Physics dependent de-featuring. Is it a prerequisite for mesh generation?

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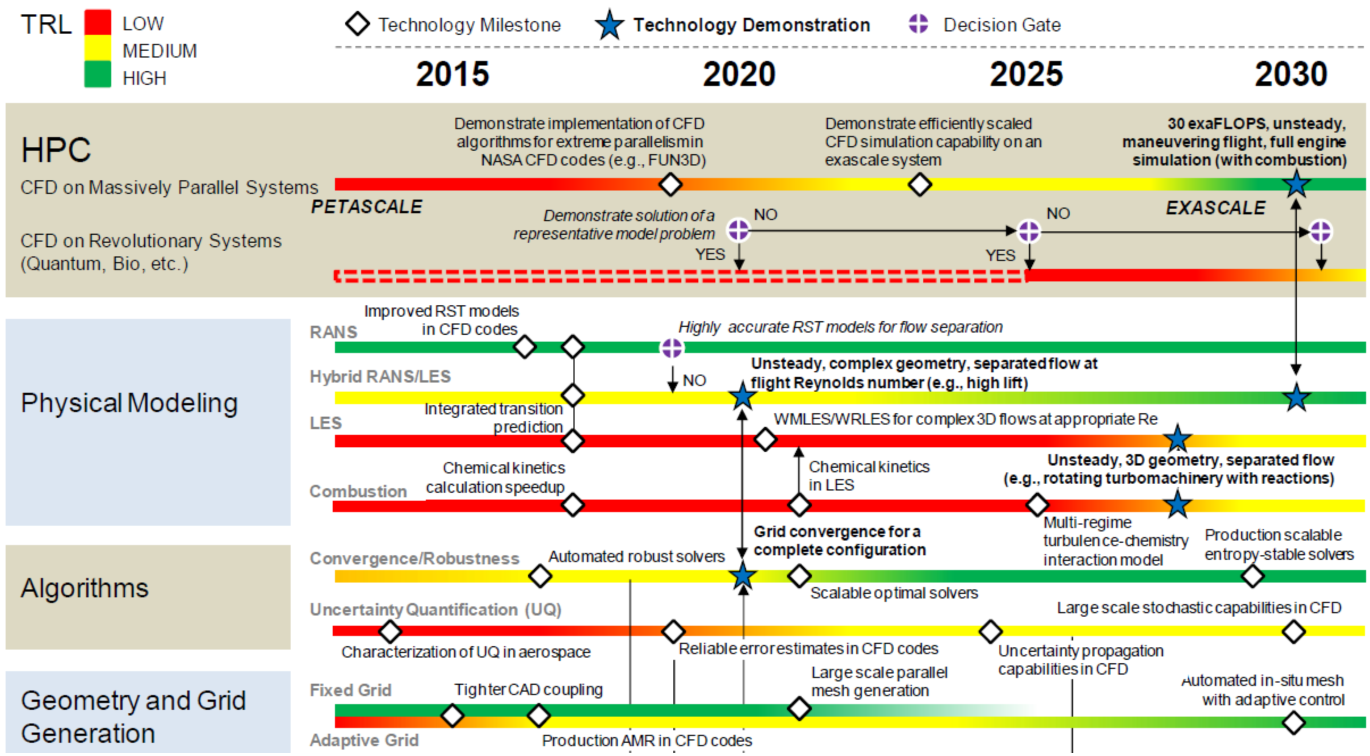
Outline

1. Motivation
2. NURBS-Enhanced FEM (NEFEM)
3. Mesh generation for NEFEM
4. Examples
5. Concluding remarks

Motivation

NASA CFD vision 2030

- Emphasis on transient phenomena and complex geometries and tigther coupling of design (CAD) and simulations

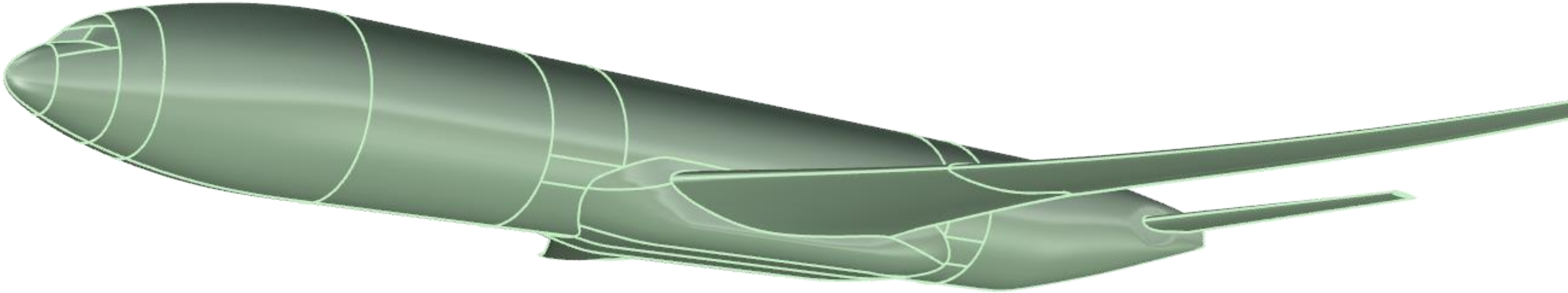


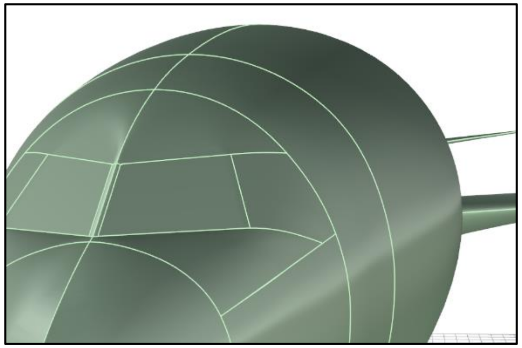
"Today, the generation of suitable meshes for CFD simulations about complex configurations constitutes a principal bottleneck in the simulation workflow process."

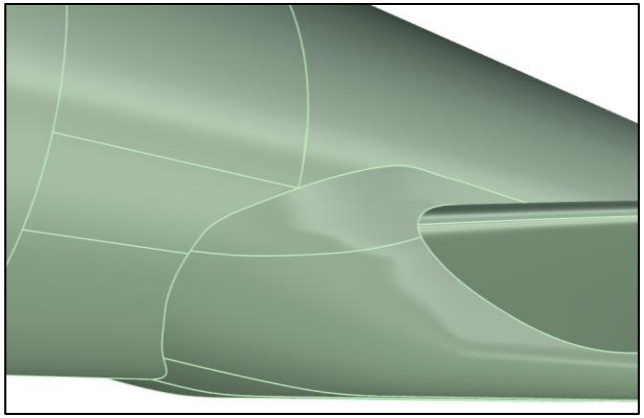
"Many existing CAD geometry definitions are poorly suited for CFD analyses due to excessive detail."

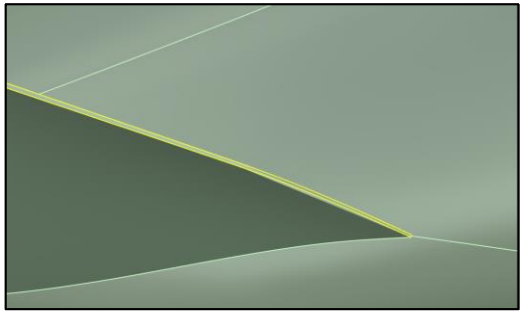
Motivation

- **Generation of suitable FE meshes from CAD models**
  - The preparation of CAD models for mesh generation is still the major bottleneck in finite element simulations within industry
  - Cleaning and de-featuring takes 80% to 90% of the time invested in performing a simulation









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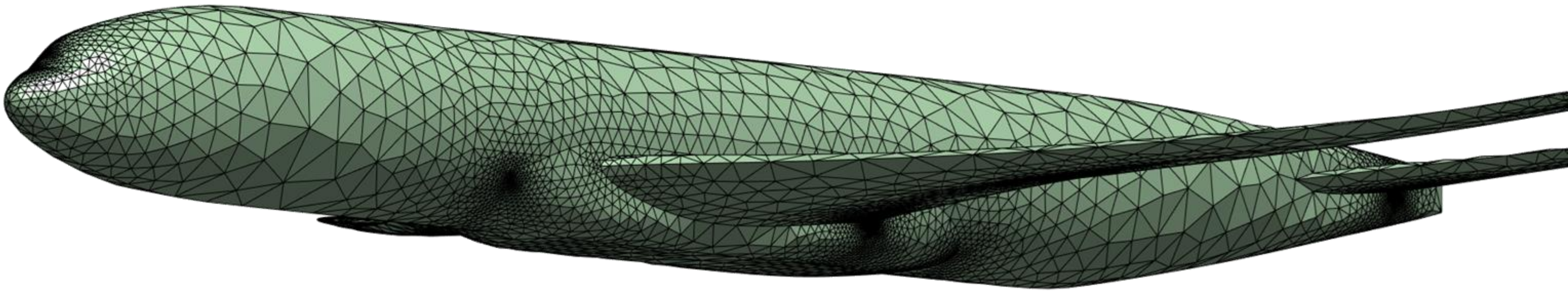
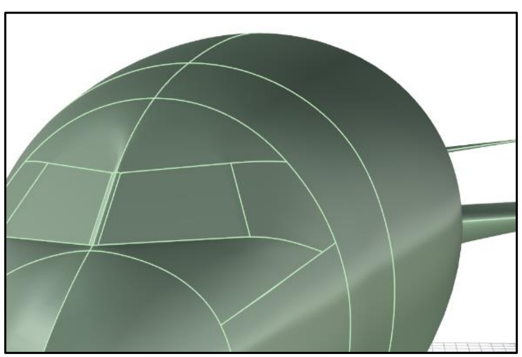
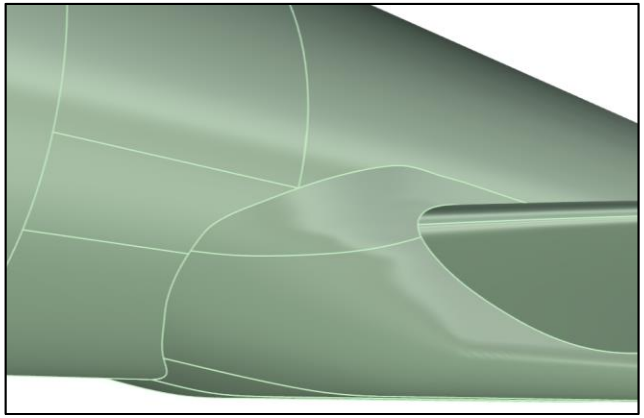
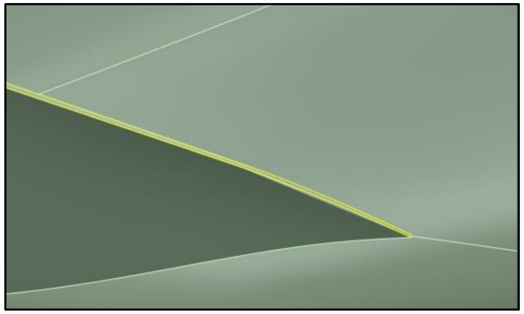


