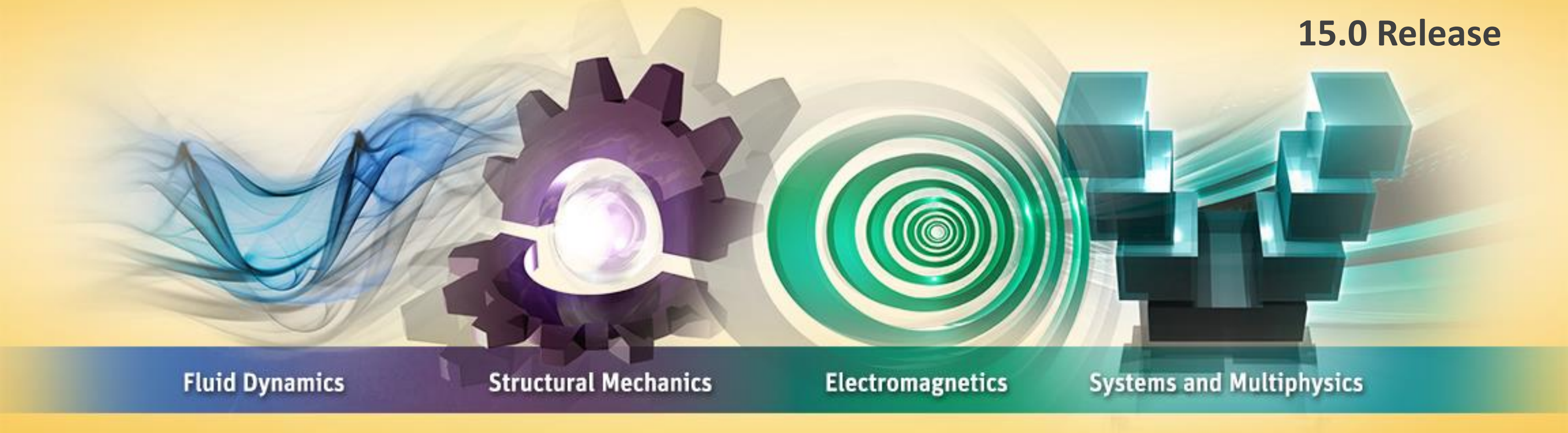
Lecture 7:
Mesh Quality & Advanced Topics

15.0 Release



Introduction to ANSYS Meshing

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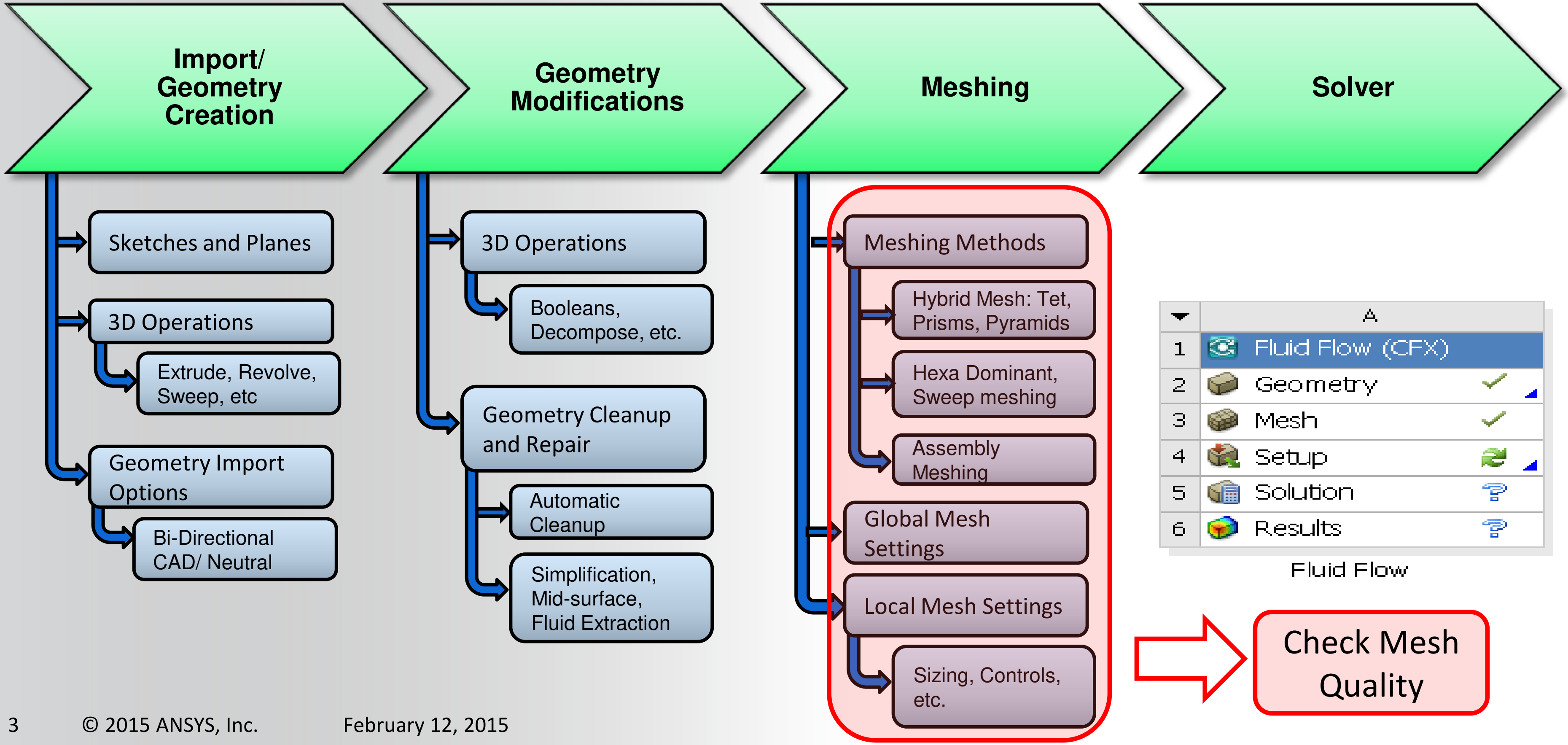
Overview

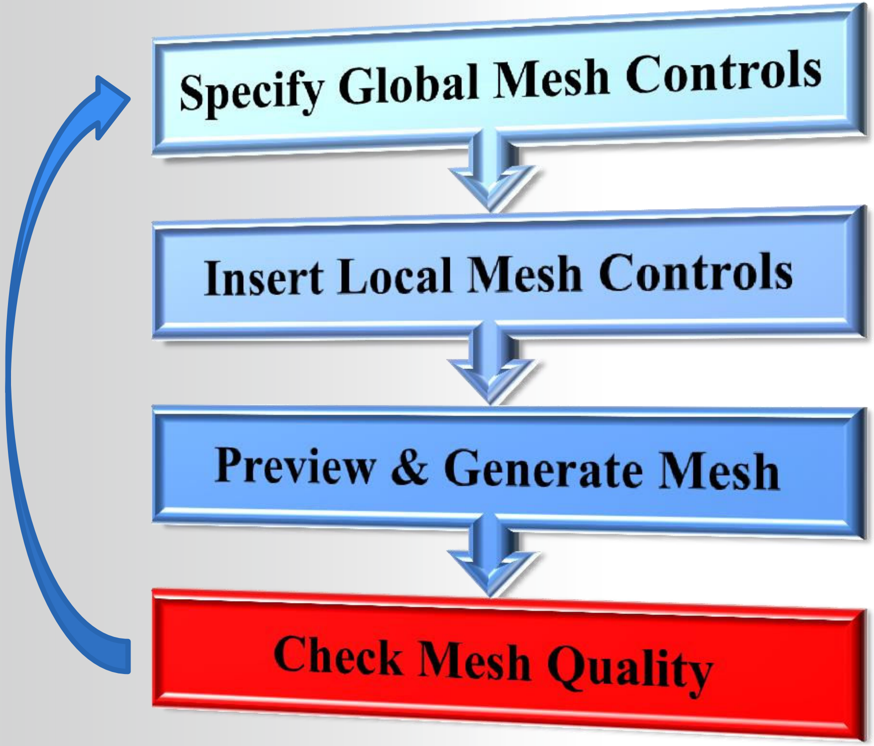
In this lecture we will learn:

- Impact of the Mesh Quality on the Solution
- Quality criteria
- Methods for checking the mesh quality
- Tools to improve quality in Meshing
- Concept of Assembly Meshing
- Assembly Meshing Methods & Controls

Preprocessing Workflow



Meshing Process in ANSYS Meshing



Impact of the Mesh Quality

Good quality mesh means that…

- Mesh quality criteria are within correct range
  - Orthogonal quality …
- Mesh is valid for studied physics
  - Boundary layer …
- Solution is grid independent
- Important geometric details are well captured

Bad quality mesh can cause;

- Convergence difficulties
- Bad physic description
- Diffuse solution

User must…

- Check quality criteria and improve grid if needed
- Think about model and solver settings before generating the grid
- Perform mesh parametric study, mesh adaption …

