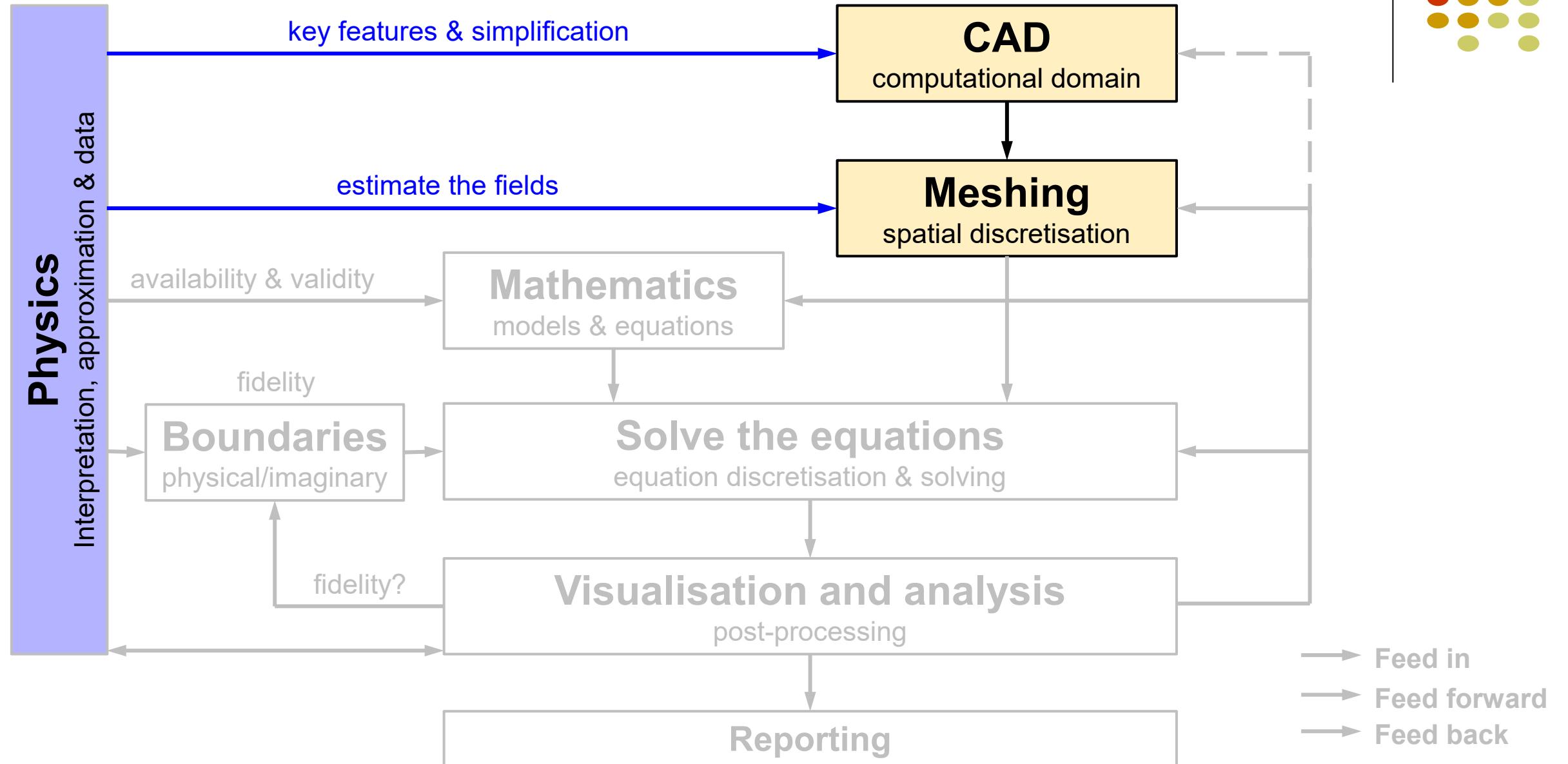
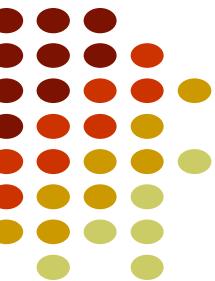


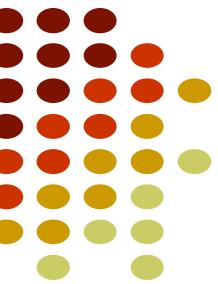
ENIGNEERING COMPUTATIONAL FLUID DYNAMICS (ECFD)

Dr Xiangdong Li

Module 5 – Geometry and mesh

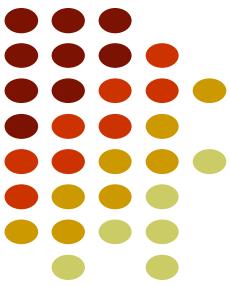
CFD workflow





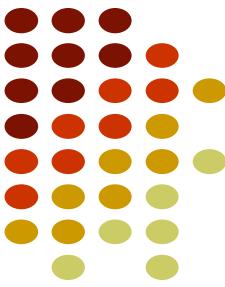
This module

- ❖ CAD model and computational domain of CFD
- ❖ Mesh and meshing



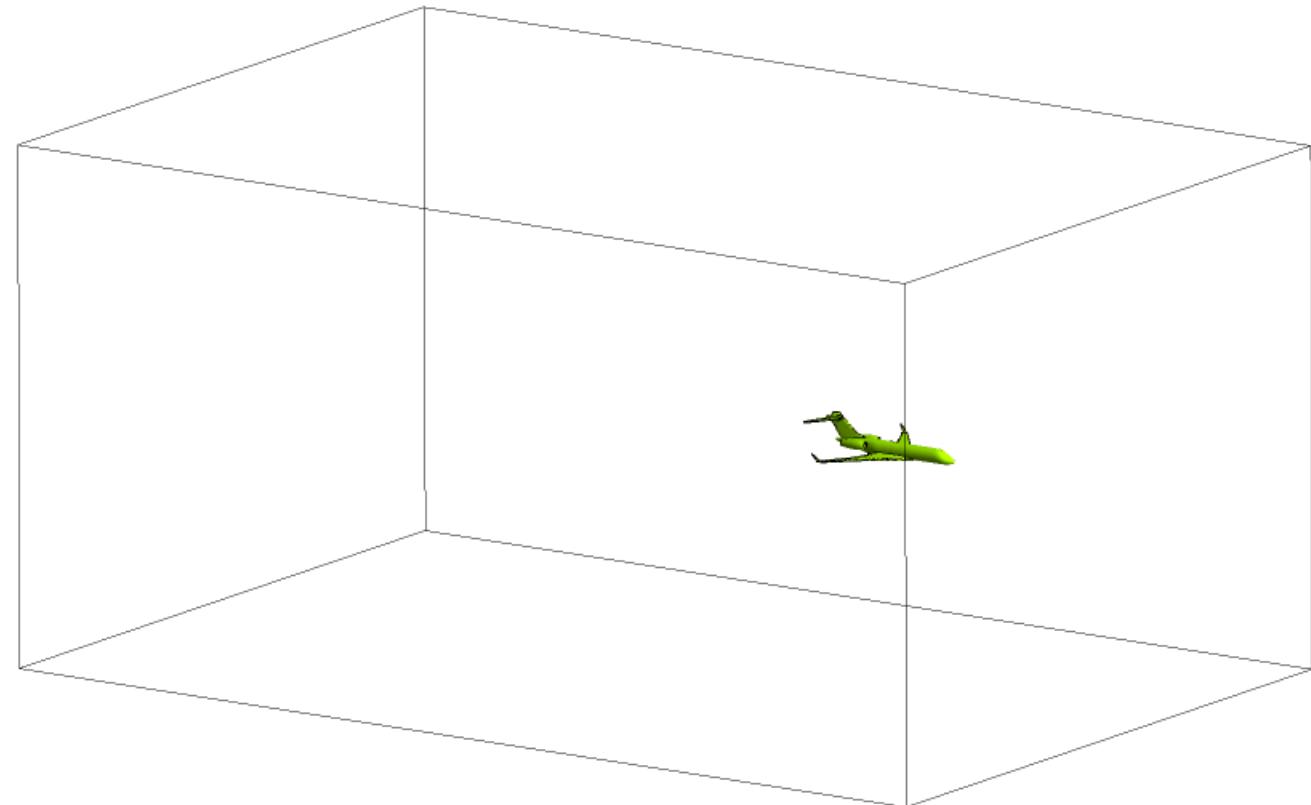
GEOMETRY

– The computational domain

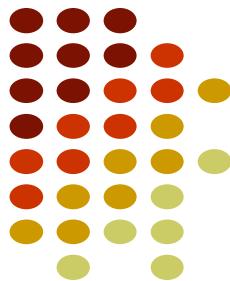


The computational domain

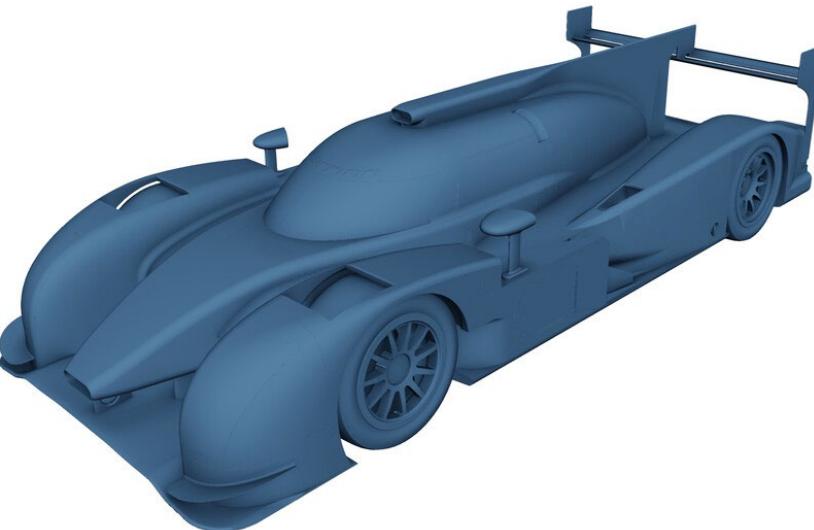
ATTN: The computational domain of CFD is the space occupied by **FLUID**, although sometimes can include solid regions.

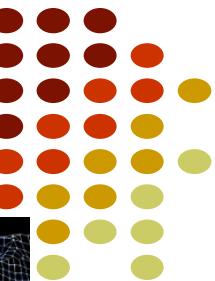


Geometry – CAD models

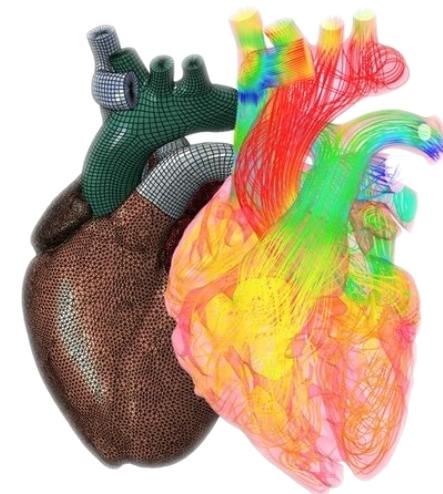
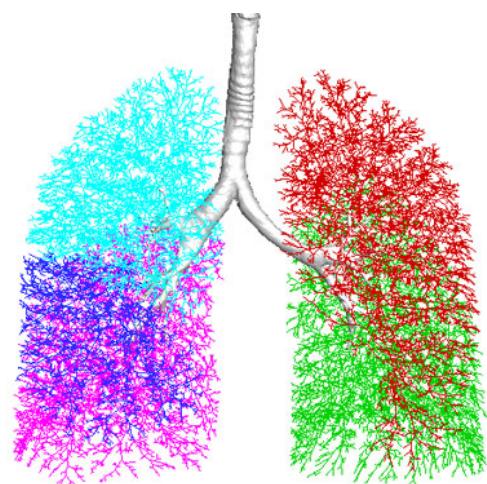
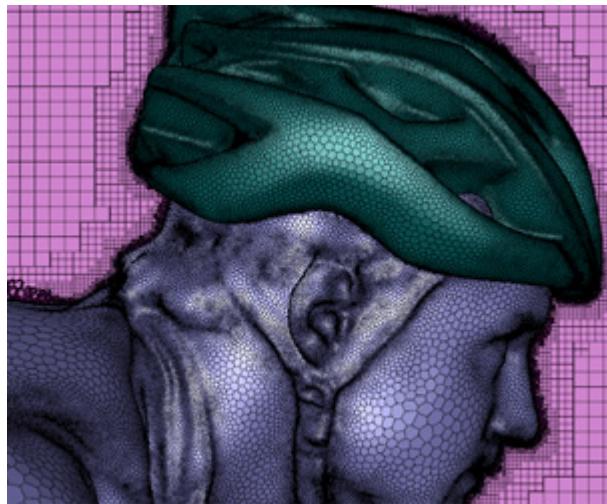
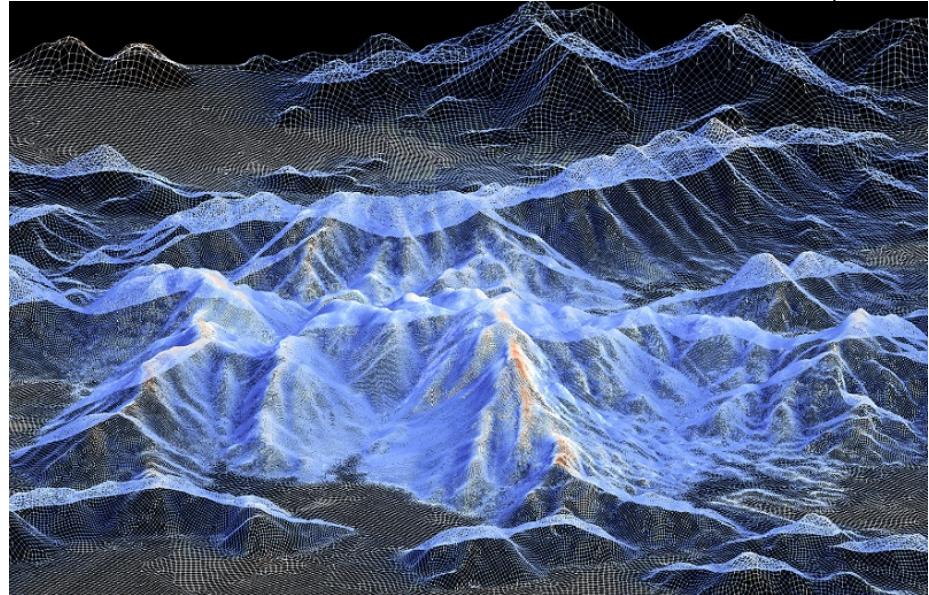
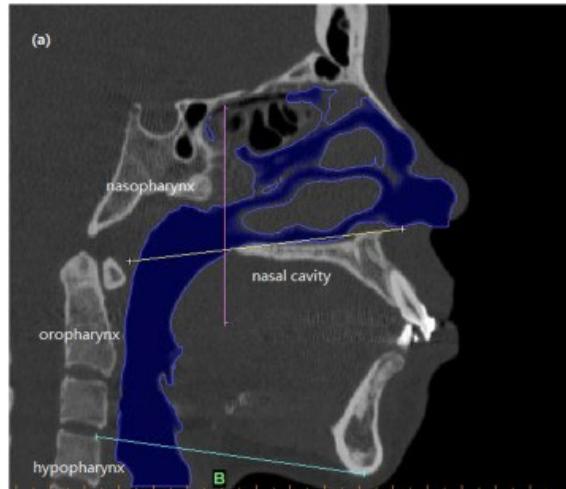
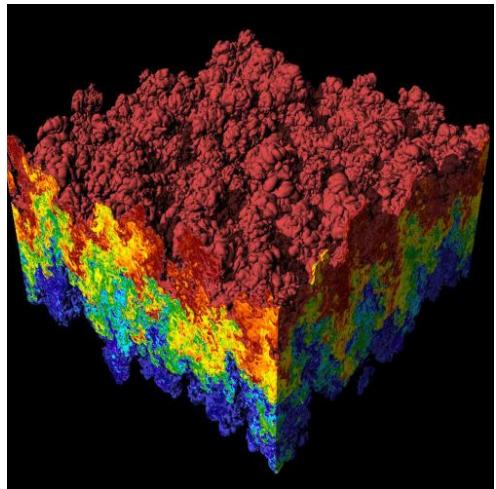


