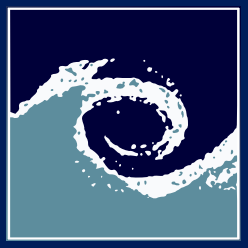


Advaced meshing options

Open-Source CFD Course 2021 – Lecture 3

Miklós BALOGH
and
Josh DAVIDSON

2021

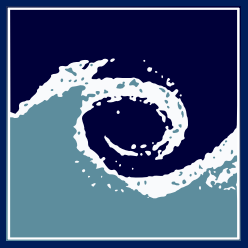
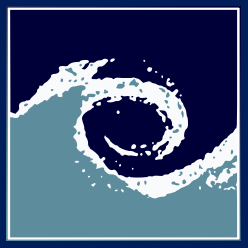
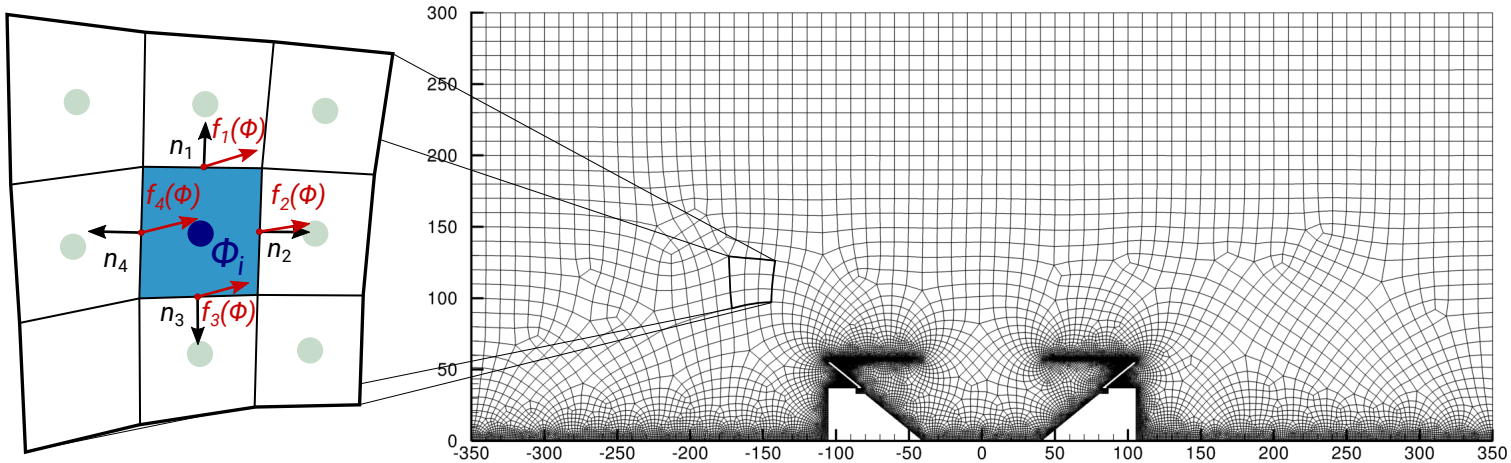


Table of Contents



Finite Volume Method (FVM)



General transport equation:

$$\frac{\partial \Phi}{\partial t} + \nabla \cdot f\left(\Phi\right) = 0$$

Its volume integral form:

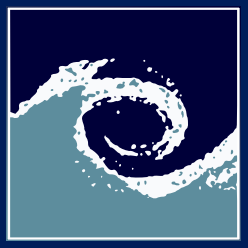
$$\int_V \left[\frac{\partial \Phi}{\partial t} + \nabla \cdot f\left(\Phi\right)\right] dV = 0$$

Using the Gauss-theorem:

$$\int_V \frac{\partial \Phi}{\partial t} dV + \int_A f\left(\Phi\right) \cdot \boldsymbol{n} dA = 0$$

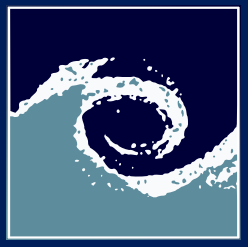
Discretized form for the i^{th} cell:

$$V_i \frac{\partial \Phi_i}{\partial t} + \sum_j f_j\left(\Phi_i\right) \cdot \boldsymbol{n}_j A_j = 0$$



Importance of meshing

- Quality of the mesh
  - Determines the accuracy of the spatial discretization, thus
  - it has a great influence on the accuracy of the simulation.
- Components of quality
  - Type of cells (tetrahedral, hexahedral, polyhedral)
  - Resolution (near wall and gradient refinement)
- Quality measures
  - Quality metrics (aspect ratio, non-ortogonality, skewness)
  - accessible via the checkMesh utility.

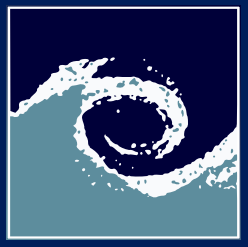


Mesh quality metrics - aspect ratio

Aspect ratio

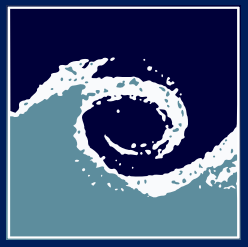
- Face aspect ratio: The ratio between the longest and the shortest length.
- Cell aspect ratio:
  - If the mesh is pseudo-2D, then it's just the ratio between the biggest and the smallest areas of the cell's bounding box.
  - If 3D, then it's the largest between the previous ratio and the result of the following expression:

$$\frac{1}{6}\frac{|a_x| + |a_y| + |a_z|}{V^{2/3}}$$



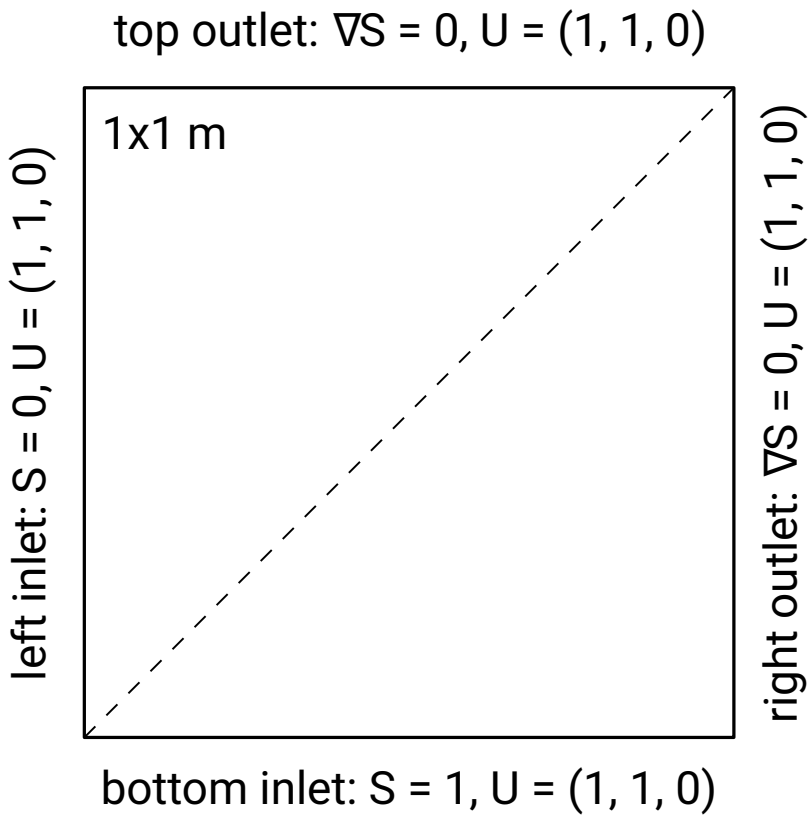
Mesh quality metrics

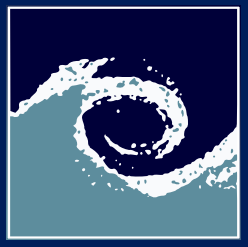
- Cell volumes: The difference between min and max should be as small as possible (or the evolution should be as smooth as possible - not check for that).
- Mesh non-orthogonality: Measure the angle between the line connecting two cell centres and the normal of their common face - 0.0 is the best.
- Skewness: Measure the distance between the intersection of the line connecting two cell centres with their common face and the centre of that face - smaller is better.
- Upper triangular ordering: determines the bandwidth of the coefficient matrices.



Mesh diffusion

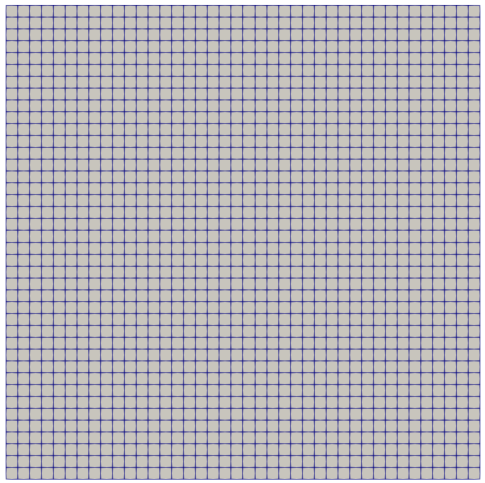
Error from the upwind differencing scheme has a diffusion-like appearance, which arise from the numerical approximations of the convection term in the conservation equations.