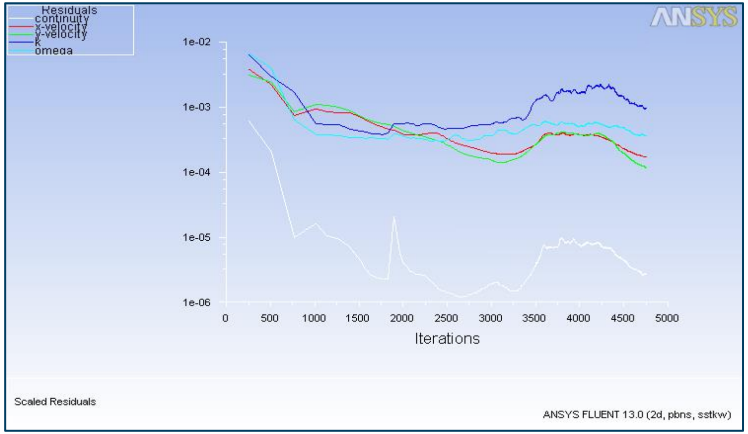
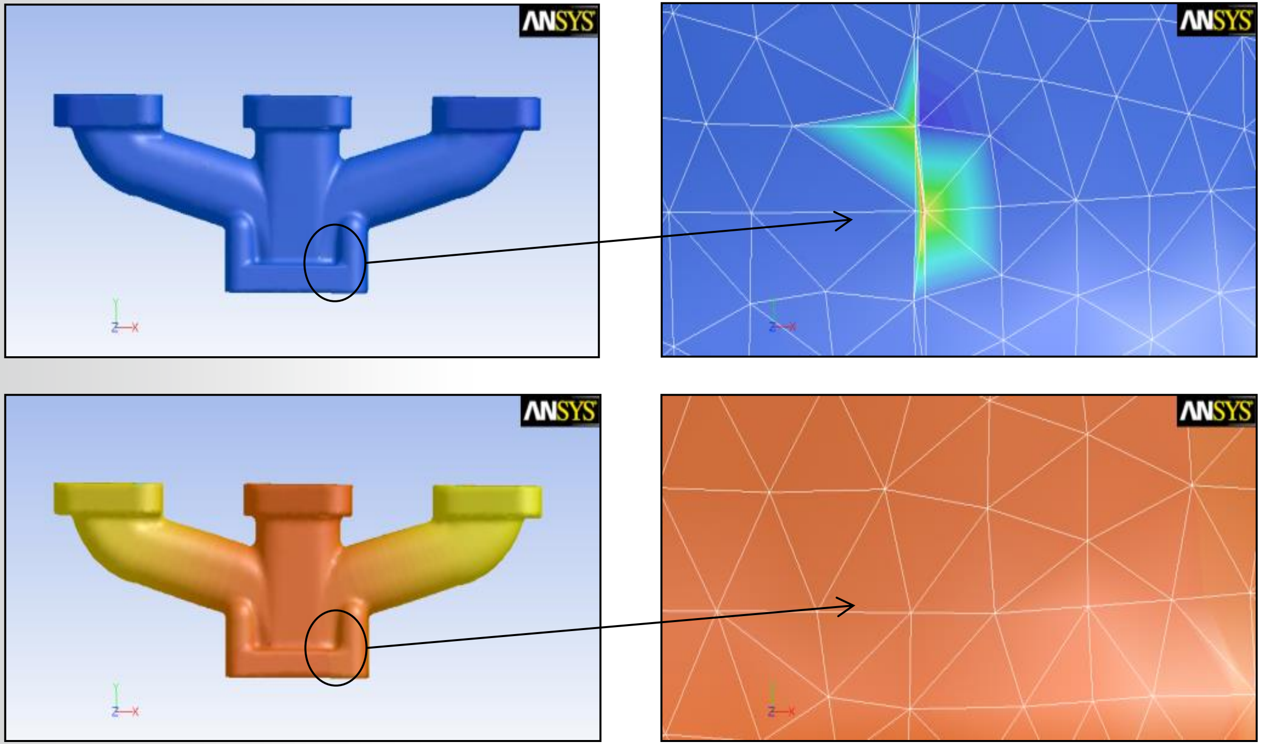


Table of Design Points

	A	B	C	D	E	F
1	Name	P1 - Sweep Method 3 Sweep Element Size	P2 - Sweep Method 2 Sweep Element Size	P3 - Sweep Method Sweep Element Size	P4 - Face Sizing Element Size	P6 - Dp
2		m	m	m	m	Pa
3	Current	0.04	0.04	0.04	0.02	747.88
4	DP 1	0.02	0.02	0.02	0.01	500.44
5	DP 2	0.01	0.01	0.01	0.005	361.4
6	DP 3	0.005	0.005	0.005	0.0025	307.6
7	DP 4	0.0025	0.0025	0.0025	0.00125	299.86
*						

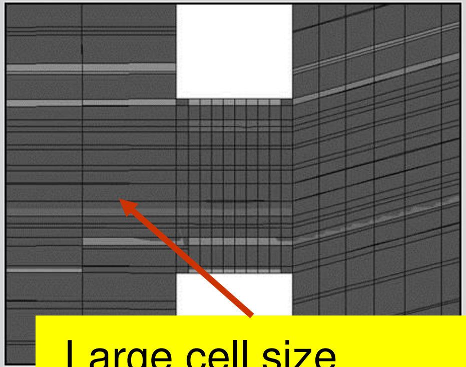
Impact of the Mesh Quality on the Solution

- **Example showing difference between a mesh with cells failing the quality criteria and a good mesh**
- **Unphysical values in vicinity of poor quality cells**

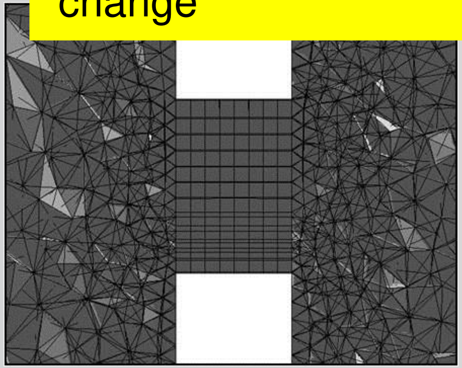


Impact of the Mesh Quality on the Solution

- Diffusion example

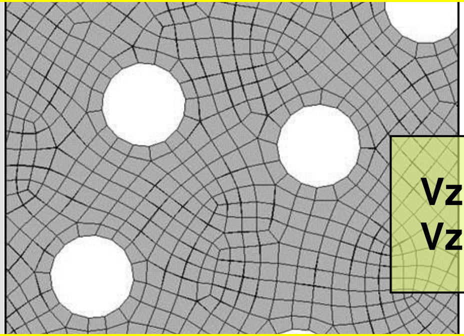


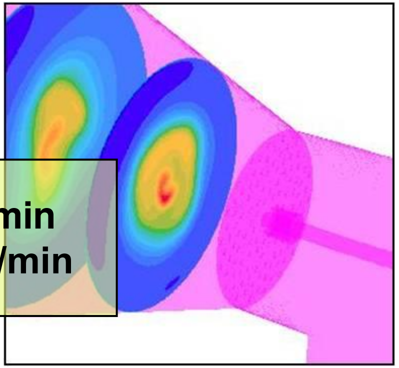
Large cell size change



Mesh 1

(max,avg)$_{CSKEW}$=(0.912,0.291)
(max,avg)$_{CAR}$=(62.731,7.402)

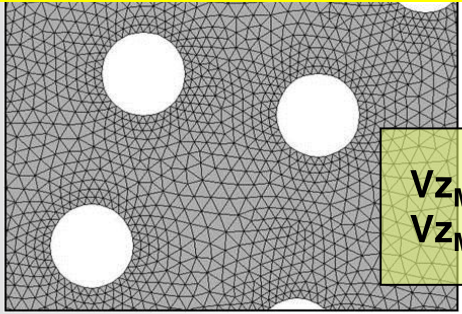


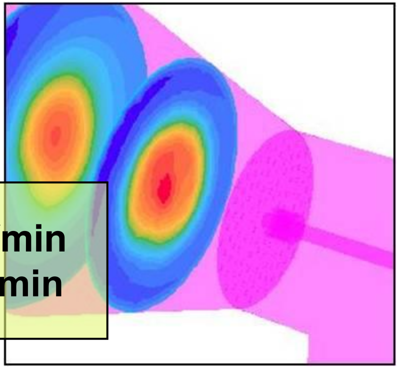


Vz_{MIN}≈-90ft/min
Vz_{MAX}≈600ft/min

Mesh 2

(max,avg)$_{CSKEW}$=(0.801,0.287)
(max,avg)$_{CAR}$=(8.153,1.298)





