Generation of meshes without de-featuring

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ZCCE

Outline

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

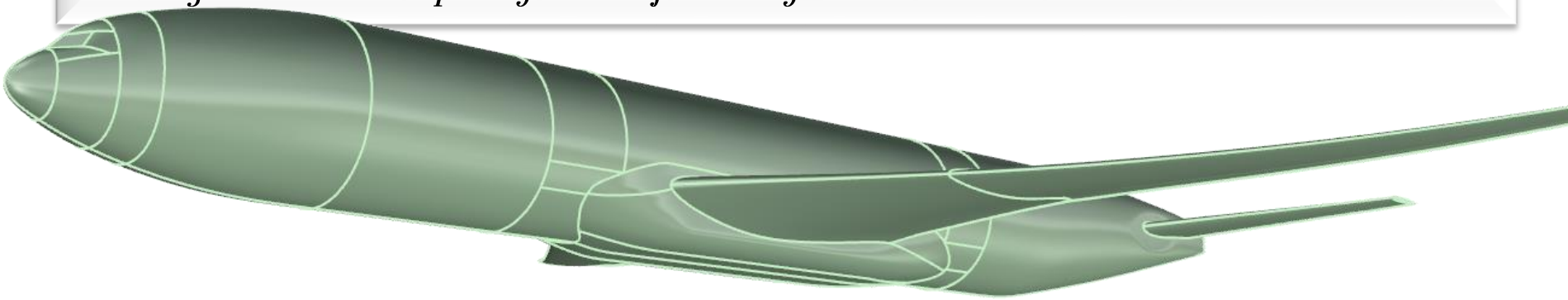
Motivation

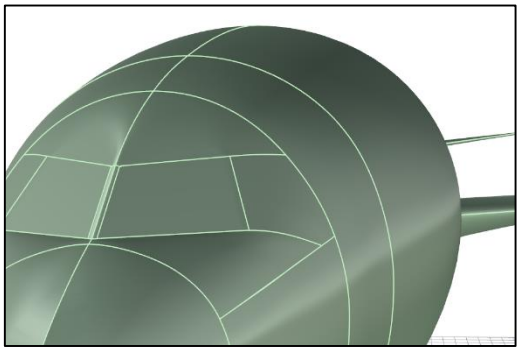
Generation of suitable FE meshes from CAD models

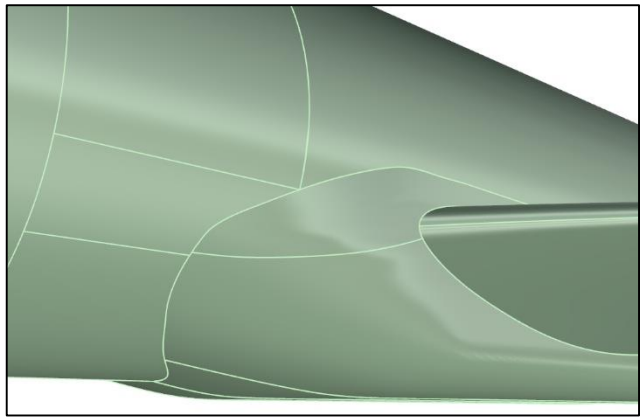
J Slotnick, A Khodadoust, J Alonso, D Darmofal, W Gropp, E Lurie & D Mavriplis, CFD vision 2030 study: a path to revolutionary computational aerosciences, 2014

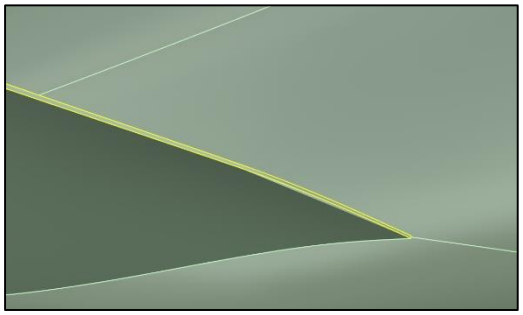
"the generation of suitable meshes for simulations about complex configurations constitutes a principal bottleneck in the simulation"

"CAD geometries are poorly suited for analyses due to excessive detail"









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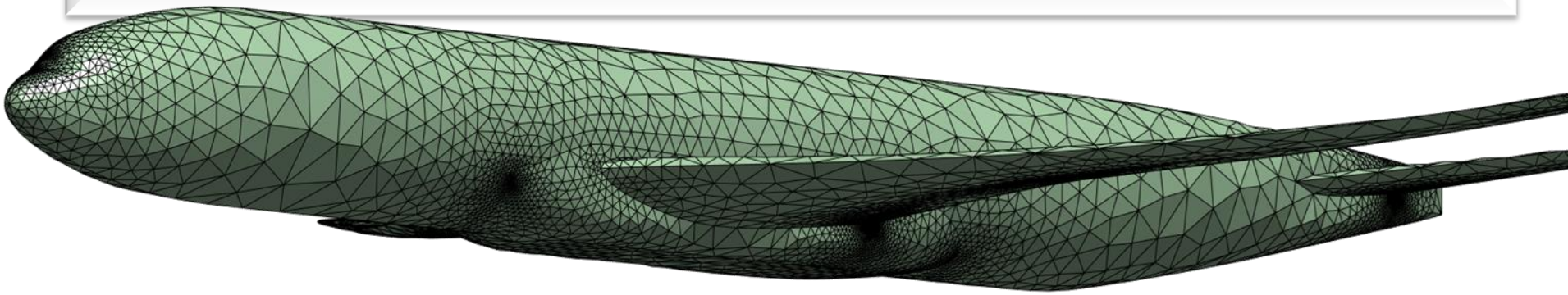

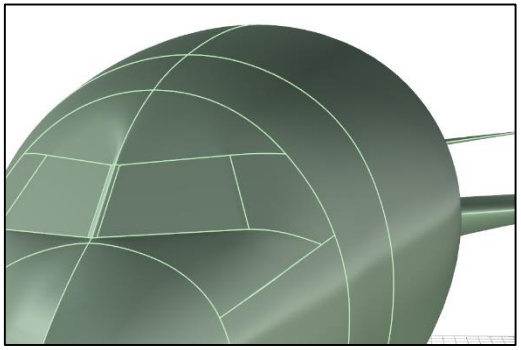

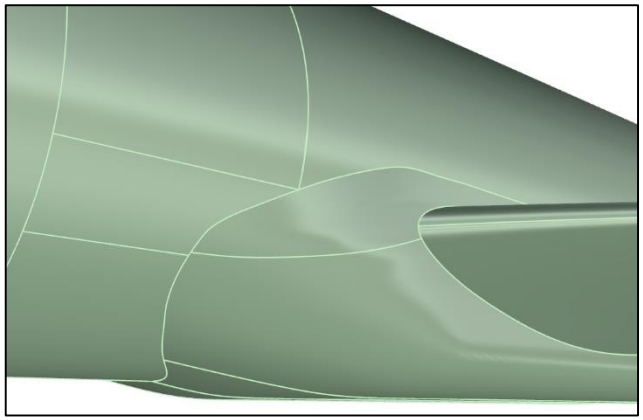

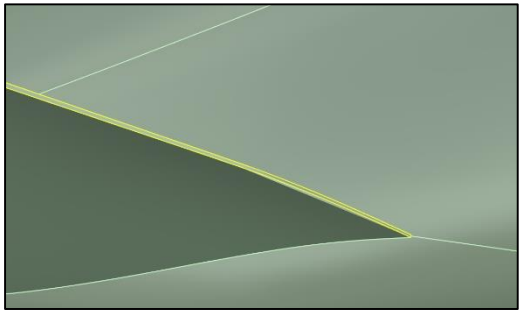

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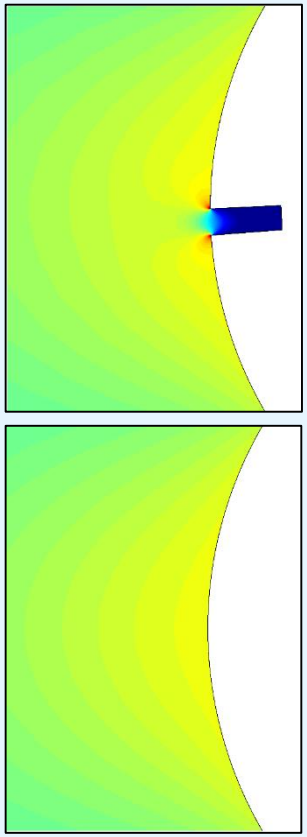
De-featuring

- Can take up to 90% of the total time invested in a simulation
- Depends upon the physics of the problem

Solid mechanics



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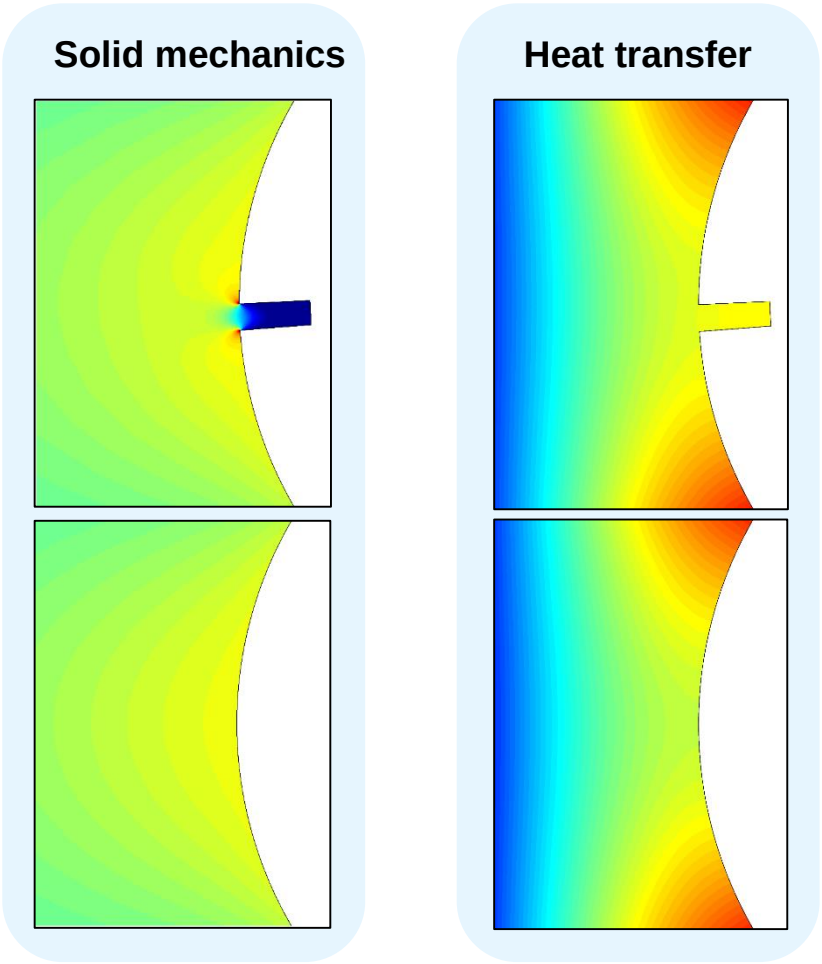

