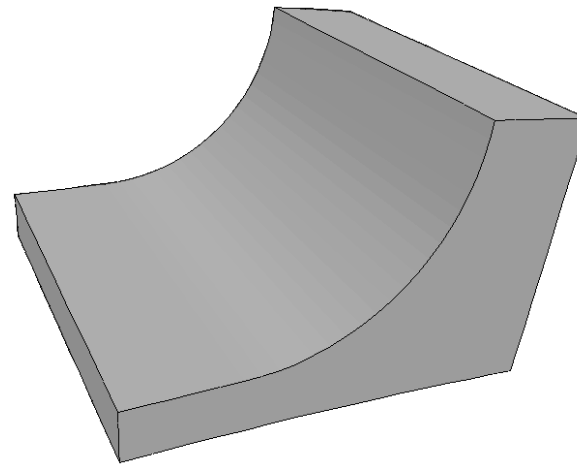
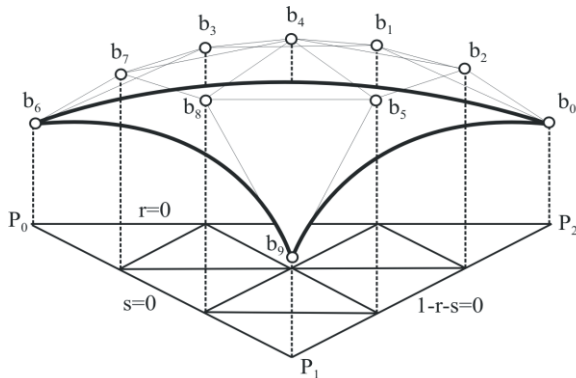
---

- Import the FE sub-model and convert it to geometric model
- Select the geometric flaw type
  - Crack (zero volume flaw)
  - Notch (finite volume flaw)
  - Void (finite volume flaw)
- Define the flaw dimensions
- Position the flaw in the model
- Define the crack front template mesh density
- Perform geometric intersection of the crack surface, crack front template and model surface
- Perform surface meshing
- Perform volume meshing

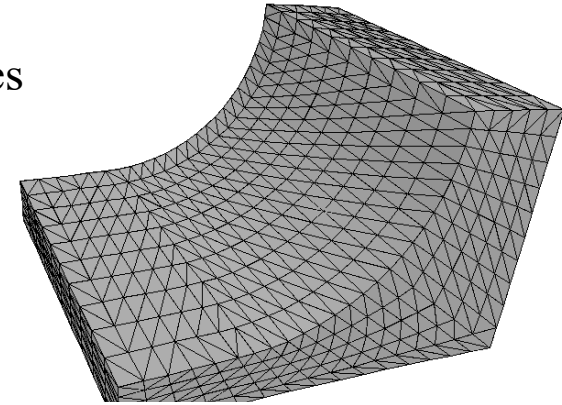
# Converting FE Mesh to Model Surface Geometry

- Model surface geometry is approximated from the faceted-surface mesh
- Converting 3D volume elements to FRANC3D geometry follows these steps:
  - 1) Read 3D FE volume mesh of sub-model
  - 2) Compute weighted average normals at all surface FE nodes
  - 3) Define 1 or 2 triangular Bezier patches for each FE facet (planar and curved surfaces can be represented)
  - 4) Identify “topological” edges and group together patches that form logical faces

Bezier triangle geometry  
with 10 control points



Topological edges & logical faces are defined based on the angle between the patches.

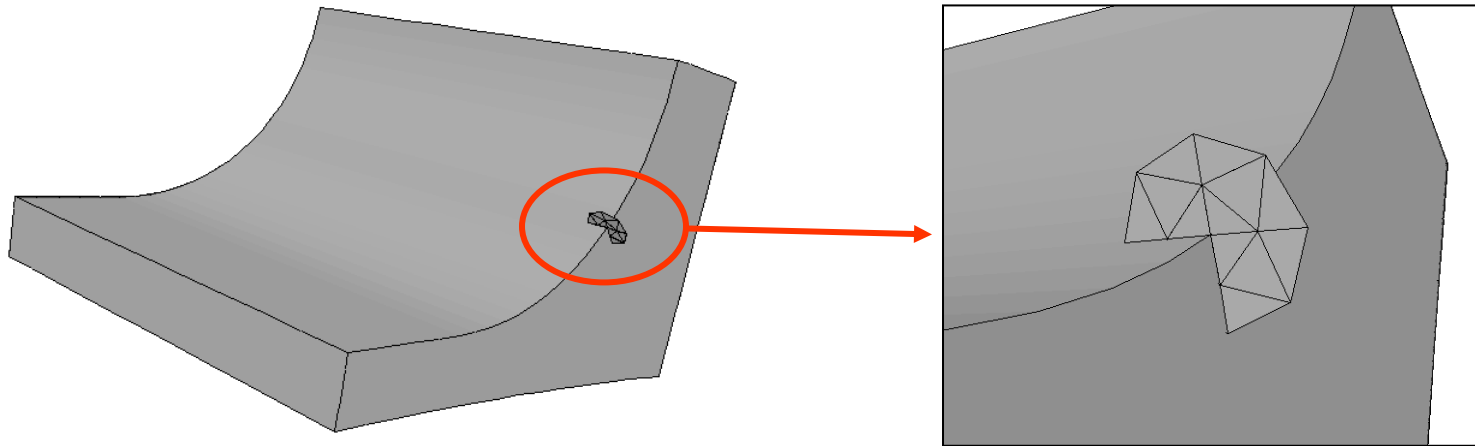


FE facets on cut surfaces retained for compatibility

# Crack Insertion – define flaw geometry

---

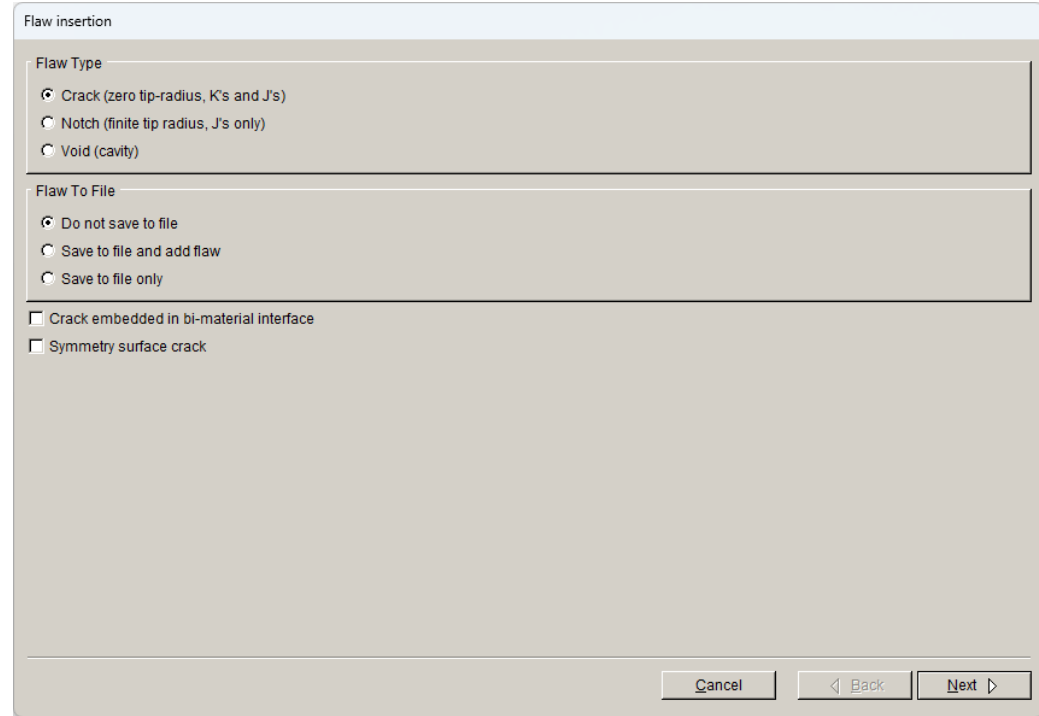
Crack shape, size, location and orientation relative to the uncracked model:



- flaw surfaces are defined using Bezier patches
- crack front edges can be curves (cubic splines) or straight lines
- initial flaw surface can be planar or non-planar
- surface-surface intersections are determined so that only the portion of the crack geometry that falls inside the model is retained when meshing

# Flaw Type Panel

- Select the flaw type to be inserted:
  - Crack (zero volume flaw)
  - Void (finite volume flaw)
- Options to save the flaw description:
  - default is to add the flaw to the model without saving to a (.crk) file
  - Save to file and add flaw: allows the user to save the flaw to a file and add it to the model
  - Save to file only: saves the flaw to a file without adding it to the model



The screenshot shows a software dialog box titled "Flaw insertion". It contains two main sections: "Flaw Type" and "Flaw To File".

**Flaw Type**

- ☒ Crack (zero tip-radius, K's and J's)
- ☐ Notch (finite tip radius, J's only)
- ☐ Void (cavity)

**Flaw To File**

- ☒ Do not save to file
- ☐ Save to file and add flaw
- ☐ Save to file only

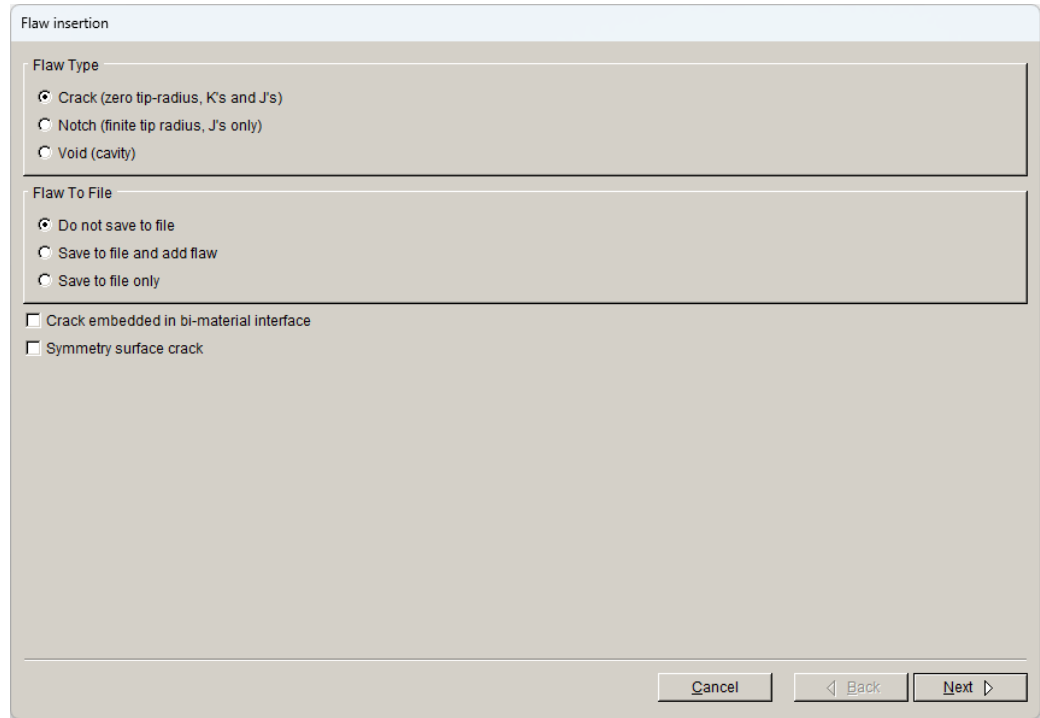
Below these sections are two unchecked checkboxes:

- ☐ Crack embedded in bi-material interface
- ☐ Symmetry surface crack

At the bottom right, there are three buttons: "Cancel", "< Back", and "Next >".

# Flaw Type Panel

- Last two options:
  - If the user is inserting a crack that is embedded in a bi-material interface, turn on the option.
  - If the user is inserting a symmetry surface crack, turn on the option.



The screenshot shows a software dialog box titled "Flaw insertion". It contains two main sections: "Flaw Type" and "Flaw To File".

**Flaw Type**

- ☒ Crack (zero tip-radius, K's and J's)
- ☐ Notch (finite tip radius, J's only)
- ☐ Void (cavity)

**Flaw To File**

- ☒ Do not save to file
- ☐ Save to file and add flaw
- ☐ Save to file only

Below these sections are two unchecked checkboxes:

- ☐ Crack embedded in bi-material interface
- ☐ Symmetry surface crack

At the bottom right of the dialog are three buttons: "Cancel", "< Back", and "Next >".

# Crack (flaw) Geometry File (.crk)

- It is a text file
- Contains triangular Bezier patches (vertices + 10 control points) for the flaw surfaces
- Contains crack front information

```

FLAWSURF
(
  VERSION: 5
  NUM_SURFS: 128
  SURF: 0
    3 35 37
      12 -1.1 11
      12 -1.1 10.9166666666667
      12 -1.00833333333333 10.9166666666667
      12 -1.1 10.8333333333333
      12 -1.00833333333333 10.8333333333333
      12 -0.916666666666667 10.8333333333333
      12 -1.1 10.75
      12 -1.00833333230208 10.75
      12 -0.916666667697917 10.75
      12 -0.825000000000001 10.75

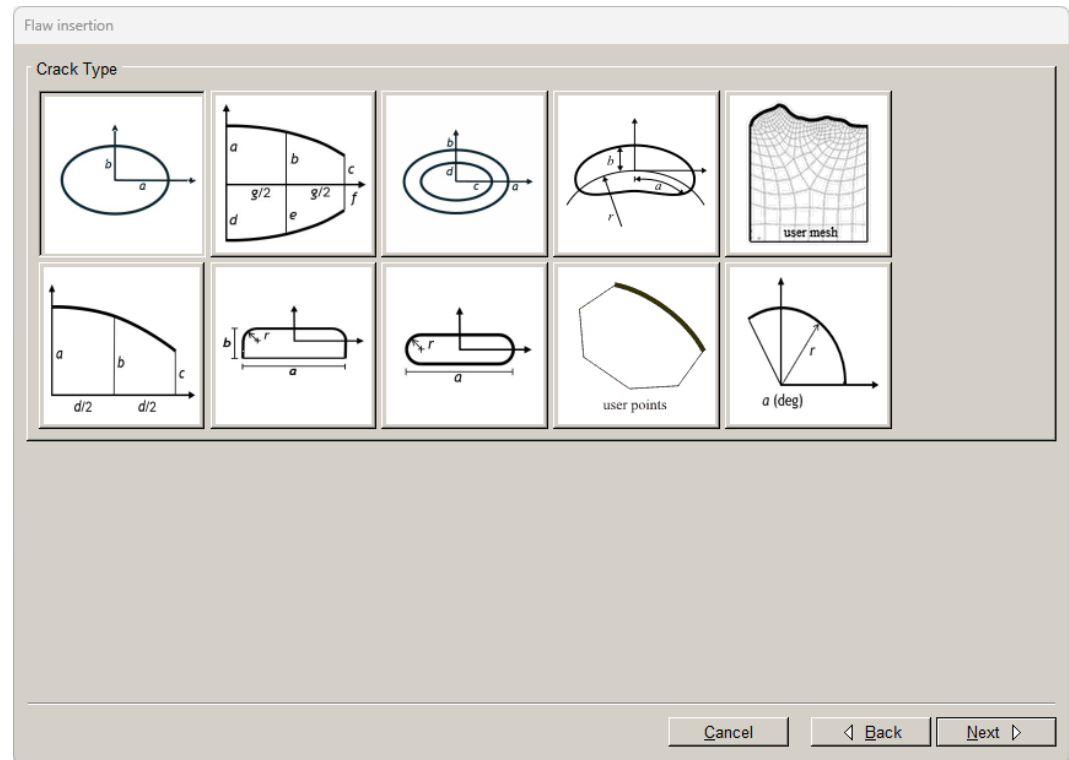
  SURF: 1
    35 10 48
      12 -1.1 10.75
      12 -1.1 10.6666666666667
      12 -1.00833333230208 10.6666666659167
      12 -1.1 10.5833333333333
      12 -1.00833333292083 10.5833333333333
      12 -0.916666667285417 10.5833333340833
      12 -1.1 10.5
      12 -1.00833333250833 10.5
      12 -0.916666666254167 10.5
      12 -0.825 10.5

  SURF: 2
    48 11 37
      12 -0.825 10.5
      12 -0.733333333745833 10.5
      12 -0.82500000020625 10.5833333340833
      12 -0.641666667491667 10.5
      12 -0.733333333745834 10.5833333333333
      12 -0.825000000206251 10.6666666659167
      12 -0.55 10.5
      12 -0.641666666666667 10.5833333333333
      12 -0.733333333333334 10.6666666666667
      12 -0.825000000000001 10.75

  SURF: 3
    35 48 37
      12 -1.1 10.75
      12 -1.00833333230208 10.6666666659167
    
```

# Zero Volume Crack Types

- Elliptical Crack
- Through-the-thickness
  - One crack front
  - Two crack fronts
- Long-shallow surface crack shape (use instead of long narrow ellipses)
- Elliptical crack shape with two fronts (use for circumferential cracks in bars)
- Long-shallow interior crack shape
- Curvilinear elliptical crack



- User-defined crack boundary
- User-mesh crack
- Partial-circle crack

# Crack Insertion Wizard (Elliptical Flaw)

Flaw insertion

Crack Type

Set crack size/shape parameters.