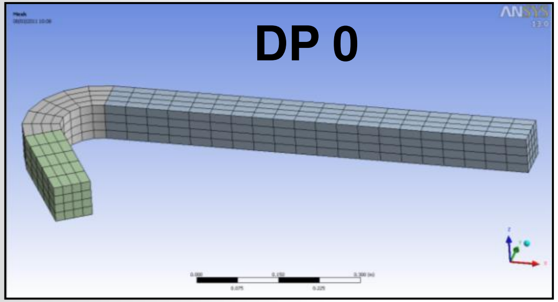
Vz_{MIN}≈-100ft/min
Vz_{MAX}≈400ft/min

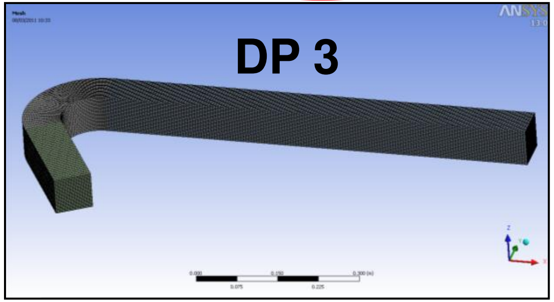
Grid Dependency

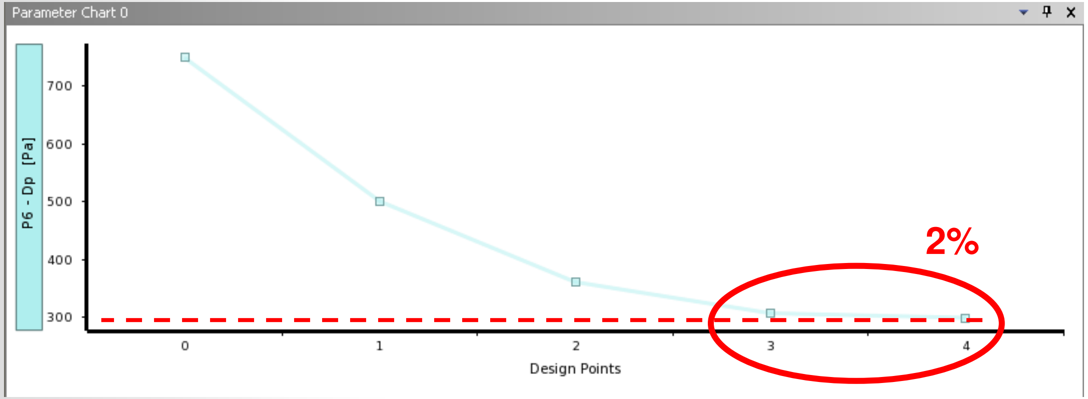
	DP 0	DP 1	DP 2	DP 3	DP 4
Nb Cells	500	3 000	24 000	190 000	1.5 M

x8

- Solution run with multiple meshes
- Note : For all runs the computed Y+ is valid for wall function (first cell not in laminar zone)

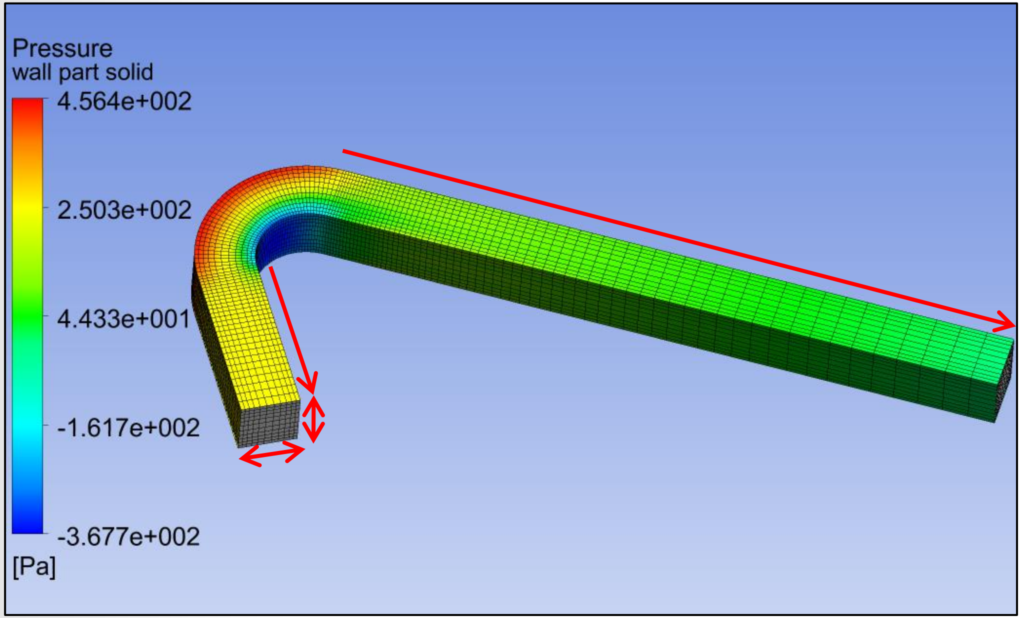






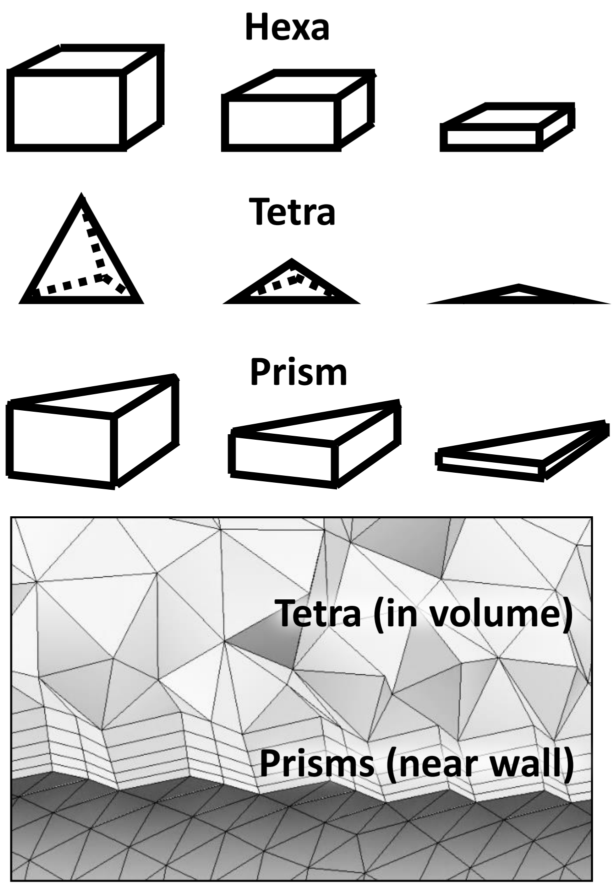
Grid Dependency

- **Hexa cells can be stretched in stream direction to reduce number of cells**
- **Bias defined on inlet and outlet walls**
- **Bias defined on inlet edges**
  - **16 000 cells (~DP2)**
  - **Delta P = 310 Pa (~DP3)**



Hexa vs. Tetra

- **Hexa: Concentration in one direction**
  - Angles unchanged
- **Tetra: Concentration in one direction**
  - Angles change
- **Prism: Concentration in one direction**
  - Angles unchanged
- **Solution for boundary layer resolution**
  - Hybrid prism/tetra meshes
  - Prism in near-wall region, tetra in volume
  - Automated
  - Reduced CPU-time for good boundary layer resolution



Mesh Statistics and Mesh Metrics

Displays mesh information for Nodes and Elements

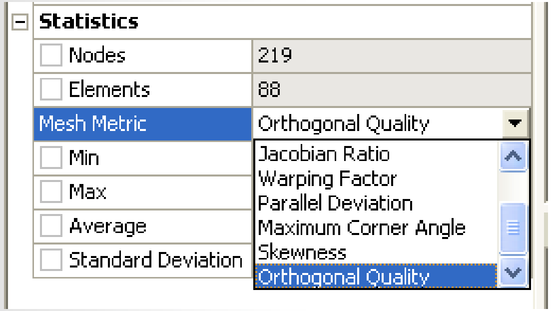
List of quality criteria for the Mesh Metric

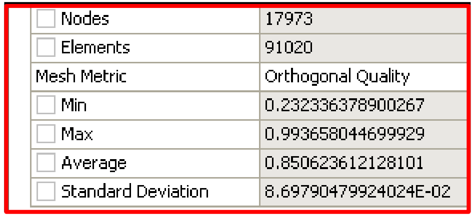
- **Select the required criteria to get details for quality**
- **It shows minimum, maximum, average and standard deviation**

Different physics and different solvers have different requirements for mesh quality

Mesh metrics available in ANSYS Meshing include:

- **Element Quality**
- **Aspect Ratio**
- **Jacobean Ration**
- **Warping Factor**
- **Parallel Deviation**
- **Maximum Corner Angle**
- **Skewness**
- **Orthogonal Quality**





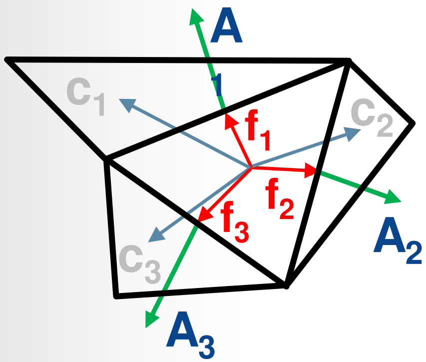
For Multi-Body Parts, go to corresponding body in Tree Outline to get its separate mesh statistics per part/body

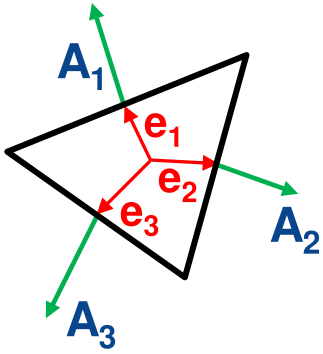
Mesh Quality Metrics

Orthogonal Quality (OQ)

On cell

On face





Derived directly from

Fluent solver discretization

- ***For a cell*** **it is the minimum of:**

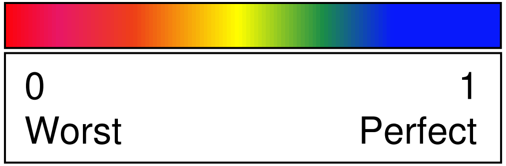
$$\frac{A_i \cdot f_i}{|\vec{A_i}||\vec{f_i}|} \qquad \frac{A_i \cdot c_i}{|\vec{A_i}||\vec{c_i}|}$$

computed for each face *i*

For the face **it is computed as the minimum of** $\frac{A_i \cdot e_i}{|\vec{A_i}||\vec{e_i}|}$ **computed for each edge *I***

Where *Ai* is the face normal vector and *fi* is a vector from the centroid of the cell to the centroid of that face, and *ci* is a vector from the centroid of the cell to the centroid of the adjacent cell, where *ei* is the vector from the centroid of the face to the centroid of the edge