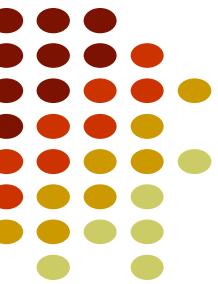
- ❖ Ansys Design Modeller
- ❖ AutoCAD
- ❖ Solidworks
- ❖ CATIA
- ❖ Pro/Engineer
- ❖ NX Graphics
- ❖ ...





Geometry – complex geometry

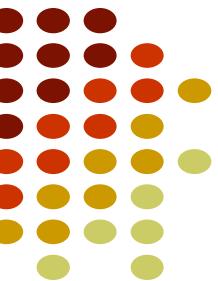




Geometry – Scanned models



Laser scans



Try it at home – Camera + MeshLab

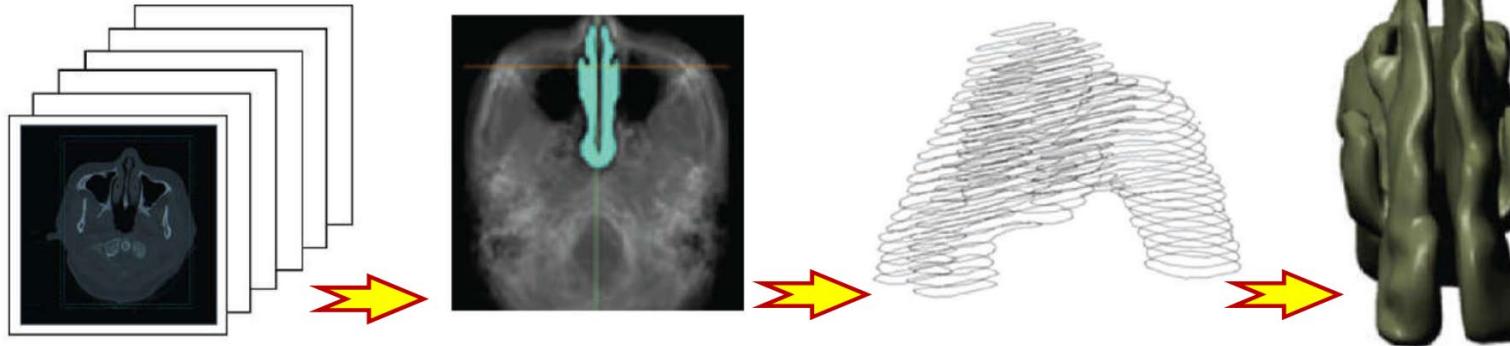
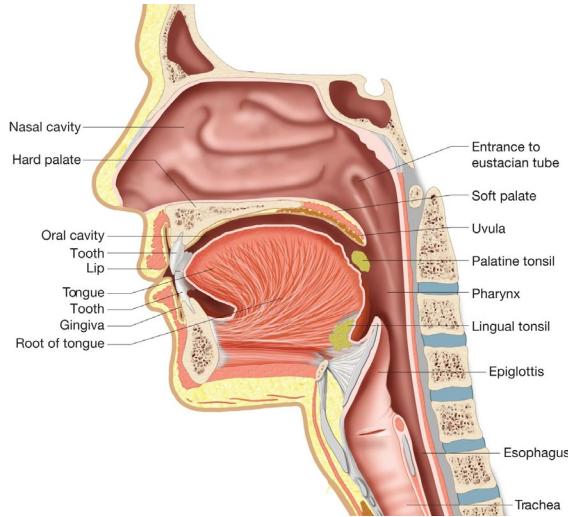
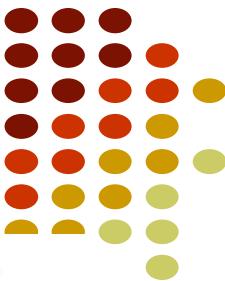
Free: <https://www.meshlab.net/>

The screenshot shows the official MeshLab website (<https://www.meshlab.net/>) with a dark-themed header and navigation bar. The main content area is divided into several sections:

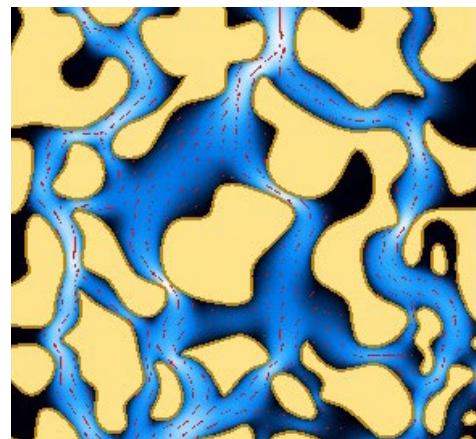
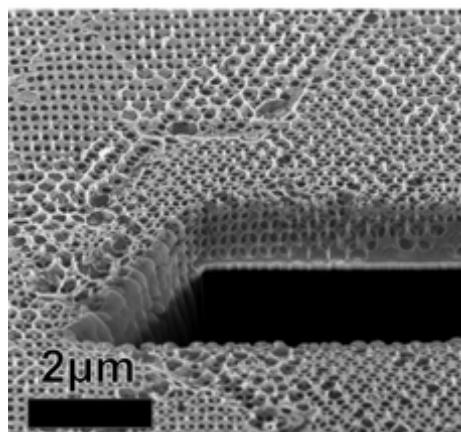
- 3D Acquisition: Reconstruction**: Describes the process of transforming independent acquisitions or point clouds into a single-surface triangulated mesh. It includes a thumbnail image of a 3D model.
- Color Processing**: Details the manipulation of vertex and face colors using Photoshop-like filters. It includes a thumbnail image of a 3D model with color variations.
- 3D Acquisition: Color Mapping and Texturing**: Explains how color information is mapped onto 3D models from uncalibrated images. It includes a thumbnail image of a 3D model with texture mapping.
- 3D Printing: Offsetting, Hollowing, Closing**: Describes preparing 3D models for printing by creating inner shells, resampling/remeshing, and closing holes. It includes a thumbnail image of a 3D model with printing-related features.

The bottom of the screenshot shows a Windows taskbar with various icons and system status indicators.

Geometry – Scanned models

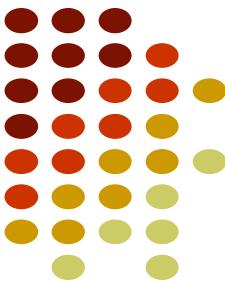


CT scans

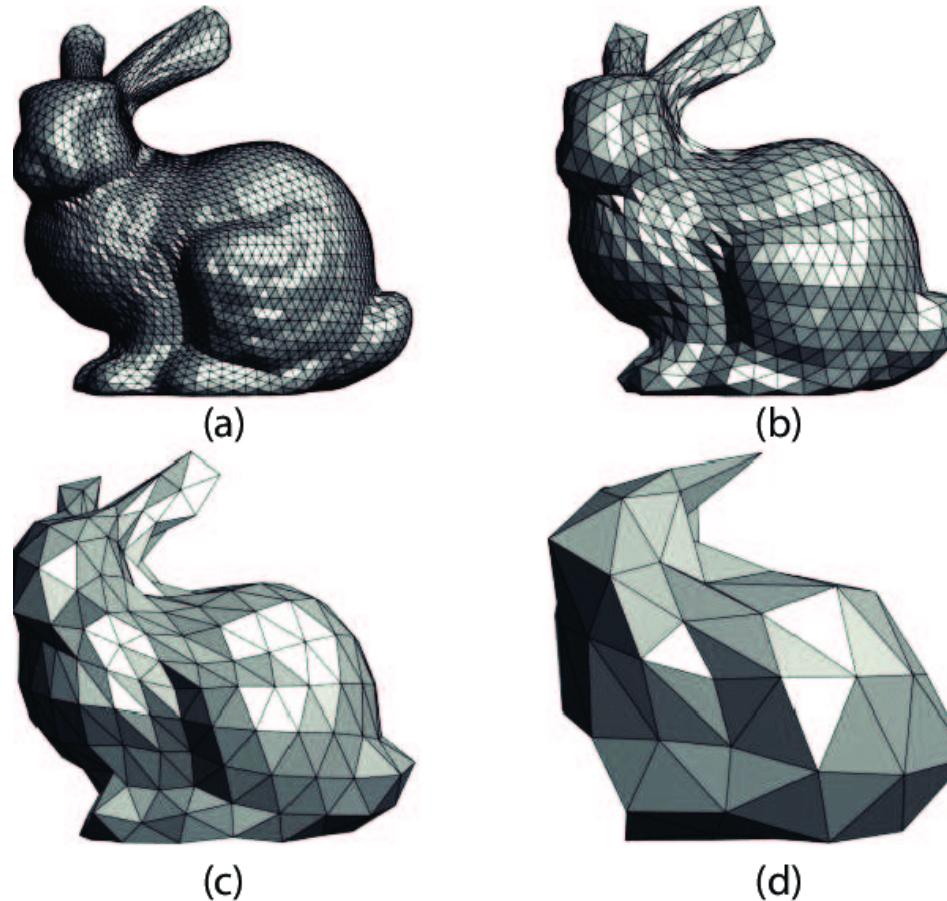


SEM/FTM

Geometry simplification



- ❖ Remove unnecessary details
- ❖ Retain main features
- ❖ MeshLab



https://www.researchgate.net/figure/Wavelet-decomposition-of-the-semi-regular-Bunny-mesh-a-dense-mesh-b-after-one_fig3_331203142

Geometry simplification



The simplified
models of o

Xiangdong Li ^a,

^a School of Aerospace, Mec
^b School of Architecture, Ts

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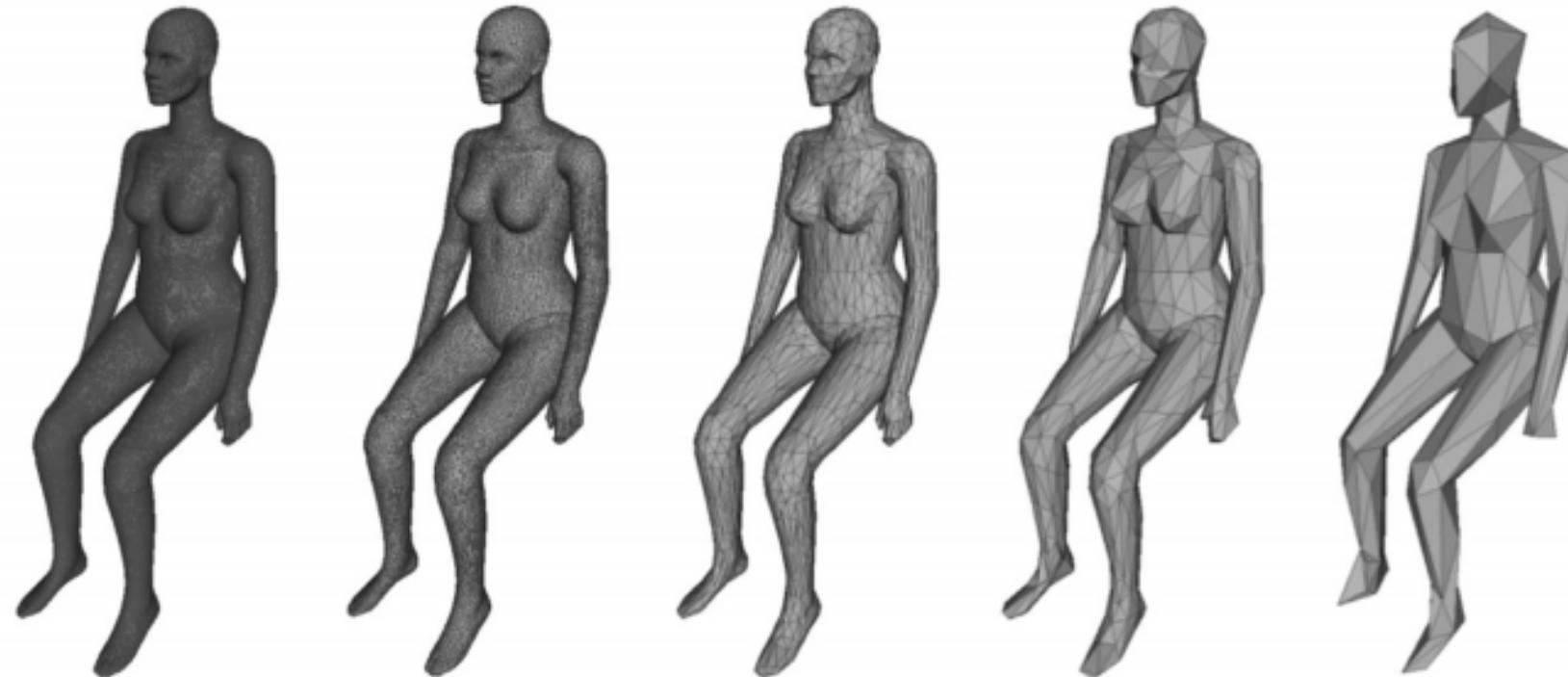
Simplification

