FRANC3D Training Workshop: Part 6

Crack Insertion

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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
- Finite Volume 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
- Define flaw geometry
- Select the geometric flaw type
  - Crack (zero 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

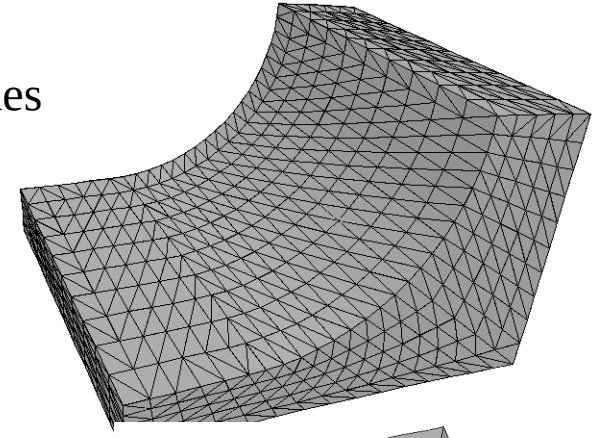
- Model surface geometry is approximated from the faceted-surface mesh
- Converting 3D volume elements to FRANC3D geometry follows these steps:

  1) Read 3D FE volume mesh of sub-model

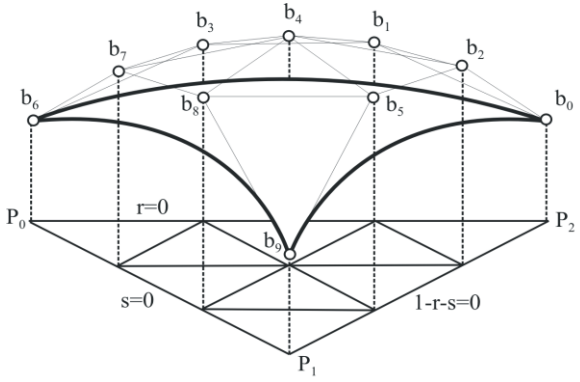
  2) Compute weighted average normals at all surface FE nodes

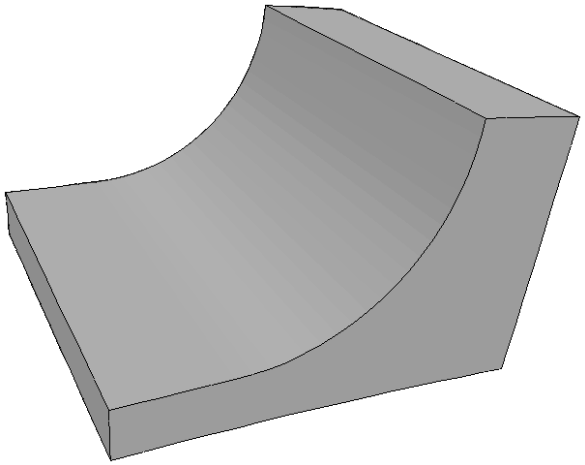
  3) Define 1 or 2 triangular Bezier patches for each FE facet (planar and curved surfaces can be represented)

  4) Identify “topological” edges and group together patches that form logical faces

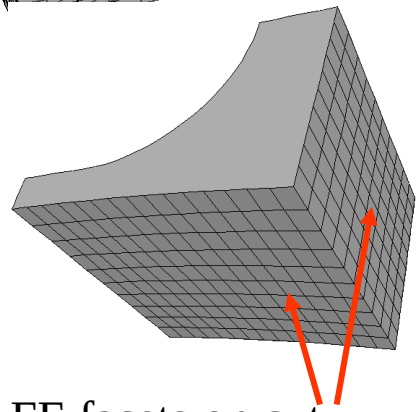


Bezier triangle geometry with 10 control points





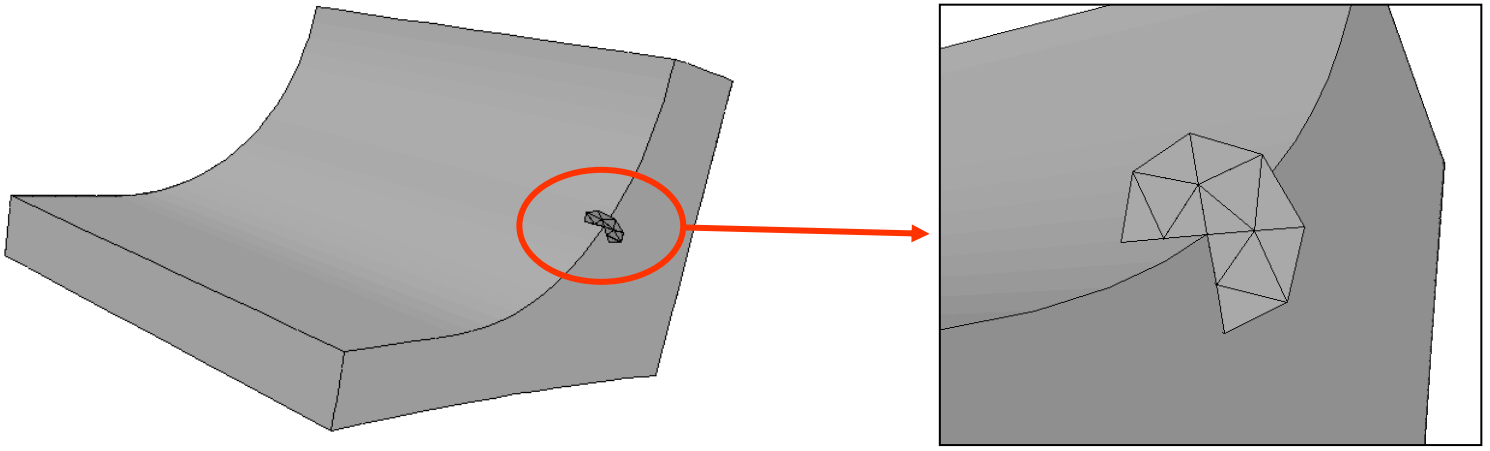
Topological edges & logical faces are defined based on the angle between the patches



FE facets on cut surfaces retained for compatibility

Crack Insertion – define flaw geometry

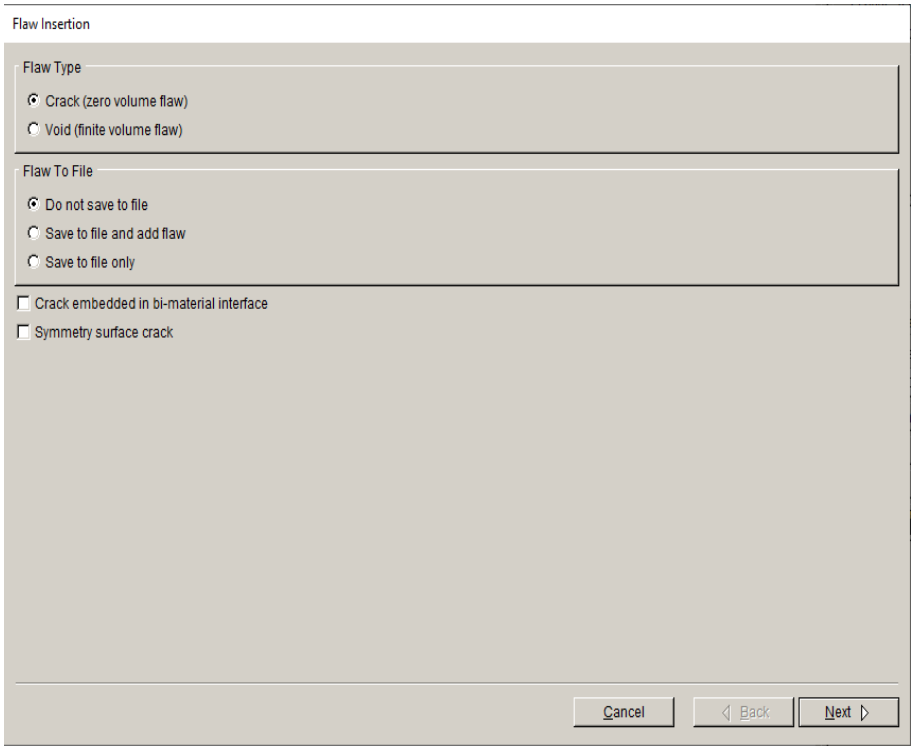
Crack shape, size, location and orientation relative to the uncracked model:



- 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

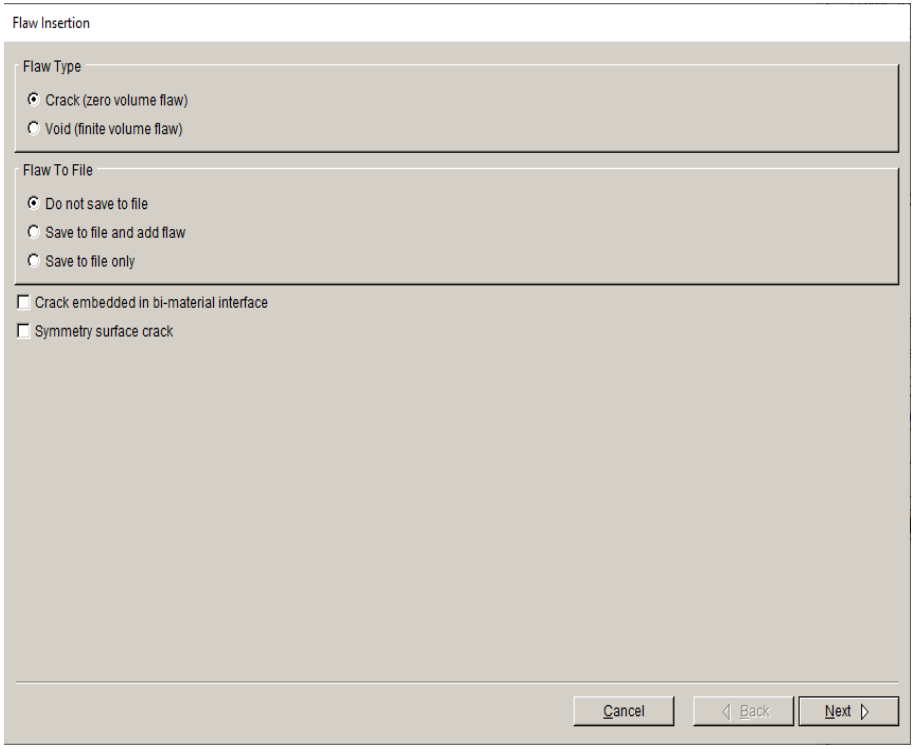
Flaw Type Panel

- 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



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 for crack embedded in bi-material interface
  - If the user is inserting a symmetry surface crack, turn on the option for symmetry surface crack



Crack (flaw) Geometry File (.crk)

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

```
FLAWSURF
(
VERSION: 5
NUM_SURFS: 128
SURF: 0
    3 35 37
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                    12                -1.1      10.9166666666667
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                    12                -1.1      10.8333333333333
                    12     -1.00833333333333      10.8333333333333
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SURF: 1
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SURF: 2
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                    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
```
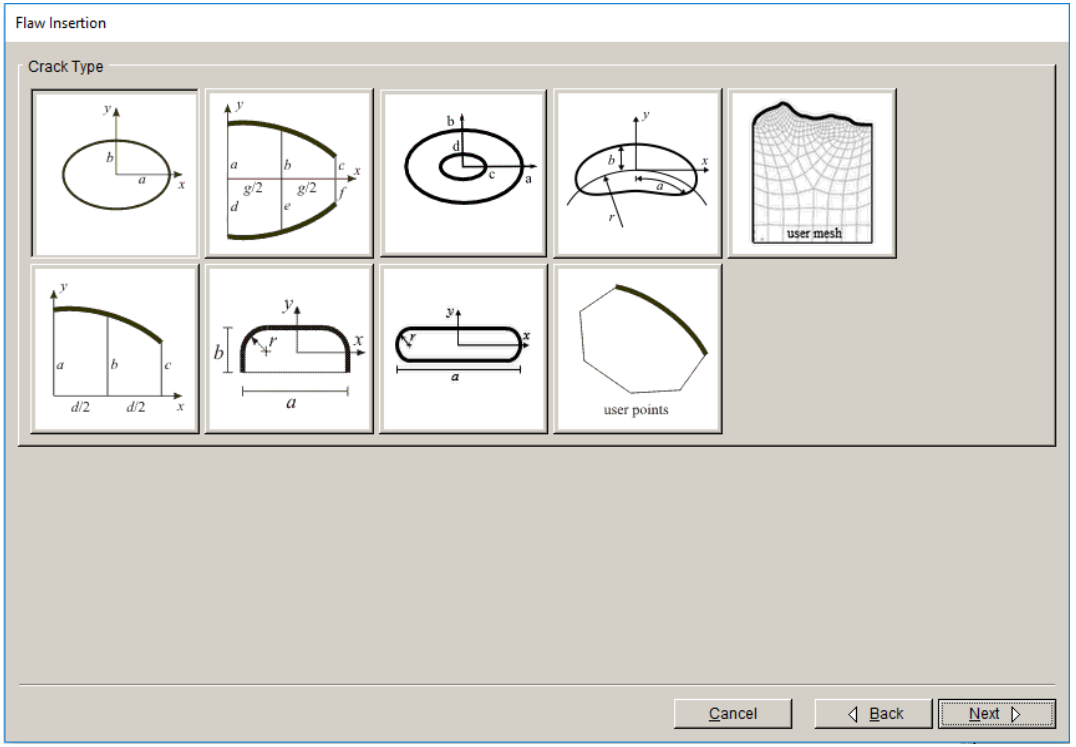
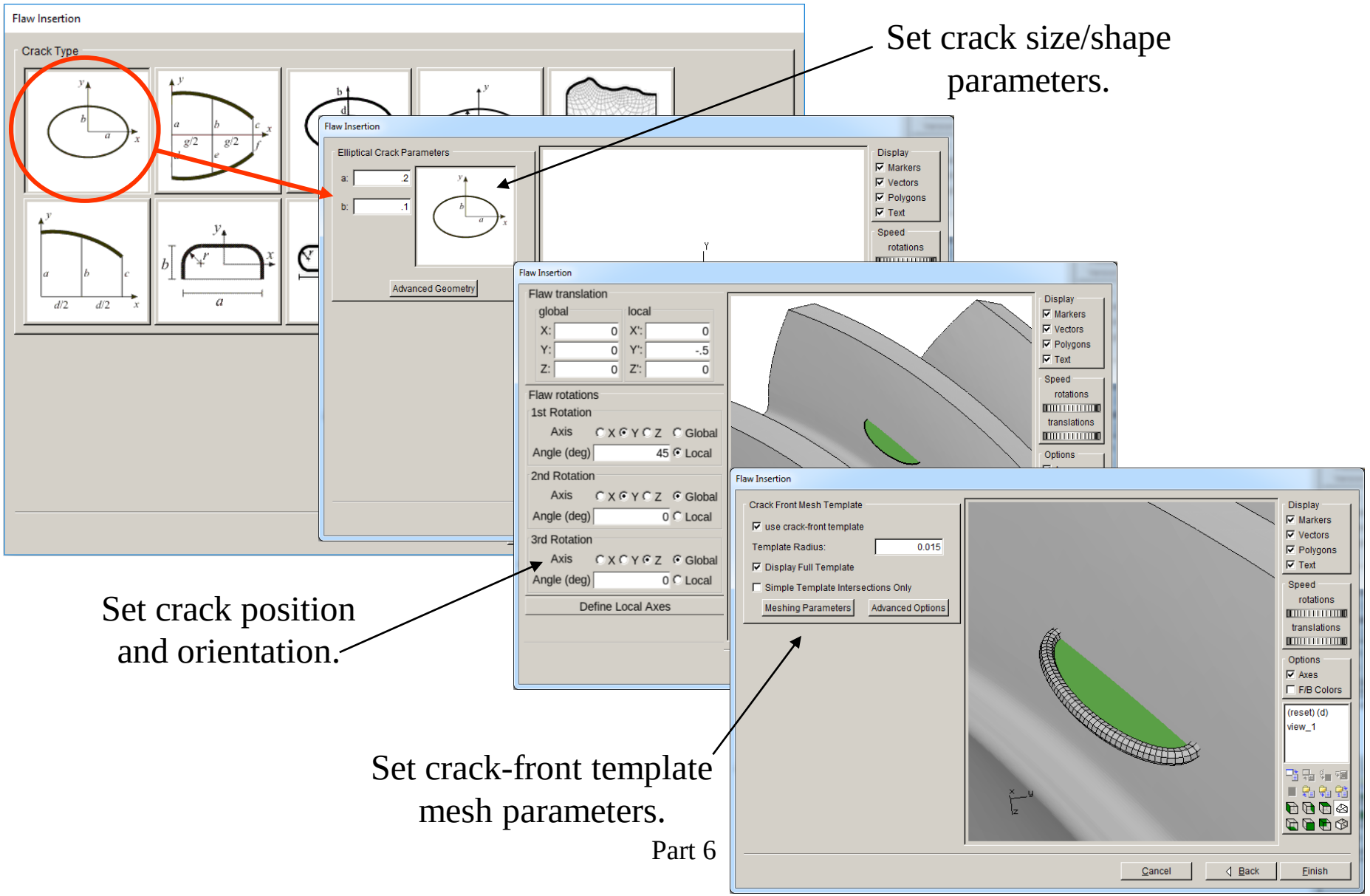

Zero Volume Crack Types

- 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

Crack Insertion Wizard (Elliptical Flaw)



