On CAD non-compliance in high-order curvilinear meshing

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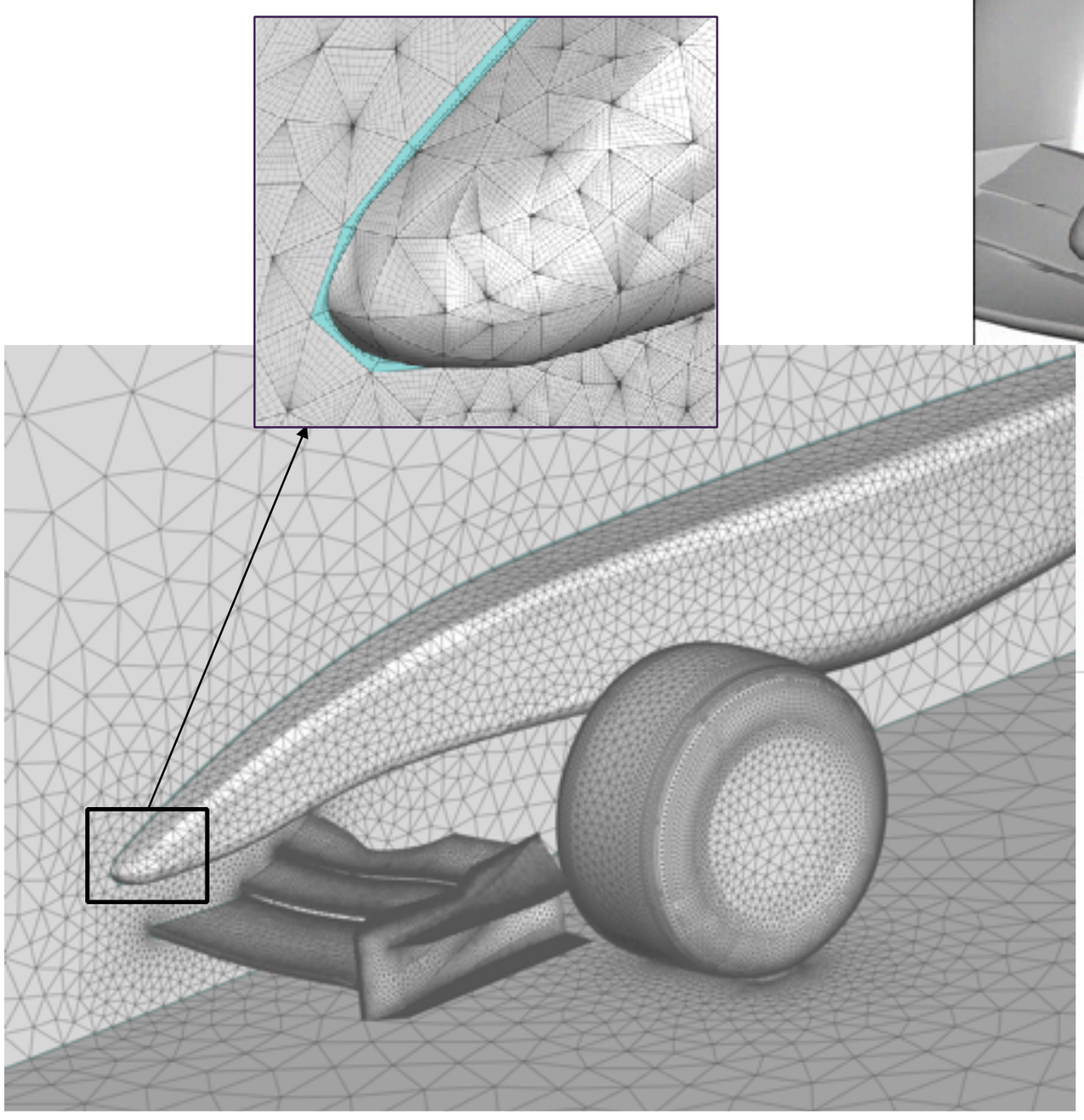
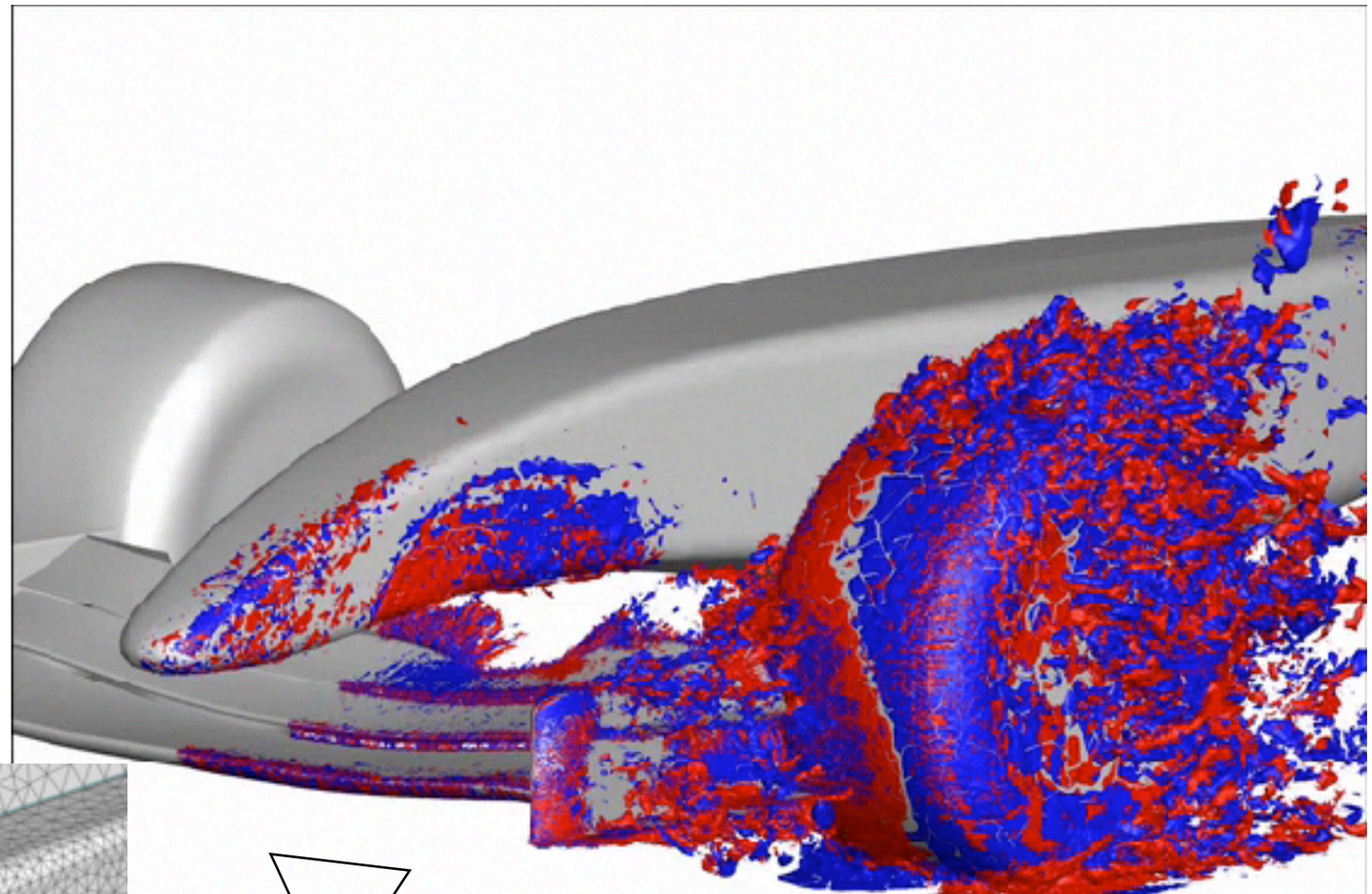
This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 955923.