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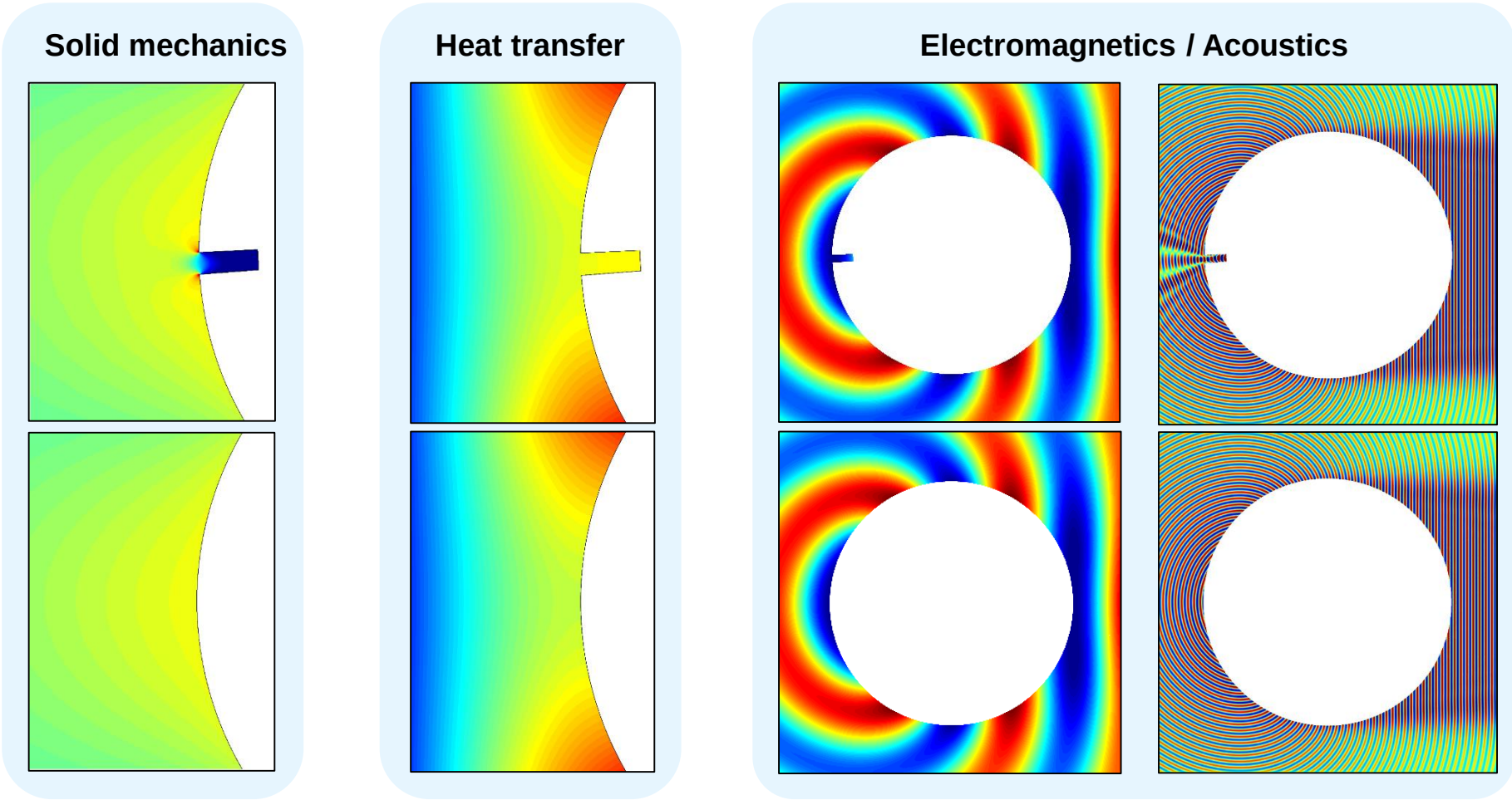

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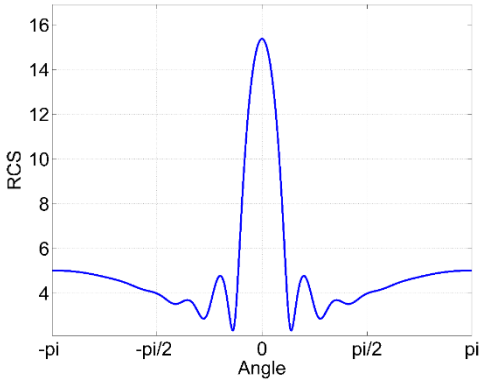