Flaw insertion

Ellipse Crack Parameters

a: 2  
b: 1

Advanced Geometry

Display

- ☐ Markers
- ☒ Vectors
- ☒ Polygons

Flaw translation

global local

X: 3.975 X: 0  
Y: -0.053 Y: 0  
Z: -2.093 Z: 0

Flaw rotations

1st Rotation

Axis ☒ X ☐ Y ☐ Z ☐ Global

Angle (deg) 55 Local

2nd Rotation

Axis ☒ X ☐ Y ☐ Z ☐ Global

Angle (deg) -34 Local

3rd Rotation

Axis ☒ X ☐ Y ☐ Z ☐ Global

Angle (deg) 27 Local

Redefine Local Axes

Crack front mesh template

☒ use crack-front template

Template radius: 0.01 Front: 1

☒ Display full template

☐ Simple template intersections only

Meshing parameters Advanced options

Display

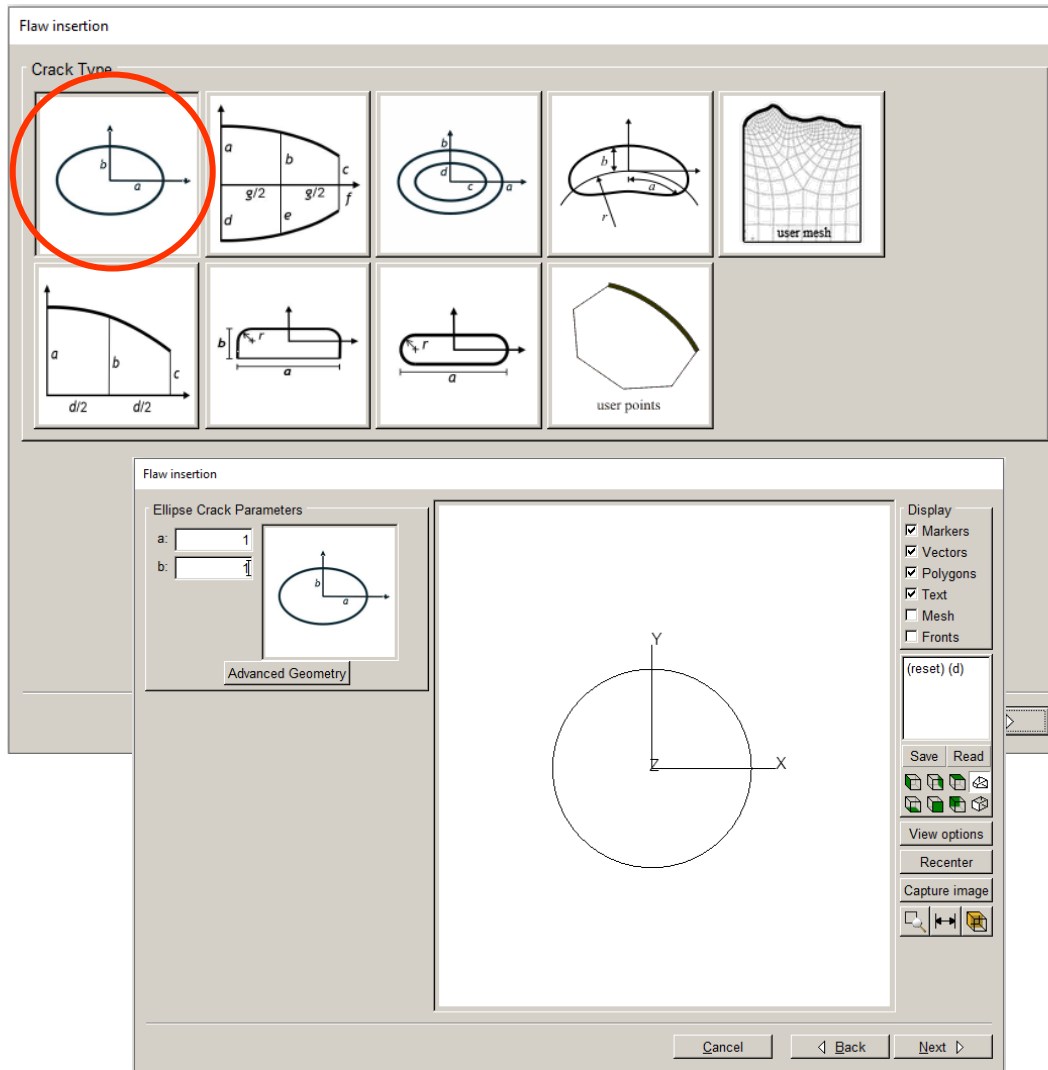
- ☐ Markers
- ☒ Vectors
- ☒ Polygons
- ☒ Text
- ☐ Mesh
- ☐ Fronts
- ☐ Node Num
- ☒ Local Axes
- ☐ Crack Axes

Set crack position and orientation.

Set crack-front template mesh parameters.

Cancel < Back Finish

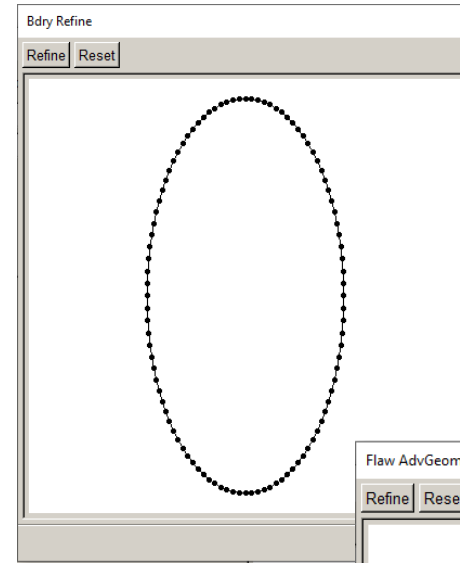
# Crack Insertion Wizard - Elliptical Flaw



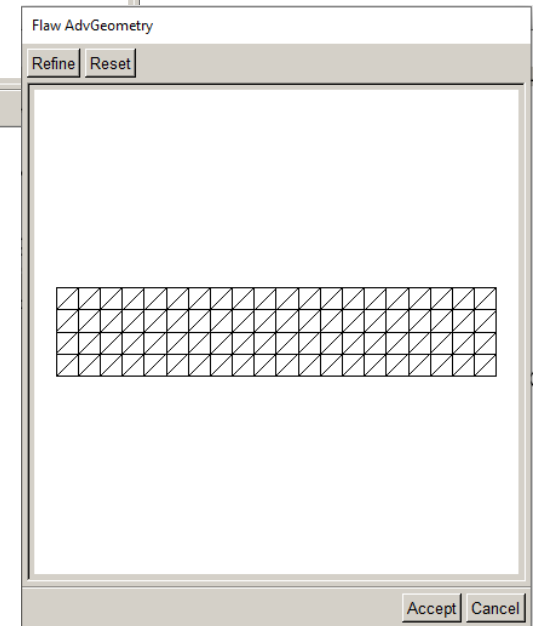
- Define the semi-axes lengths (a and b)
- After entering the values of a and b the ellipse is displayed in the 3D view window
- The ellipse is displayed in its local orientation, which is in the  $x$ - $y$  plane and centered at the global Cartesian origin
- Advanced Geometry button is common to all predefined crack shapes

# Crack Insertion Wizard (Elliptical Flaw)

- **Advanced Geometry** button
  - Selecting the **Advanced Geometry** button on any of the predefined crack shapes leads to the Advanced Geometry dialog
  - Triangular cubic-Bezier patches represent the crack surface geometry, not a finite element surface mesh
  - There are two buttons on the top menu bar: **Refine** and **Reset**; the Refine button increases the patch density.

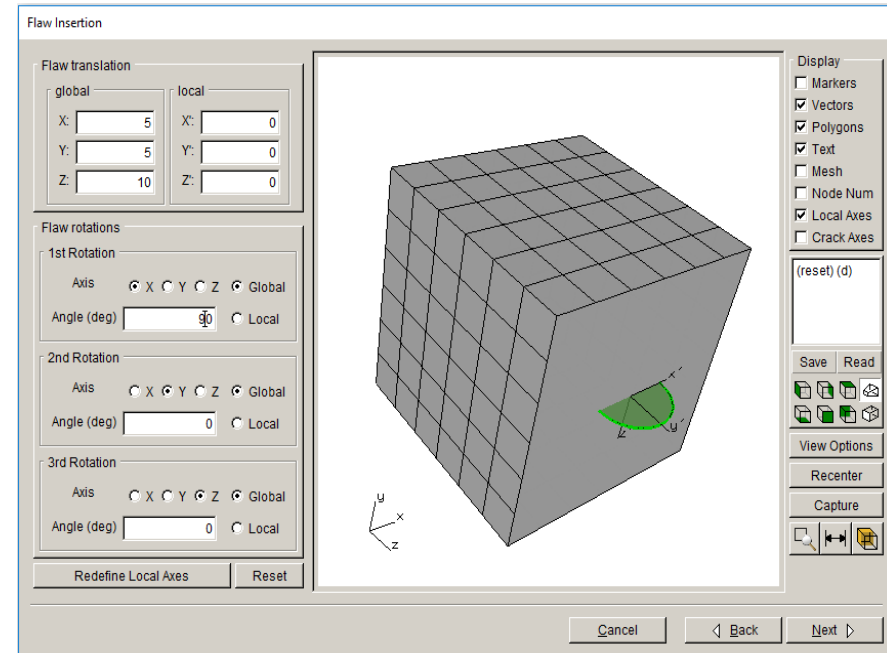


The boundary is displayed for some library flaws.



# Crack Insertion Wizard (Elliptical Flaw)

- Translations and rotations can be specified in the global or a local coordinate system
- Flaw Translation
  - Translations move the local origin of the flaw to a location in the Cartesian space of the body
- Flaw Rotation
  - Specify sequence of rotations
- The **Define Local Axes** button allows one to specify a local Cartesian coordinate system



# Crack Insertion Wizard (Elliptical Flaw)

- The **Define Local Axes** dialog box has the following options for defining the local Cartesian coordinate system
  - Anchor at node normal to surface
  - Anchor at point normal to surface
  - Define by three nodes
  - Define by three points
  - Define by angles

Define Local Coordinate System

☒ Anchor at node  
Node Number:  ☒ Normal to Surface

☐ Anchor at point normal to surface  
X coord:  Y coord:  Z coord:

☐ Define by three nodes  
node at origin:   
node on X axis:   
node in XY plane:

☐ Define by three points  

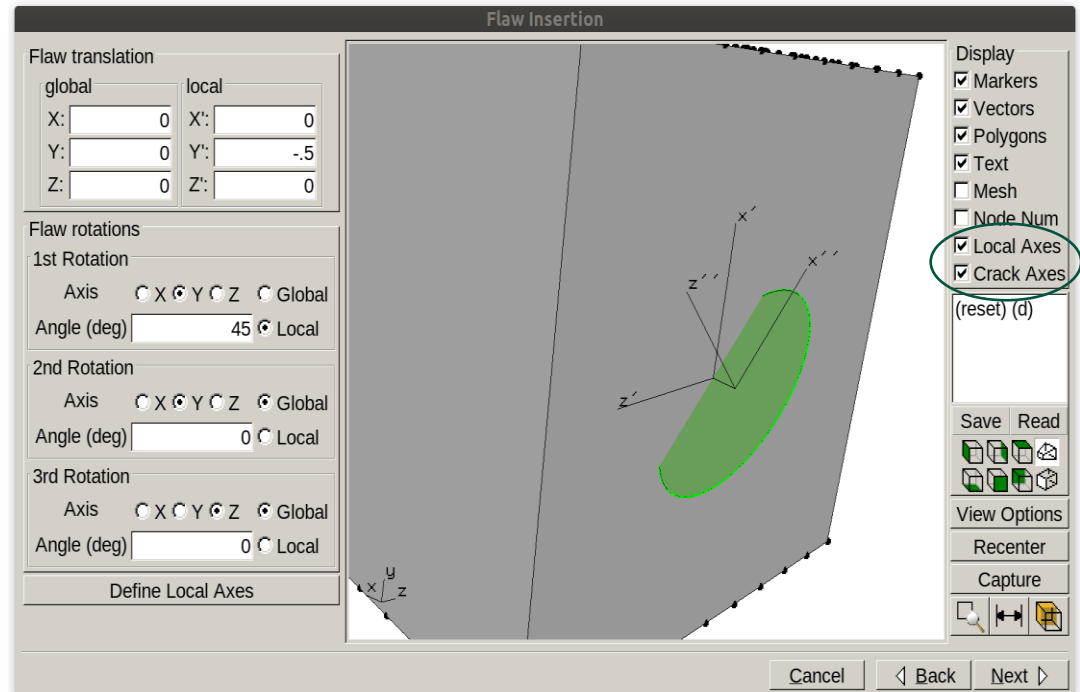
| origin                            | X axis point                      | X-Y plane point                   |
|-----------------------------------|-----------------------------------|-----------------------------------|
| X: <input type="text" value="1"/> | X: <input type="text" value="0"/> | X: <input type="text" value="0"/> |
| Y: <input type="text" value="0"/> | Y: <input type="text" value="1"/> | Y: <input type="text" value="0"/> |
| Z: <input type="text" value="0"/> | Z: <input type="text" value="0"/> | Z: <input type="text" value="1"/> |

☐ Define by angles  

| origin                            | 1st rotation                                                                             | 2nd rotation                                                                             | 3rd rotation                                                                             |
|-----------------------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| X: <input type="text" value="0"/> | Axis: <input checked="" type="radio"/> X <input type="radio"/> Y <input type="radio"/> Z | Axis: <input type="radio"/> X <input checked="" type="radio"/> Y <input type="radio"/> Z | Axis: <input type="radio"/> X <input type="radio"/> Y <input checked="" type="radio"/> Z |
| Y: <input type="text" value="0"/> | Angle: <input type="text" value="0"/>                                                    | Angle: <input type="text" value="0"/>                                                    | Angle: <input type="text" value="0"/>                                                    |
| Z: <input type="text" value="0"/> |                                                                                          |                                                                                          |                                                                                          |

# Crack Insertion Wizard (Elliptical Flaw)

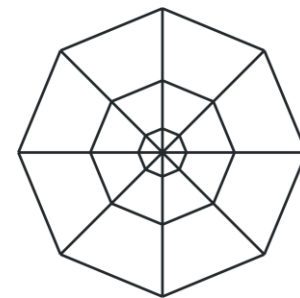
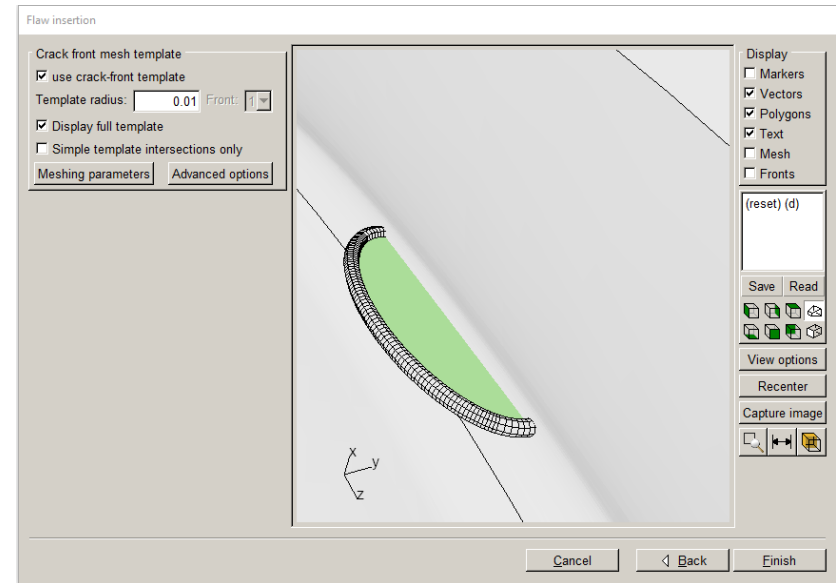
- There are three coordinate systems when orienting a flaw:
  - Global Cartesian system
  - Local user defined coordinate system (single prime)
  - Crack coordinate system (double prime)
- The Display panel on the right side has two additional options to display the local axes and the crack axes