At boundaries and internal walls *ci* is ignored in the computations of OQ



Mesh Quality Metrics

Skewness

Two methods for determining skewness:

1. Equilateral Volume deviation:

$$\text{Skewness} = \frac{\text{optimal cell size} - \text{cell size}}{\text{optimal cell size}}$$

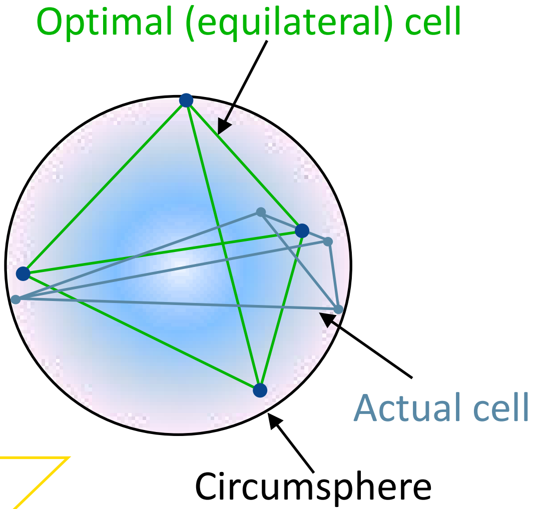
   Applies only for triangles and tetrahedrons

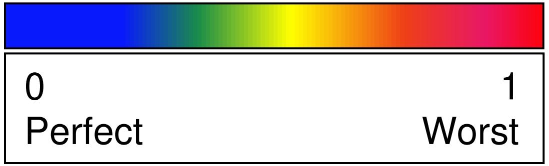
2. Normalized Angle deviation:

$$\text{Skewness} = \max\left[\frac{\theta_{max} - \theta_e}{180 - \theta_e}, \frac{\theta_e - \theta_{min}}{\theta_e}\right]$$

   Where θ_e is the equiangular face/cell (60 for tets and tris, and 90 for quads and hexas)

   – Applies to all cell and face shapes
   – Used for hexa, prisms and pyramids





Mesh Quality

Mesh quality recommendations

Low Orthogonal Quality or high skewness values are not recommended

Generally try to keep minimum orthogonal quality > 0.1, or maximum skewness < 0.95. However these values may be different depending on the physics and the location of the cell

Fluent reports negative cell volumes **if the mesh contains degenerate cells**

Skewness mesh metrics spectrum

Excellent	Very good	Good	Acceptable	Bad	Unacceptable
0-0.25	0.25-0.50	0.50-0.80	0.80-0.94	0.95-0.97	0.98-1.00

Orthogonal Quality mesh metrics spectrum

Unacceptable	Bad	Acceptable	Good	Very good	Excellent
0-0.001	0.001-0.14	0.15-0.20	0.20-0.69	0.70-0.95	0.95-1.00

Aspect Ratio

2-D:

- Length / height ratio: $\delta x/\delta y$

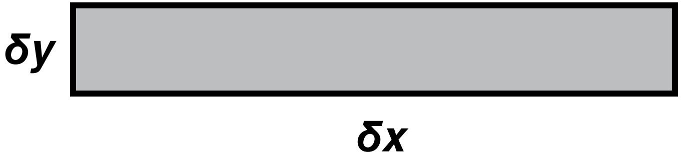
3-D

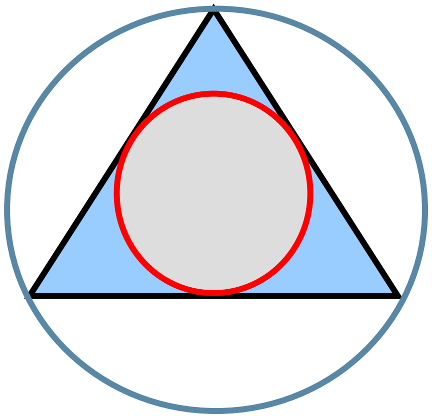
- Area ratio
- Radius ratio of circumscribed / inscribed circle

Limitation for some iterative solvers

- A < 10 … 100
- (CFX: < 1000)

Large aspect ratio are accepted where there is no strong transverse gradient (boundary layer ...)

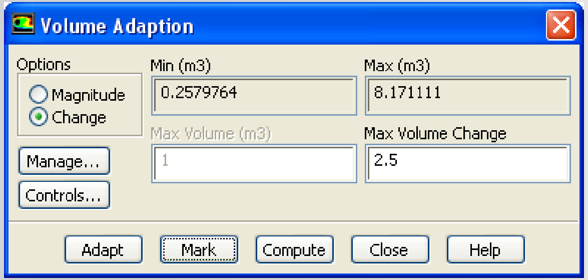




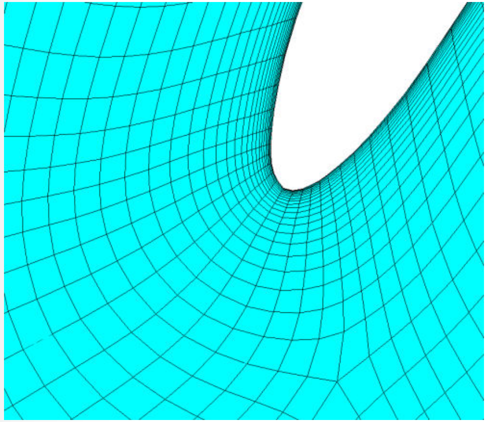
Smoothness

Checked in solver

- **Volume Change in Fluent**
  - Available in Adapt/Volume
  - *3D :* $\sigma_i = V_i / V_{nb}$

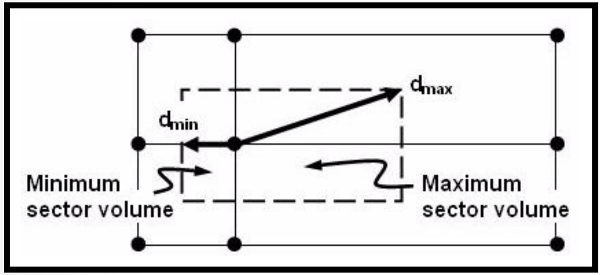


- **Expansion Factor in CFX**
  - Checked during mesh import
  - Ratio of largest to smallest element volumes surrounding a node

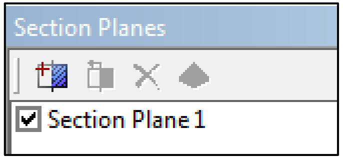


Recommendation:

Good: 1.0 < σ < 1.5
Fair: 1.5 < σ < 2.5
Poor: σ > 5 … 20



Section Planes



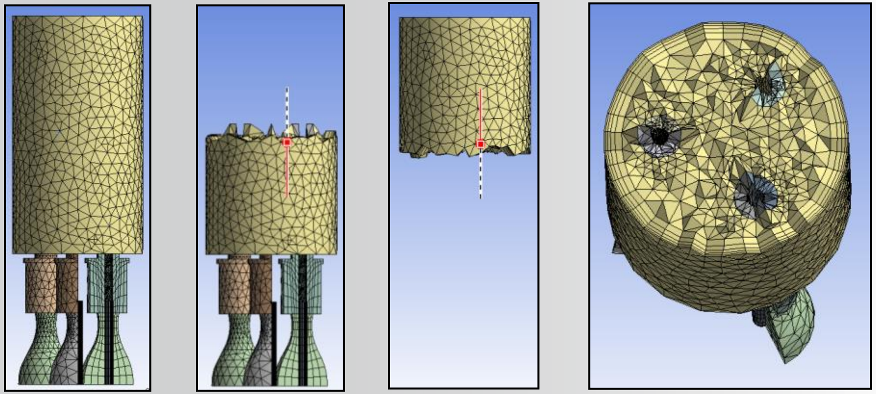
Displays internal elements of the mesh

- Elements on either side of plane can be displayed
- Toggle between cut or whole elements display
- Elements on the plane

Edit Section Plane button can be used to drag section plane to new location

- Clicking on "Edit Section Plane" button will make section plane's anchor to appear

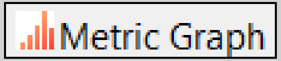
Multiple section planes are allowed



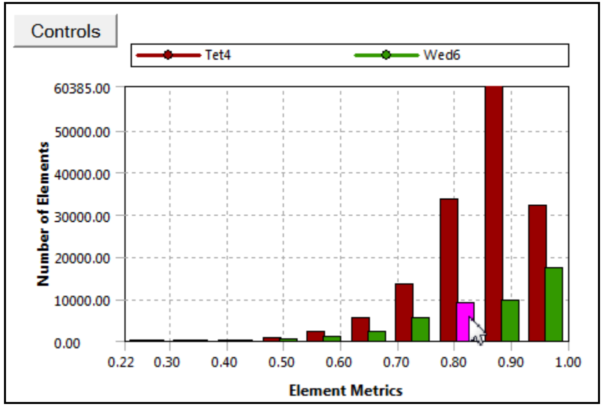
For large meshes, it is advisable to switch to geometry mode (click on geometry in the Tree Outline), create the section plane and then go back to mesh model