The mesh decimating alg

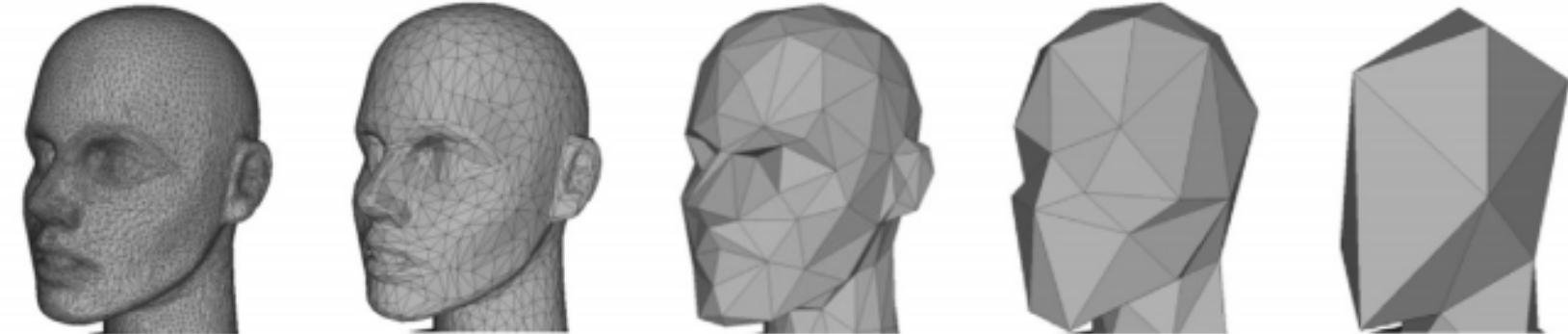
Occupied indoor spaces

Predictive error

Overall geometry



Head zoom-in



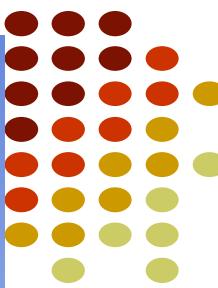
Original

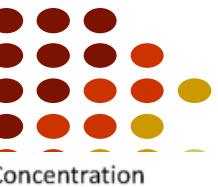
10 iterations

20 iterations

25 iterations

30 iterations





Geometry simplification

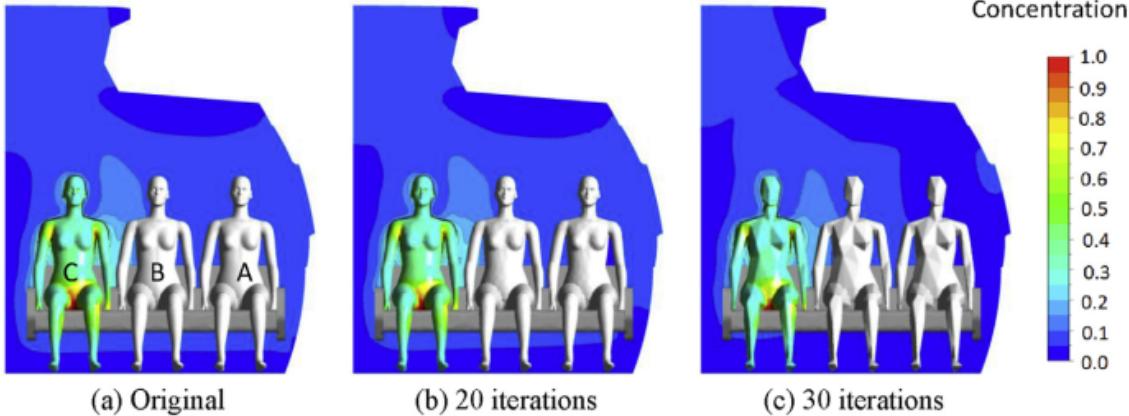
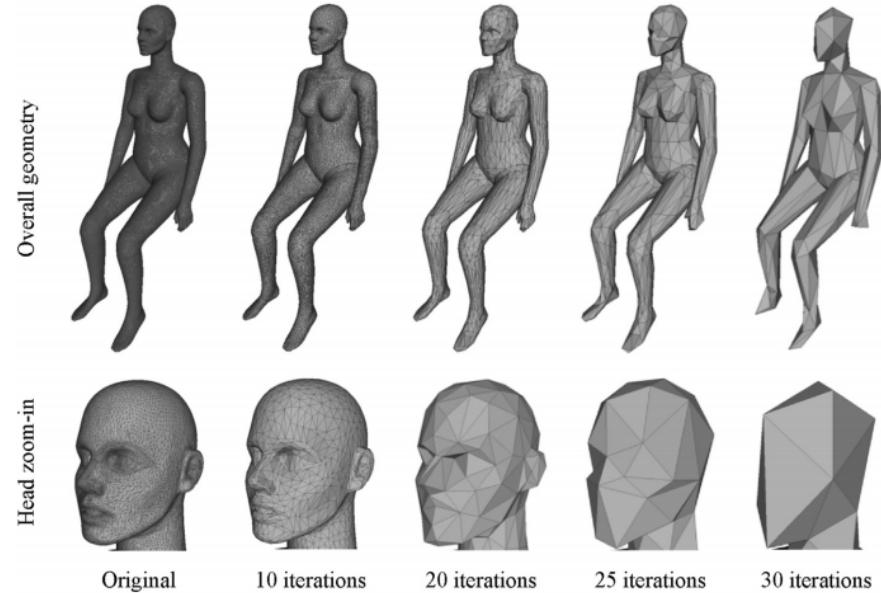


Fig. 12. Predicted squalene concentration in Plane 1.

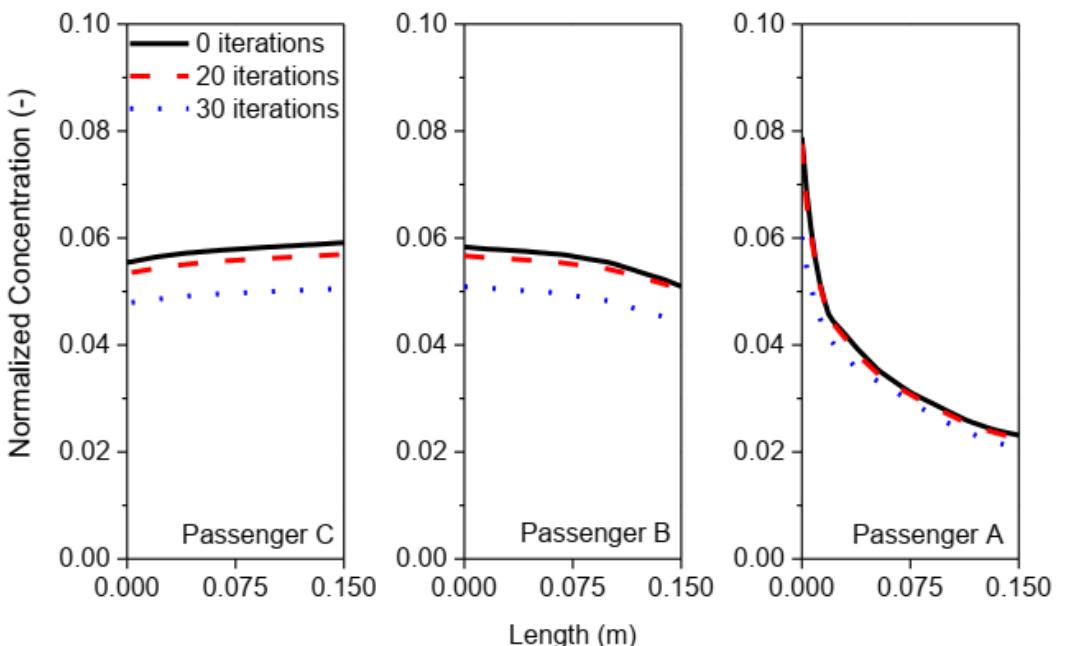
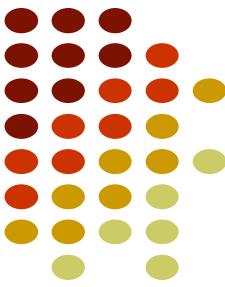


Fig. 13. Normalized squalene concentration in the passenger breathing zones.

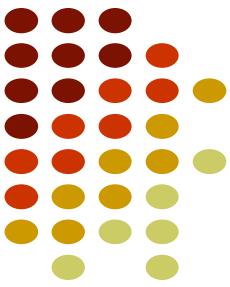
Benefits

- ❖ Less CPU time
- ❖ Numerically more stable
- ❖ Acceptable accuracy



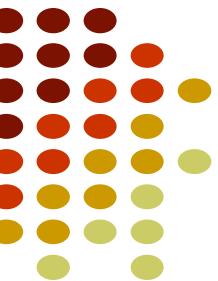
Tips for geometry building

- ❖ Check and create closed geometries
 - A common problem for imported CAD model
- ❖ De-feature and simplify geometry
 - Remove unimportant small features
 - Retain key features
 - Quantifiable simplification
 -
- ❖ Define subdomains and boundaries
 - Subdomain
 - Inlet/outlet/opening
 - Wall
 - Symmetry/Periodic boundary
 - Other boundary of interest



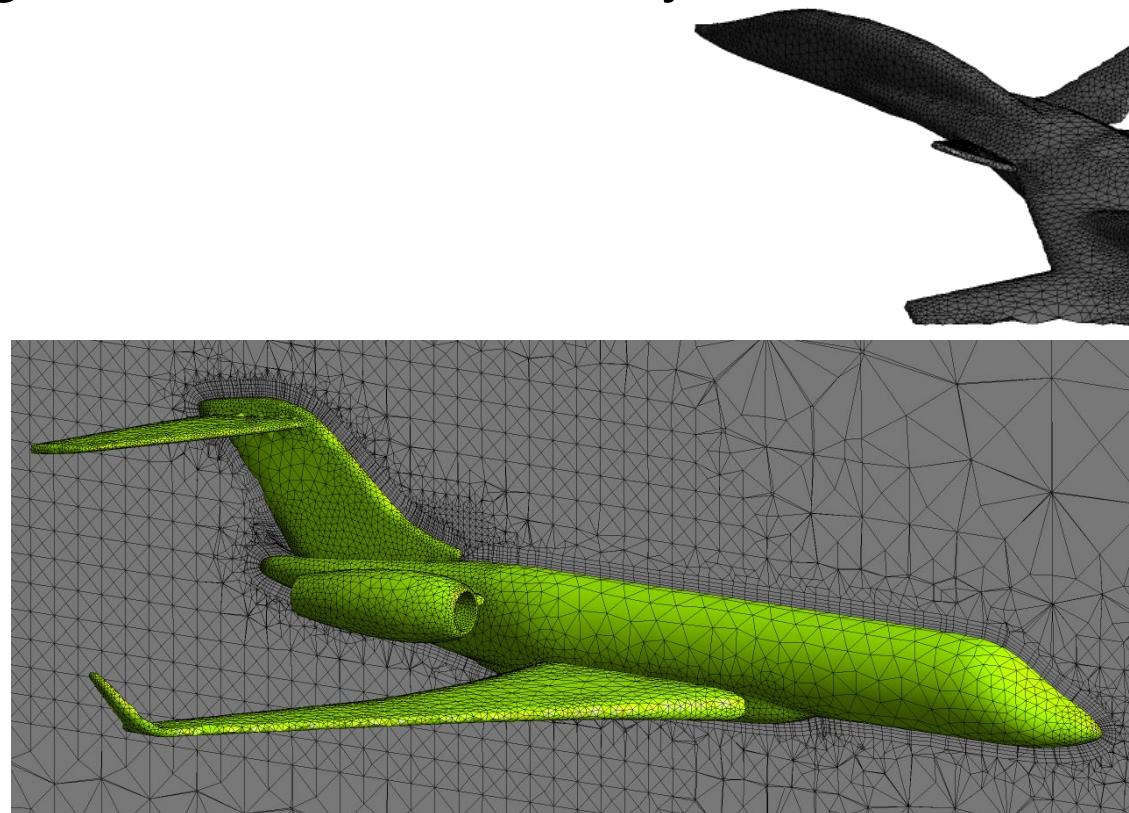
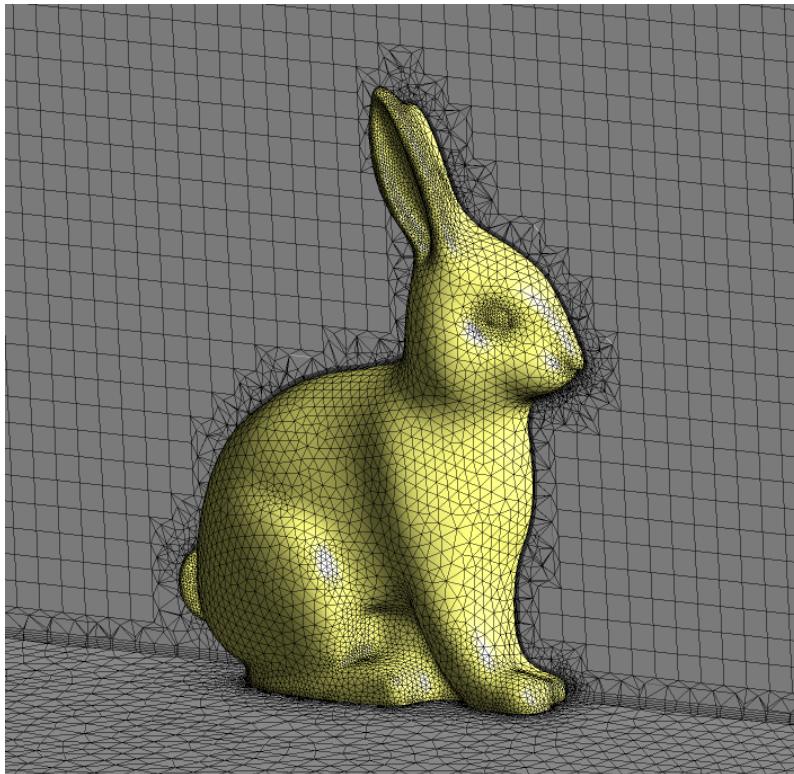
MESHING

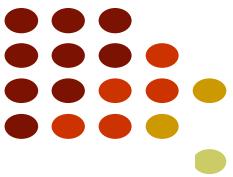
– Discretising the computational domain



What are mesh and meshing?