# Crack Insertion Wizard (Elliptical Flaw)

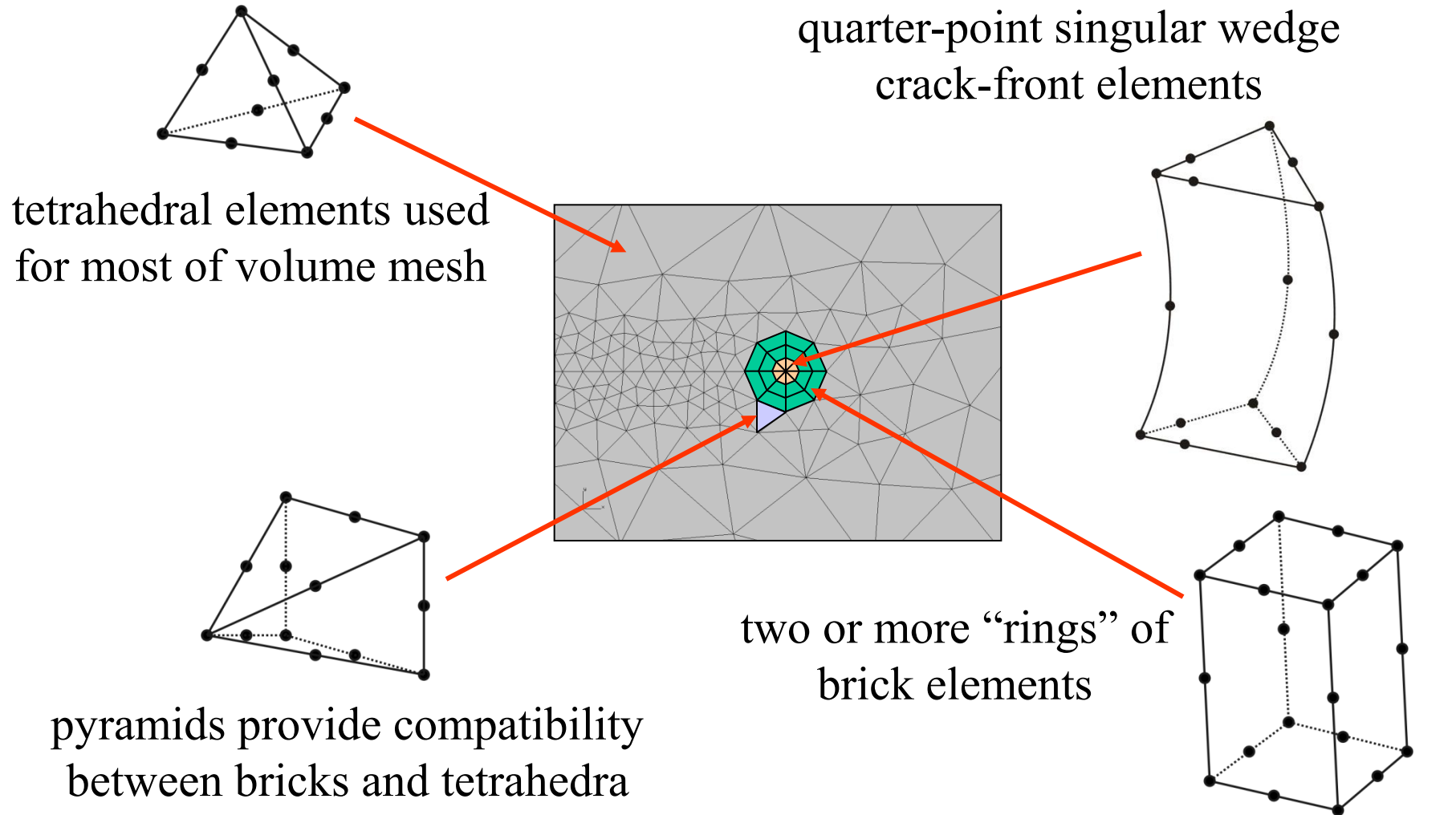
## Crack Front Mesh Template Panel

- For **accurate SIF computations**, a "template" of elements with controlled sizes and shapes is placed about all crack fronts.
- A template has the form of generalized cylindrical tubes of elements, with crack fronts serving as the axes of the cylinders.
- Wedge shaped elements are placed immediately adjacent to the crack fronts. These are surrounded by rings of brick elements.



Typical template cross-section

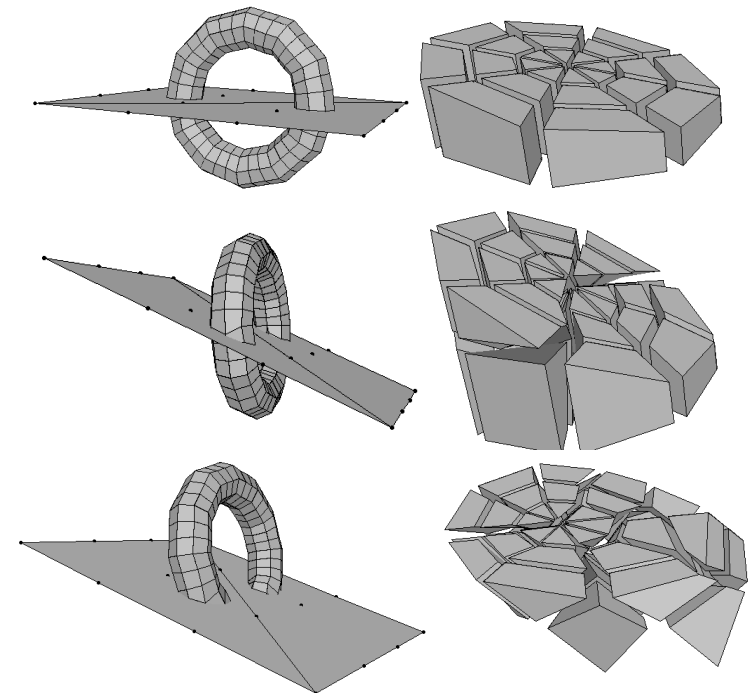
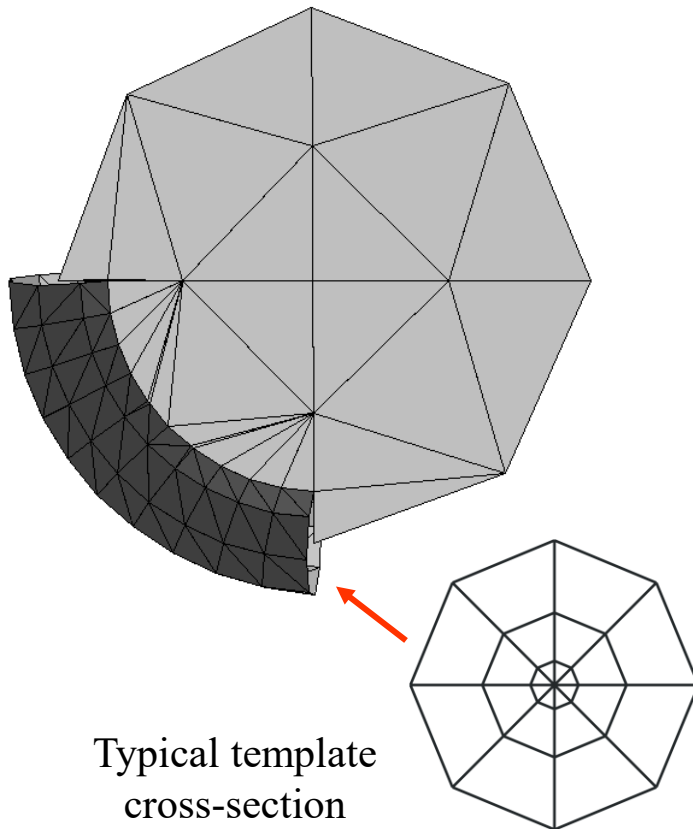
# Crack-Front Element Types



*The FRANC3D default template has 8 wedge elements around the front and 2 rings of bricks.*

# Crack Insertion – crack-front template mesh

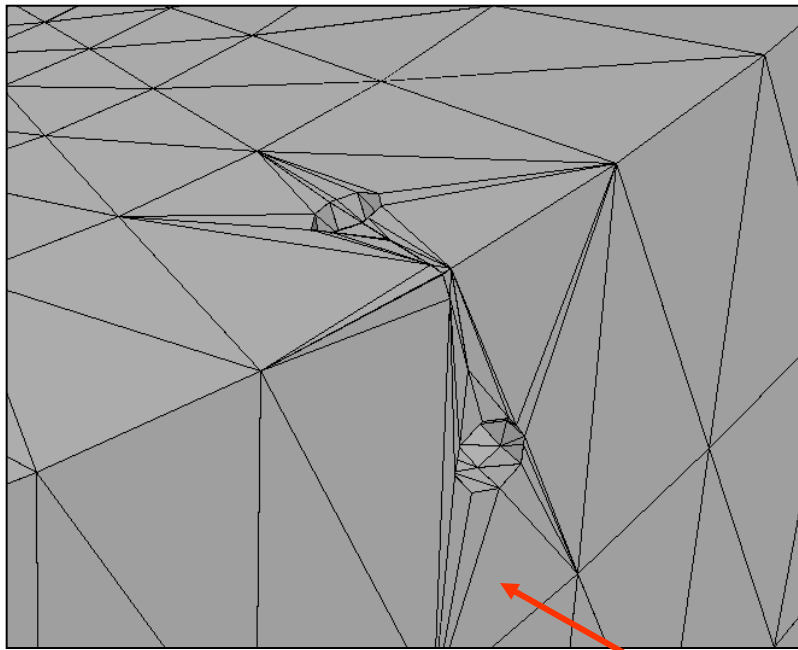
- templates are used to place well-shaped elements at/near crack fronts
  - templates are a combination of brick and quarter-point wedge elements
- where templates intersect model surfaces, element topology and geometry might be modified to conform to the surface geometry



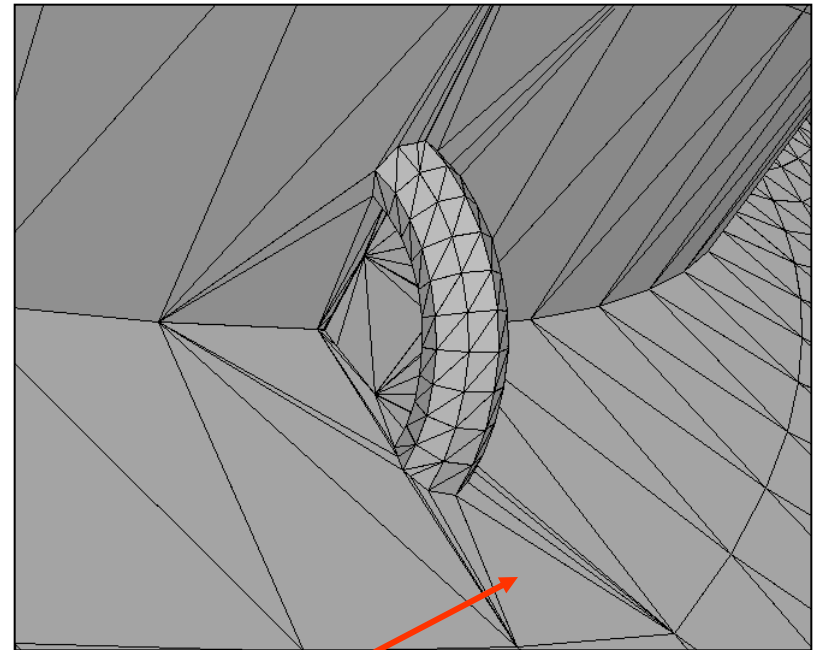
# Crack Insertion – intersection and trimming

- surface/surface intersections are computed for all model and flaw patches
- patches are trimmed and combined into composite objects

Outside View



Inside View

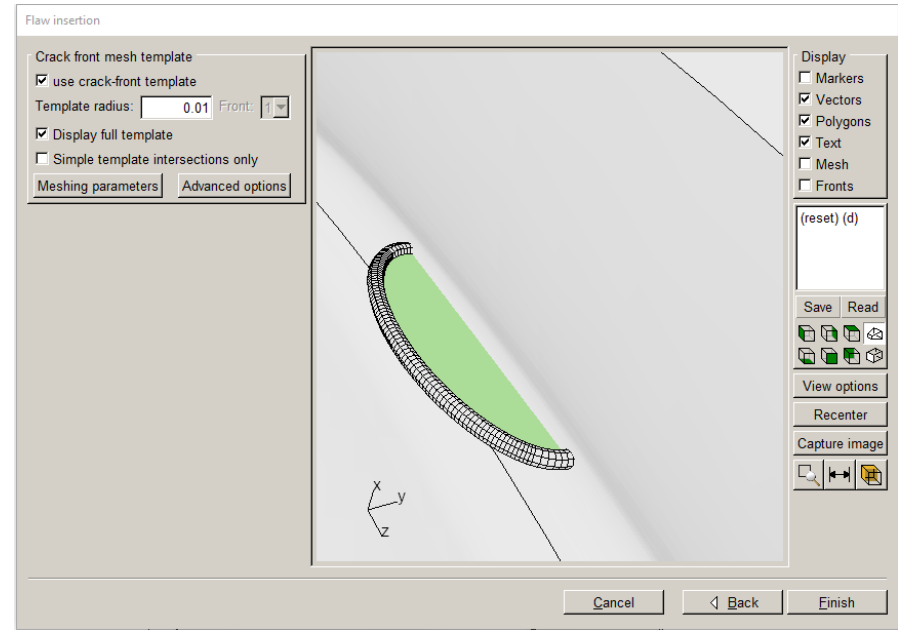


Trimmed patches are divided into triangular sub-patches to keep the model “water-tight”.

*Note that these images show **geometry**, not a surface mesh.*

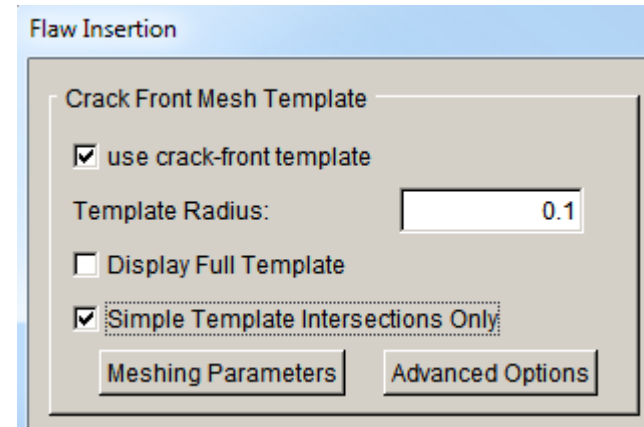
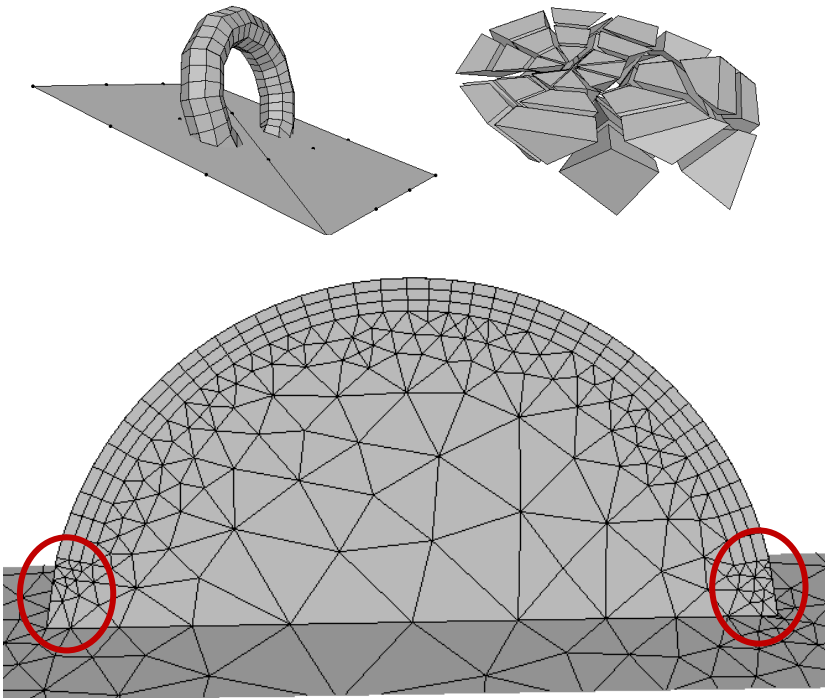
# Crack Front Mesh Template Panel

- Template Radius field
  - Default value of the radius is based on a notion of the crack size
- Simple Template Intersections Only : Allows the user to terminate the template inside the model surfaces
- **Meshing Parameters** button
  - Specify surface and volume meshing parameters
  - Choose the volume mesher
- **Advanced Options** button allows the user to adjust the template parameters such as number of rings of elements.