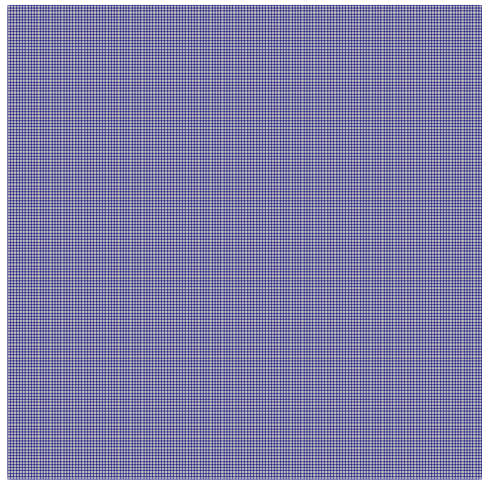


Mesh diffusion - quadrilateral mesh

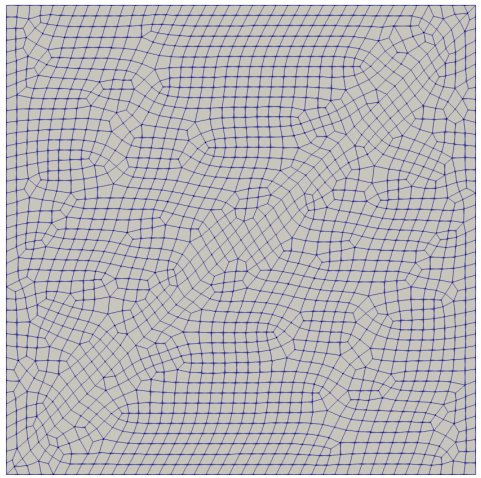
Quad-regular coarse



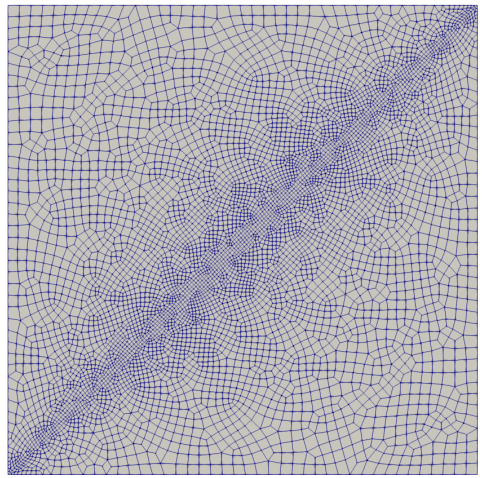
Quad regular fine

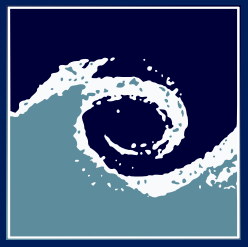


Quad-pave coarse aligned



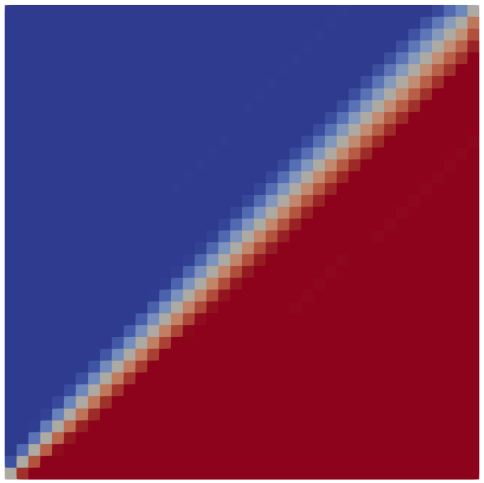
Quad-pave aligned refine





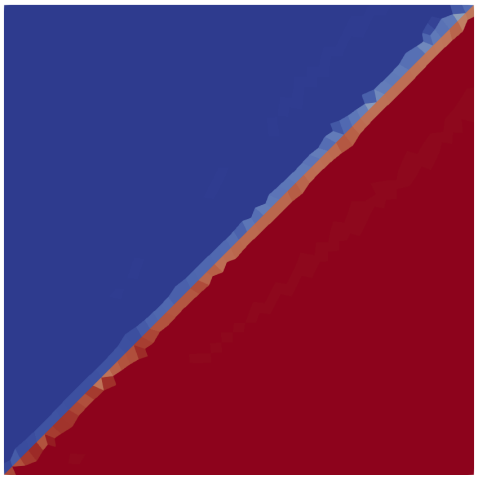
Mesh diffusion - quadrilateral mesh

Quad-regular coarse

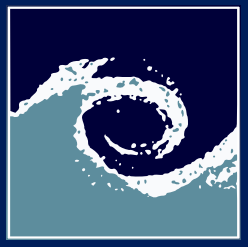


Quad regular fine