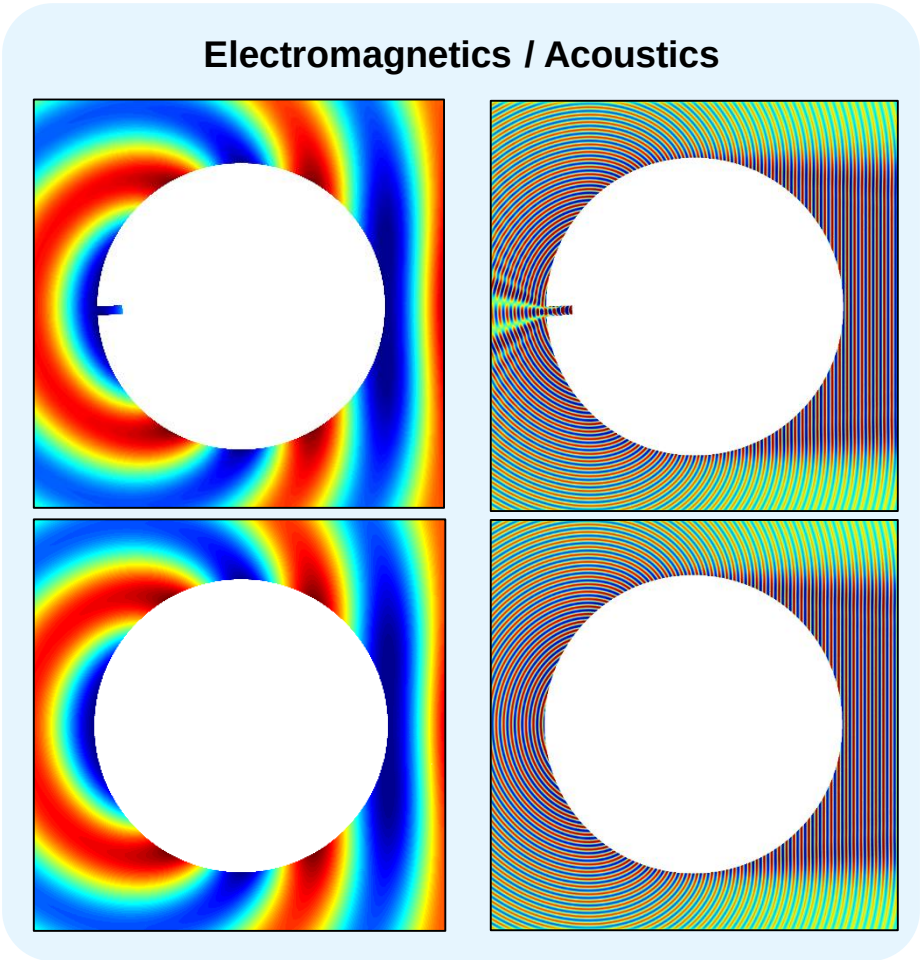

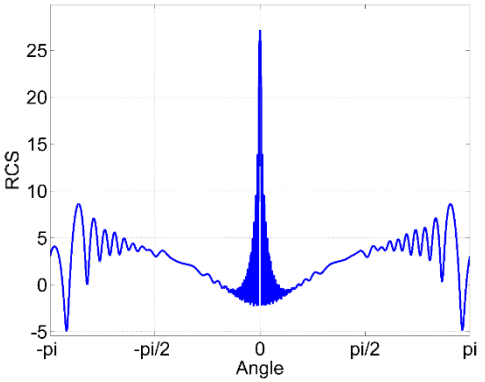

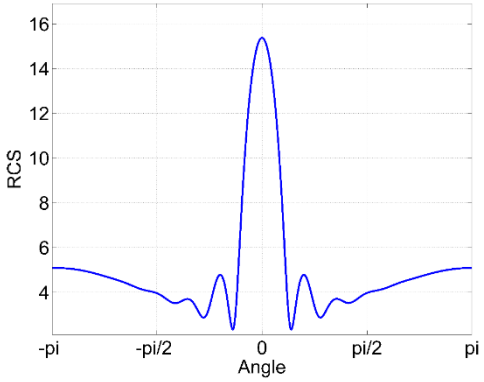

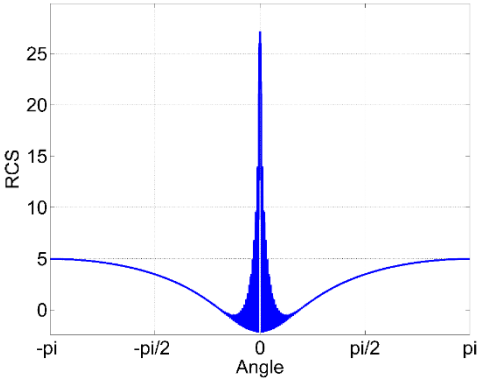

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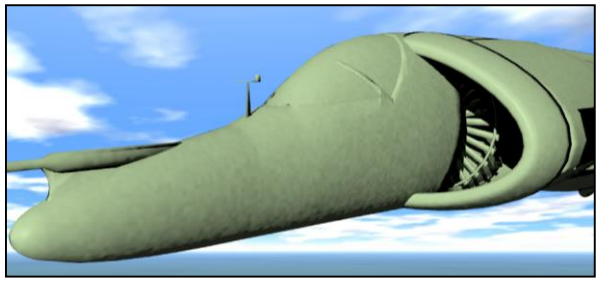
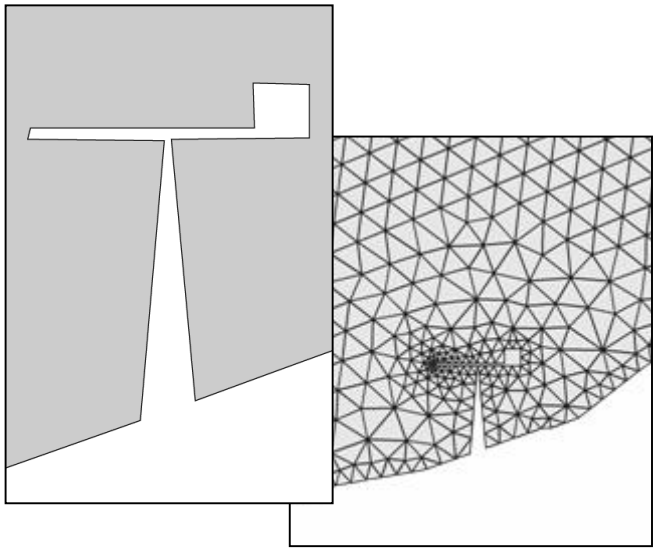
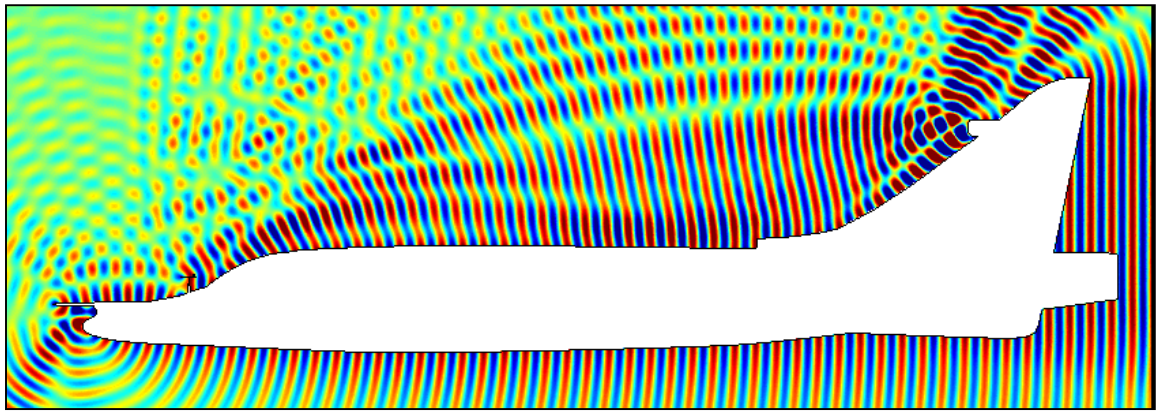
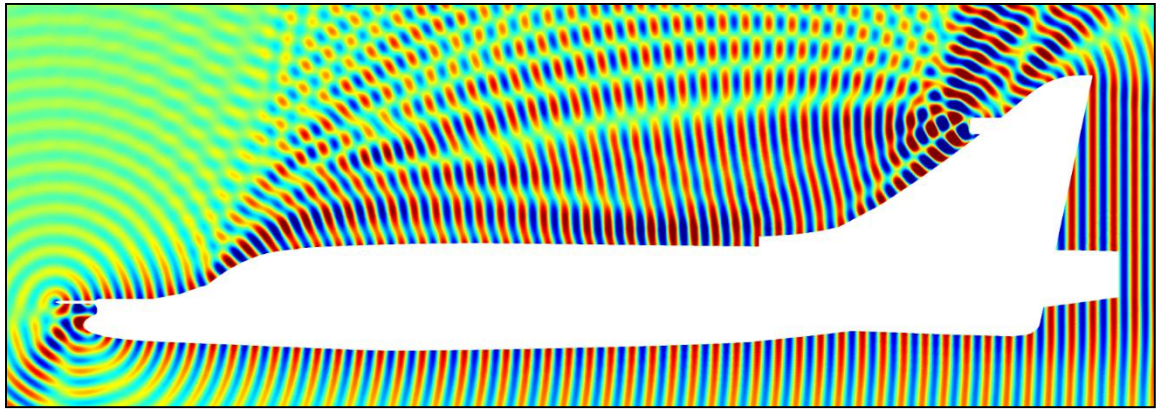


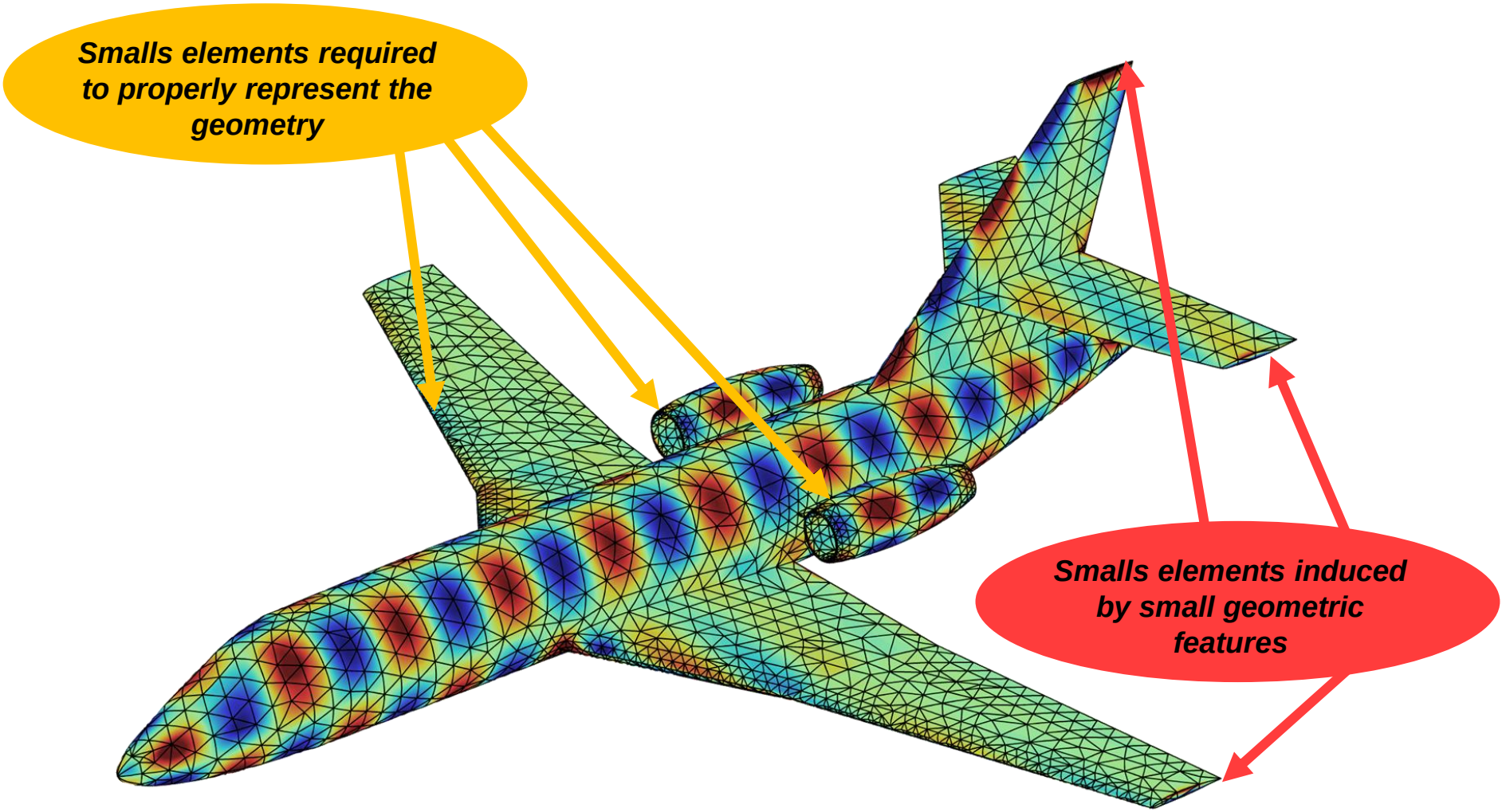






Motivation

- This is particularly problematic for high-order schemes



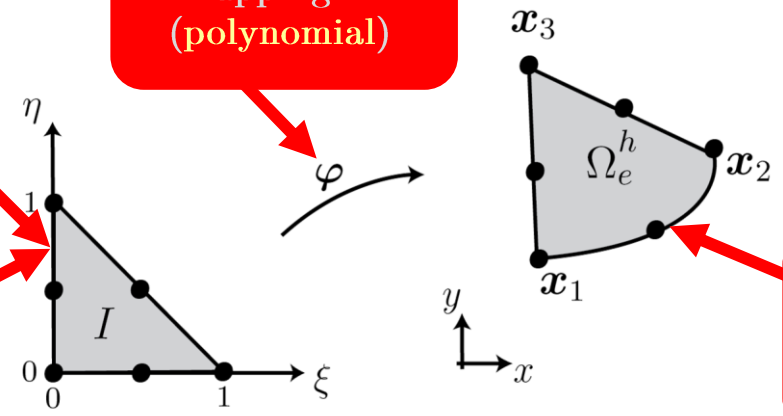
NURBS-Enhanced FEM (NEFEM)

