Meshing

The mesh represents the actual geometry we are modelling
Discrete approximation of the geometry and field

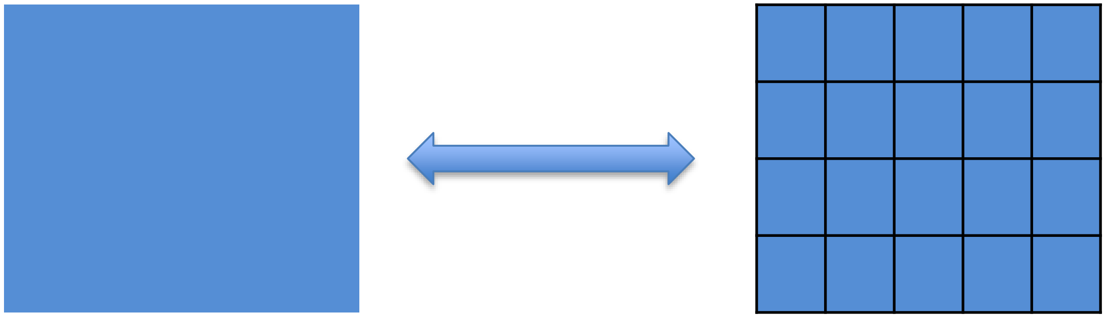
1. Type of cells
2. Type of grids
3. Adaption to geometry / flow
4. Mesh quality parameters
5. Boundary layer mesh
6. Comparison and guidelines

Meshing

Why do we need a grid?

Remember:

$$\left(\frac{\partial f}{\partial x}\right)_{x_i} = \lim_{\Delta x \to 0} \frac{f(x_i + \Delta x) - f(x_i)}{\Delta x}$$



Meshing

Limit cell number ← → Geometric complexity ← → Accuracy

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Meshing – *Definitions*

Vertex → Edge → Face → Volume

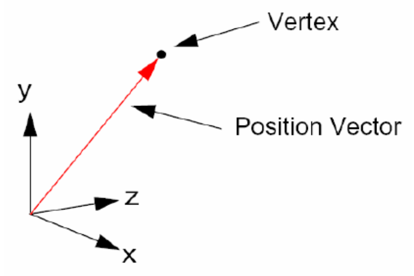
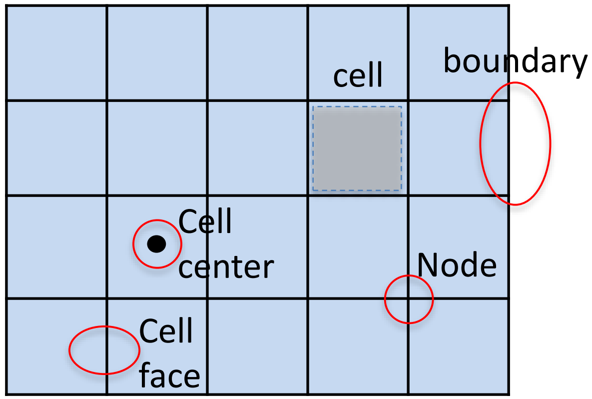


Figure 5.2.1: To the definition of vertex



2D domain

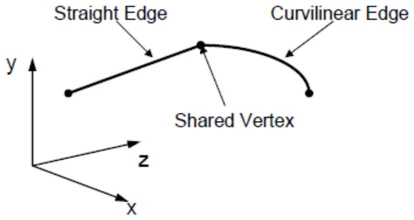
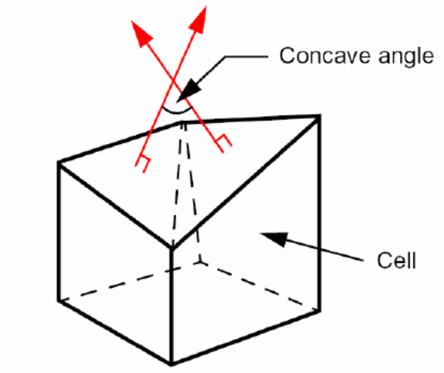
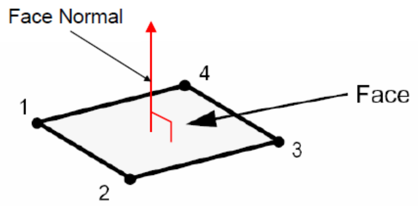


Figure 5.2.2: Straight and curvilinear edges



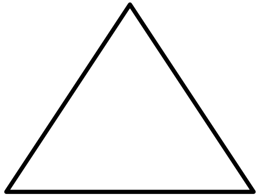


Meshing – *Cell shapes*

2D

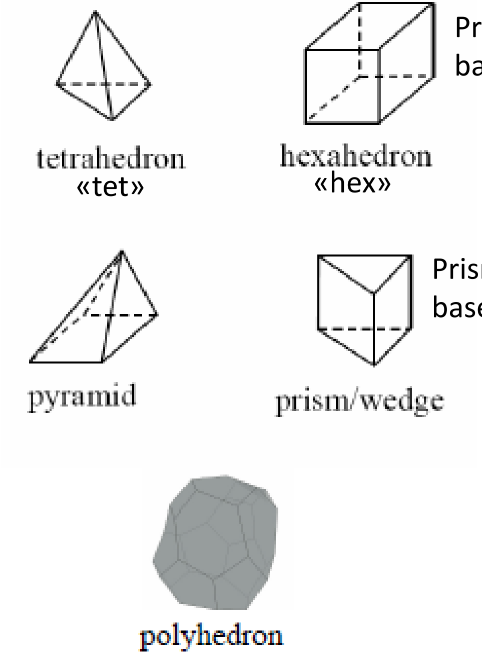
2D prism

Quadrilateral («quad»)



Triangle («tri»)

3D



Prism with “quad” base

Prism with “tri” base

Meshing – *Cell shapes*

1. Hexahedral cells: Easy to use in structured grids, high quality with minimum skewness, excellent numerical properties and less numerical diffusion if aligned with flow direction. May have concave faces. 6 neighbor cells. Structured and unstructured grid
2. Tetrahedral cells: Easy to generate, only planar faces, suitable with complex geometry, only 4 neighbor cells → more cells needed for same accuracy as with hex cells. Should avoid them in highly viscous regions (boundary layer). Unstructured grids
3. Prism and pyramid: Mostly used in boundary layer mesh and in transition between boundaries and core mesh. Get a prism when a hex is split into two.
4. Polyhedral cells: Very good automated mesh properties. Many neighbors (up to 10) and therefore better approximations of gradients. More memory usage. Requires good surface mesh. Unstructured grids