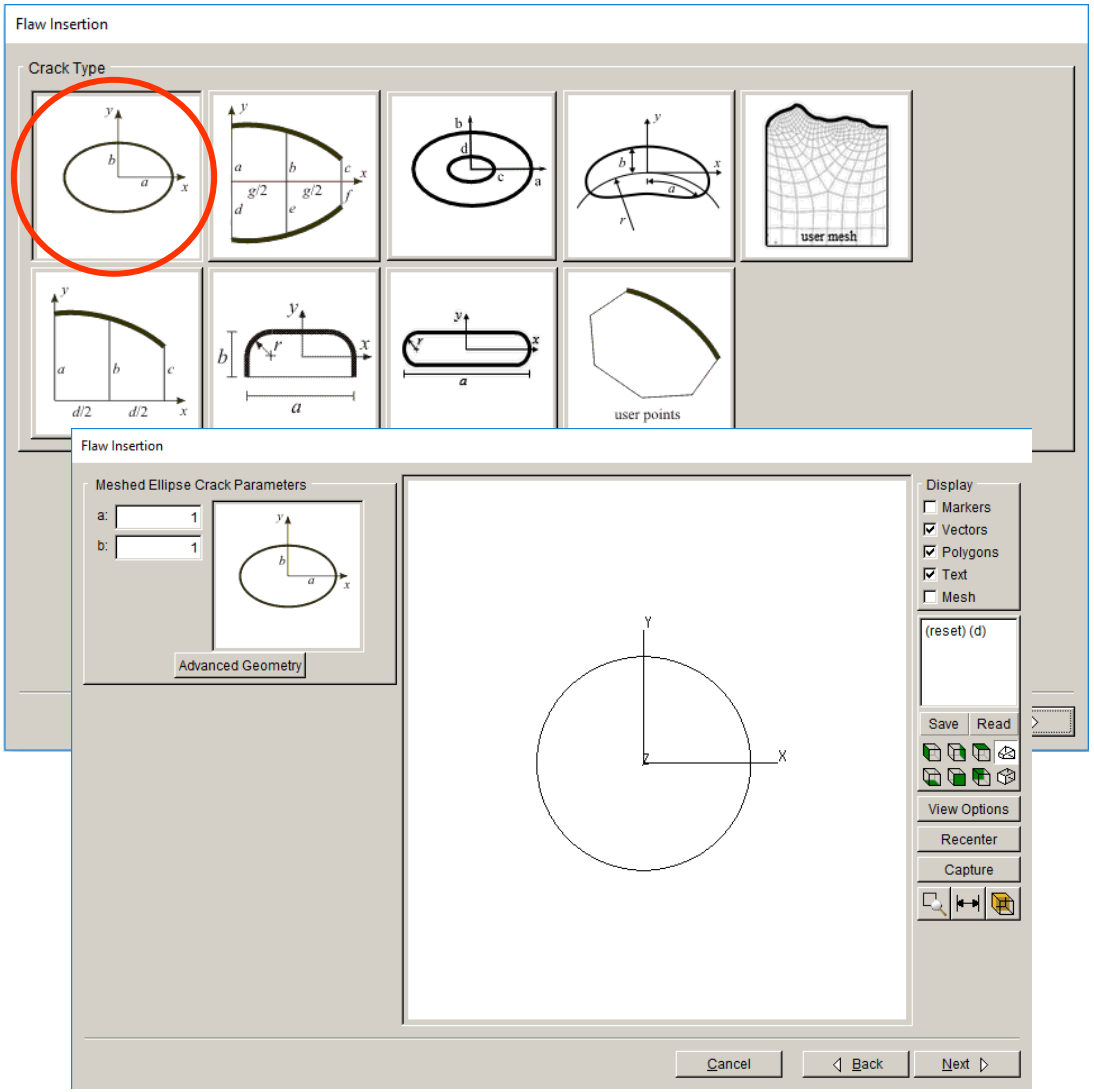
Set crack size/shape parameters.

Set crack position and orientation.

Set crack-front template mesh parameters.

Part 6

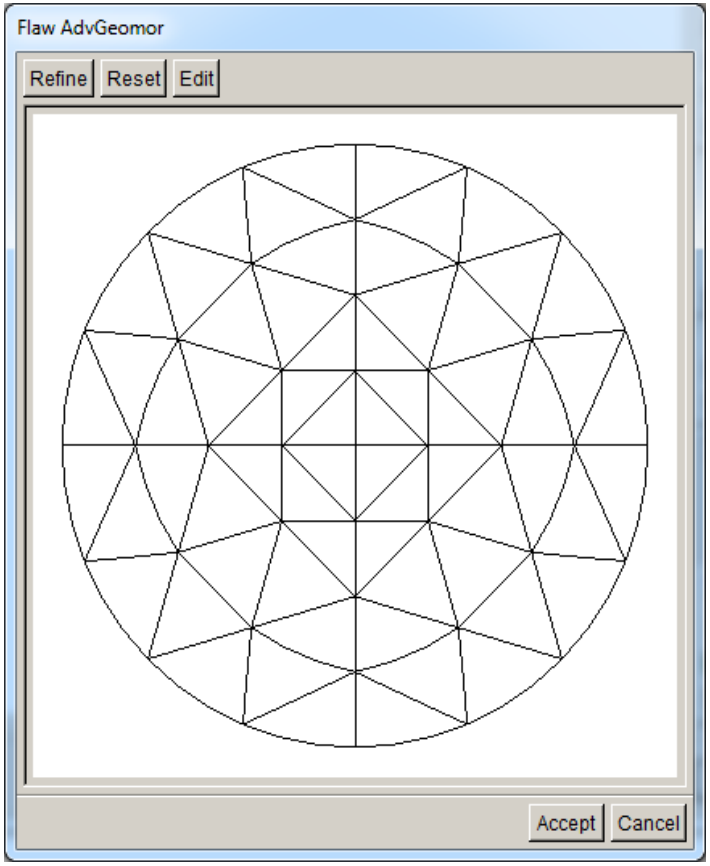
Crack Insertion Wizard - Elliptical Flaw



- 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)

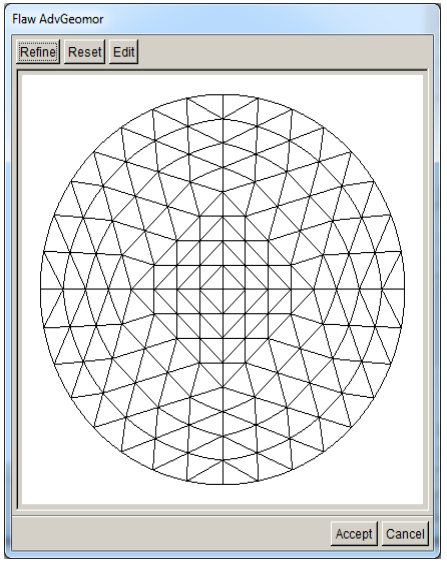
- **Advanced Geometry** button
  - Selecting the **Advanced Geometry** button on any of the predefined crack shapes leads to the Advanced Geometry dialog
  - Triangular cubic-Bezier patches represent the crack geometry, not a finite element surface mesh
  - There are three buttons on the top menu bar: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

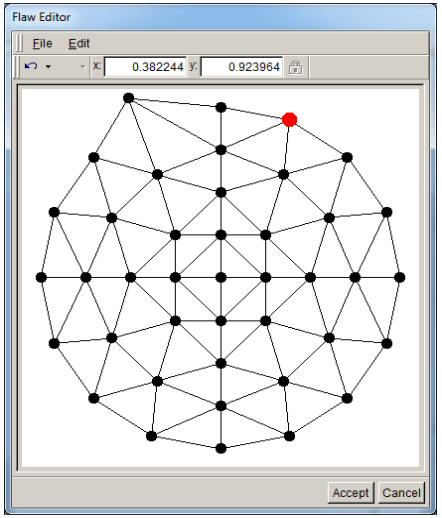


Crack Insertion Wizard (Elliptical Flaw)

- **Advanced Geometry** button
  - **Refine:** performs a uniform refinement of the patches, where each patch is divided into four smaller patches
  - **Reset:** sets the crack geometry back to the original default configuration
  - **Edit:** invokes the Flaw Editor which allows the user to modify the default shape of the flaw

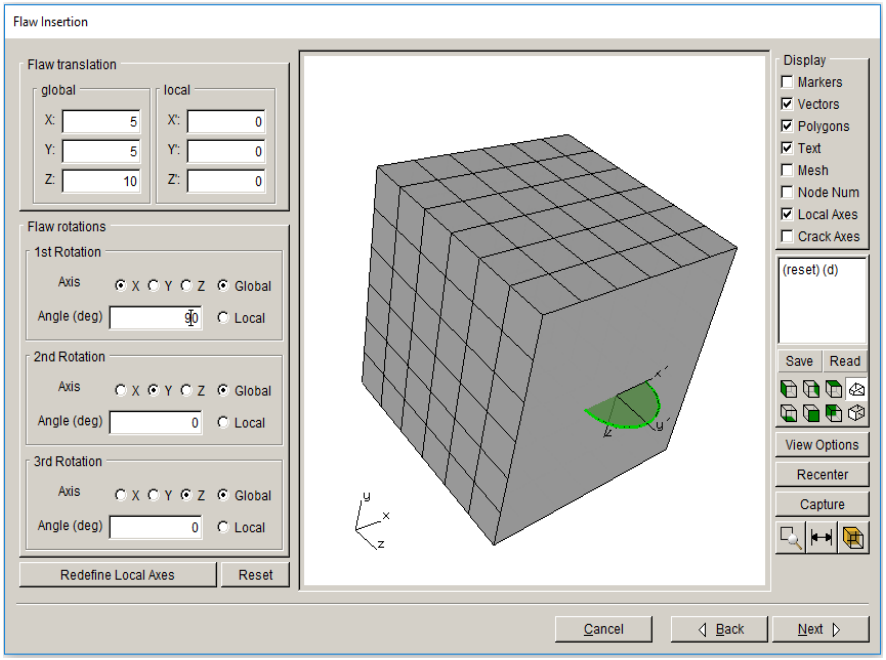
Note that the Advanced Geometry dialog is rarely needed.





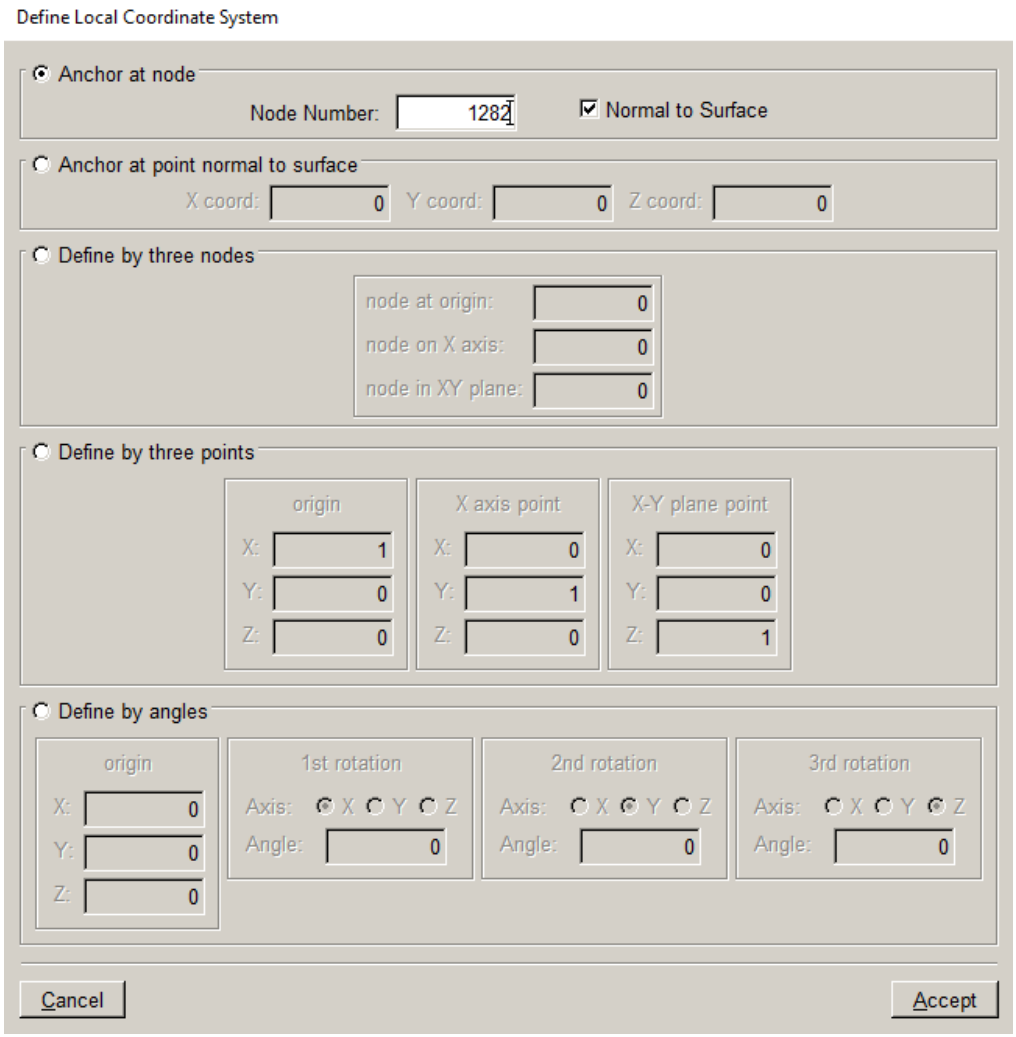
Crack Insertion Wizard (Elliptical Flaw)

- 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



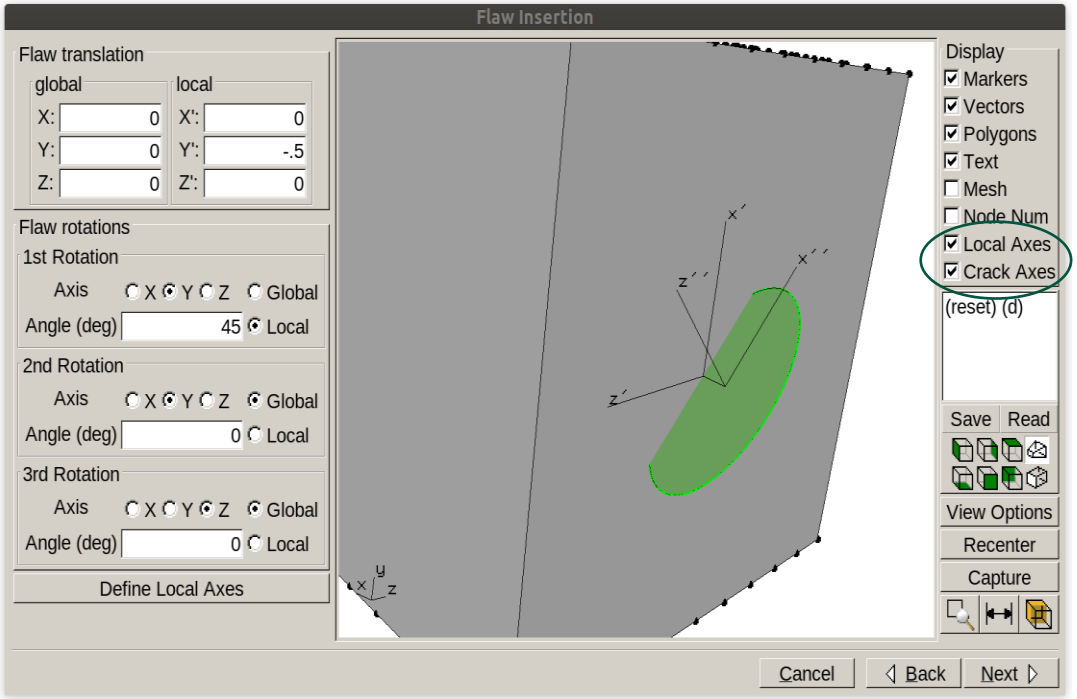
Crack Insertion Wizard (Elliptical Flaw)

- 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



Crack Insertion Wizard (Elliptical Flaw)

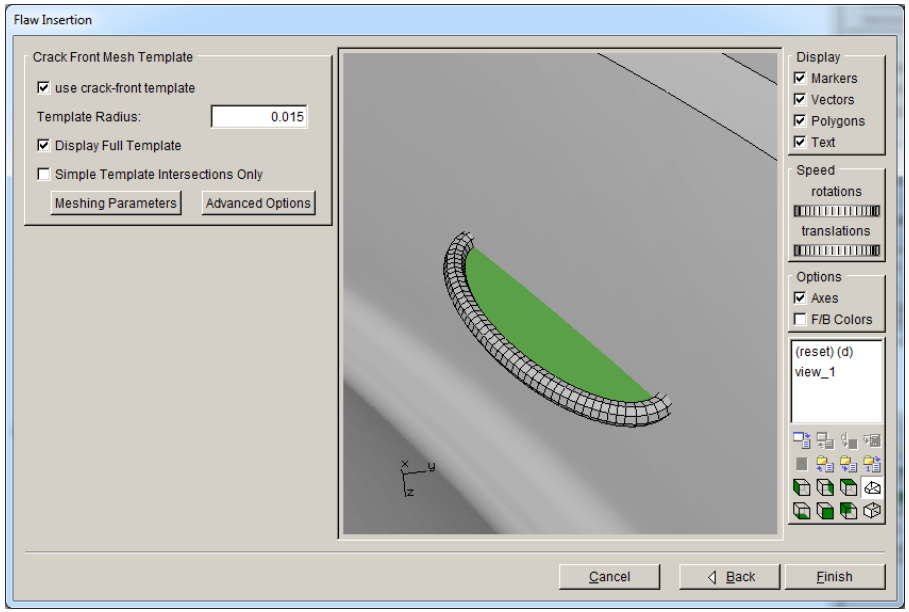
- There are three coordinate systems when orienting a flaw:
  - Global Cartesian system
  - Local user defined coordinate system (single prime)
  - Crack coordinate system (double prime)
- The Display panel on the right side has two additional options to display the local axes and the crack axes