# Simple Template Intersections Only

- Simple Template Intersections means that the template does not extend to model surface.
- Allows the user to terminate the template inside the model surface
- If the template intersects the model surface at shallow angles, the elements are highly distorted and do not provide accurate SIFs.



FRANC3D attempts to recognize instances where the template will intersect model surfaces at shallow angles and **automatically uses this option if needed.**

# Meshing Parameters

## Surface and volume meshing controls

- Maximum Generated Elements: limits the total number of volume elements that FRANC3D will create during volume meshing
- Maximum Volume Mesh Restarts: limits the number of volume meshing restarts
- FRANC3D uses an *advancing front* volume meshing algorithm
- FRANC3D generated volume elements are smoothed to improve element quality; ANSYS and ABAQUS generated meshes are imported as created
- For ANSYS or ABAQUS: write files only - allows the user to write the surface mesh and the commands to generate the volume mesh from the surface mesh to files, and the volume meshing must be done manually by the user.

Meshing parameters

Meshing parameters/options

Maximum generated elements: 500000

Maximum volume mesh restarts: 4

☒ Do coarsen crack mouth mesh

☒ Do crack proximity refinement

☒ Do not coarsen more than uncracked mesh

Volume mesh using: ☒ FRANC3D ☐ ANSYS ☐ ABAQUS

ANSYS executable: ansys192.exe Browse

ANSYS license: ansys

ABAQUS executable: abaqus.bat Browse

For ANSYS or ABAQUS: ☐ write files only

Cancel Accept

# Meshing Parameters

## Surface mesh refinement

- Do Coarsen Crack Mouth Mesh - produces a less refined mesh on the crack surface
- Do Local Surface Refinement - refines any surface mesh near the crack
- Do Not Coarsen More Than Uncracked Mesh - produces a surface mesh that resembles the original mesh density

Meshing parameters

Meshing parameters/options

Maximum generated elements: 500000

Maximum volume mesh restarts: 4

☒ Do coarsen crack mouth mesh

☒ Do crack proximity refinement

☒ Do not coarsen more than uncracked mesh

Volume mesh using: ☒ FRANC3D ☐ ANSYS ☐ ABAQUS

ANSYS executable: ansys192.exe Browse

ANSYS license: ansys

ABAQUS executable: abaqus.bat Browse

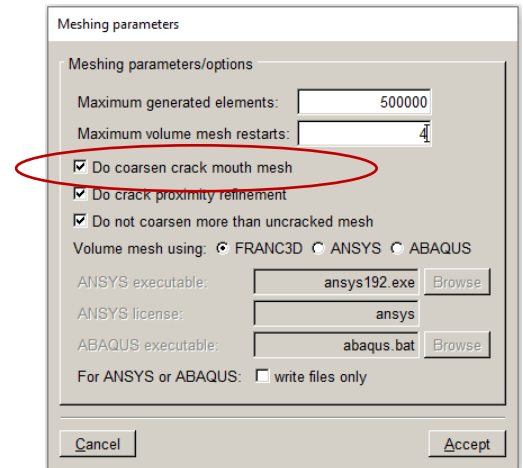
For ANSYS or ABAQUS: ☐ write files only

Cancel Accept

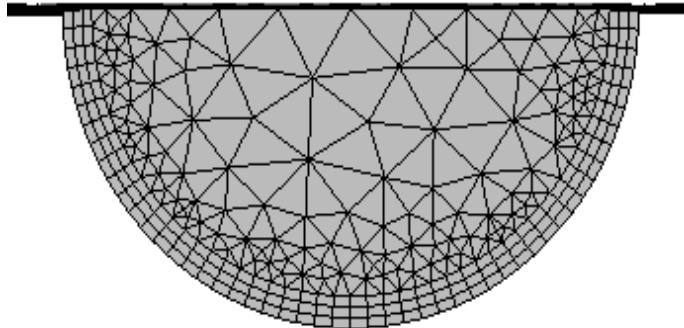
Example surface meshes are shown in the next two slides.

# Surface mesh refinement

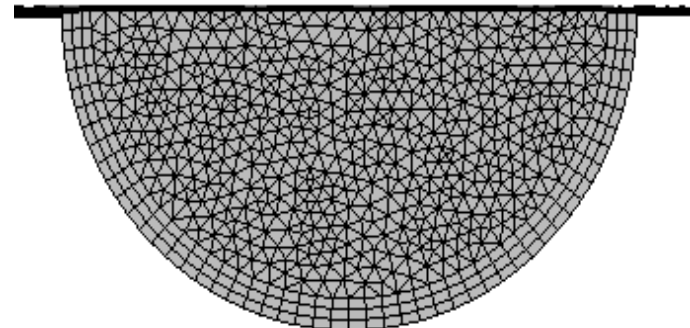
## Effects of Do Coarsen Crack Mouth Mesh



on

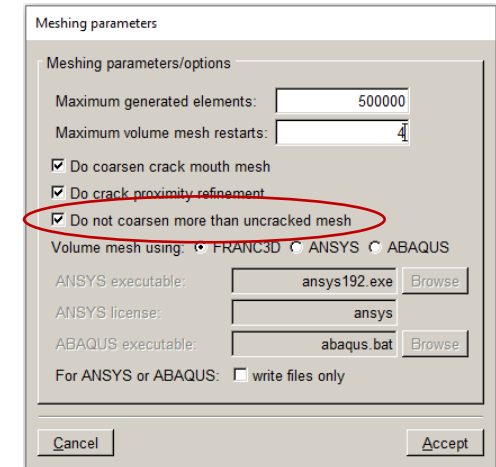


off

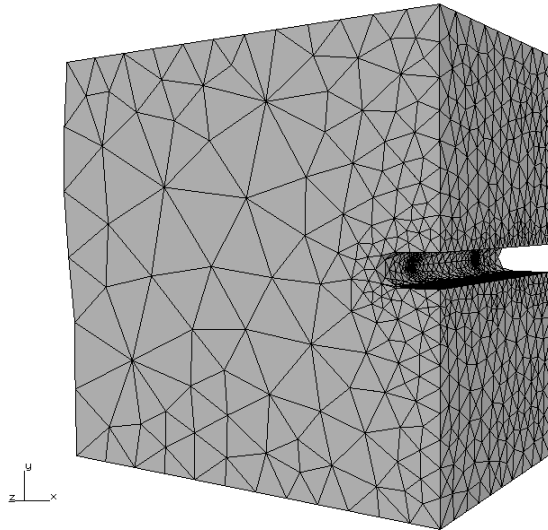


# Surface mesh refinement

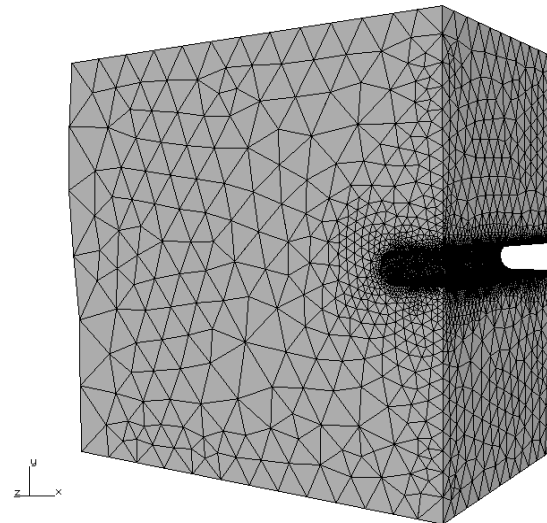
## Effects of Do Not Coarsen More Than Uncracked Mesh



**off**

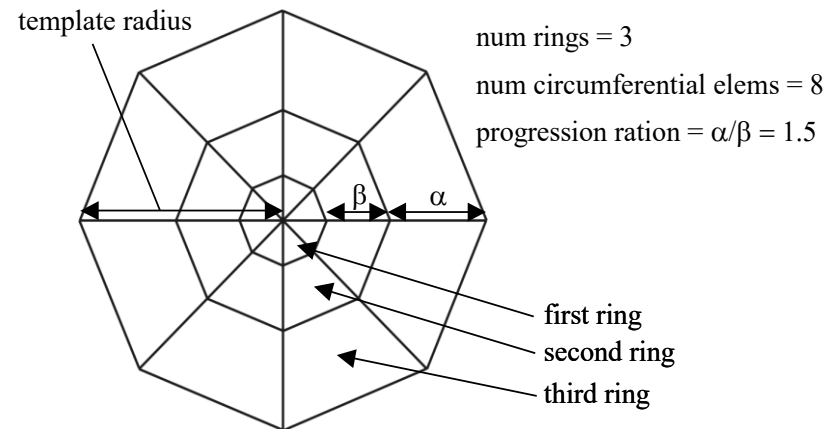
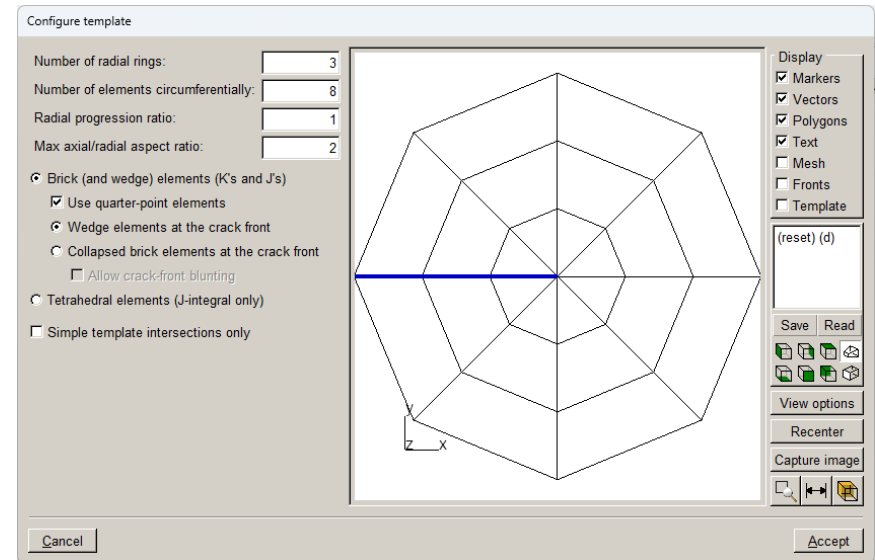


**on**



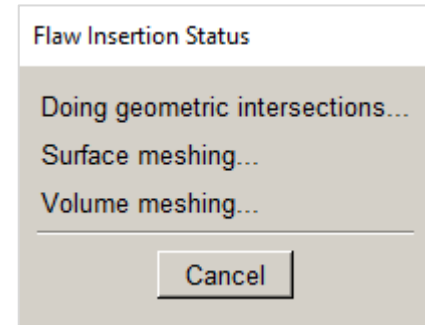
# Configure Template

- Progression Ratio sets the relative width of the element (in the direction perpendicular to the crack front) going from the crack front to the outer surface of the template
- Number of rings sets the number of rings of elements in the template
- Number of circumferential elements sets the number of elements in the circumferential direction around the crack front
- Max aspect ratio controls the aspect ratio of the quadrilateral faces on the outer surface of the template that will trigger 1:2 or 1:3 transitions in the outer ring of elements



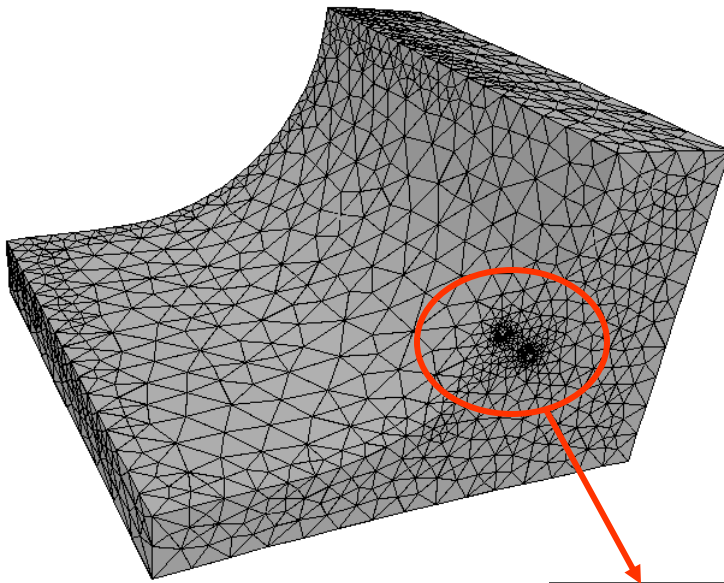
# Flaw Insertion Status

- After one selects **Finish** on the crack front mesh template panel, the flaw is inserted into the body and the model is remeshed
- The crack geometry is inserted into the model geometry first, represented by the Doing geometric intersections... status. Once the crack geometry has been inserted, trimmed, and tied to the model geometry, the surface and then volume meshing occur
- If FRANC3D volume meshing is used, the final volume mesh is **smoothed to improve the element quality**

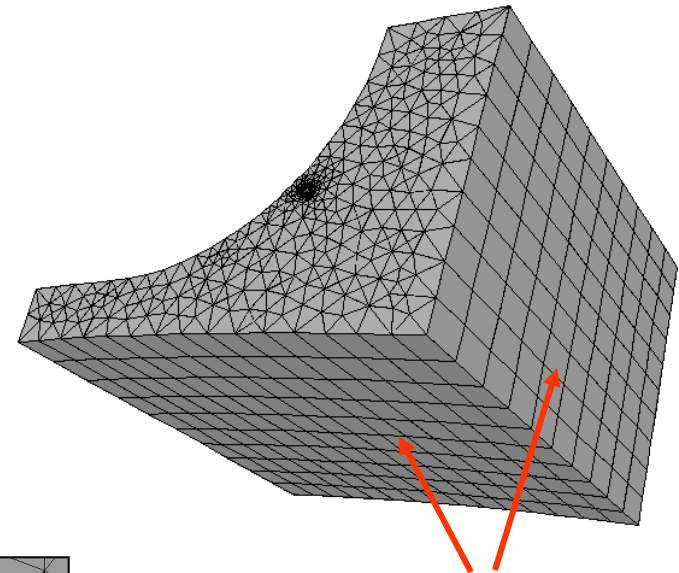
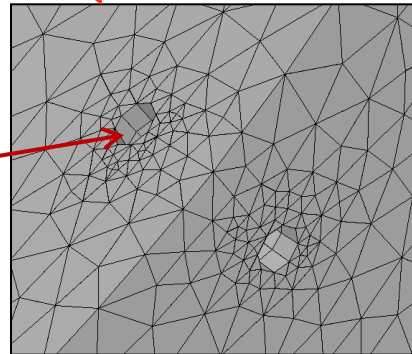


# Crack Insertion – surface remeshing

- triangular surface meshes generated for all “logical” model surfaces
- meshes conform to the mesh on retained surfaces



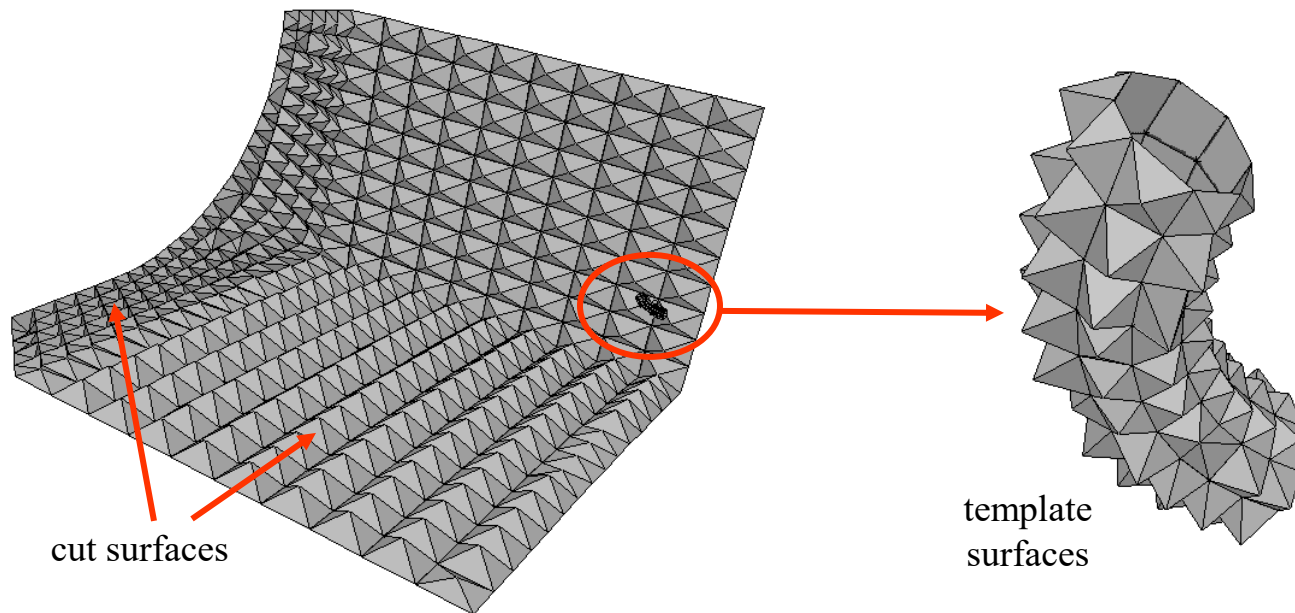
Template mesh  
extracted as it is  
already meshed



retained cut-surface  
meshes

# Crack Insertion – pyramids and tetrahedra

- pyramid elements generated for compatibility:
  - between quadrilateral facets (on the template or retained surfaces) and the triangular faces of tetrahedra in the volume mesh



- advancing front meshing algorithm\* used to generate tetrahedral volume mesh
- algorithm respects geometrically coincident but distinct nodes on opposite sides of crack faces

\*Neto, J.B., Wawrzynek, P.A., Martha, L.F., and Ingraffea, A.R., "An algorithm for three-dimensional mesh generation for arbitrary regions with cracks," *Engng with Comp.*, Vol. 17, 75-91 (2001)

# Crack Insertion Wizard – Library Shapes

Crack Insertion Wizard – Library Shapes

Crack Type

Crack geometry is a little 'bigger' than the model.