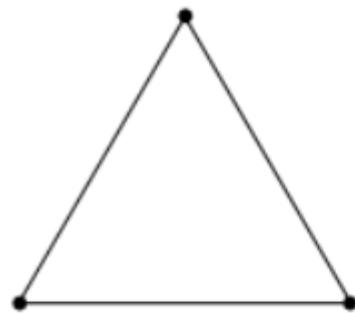
- ❖ A mesh is a representation of a larger geometric domain by smaller discrete **cells or elements**.
- ❖ Meshing is the process of building the mesh.
- ❖ Impact on rate of convergence, solution accuracy, CPU time, etc.





Mesh elements/cells

2D CELL TYPES

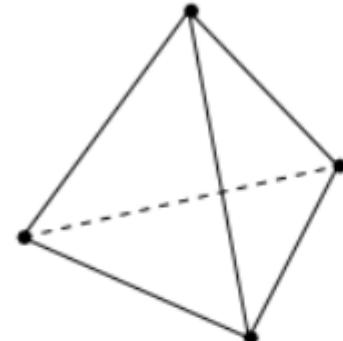


triangle

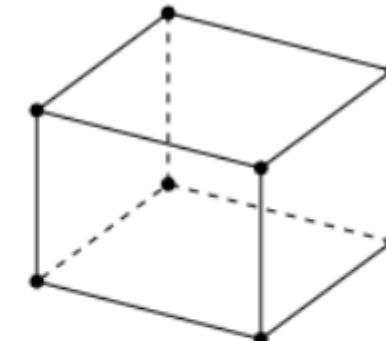


quadrilateral

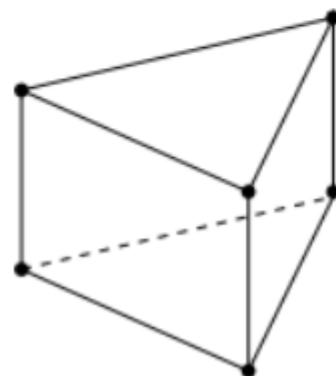
3D CELL TYPES



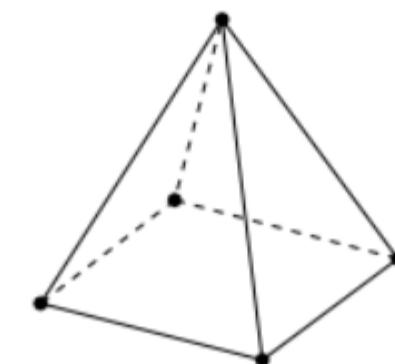
tetrahedron



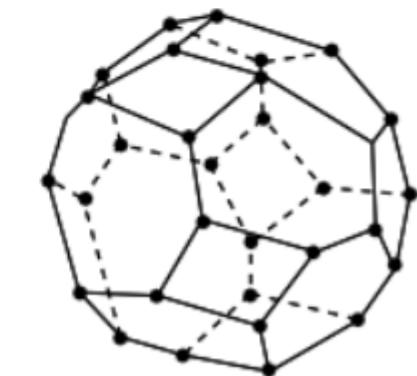
hexahedron



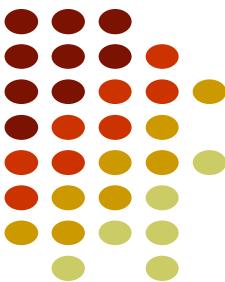
wedge



pyramid

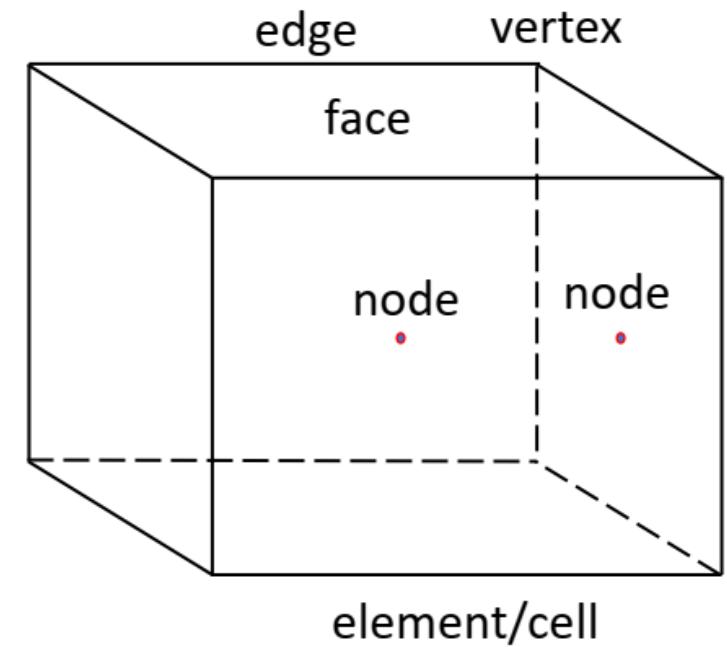


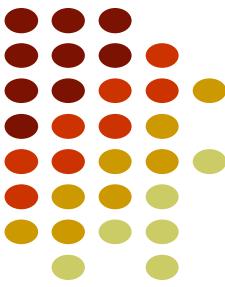
polyhedron



Terminology

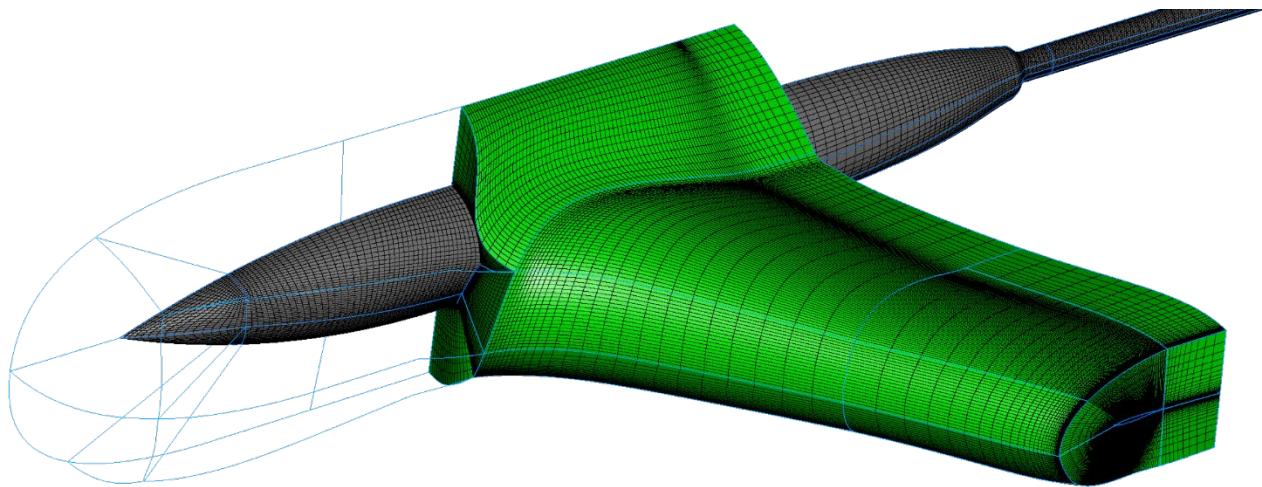
- ❖ Domain: The geometry space of interest for CFD
- ❖ Zone: 2D or 3D subdomains in the domain
- ❖ Mesh: A set of discrete cells dividing the domain or zone
- ❖ Element: The control volume
- ❖ Face: Face of an element
- ❖ Edge: Edge of an element
- ❖ Node: Mesh point where information can be stored
- ❖ Vertex: Vertex of an element
- ❖ Spatial discretisation: meshing



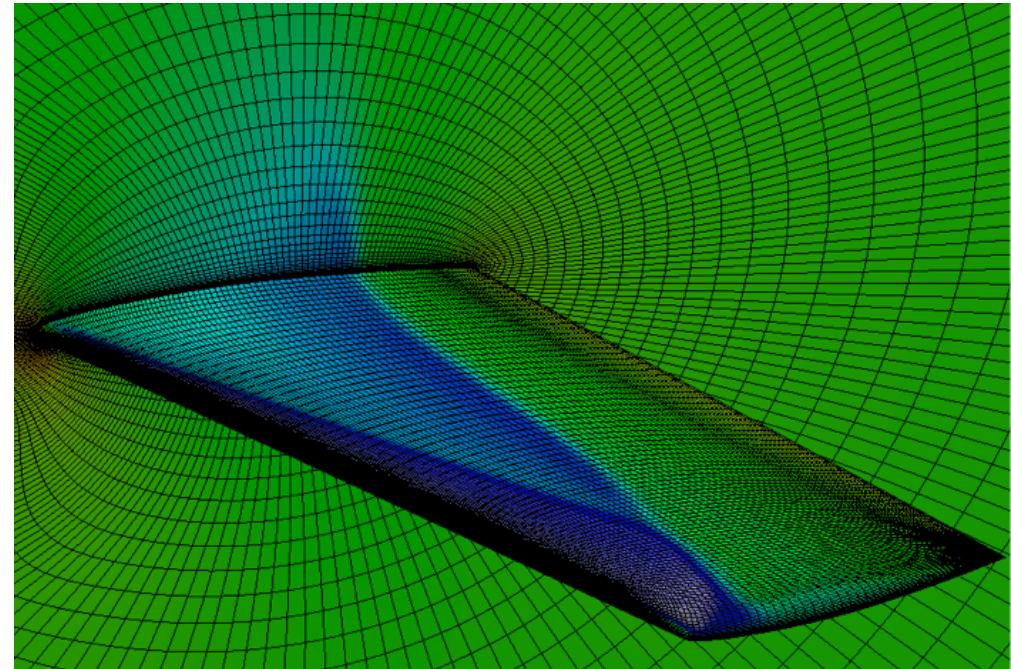


Mesh types – Structured mesh

Structured mesh is identified by **regular connectivity of mesh elements**. The possible element choices are quadrilateral in 2D and hexahedra in 3D.