Complex geometries and flows

Mesh





Flow simulation

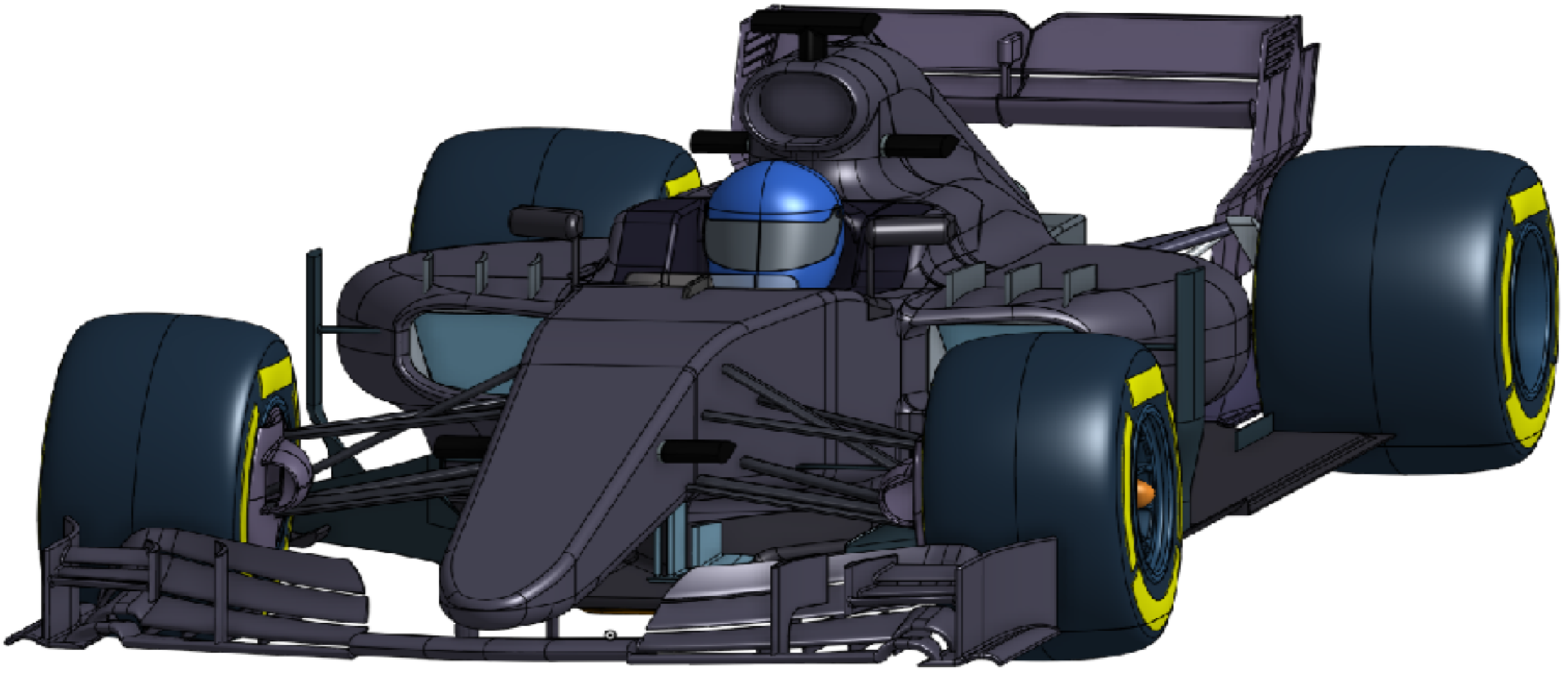
Meshes are curvilinear because …

Complex geometries

Look like this

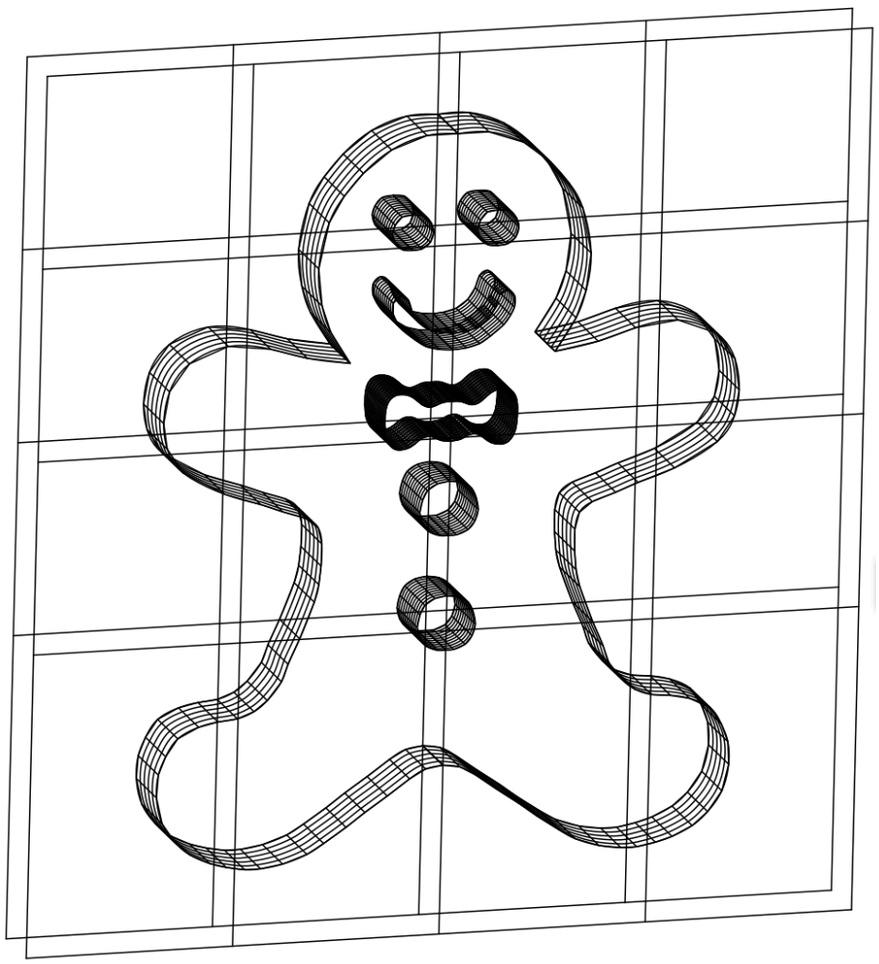
Not like this

Target simulation

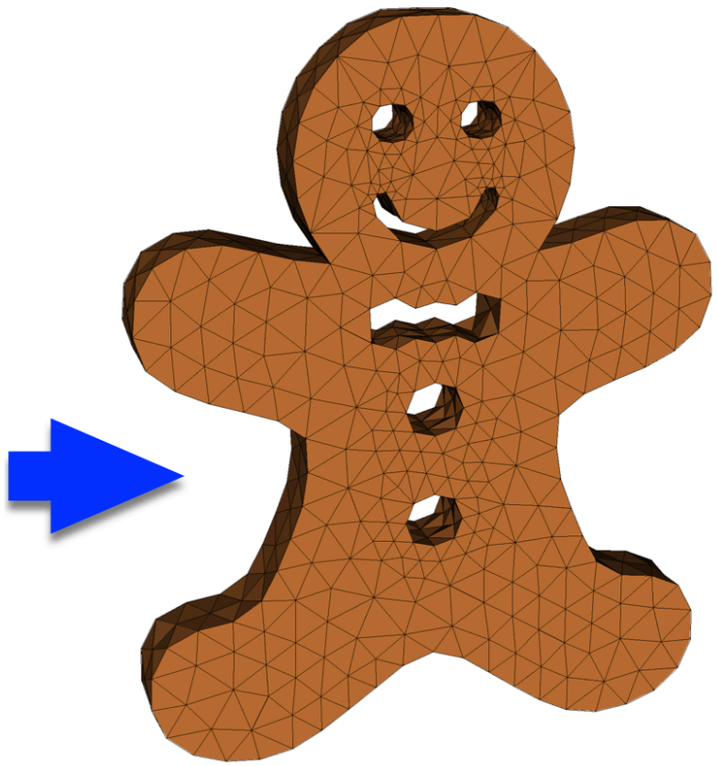


Perrinn F1 Open Geometry

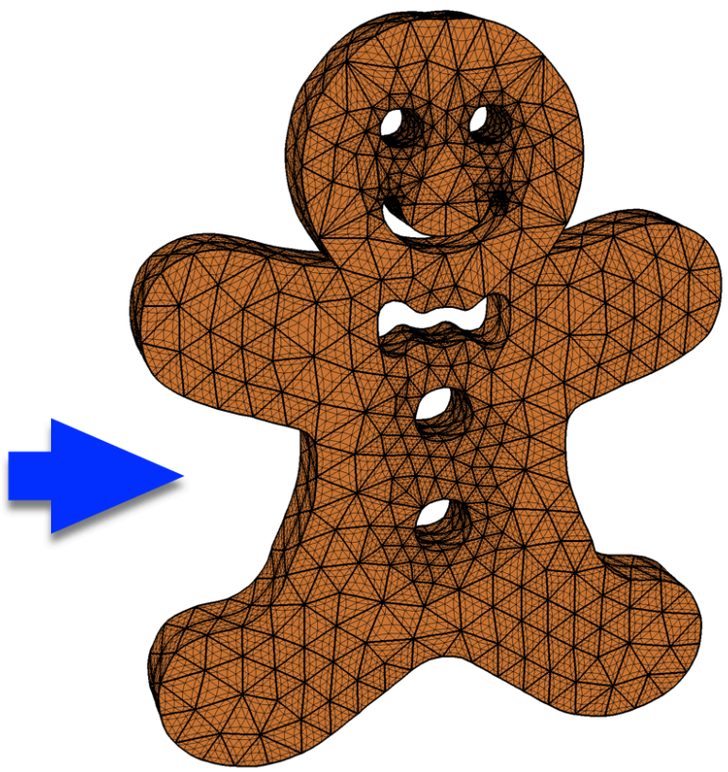
A posteriori high-order mesh generation



B-Rep



Linear mesh

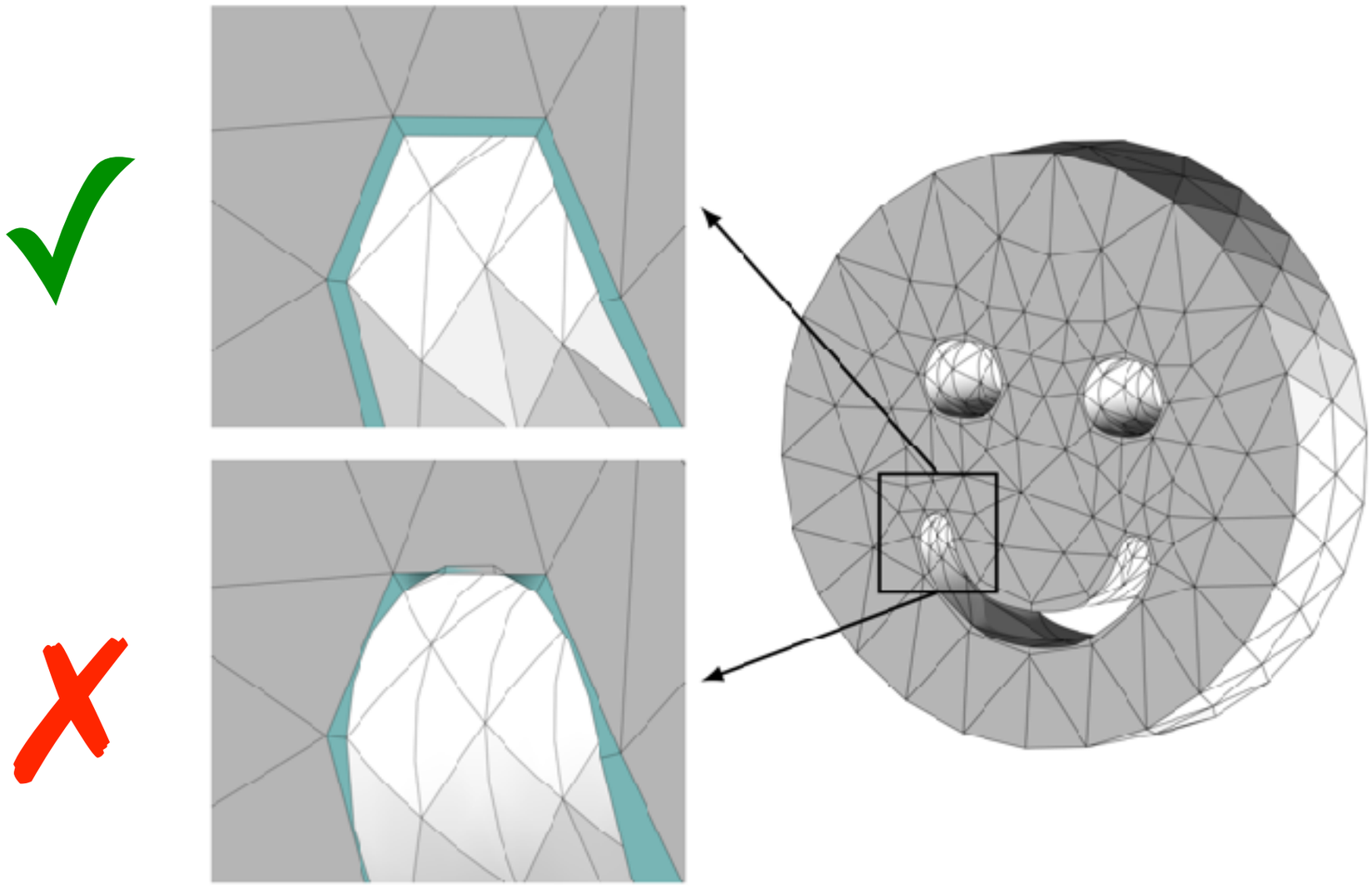


High-order mesh

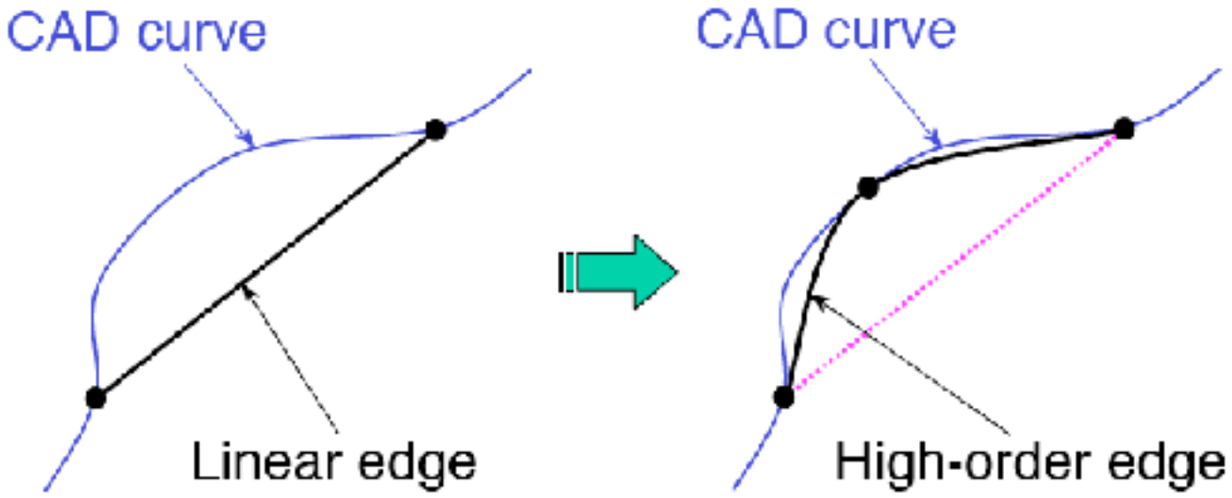
S.J. Sherwin and J. Peiró, *Mesh generation in curvilinear domains using high-order elements*, Int. J. Num. Meth. Eng. 2002.