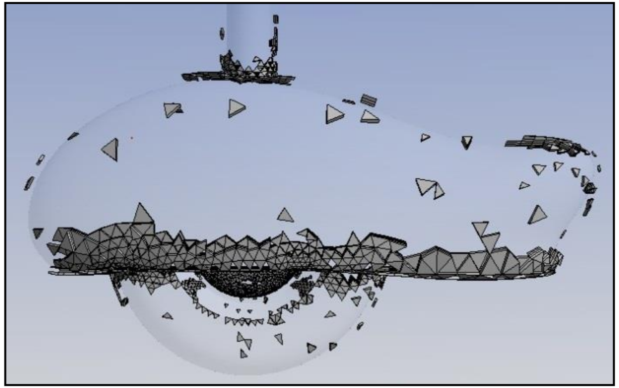
Mesh Metric Graph

- **Displays Mesh Metrics graph for the element quality distribution**
- **Different element types are plotted with different color bars**
- **Can be accessed through menu bar using Metric Graph button**



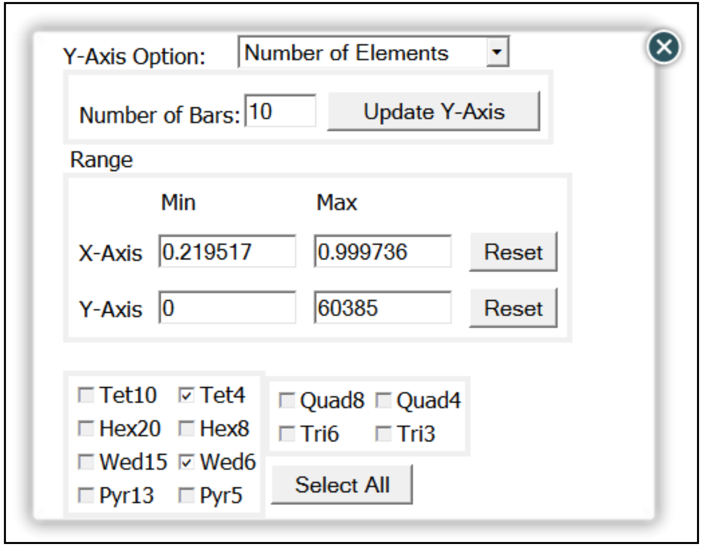
- **Axis range can be adjusted using controls button (details next slide)**
- **Click on bars to view corresponding elements in the graphics window**
  - Use to help locate poor quality elements





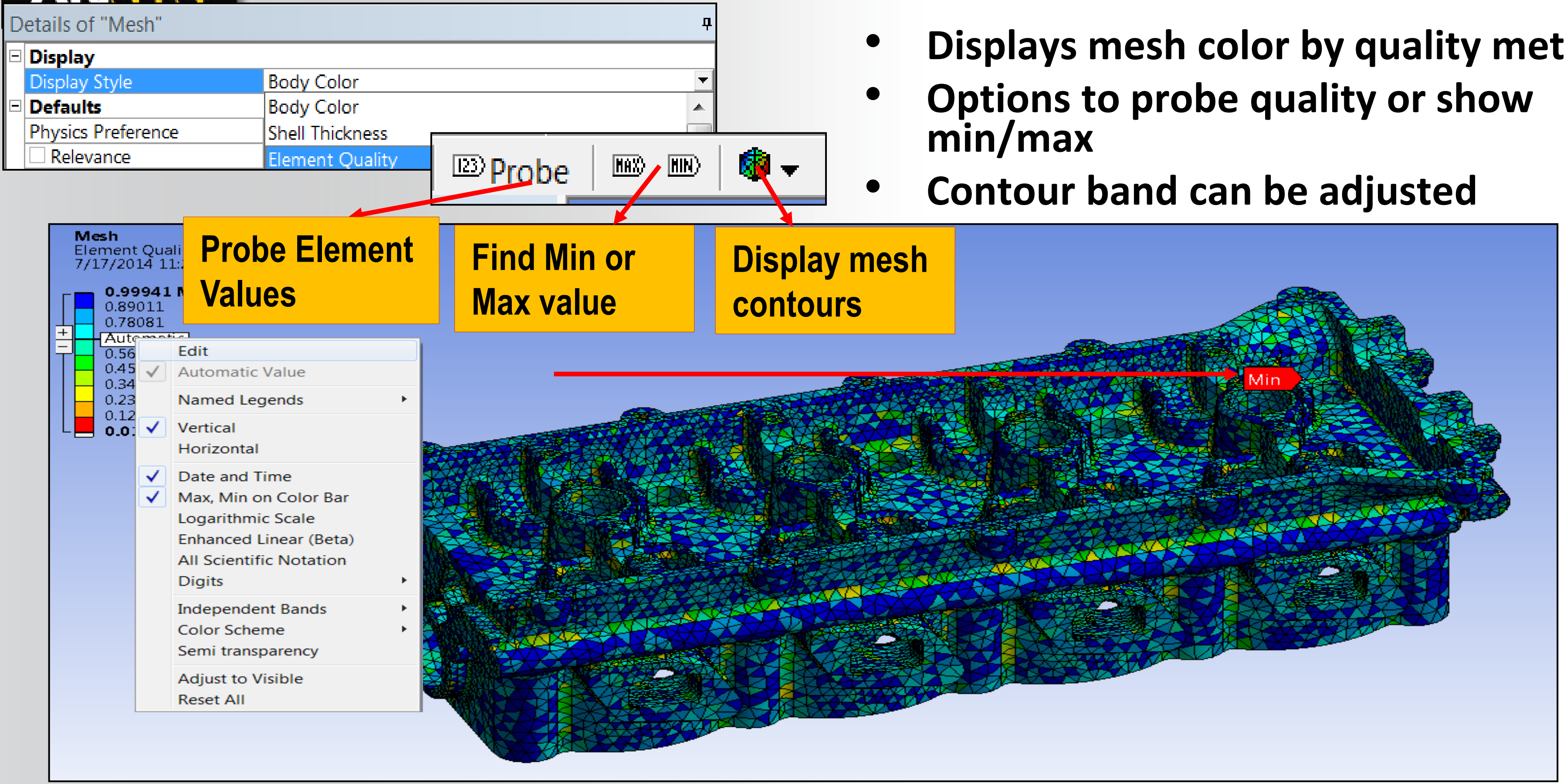
Mesh Metric Graph Controls

- **Elements on Y-Axis can be plotted with two methods;**
  - Number of Elements
  - Percentage of Volume/Area
- **Options to change the range on either axis**
- **Specify which element types to include in graph**
  - Tet4 = 4 Node Linear Tetrahedron
  - Hex8 = 8 Node Linear Hexahedron
  - Wed6 = 6 Node Linear Wedge (Prism)
  - Pyr5 = 5 Node Linear Pyramid
  - Quad4 = 4 Node Linear Quadrilateral
  - Tri3 = 3 Node Linear Triangle
    - Te10, Hex20, Wed15, Pyr13, Quad8 & Tri6 non-linear elements



Display Option: Color by quality

- Displays mesh color by quality metrics
- Options to probe quality or show min/max
- Contour band can be adjusted



Mesh Quality Check for CFX

- The CFX solver calculates 3 important measures of mesh quality at the start of a run and updates them each time the mesh is deformed
- Mesh Orthogonality
- Aspect Ratio
- Expansion Factor

```
 +--------------------------------------------------------------------+
 |                          Mesh Statistics                           |
 +--------------------------------------------------------------------+
 Domain Name: Air Duct
     Minimum Orthogonality Angle [degrees]                =     20.4 ok
     Maximum Aspect Ratio                                 =     13.5 OK
     Maximum Mesh Expansion Factor                        =    700.4  !
 Domain Name: Water Pipe
     Minimum Orthogonality Angle [degrees]                =     32.8 ok
     Maximum Aspect Ratio                                 =      6.4 OK
     Maximum Mesh Expansion Factor                        =     73.5  !
Global Mesh Quality Statistics :
     Minimum Orthogonality Angle [degrees]                =     20.4 ok
     Maximum Aspect Ratio                                 =     13.5 OK
     Maximum Mesh Expansion Factor                        =    700.4  !
```

Good
(OK)

Acceptable
(ok)

Questionable
(!)

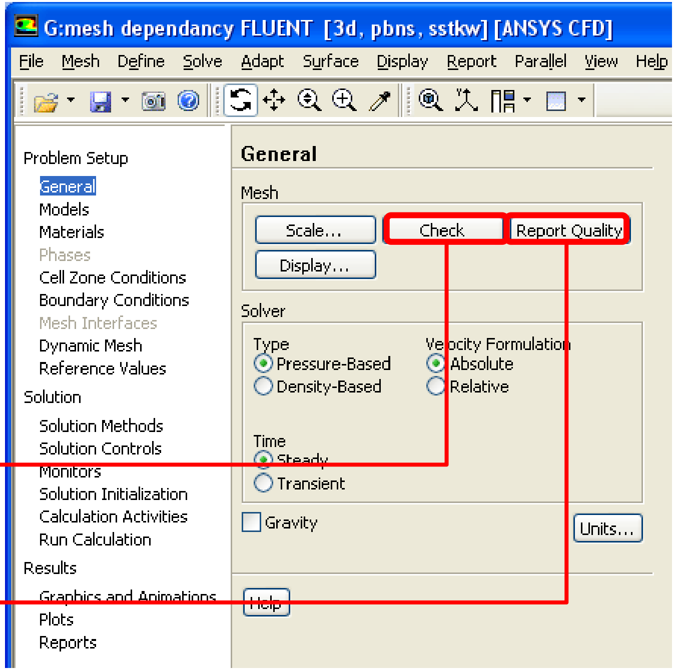
Mesh Quality Check for Fluent

Grid check tools available

- *Check* : Perform various mesh consistency checks
- *Report Quality* : lists worse values of orthogonal quality and aspect ratio
- TUI command *mesh/check-verbosity* sets the level of details in the report

```
Domain Extents:
  x-coordinate: min (m) = -1.349580e-01, max (m) = 8.000000e-01
  y-coordinate: min (m) = -2.407051e-01, max (m) = 1.350000e-01
  z-coordinate: min (m) = -3.500000e-02, max (m) = 3.500000e-02
Volume statistics:
  minimum volume (m3): 2.067421e-08
  maximum volume (m3): 3.187442e-07
    total volume (m3): 5.925829e-03
Face area statistics:
  minimum face area (m2): 6.187846e-06
  maximum face area (m2): 1.274684e-04
Checking mesh.........................
Done.

Mesh Quality:
 Orthogonal Quality ranges from 0 to 1, where values close to 0 correspond to low quality.
Minimum Orthogonal Quality =   9.99641e-01
Maximum Aspect Ratio =   2.03929e+01
```



Factors Affecting Quality

Geometry problems

- Small edge
- Gaps
- Sharp angle

⇒ **Geometry cleanup in Design Modeler**
or
Virtual topology & pinch in Meshing

Meshing parameters

- Sizing Function On / Off
- Min size too large
- Inflation parameters
  - Total height
  - Maximum angle
- Hard sizing

⇒ **Mesh setting change**

Meshing methods

- Patch conformal or patch independent tetra
- Sweep or Multizone
- Cutcell

⇒ **Mesh setting change**

Virtual Topology

When to use?