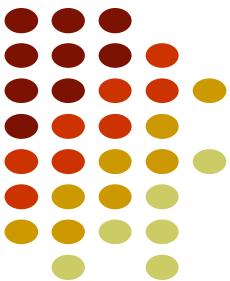


<https://www.design-engineering.com/cfd-automeshing-1004028397-1004028397/>

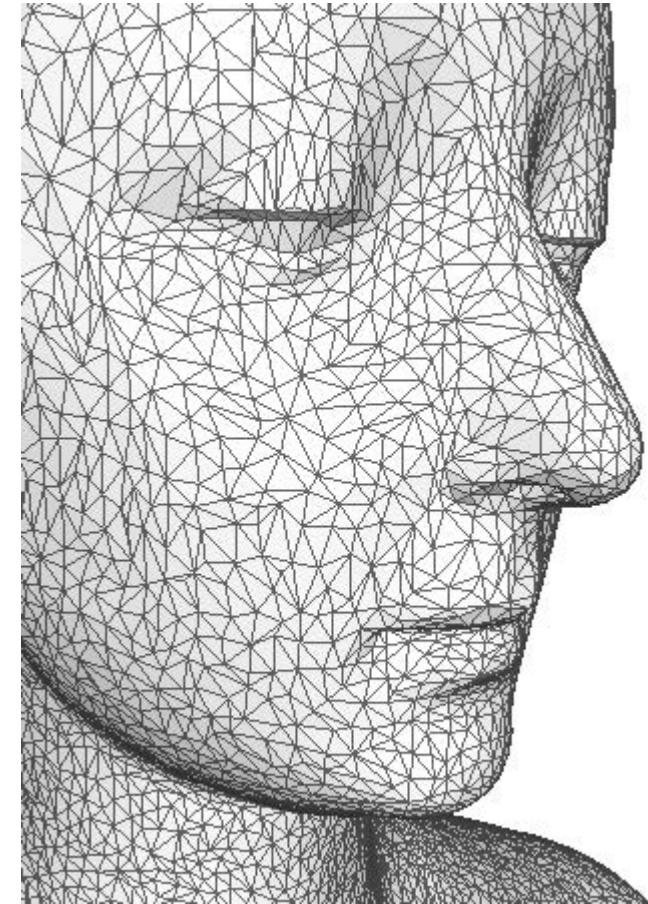
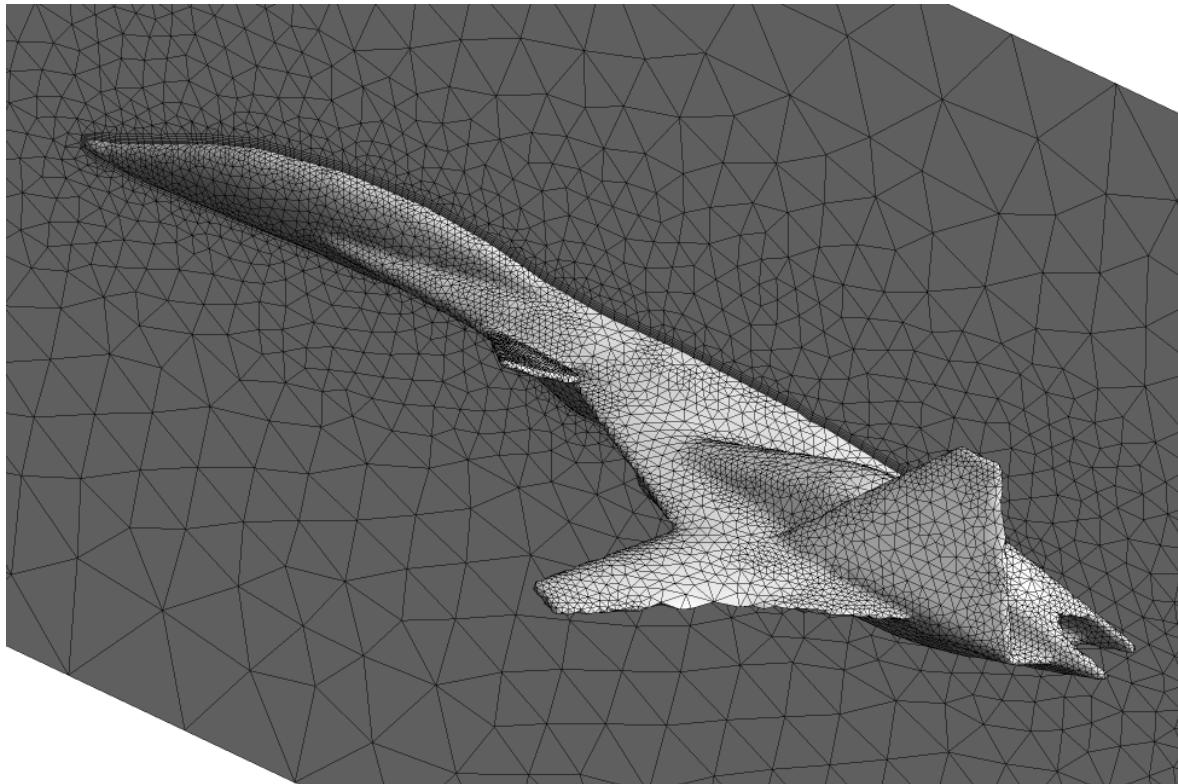


<https://blog.gridpro.com/do-meshes-still-play-a-critical-role-in-cfd/>

Mesh types – Unstructured mesh

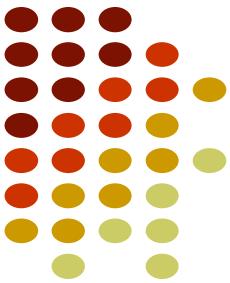


Unstructured mesh is identified by **irregular connectivity of mesh elements**.



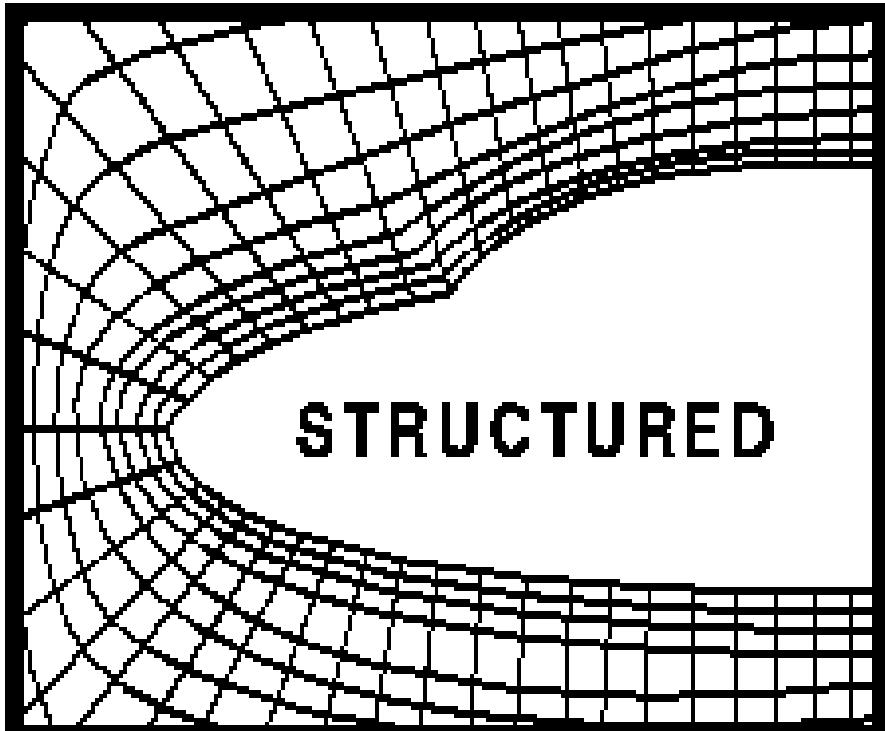
<https://www.sci.utah.edu/the-institute/highlights/24-research-highlights/cibc-highlights/439-cleaver.html>

Structured vs unstructured mesh



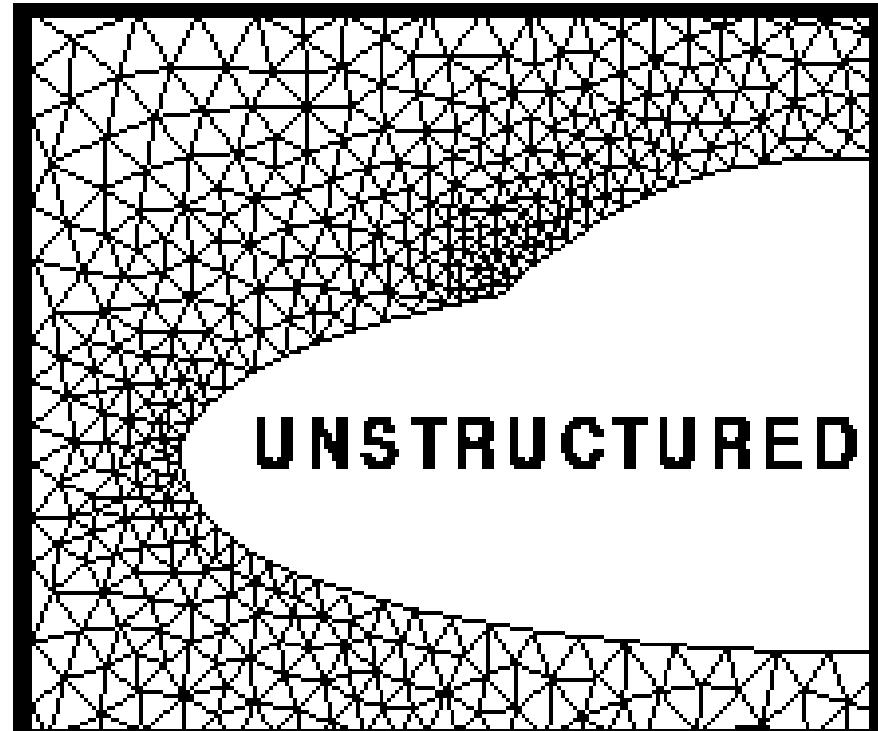
Structured

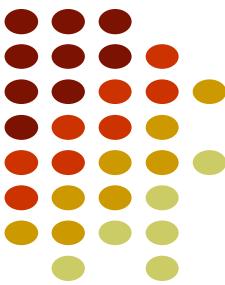
- Numerically stable
- Cost-efficient



Unstructured

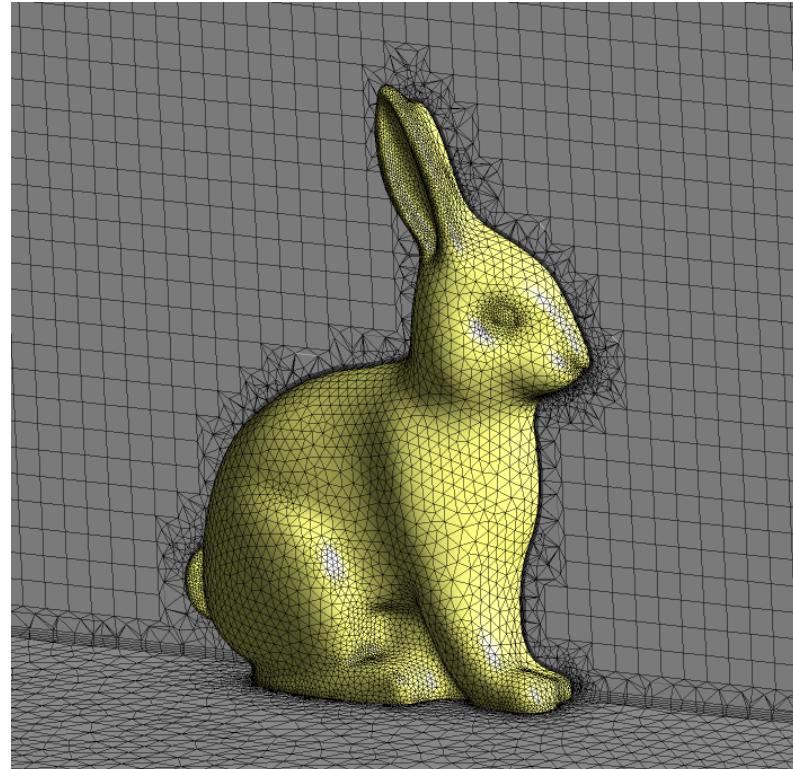
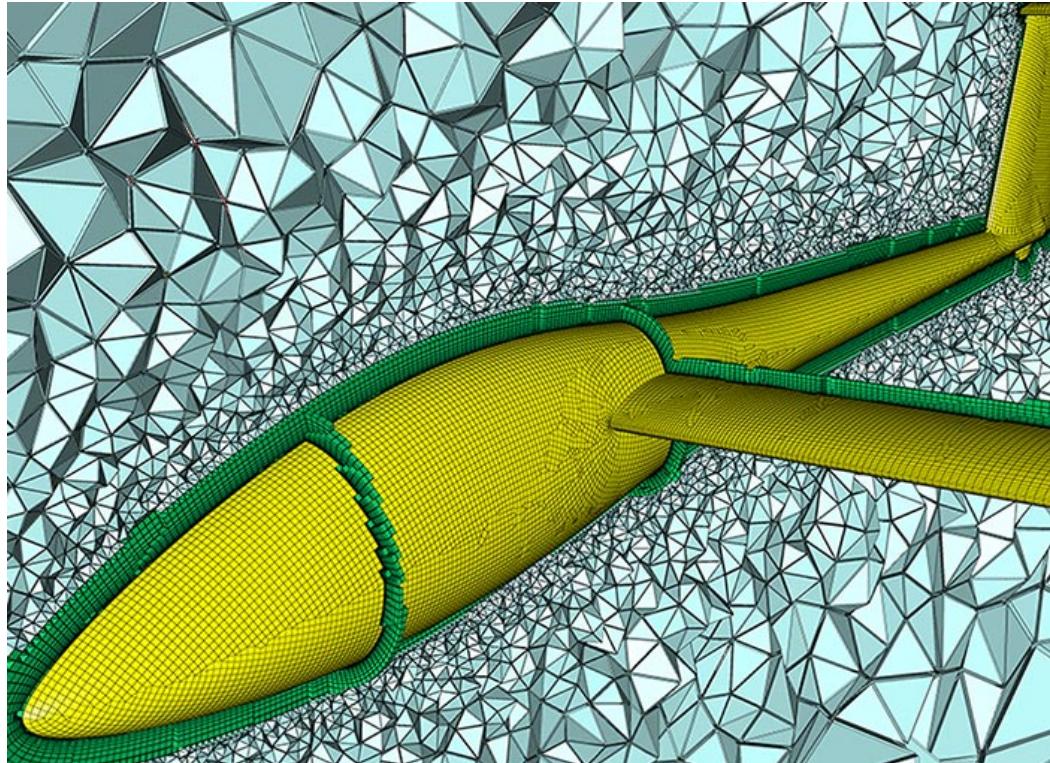
- Flexible and easy to apply
- Geometrically robust