Flaw insertion

Flaw translation

Flaw rotations

1st Rotation

2nd Rotation

3rd Rotation

Display

Crack front mesh template

use crack-front template

Template radius: 0.15 Front: 2

Display full template

Simple template intersections only

Meshing parameters Advanced options

Display

Markers

Vectors

Polygons

Text

Mesh

Fronts

(reset) (d)

Save Read

View options

Recenter

Capture image

Flaw insertion

Flaw translation

Flaw rotations

1st Rotation

2nd Rotation

3rd Rotation

Display

Markers

Vectors

Polygons

Text

Mesh

Fronts

Node Num

Local Axes

Crack Axes

(reset) (d)

Save Read

View options

Recenter

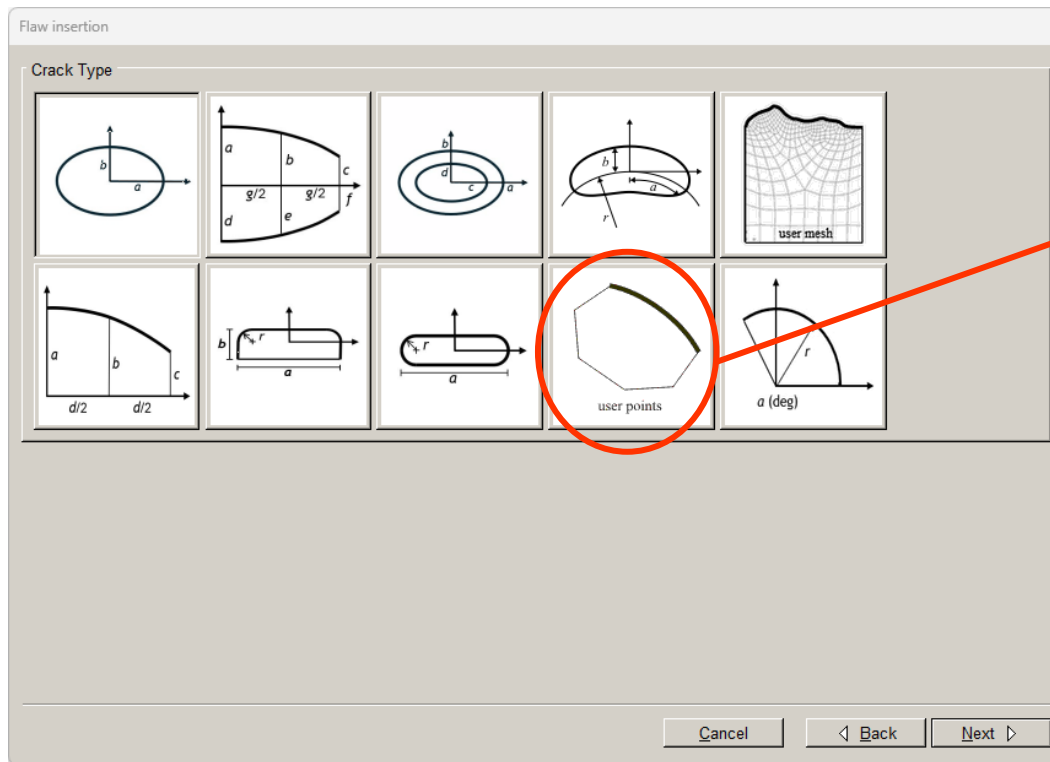
Capture image

Redefine Local Axes Reset

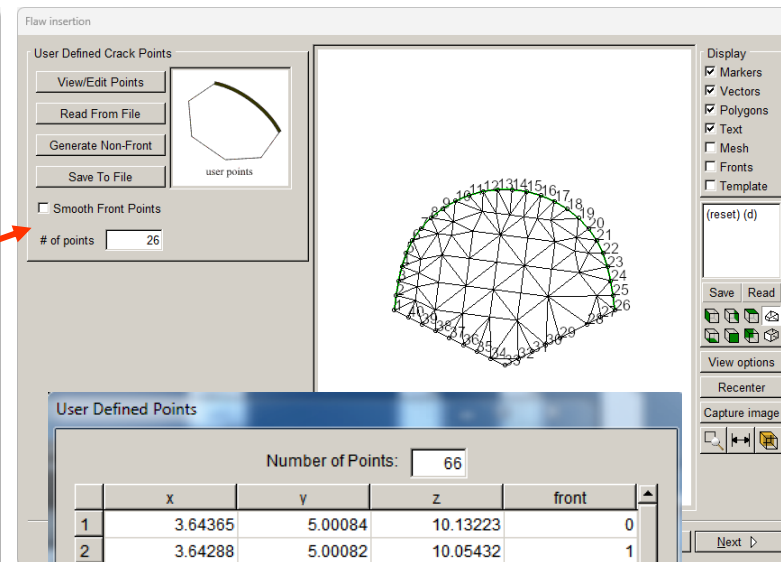
Cancel Back Next

Cancel Back Next

# User-Defined Crack Shape



User-defined crack allows for an arbitrary (planar) shape; enter (or read from a file) a series of points that define the exterior vertices of a polygon.



User Defined Points

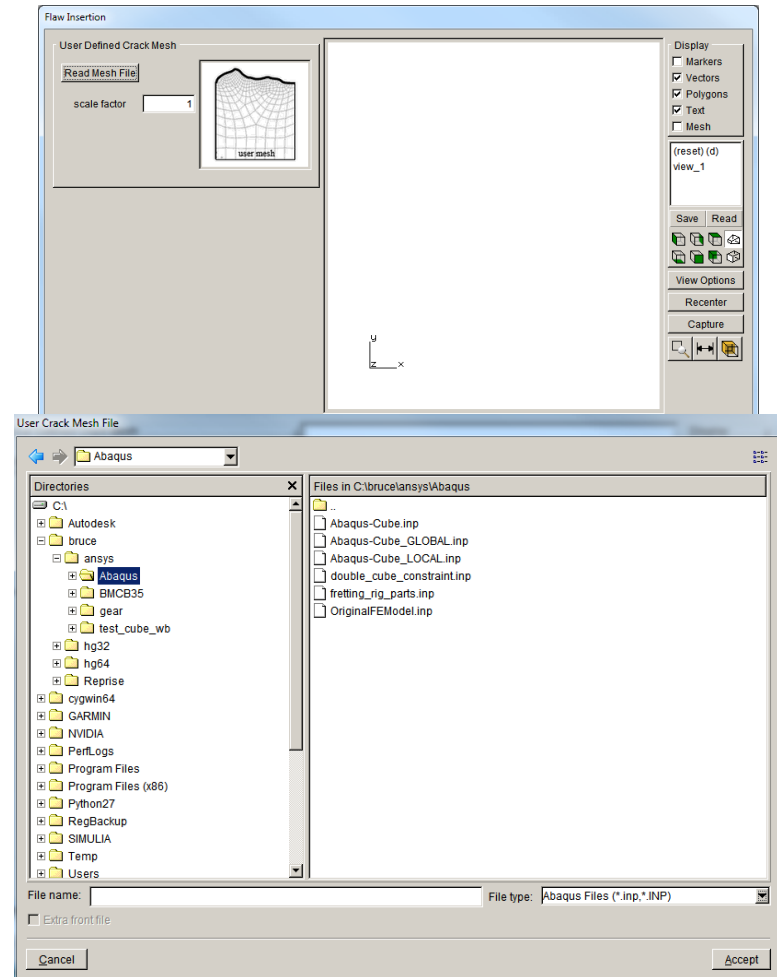
Number of Points: 66

|    | x       | y       | z        | front |  |
|----|---------|---------|----------|-------|--|
| 1  | 3.64365 | 5.00084 | 10.13223 | 0     |  |
| 2  | 3.64288 | 5.00082 | 10.05432 | 1     |  |
| 3  | 3.64518 | 5.00079 | 9.98399  | 1     |  |
| 4  | 3.65080 | 5.00077 | 9.91044  | 1     |  |
| 5  | 3.66035 | 5.00074 | 9.83414  | 1     |  |
| 6  | 3.67245 | 5.00072 | 9.76527  | 1     |  |
| 7  | 3.68871 | 5.00069 | 9.69398  | 1     |  |
| 8  | 3.70967 | 5.00066 | 9.62080  | 1     |  |
| 9  | 3.73424 | 5.00063 | 9.55056  | 1     |  |
| 10 | 3.76225 | 5.00061 | 9.48326  | 1     |  |
| 11 | 3.79358 | 5.00058 | 9.41891  | 1     |  |
| 12 | 3.83032 | 5.00055 | 9.35374  | 1     |  |
| 13 | 3.87045 | 5.00052 | 9.29189  | 1     |  |
| 14 | 3.91380 | 5.00049 | 9.23325  | 1     |  |
| 15 | 3.96020 | 5.00046 | 9.17812  | 1     |  |

Crack front vertices flagged as "1".

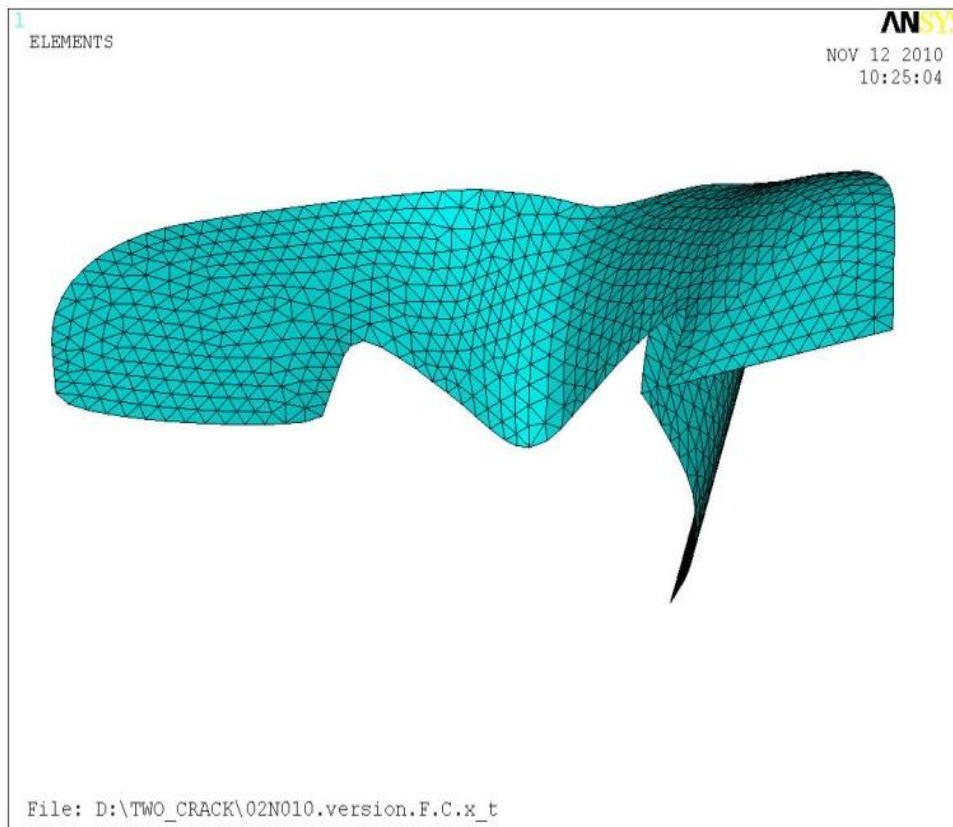
# User-mesh Crack

- User-mesh crack allows one to convert a surface mesh (planar or shell elements) or STL surface into a crack
- FRANC3D reads ANSYS, ABAQUS or NASTRAN surface meshes
- FRANC3D reads STL files
- Crack front nodes should be collected in a group (component or set).



# User-mesh Crack

---

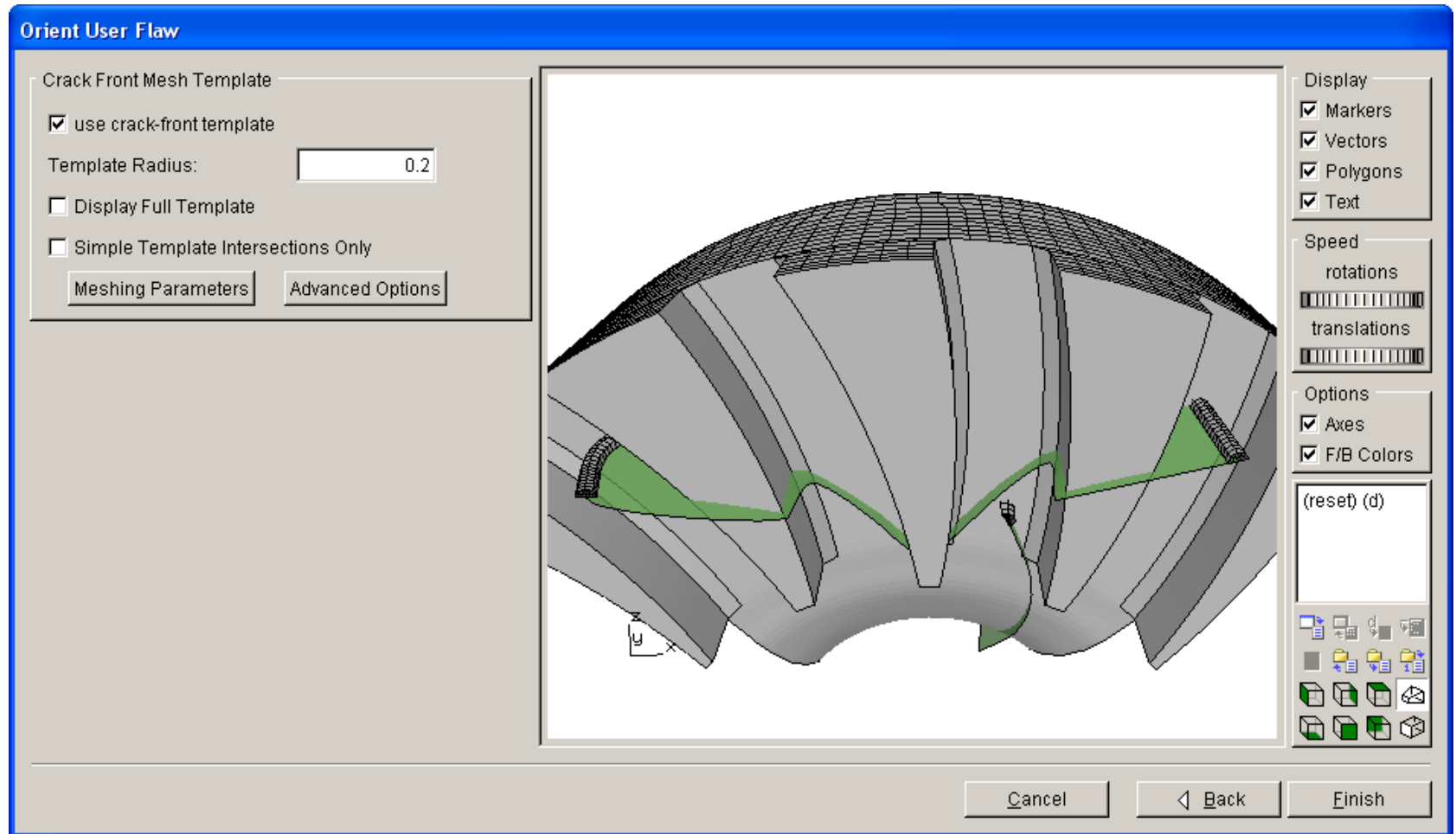


Element normal directions must be consistent.