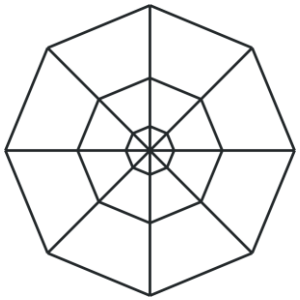


Crack Insertion Wizard (Elliptical Flaw)

Crack Front Mesh Template Panel

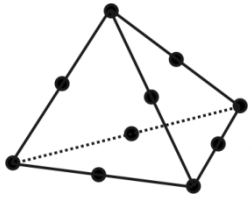
- For accurate SIF computations, a "template" of elements with controlled sizes and shapes is placed about all crack fronts.
- A template has the form of generalized cylindrical tubes of elements, with crack fronts serving as the axes of the cylinders.
- Wedge shaped elements are placed immediately adjacent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





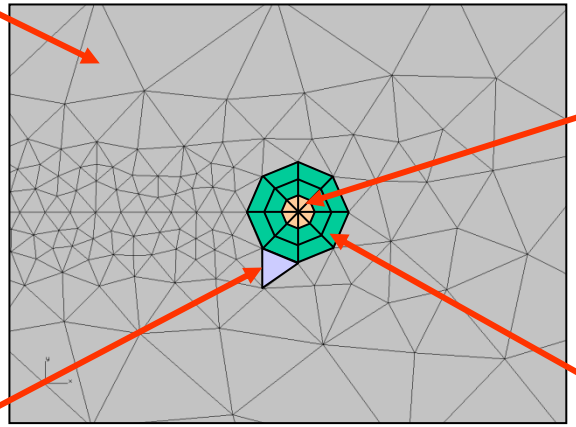
Typical template cross-section

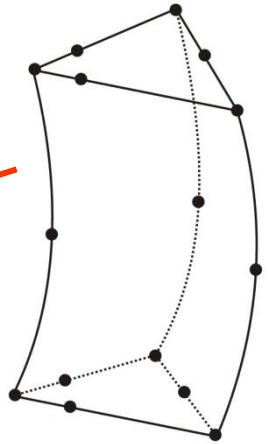
Crack-Front Element Types

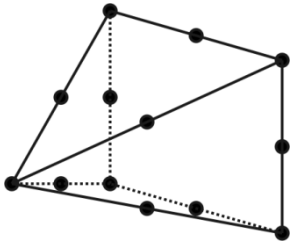


tetrahedral elements used for most of volume mesh

quarter-point singular wedge crack-front elements

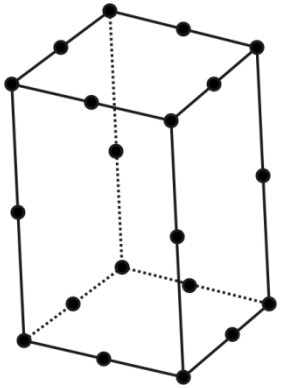






pyramids provide compatibility between bricks and tetrahedra

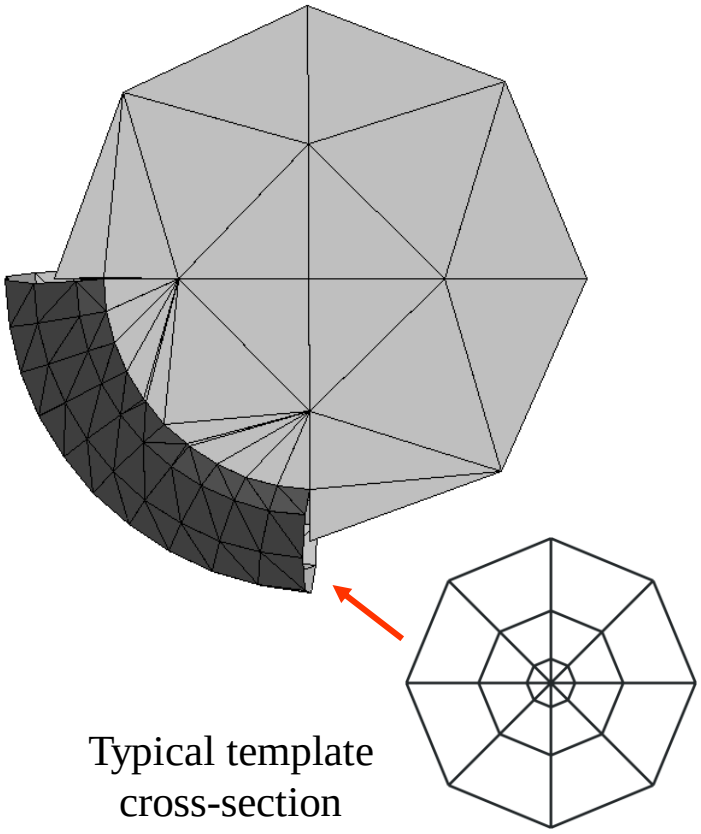
two or more “rings” of brick elements



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

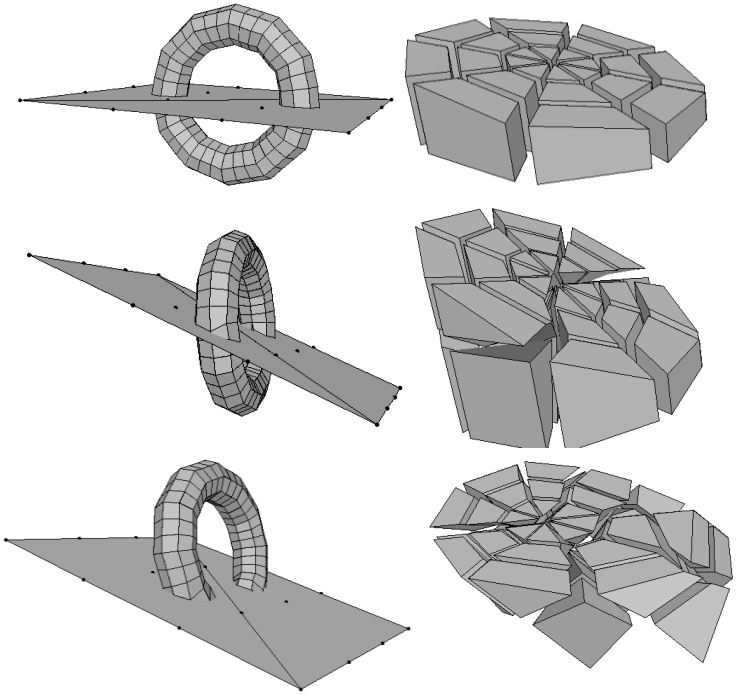
Crack Insertion – crack-front template mesh

- templates are used to place well-shaped elements at/near crack fronts
- templates are a combination of brick and quarter-point wedge elements



Typical template cross-section

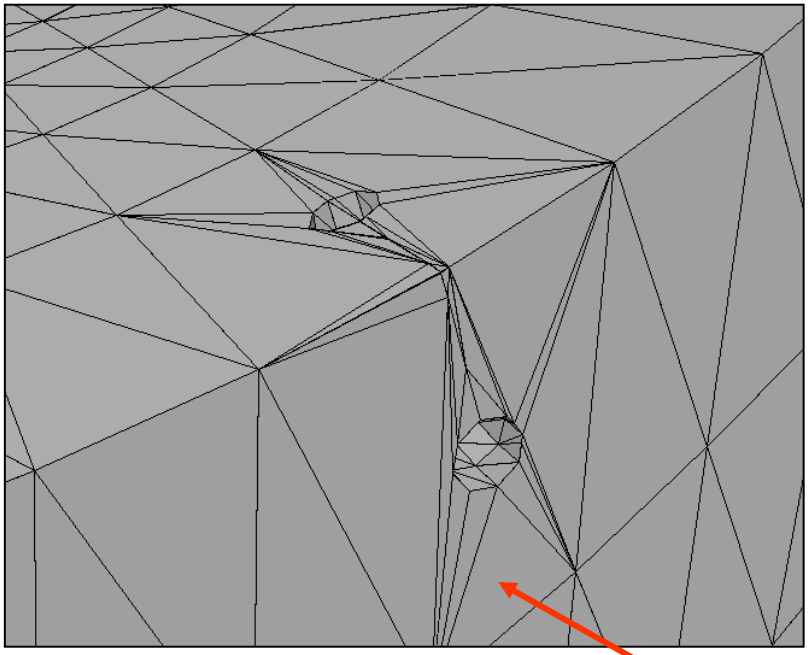
- where templates intersect model surfaces, element topology and geometry might be modified to conform to the surface geometry



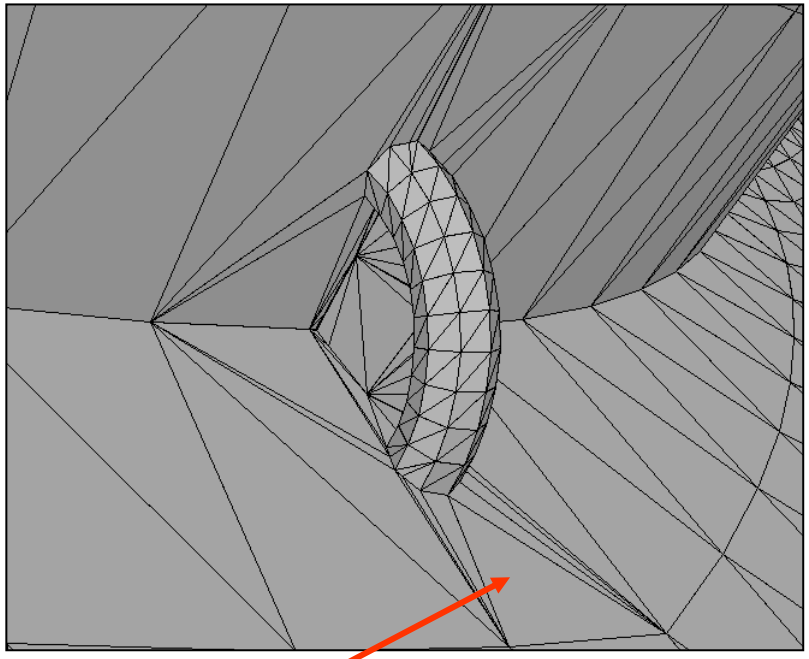
Crack Insertion – intersection and trimming

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

Outside View



Inside View

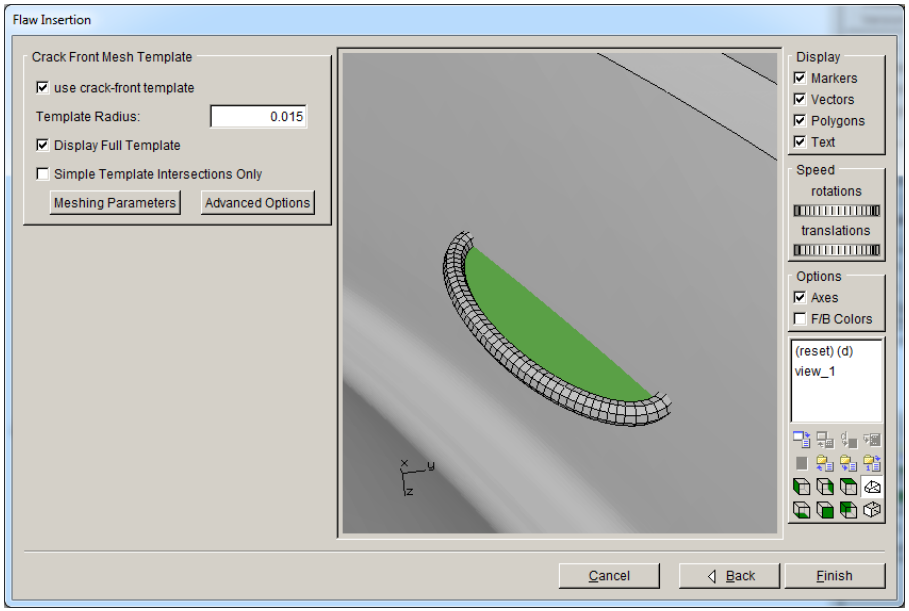


Trimmed patches are divided into triangular sub-patches to keep the model “water-tight”.

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

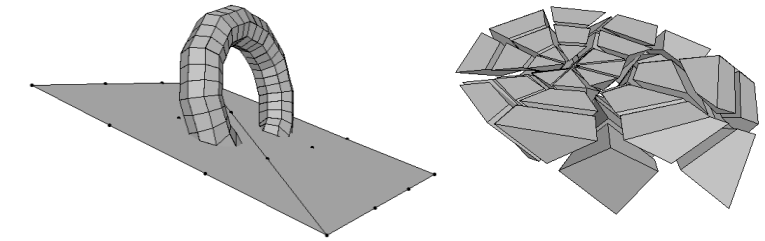
Crack Front Mesh Template Panel

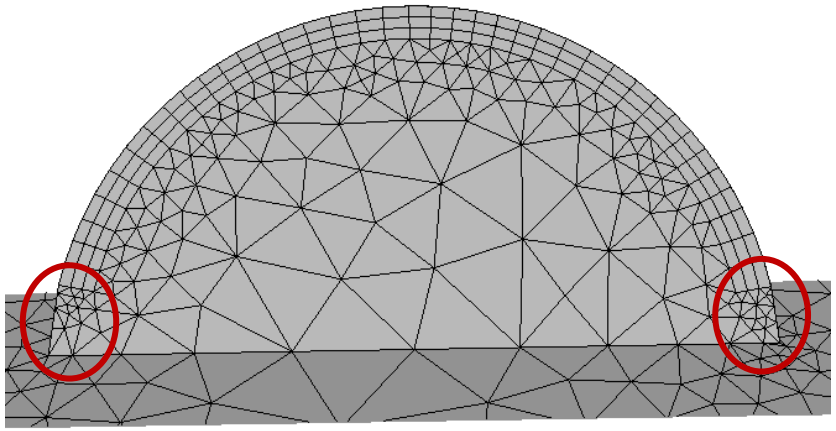
- Template Radius field
  - Default value of the radius is based on a notion of the crack size
- Simple Template Intersections Only : Allows the user to terminate the template inside the model surfaces
- **Meshing Parameters** button
  - Specify surface and volume meshing parameters
  - Choose the volume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

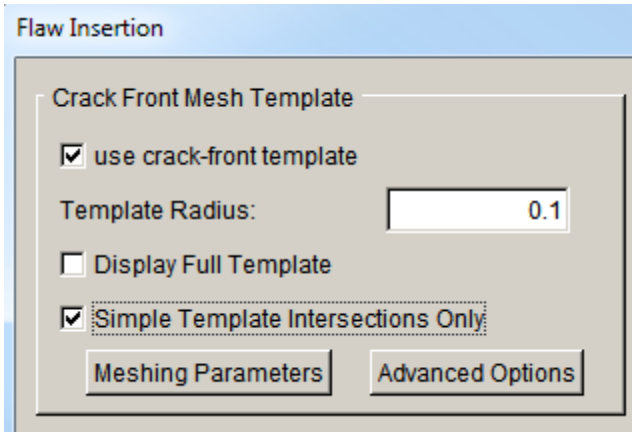


Simple Template Intersections Only

- 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.





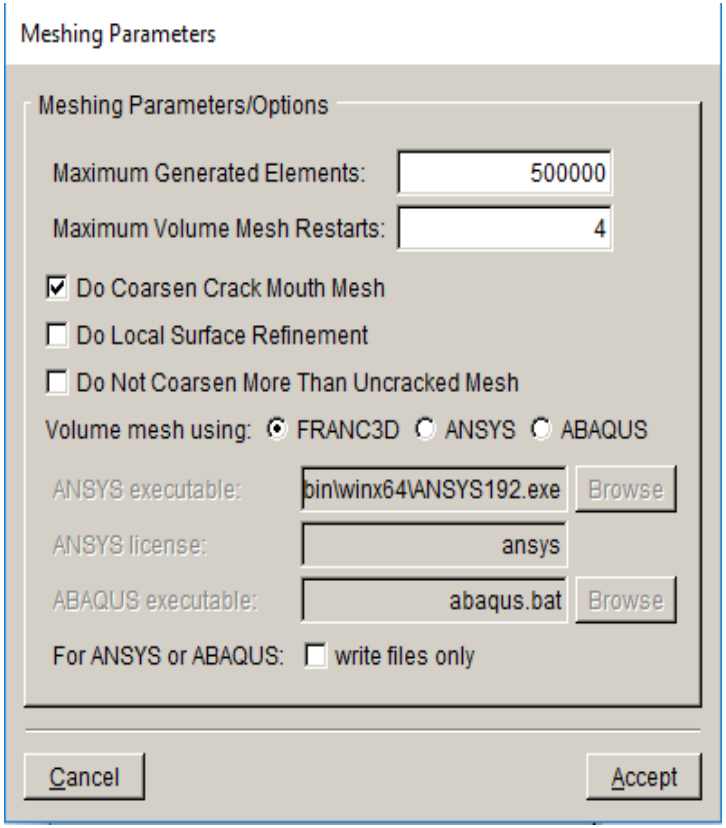


Simple Template Intersections means that the template does not extend to model surface.