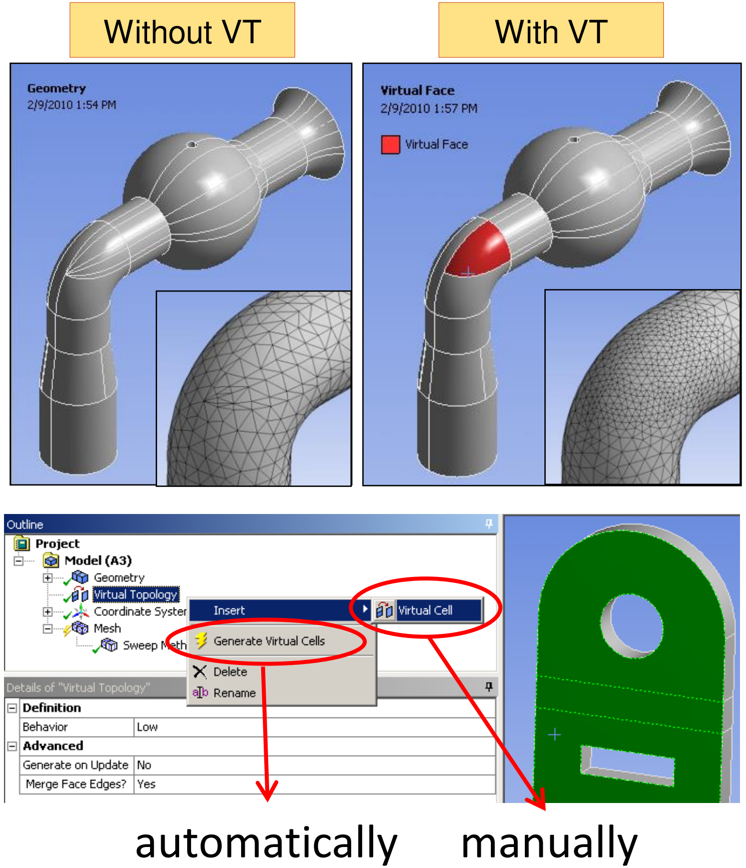
- To merge together a number of small (connected) faces/edges
- To simplify small features in the model
- To simplify load abstraction for mechanical analysis
- To create edge splits for better control of the surface mesh control

Virtual cells modify topology

- Original CAD model remains unchanged
- New faceted geometry is created with virtual topology

Restrictions

- Limited to “developable” surfaces
- Virtual Faces cannot form a closed region



Automatic Virtual Topology

Automatically creating *Virtual Faces*

- Left Click *Virtual Topology* in *Model Tree*
- Set *Behaviour* in *Details*
  - Controls aggressiveness of automatic VT algorithm
  - Low: merges only the worst faces (and edges)
  - Medium & High: try to merge more faces
  - Custom: User Defined values for custom cleanup
  - Repair: Just does some limited cleanup for small faces and edges
- Select if Face Edges shall be merged
- Right Click *Virtual Topology* and click *Generate Virtual Cells*

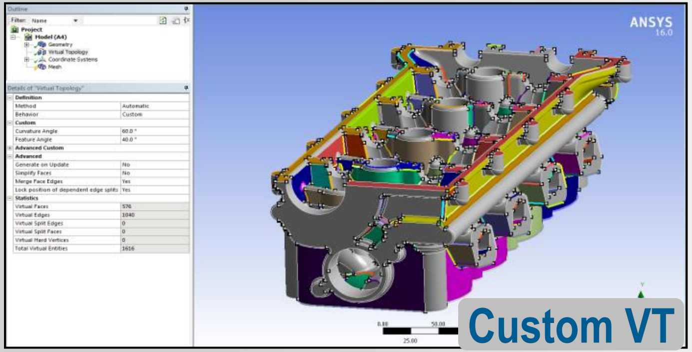
Manually creating a Virtual Face

- RMB on Model tree and select Insert Virtual Topology
- Select Virtual Topology from the Tree Outline
- Pick faces or edges, RMB and Insert Virtual Cell

All VT entities created can be seen in different colors if Virtual Topology is selected in Tree Outline

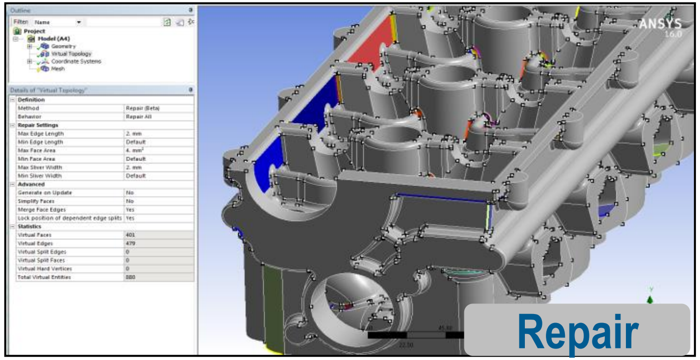
Auto-VT Methods

Custom Auto-VT & VT Repair operations provide automated ways of simplifying geometry:



Advantages:

- More control over curvature. Creating VTs w/too much curvature can some times make meshing less successful.



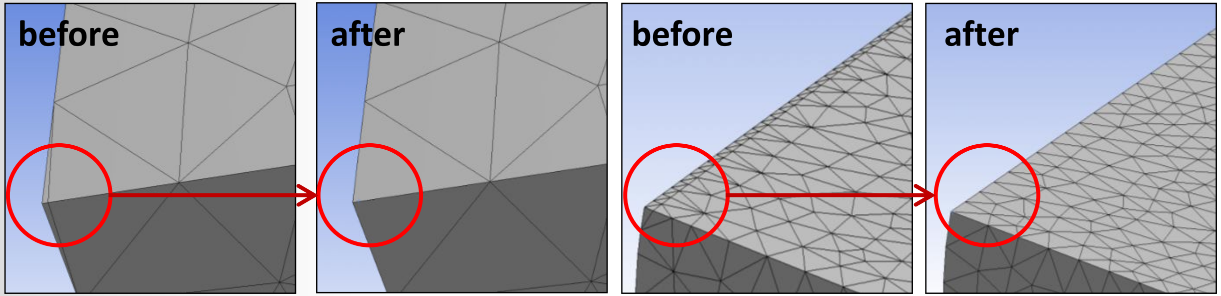
Advantages:

- Targeted ways of removing small edges, faces and slivers
- Can be used with other Auto-VT methods or in place of them.

Note: Mesh Based Defeaturing is the recommended approach for detailed models cleanup. It is much more robust, as it cleans at mesh level. Virtual Topology is recommended for only those cases/bodies where Mesh Based Defeaturing is not effective. VT can also be used for any selective local cleanup which was not handled by mesh based defeaturing.

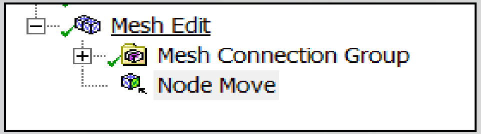
Pinch

- **Pinch control removes small features automatically or manually at the mesh level**
  - Slivers
  - Short Edges
  - Sharp Angles
- **The Pinch feature works on vertices and edges only**
- **The Pinch feature is supported for the following mesh methods:**
  - Patch Conforming Tetrahedrons
  - Thin Solid Sweeps
  - Hex Dominant meshing
  - Quad Dominant Surface meshing
  - Triangles Surface meshing
- **Not supported for**
  - CutCell
  - Patch Independent
  - Multizone & General Sweep