Crack front nodes should be collected in a component.

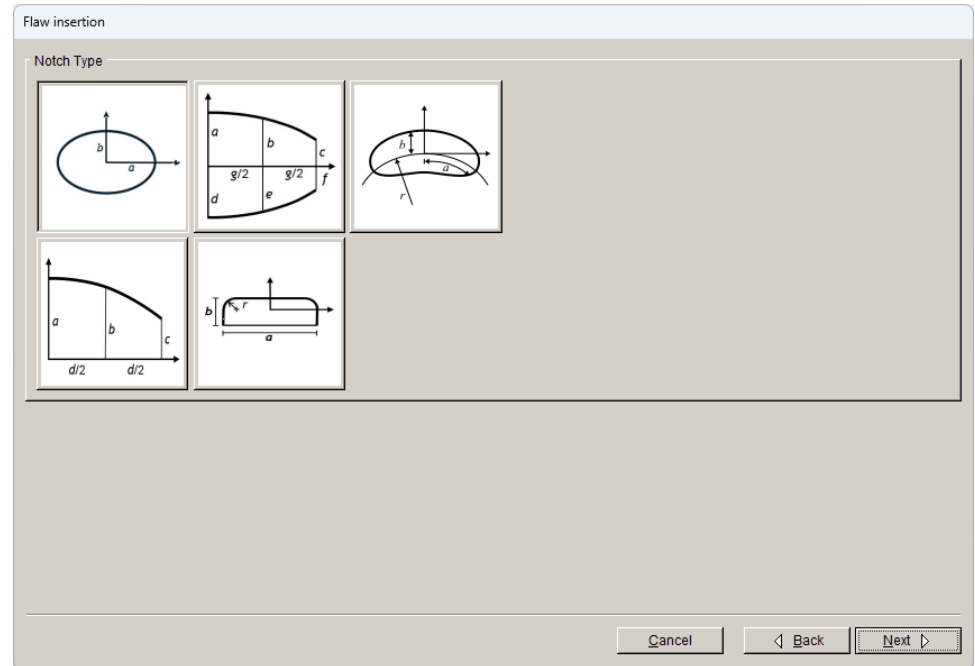
ANSYS surface mesh of two cracks

# User-mesh Crack

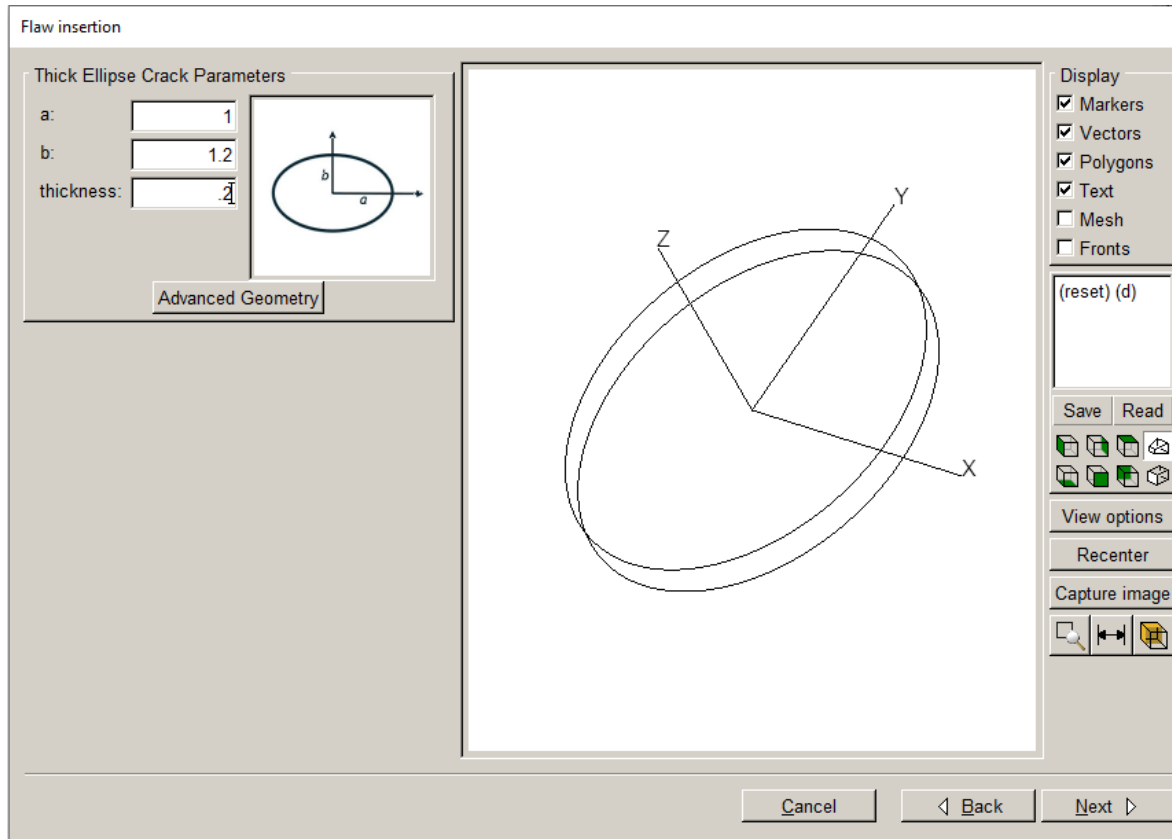


# Finite Volume Notch Insertion

- Thick ellipse – top middle
- Thick through-thickness with two fronts – top right
- Thick through-thickness with one front – bottom left
- Thick long-shallow surface – bottom middle
- Thick curvilinear ellipse – bottom right



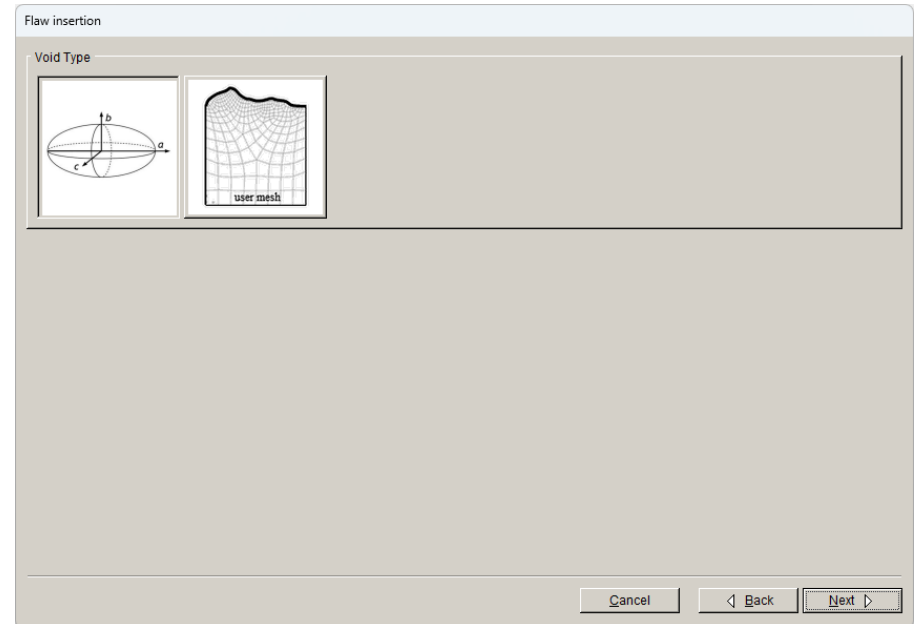
# Elliptical Notch Panel



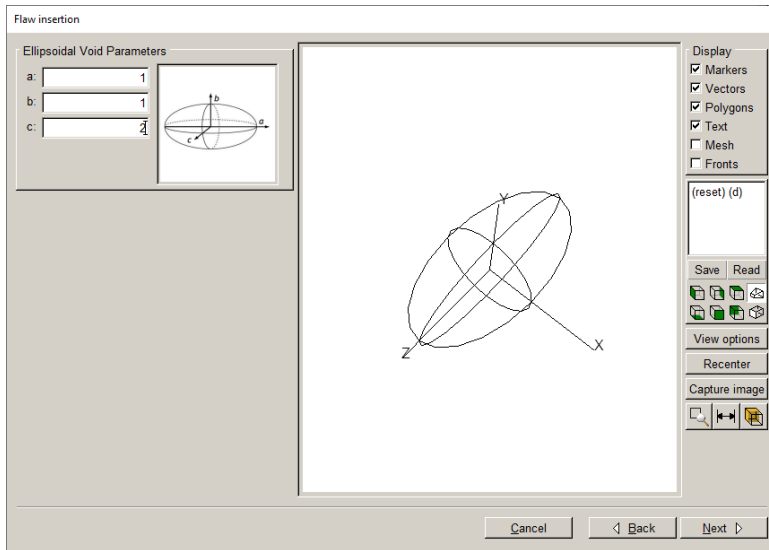
Thick (void) cracks are the same as the zero-thickness cracks, except for the extra thickness dimension.

# Finite Volume Void Insertion

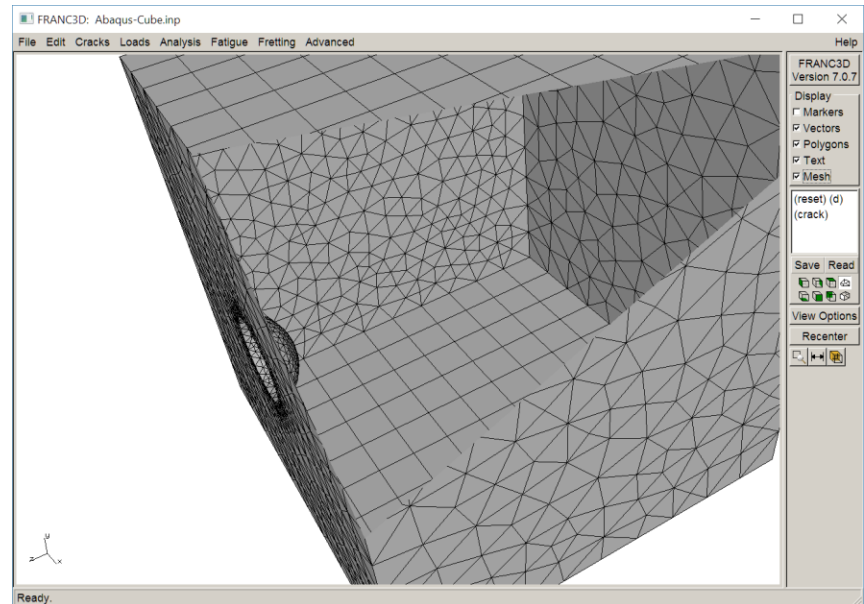
- Ellipsoid
- User-mesh void – top far right



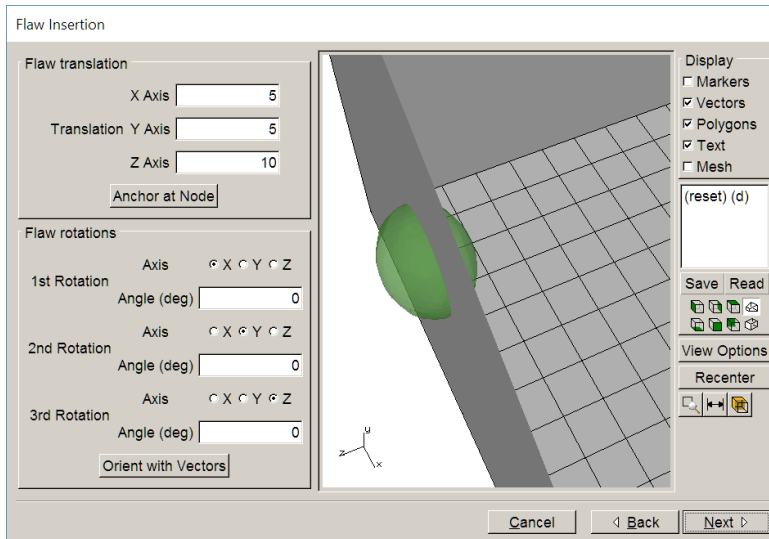
# Ellipsoid Panel



Ellipsoid void can be  
internal or intersect a surface

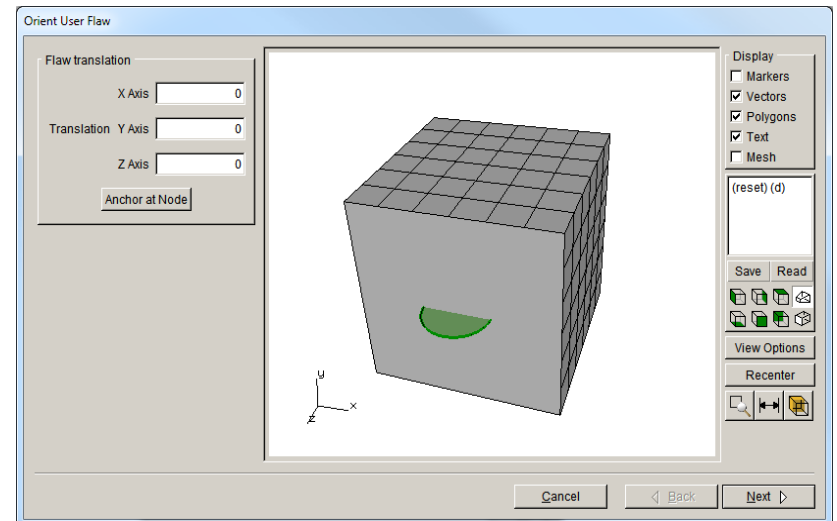
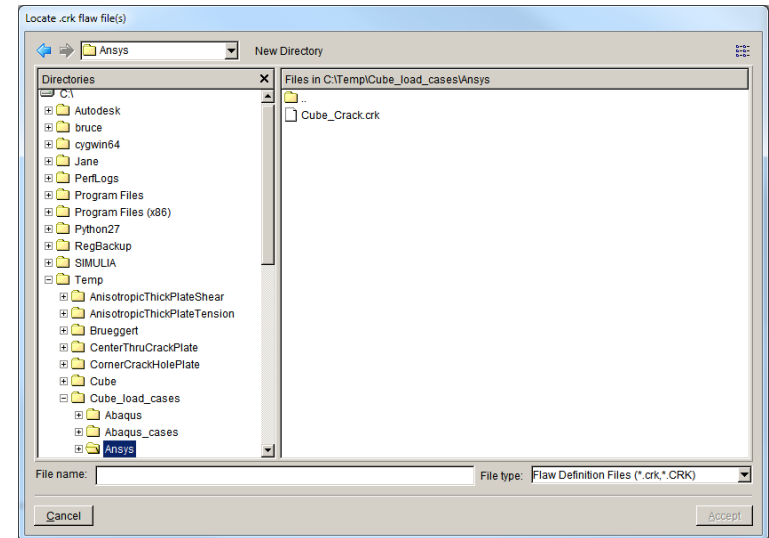


No void growth!