A posteriori high-order mesh generation

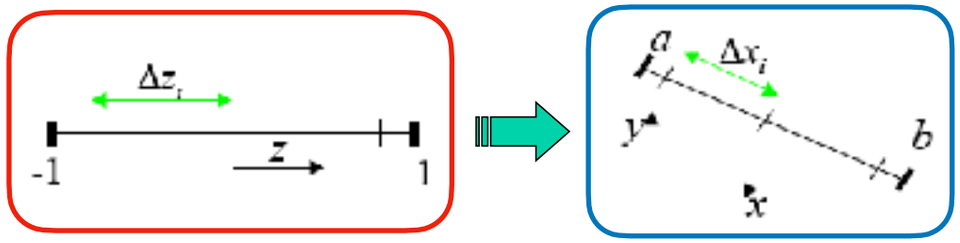
Curving mesh often leads to invalid elements



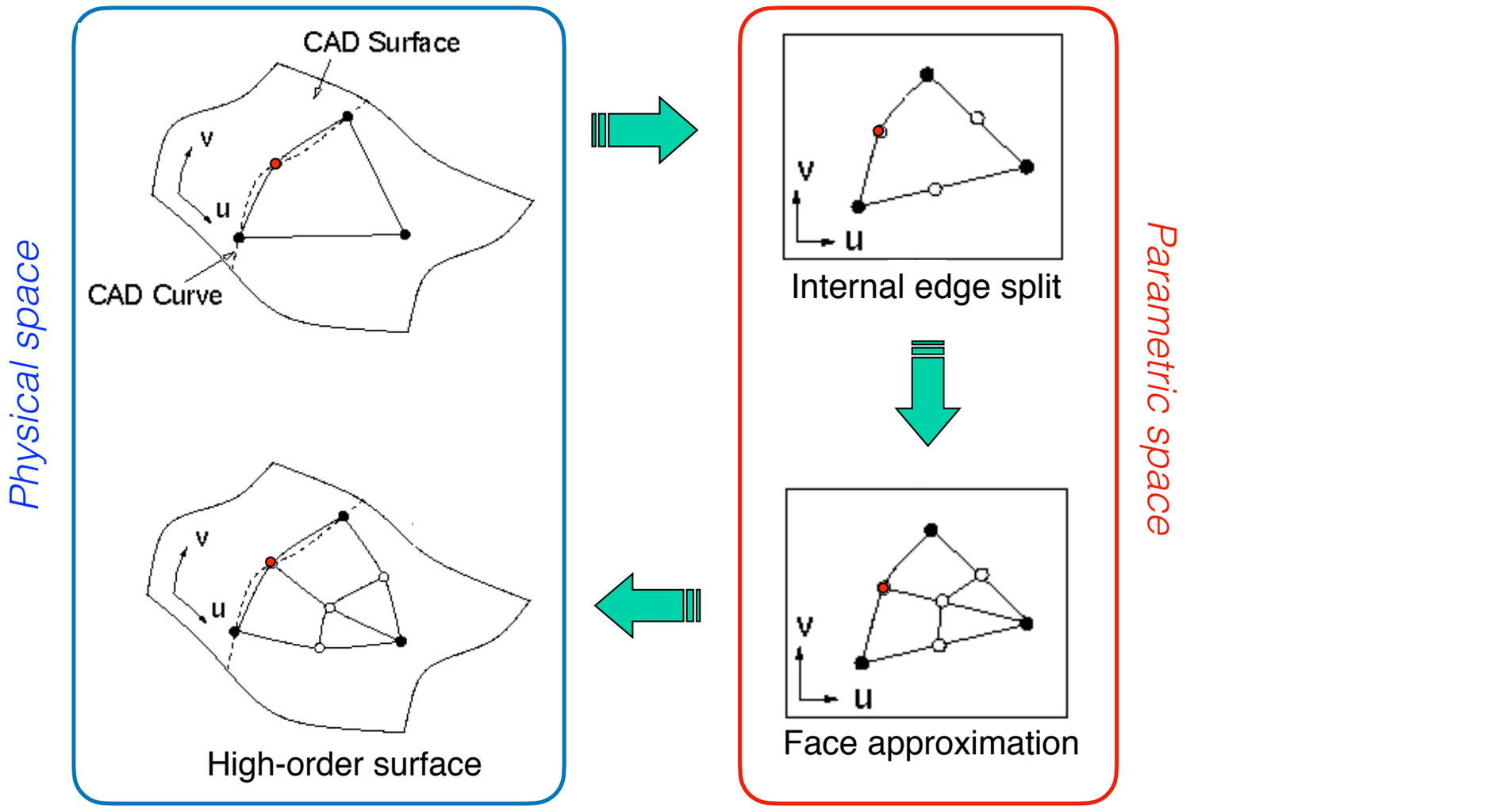
CAD's role in curving a linear mesh



Parametric space *Physical space*



$$x_i = a\left(\frac{1-z_i}{2}\right) + b\left(\frac{1+z_i}{2}\right) \qquad J = \left(\frac{b-a}{2}\right)$$



CAD: The Missing Link

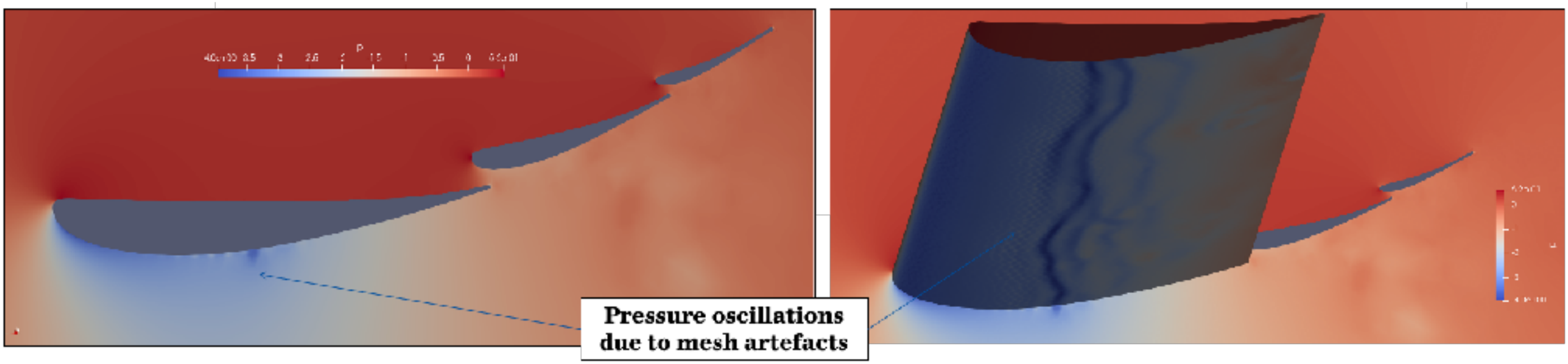
All generators use CAD information to generate a straight-sided mesh, but some do not provide this information to the user of the mesh.

This presents two issues:

1. Is the mesh boundary compliant?
2. How do we curve the mesh to be?

Effect of CAD non-compliance

Errors in boundary geometry could have a significant impact on simulation accuracy.

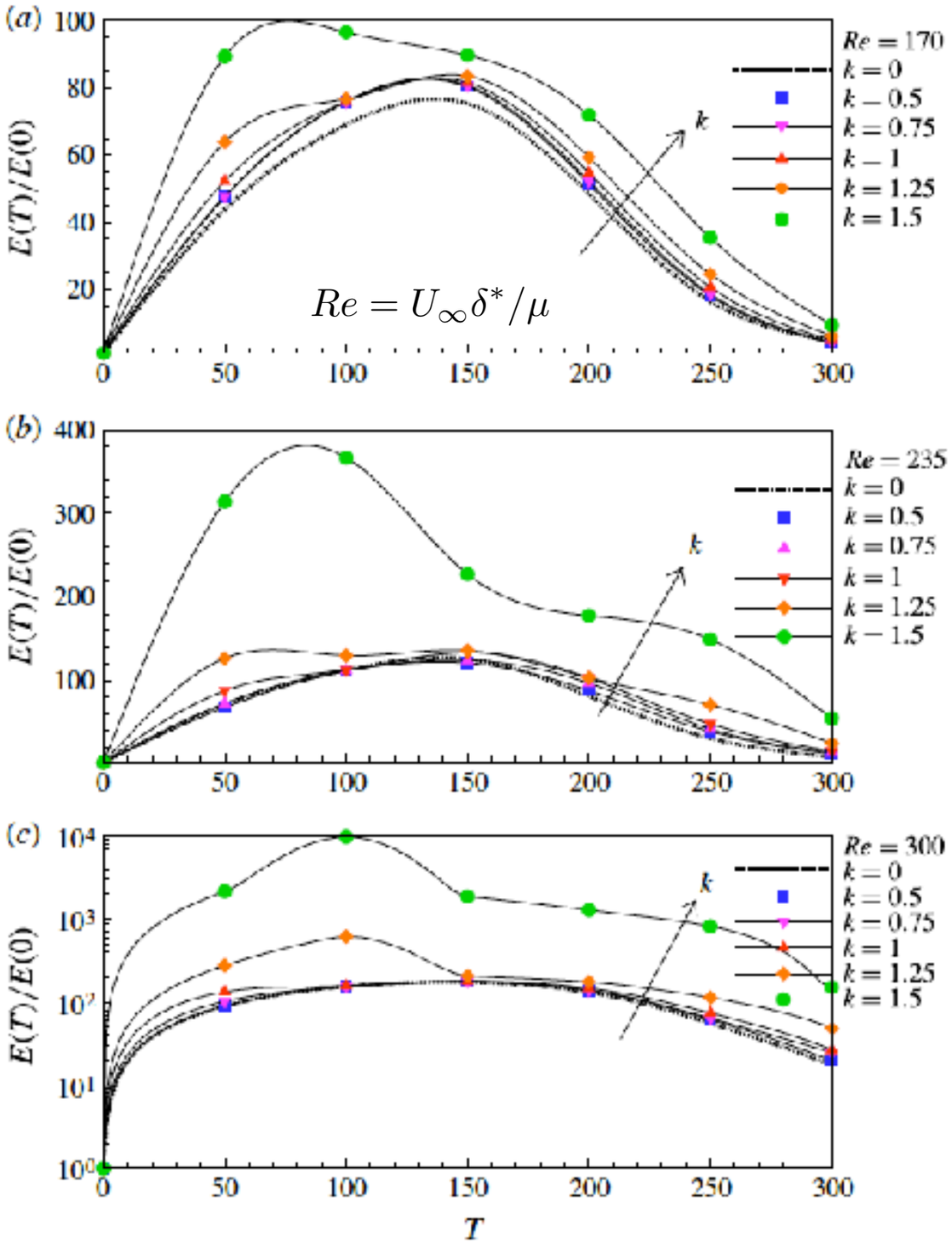


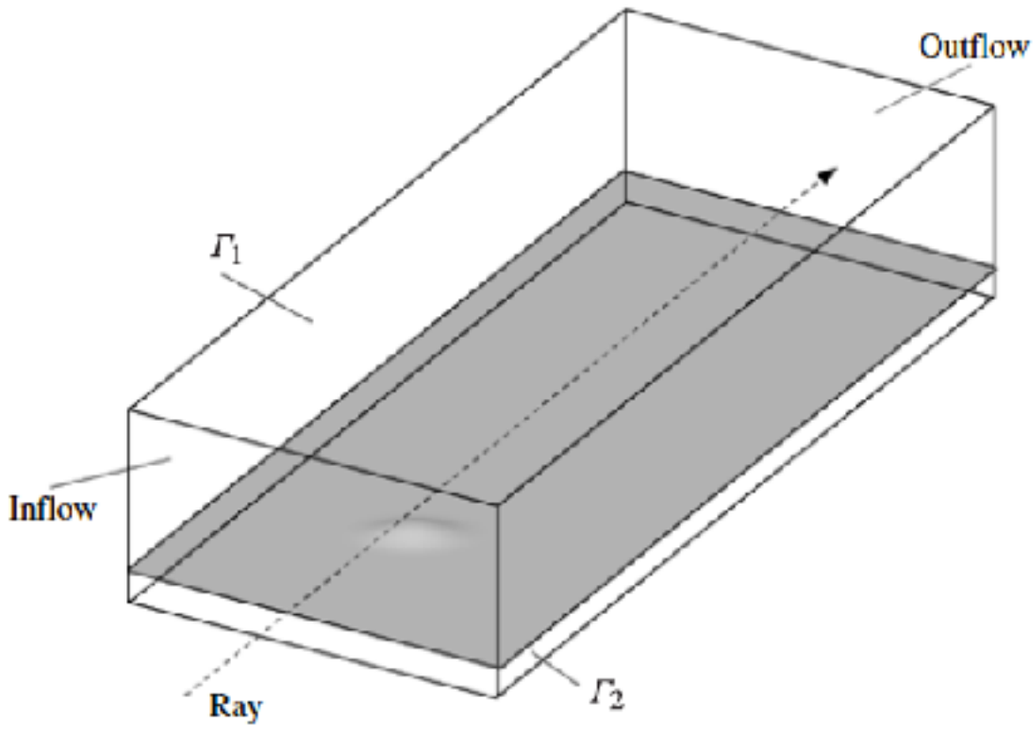
Small-scale roughness induces boundary-layer perturbations that destabilize the separated shear layer and lead to the development of turbulence downstream.