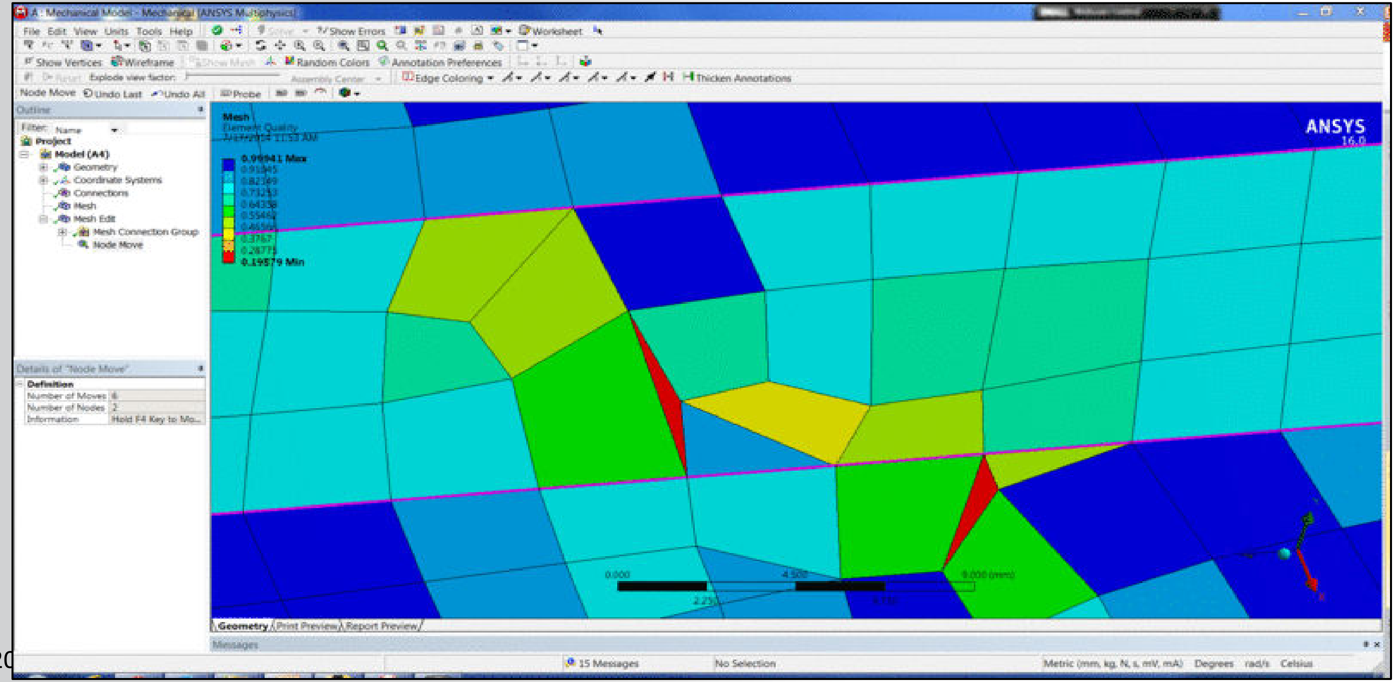


Vertex-Vertex **Edge-Edge**

Mesh Editing: Move node

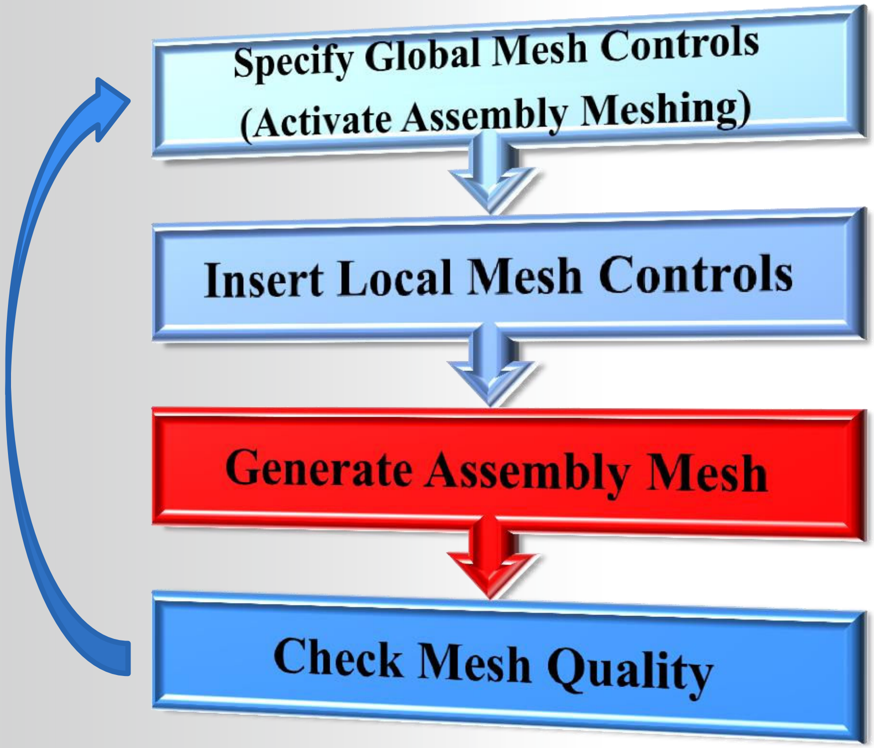


- **Dynamically pick and drag nodes around (quality plots updated real time)**
- **History of moves is recorded in Worksheet and allows for "Undo"**



Assembly Meshing

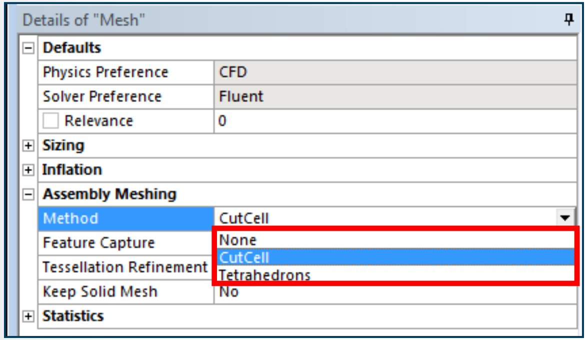
Meshing Process in ANSYS Meshing

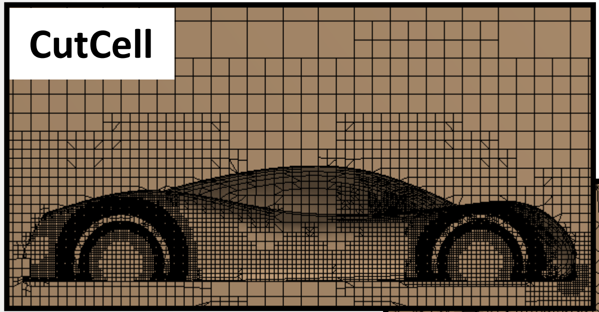


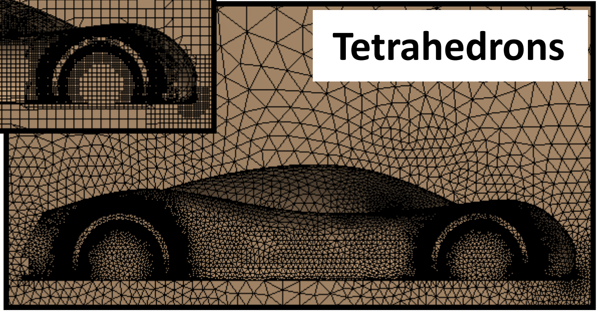
Assembly Meshing

Behavior

- **Meshes an entire model as single process**
  - Mesh Methods covered so far are part or body based methods
  - Not compatible with part/body methods
- **Two Algorithms available**
  - CutCell & Tetrahedrons







Note that some global and local controls are not available for Assembly Meshing (eg. Match Control)

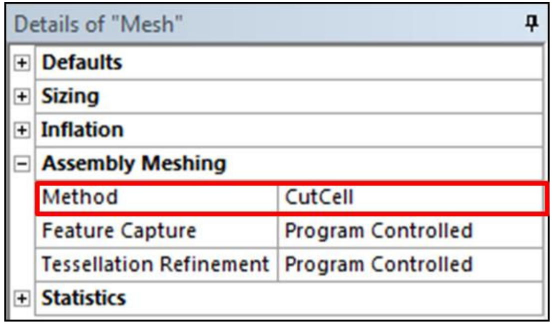
Access

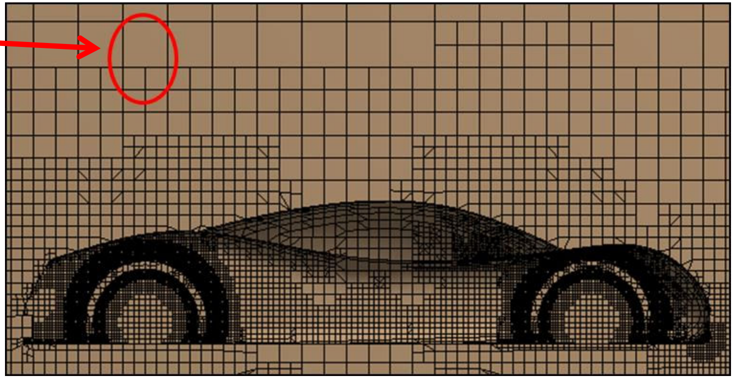
- **Assembly Meshing is accessible only when Physics and Solver Preferences are set to CFD and Fluent respectively**
- **To activate, replace None by Cutcell or Tetrahedrons**

Assembly Meshing - CutCell

CutCell Behavior

- **Cartesian meshing method designed for the ANSYS FLUENT solver**
- **Generates a majority of hex cells**
  - Some wedges, tets and pyramids at boundaries to capture geometry
  - During transfer to Fluent hexa cells at size transition are converted into Polyhedra
- **Supports Inflation**
  - Post-inflation (TGrid algorithm)
    - Baffles not supported
    - High inflation may fail
  - Cutcell mesh generated first, inflation generated second (Post)