Meshing Parameters

Surface and volume meshing controls

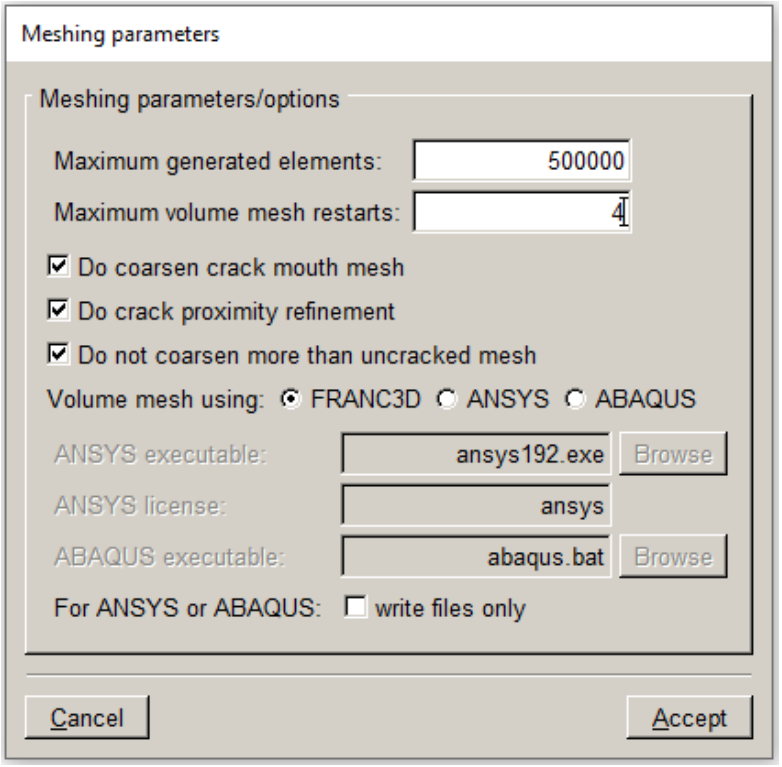
- Maximum Generated Elements: limits the total number of volume elements that FRANC3D will create during volume meshing
- Maximum Volume Mesh Restarts: limits the number of volume meshing restarts
- FRANC3D uses an *advancing front* volume meshing algorithm
- FRANC3D generated volume elements are smoothed 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

Surface mesh refinement

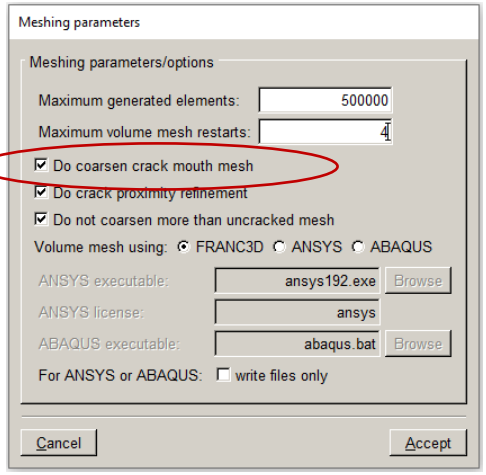
- Do Coarsen Crack Mouth Mesh - produces a less refined mesh on the crack surface
- Do Local Surface Refinement - refines any surface mesh near the crack
- Do Not Coarsen More Than Uncracked Mesh - produces a surface mesh that resembles the original mesh density



Example surface meshes are shown in the next two slides.

Surface mesh refinement

Effects of Do Coarsen Crack Mouth Mesh



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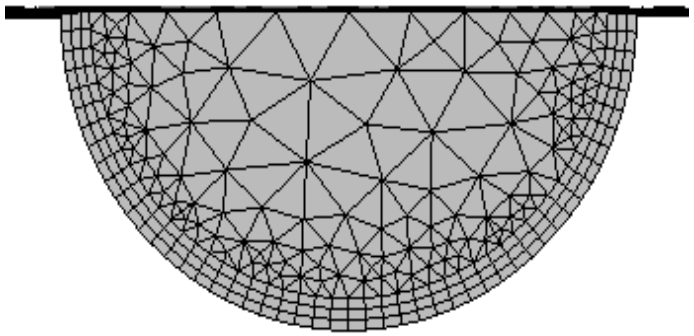

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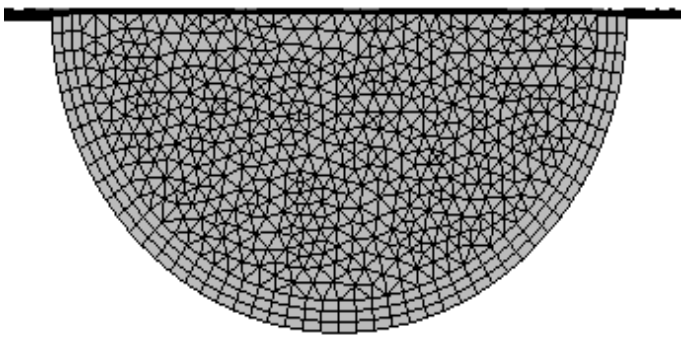
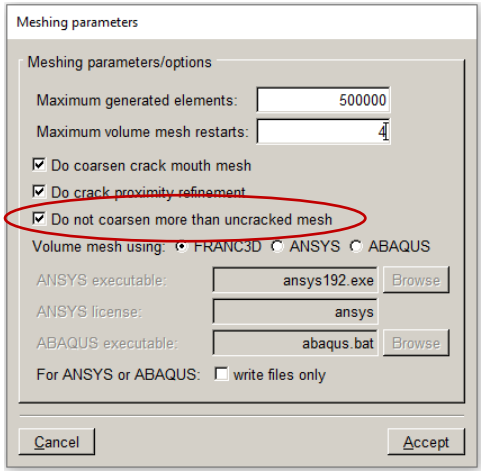


Surface mesh refinement

Effects of Do Not Coarsen More Than Uncracked Mesh



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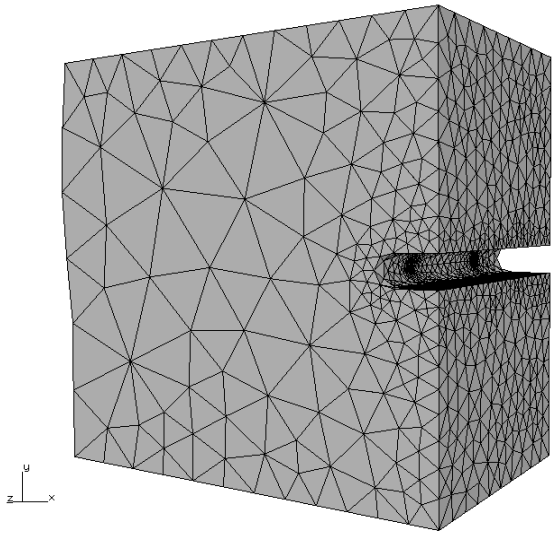
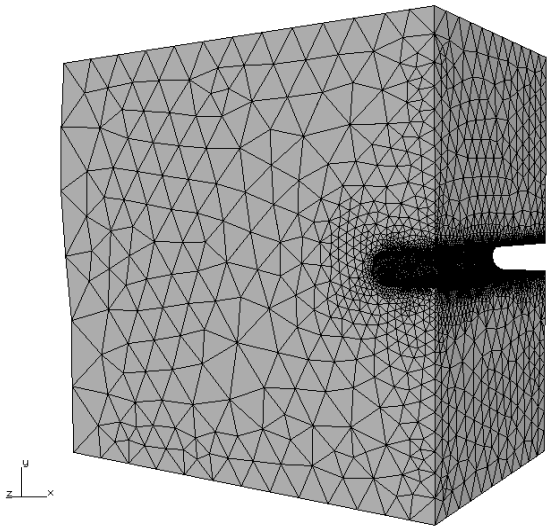
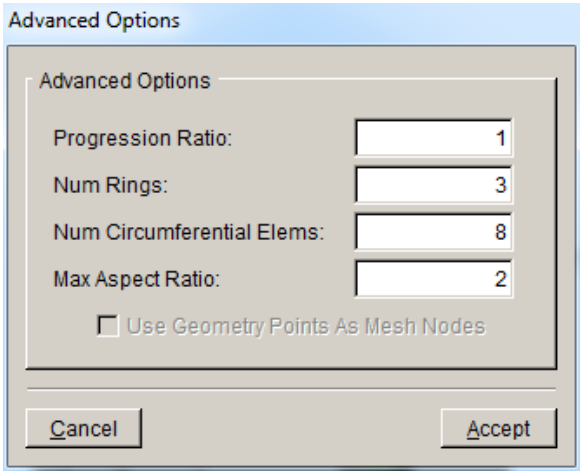


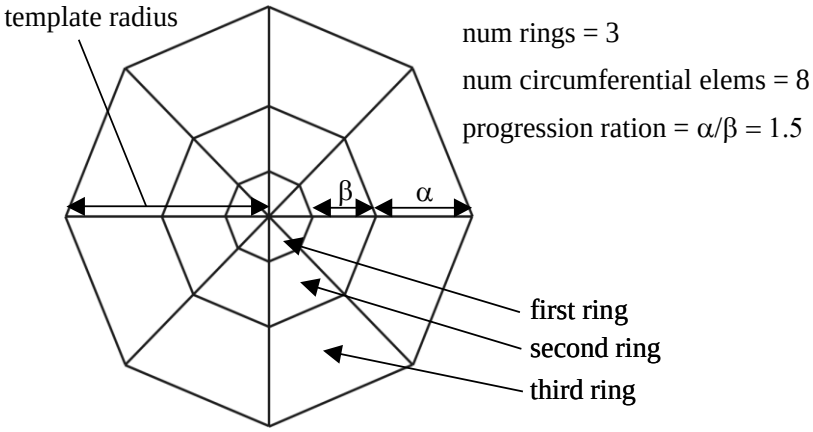
on



Advanced Template Options

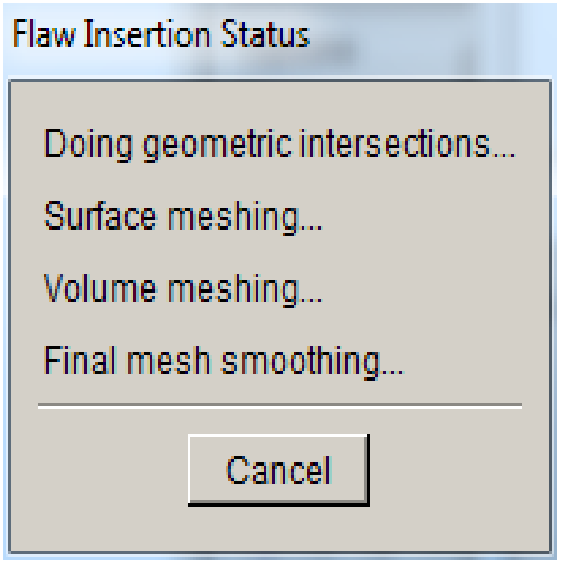
- Progression Ratio sets the relative width of the element (in the direction perpendicular to the crack front) going from the crack front to the outer surface of the template
- Num Rings sets the number of rings of elements in the template
- Num Circumferential Elem sets the number of elements in the 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





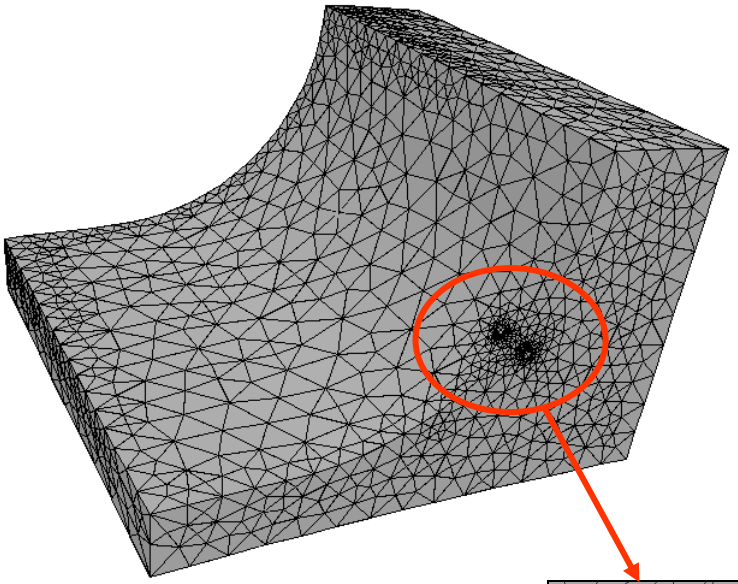
Flaw Insertion Status

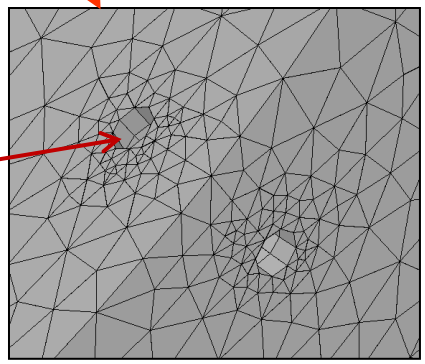
- After one selects **Finish** on the crack front mesh template panel, the flaw is inserted into the body and the model is remeshed
- The crack geometry is inserted into the model geometry first, represented by the Doing geometric intersections... status. Once the crack geometry has been inserted, trimmed, 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



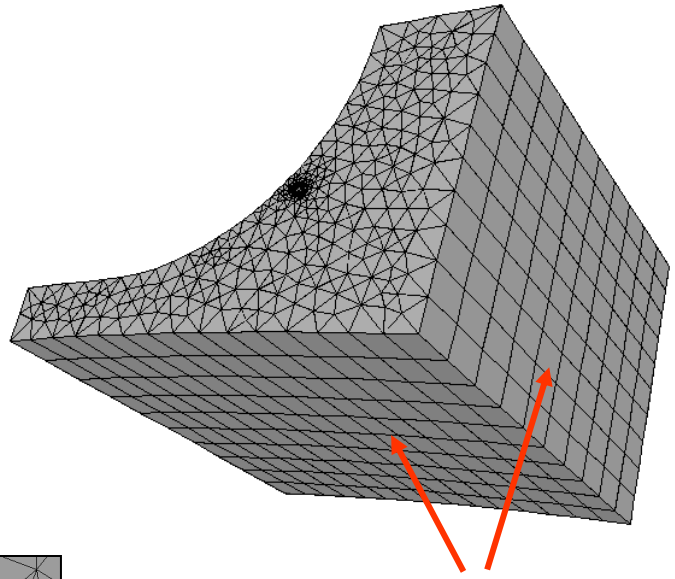
Crack Insertion – surface remeshing

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





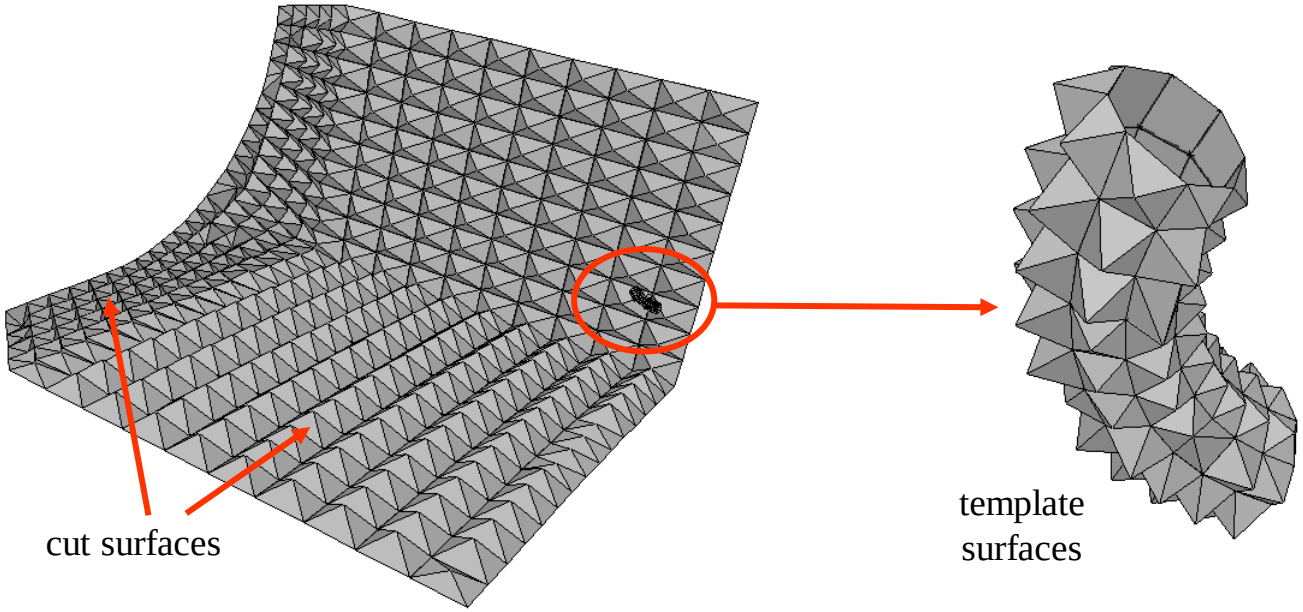
Template mesh extracted as it is already meshed



retained cut-surface meshes

Crack Insertion – pyramids and tetrahedra

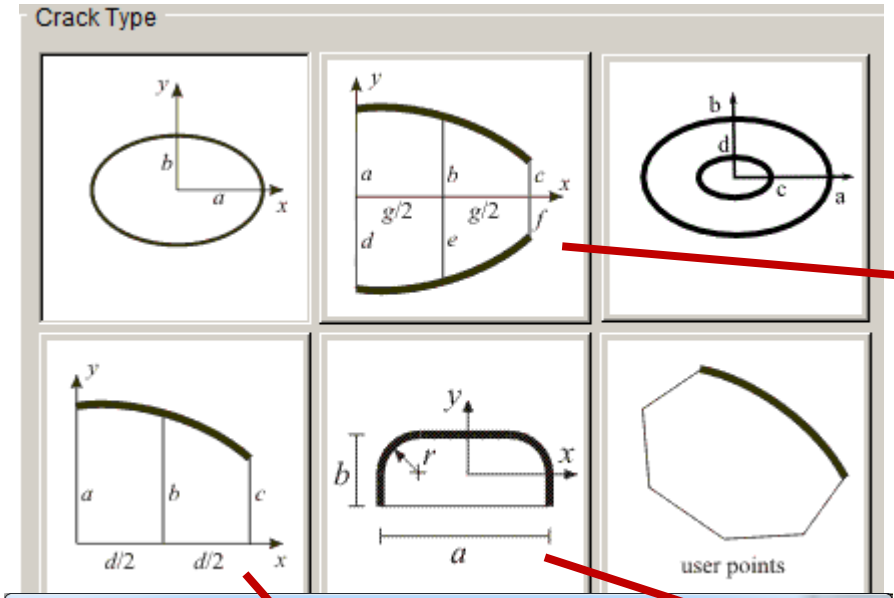
- pyramid elements generated for compatibility:
  - between quadrilateral facets (on the template or retained surfaces) and the triangular faces of tetrahedra in the volume mesh