High-order methods are particularly susceptible because perturbations induced by small-scale geometric imperfections are not attenuated by numerical dissipation.

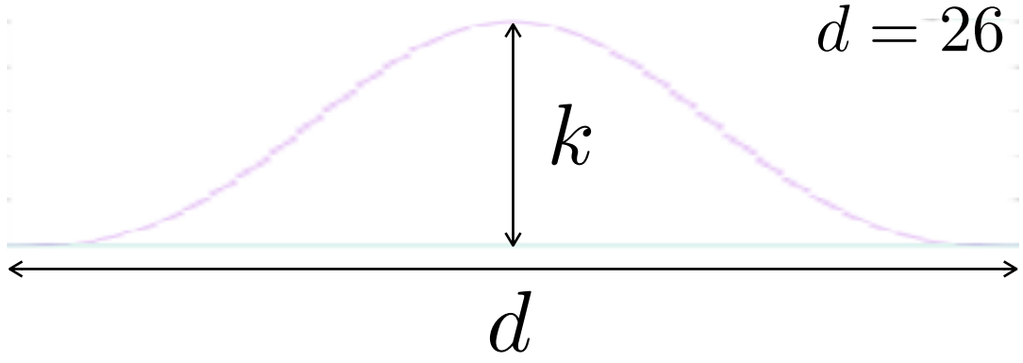
Sensitivity of flows to surface imperfections

Disturbance energy $E(t) = \int_V \left(u'^2(t) + v'^2(t) + w'^2(t) \right) \, dV$





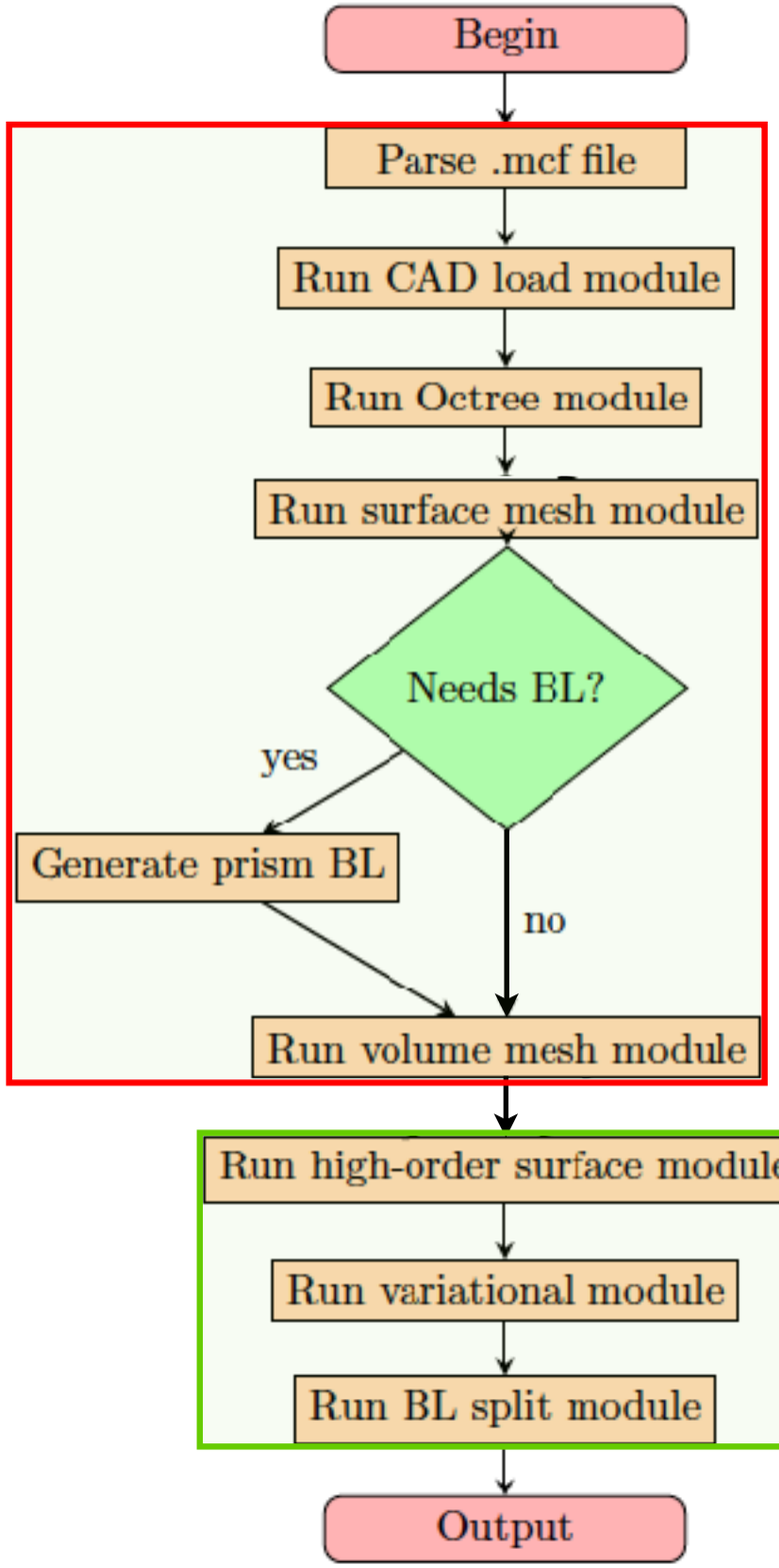
$L_x = 216, \; L_y = 27.5, \; L_z = 72$



$h(r) = k \cos^3(\pi r / d)$

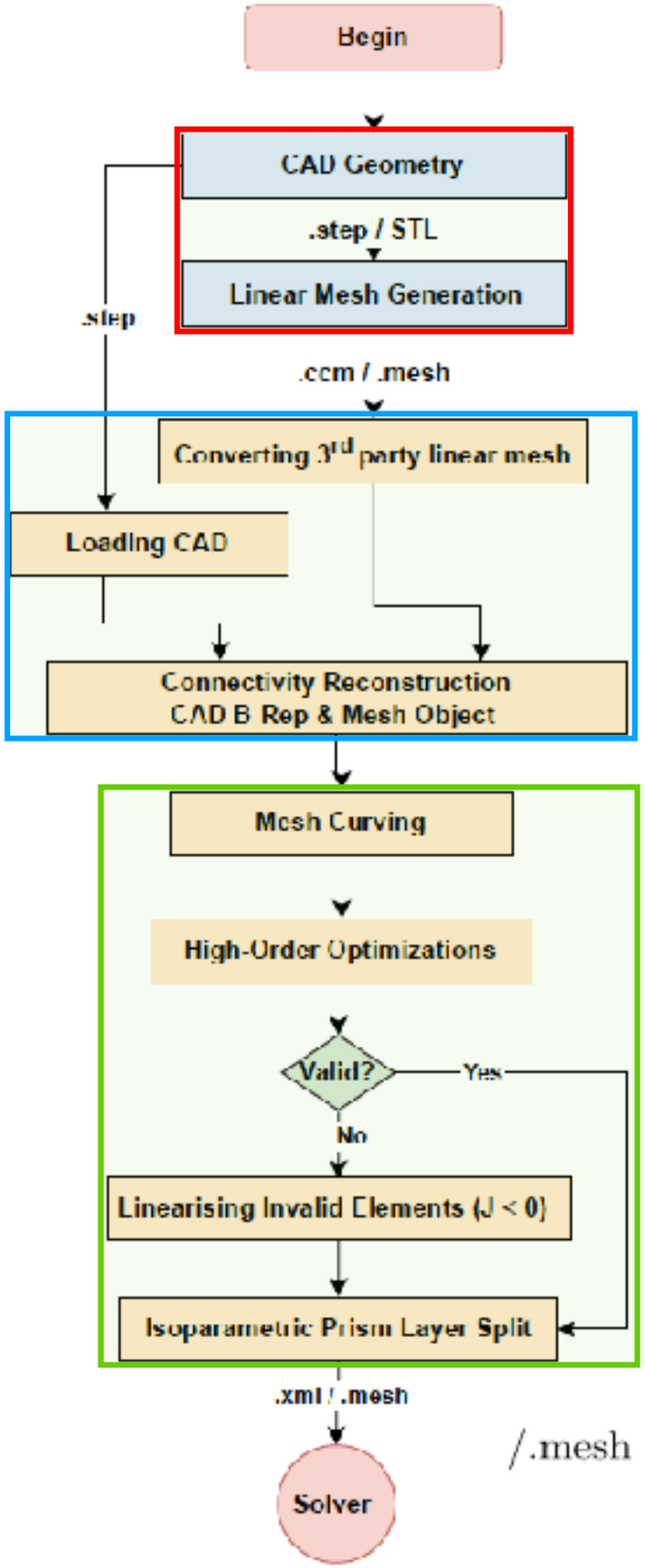
Transient growth in the flow past a three-dimensional smooth roughness element, S. Cherubini, M. D. De Tullio, P. De Palma and G. Pascazio, J. Fluid Mech. (2013), vol. 724, pp. 642 670.

Third-party mesh curving redesign



Linear Meshing

High-order Meshing



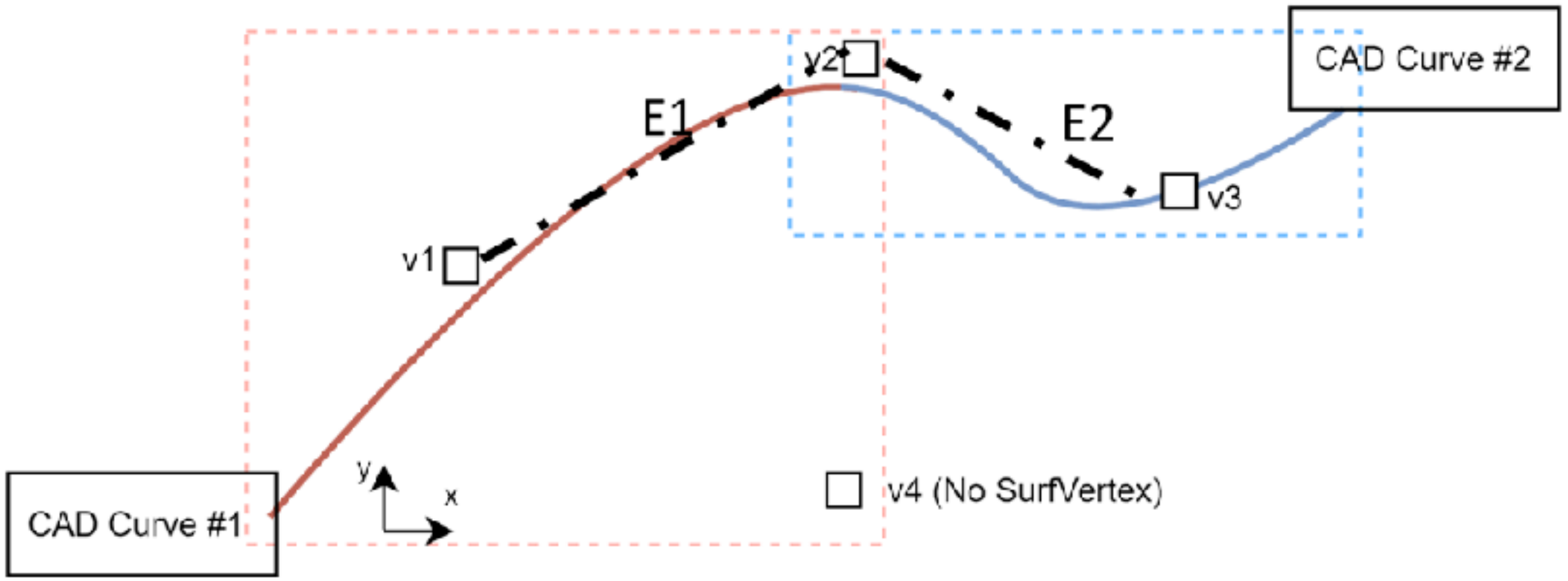
Third-party Meshing

CAD Information Recoverv

High-order Meshing

Recovering the CAD curve information

- Sample coordinates of CAD objects, calculate bounding boxes and store them in a k-D tree for efficient range search.
- Next steps:
    1. Associate vertex to CAD curve
    2. Project vertex onto curve



Note that none of the vertices is “exactly on” the CAD curve.