- Isoparametric FEM

Quadrature defined here

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

Isoparametric mapping (polynomial)



Approximate boundary (polynomial)

RS, S Fernández-Méndez and A Huerta, "NEFEM: A seamless bridge between CAD and FEA", Arch. Comp. Meth. Eng., 2011

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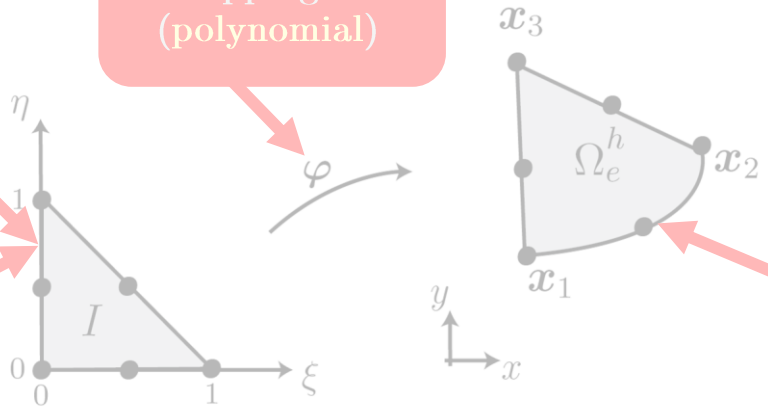


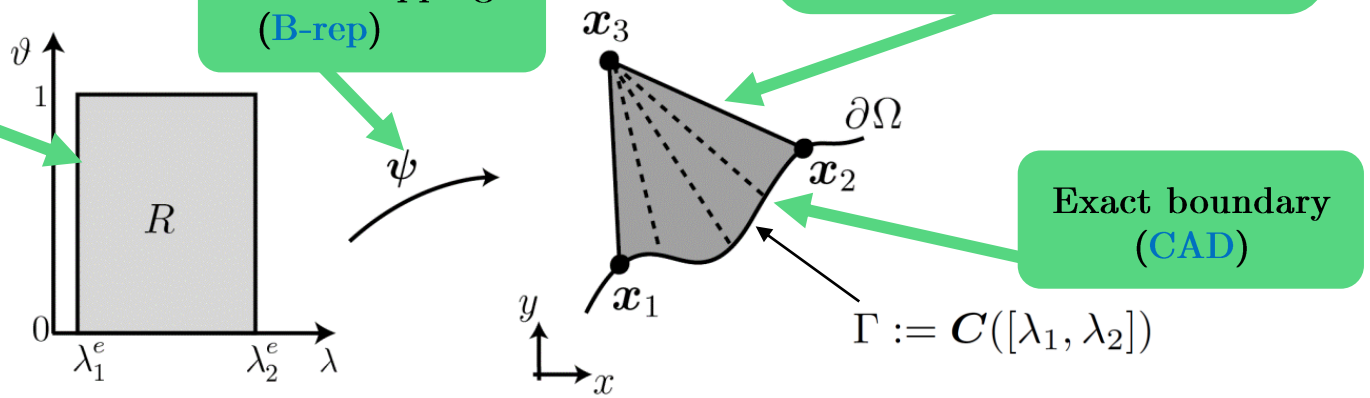
- NURBS-Enhanced FEM

Quadrature defined here

New mapping (B-rep)

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

Exact boundary (CAD)



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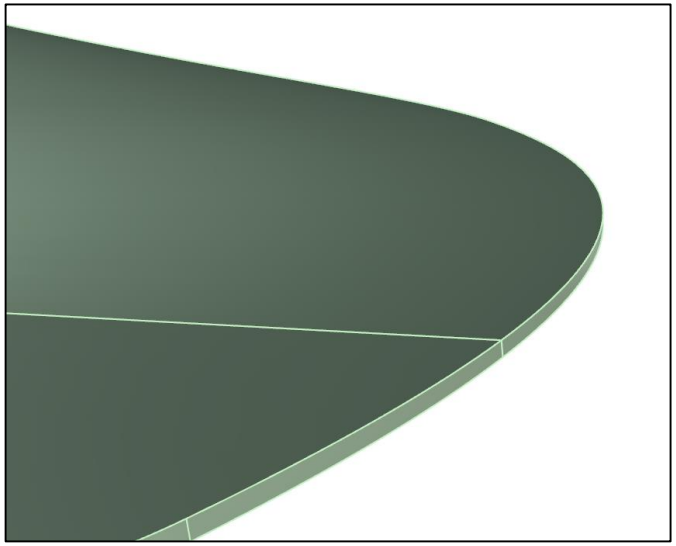
NEFEM mesh generation

- Element size should not be dictated by geometric details



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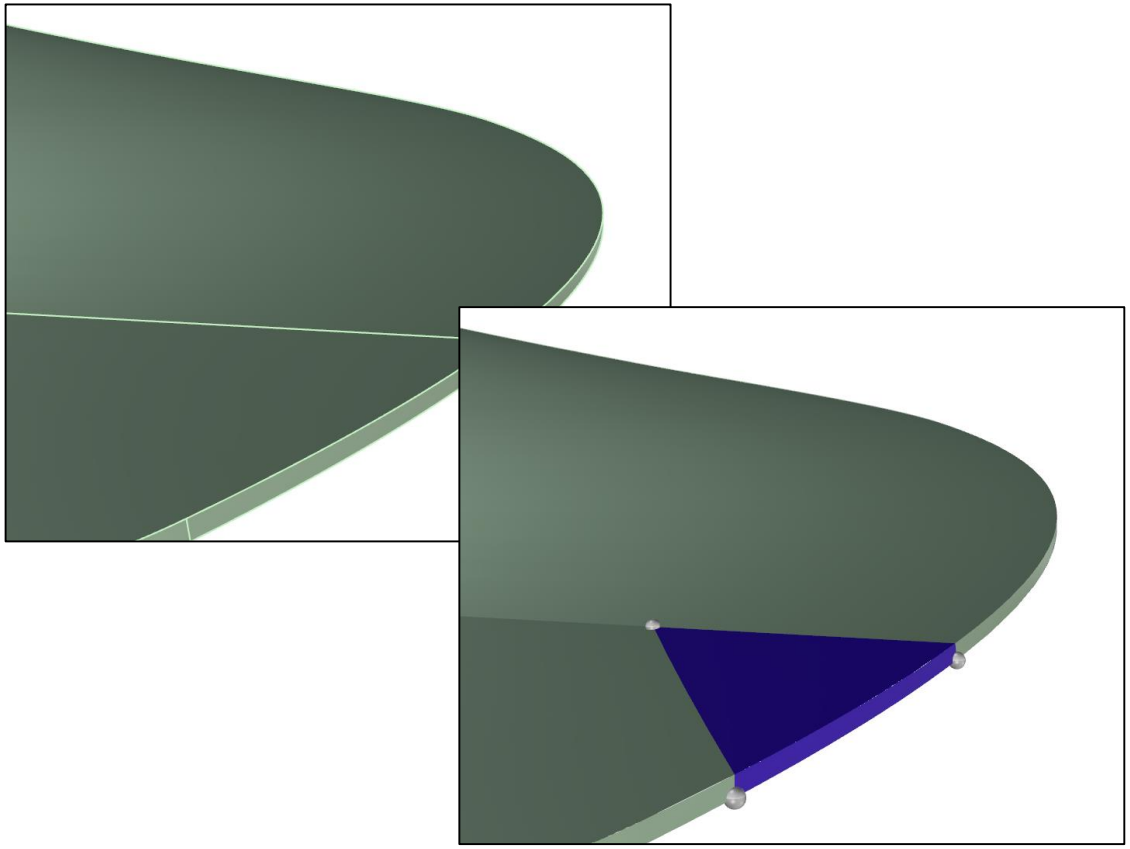