Quad-pave coarse aligned

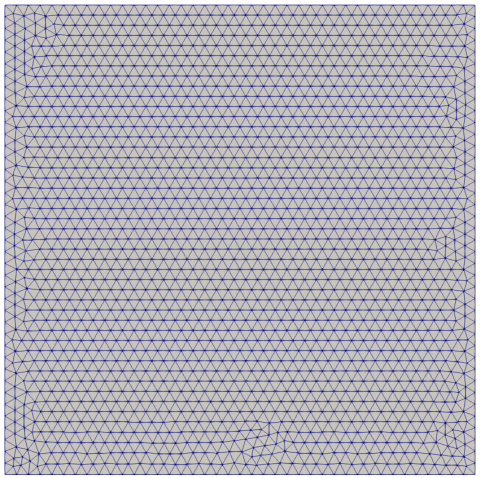


Quad-pave aligned refine

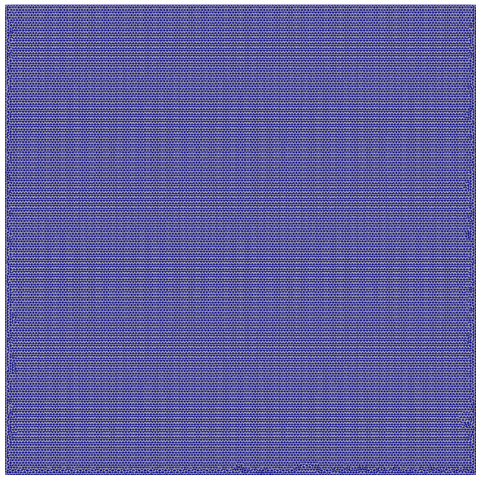


Mesh diffusion - triangular mesh

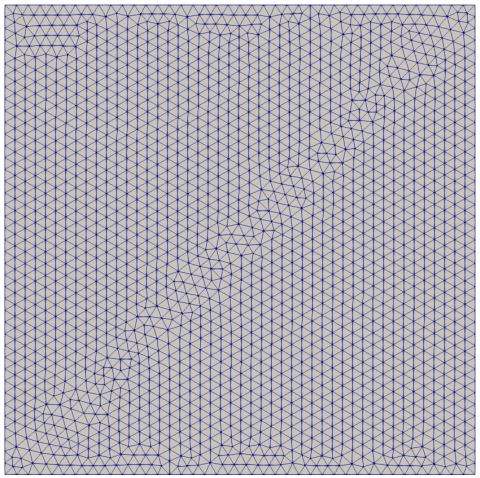
Tri-wedge coarse



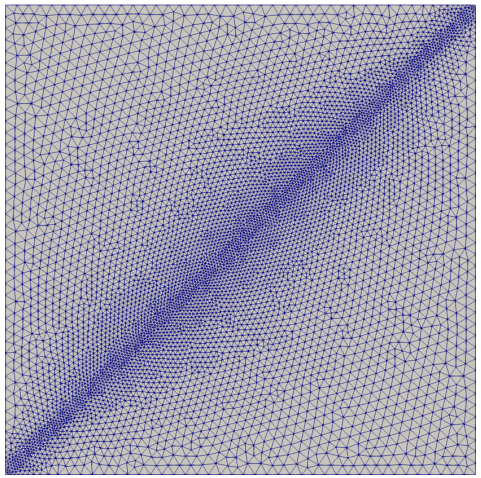
Tri-wedge fine

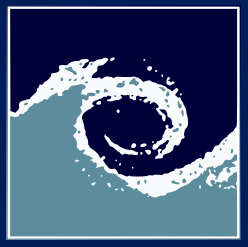


Tri-wedge aligned



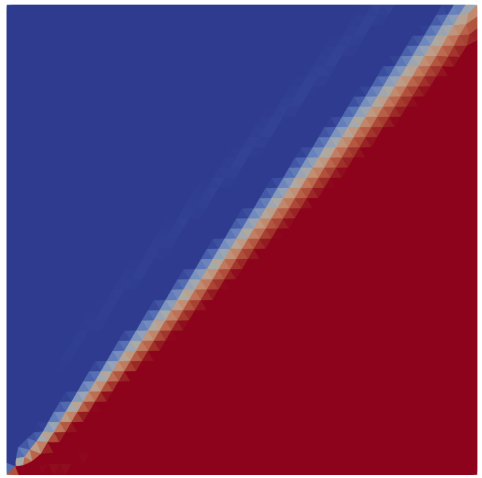
Tri-wedge aligned refine





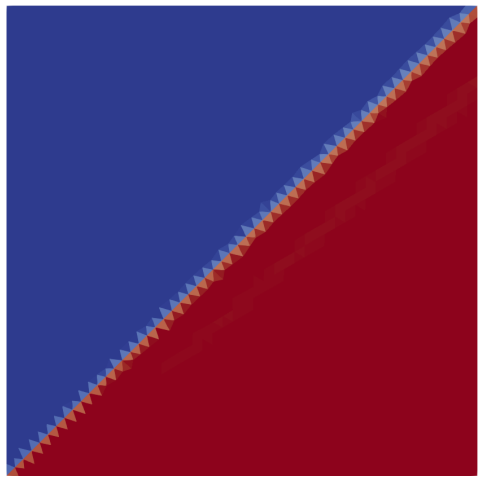
Mesh diffusion - triangular mesh

Tri-wedge coarse