Candidate Curve ID?: $\mathbf{v}_1$ to Curve #1; $\mathbf{v}_3$ to Curve #2; $\mathbf{v}_2$ to both curves

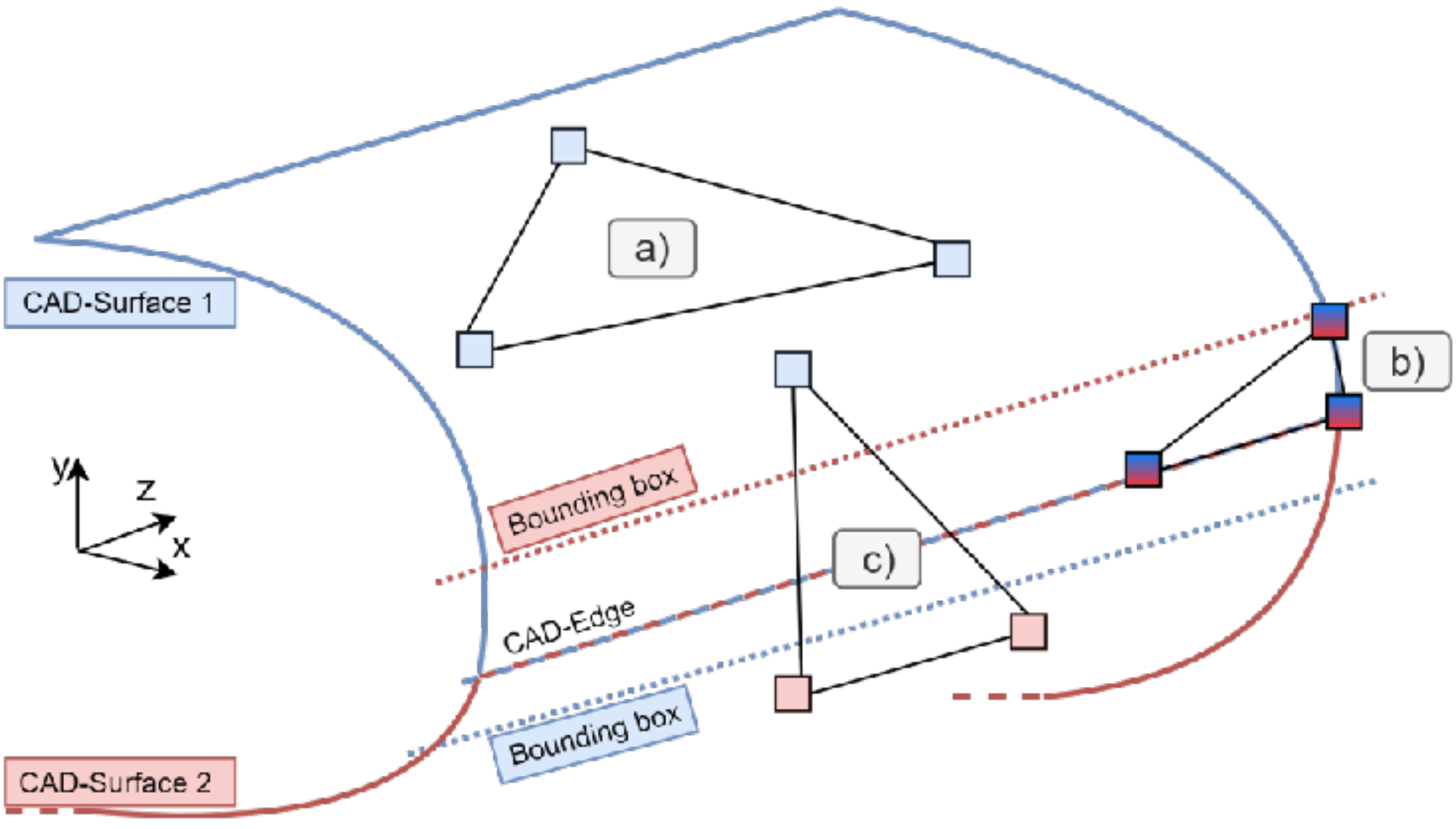
Recovering the CAD surface information

Possible cases:

a) Internal: Element face on CAD surface

b) Corner: Two face edges on CAD curves

c) Multi-patch: Face spanning over two CAD surfaces

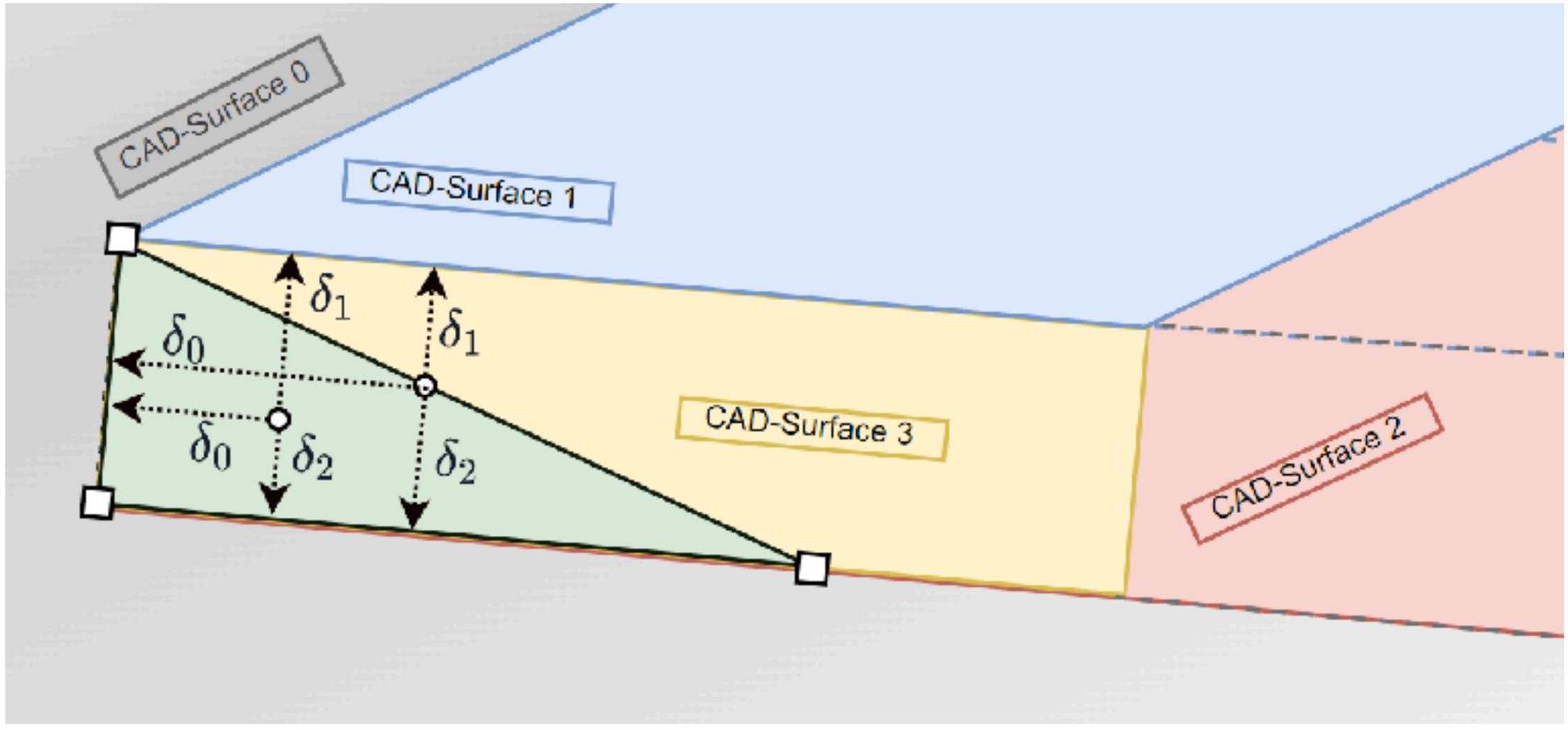


Multi-patch case

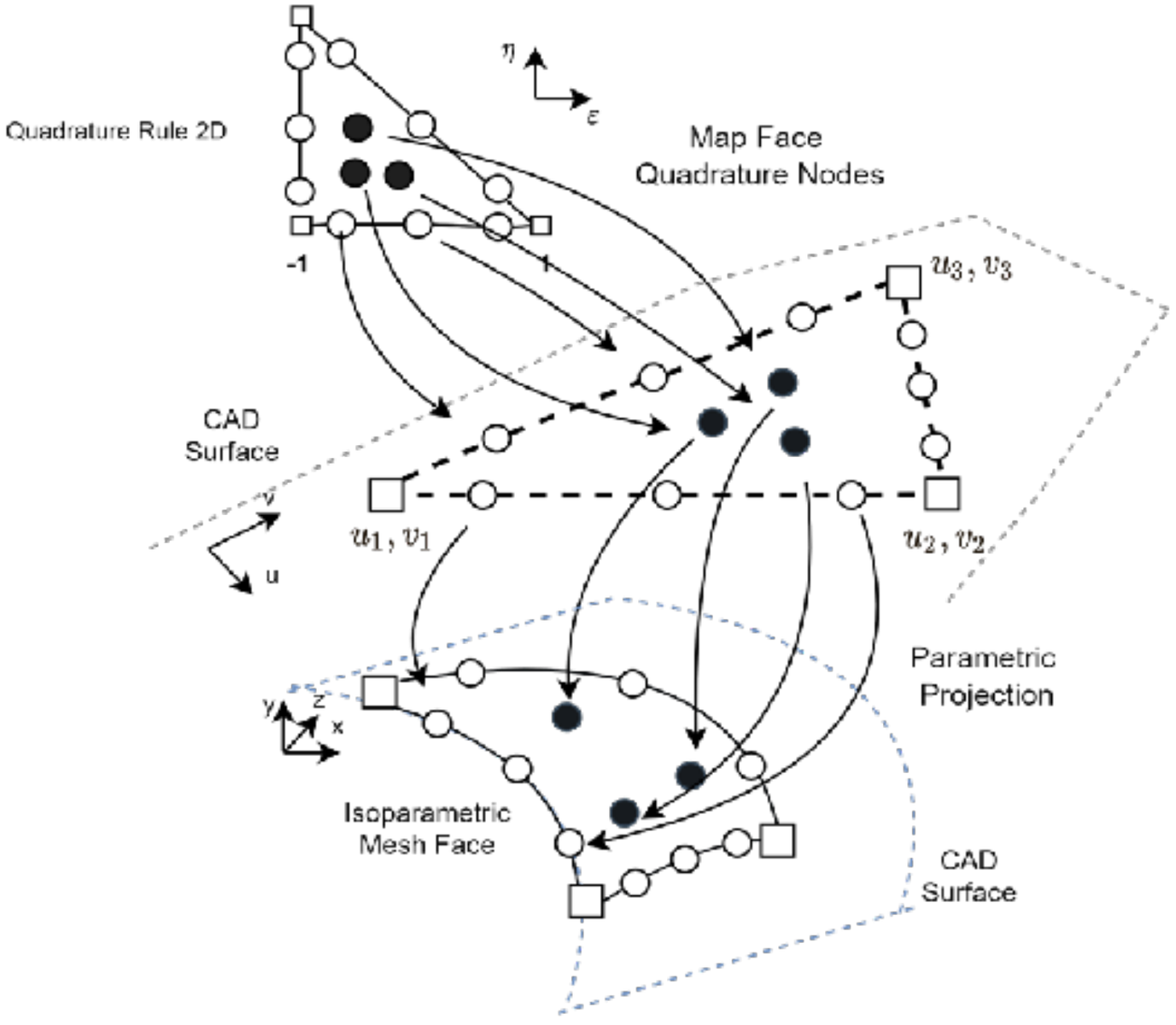
The surface ID of vertex $\mathbf{x}_j$ is obtained as