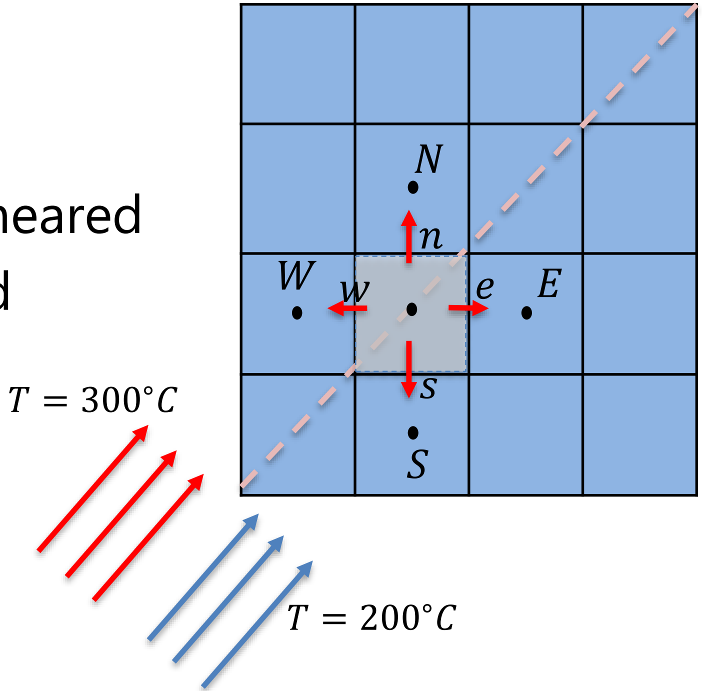
Meshing – *General about cell shapes*

- Tetrahedral use less memory, and the mesh can be generated much faster.
- Tetrahedral requires 5 to 8 times as many cells as with trimmed or polyhedral for same accuracy
- Trimmed (hex) and polyhedral generally more accurate.
- Tetrahedral and polyhedral rely on proper surface meshing (starting point).
- Polyhedral quality of volume mesh can be poorer than tetrahedral starting with a bad surface mesh

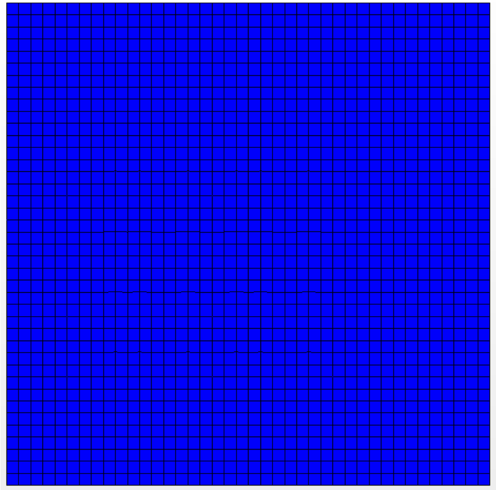
Meshing– False diffusion, example Star CCM+

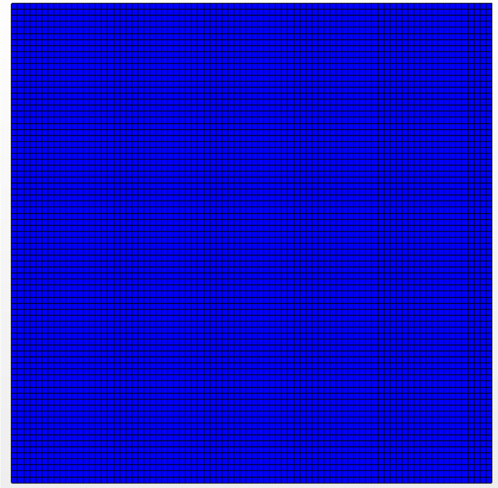
- Assume no physical diffusion
- The solution to this is 300 degC above the diagonal and 200 degC under
- With first order upwind, the solution is smeared
- Need finer grid, and combine with second order upwind

Gridlines should be as parallel with the flow direction as possible



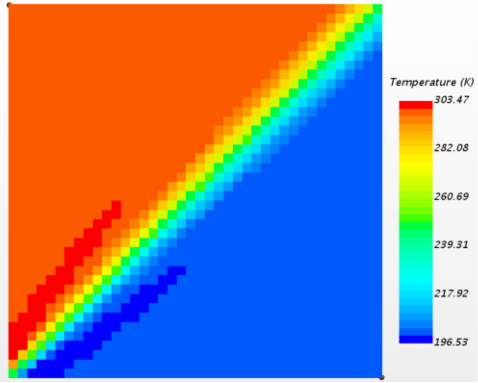
Meshing– *False diffusion, example Star CCM+*

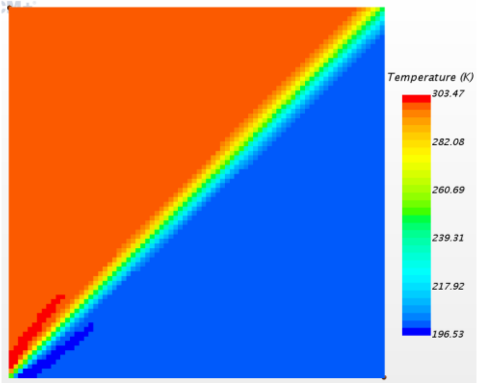




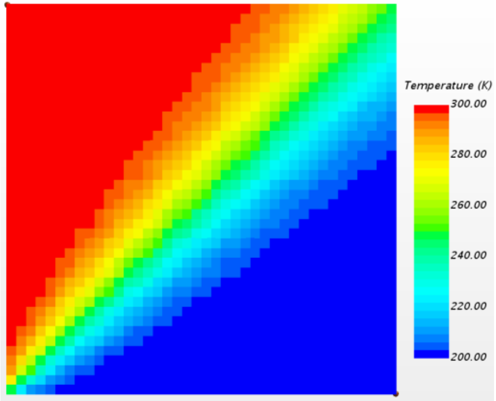
Meshing– *False diffusion, example Star CCM+*

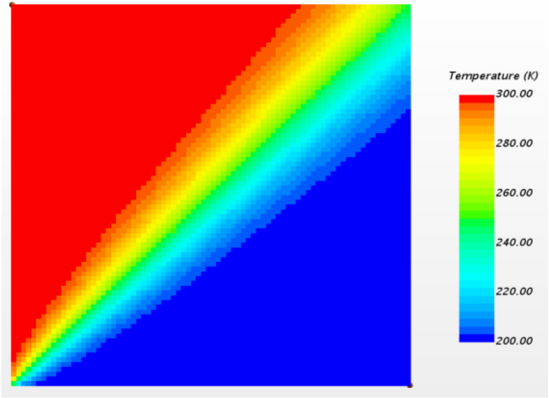
2nd order convection





1st order convection





Meshing – *General Mesh types*

Structured type

Hexahedral mesh + some prisms/pyramids

Multi-block

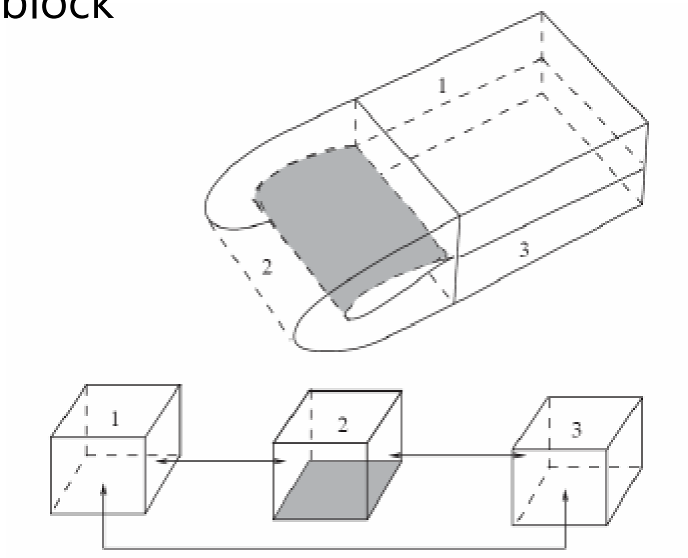


Figure 5.2.15: Sub-division of computation domain around an airfoil for multi-block mesh generation