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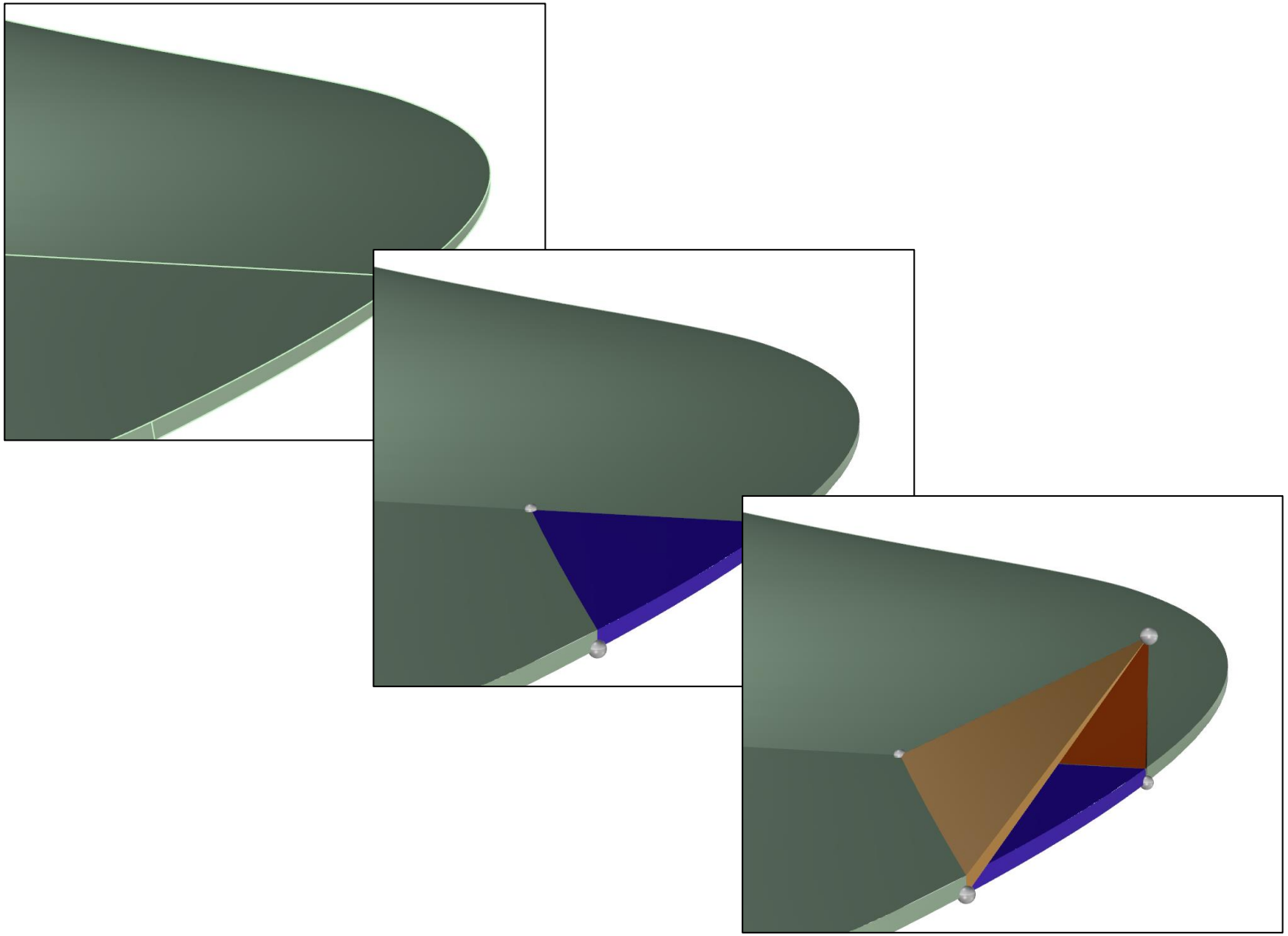
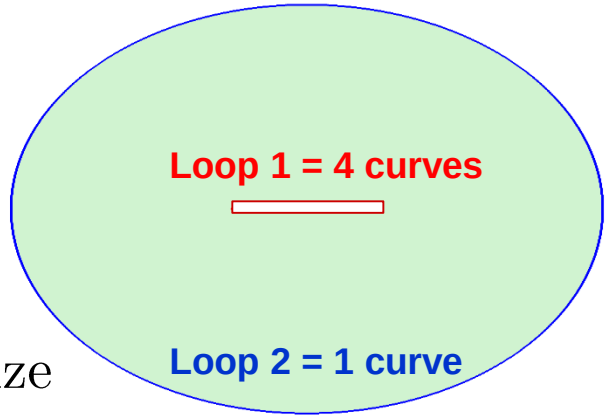
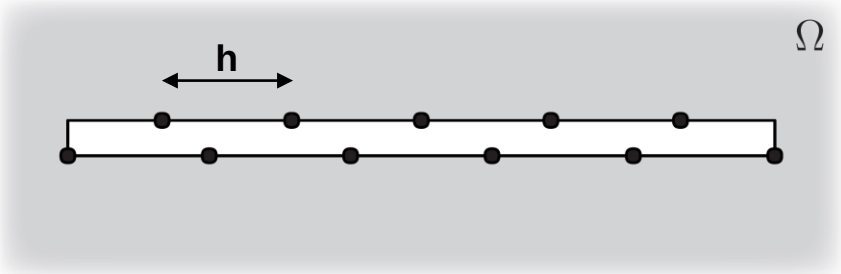


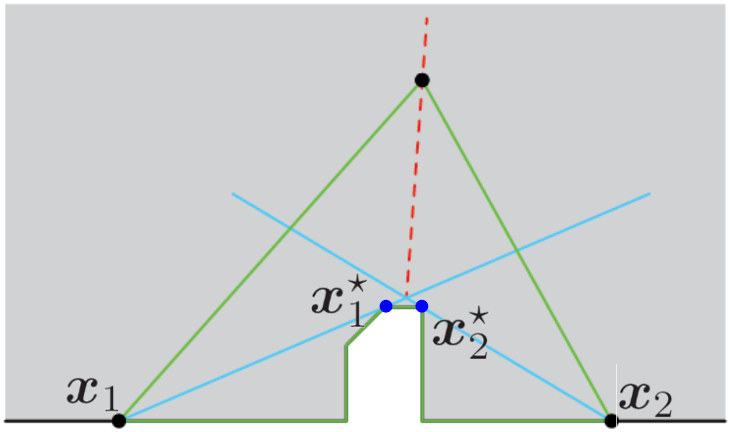
Mesh generation – A priori approach



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



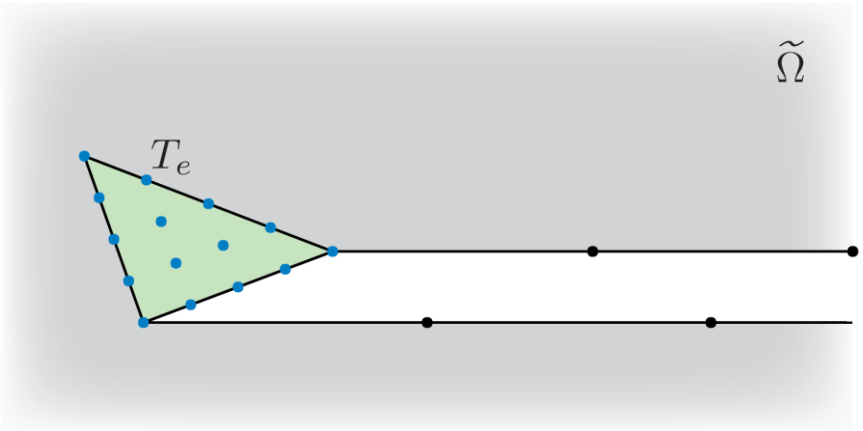
- **Domain discretisation**
  - Define the horizon of each boundary node
  - Look for a candidate interior node in the bisector of the two horizons
  - Ensure visibility of boundary nodes from interior node
  - Ensure interior edges with the required spacing

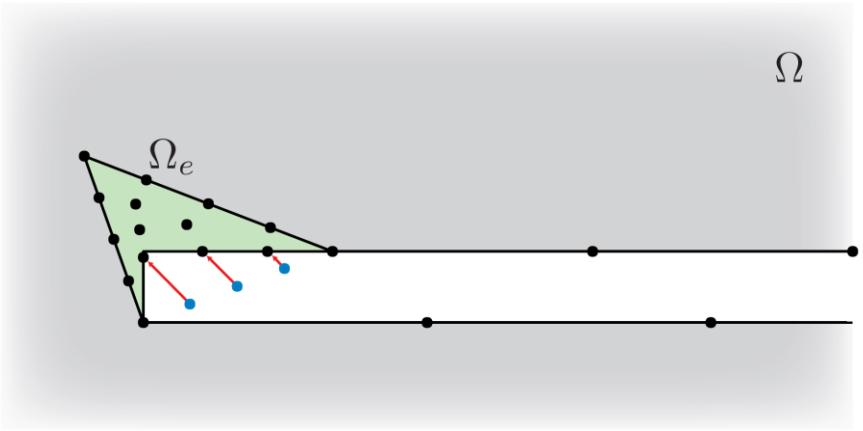


RS, L Rees and O Hassan, "The generation of triangular meshes for NEFEM", Int. J. Num. Meth. Eng., 2016

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





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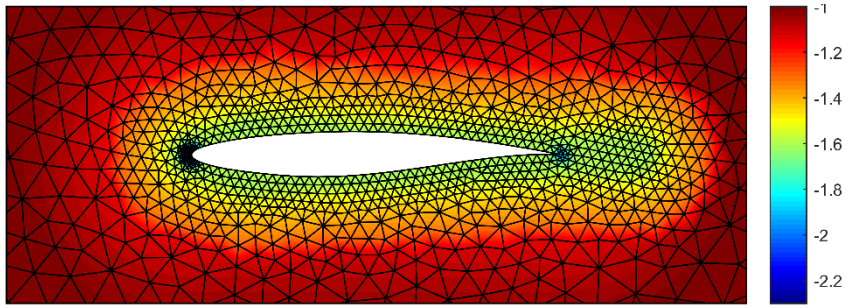
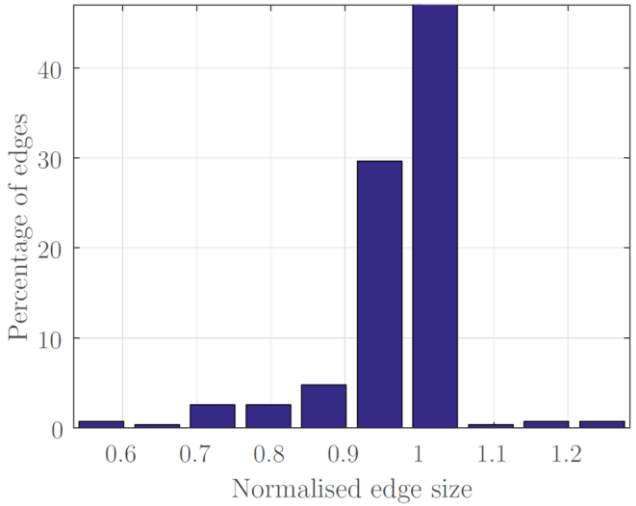
Examples