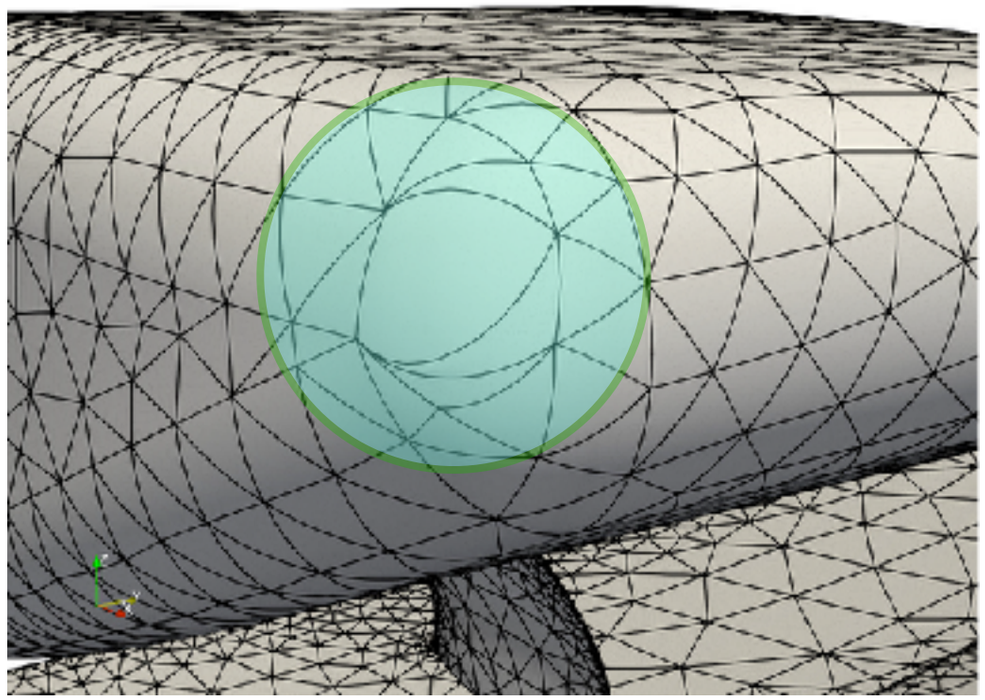
$$\mathrm{ID} = \arg\min_k \sum_{j=1}^{3} \|\mathbf{x}_j - \mathbf{P}_k(\mathbf{x}_j)\| \; \delta_k$$