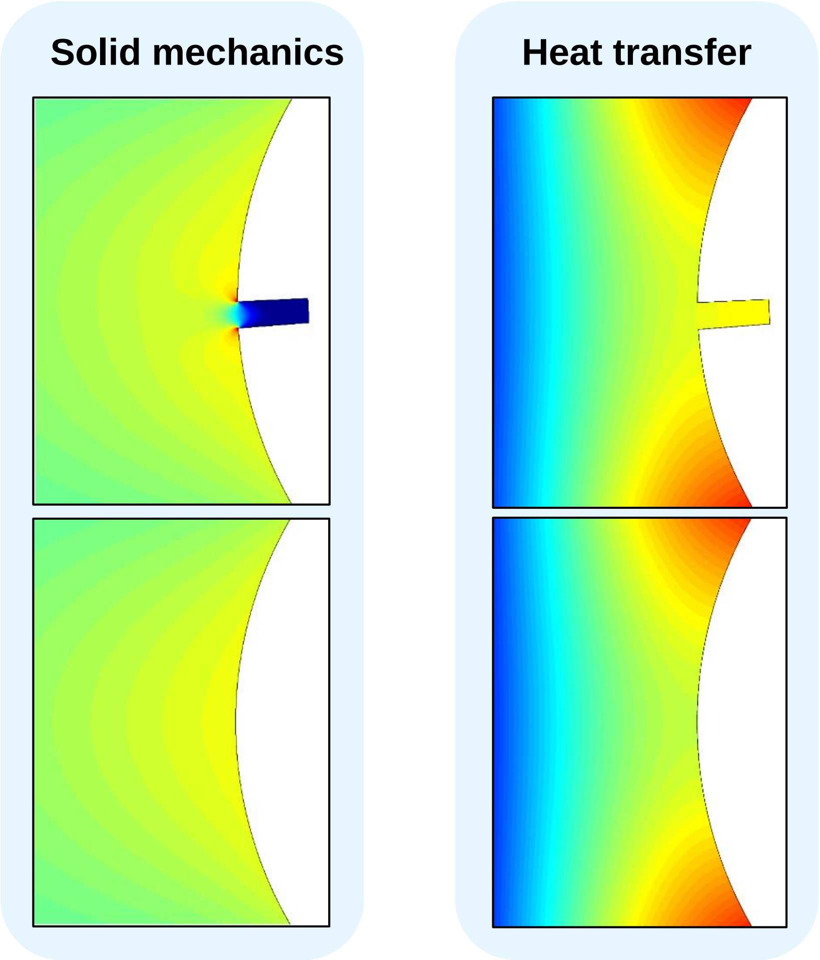






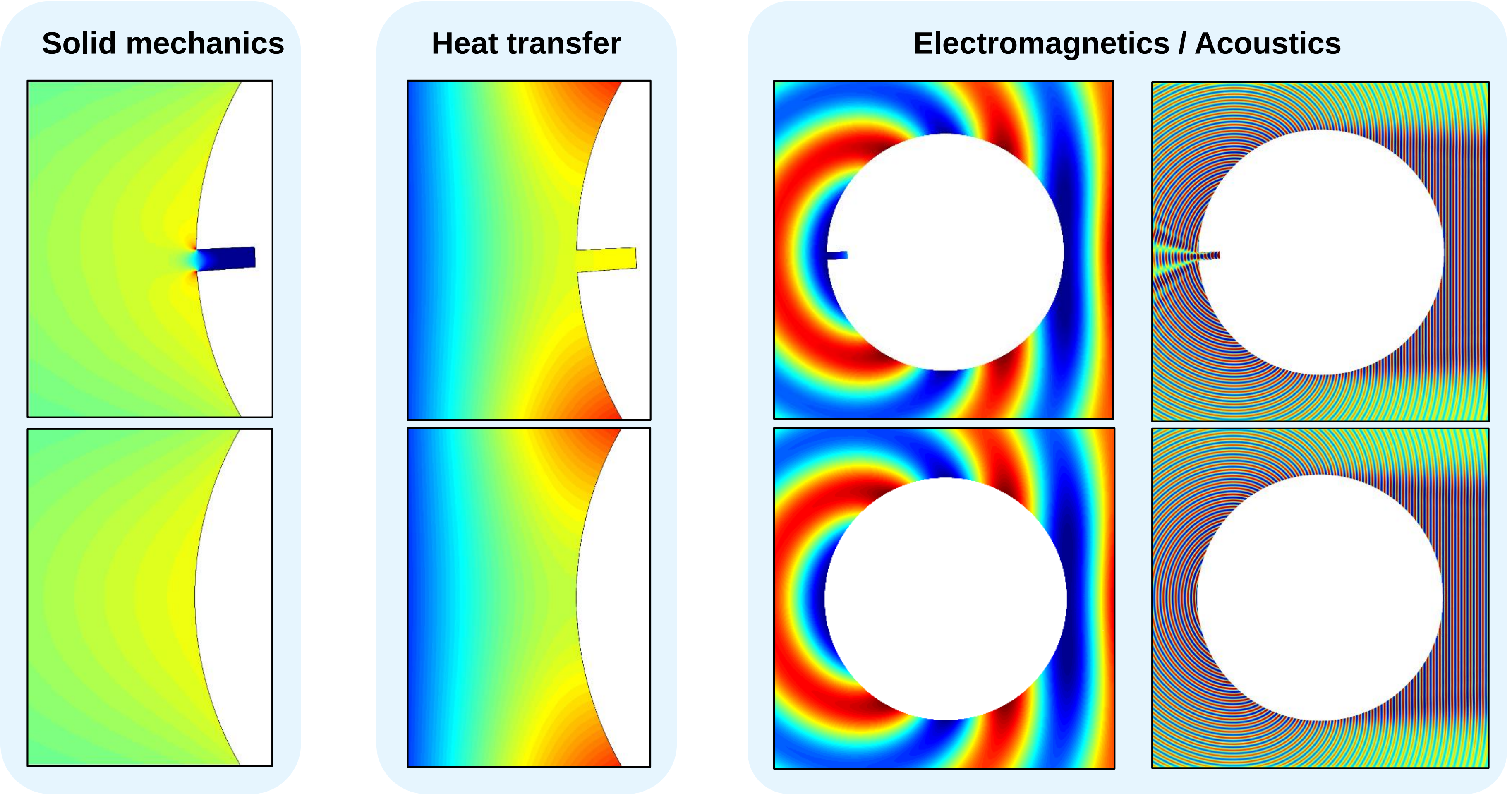
Motivation

- **De-featuring**
  - A major drawback of the de-featuring is that is dependent on the physics of the problem



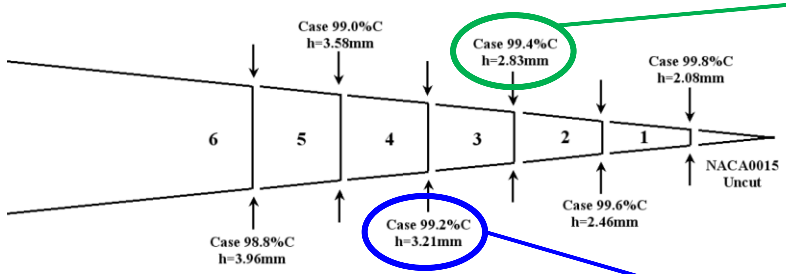
Motivation

- **De-featuring**
  - A major drawback of the de-featuring is that is dependent on the physics of the problem or even on the problem parameters!

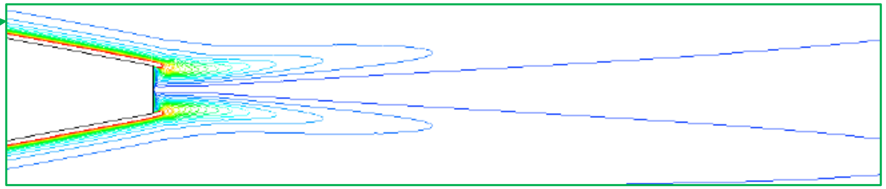


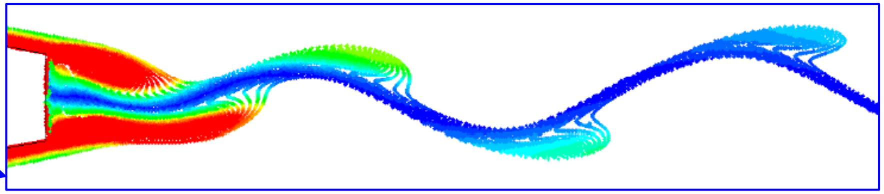
Motivation

- **De-featuring**
  - Blunt trailing edges crucial to accurately describe the physics (vortex shedding, vibrations, noise)