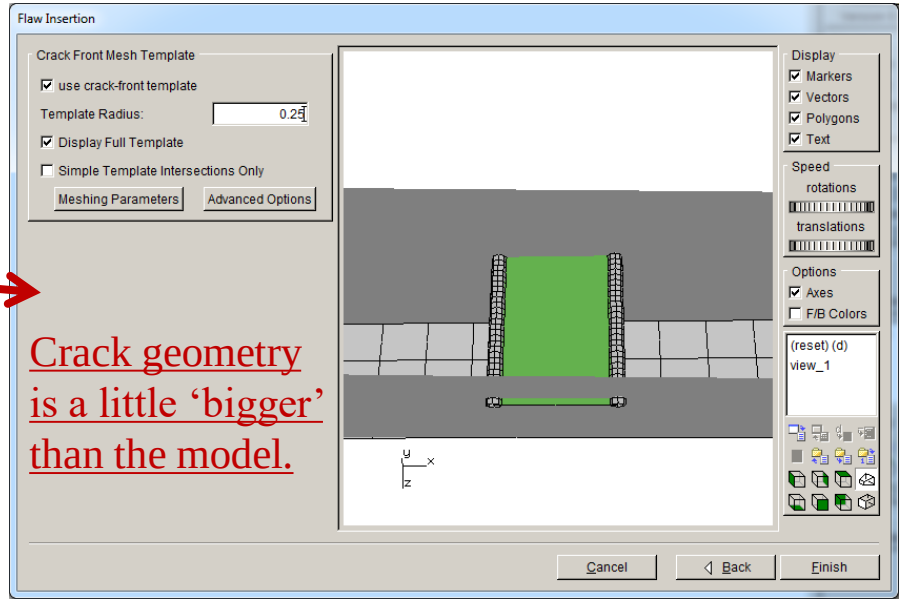


- advancing front meshing algorithm* used to generate tetrahedral volume mesh
- algorithm respects geometrically coincident but distinct nodes on opposite sides of crack faces

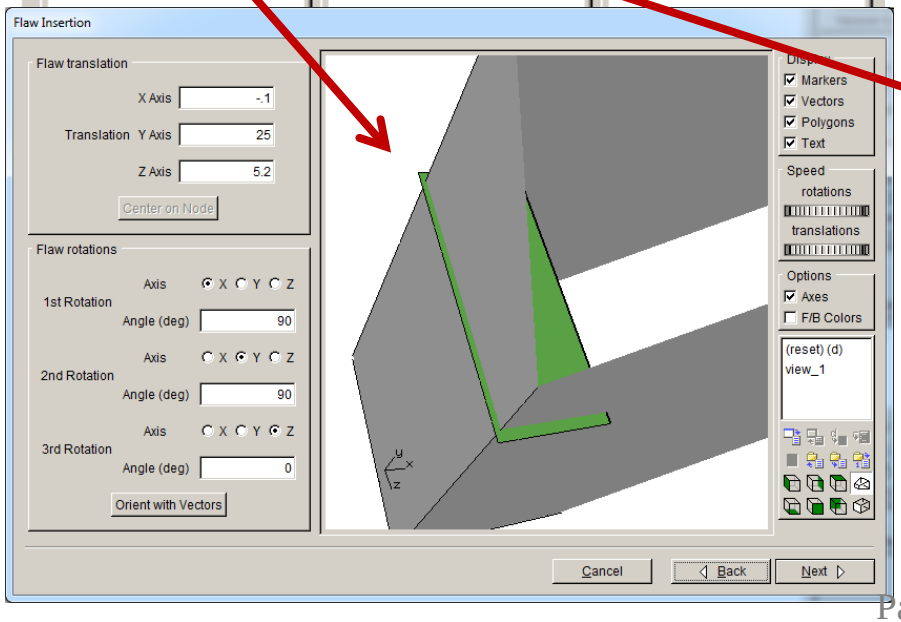
*Neto, J.B., Wawrzynek, P.A., Martha, L.F., and Ingraffea, A.R., "An algorithm for three-dimensional mesh generation for arbitrary regions with cracks," *Engng with Comp.*, Vol. 17, 75-91 (2001)

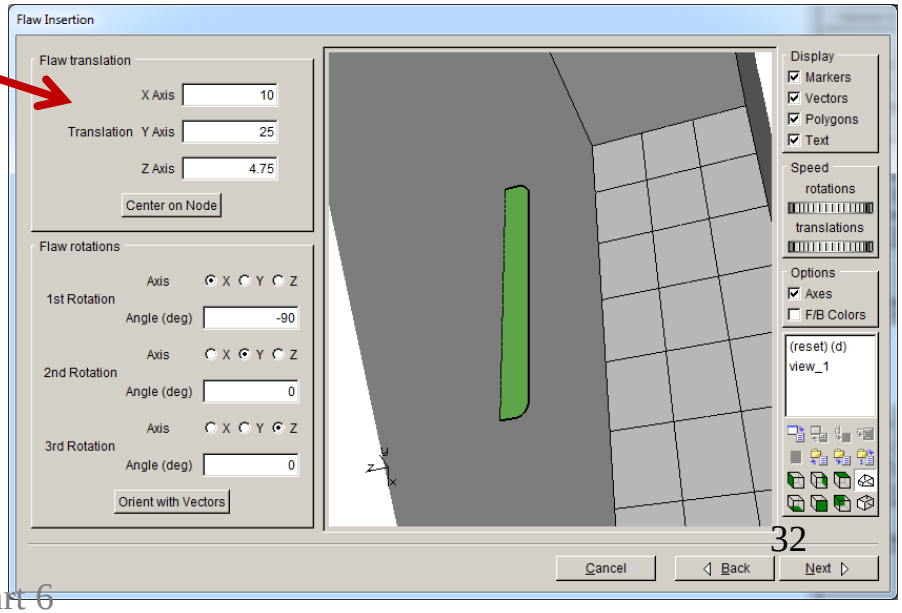
Crack Insertion Wizard – Library Shapes



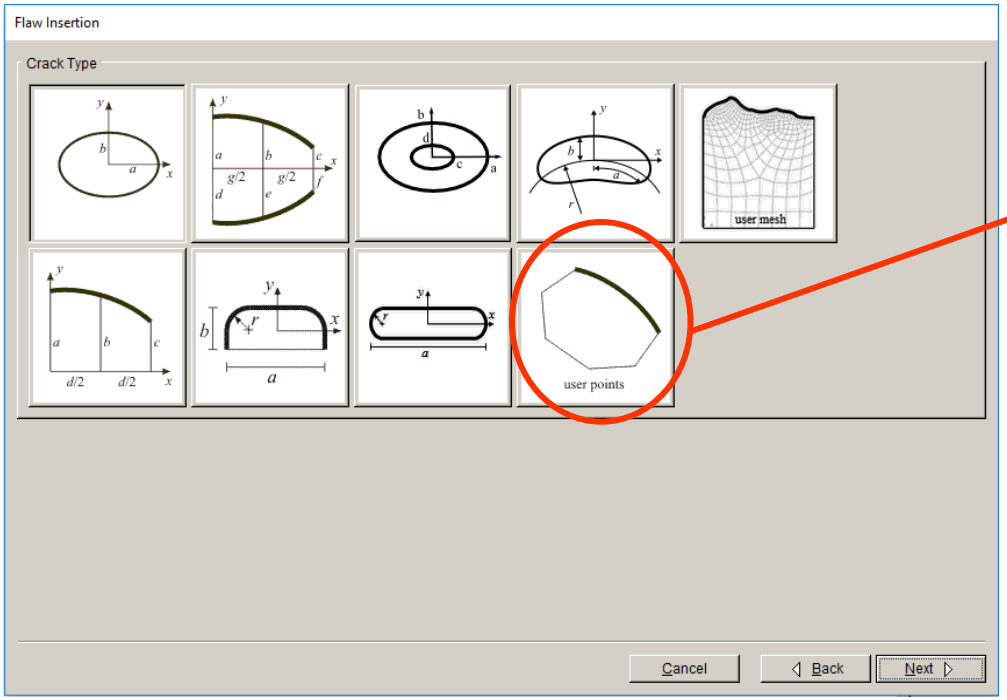


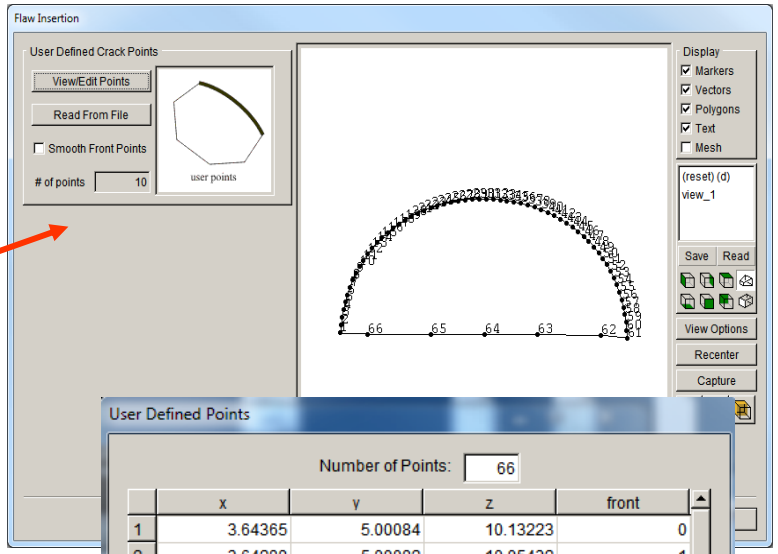
Crack geometry is a little 'bigger' than the model.

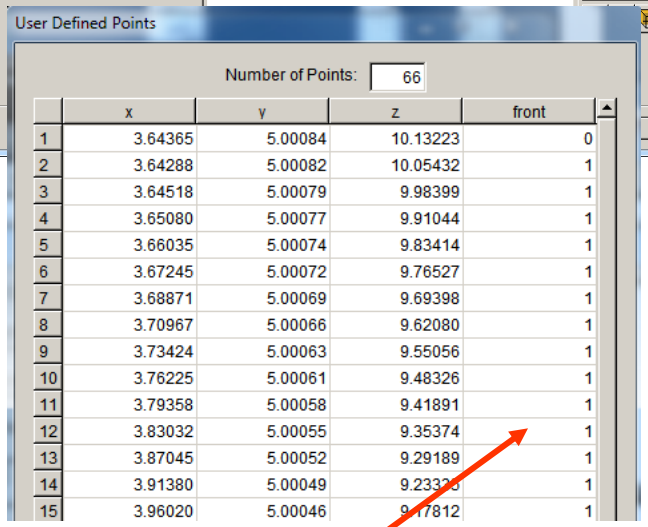




User-Defined Crack Shape







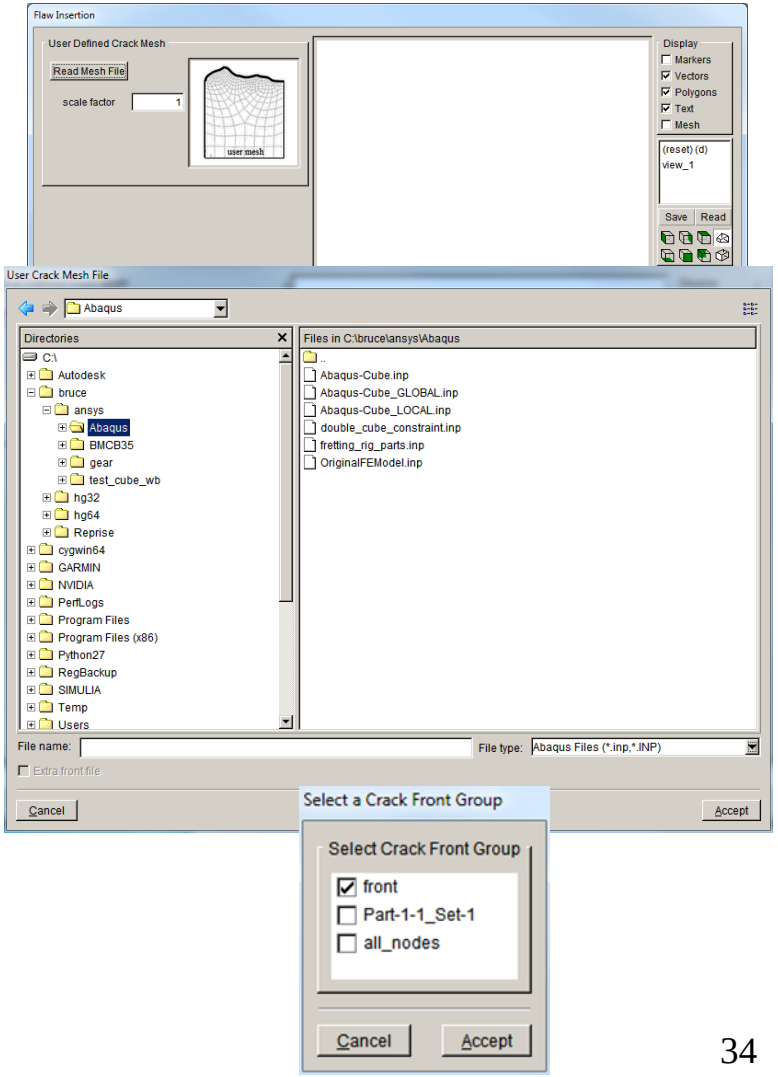
	x	y	z	front
1	3.64365	5.00084	10.13223	0
2	3.64288	5.00082	10.05432	1
3	3.64518	5.00079	9.98399	1
4	3.65080	5.00077	9.91044	1
5	3.66035	5.00074	9.83414	1
6	3.67245	5.00072	9.76527	1
7	3.68871	5.00069	9.69398	1
8	3.70967	5.00066	9.62080	1
9	3.73424	5.00063	9.55056	1
10	3.76225	5.00061	9.48326	1
11	3.79358	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	9.23338	1
15	3.96020	5.00046	9.17812	1

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.

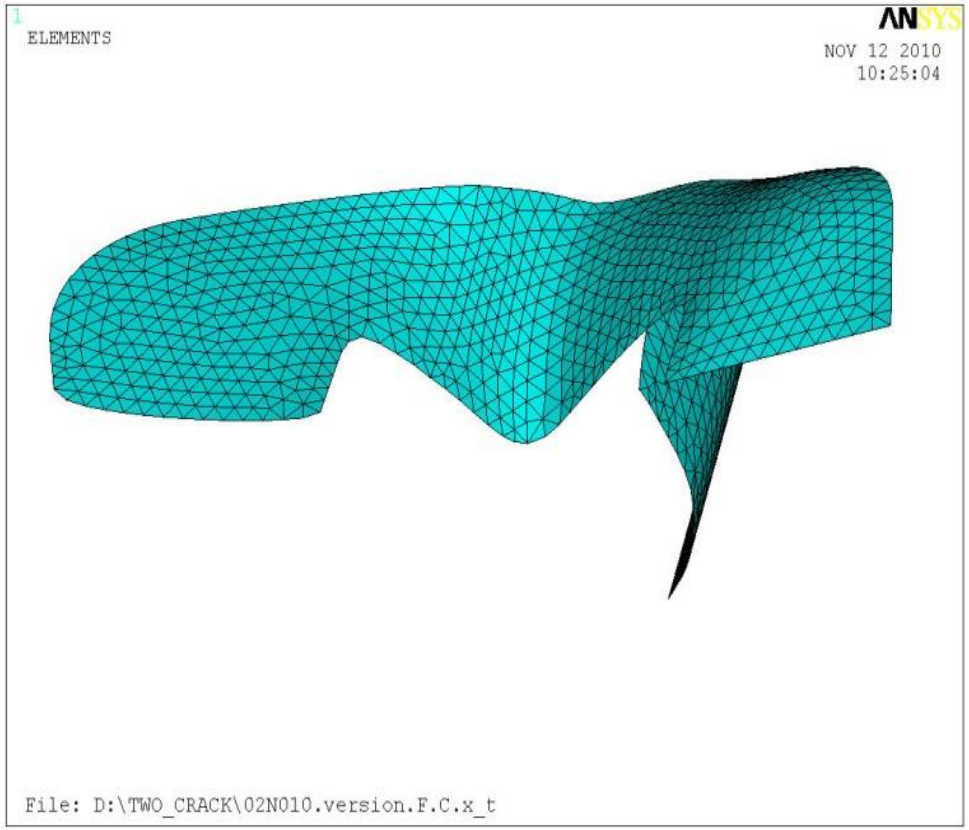
Crack front vertices flagged as “1”.