$\mathbf{P}_k(\mathbf{x}_j)$ is the projection of the vertex on surface ID k

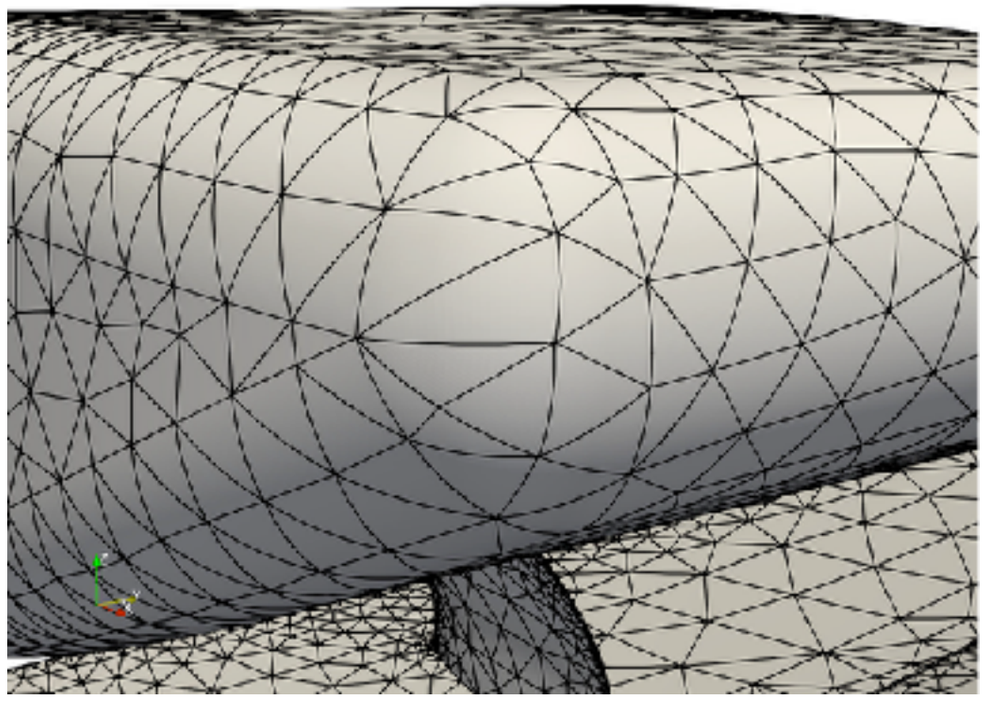


Mesh curving on a surface





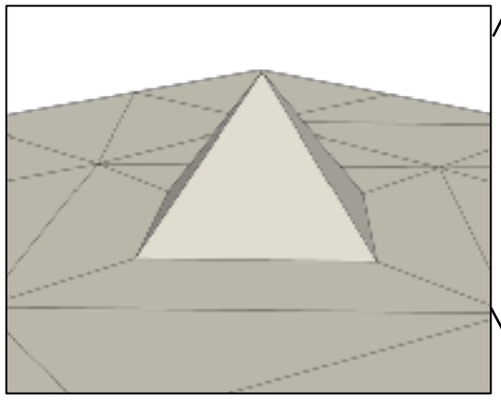
Closest CAD projection



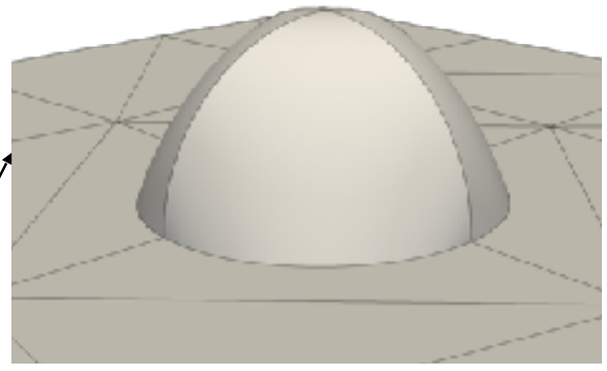
Optimised

Performance assessment

Hemisphere domain test case

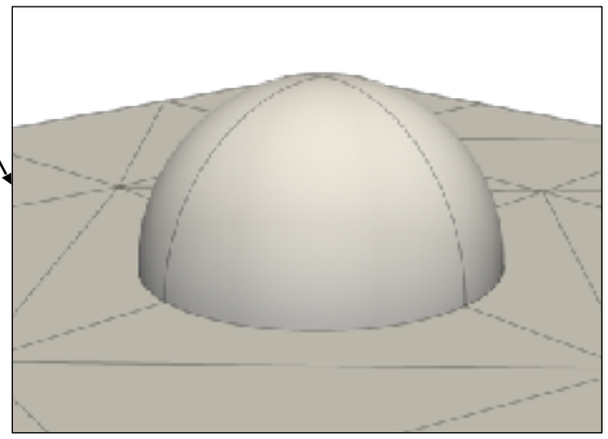


Linear surface mesh



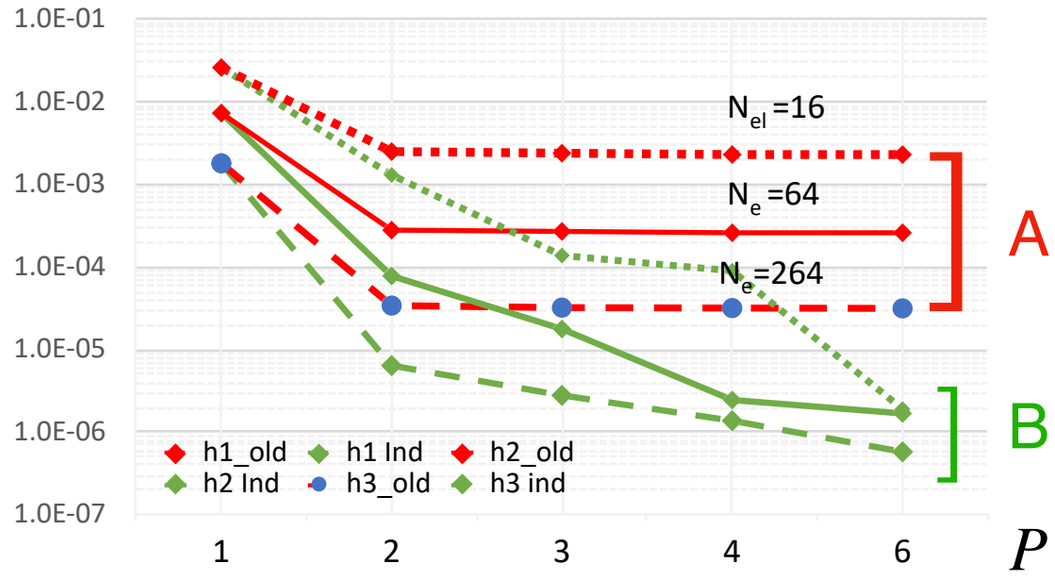
A. Non CAD-conformal workflow

$P = 6$

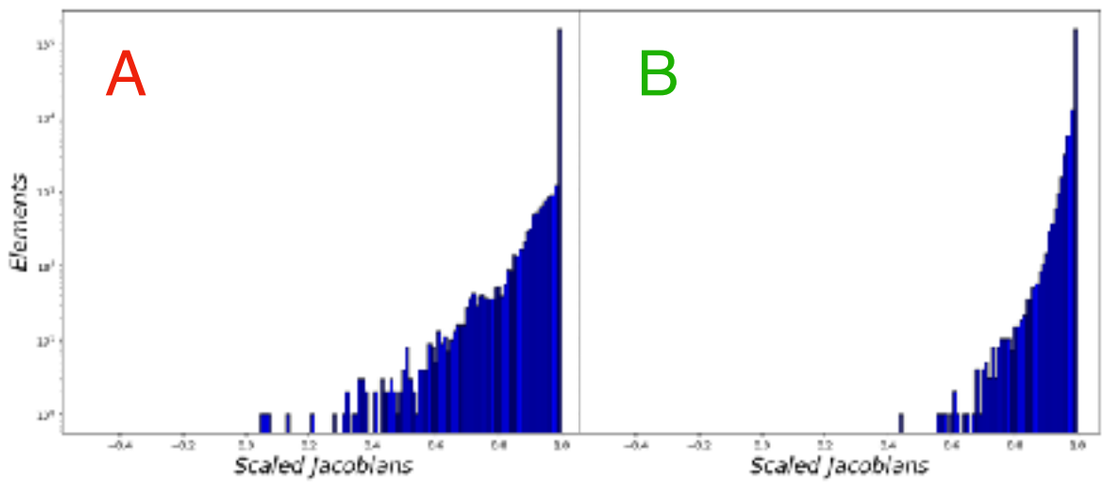


B. Updated CAD-conformal workflow

Geometrical accuracy

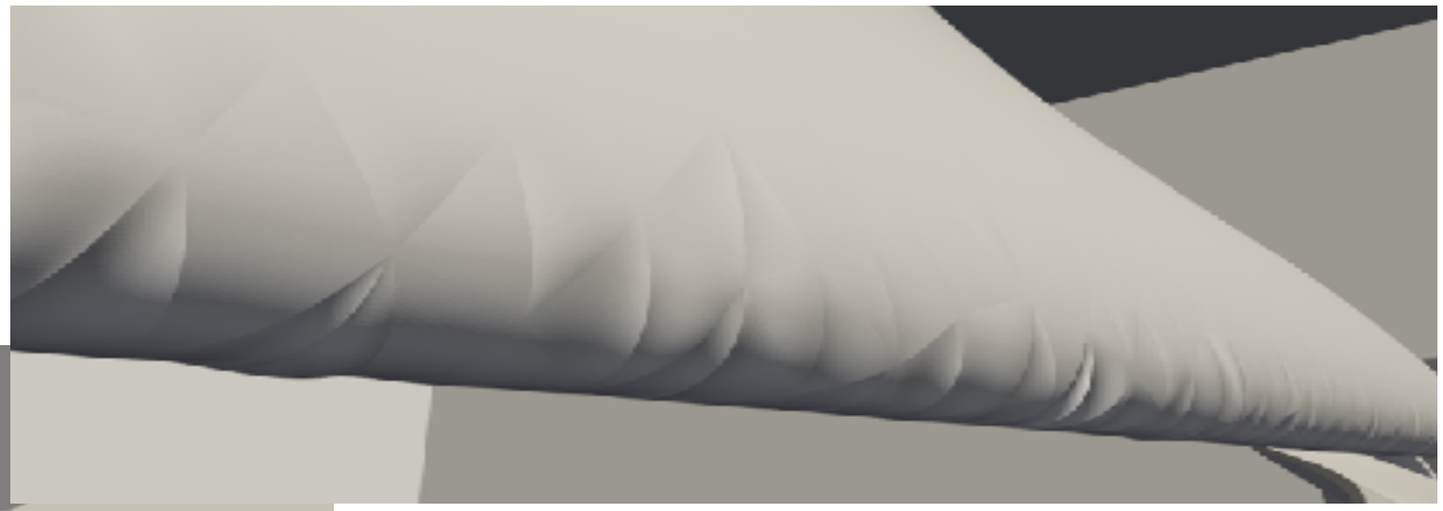


Mesh quality



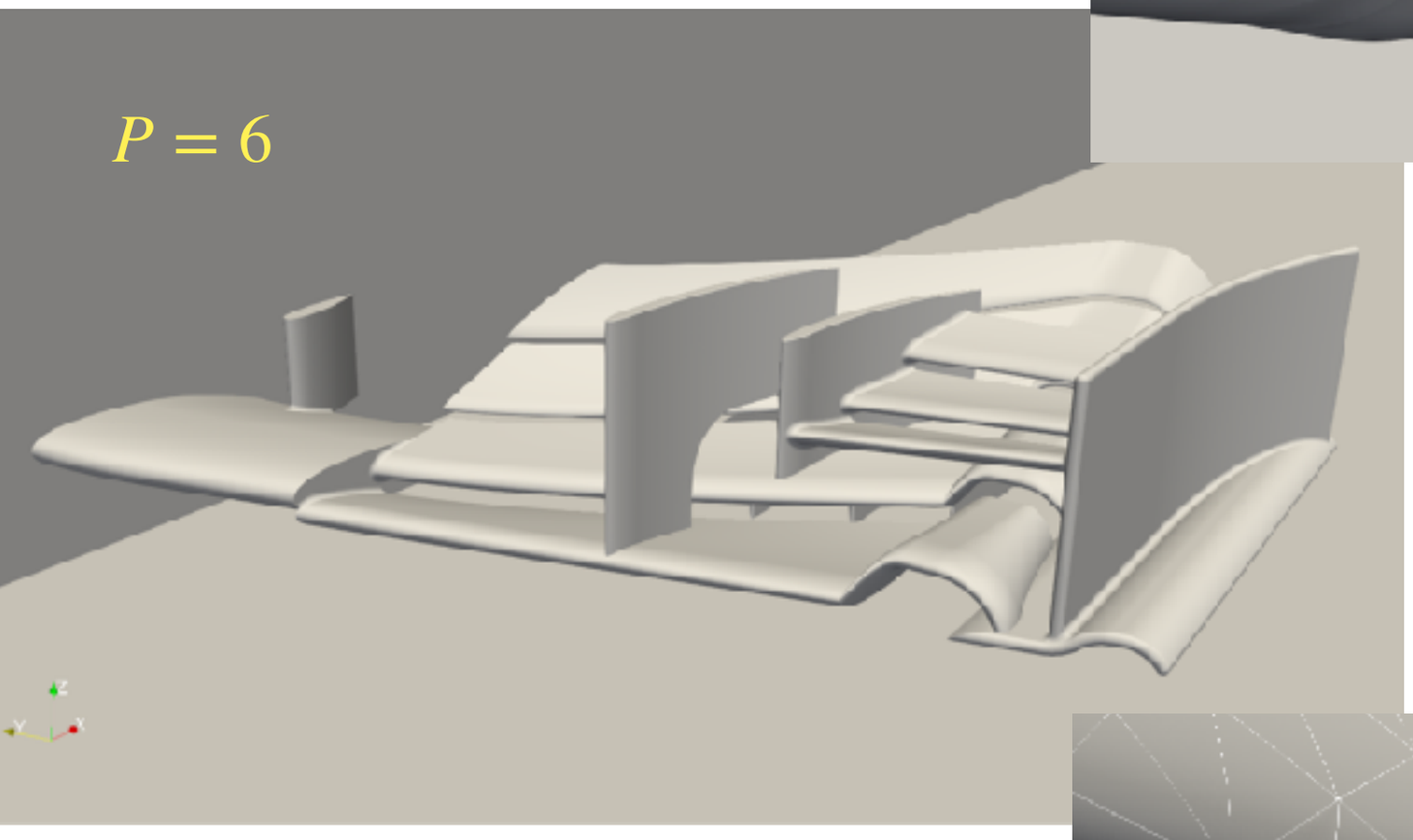
Perring F1 front wing

Non-CAD conformal high-order mesh

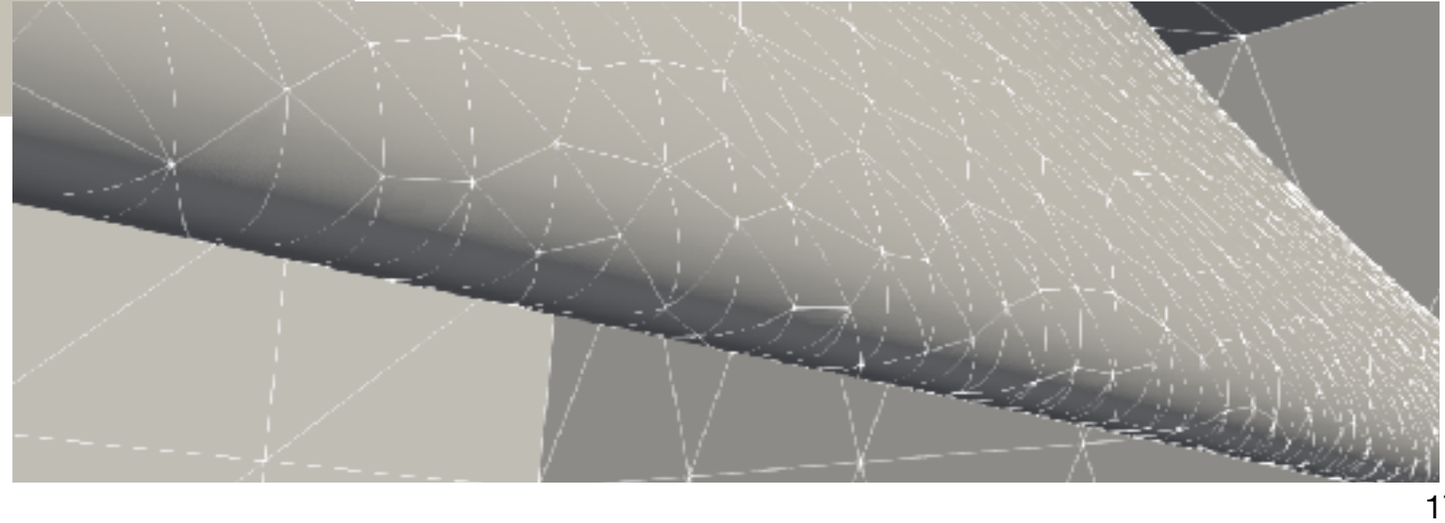


50k Surface Elements