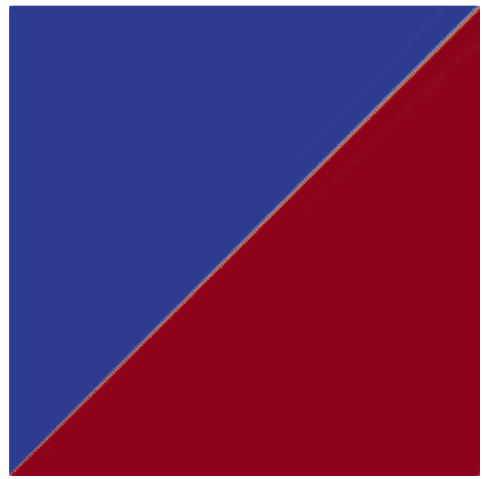


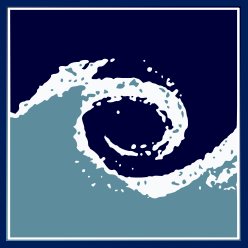
Tri-wedge fine

Tri-wedge aligned



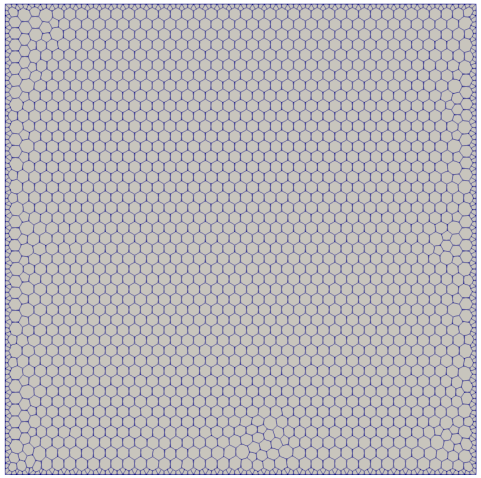
Tri-wedge aligned refine



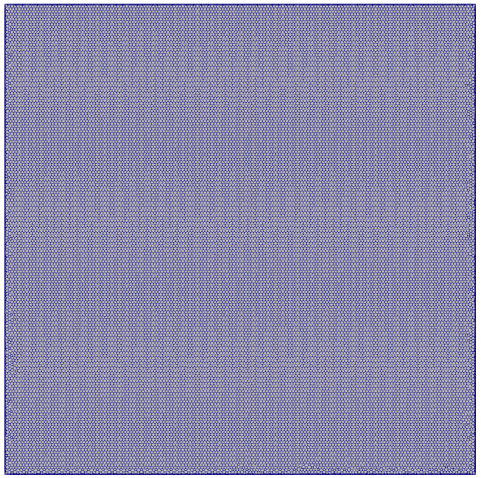


Mesh diffusion - polyhedral mesh

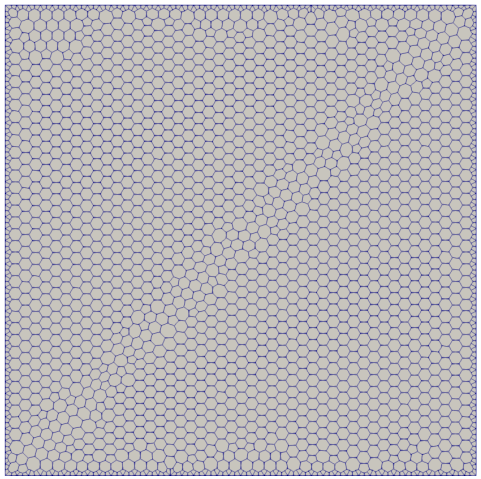
Poly coarse



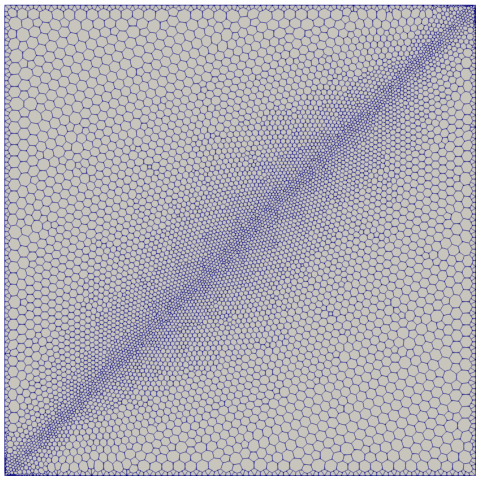
Poly fine

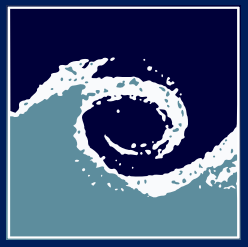


Poly coarse aligned



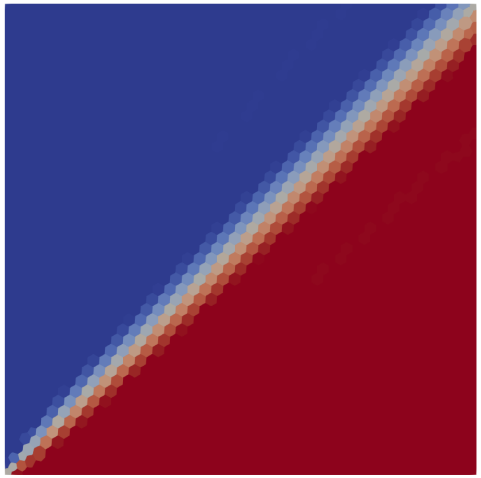
Poly aligned refine