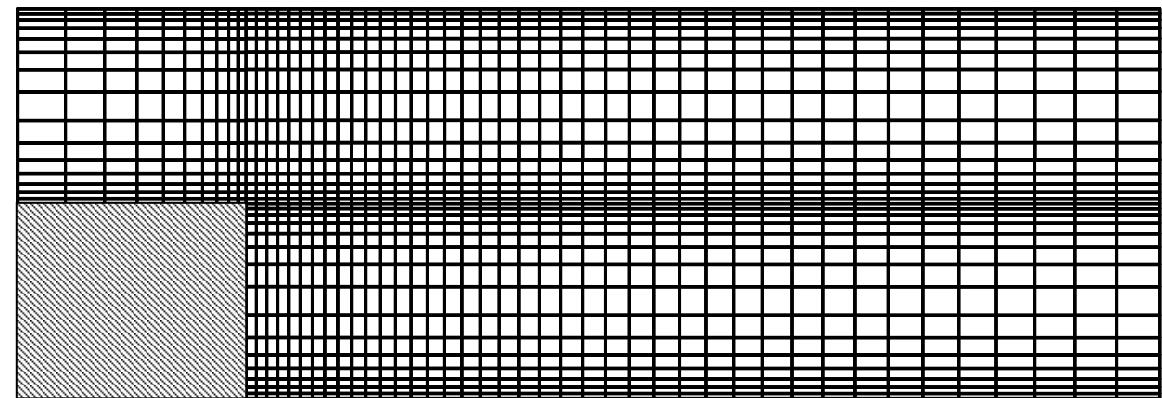
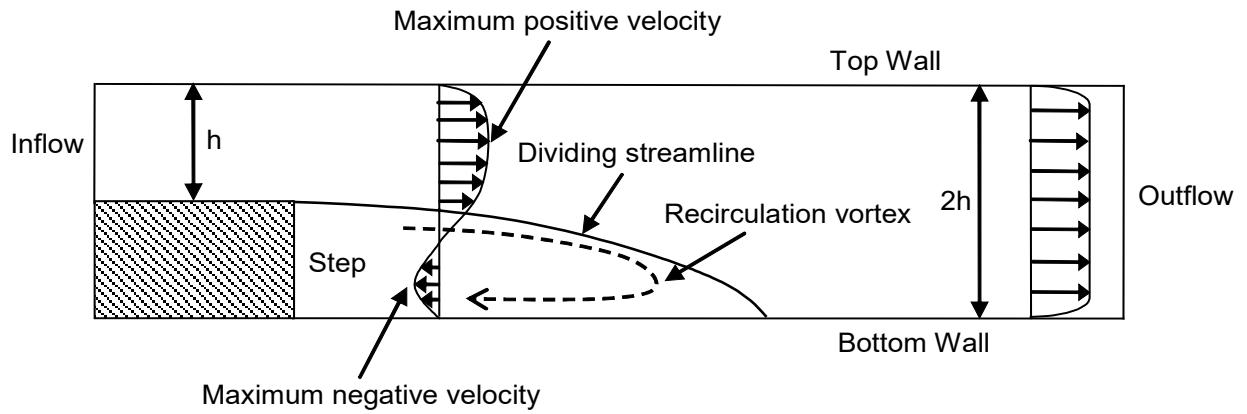
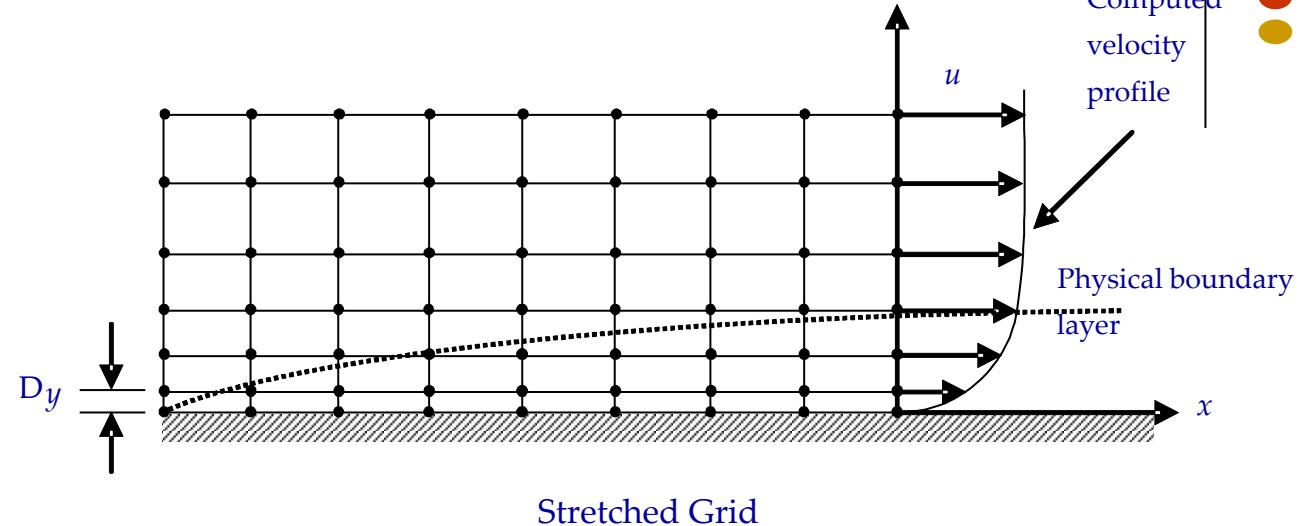
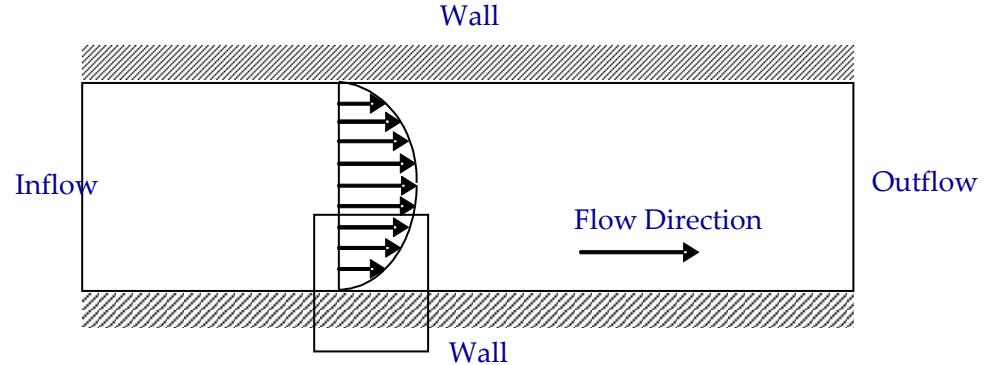
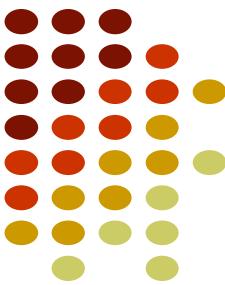


Mesh types – Hybrid mesh

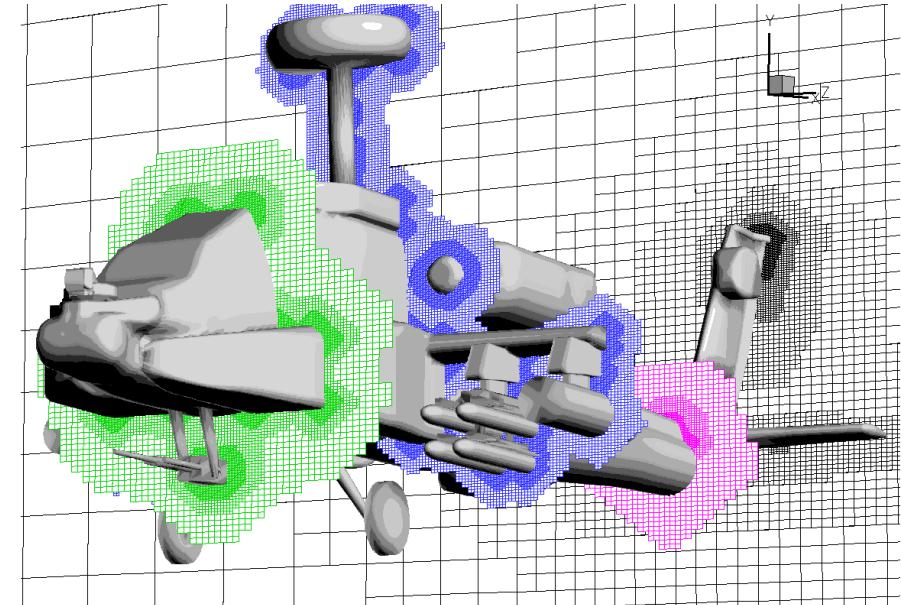
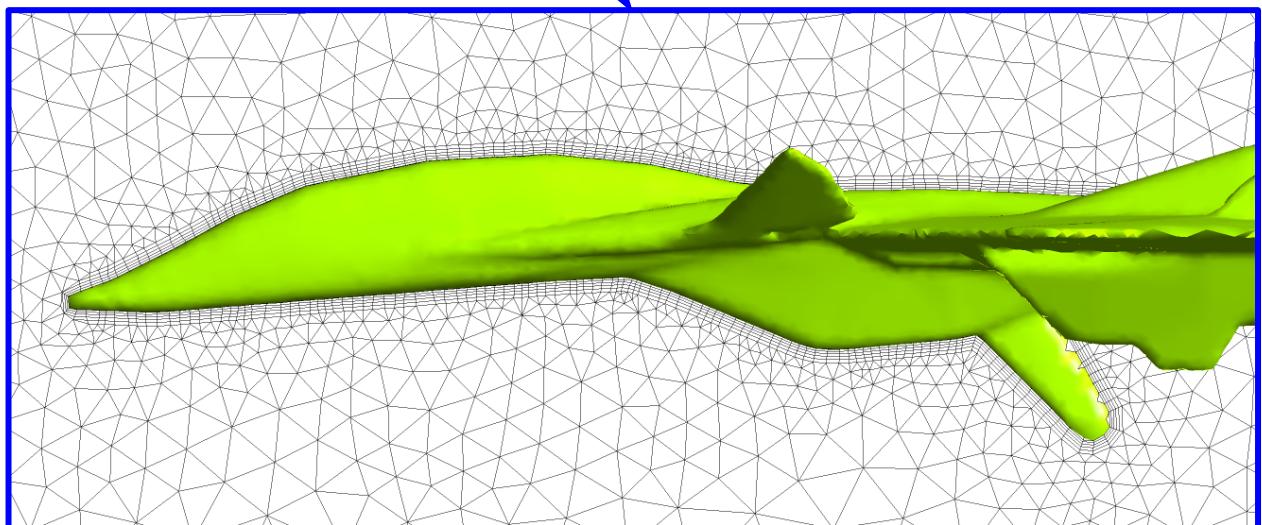
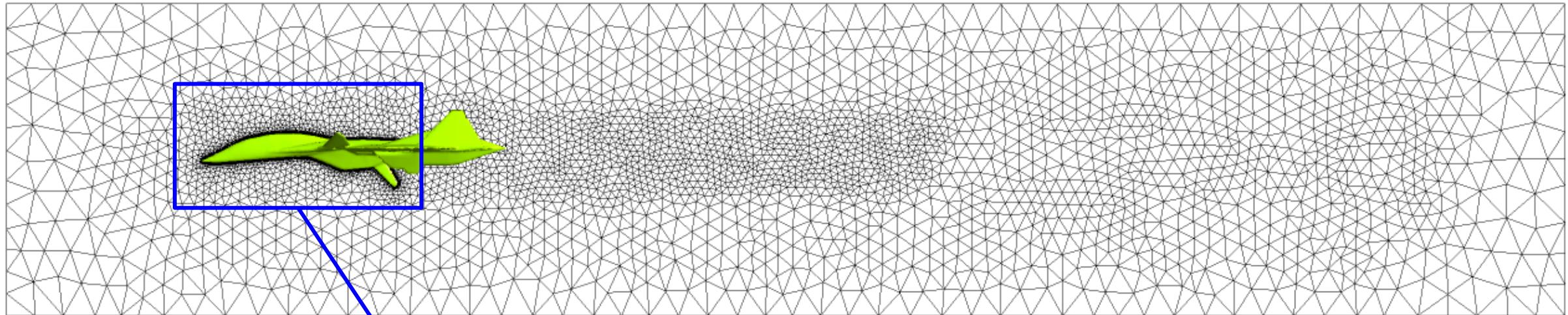
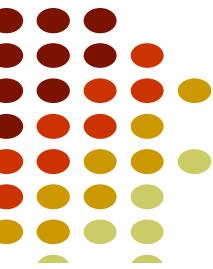
Hybrid mesh is a **combination** of structured and unstructured mesh.



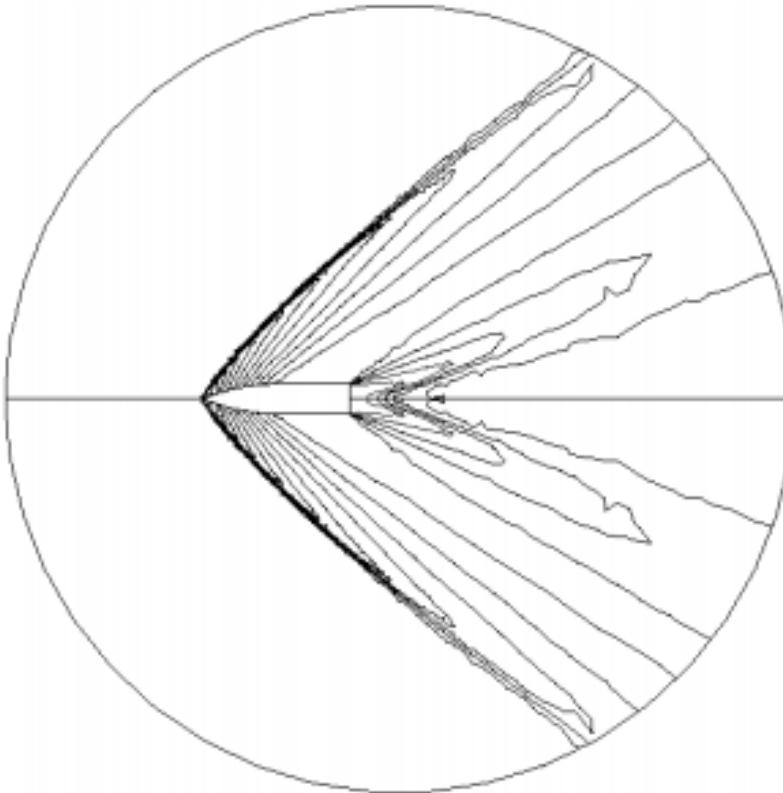
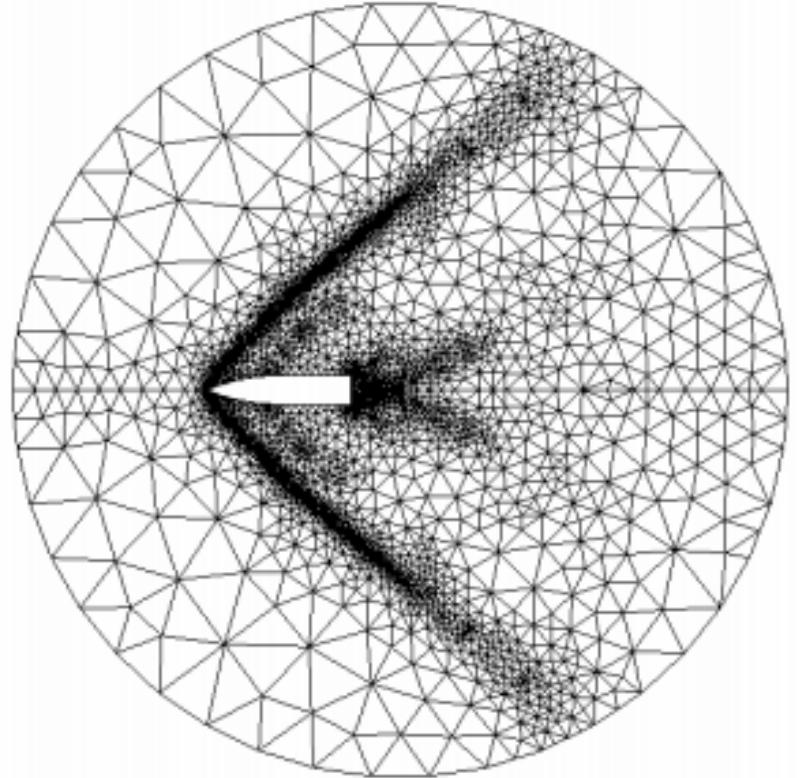
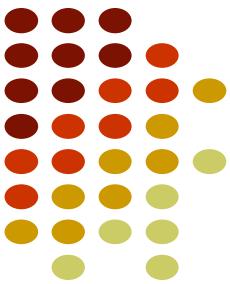
Estimate your flow field before meshing



Local refinement – where?