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

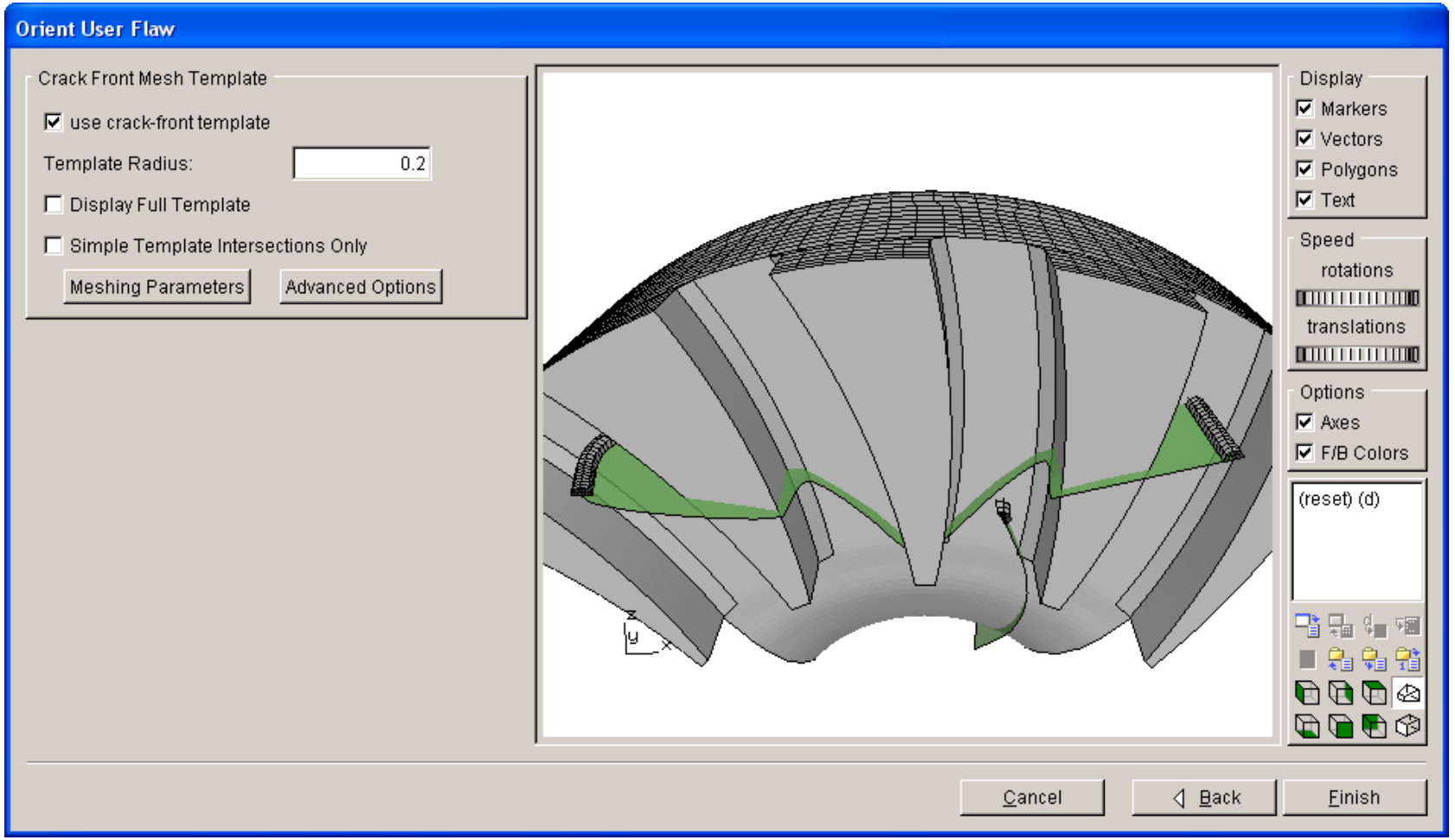


ANSYS surface mesh of two cracks

Element normal directions must be consistent.

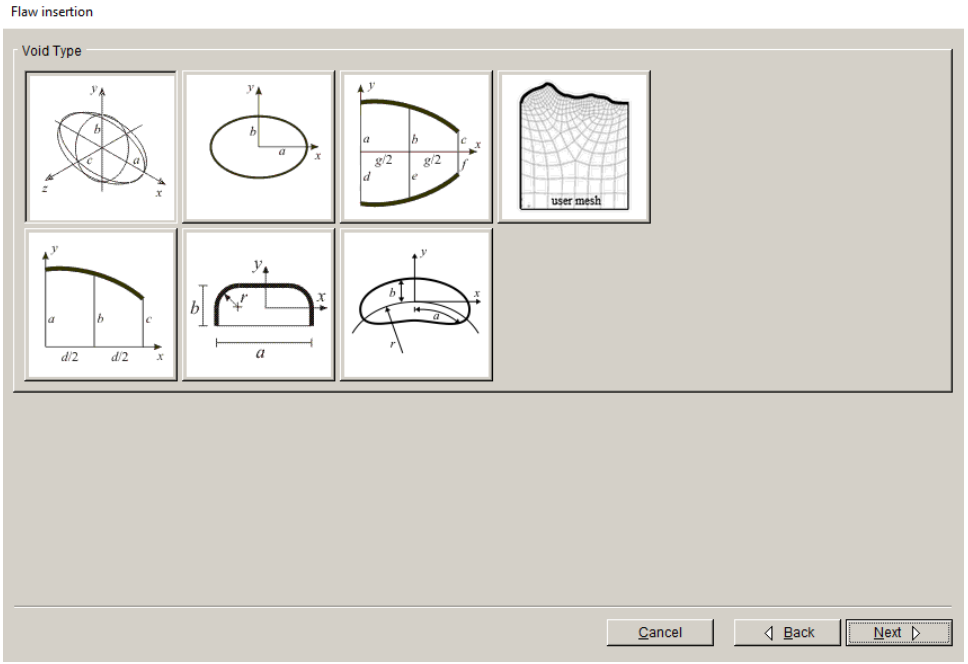
Crack front nodes should be collected in a component.

User-mesh Crack

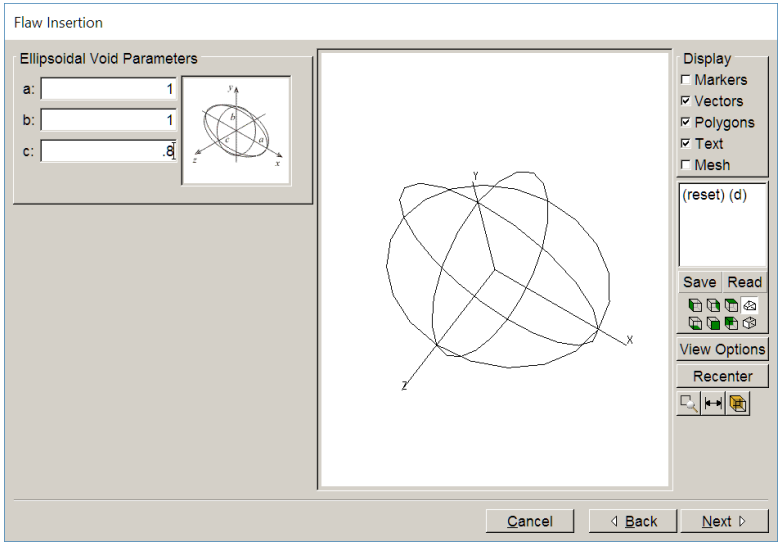


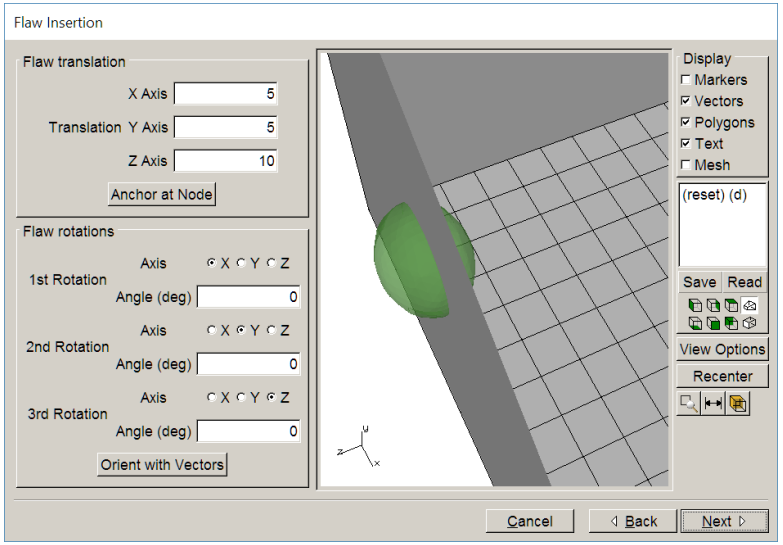
Finite Volume Void Insertion

- Ellipsoid
- 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
- User-mesh void – top far right

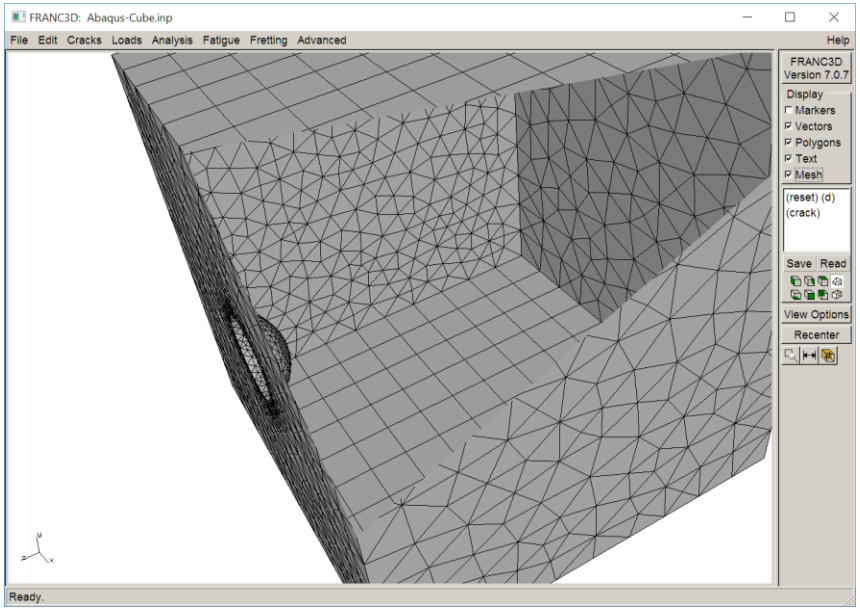


Ellipsoid Panel



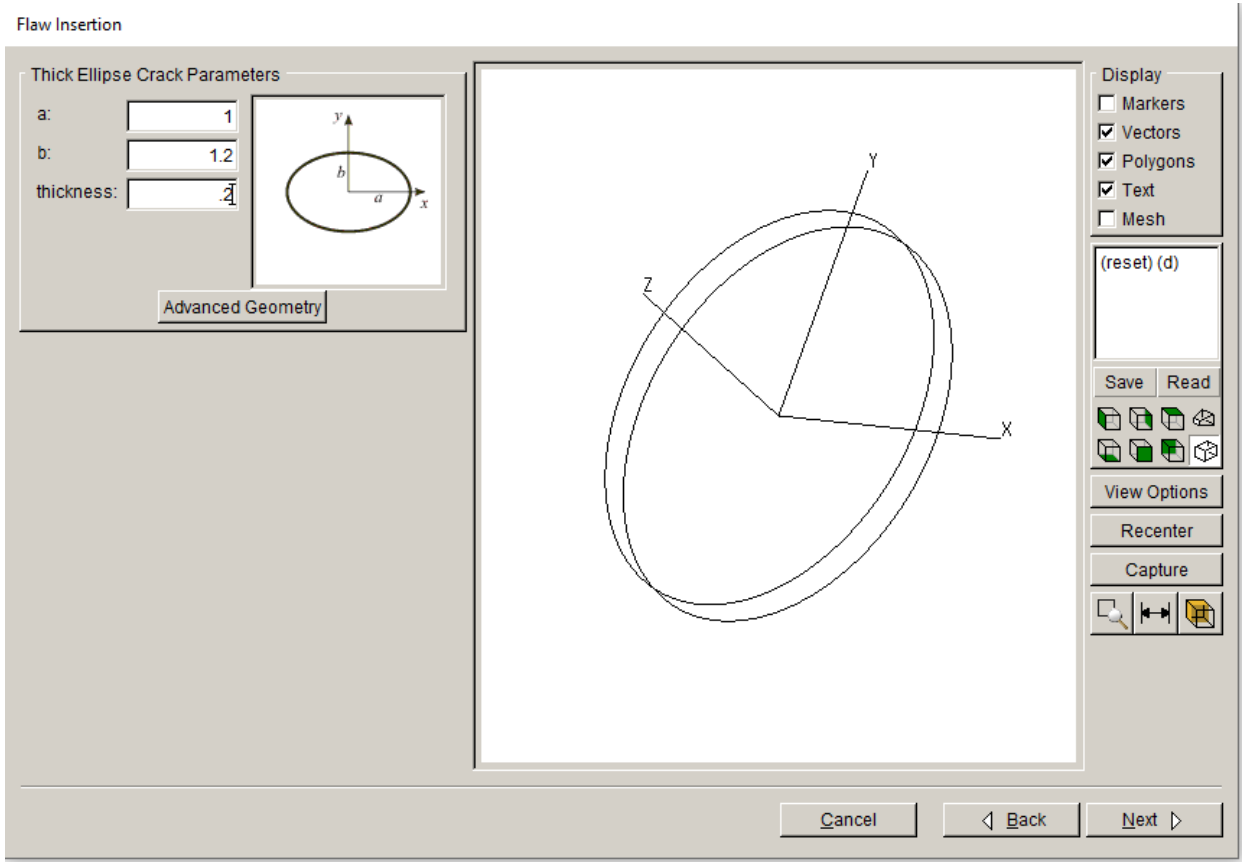


Ellipsoid void can be internal or intersect a surface



No void growth!

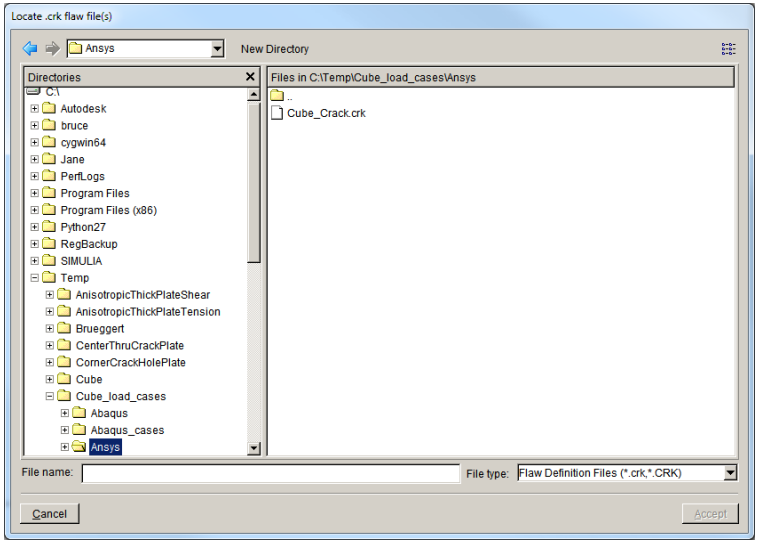
Thick (flat) Elliptical Void Panel

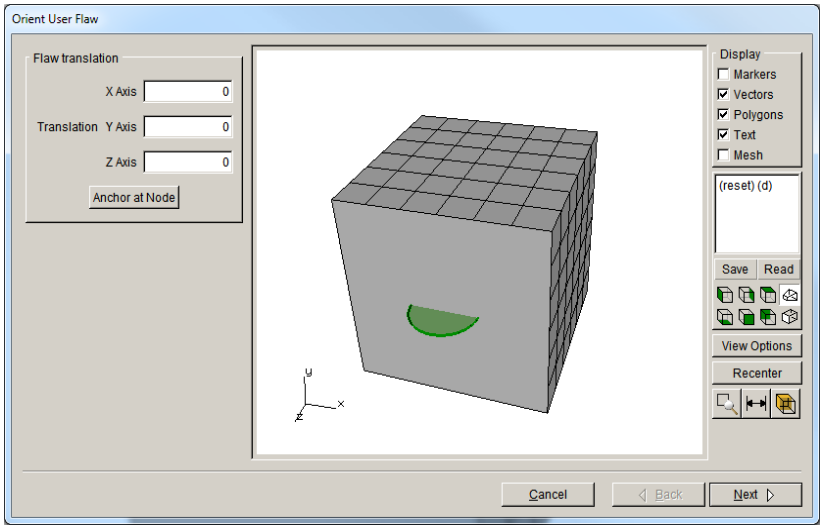


Thick (void) cracks are the same as the zero-thickness cracks, except for the extra thickness dimension.