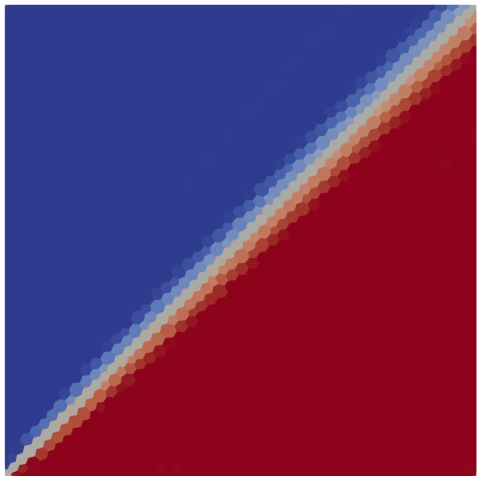
Mesh diffusion - polyhedral mesh

Poly coarse

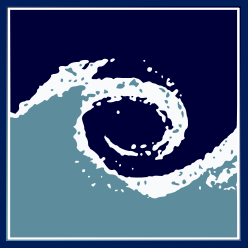


Poly fine

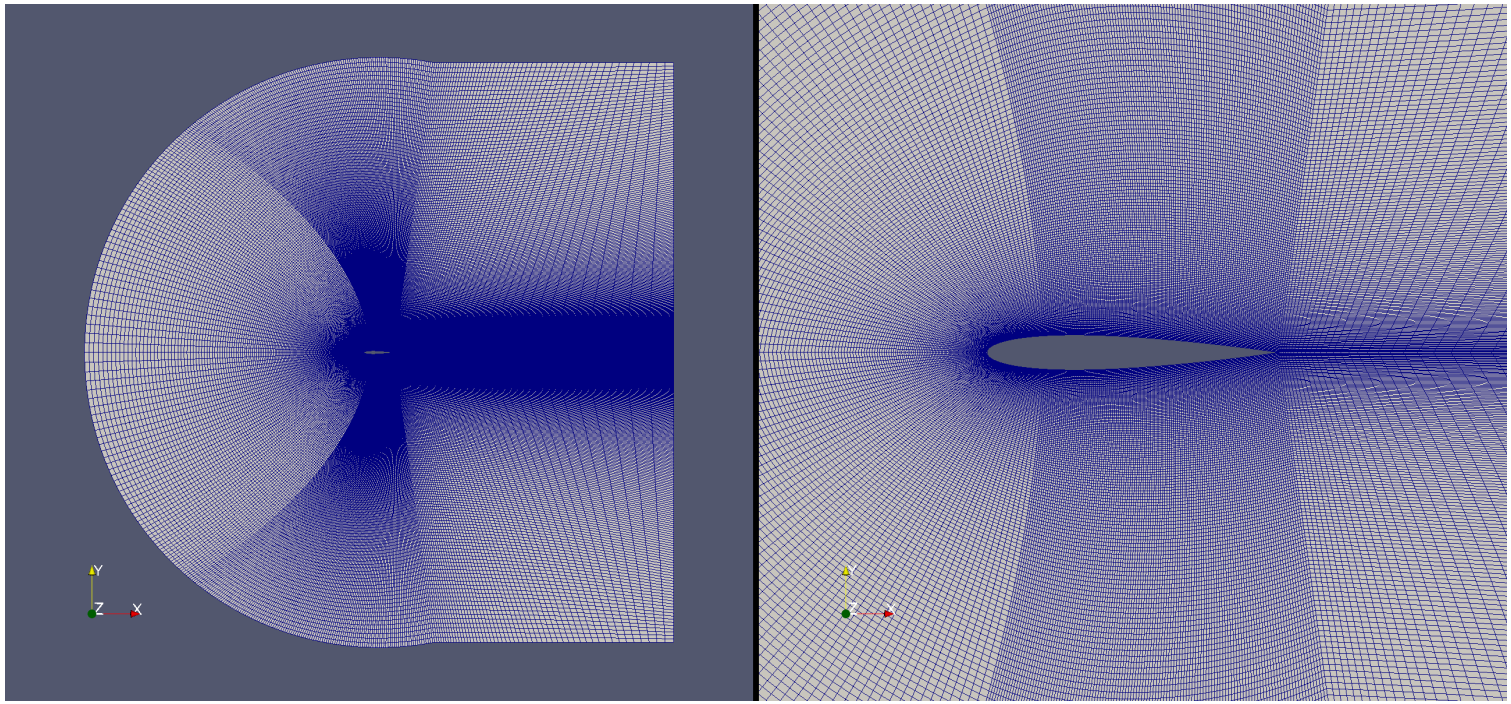
Poly coarse aligned



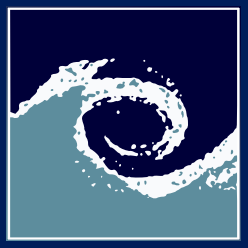
Poly aligned refine



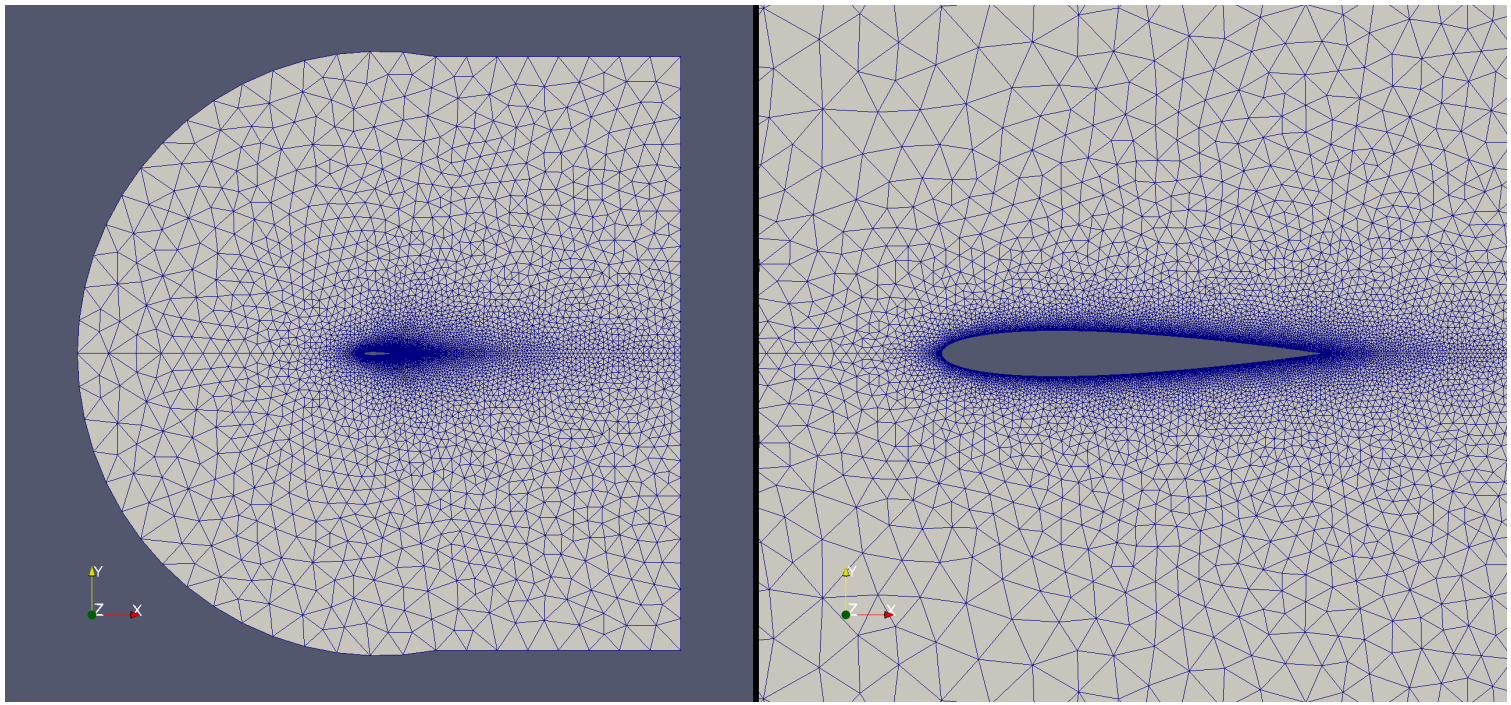
Finite volume meshes - structured



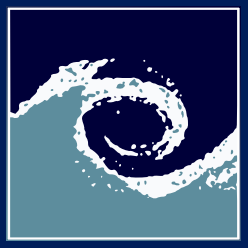
Number of hexahedral cells: 115584



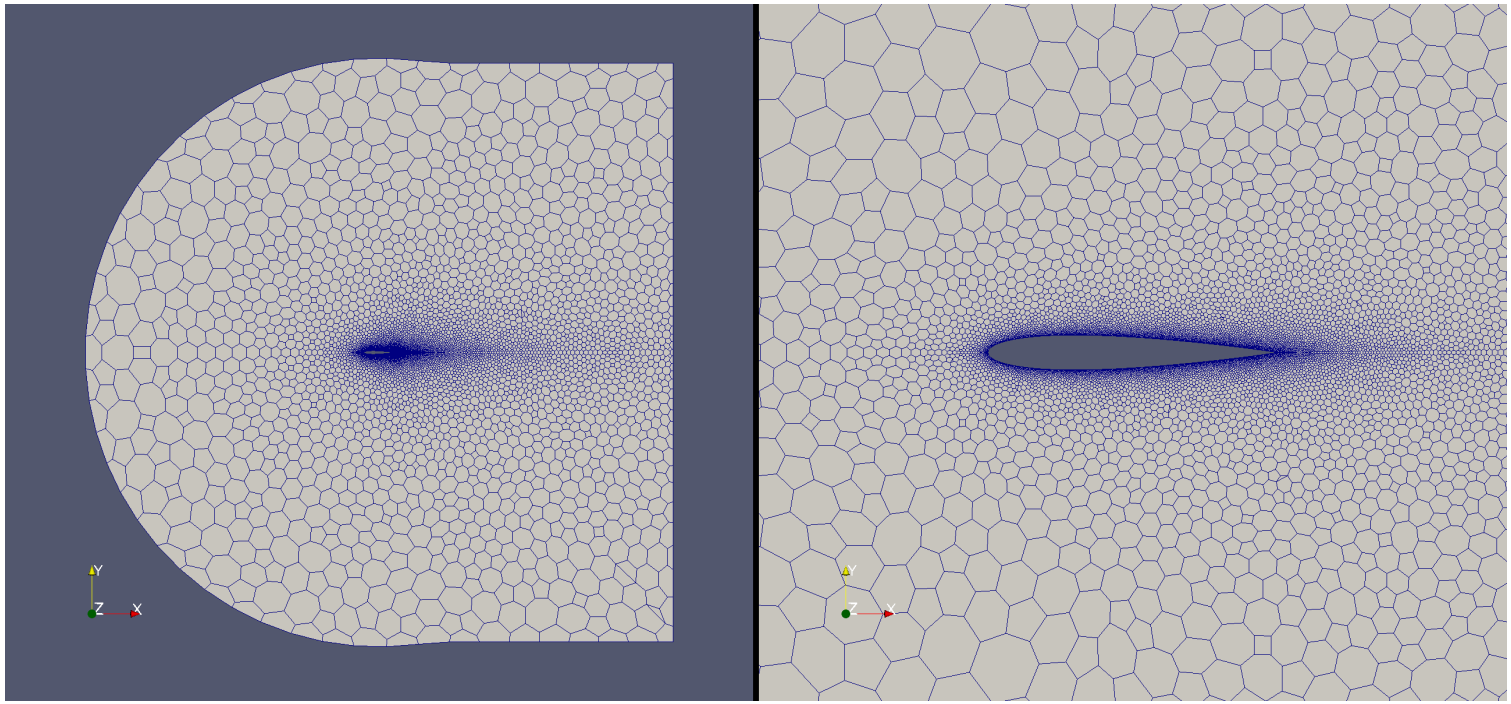
Finite volume meshes - unstructured prisms