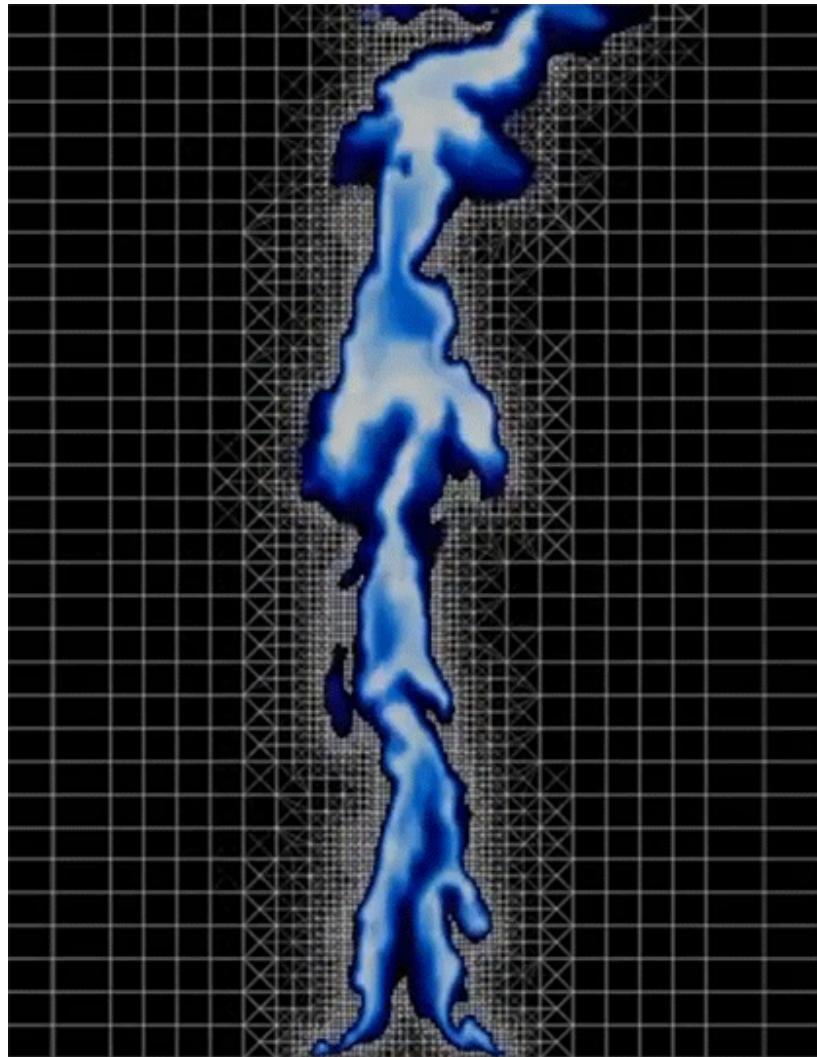


Local refinement – where?

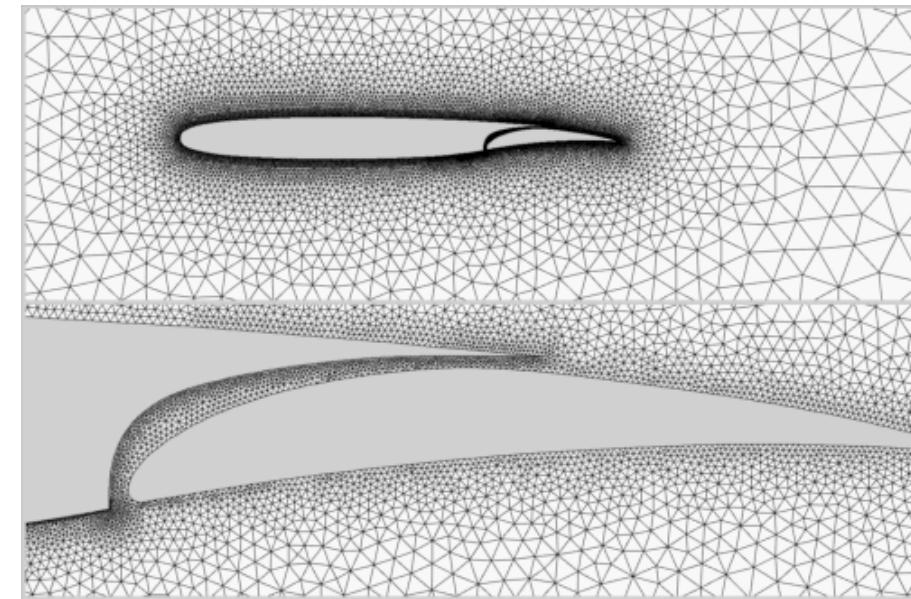


Often you need to go back to re-meshing according to your initial results

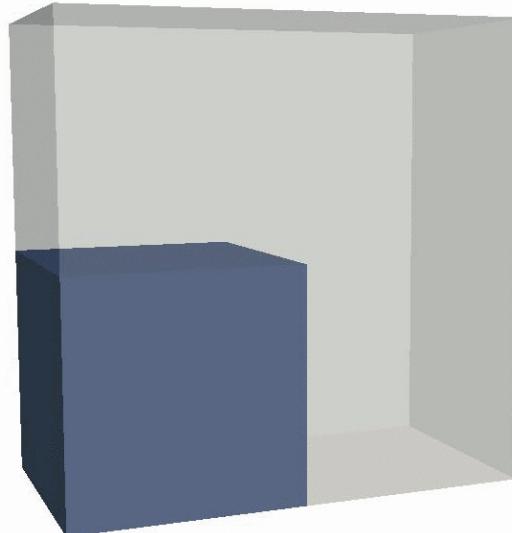
Solution adaptive refinement



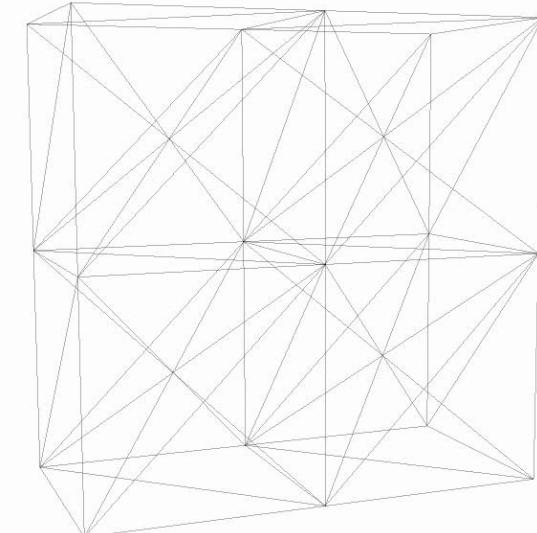
<https://fyfluidynamics.com/2019/12/adapting-to-the-flow/>

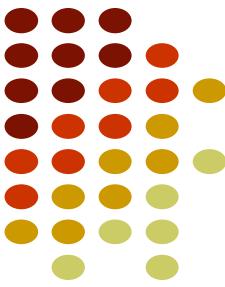


https://home.aero.polimi.it/flowmesh/activity_6.html



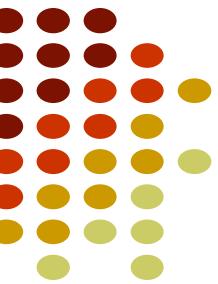
<https://www.simscale.com/docs/content/simwiki/preprocessing/whatisamesh.html?highlight=mesh>





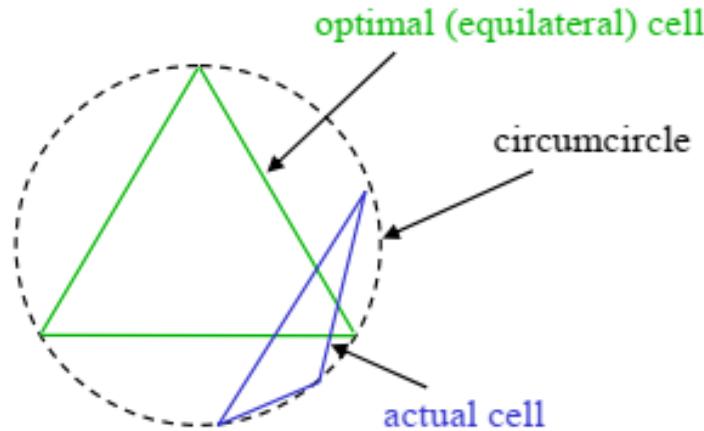
Mesh quality

- ❖ The measures of mesh quality
 - skewness
 - smoothness
 - Aspect ratio
- ❖ For the same element number, hexahedral mesh gives more accurate solutions, especially when the mesh lines are aligned with the flow.
- ❖ Mesh density should be high enough to capture flow features
- ❖ Wall-adjacent mesh elements (hexa, prism/wedge) should be fine enough to capture the boundary layer



Mesh quality – skewness

❖ 0 best, 1 worst



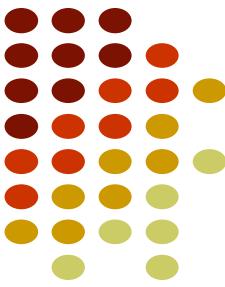
$$\text{skewness} = \frac{\text{optimal cell size} - \text{cell size}}{\text{optimal cell size}}$$



Equiangle skewness

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

$$\theta_e = \begin{cases} 60 & \text{triangle} \\ 90 & \text{square} \end{cases}$$

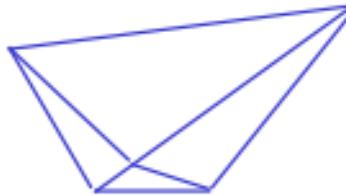


Mesh quality – smoothness

- ❖ Change of mesh size should be gradual



smooth change
in cell size



large jump in
cell size

Mesh quality – Aspect ratio

- ❖ Aspect ratio = 1.0 is ideal



aspect ratio = 1



high-aspect-ratio quad



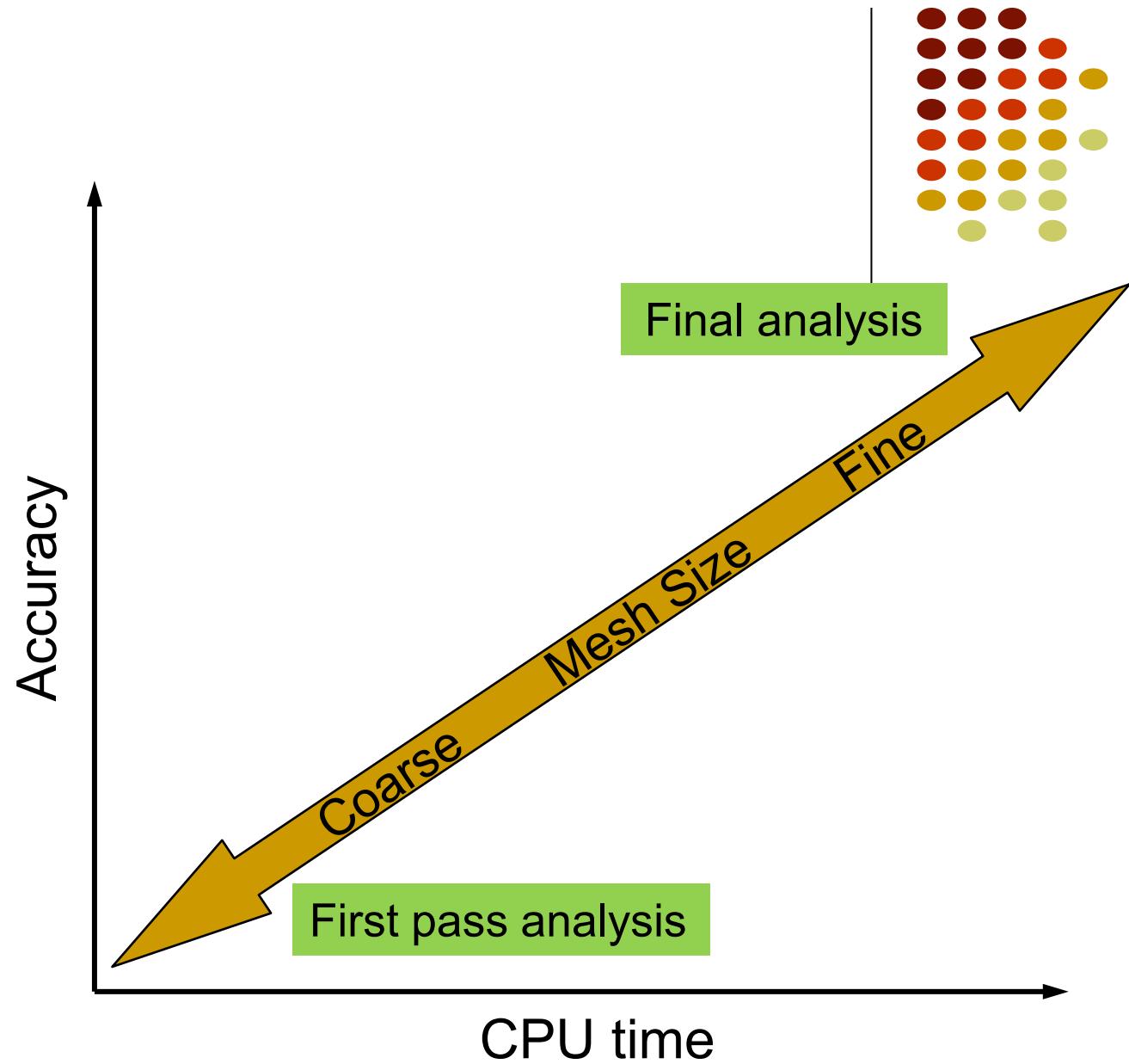
aspect ratio = 1

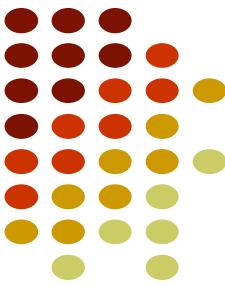


high-aspect-ratio triangle

Tips for meshing

- ❖ Start with coarse mesh to estimate the fields
- ❖ Refine mesh to capture curvature and high gradients of velocity, pressure, temperature, concentration, etc
- ❖ Local refinement
- ❖ Use combination of different mesh types