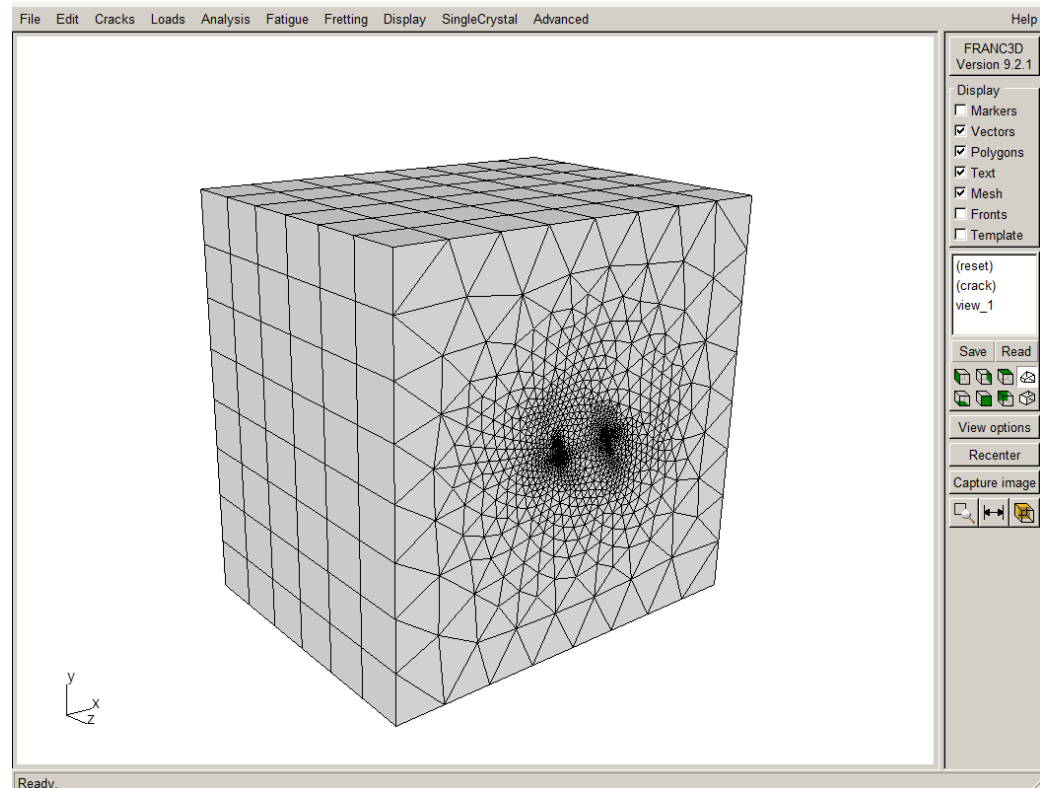
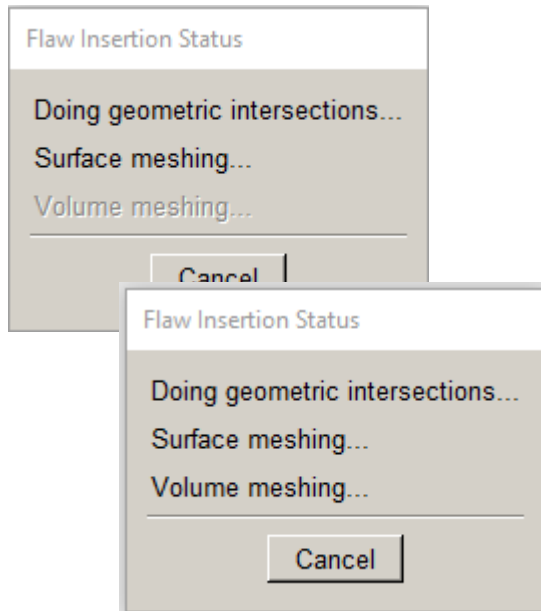
# Flaw From Files

- Flaw can be saved to a .crk file after being defined
- **Flaw from Files** menu option allows the user to read one or more .crk files and insert these crack(s) into the model
- **Locate .crk flaw file** dialog
  - Allows the user to select one or multiple .crk files; the Shift-key is used to select multiple files
  - After pressing **Accept**, the flaw is displayed in the model
  - The flaw can be translated, **but rotation is not allowed**

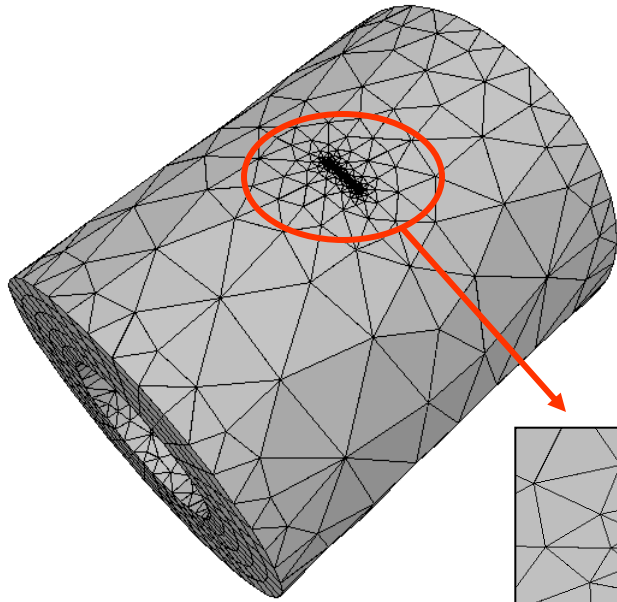


# Insertion and Remeshing

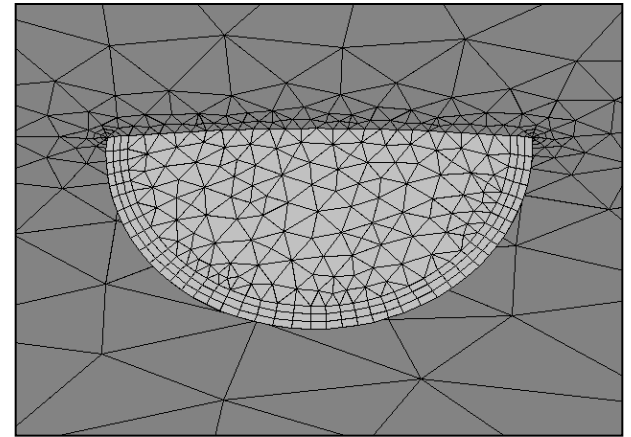
Insertion and remeshing happens automatically after selecting **Next** or **Finish** in the crack insertion wizards.



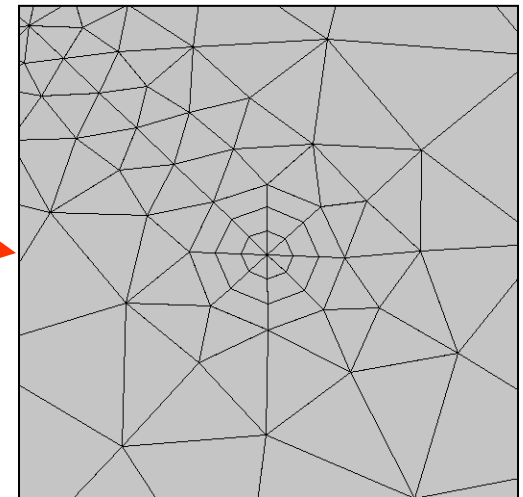
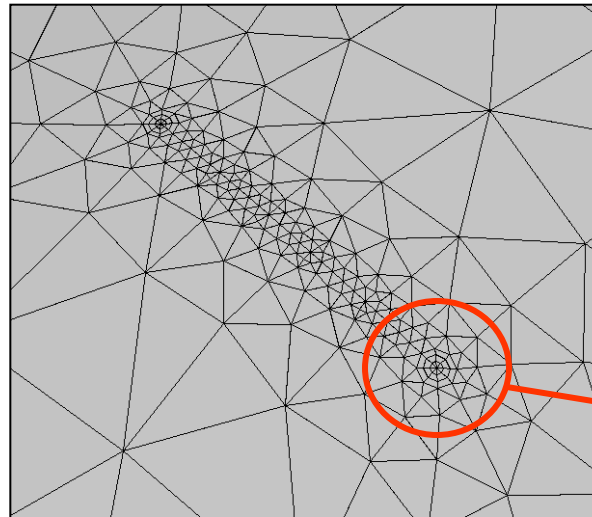
# Surface Mesh after Crack Insertion



Model surface mesh

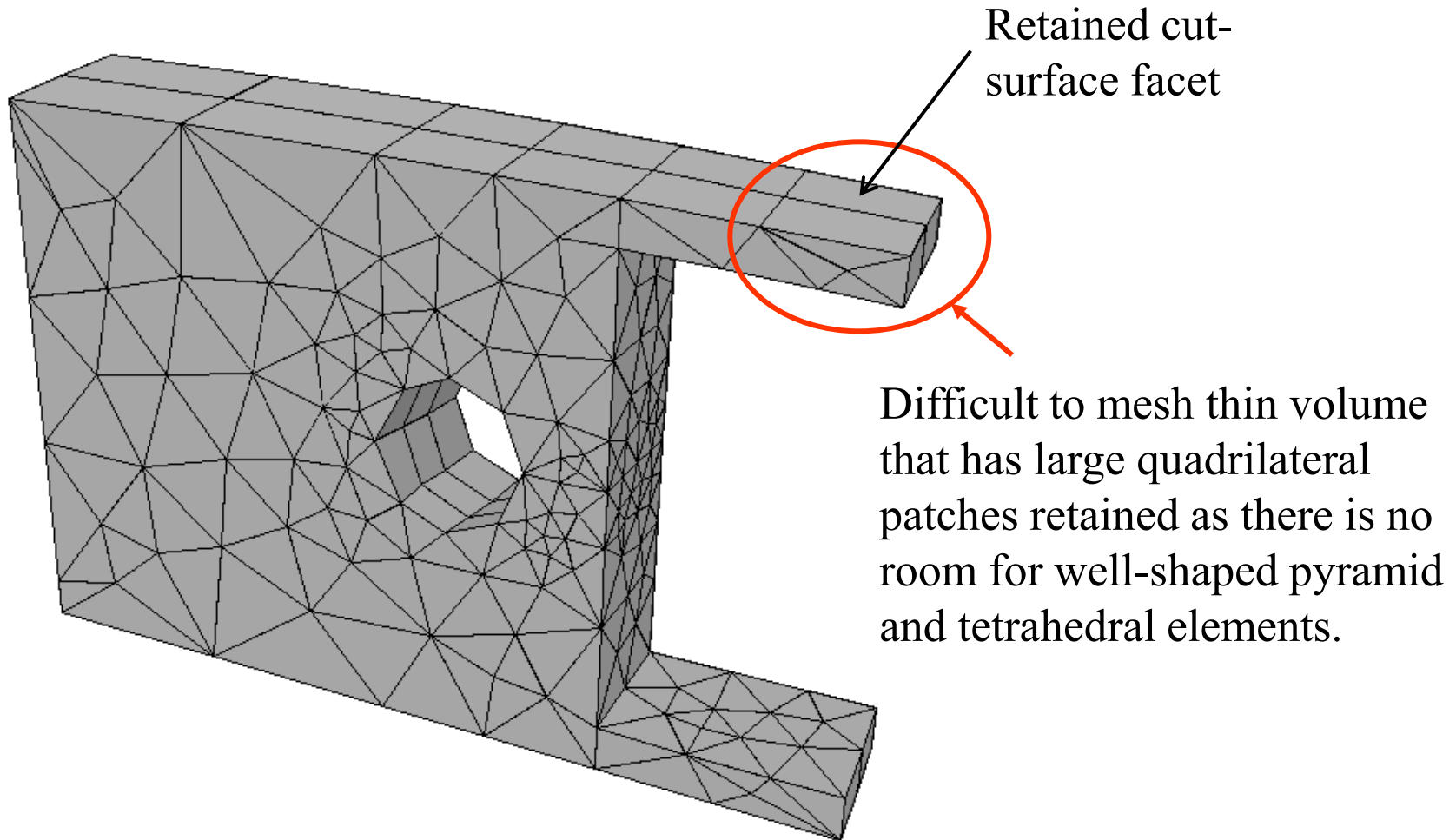


Crack surface mesh



# Crack Insertion – sub-model limitation

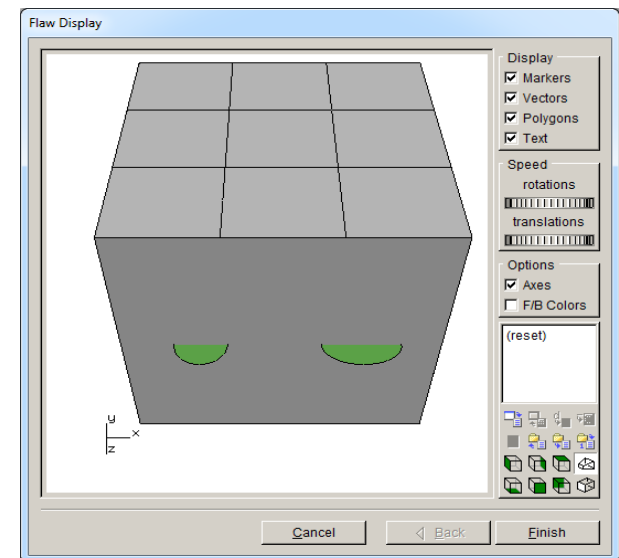
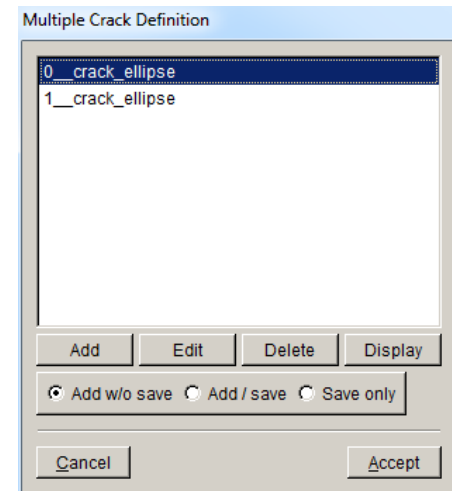
---



Meshing is constrained by the underlying geometry/topology.

# Multiple Flaw Insertion

- **Multiple Flaw Insertion** wizard allows one to add multiple cracks to a model
- Each crack can be defined using the **Flaw Insertion** wizard
- When all cracks have been defined, they can be added to the model and/or saved to a file
- By selecting the **Add** button this will lead to the flaw insertion wizard panels
- Once a crack has been added to the list, it can be edited or deleted
- Select **Accept** to close the dialog and begin the process of crack insertion and re-meshing

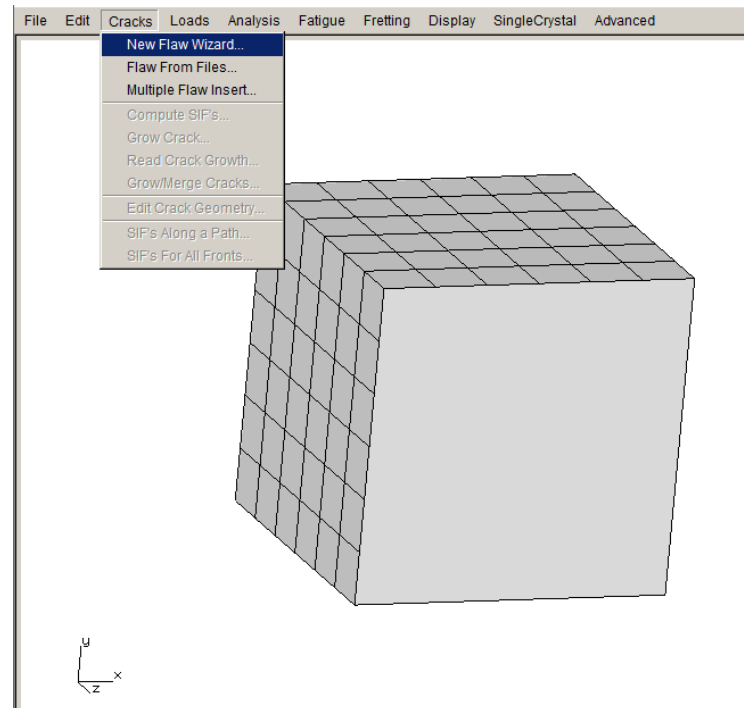
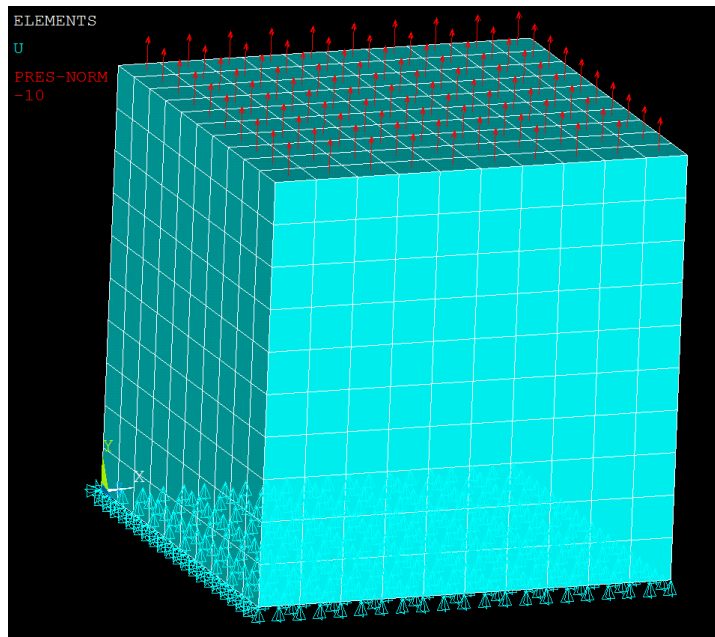