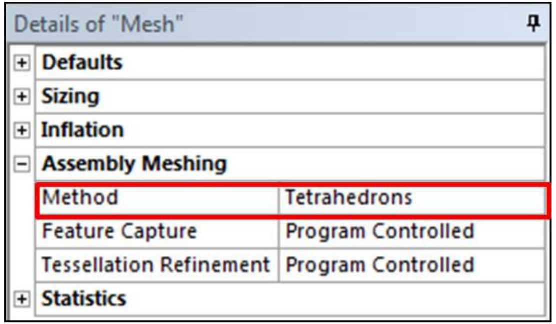


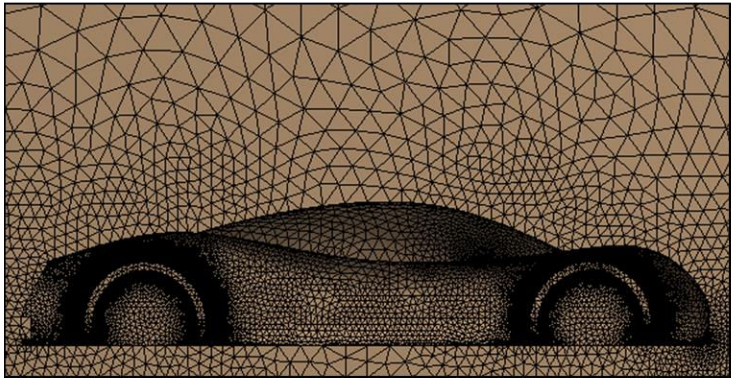


Assembly Meshing - Tetrahedrons

Tetrahedrons Behavior

- **Generates a Patch Independent tetra mesh with automatic defeaturing**
- **Following steps occur in background**
  - Generate CutCell
  - Delete volume mesh
  - Triangulate surface mesh and improve
  - Fill with tetra mesh
- **Compatible with inflation**
  - Pre-inflation
    - Algorithm similar to Tetra Patch Conformal





Assembly Meshing - Controls

Controls

- **Set Advanced Size Functions**
  - Proximity SF Sources : 'edges', ‘faces’ or ‘edges and faces’
  - Define correct Min Size (details next slide)
- **Inflation defined by Global or Local controls**
  - Combined Global & Local not supported
  - Program Control acts on Fluid bodies only
    - Bodies can be set as Fluid in Body properties
  - For Virtual Bodies, only automatic Program Controlled inflation can be used
- **Define Feature and Tesselation controls** (see next slide)
- **Apply any required local size controls**
- **Statistics**
  - Use Orthogonal Quality for Cutcell meshes

Details of "Mesh"

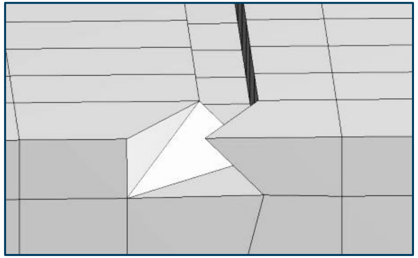
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Relevance	0
Sizing	
Use Advanced Size Function	On: Proximity and Curvature
Relevance Center	Coarse
Smoothing	Medium
Curvature Normal Angle	Default (18.0 °)
Proximity Accuracy	0.5
Num Cells Across Gap	Default (3)
Proximity Size Function Sources	Edges
Min Size	Default (8.2788e-003 m)
Proximity Min Size	Default (8.2788e-003 m)
Max Size	Default (1.05970 m)
Growth Rate	Default (1.20)
Minimum Edge Length	1.9229e-004 m
Inflation	
Use Automatic Inflation	Program Controlled
Inflation Option	Smooth Transition
Transition Ratio	0.272
Maximum Layers	5
Growth Rate	1.2
View Advanced Options	No
Assembly Meshing	
Method	CutCell
Feature Capture	Program Controlled
Tessellation Refinement	Program Controlled
Statistics	
Nodes	326725
Elements	283508
Mesh Metric	Orthogonal Quality
Min	0.167464835445925
Max	1
Average	0.940532742181809
Standard Deviation	8.70021192618728E-02

Assembly Meshing - Controls

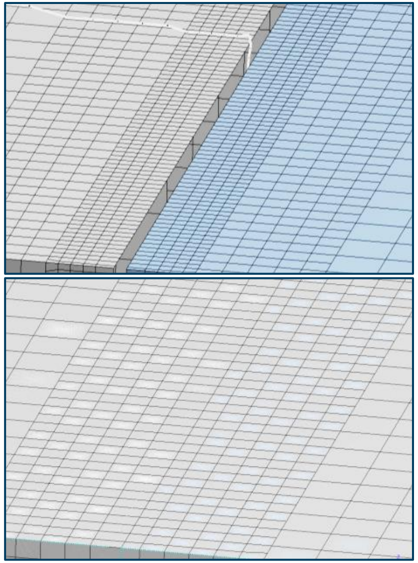
Min Size definition

- **Assembly Meshing is Patch Independent, geometry recovery and leakage depend on local sizes**
- **Local sizes are driven by global min sizes and local hard sizing**
  - ‘Min Size’ and ‘Prox Min Size’ must be set with care
- **Local mesh size recommendation to capture 3D features**
  - Local size < ½ feature size
- **Local mesh size recommendation to close gaps**
  - $^{1}/_{10}$ local size < gap size < ¼ local size : contact sizing can be defined to close gap
  - Gap size < $^{1}/_{10}$ local size : gap closed
- **Prior to meshing the user is advised to resolve geometry features properly in CAD/DM**
  - Avoid unnecessary geometry details
  - Features aligned with Coord. Syst. will be more easily recovered

Example 1. Min Size too large compared to the size of the geometric detail

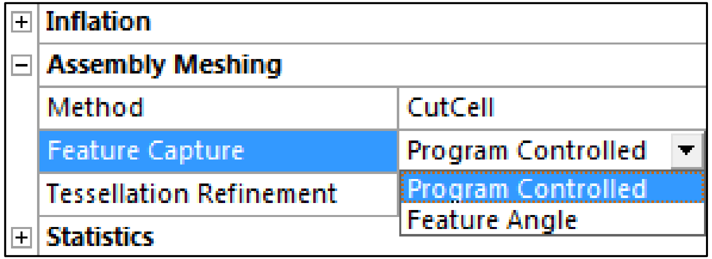


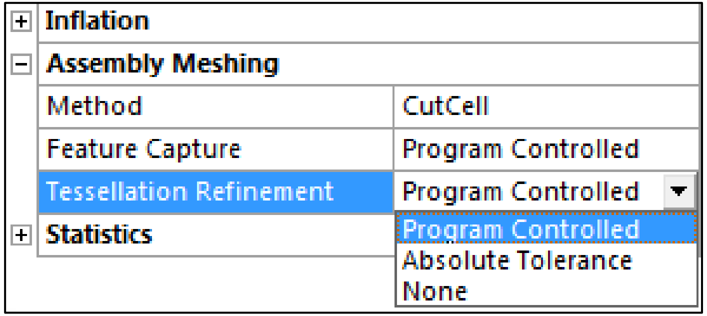
Example2 . Doubling the Min Size closes the gap



Assembly Meshing - Controls

- **Feature Capture**
  - **Program Controlled** : default which sets feature angle = 40
  - **Feature Angle** : user angle to define features to recover
    - 0 to capture all
- **Tessellation (faceting) refinement**
  - **Program Controlled** - default which sets tessellation refinement to 10% of the value of smallest global min size
  - **Absolute Tolerance – user defined tolerance**
    - Must be set to 5-10% of smallest size (global min sizes or local hard sizing)
  - **None** - Sets tessellation refinement to the CAD program or DesignModeler default setting

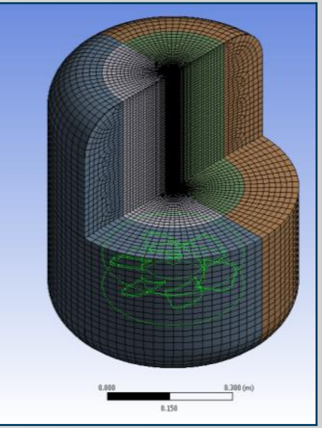




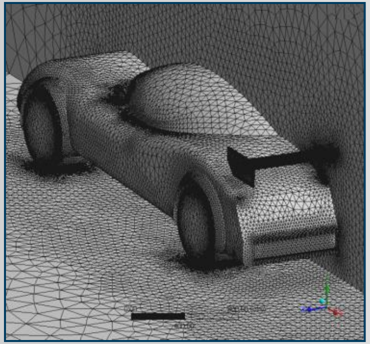
Incorrect tessellation may lead to leakage

Workshops

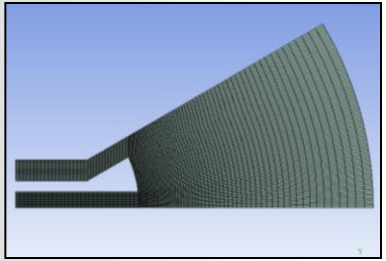
Do any 2 OR 3 workshops from Workshops number 7a, 7b, 7c, 7d and 7e



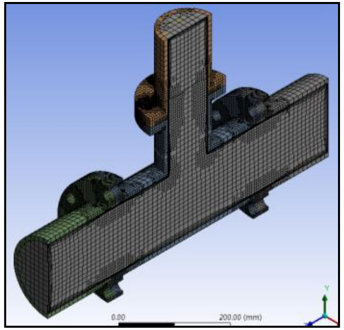
7a



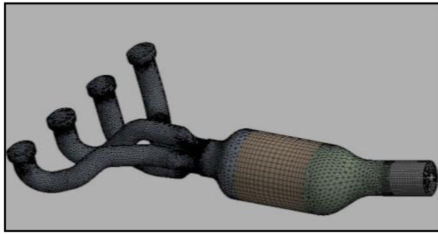
7b



7c



7d



7e