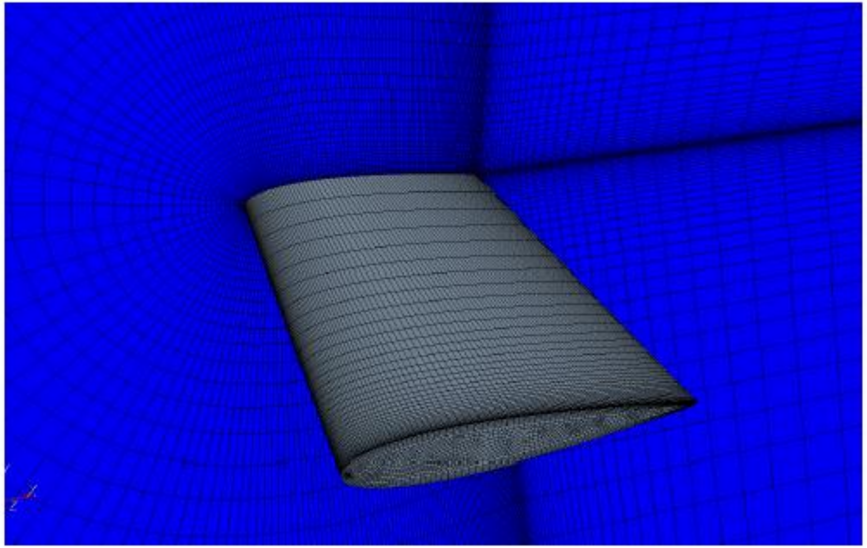


Figure 5.2.16: Multi-block structured hexahedral mesh using H- and C- topologies around an airfoil

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Meshing – *General Mesh types*

Structured type

Trimmed

(Octree decomposition)

Hexahedral mesh

+ some prisms/pyramids

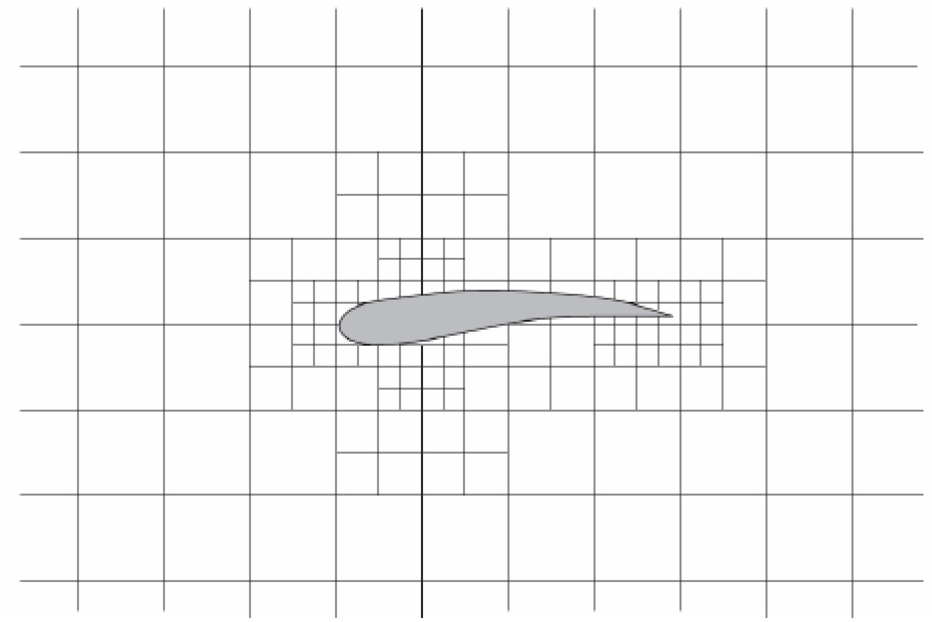
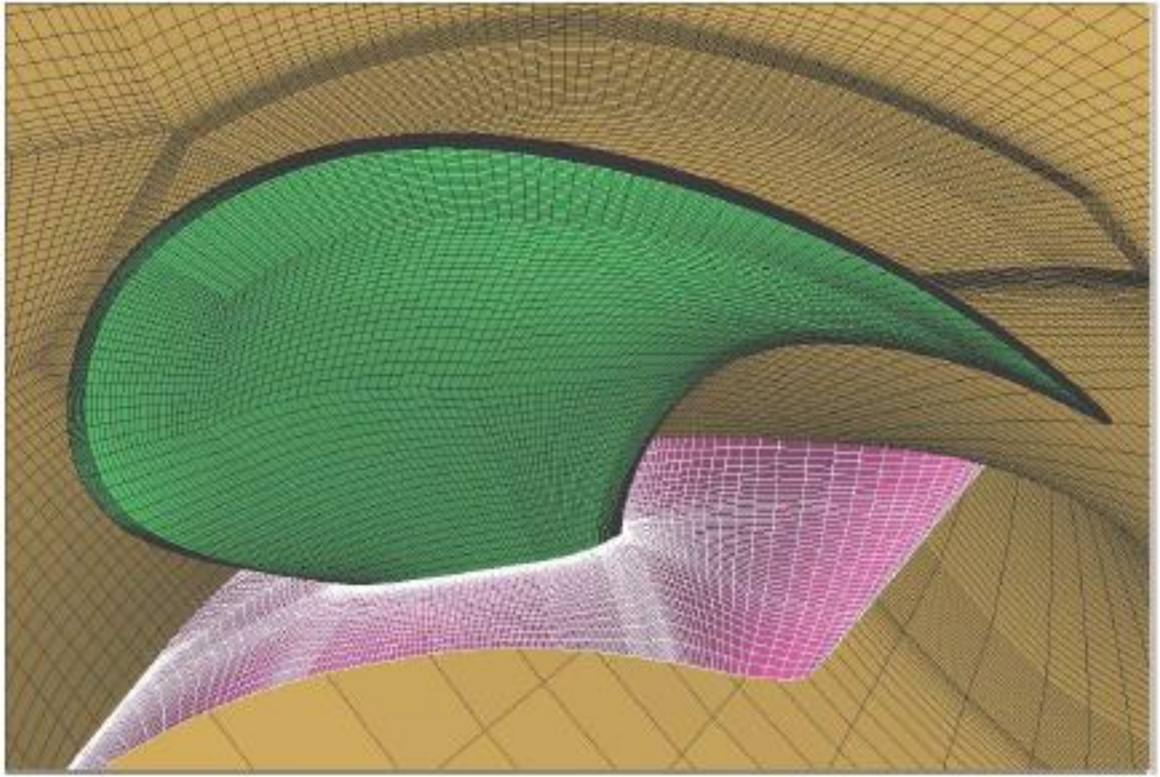


Figure 5.2.12: 2D illustration of Octree decomposition used in the generation of trimmed mesh