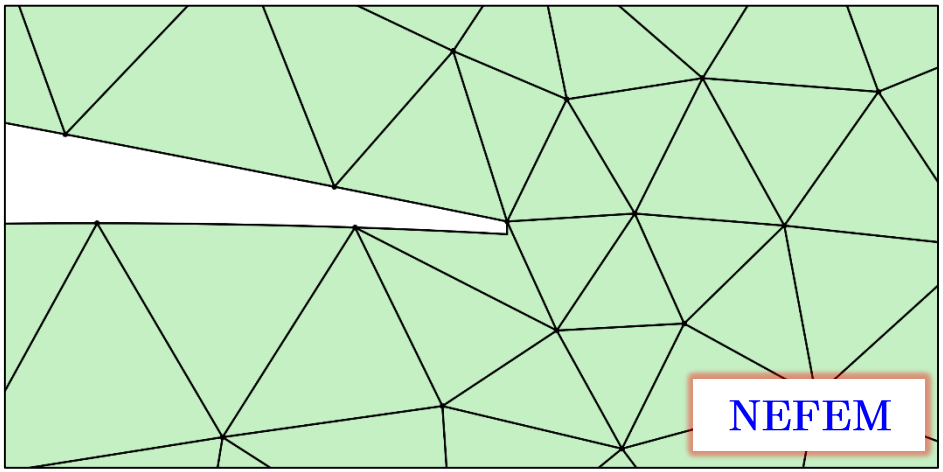
- Desired element spacing with no de-featuring
  - Aerofoil with blunt trailing edge

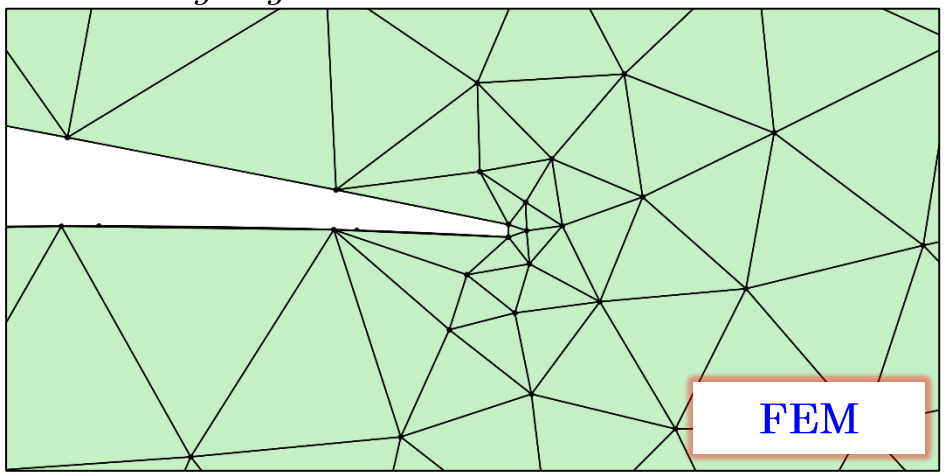


Linear mesh and specified spacing



Zoom near the blunt trailing edge





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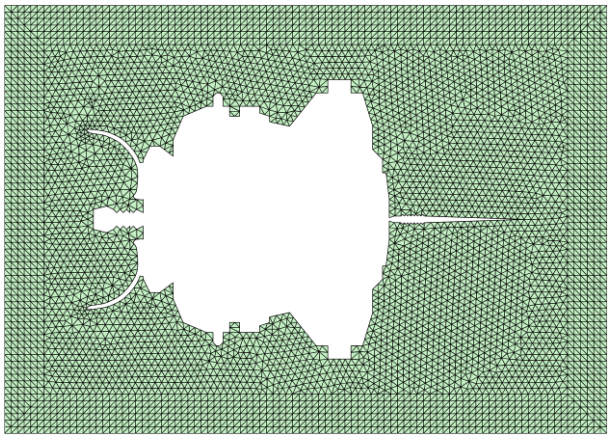
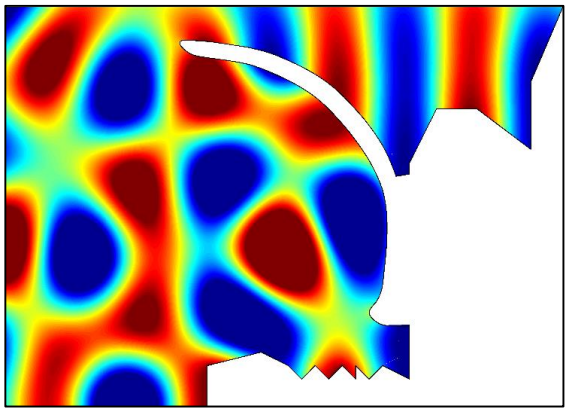
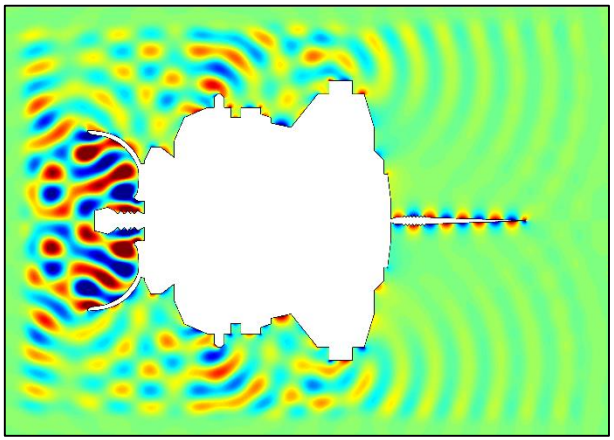
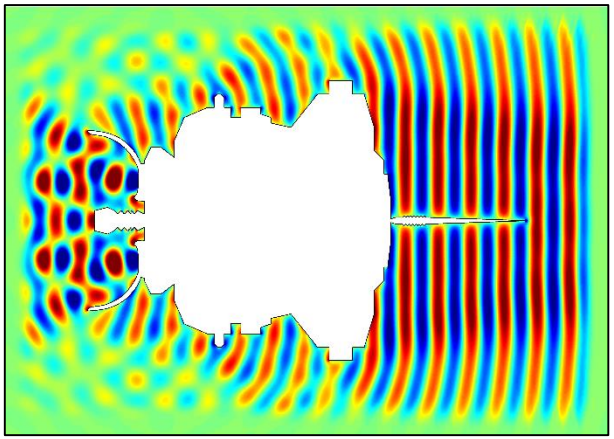
Examples

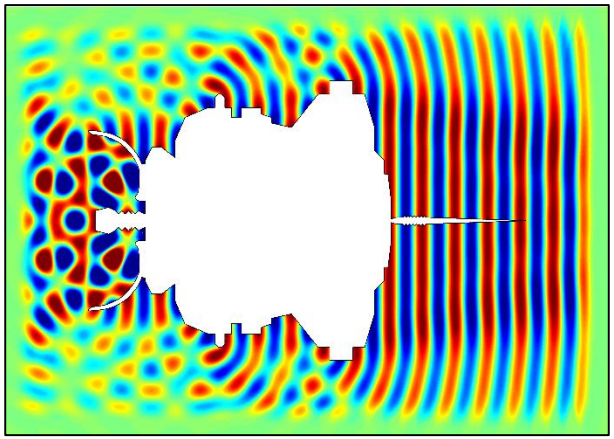
- Feasibility of explicit time marching
  - Electromagnetic scattering











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Examples

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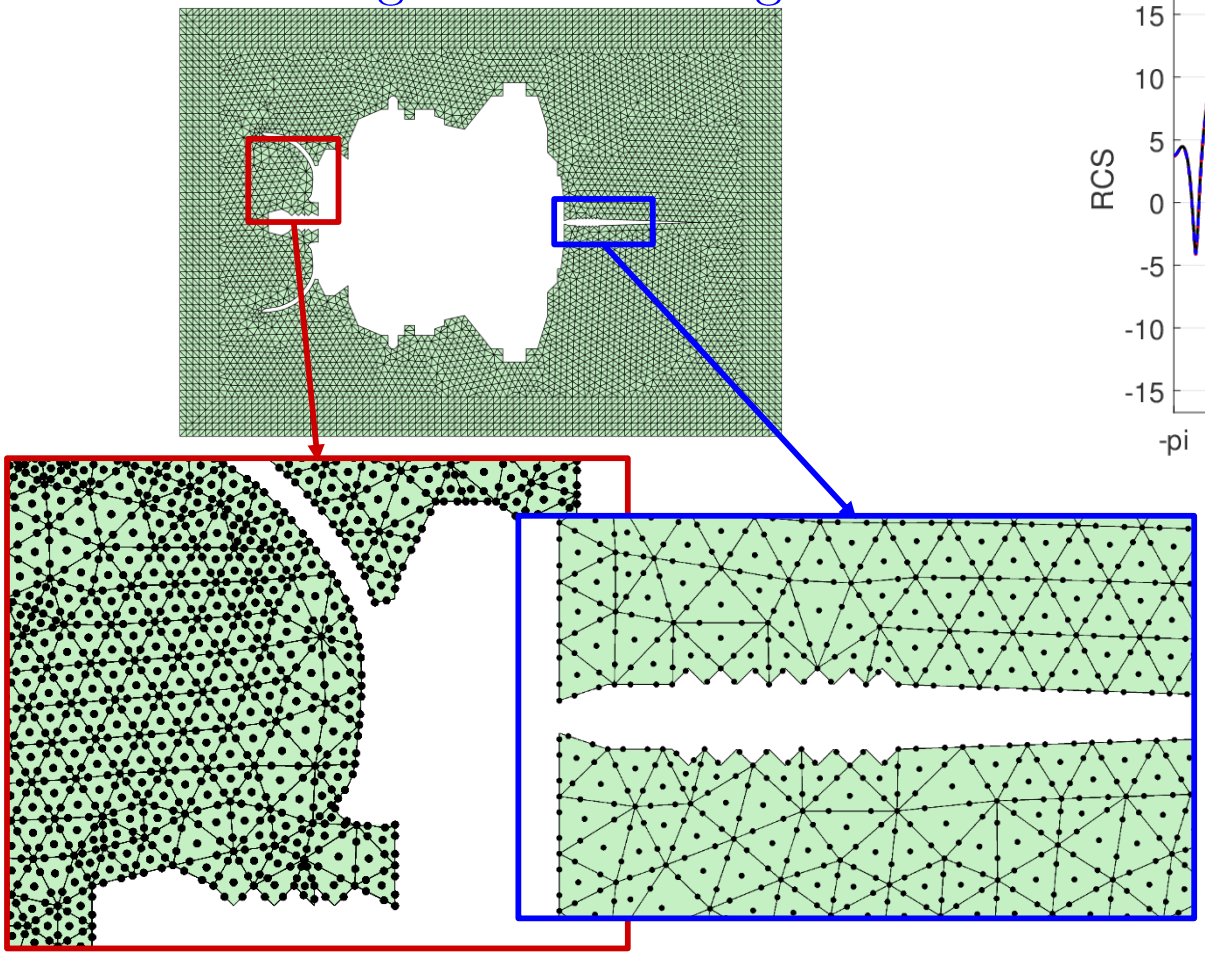
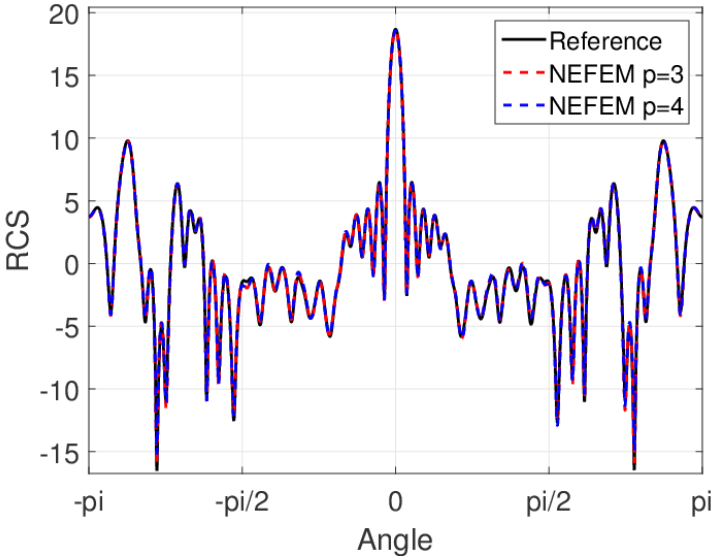
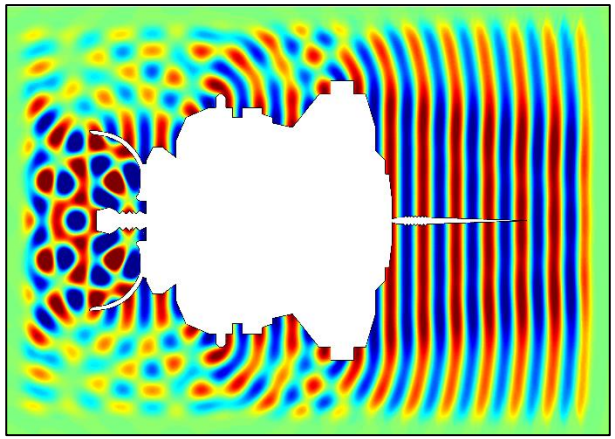
  - Electromagnetic scattering