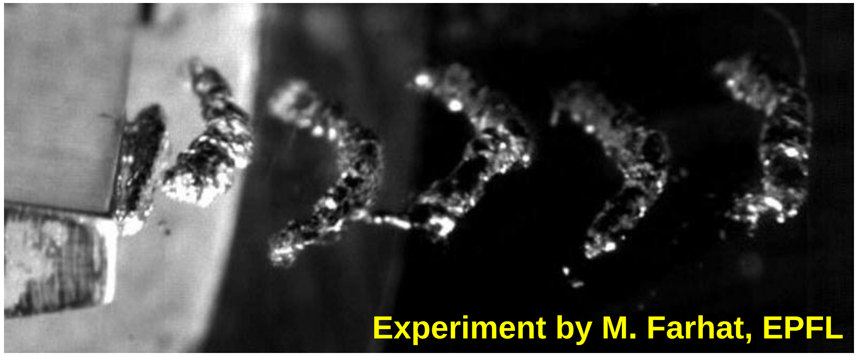


R. Do, L. Chen & J. Tu, ANZIAM, 2007



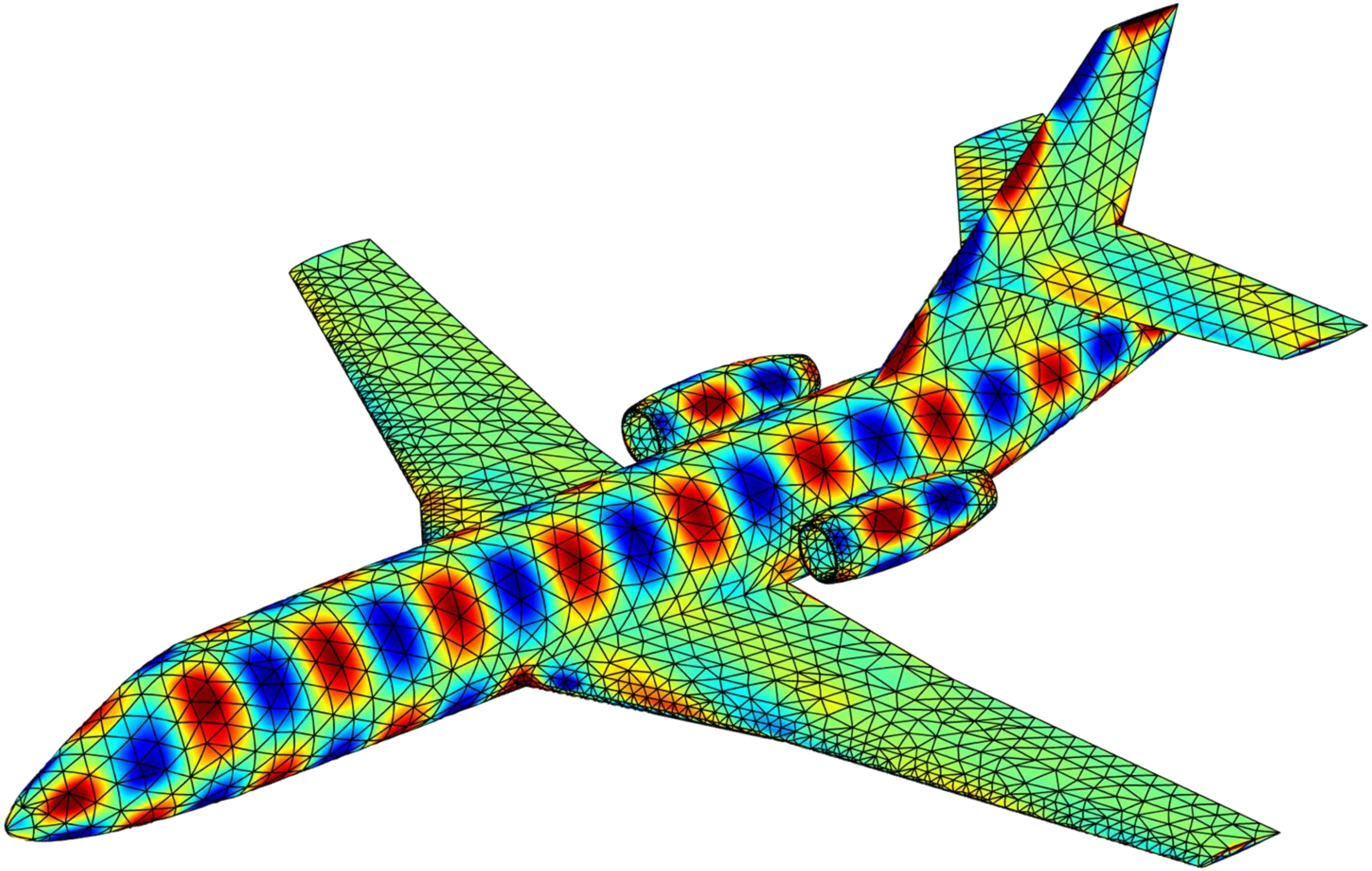


Case	Vortex Shedding	$f_s(Hz)$
$99.8\%C$	No	-
$99.6\%C$	No	-
$99.4\%C$	No	-
$99.2\%C$	Yes	137
$99.0\%C$	Yes	128
$98.8\%C$	Yes	113



Motivation

- The situation is even worse in a **high-order** context



Z.Q. Xie, RS, O. Hassan and K. Morgan, Computational Mechanics, 2013
R. Poya, RS and A. J. Gil, Computaitonal Mechanics, 2016

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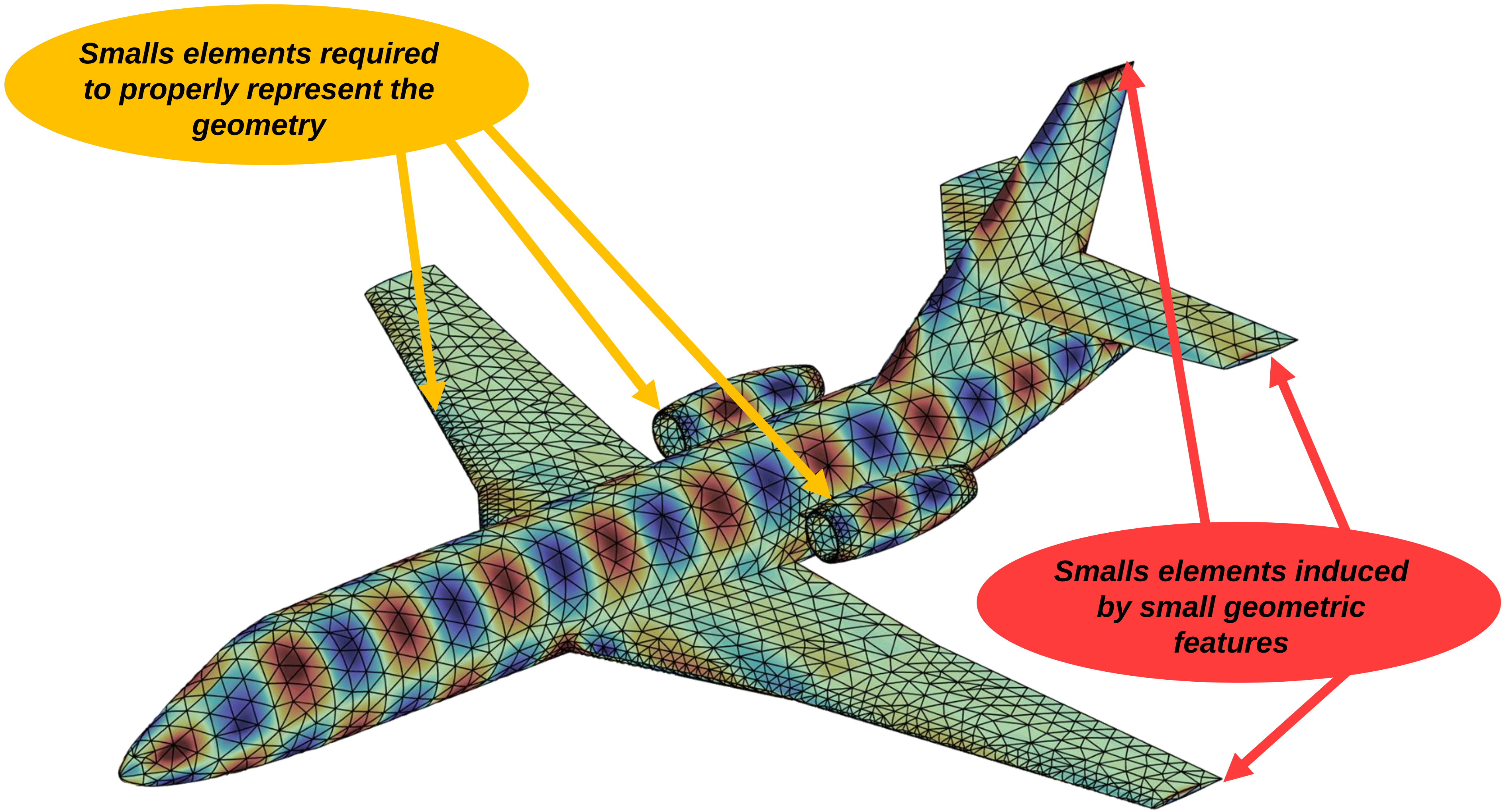
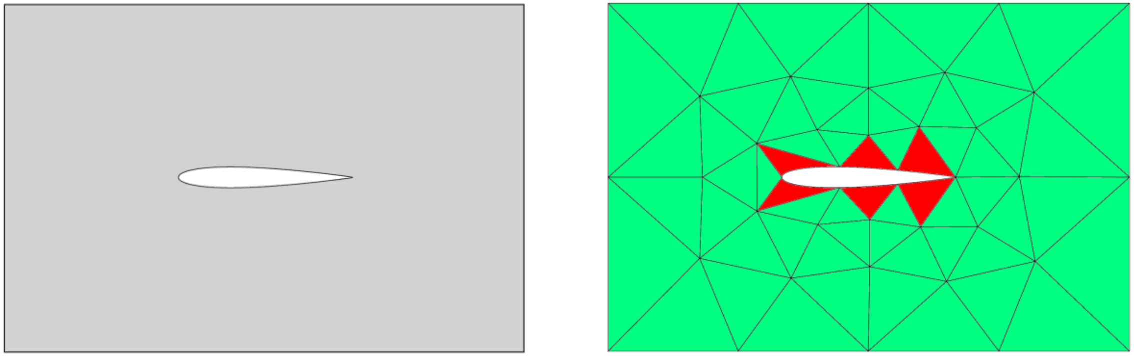
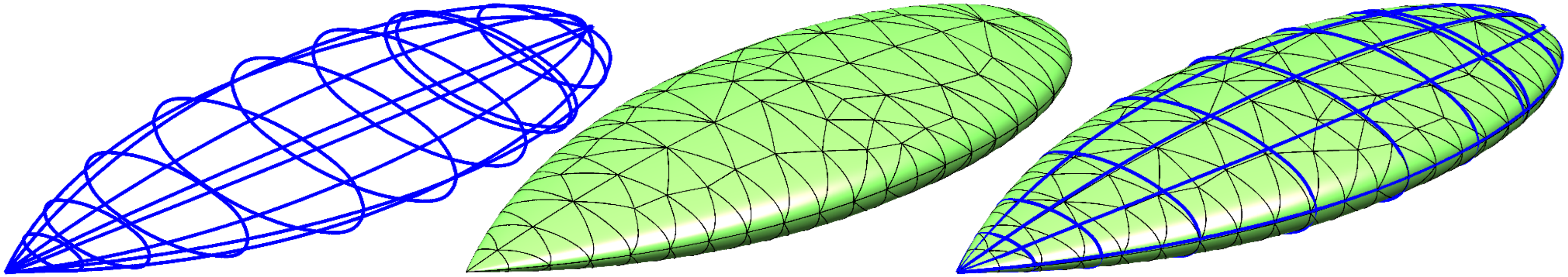


NURBS-Enhanced Finite Element Method (NEFEM)

- Interior elements (straight edges/faces): standard FEs
- Curved elements (NURBS edges/faces): interpolation and integration with exact geometry description (overhead reduced to boundary elements)



- Spatial discretisation independent on the geometric definition



RS, S. Fernández-Méndez and A. Huerta, International Journal for Numerical Methods in Engineering, 2008

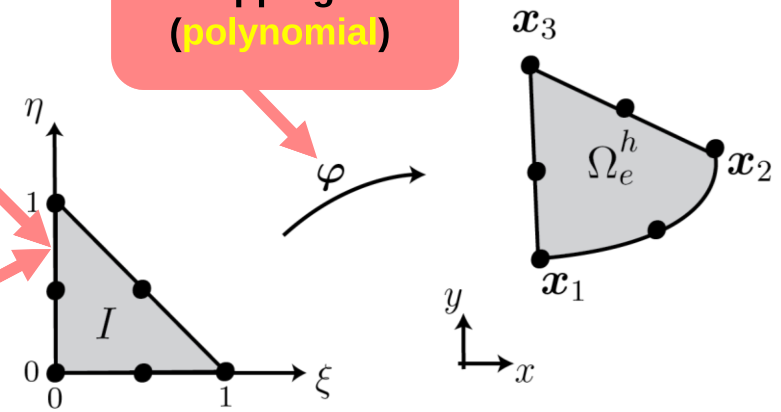
NURBS-Enhanced Finite Element Method (NEFEM)

- Isoparametric FEM

Quadrature defined here

Isoparametric mapping (polynomial)

Polynomials defined here (i.e. Jacobian of the mapping can severely affect your approximation properties)