Meshing – *General Mesh types*

Structured type

Multi-block



Meshing – *General Mesh types*

Un-Structured type

No regularity

Tetrahedral

Polyhedral

also Hex cells

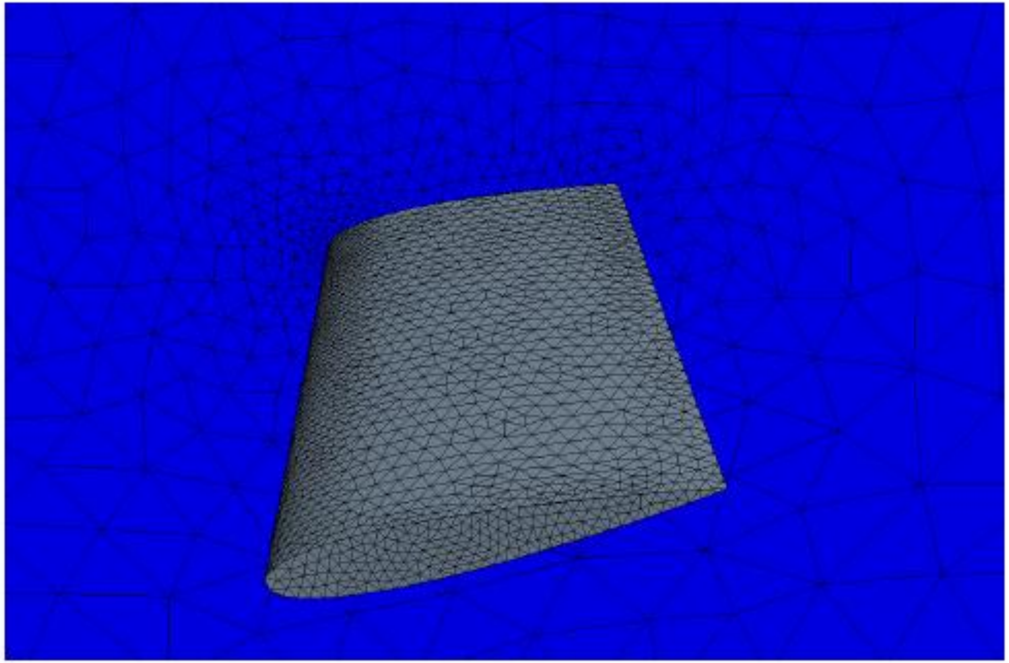


Figure 5.2.19: Fully unstructured tetrahedral mesh around an airfoil

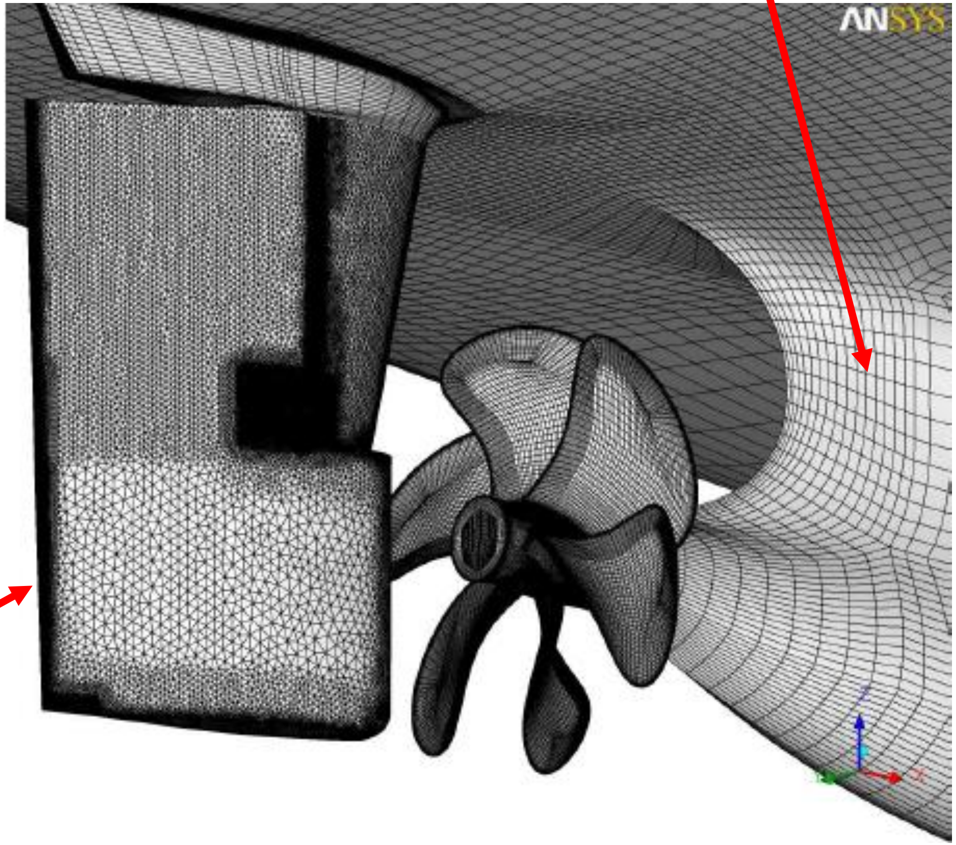
Meshing – *General Mesh types*

Hexahedral

Hybrid type

Propeller and rudder

Aft ship



Tetrahedral

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Meshing – *General Mesh types*

Structured grid:

Gridlines of same family do not cross each other, cross the other family gridlines only ones.

Cartesian mesh is the simplest form with one block of hexahedral cells.

Curvilinear gridlines to account for geometry with curved edges.

Multi-block to get good grid. O-, H- and C- grid.

More time consuming to generate, but offers increased accuracy

More difficult to adapt it to the actual CAD model

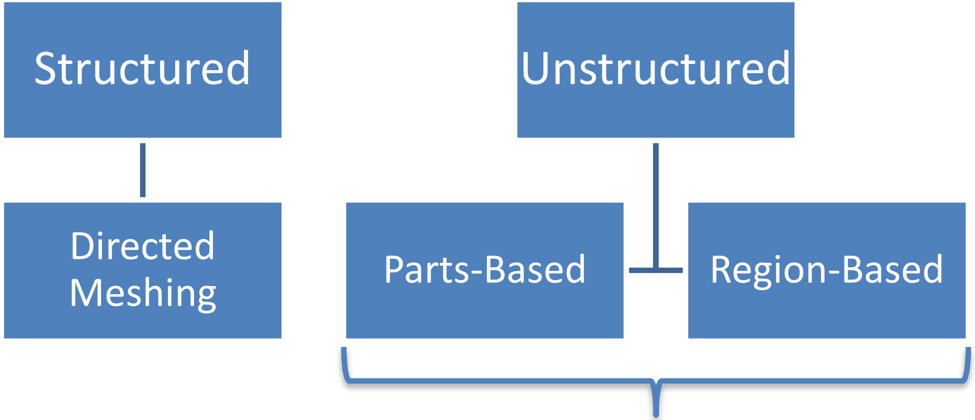
Surface mesh just a byproduct from volume mesh, need good CAD quality