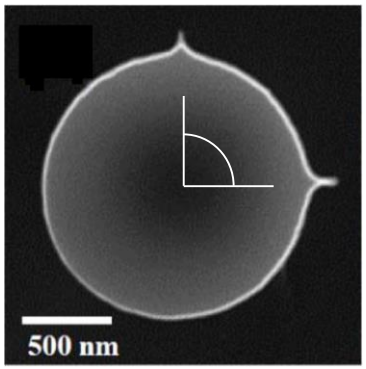


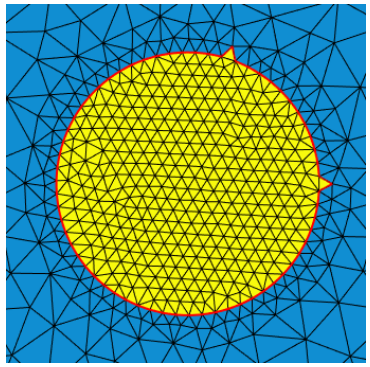
Computation 140 faster with NEFEM

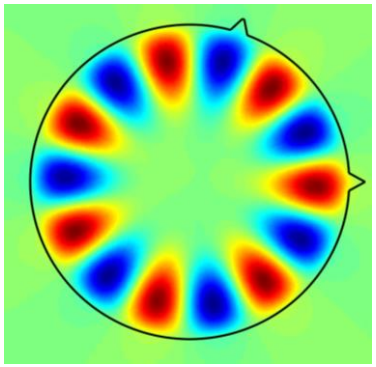
RS, L Rees and O Hassan, "The generation of triangular meshes for NEFEM", Int. J. Num. Meth. Eng., 2016

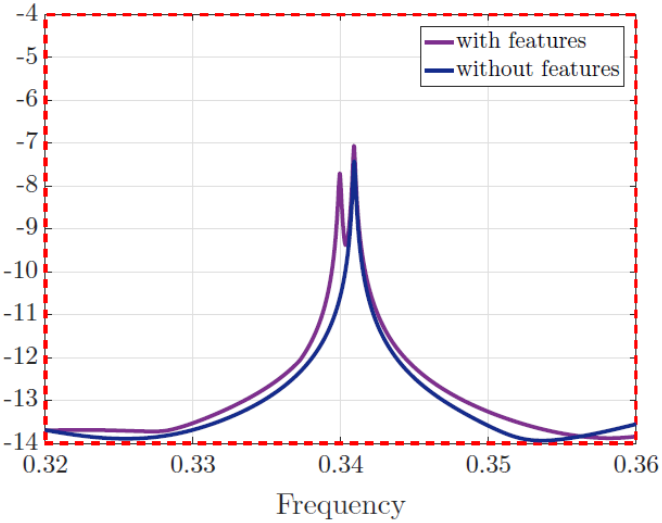
Examples

- Capture correct physics without refinement or de-featuring
  - Optical and photonic devices









M Kim et al., "Partially directional microdisk laser with two Rayleigh scatterers", Optics Letters, 2014

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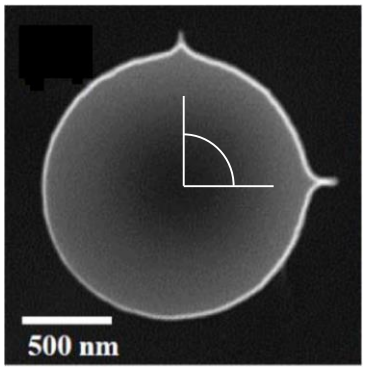
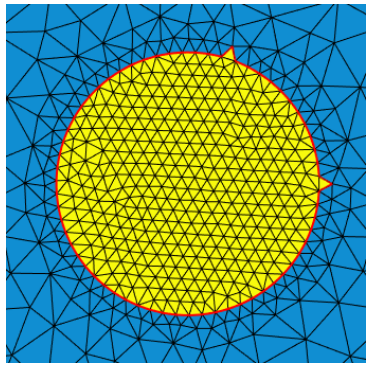
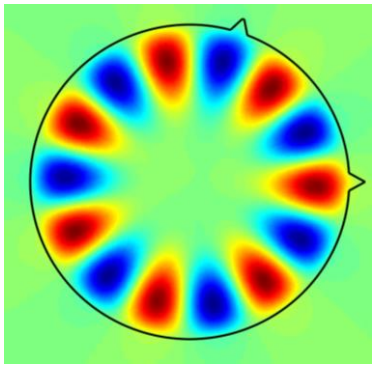
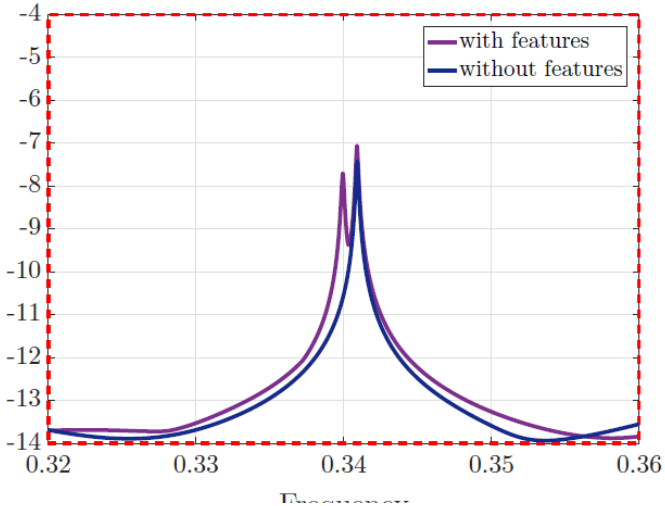
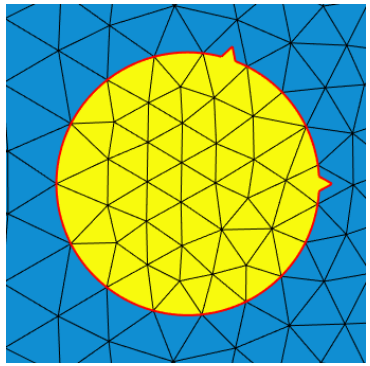
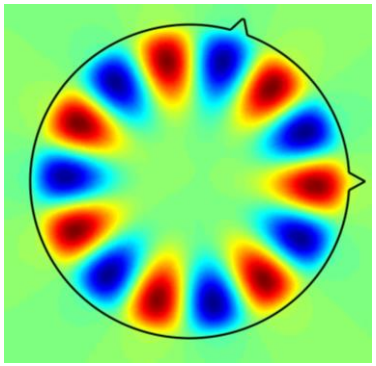