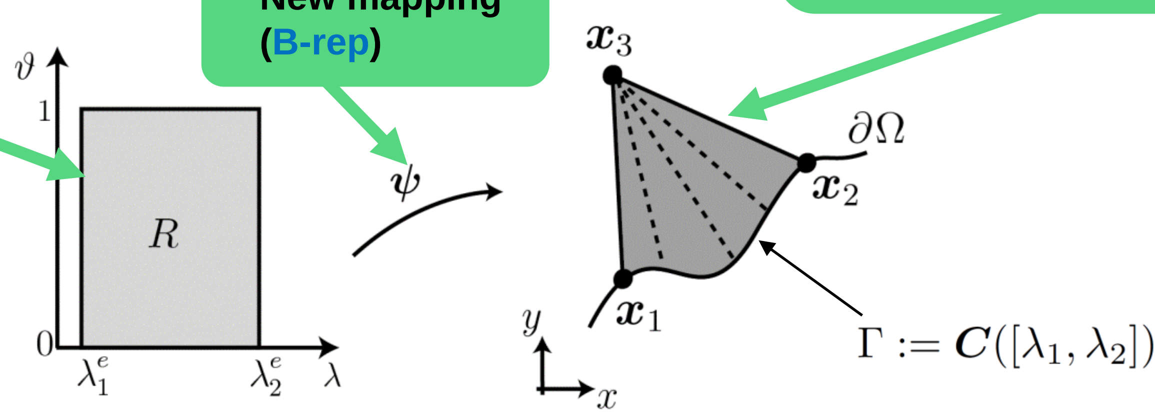


- NEFEM

Polynomials defined here (i.e. NO mapping involved, better approximation properties)

Quadrature defined here

New mapping (B-rep)

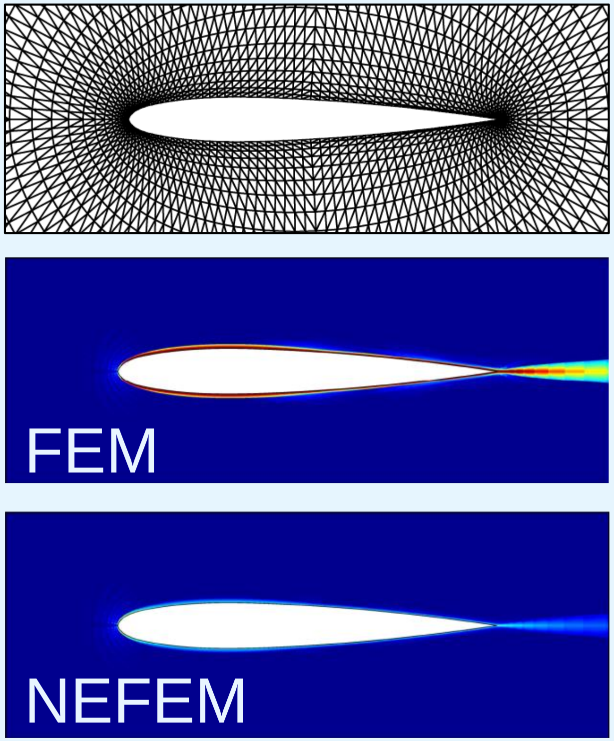


RS, S. Fernández-Méndez and A. Huerta, International Journal for Numerical Methods in Engineering, 2011

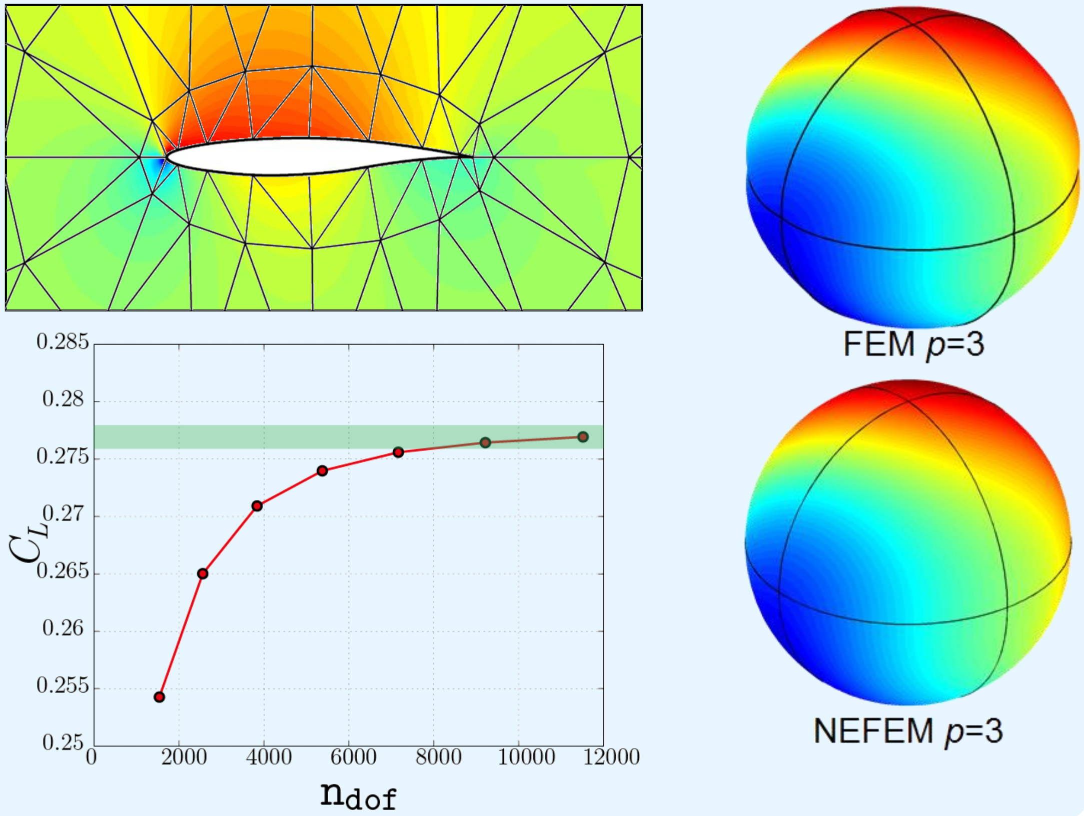
NURBS-Enhanced Finite Element Method (NEFEM)

- Encapsulates the "exact" (CAD) boundary representation in the analysis stage. Advantages for both low and high-order

Low-order (linear)



High-order

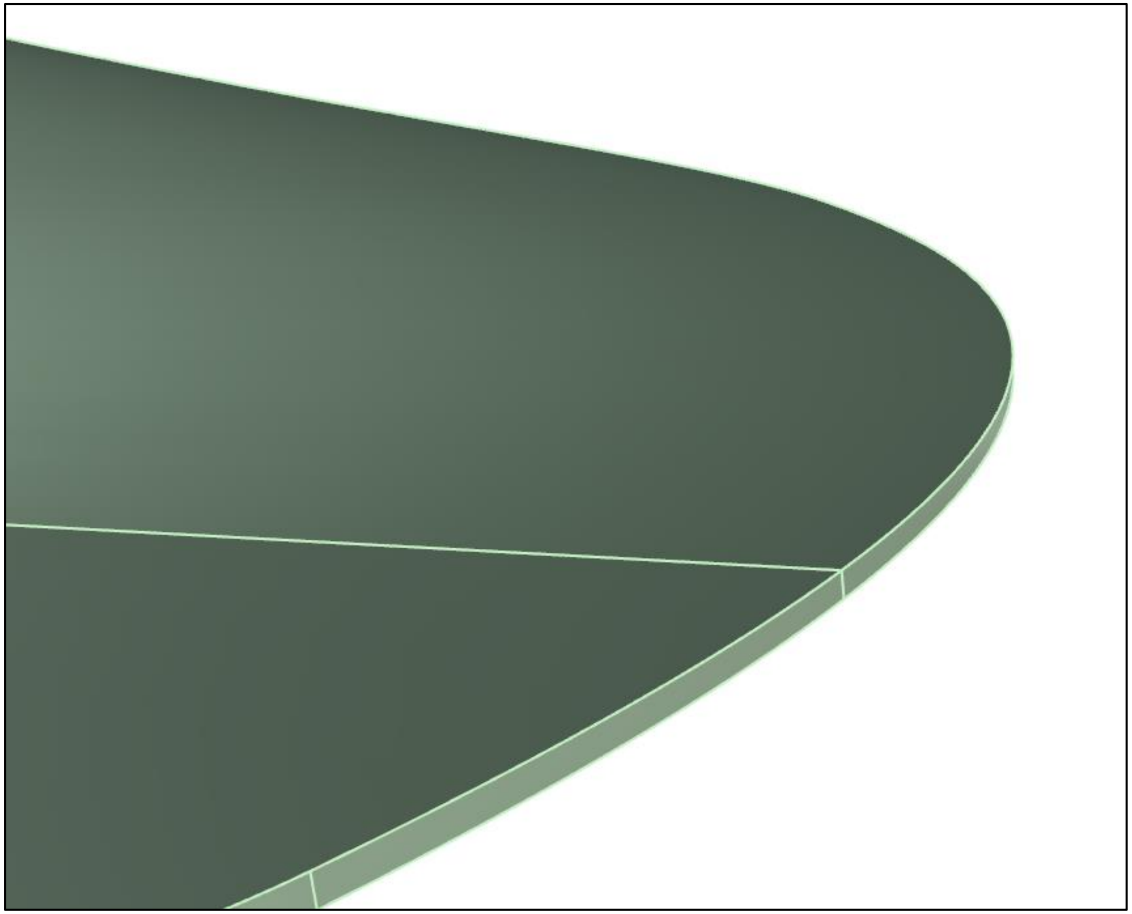


- Spatial discretisation independent on the geometric definition

RS, S. Fernández-Méndez and A. Huerta, Archives Computational Methods in Engineering, 2011

NURBS-Enhanced Finite Element Method (NEFEM)

- De-featuring is no longer needed!