Surface re-meshing should be used

Meshing – *Mesh types in Star CCM+*

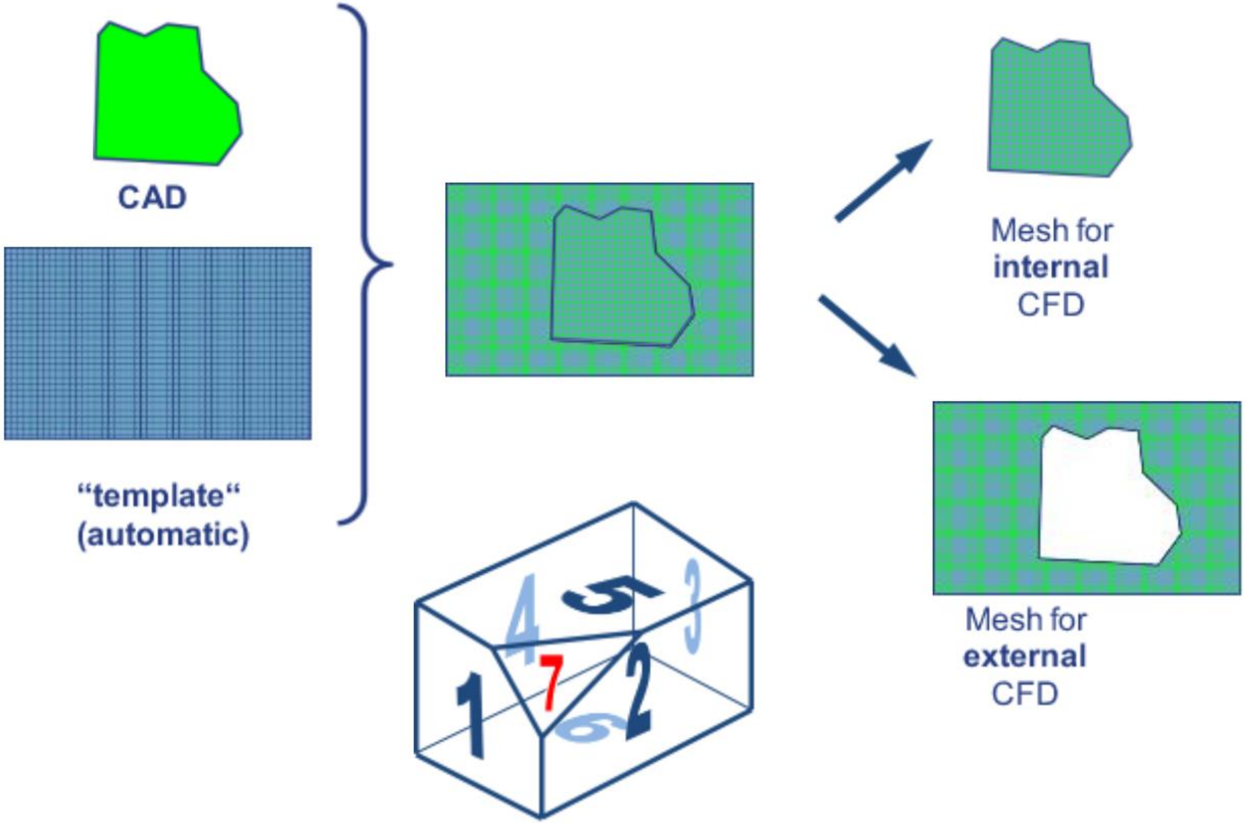
From User-Guide->Pre-Processing->Meshing

<u>FINITE VOLUME MESH TYPES</u>



Surface wrapper
Surface remesher
Polyhedral
Trimmed
....

Generation of Trimmed Volume Mesh



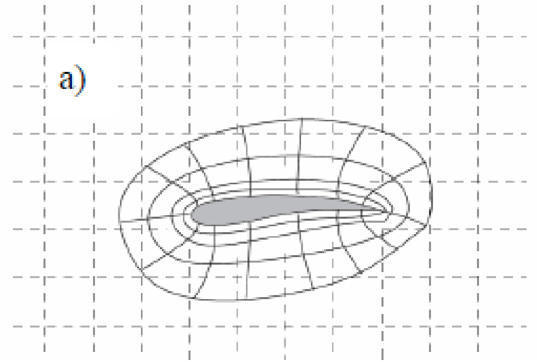
Meshing – *Mesh interface*

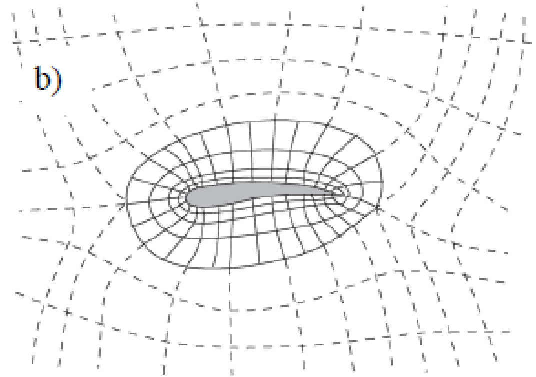
Structured grid:

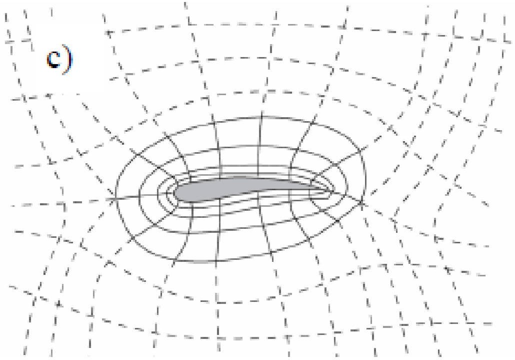
With multi-block it is necessary to have some connectivity between the blocks

Common block interfacing mesh methods:

Overlapping(chimera), non-matching interface, matching interface







Meshing – *Mesh interface*

The same as previous slide is true with multi-region mesh of unstructured type and hybrid mesh.

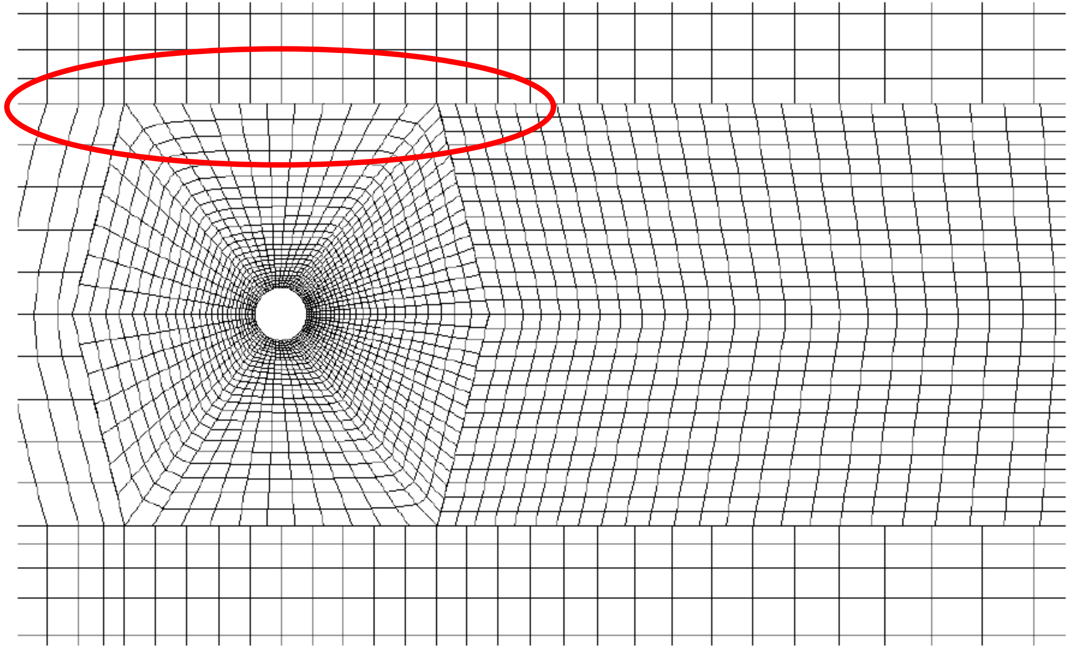
If the mesh between regions of different mesh is non-conformal, should check if the solver can handle this.