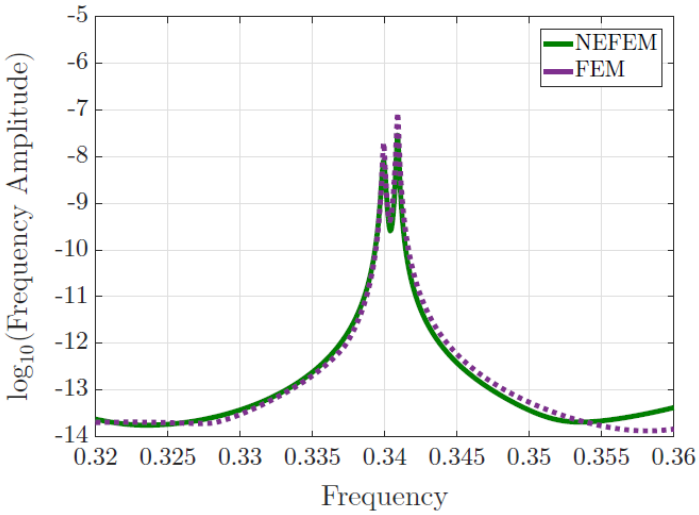








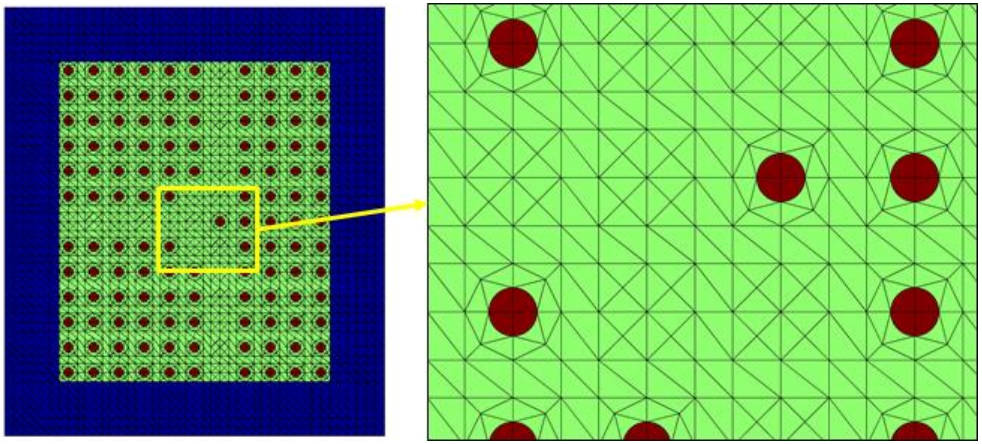


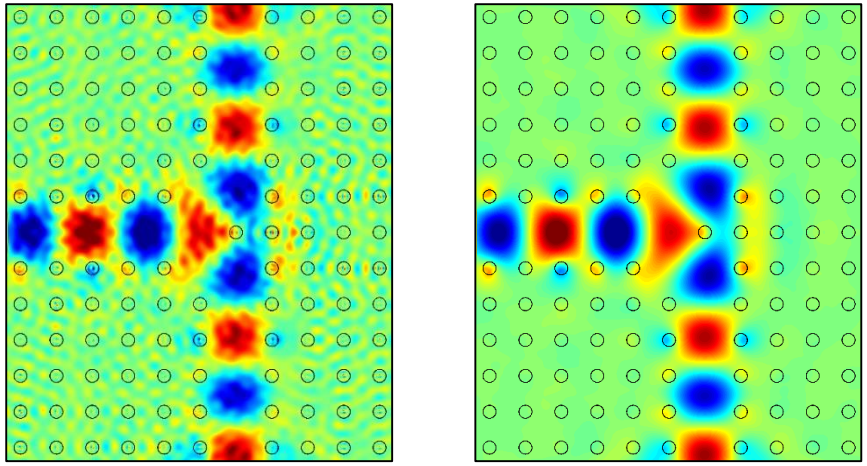


M Dawson, RS, O Hassan and K Morgan., "Computation of electromagnetic cavity modes using the DGTD method", UKACM, 2015

Examples

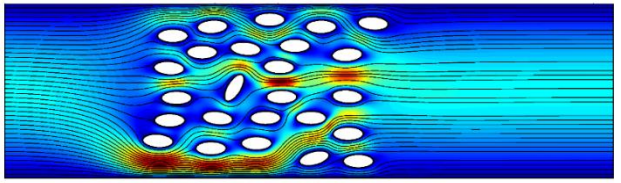
- Capture correct physics without refinement or de-featuring
  - Optical and photonic devices





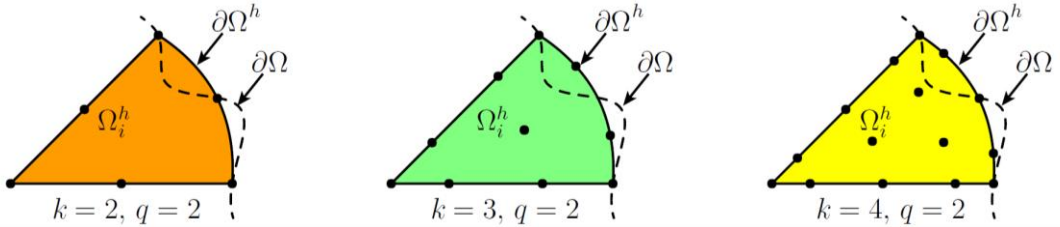
RS, M Dawson, O Hassan and K Morgan., "Computation of electromagnetic cavity modes using the DGTD method", WCCM, 2014

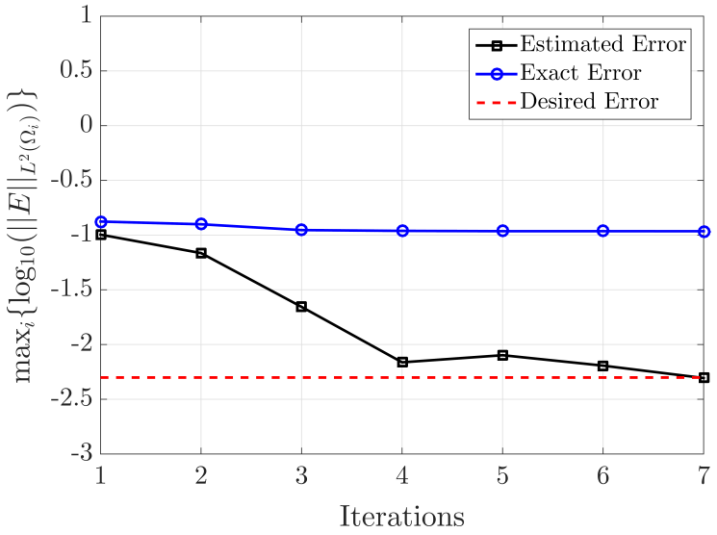
Examples



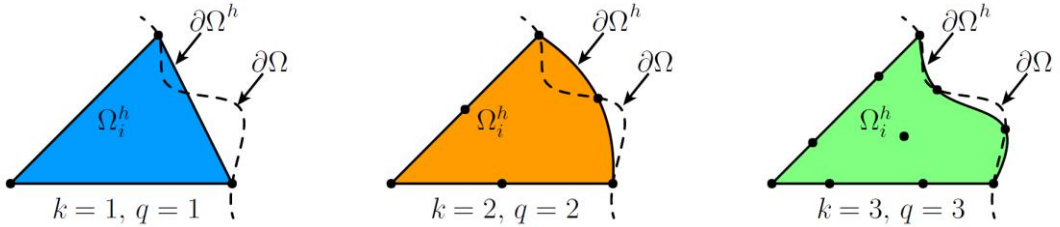
- Reliable and efficient adaptivity without pre-adaptation
  - Degree adaptive process

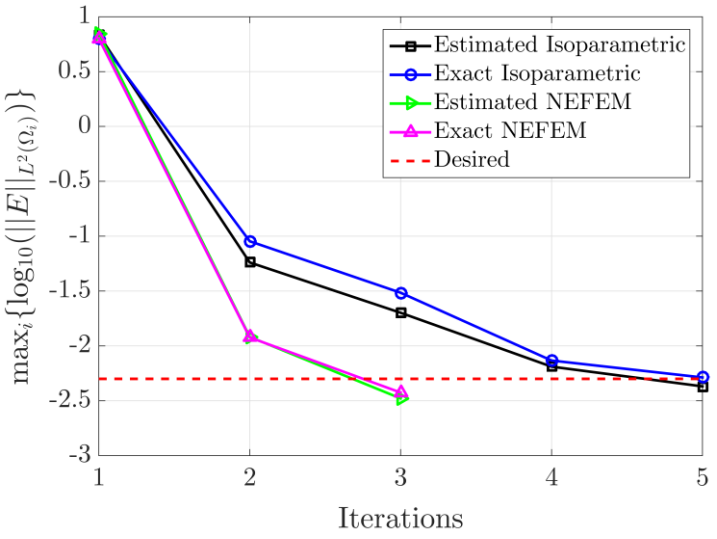
1. Fixed geometry (quadratic/cubic)



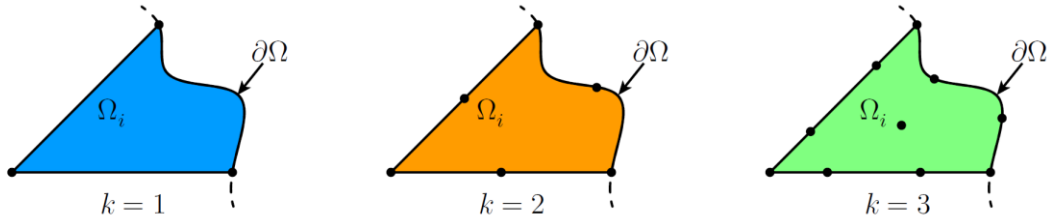


2. Change geometry (CAD access)





3. NEFEM (fixed exact geometry)



RS and A Huerta, "HDG-NEFEM with degree adaptivity for Stokes flows", To appear

Concluding remarks

- Development of a new (non-hierarchical) fully automatic mesh generation technique
  - CAD boundary representation of the domain
  - Element size is independent on the geometric complexity
  - De-featuring is not required
- A priori technique based on
  - The boundary discretisation of loops instead of curves
  - A modified advancing front technique
- Numerical examples demonstrate the potential
  - Less elements and more efficient with explicit time marching
  - Capture correct physics without refinement or de-featuring
  - Reliable and efficient adaptivity without pre-adaptation

- Still some work to be done in 3D...