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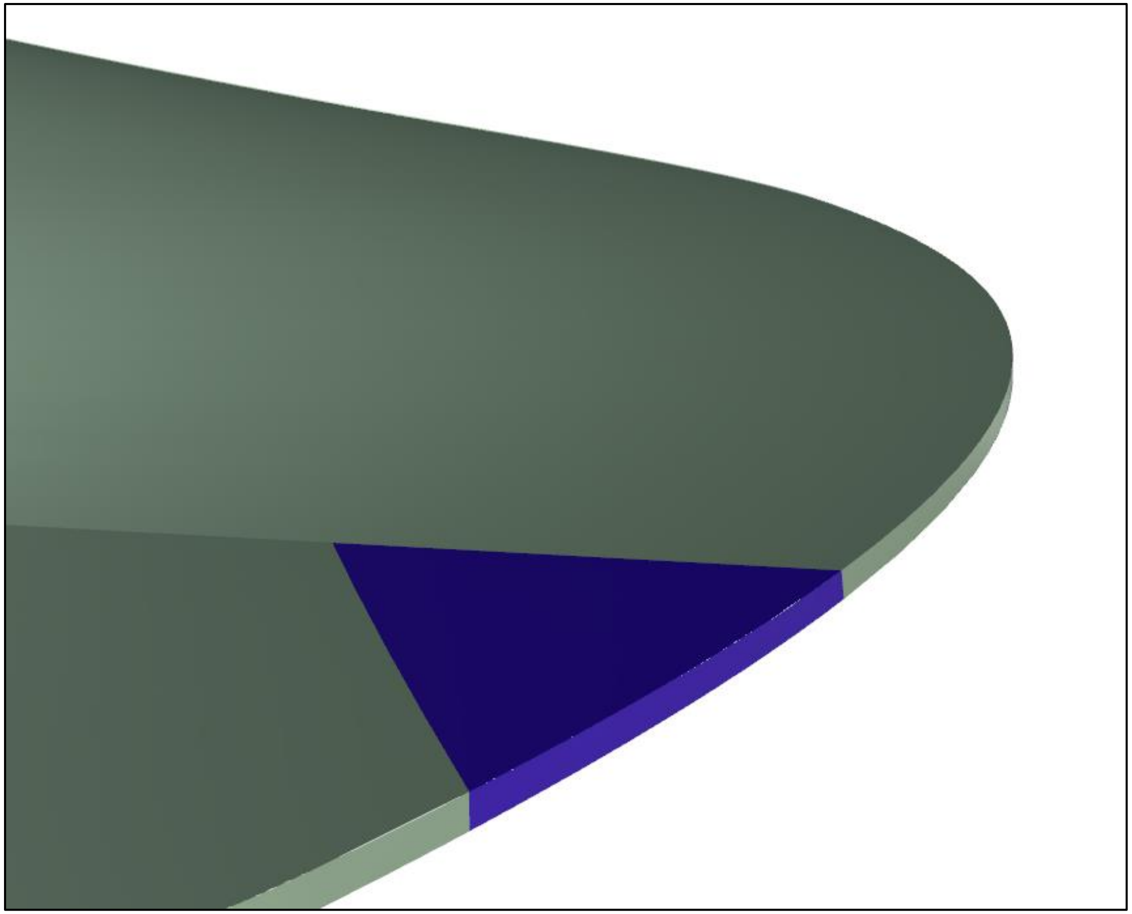

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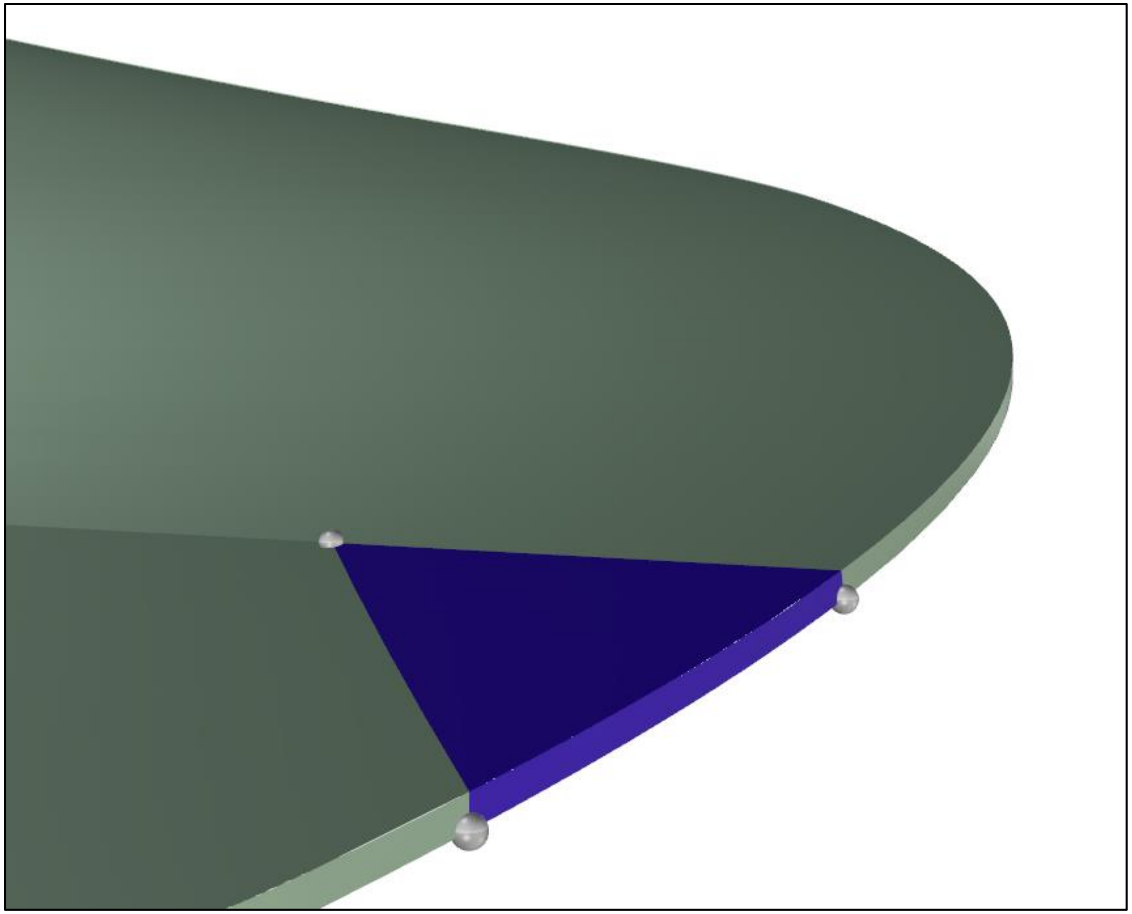

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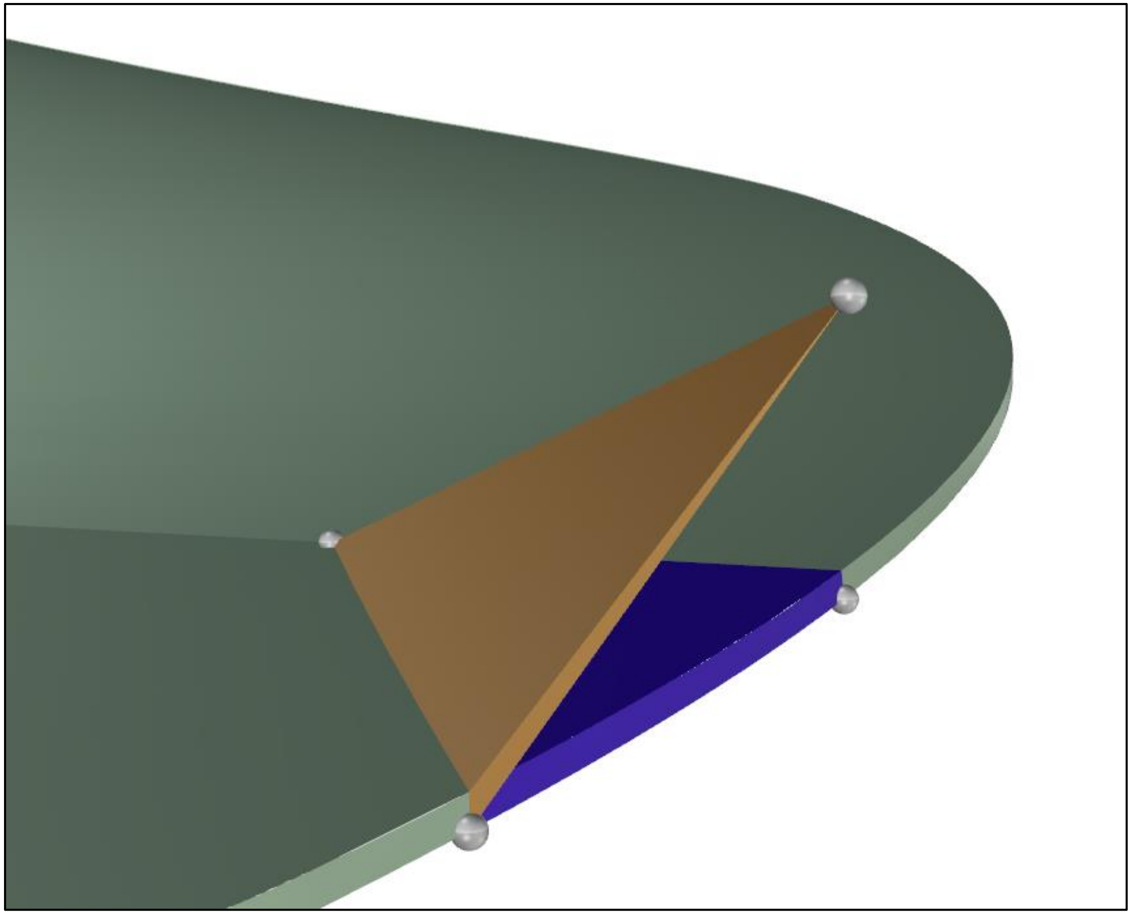

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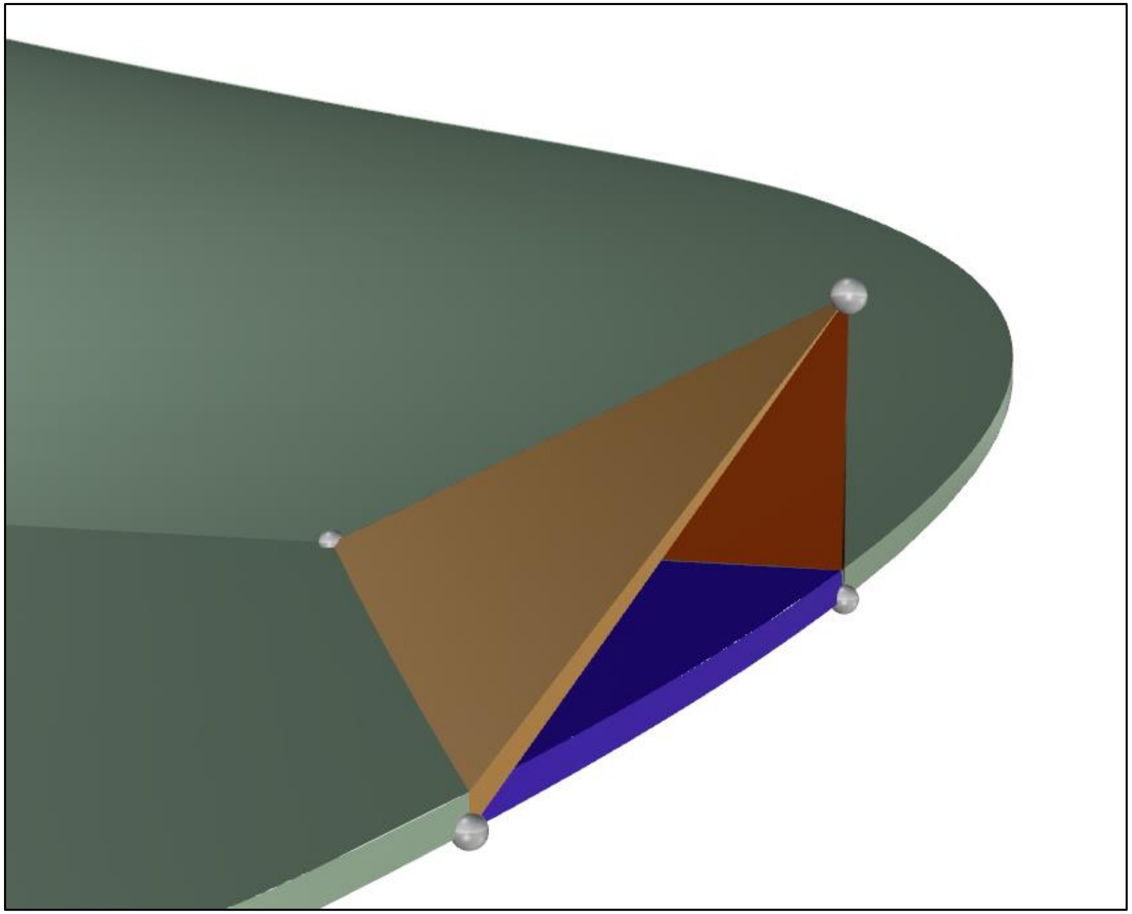