Star CCM+ tries to mesh conformal automatically. If not, can modify the CAD model

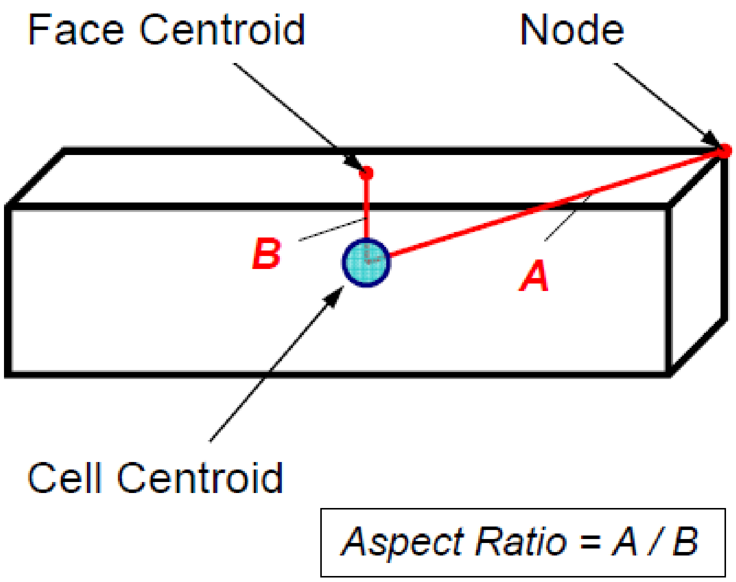
Meshing – *Mesh interfaces*

Non-matching grid

A block-structured, non-matching grid



Meshing – *Mesh quality*



Aspect Ratio:

Measure of stretching

Consequence for resolution of convective fluxes

Stretching along flow direction is less critical

Max 5:1 in interior domain, 10:1 in boundary layer with cells aligned with flow direction.

As low as possible where the flow is multi-dimensional

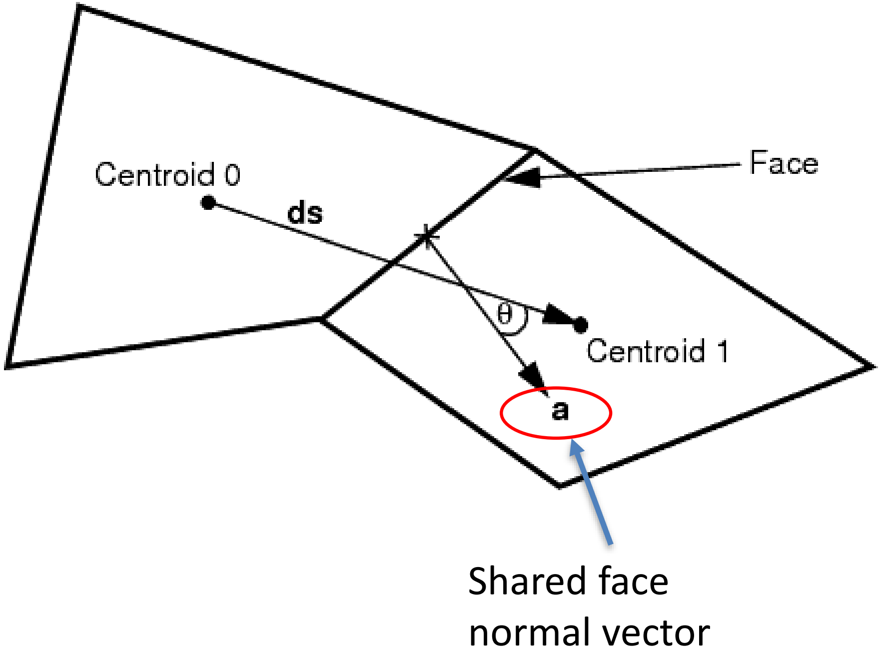
Meshing – *Mesh quality*

Skewness:

Measure non-orthogonality

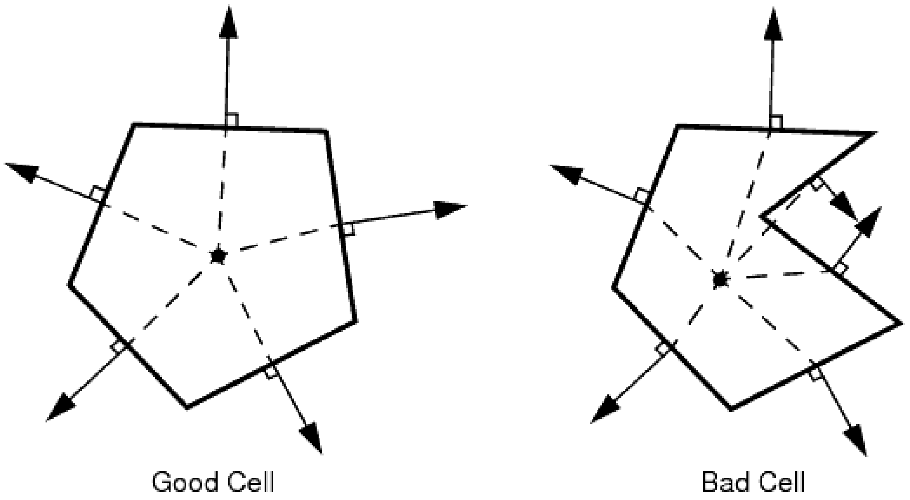
Should never be over 85°

Results in convergence problems



Meshing – *Mesh quality*

<u>Face validity:</u>



Value should not be less than unity

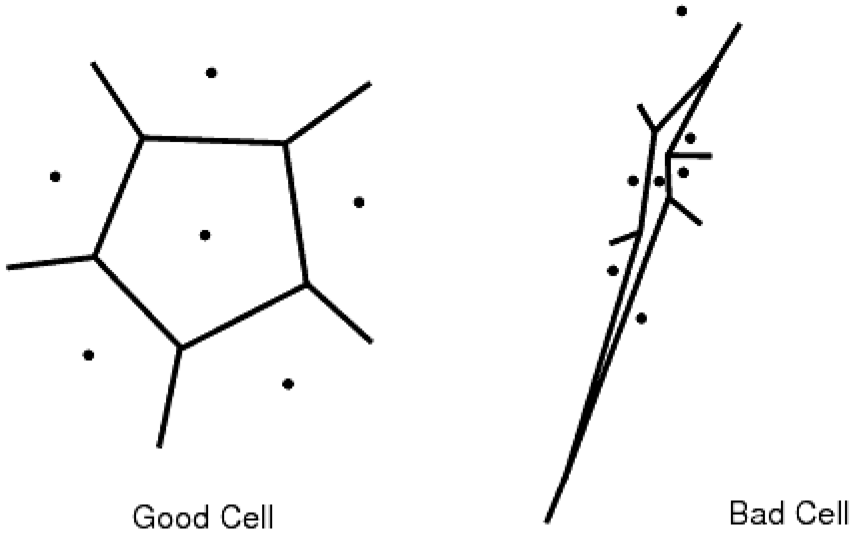
If less than 0.5, face vector points inwards