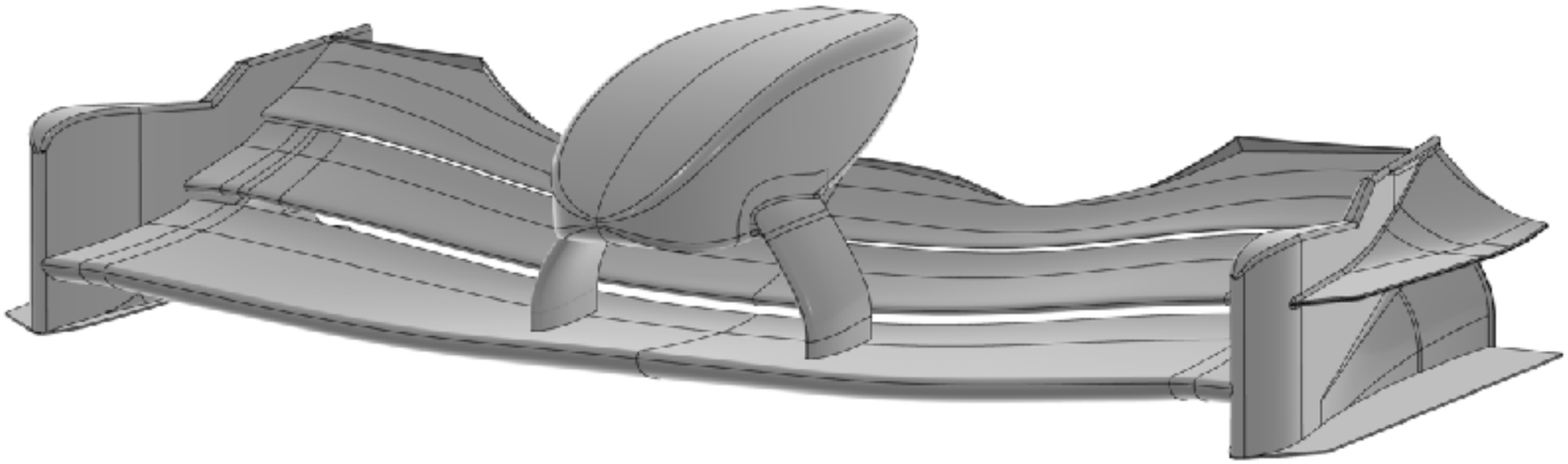
$P = 6$

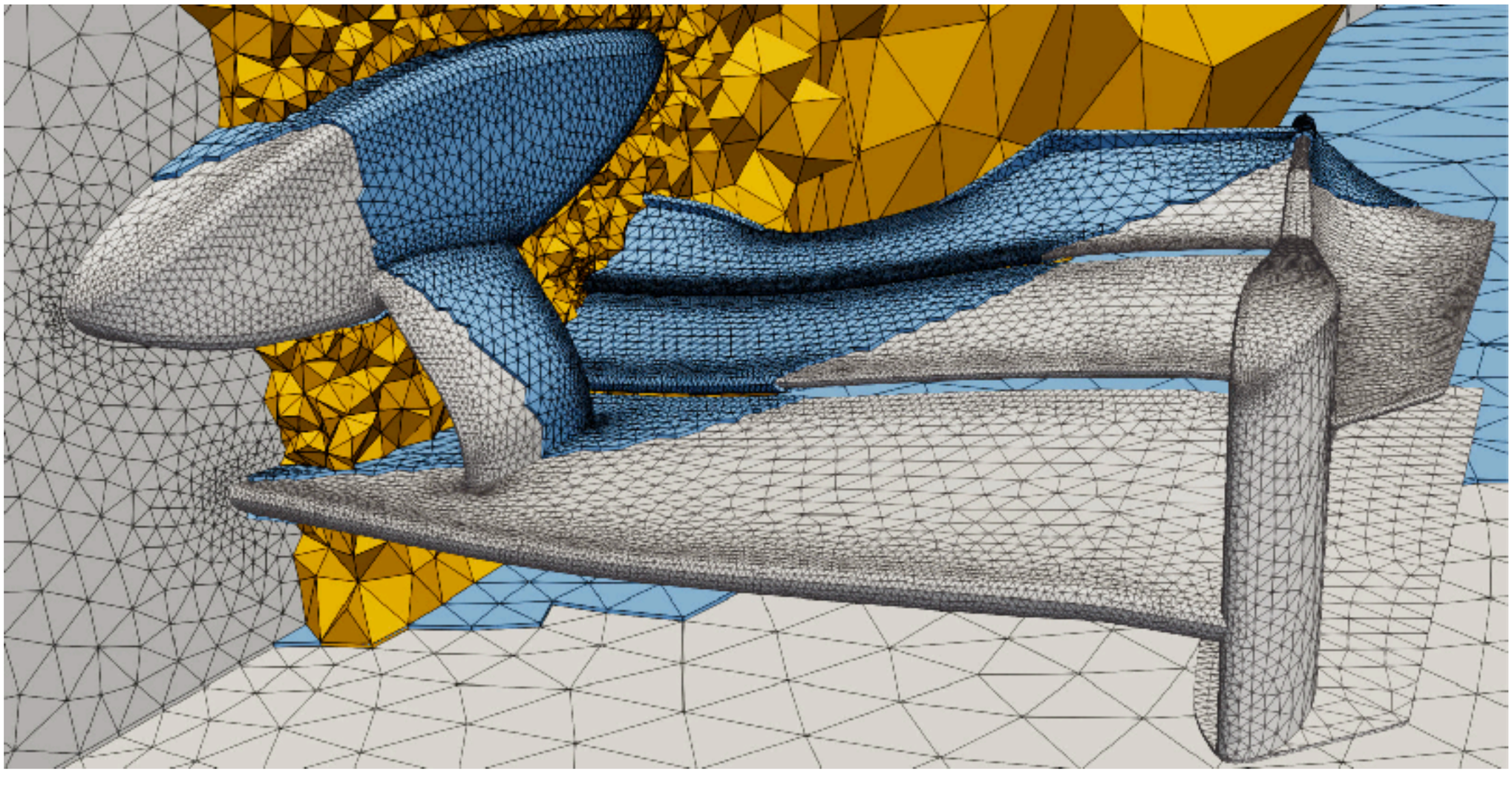


CAD-conformal high-order mesh



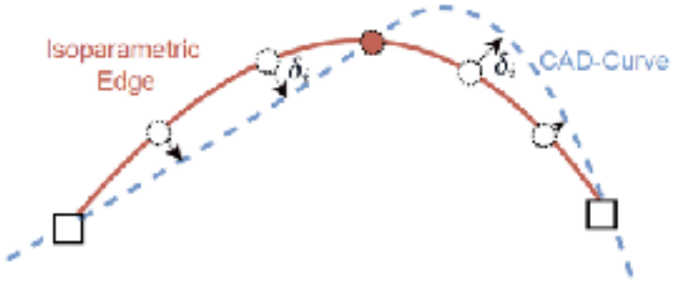
Imperial front wing geometry

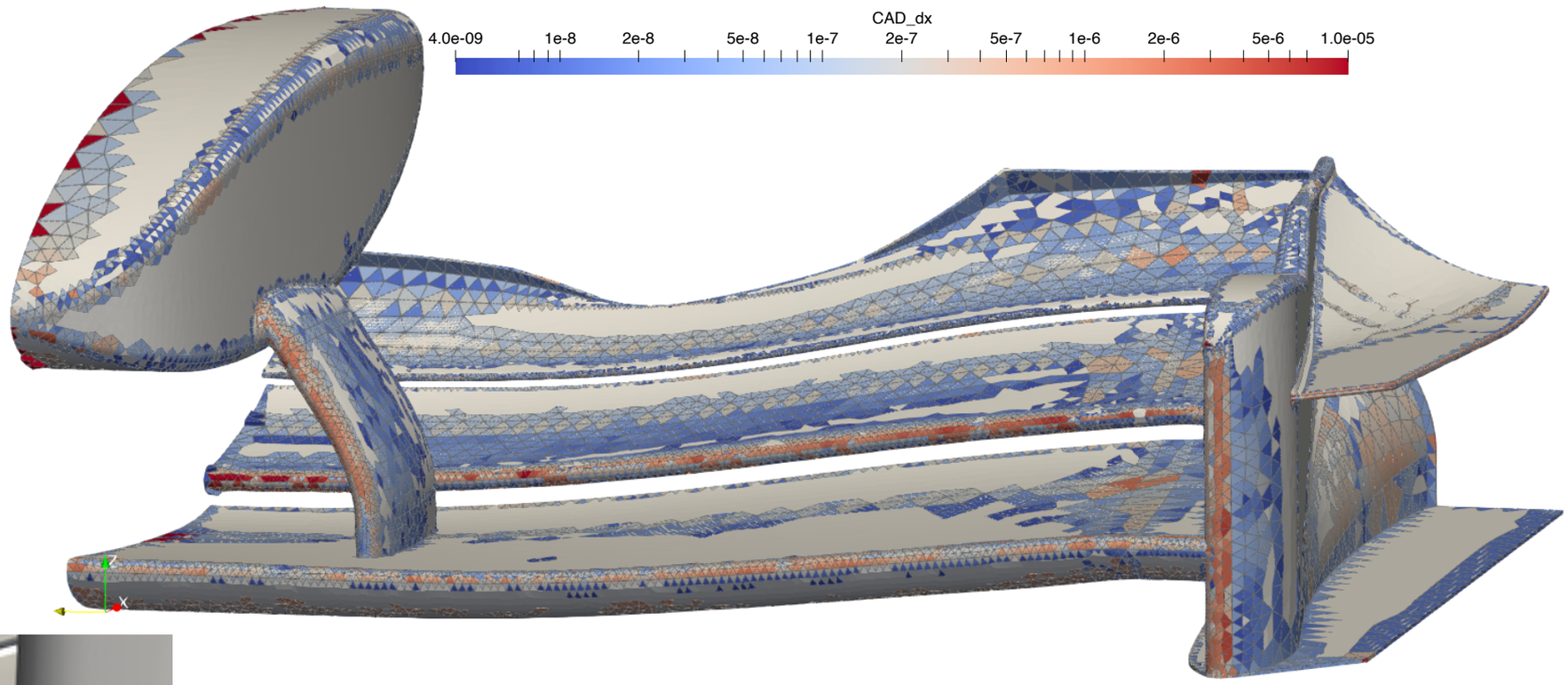


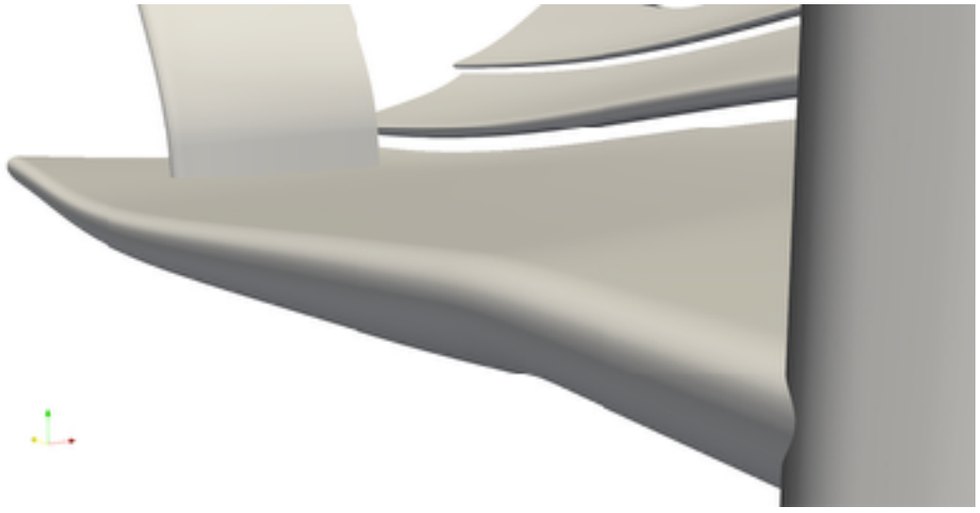


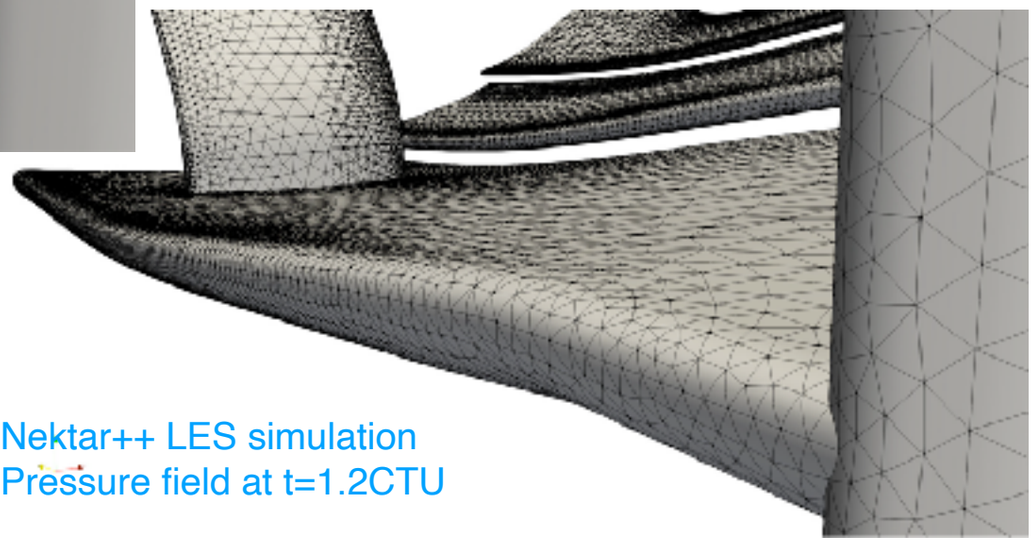
IFW assessment

Geometrical accuracy



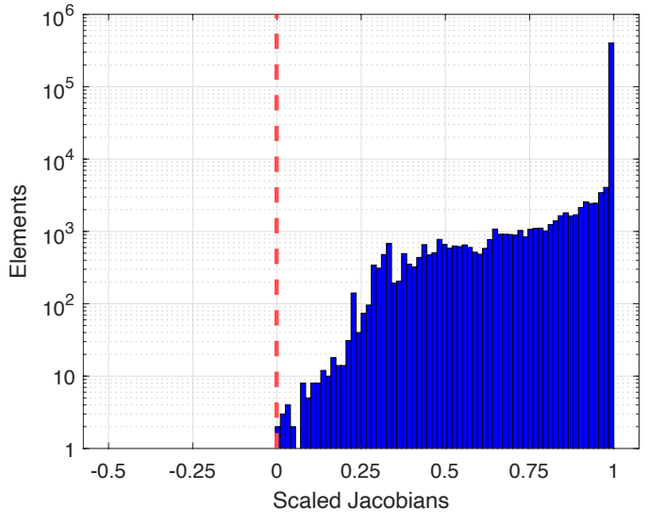






Nektar++ LES simulation
Pressure field at t=1.2CTU

Mesh quality



Final comments

- Benefits from the robustness of third-party linear mesh generators.
- Incorporates a multi-patch option not currently available in Nekmesh.
- Facilitates the assessment of geometrical accuracy of both linear and high-order meshes.
- Robustness of high-order meshing significantly improved but still work to be done.