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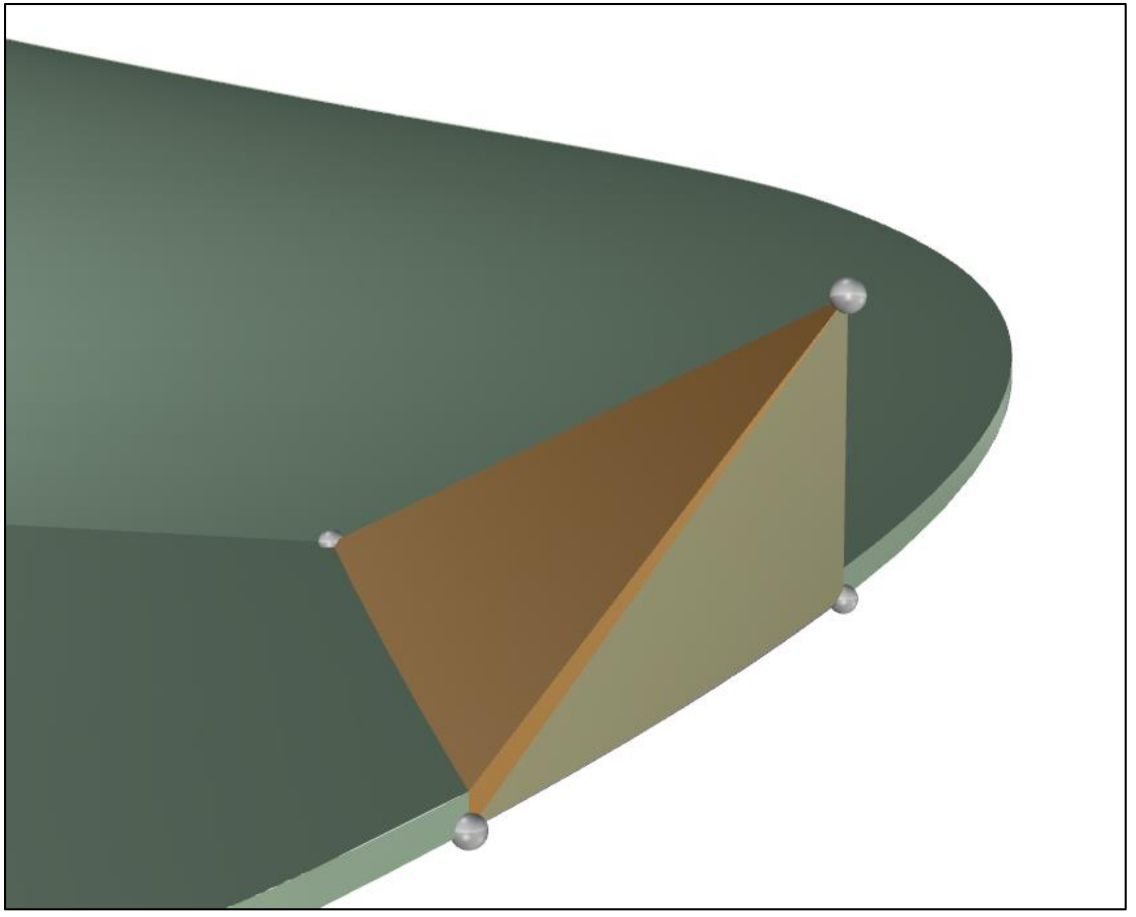
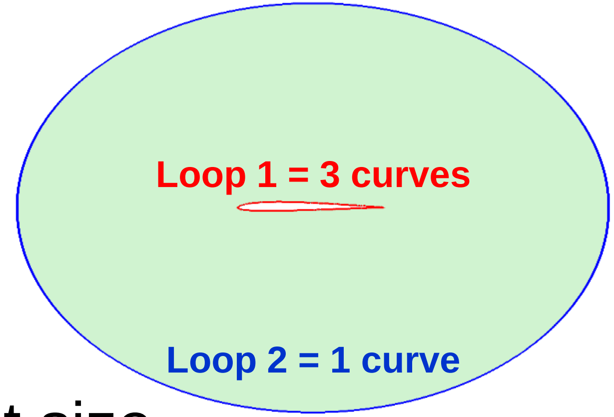
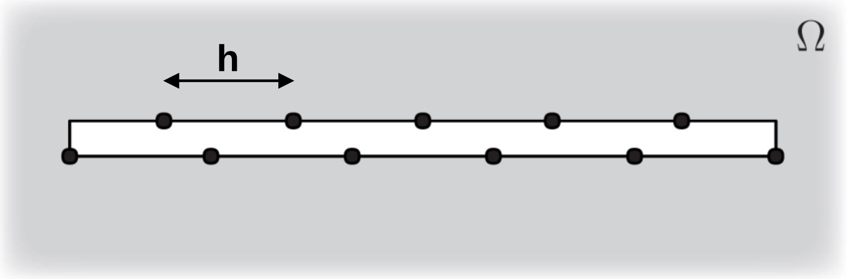


- But, how can we generate such meshes?

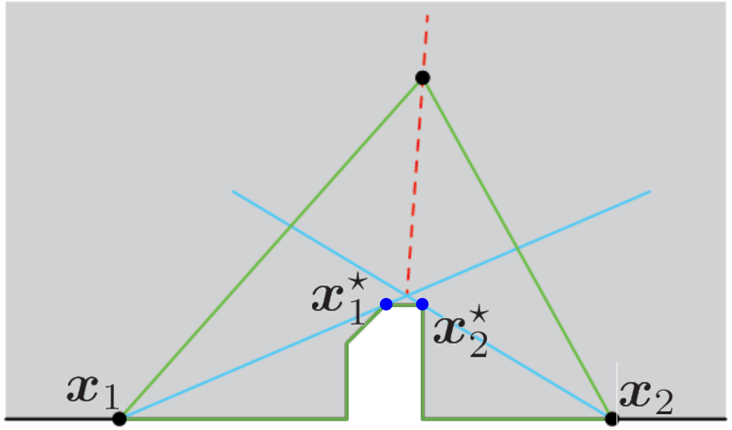
Mesh generation – A priori approach



- **Boundary discretisation**
- Combine boundary curves into loops
- Discretise each loop with a desired element size



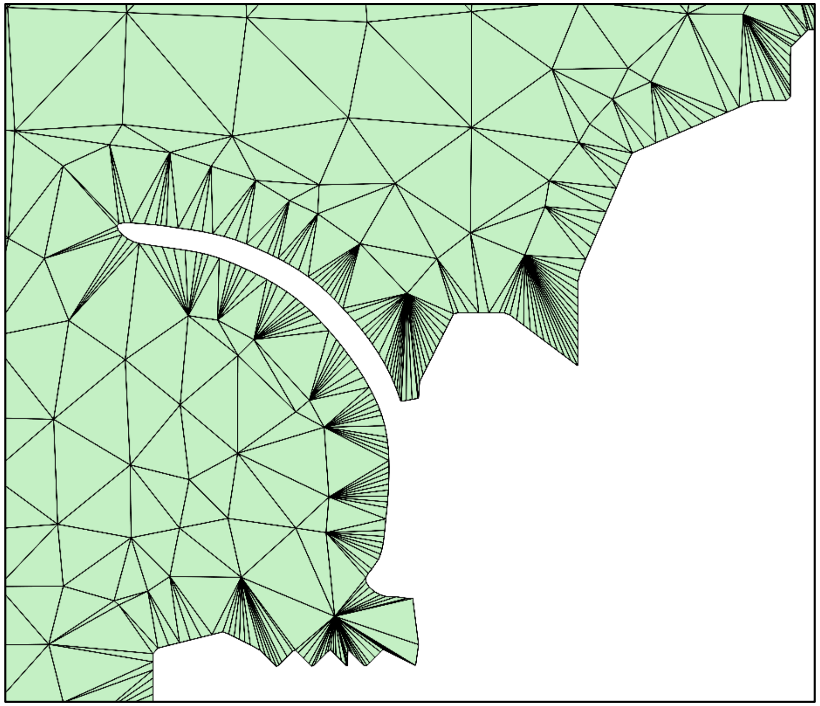
- **Volume discretisation**
- Define the horizon of each boundary node
- Look for a candidate interior node in the bisector of the two horizons
  - Ensure visibility of boundary nodes from interior node
  - Ensure interior edges with the required spacing

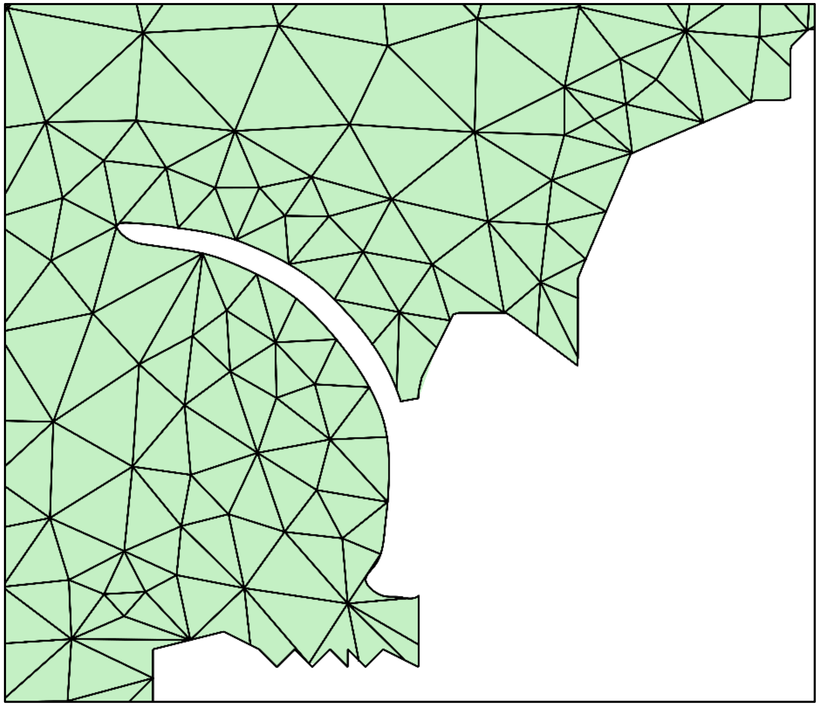


RS, L. Rees and O. Hassan, International Journal for Numerical Methods in Engineering, 2016