# Demo & Hands On (Homework):

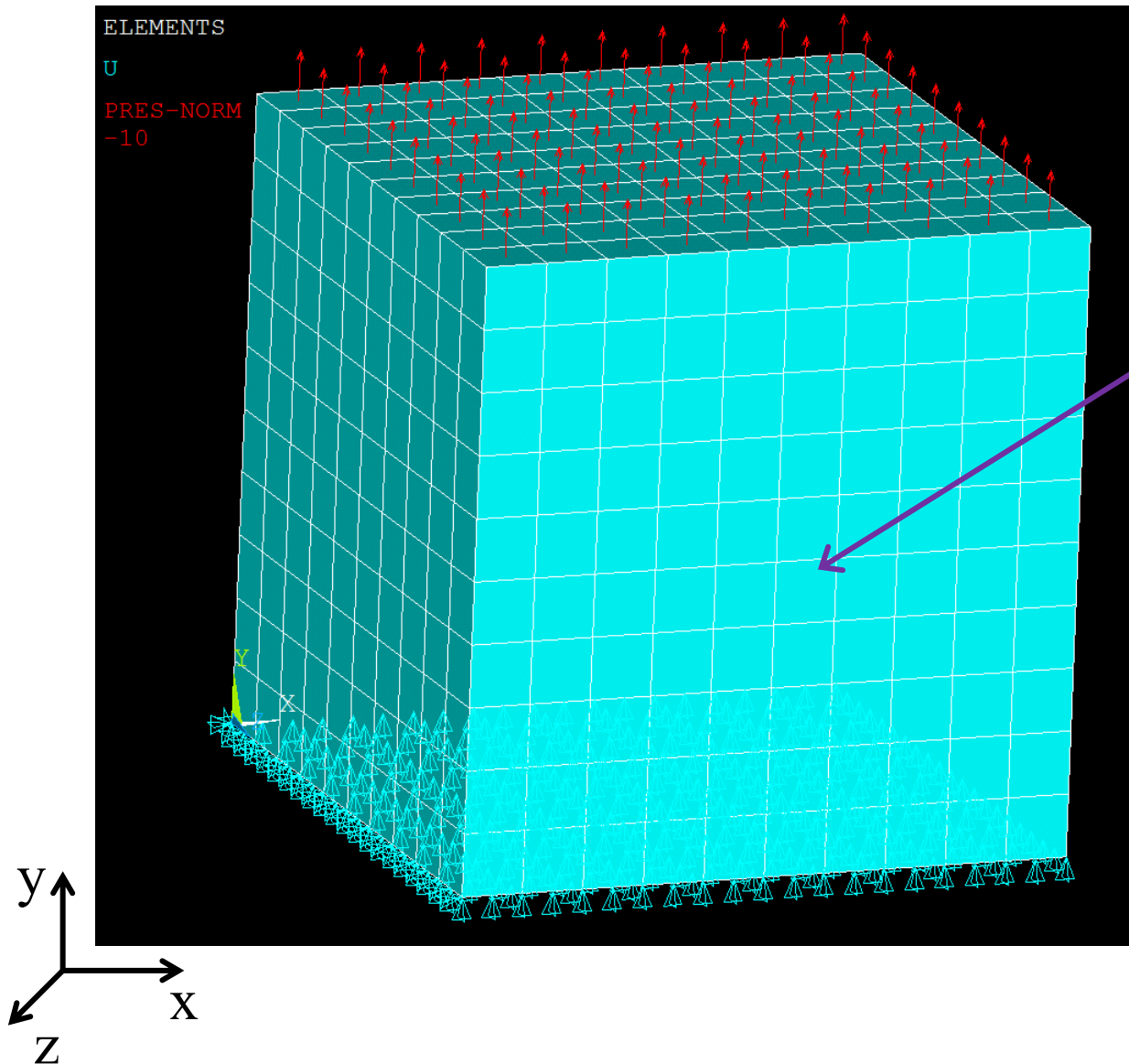
## Crack Insertion – in a cube

### Tutorial #1:

### Crack Insertion and Growth in a Cube

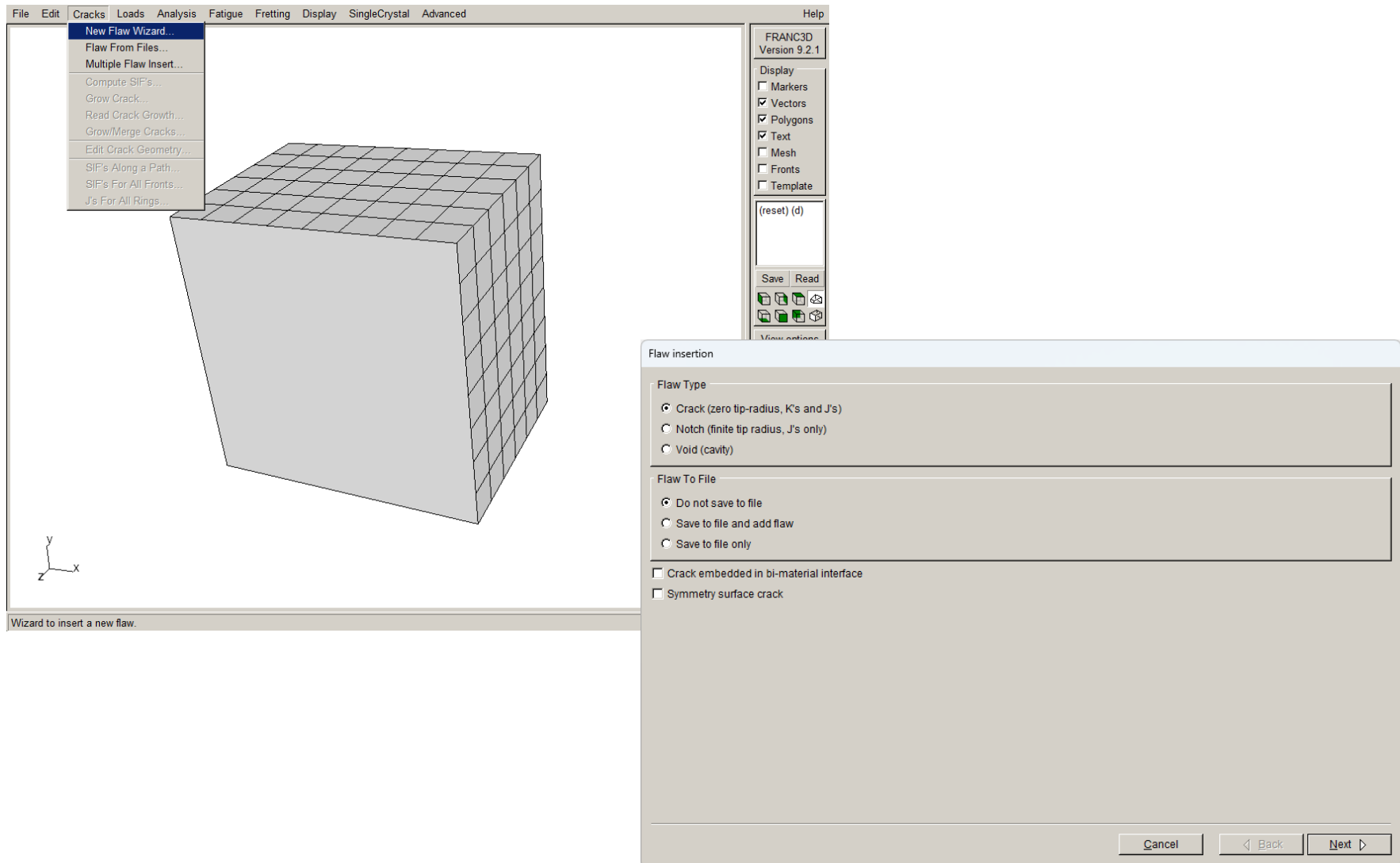


# Crack Insertion in a Cube

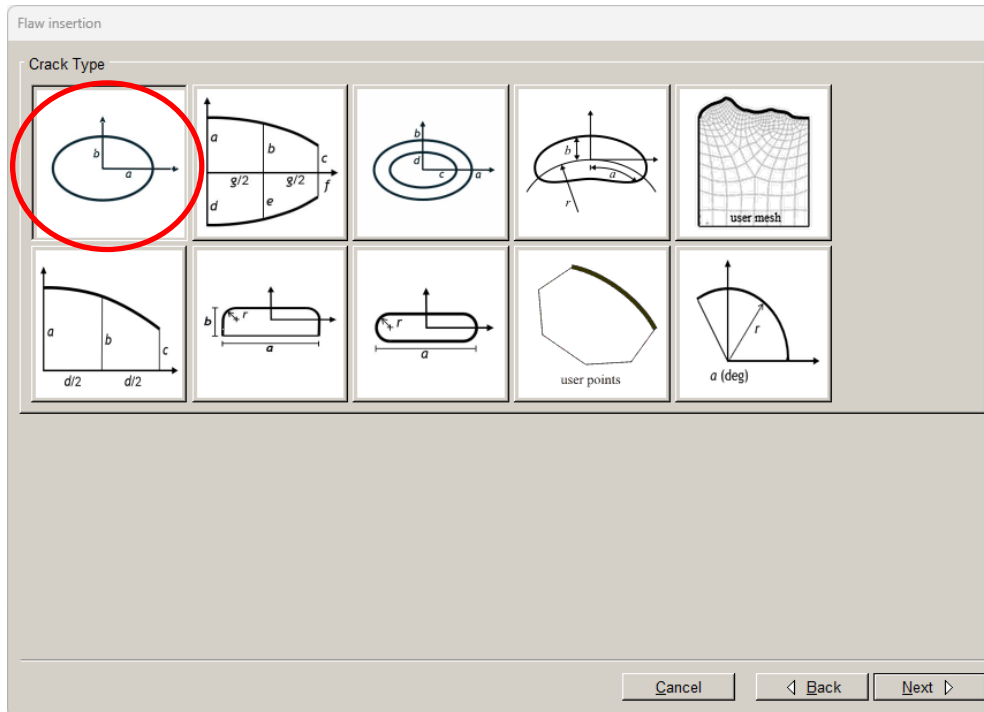


Unit penny-shaped crack oriented normal to tensile (y-direction) load and inserted into the +z face to make a half-penny surface crack.

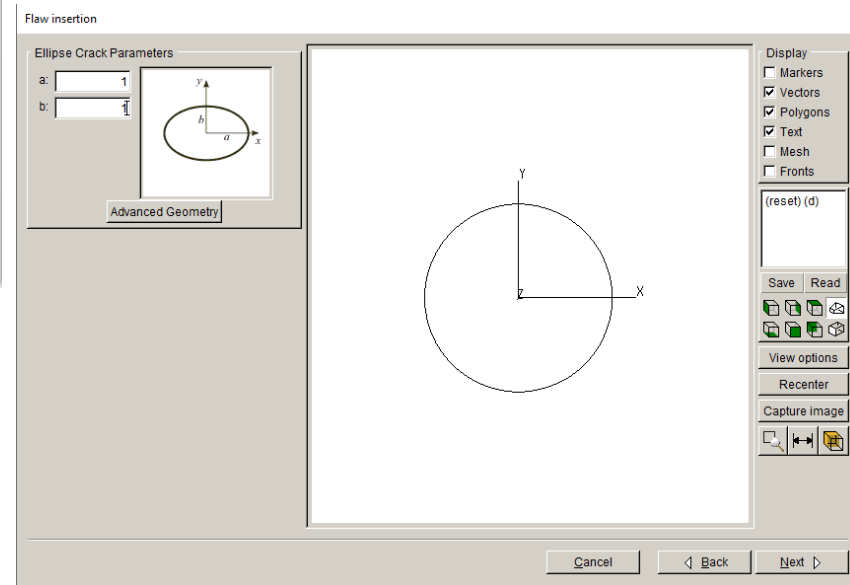
# FRANC3D Tutorial 1 – Crack Insertion



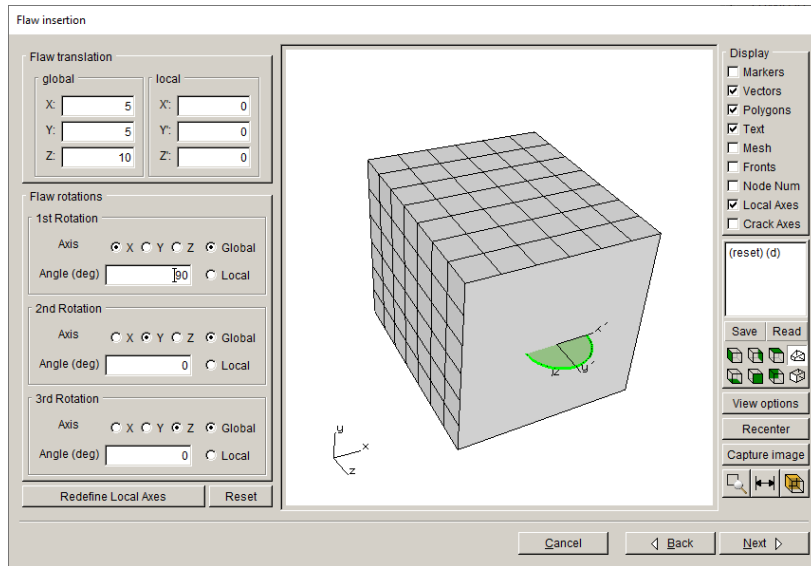
# FRANC3D Tutorial 1 – Crack Insertion



Unit penny-shape crack

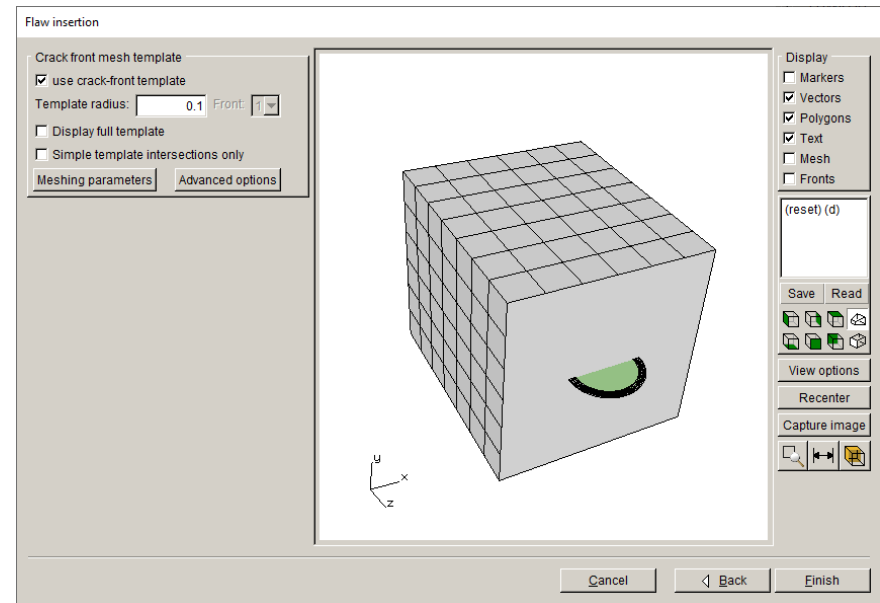


# FRANC3D Tutorial 1 – Crack Insertion

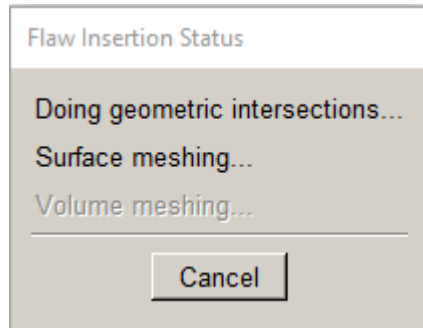


Located in the middle of the +z cube face, and normal to the y-axis.

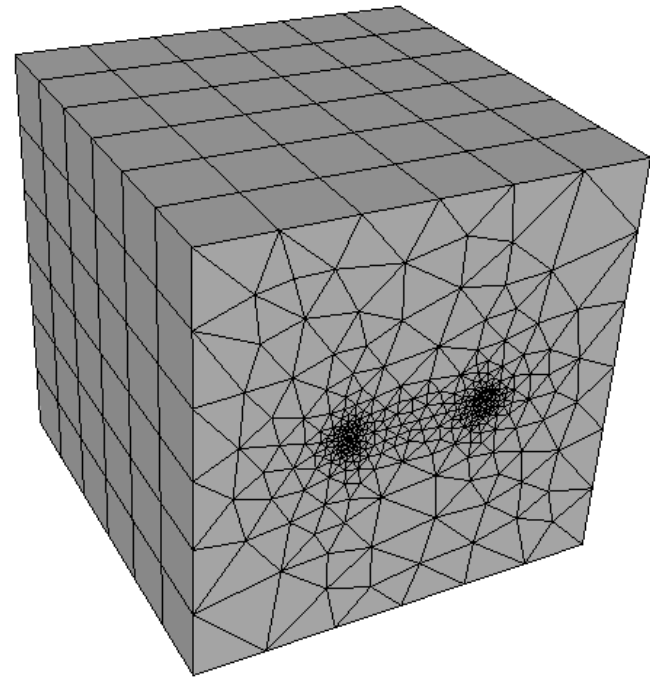
Template radius might need to be adjusted depending on the crack and the model geometry.



# FRANC3D Tutorial 1 – Crack Insertion



Crack insertion involves geometry intersections and remeshing of surfaces and volume(s).



# End Part 6