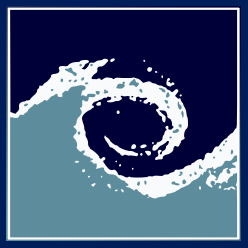
Number of prismatic cells: 28284



Finite volume meshes - unstructured polyhedra

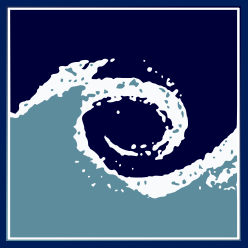


Number of hexahedral/polyhedral cells: 279/14364



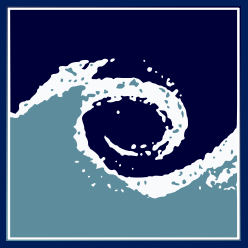
Mesh quality - checkMesh (stats.)


```
Mesh stats
    points:              29286
    internal points:     0
    faces:               99495
    internal faces:      41925
    cells:               28284
    faces per cell:      5
    boundary patches:    5
    point zones:         0
    face zones:          0
    cell zones:          1
```



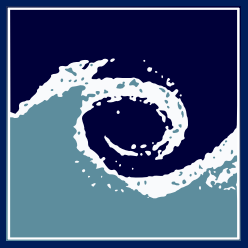
Mesh quality - checkMesh (cell types)


```
Overall number of cells of each type:
    hexahedra:      0
    prisms:         28284
    wedges:         0
    pyramids:       0
    tet wedges:     0
    tetrahedra:     0
    polyhedra:      0
```



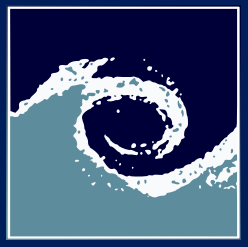
Mesh quality - checkMesh (mesh topology


```
Checking topology...
    Boundary definition OK.
    Cell to face addressing OK.
    Point usage OK.
    Upper triangular ordering OK.
    Face vertices OK.
    Number of regions: 1 (OK).
```



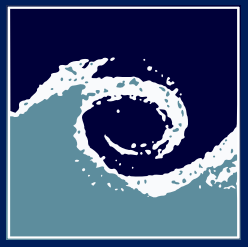
Mesh quality - checkMesh (patch topology)


```
Checking patch topology for multiply connected surfaces...
    Patch               Faces     Points    Surface topology
    side1               28284     14643     ok (non-closed singly connected)
    side2               28284     14643     ok (non-closed singly connected)
    walls               918       1836      ok (non-closed singly connected)
    inlet               48        98        ok (non-closed singly connected)
    outlet              36        74        ok (non-closed singly connected)
```



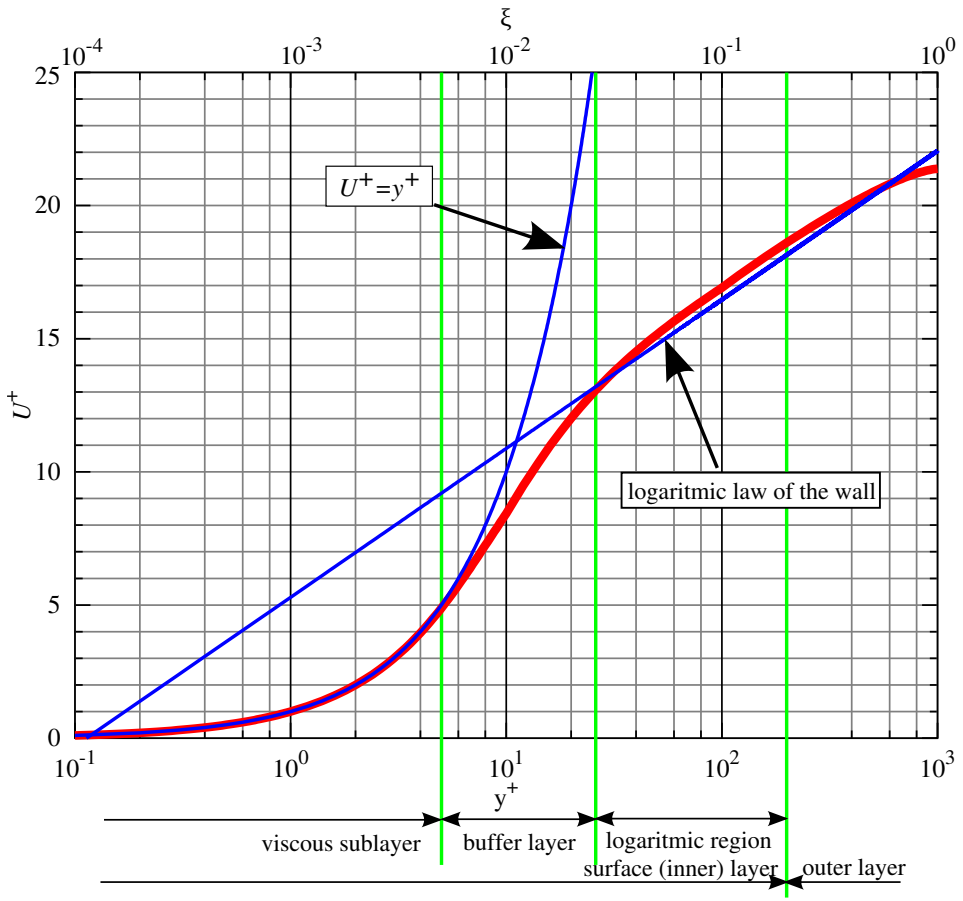
Mesh quality - checkMesh (metrics)