Mesh generation – A posteriori approach

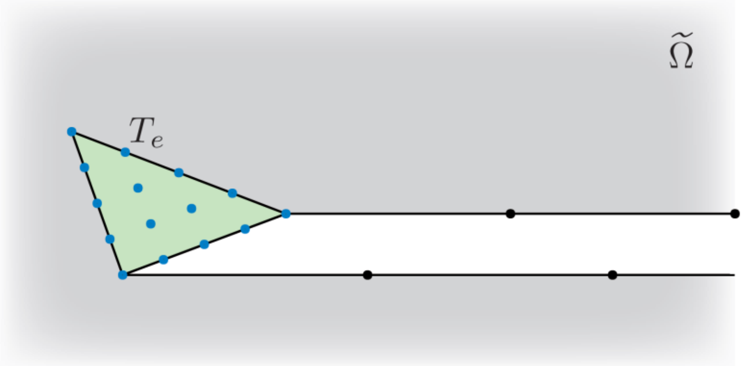
- Using a standard mesh generator
  - Create a mesh with the desired element size
- Merge elements to achieve the desired spacing
  - Collapse edge
- Final cosmetics

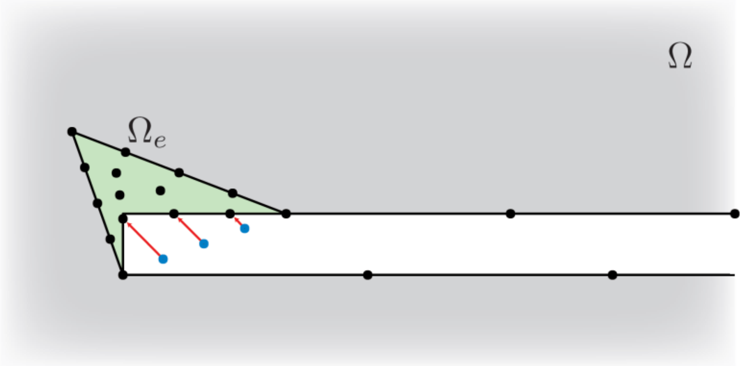




Mesh generation – High-order

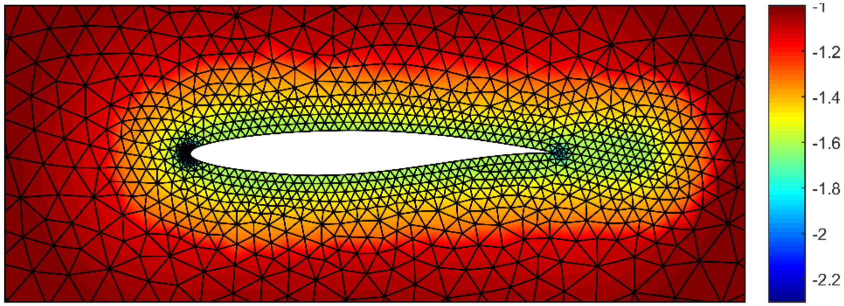
- **Element-by-element elastic analogy**
- Introduce high-order nodal distributions in each straight-sided element defined by its vertices
- Compute a high-order boundary nodal distribution over the true geometry. The new position of the boundary nodes is used to imposed the desired displacement on the boundary nodes
- On interior nodes impose zero displacement IF straight internal edges are desired
- Solve the elastic problem to find the position of interior nodes