Meshing – *Mesh quality*

<u>Cell quality:</u>

Perfect has quality 1.0

Bad towards zero

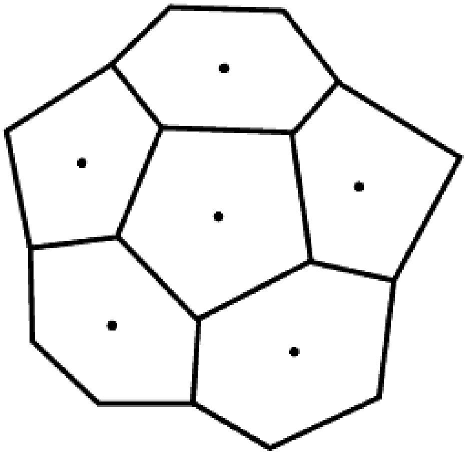


Meshing – *Mesh quality*

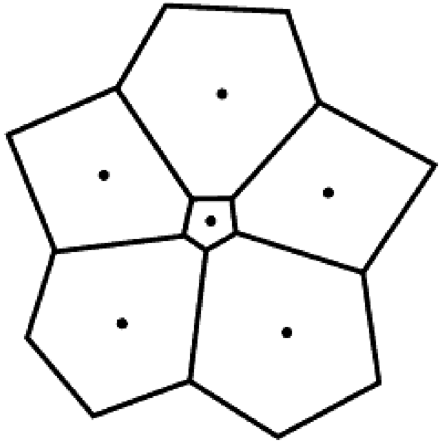
Volume change:

No volume change is 1.0

Less than 0.01 is bad



Good Cells



Bad Cells

Meshing – *Mesh quality*

More quality criteria, find in Star CCM+ user guide.

Search «mesh metrics»

Coarse mesh is a source to error.

Must be refined in regions where large gradients are expected to occur. Example behind cylinder (wake)

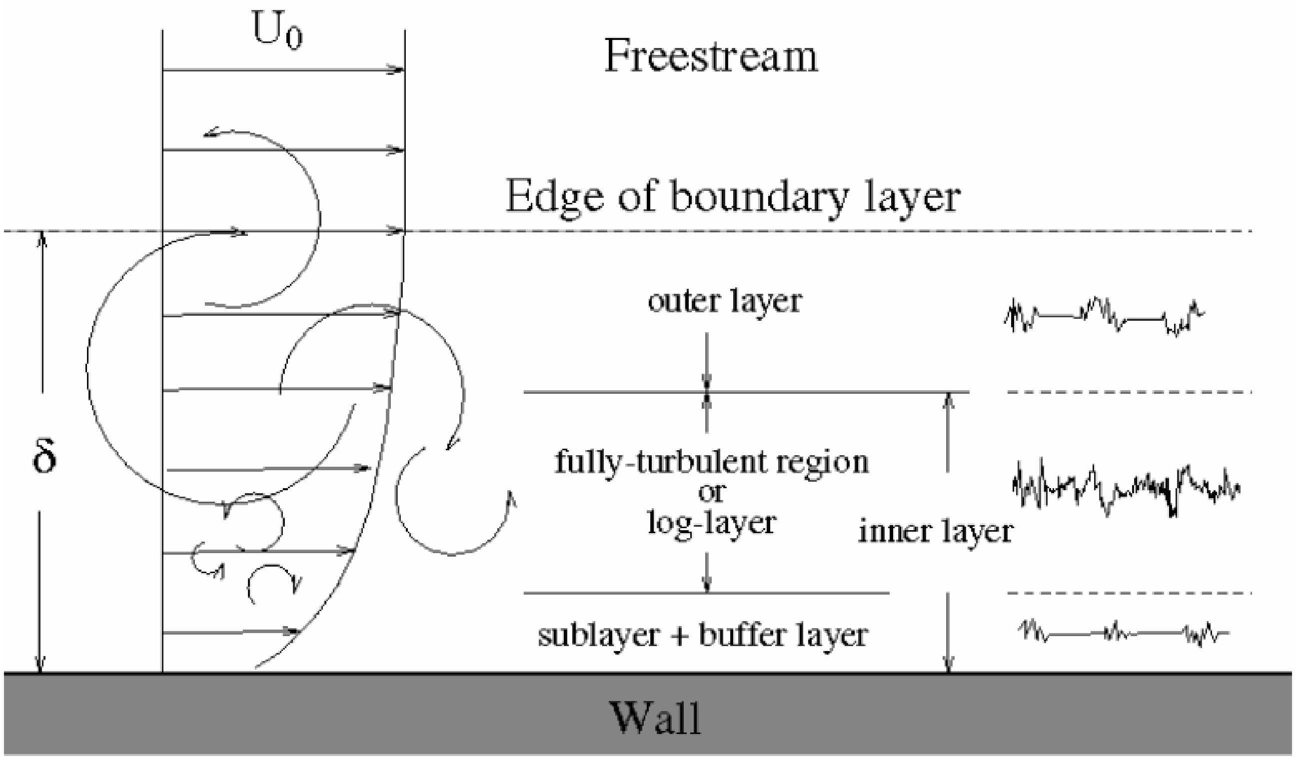
Meshing – *Boundary layer mesh*

Turbulent boundary layers can be modelled by semi-empirical approach or entirely resolved.

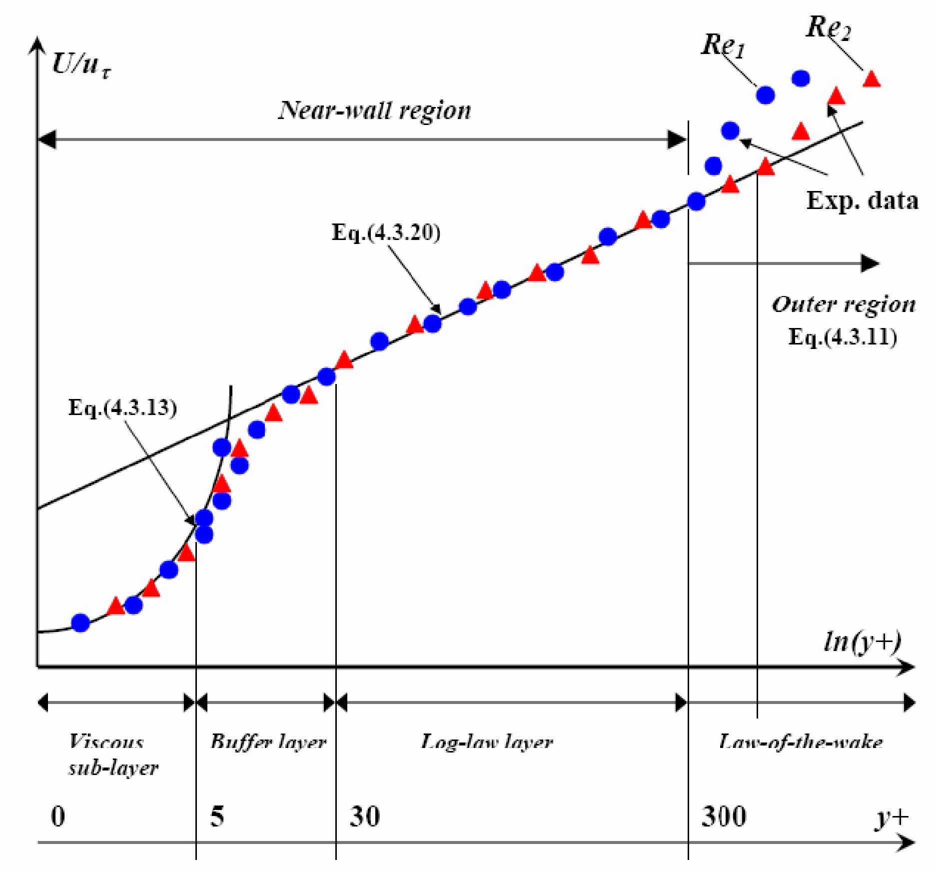
In the first approach, wall functions are used to predict the inner part of the boundary layer, called the viscous sub-layer and buffer layer. This means the mesh can be coarser, since the inner part of the boundary layer is not resolved.