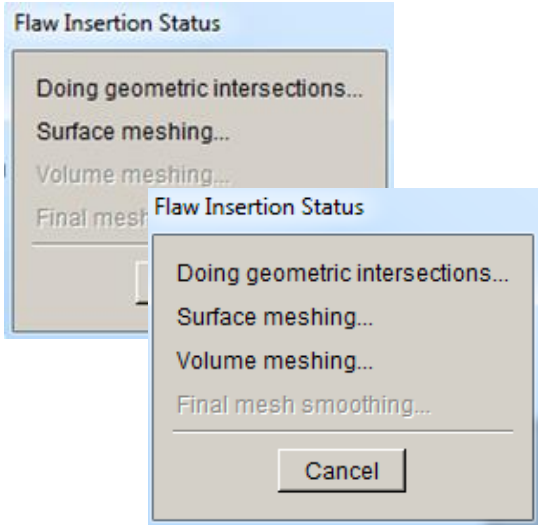
Flaw From Files

- 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

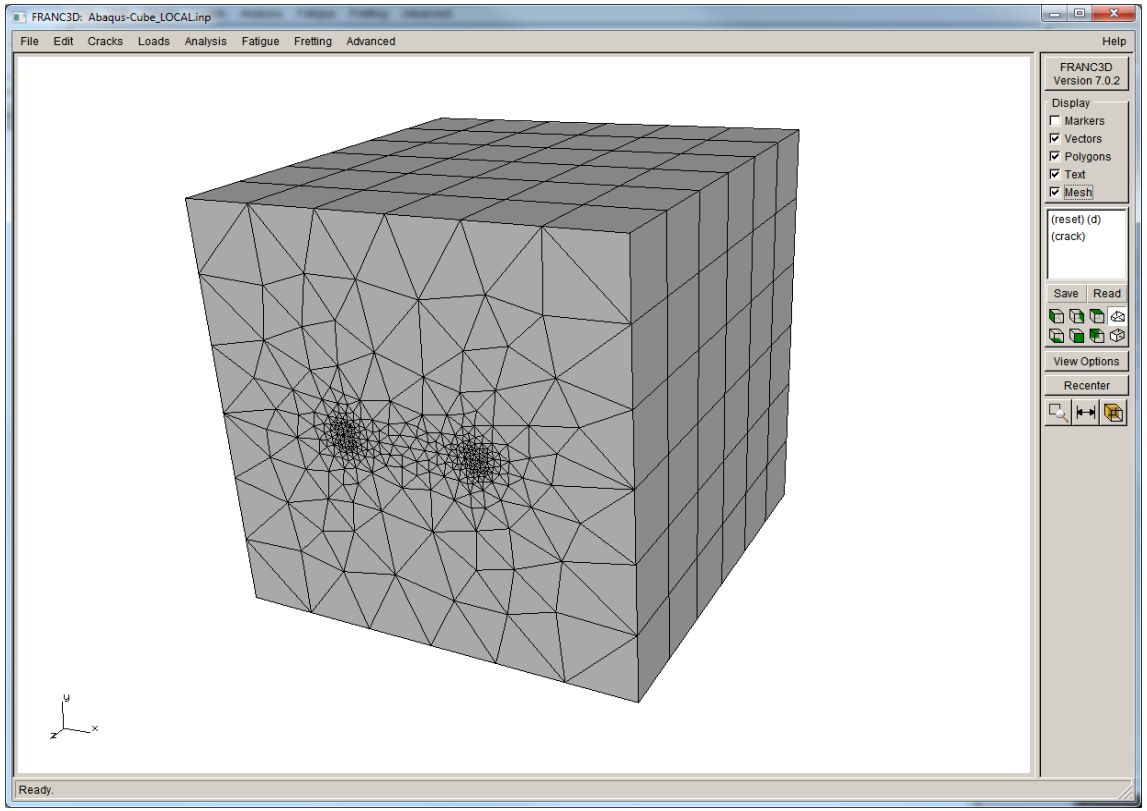




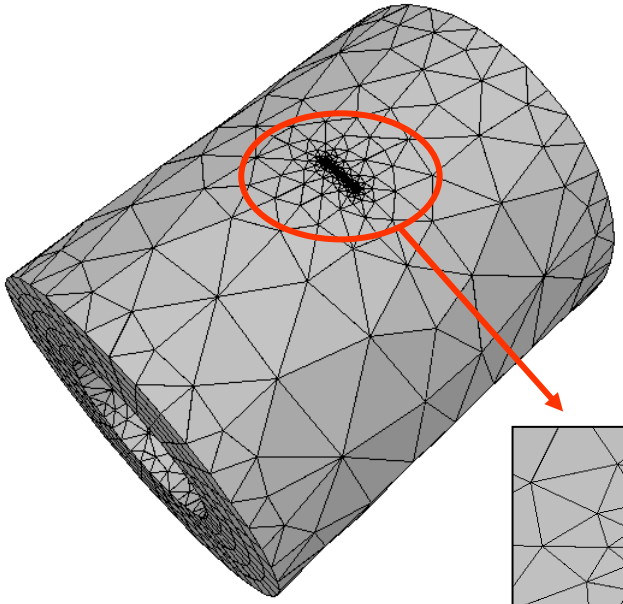
Insertion and Remeshing



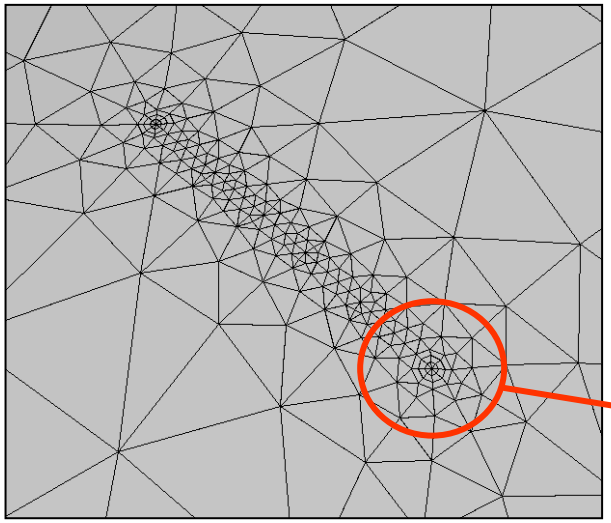
Insertion and remeshing happens automatically after selecting **Next** or **Finish** in the crack insertion wizards.

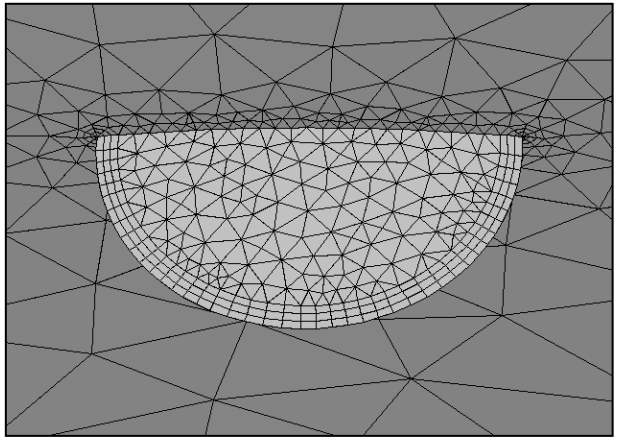


Surface Mesh after Crack Insertion

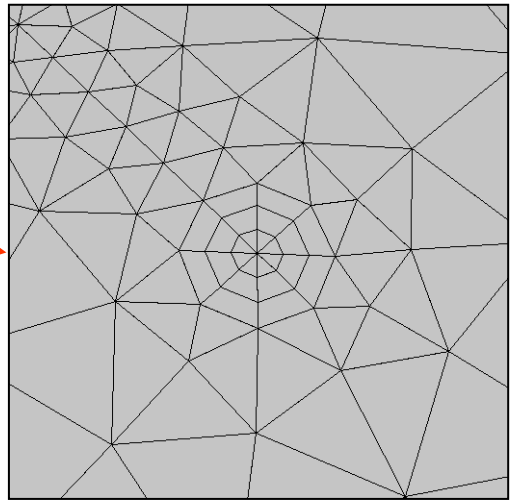


Model surface mesh

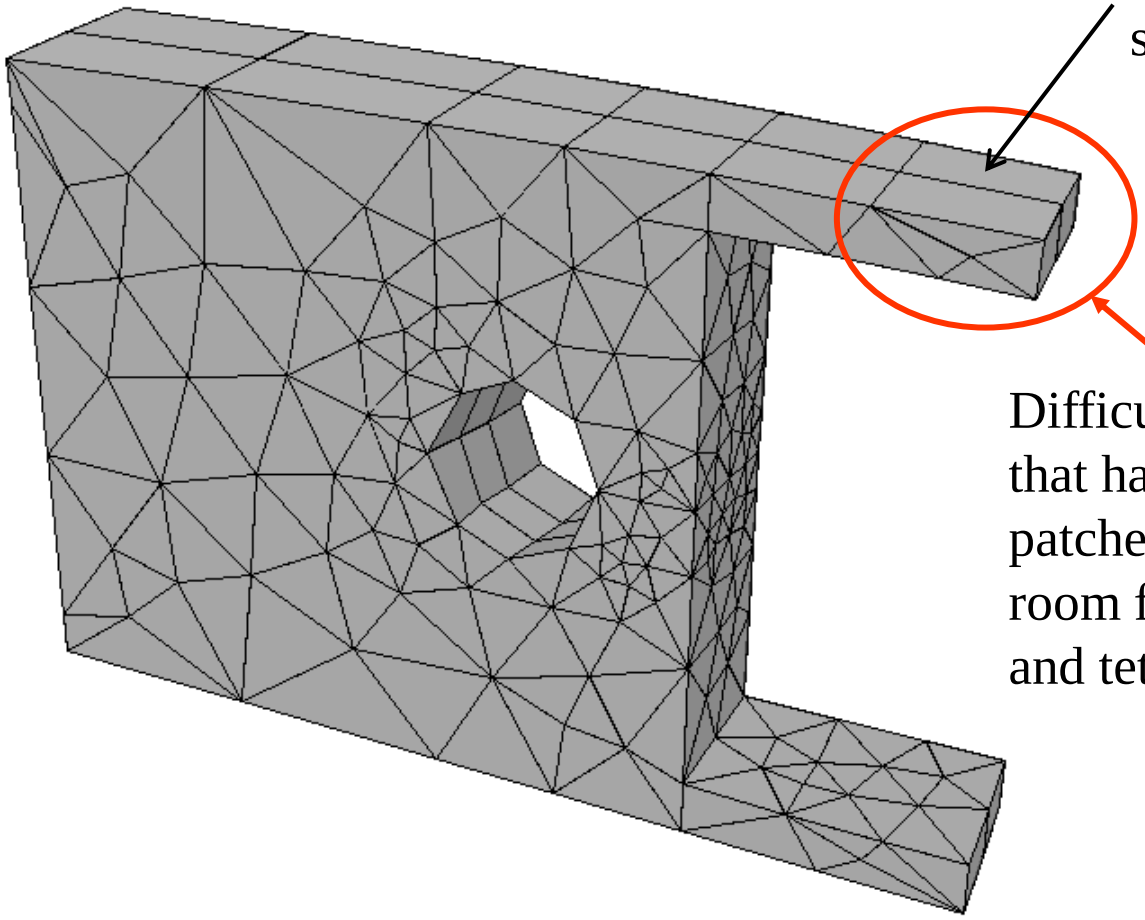




Crack surface mesh



Crack Insertion – sub-model limitation

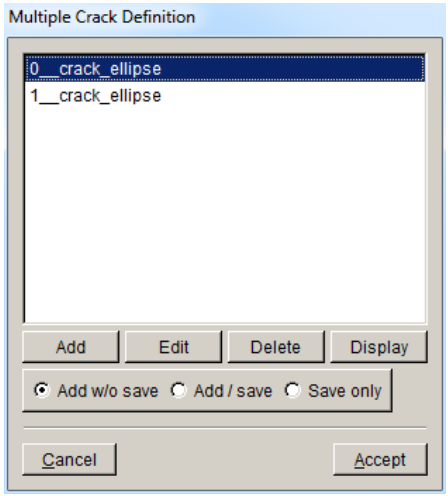


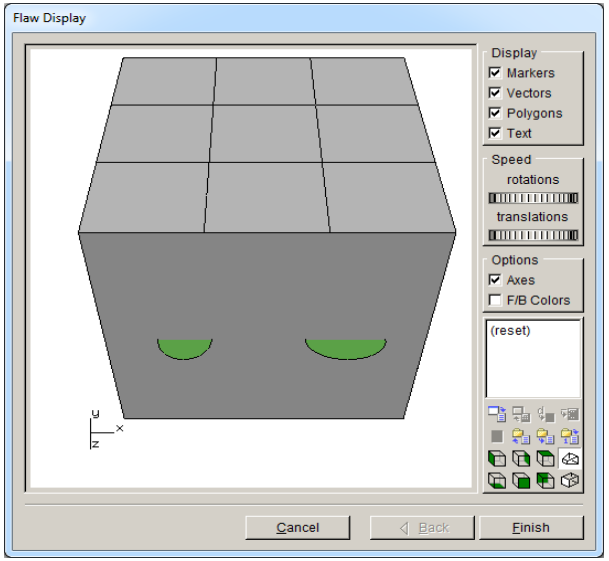
Difficult to mesh thin volume that has large quadrilateral patches retained as there is no room for well-shaped pyramid and tetrahedral elements.

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

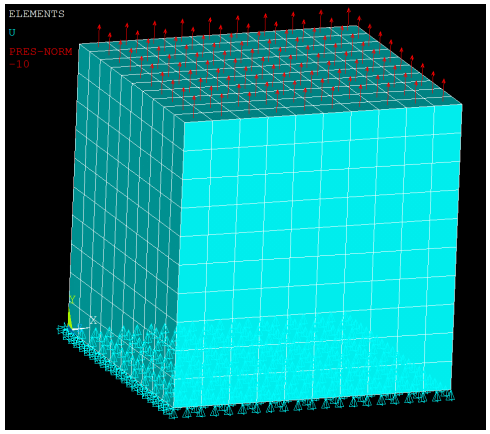
FRANC3D Documentation

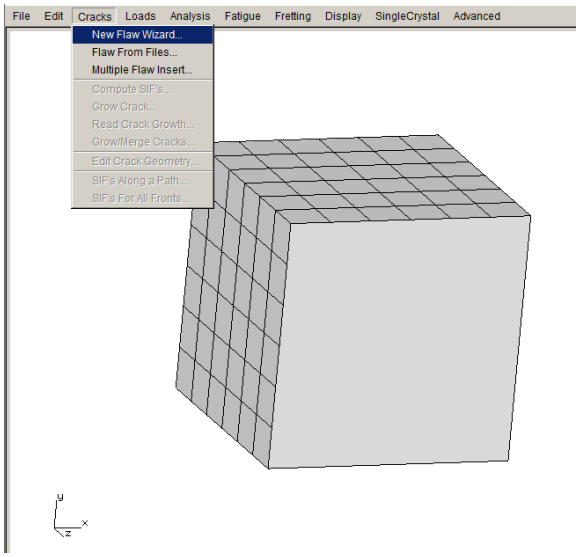
- Download & Install Instructions
- Brochure
- Reference Manual
- Tutorial for ABAQUS Users
- Tutorial for ANSYS Users
- Tutorial for NASTRAN Users
- Tutorial for SIERRA Users
- Tutorials 2-14
- User's Guide
- Command Line & Python Interface
- Benchmark Reference