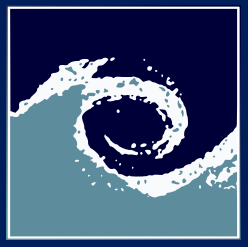

```
Checking geometry...
    Overall domain bounding box (-10 -9.99555 -1.11254) (10 9.99555 1.11254)
    Mesh has 2 geometric (non-empty/wedge) directions (1 1 0)
    Mesh has 2 solution (non-empty) directions (1 1 0)
    All edges aligned with or perpendicular to non-empty directions.
    Boundary openness (-7.78764e-18 -3.06399e-18 -2.95284e-16) OK.
    Max cell openness = 2.2017e-16 OK.
    Max aspect ratio = 2.62246 OK.
    Minimum face area = 1.26311e-06. Maximum face area = 3.04966. Face area magnitudes OK.
    Min volume = 2.81052e-06. Max volume = 1.33014. Total volume = 786.54. Cell volumes OK.
    Mesh non-orthogonality Max: 35.0366 average: 7.36715
    Non-orthogonality check OK.
    Face pyramids OK.
    Max skewness = 0.550881 OK.
    Coupled point location match (average 0) OK.

Mesh OK.
```



Law of the wall

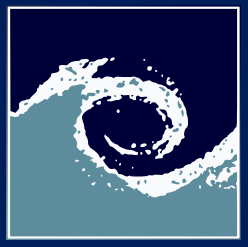
With u_τ friction velocity: $u^+ = \dfrac{u}{u_\tau}$ and $y^+ = \dfrac{y u_\tau}{\nu}$





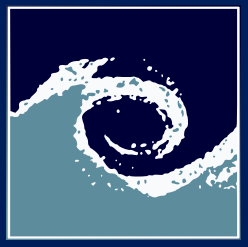
Wall spacing requirements

- LES:
  - Wall normal direction: $y^+ < 1$
  - Streamwise direction: $x^+ < 50$
  - Spanwise/crosswise direction: $z^+ < 20$
- RANS:
  - Low-Reynolds threatment: $y^+ \approx 1$
  - High-Reynolds threatment: $30 < y^+ < 300$
  - Universal wall threatment: $0 < y^+ < 300$



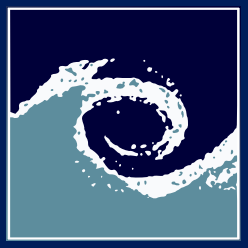
Wall spacing estimation

- Information about the flow:
  - Flow velocity: U_∞
  - Characteristic length: L or d
  - Viscosity and density of the fluid: ν, ρ
- Estimation:
  - Reynolds number: $Re_x = \dfrac{U_\infty L}{\nu}$
  - Friction coefficient: $C_f = \dfrac{0.026}{Re_x^{1/7}}$
  - Wall shear stress: $\tau_w = C_f \dfrac{\rho}{2} U_\infty^2$
  - Friction velocity: $u_\tau = \sqrt{\dfrac{\tau_w}{\rho}}$
  - Wall normal size of the wall adjacent cell: $\Delta s_y = \dfrac{2\nu y^+}{u_\tau}$



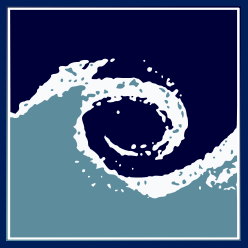
Mesh grading

- Grading is based on geometric progression: $a_n = a_1 q^{n-1}$,
- where n is the number of interval,
- a_1 and a_n is the size of the first and n^{th} interval,
- q is the expansion ratio or progression $(0.77 < q < 1.3)$.
- The edge length (sum of a_i) is: $S_n = a_1 \dfrac{q^n - 1}{q - 1}$
- In blockMesh, the simpleGrading parameter gives the progression as the last-first ratio: $\dfrac{a_n}{a_1}$
- In GMSH, progression should defined with the number of mesh points along the edge $(n + 1)$ and q.



Mesh related utilities in OpenFOAM

- Meshing
  - blockMesh (wedge and hexahedral mesh)
  - snappyHexMesh (hex dominant polyhedral mesh)
  - foamyHexMesh (hexahedral mesh)
  - foamyQuadMesh (quadrilateral 2D mesh)
  - cfMesh (tetrahedral, hexahedral and polyhedral mesh)
- Conversion:
  - fluentMeshToFoam (from ANSYS-Fluent)
  - starToFoam (from starCD)
  - gambitToFoam (from ANSYS-Gambit)
  - cfx4ToFoam (from ANSYS-CFX)
  - ideasToFoam (from ANSYS-ans format)
- Manipulation:
  - polyDualMesh: creates the poly-dualized version of meshes
  - a lot of other tool: see this link



Useful open-source applications

- GMSH (FEM and FVM mesher: GMSH web page)
- enGrid (FVM mesher: enGrid web page)
- Salome (CAD software + mesher: Salome web page)
- Blender (CAD software: Blender web page)
- FreeCAD (CAD software: FreeCAD web page)