In the second approach, the entire boundary layer is modelled. A much finer mesh is required.

Meshing – *Turbulent boundary layer*



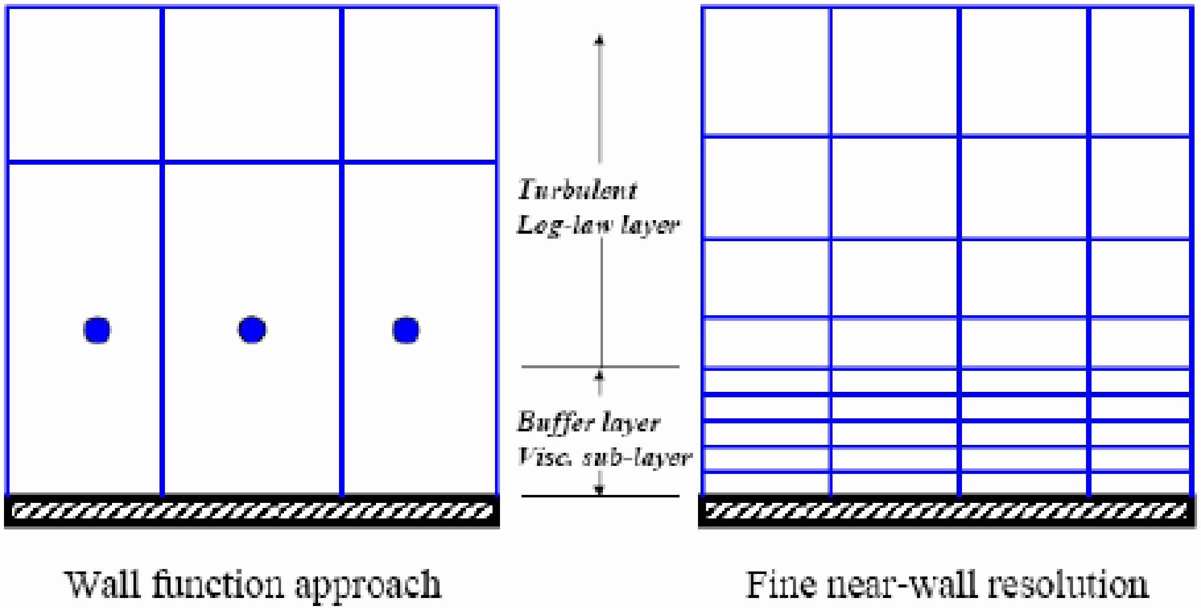
Meshing – *Turbulent boundary layer*



Meshing – *Prism layer*

$$y^+ = \frac{u_\tau y}{\nu}$$

$$u_\tau = \sqrt{\frac{\tau_w}{\rho}}$$



$30 < y^+ < 300$

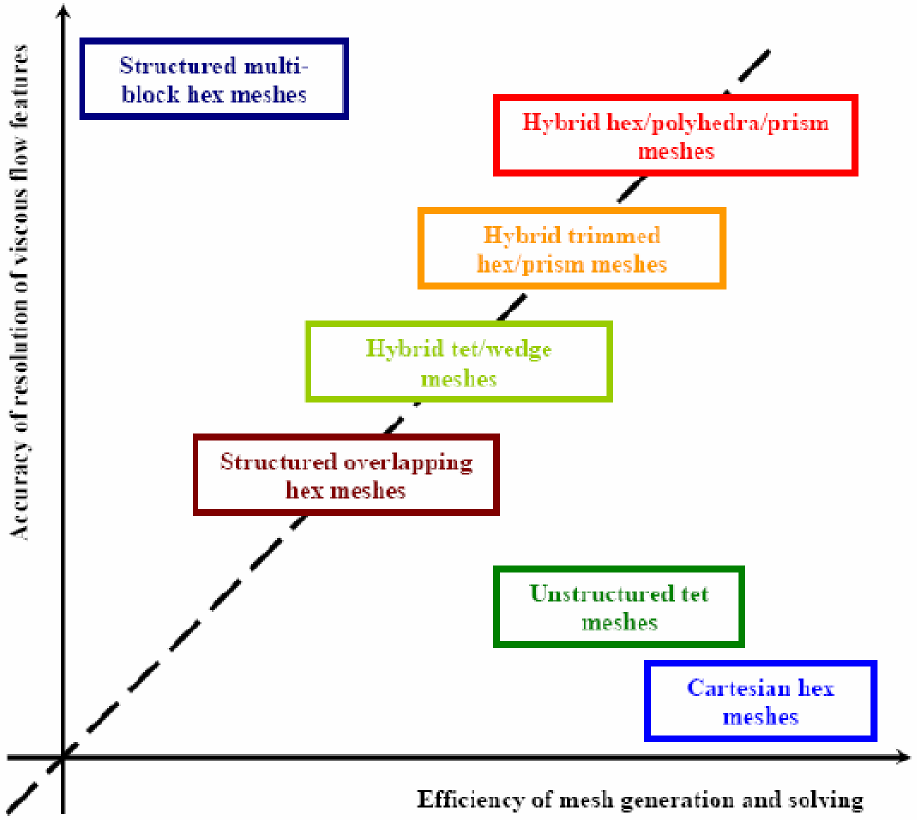
$y^+ \leq 1$

Meshing – *Prism layer*

In Star CCM+ there is an enhanced y+ wall treatment (All y+ wall treatment), which makes an adequate solution for both cases. This makes it easier for the user.

Still it is recommended that the y+ value do not exceed the upper limit of y+ values with wall functions (200-300).

Meshing – *Comparison between mesh strategies*



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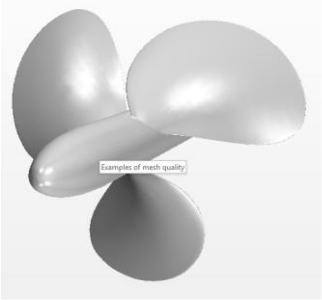
How to perform mesh check – *surface mesh*

<u>Check CAD model</u>

-Visualize

-Surface Repair tool



<u>Surface mesh</u>

-Visualize

-Run diagnostics

-Threshold on boundaries

-Automatic surface repair tool

Meshing – *General Guidelines*

1. Clean CAD model
2. Reduce cell skew, especially on hex cells. Should be less than 85 deg
3. Angle of gridlines on outer boundary of mesh should be close to 90 degrees
4. Avoid tetrahedral cells in the wall boundary layer
5. In the interior (away from boundaries) aspect ratio less than 20
6. Parallel alignment with flow if it is possible to predict
7. 5-10 layers of boundary cells (prism layers). If no wall function is used, and low *Re* flow, must have many more cells (15 cells).
8. As long as the surface geometry is well predicted, and the flow direction is fairly parallel, use “hex” mesh (trimmed)

Meshing – *Conclusion*

- A structured mesh is most accurate. It is much more time consuming to generate for complex geometry.
- Unstructured mesh is efficient to generate, use less memory. Using tetrahedral cells is not as accurate, and need more cells to produce same accuracy.
- Hybrid mesh can be a good compromise