Training Slides

- Download Files

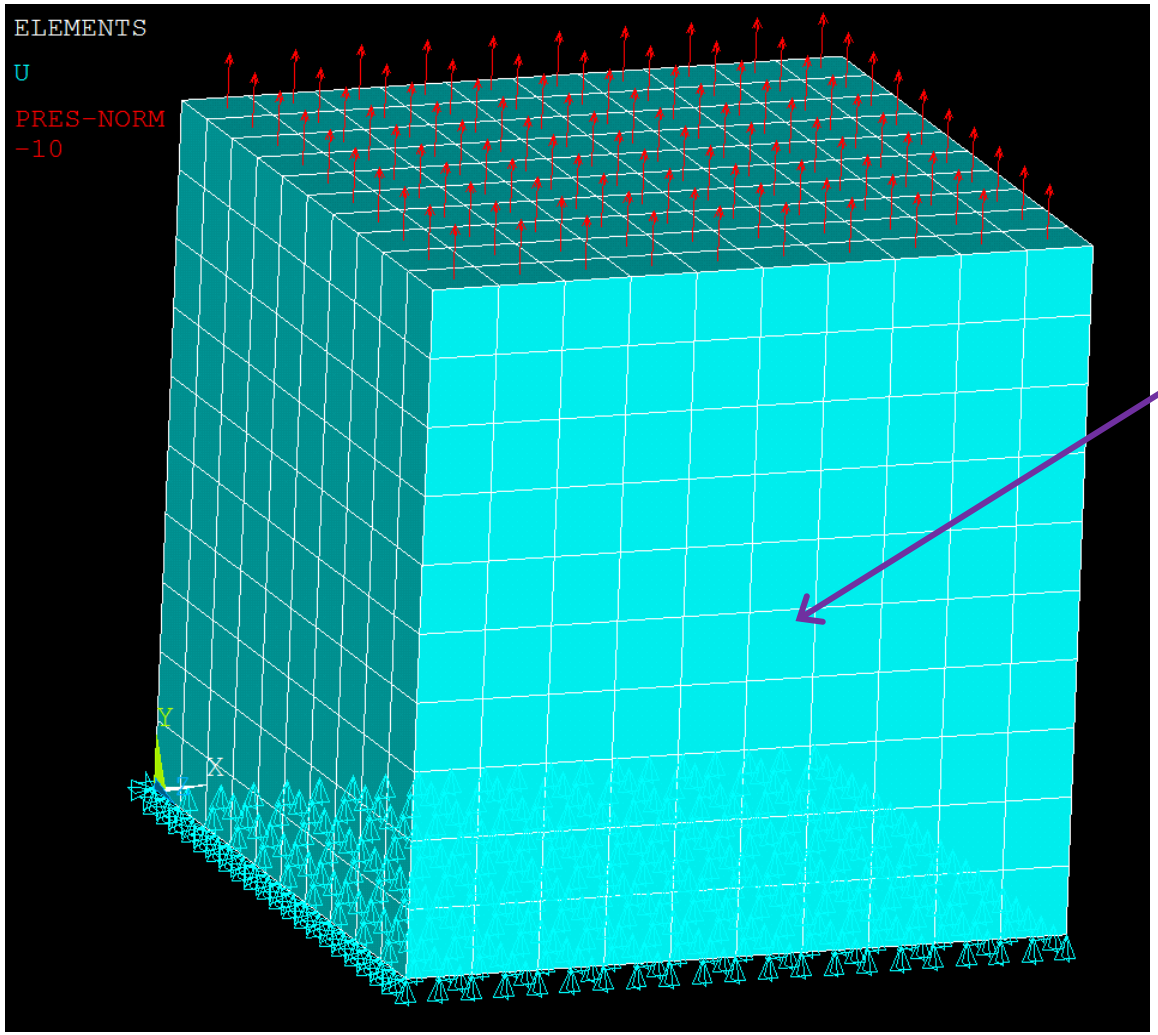
Tutorial #1:
Crack Insertion and Growth in a Cube

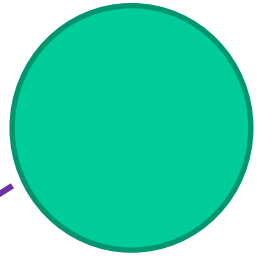




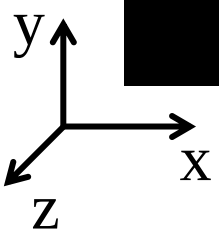
http://www.fracanalysis.com/software.html

Crack Insertion in a Cube

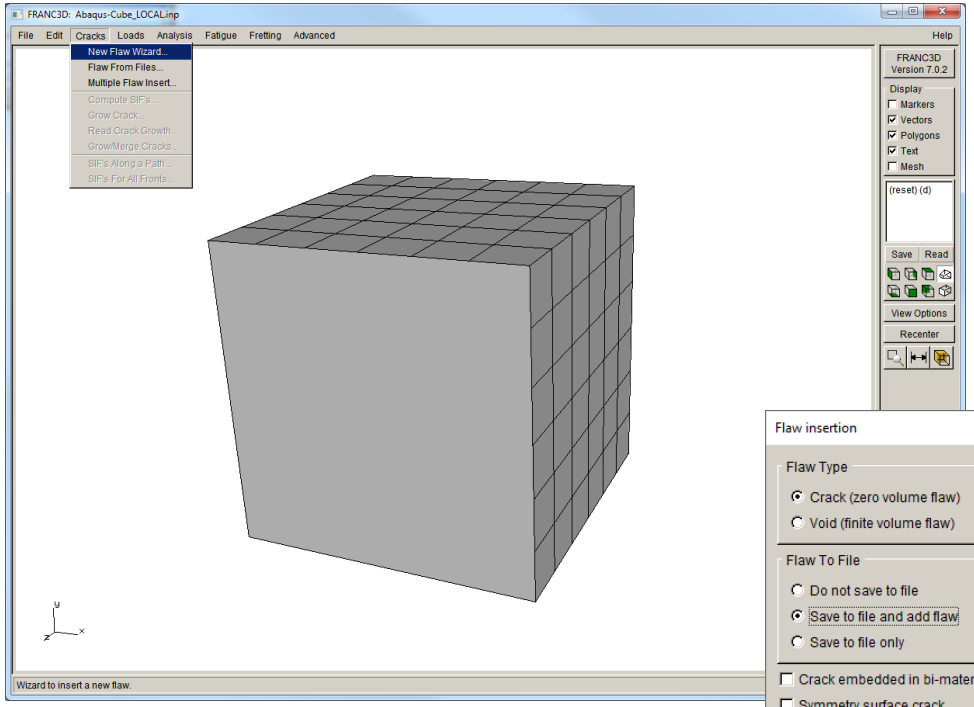


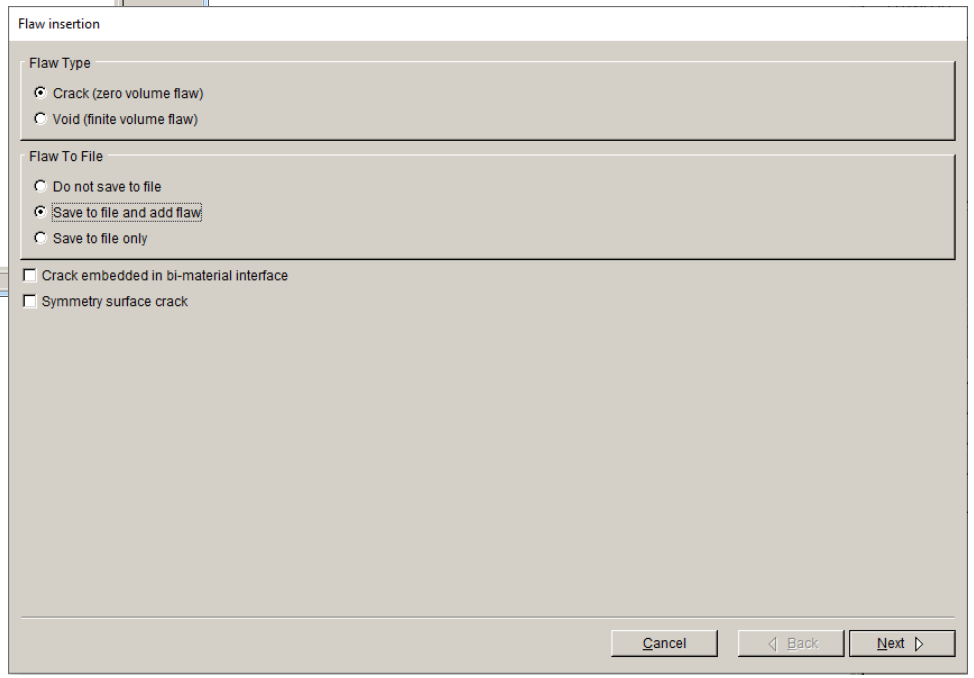


Unit penny-shaped crack oriented normal to tensile (y-direction) load and inserted into the +z face to make a half-penny surface crack.

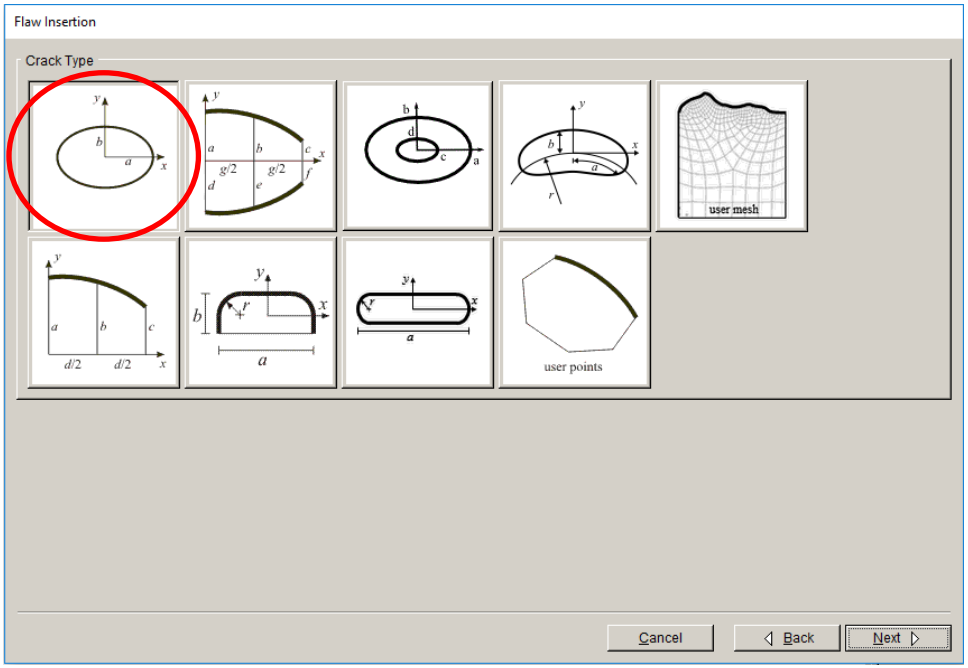


FRANC3D Tutorial 1 – Crack Insertion

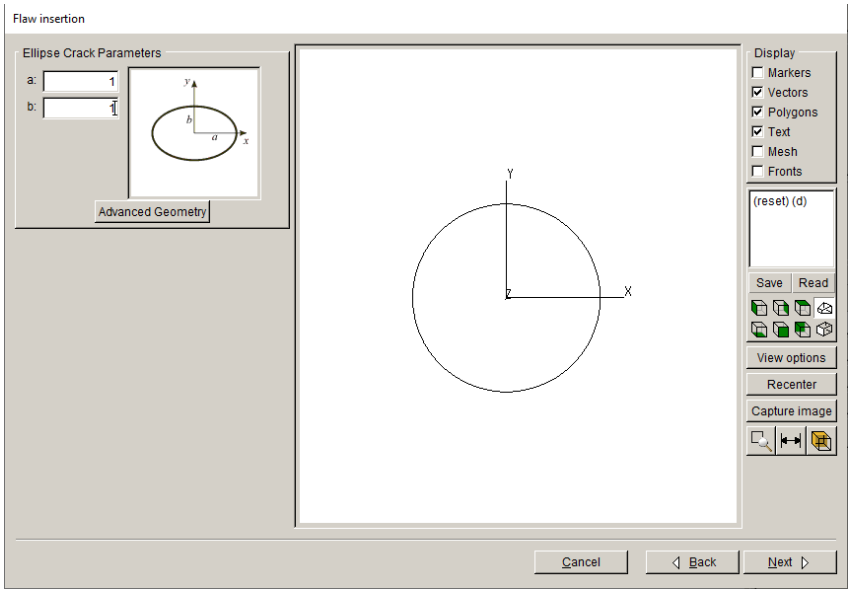




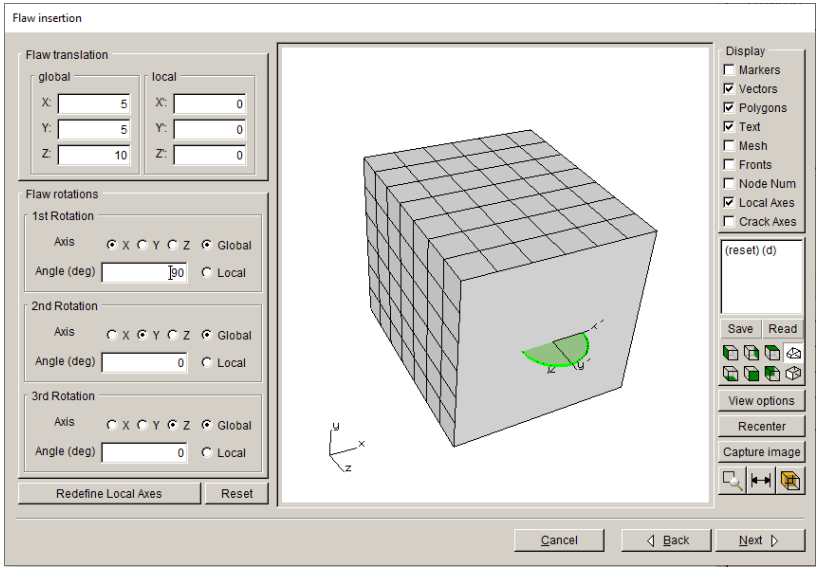
FRANC3D Tutorial 1 – Crack Insertion



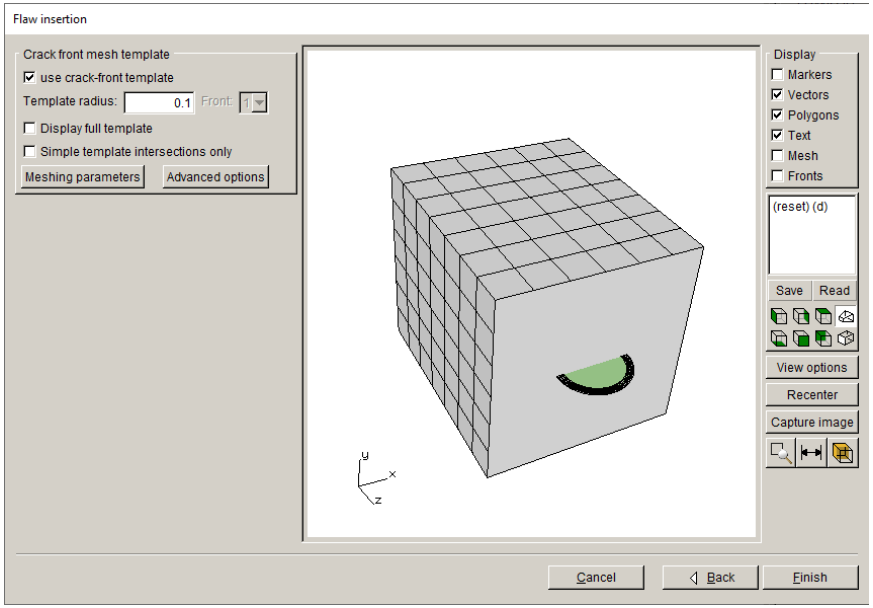
Unit penny-shape crack



FRANC3D Tutorial 1 – Crack Insertion

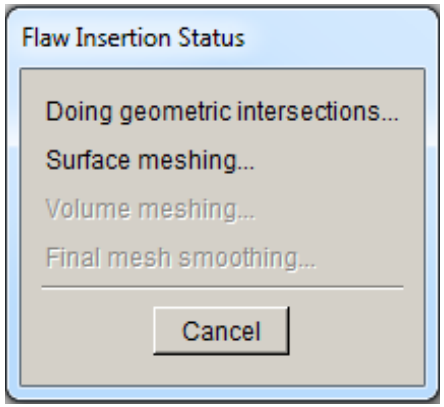


Template radius might need to be adjusted depending on the crack and the model geometry.



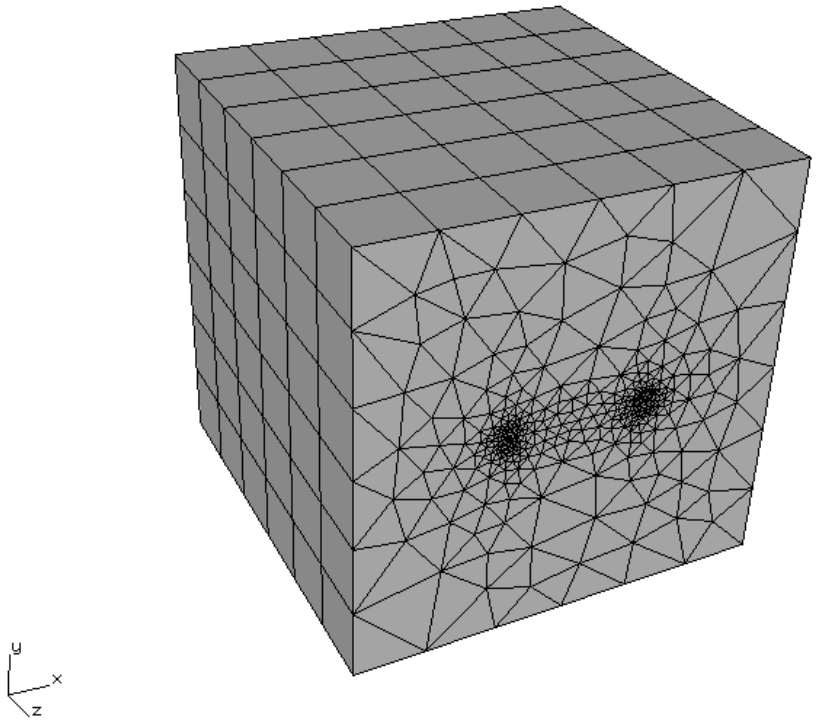
Located in the middle of the +z cube face, and normal to the y-axis.

FRANC3D Tutorial 1 – Crack Insertion



Crack insertion involves geometry intersections

and remeshing of surfaces and volume(s).



End Part 6