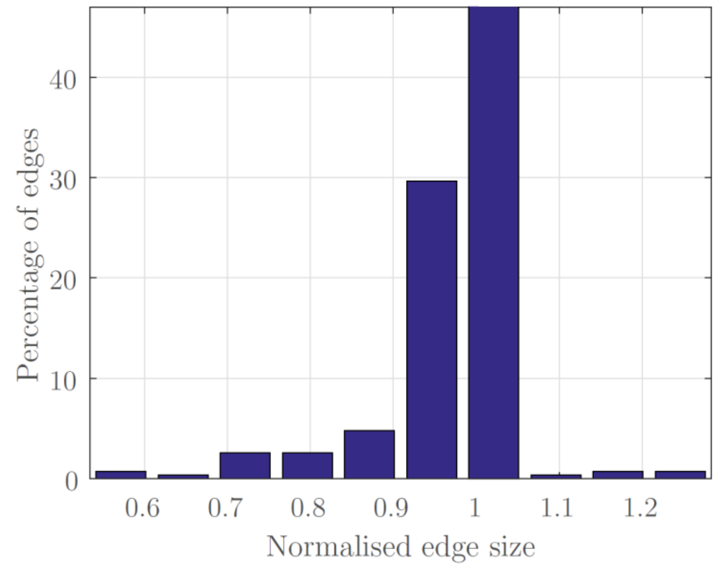




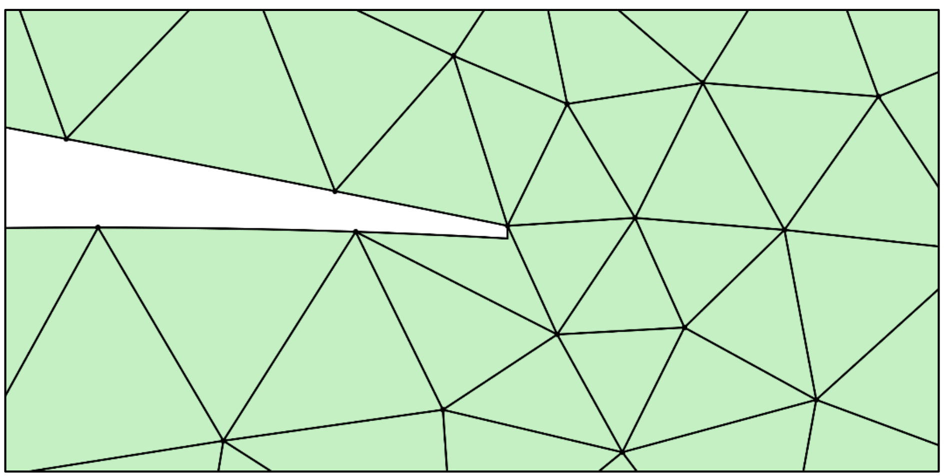
Examples

- **Aerofoil with blunt trailing edge**
  - Linear mesh with specified spacing

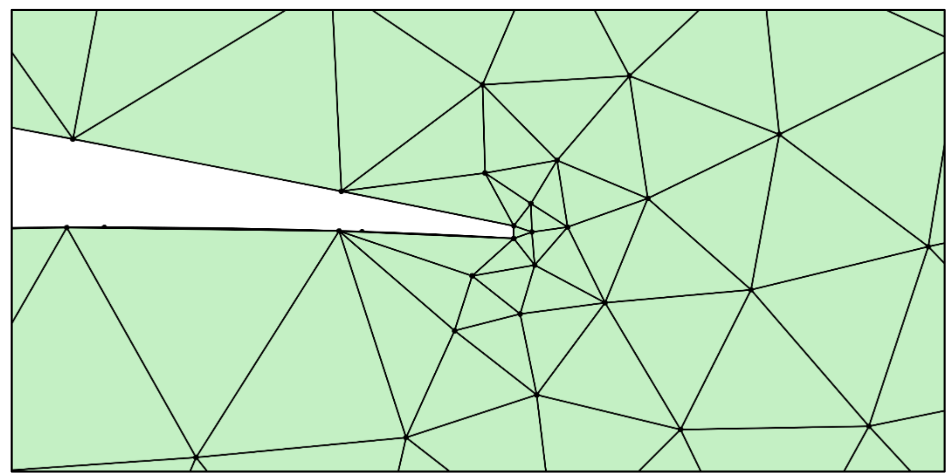




  - Detailed view near the blunt trailing edge



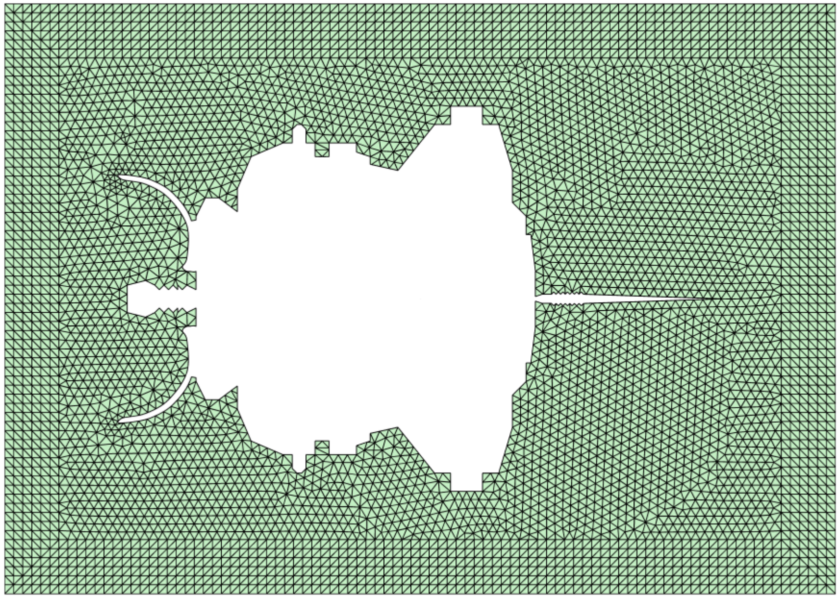
Proposed approach

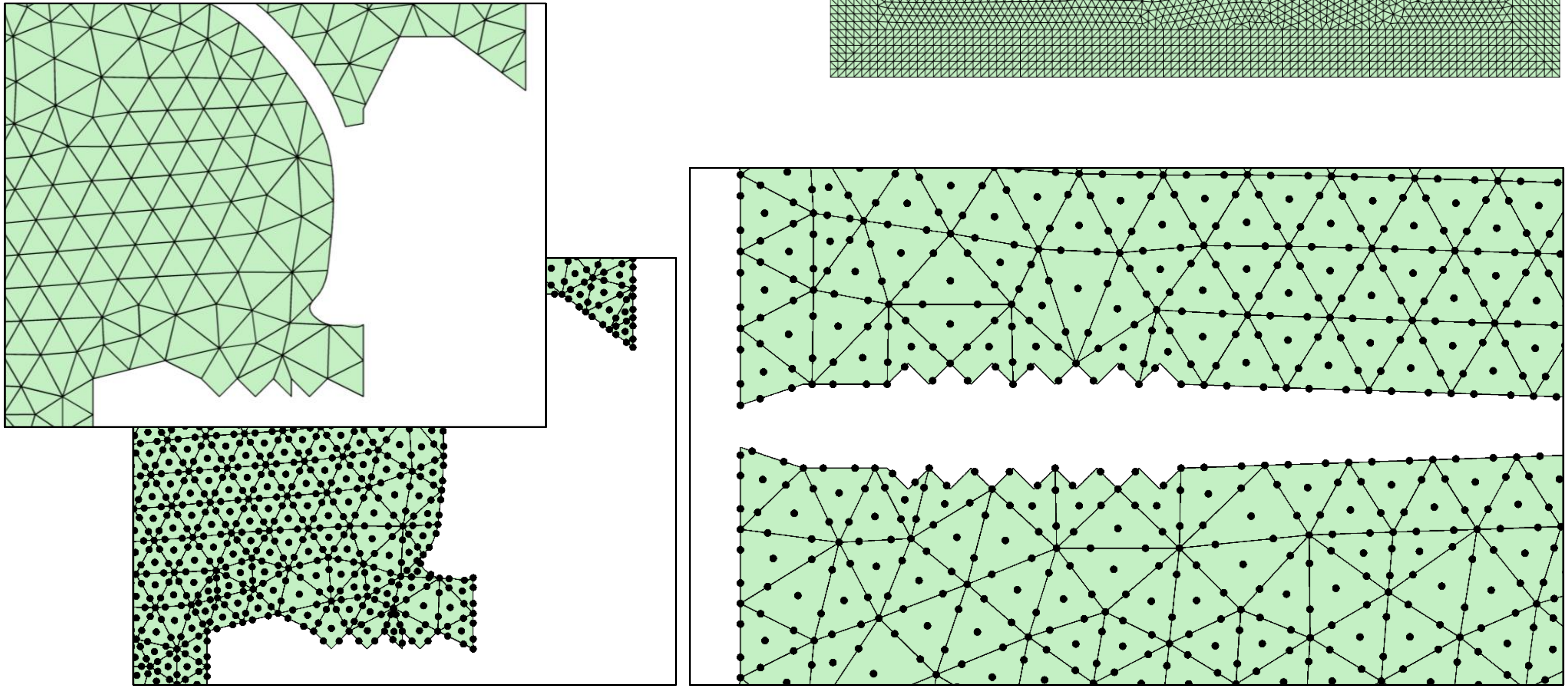


Standard FEM mesh

Examples – Application to electromagnetic scattering

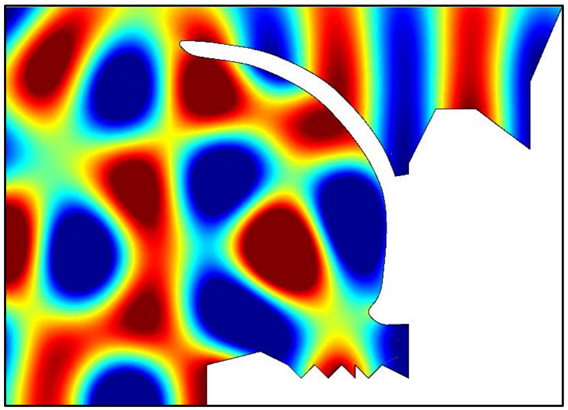
- **Satellite profile**
- Element size 3 times larger than the smallest feature
- 139 curves
- Details of the NEFEM mesh

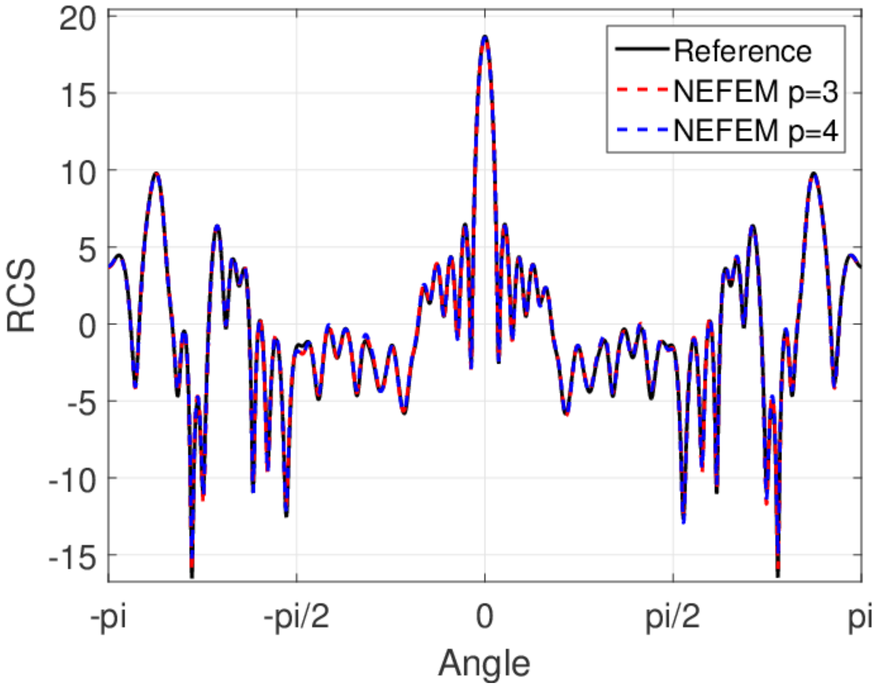


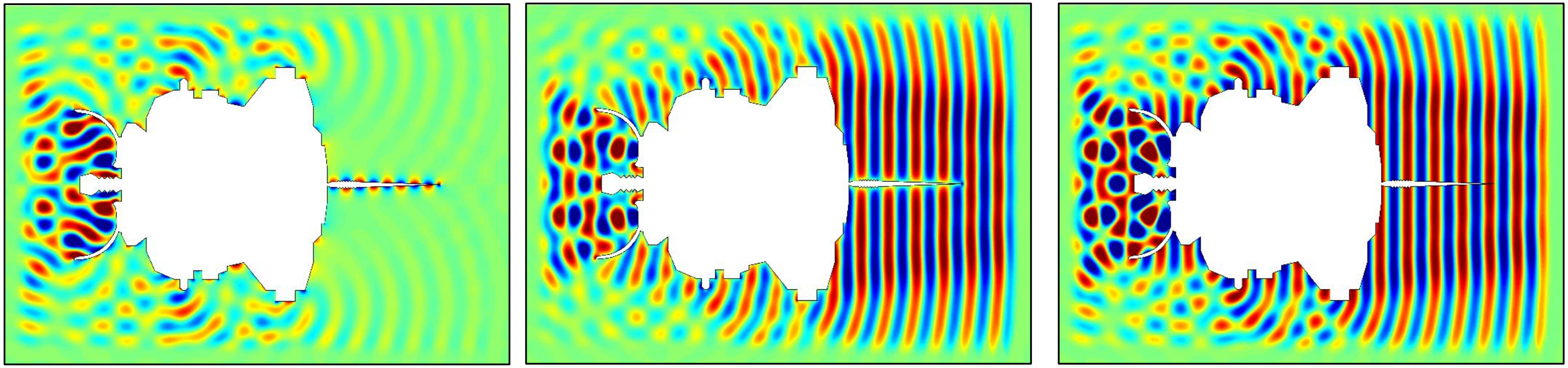


Examples – Application to electromagnetic scattering

- **Satellite profile**
- Scattered field and RCS

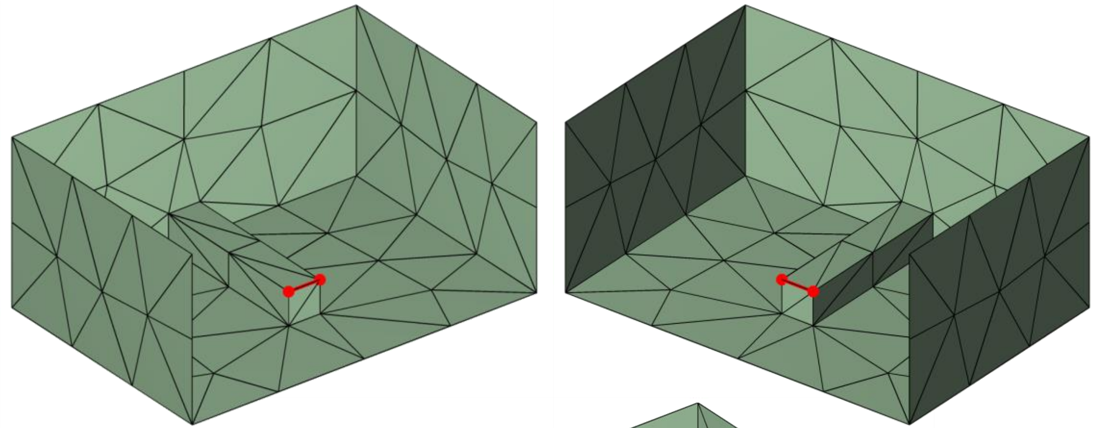




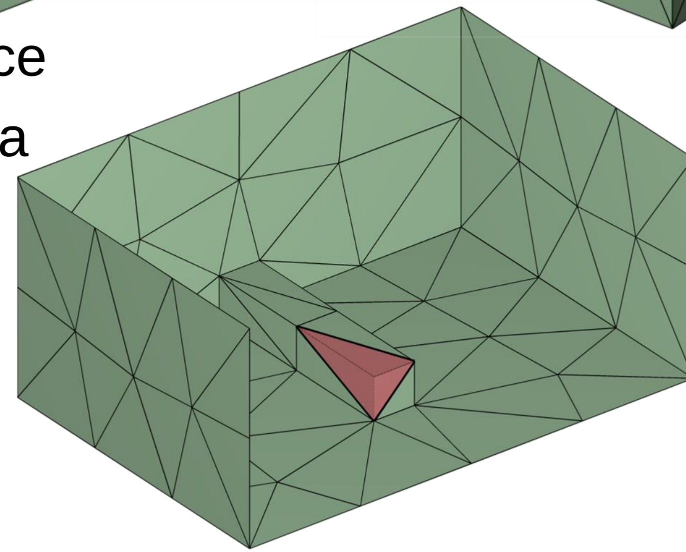


- Computation 140 times faster with NEFEM and p=4

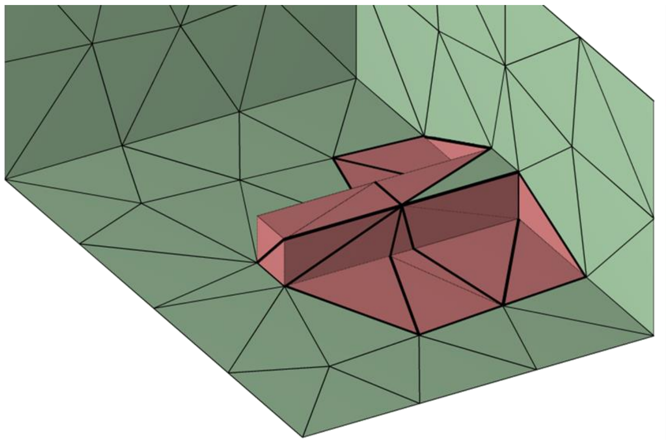
Ongoing work – 3D



- 3D A posteriori approach
  - Given a surface mesh
  - Identify smallest edge
  - Identify edge node with lower valence
  - Edge collapse and remove zero area elements



- The original mesh can be
  - Linear
  - High-order (curved)
  - CAD compliant
- Advantages
  - CFL restriction
  - Substantial reduction of elements



Concluding remarks

- Development of a new and fully automatic mesh generation technique
  - Uses the CAD boundary representation of the domain
  - The element size is independent on the geometric complexity and on small geometric features
  - Circumvents the problem of de-featuring
- An a priori technique is based on
  - The boundary discretisation of loops instead of curves
  - A modified advancing front technique
- An a posteriori approach is based on merging
- Numerical examples demonstrate the applicability and potential of the proposed approach
  - Reduction of the total number of elements
  - Advantages when explicit time marching algorithms are used