Tips for meshing

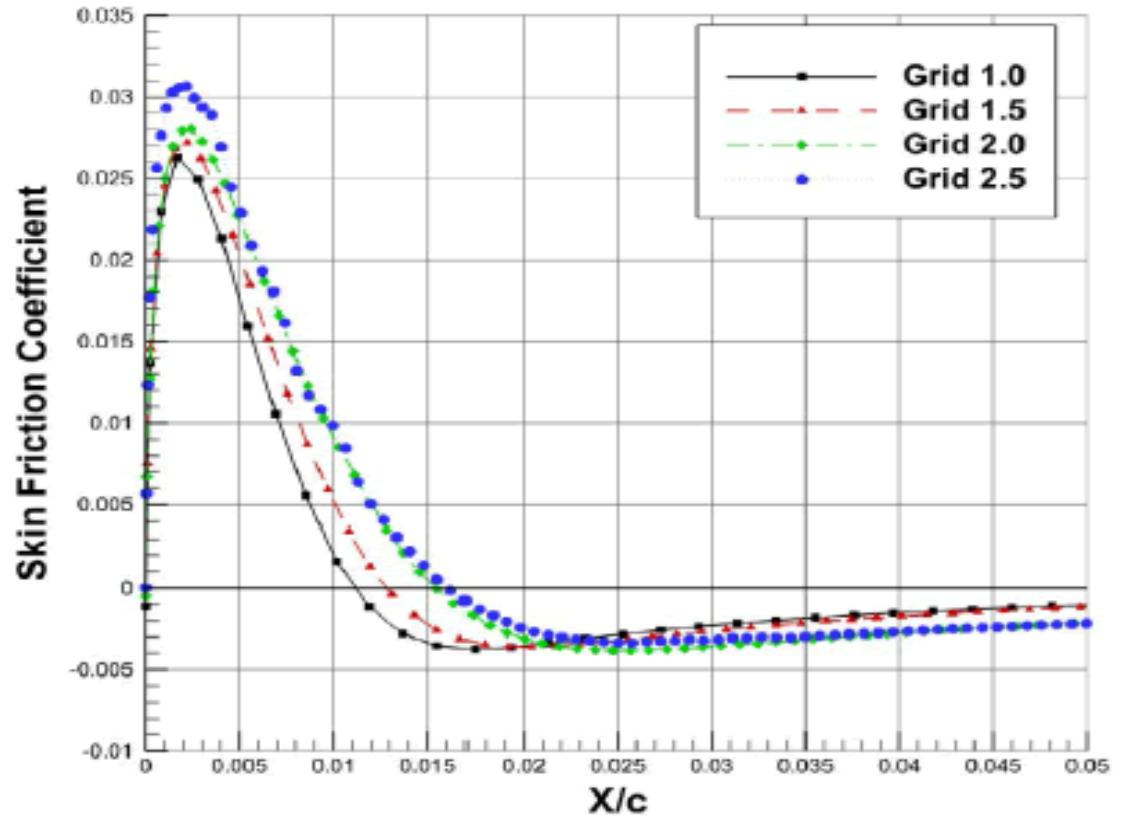
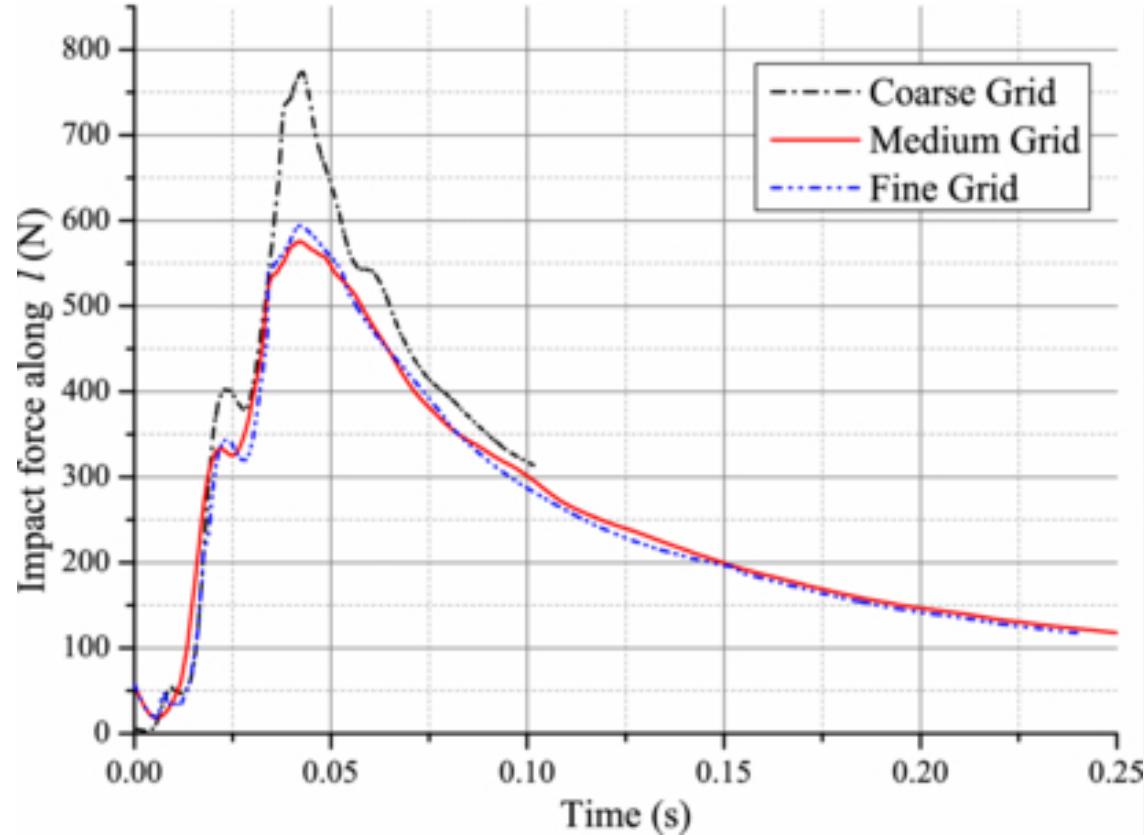
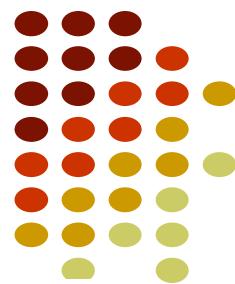
- ❖ Minimise the equiangle skewness

Value of Skewness	0-0.25	0.25-0.50	0.50-0.80	0.80-0.95	0.95-0.99	0.99-1.00
Cell Quality	excellent	good	acceptable	poor	sliver	degenerate

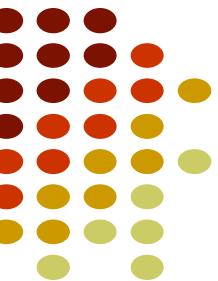
<http://www.bakker.org/>

- ❖ Minimise local variations in cell size - smooth
- ❖ Keep your mesh element count down, for your laptop:
 - 1E4 – relatively small
 - 1E5 – Intermediate
 - 1E6 – Large
 - 1E7 – Huge, but common for aircraft and automotive analysis
 - 1E8 – Defense level

Mesh independence

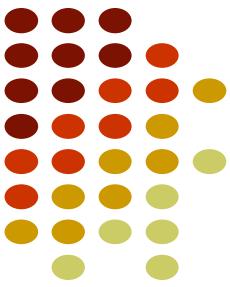


Mesh independence must be achieved during diagnostic runs before moving to production runs.

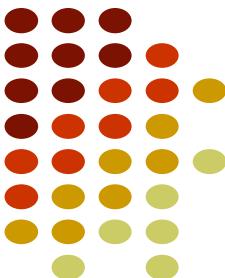


KEY TAKEAWAYS

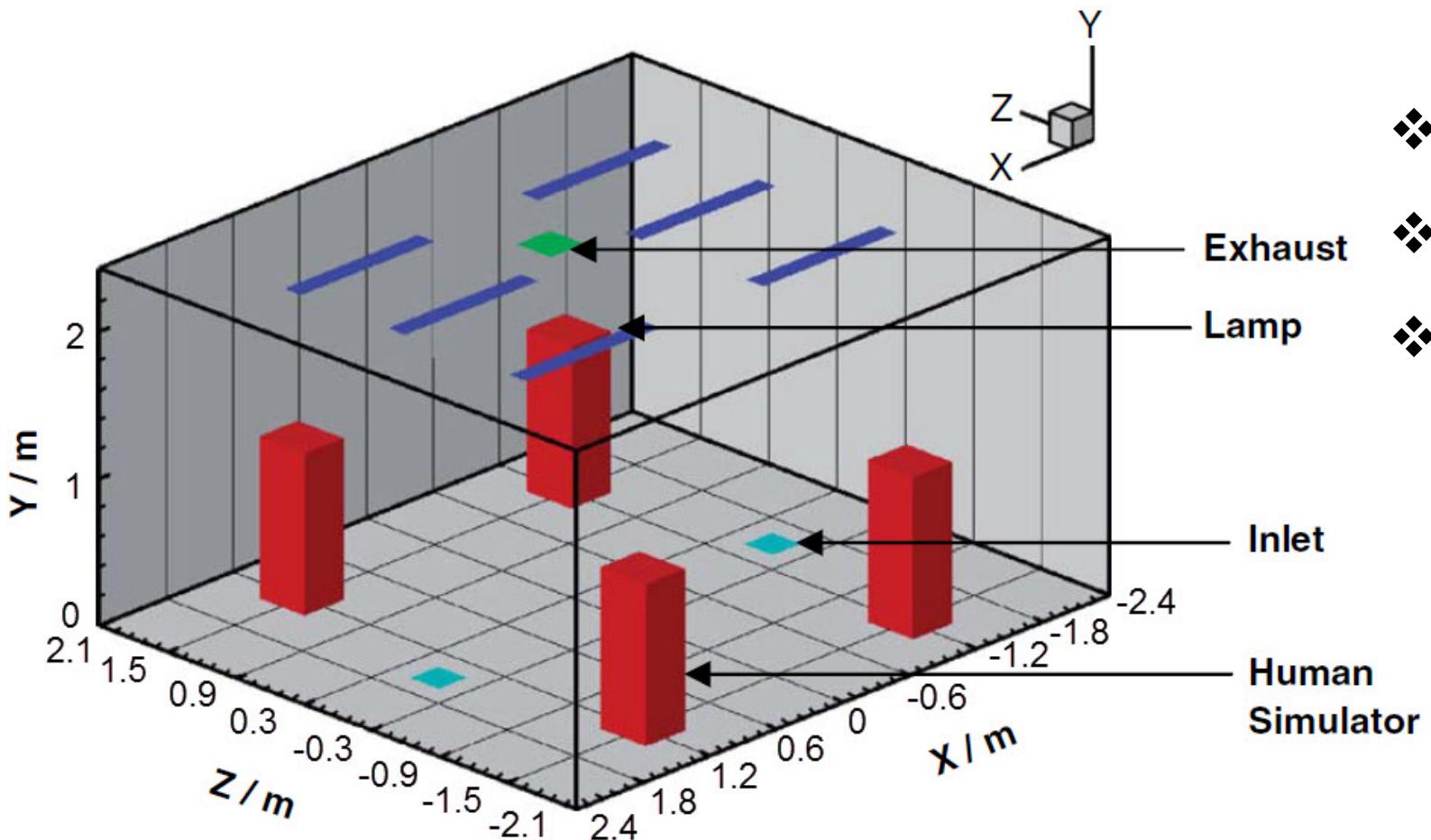
- ❖ Know the methods of geometry manipulation for CFD simulations
- ❖ Master the principles and methods of spatial discretisation
- ❖ Recite the pros and cons of different mesh types
- ❖ Mesh a domain and properly apply local mesh refinement
- ❖ Analyse the quality of mesh



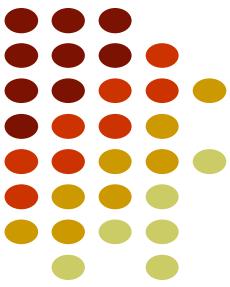
LET'S DO IT



Module 2 assignment



- ❖ Mesh independence test
- ❖ Inflation layers
- ❖ Mesh type: tetrahedral, hexahedral, hexacore...



Q&A