Mesh generation for crack simulation and surface modeling

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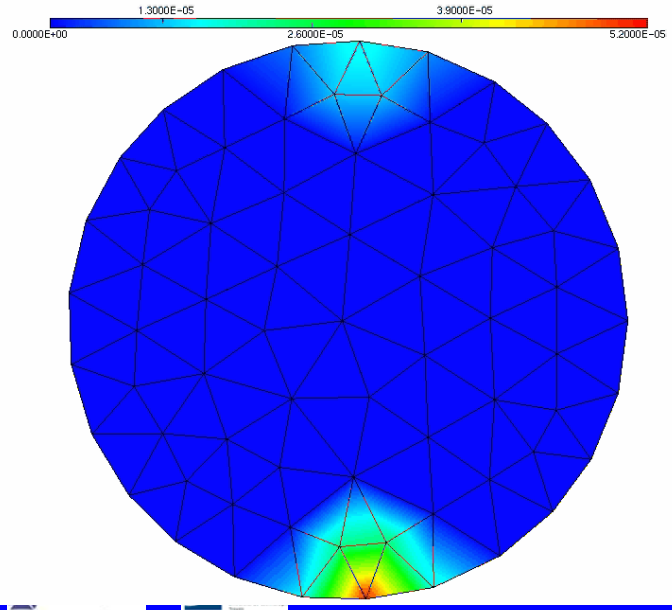
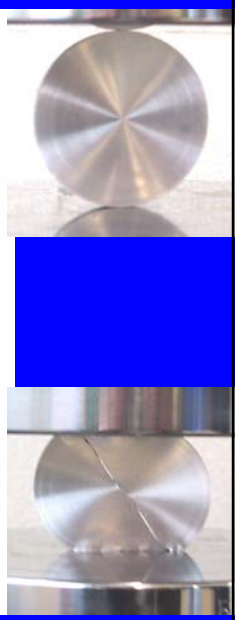
Outline

- Crack simulation
  BL2D + ABAQUS Explicit
- Surface modeling
  BLSURF + "CAD"

Full cylinder (crushing)





Adaptive computational scheme

- Initial mesh of the domain
- Definition of material properties
- Coupled damage computation
- Computational loop
  - Mechanical computation for a small load
  - Error estimation
  - Adaptive remeshing
  - Mechanical field interpolation

Remeshing scheme

- New geometry $G(\Gamma)$ after deformation in a discrete form $T(\Gamma)$
- Size map $H(\Omega)$ = intersection of:
  - $H_g(\Gamma)$: geometric error estimation
  - $H_{\Phi 1}(\Omega)$: physical error estimation
  - $H_{\Phi 2}(\Omega)$: accordance to the damage
- Adaptive rediscretization $T'(\Gamma)$ w.r.t. $H(\Omega)$
- Adaptive remeshing $T'(\Omega)$ w.r.t. $H(\Omega)$
- Linear interpolation of mechanical fields

Definition of the new geometry $G(\Gamma)$ after deformation

- Free deformations: mechanical constraints (for instance equilibrium conditions)
- Bounded deformations: piece in contact with tool
- Imposed deformations: elimination of totally damaged elements

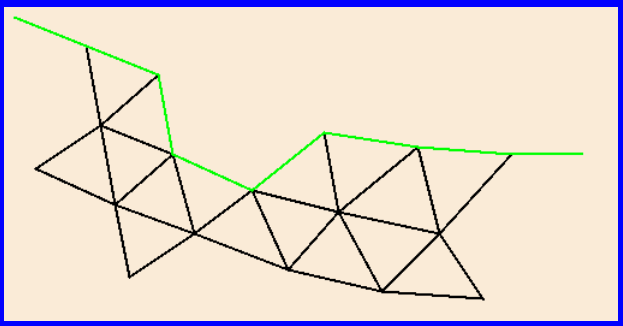
Definition of size maps $H_g(\Gamma)$, $H_{\Phi 1}(\Omega)$, $H_{\Phi 2}(\Omega)$

- $H_g(\Gamma)$:
  - Free node $\Rightarrow$ size proportional to the curvature radius of the piece
  - Bounded node $\Rightarrow$ size proportional to the curvature radius of the neighboring tool
  - Imposed node $\Rightarrow$ size depending of the lengths of the adjacent edges
- $H_{\Phi 1}(\Omega)$: deviation between the computed solution and the exact solution
- $H_{\Phi 2}(\Omega)$: minimal size for the damaged elements

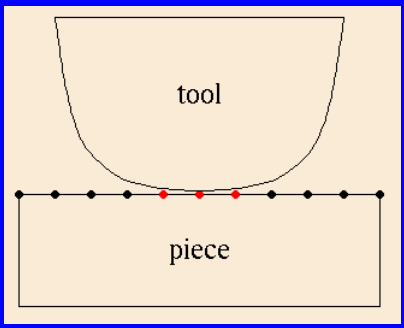
Generation of discretization $T'(\Gamma)$ and mesh $T'(\Omega)$

- Intersection of $H_g(\Gamma)$, $H_{\Phi 1}(\Omega)$, $H_{\Phi 2}(\Omega)$ $\Rightarrow$ unique size map $H(\Omega)$
- Adaptive rediscretization of Γ with respect to $H(\Gamma)$
- Adaptive remeshing of Ω with respect to $H(\Omega)$, using a combined advancing-front – Delaunay approach

Identification of the imposed nodes

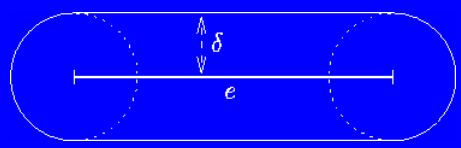


Identification of the bounded nodes

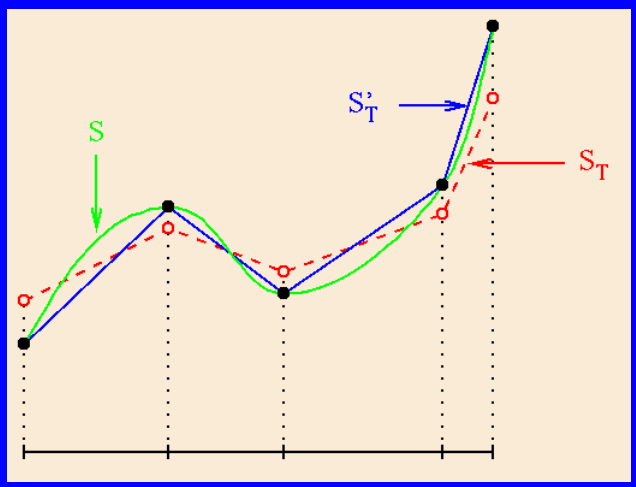


Identification of the bounded nodes

- Hausdorff distance
- $\Re\delta(e) = \{X \in R2,\ d(X,e) \leq \delta\}$



Interpolation error



$$|S-S_T| \leq C\ |S-S'_T|$$

Error based on local deformation

- Taylor at the vicinity of P = $\Phi(0,0)$:

$$\Phi(u,v) = P + \Phi'_u\, u + \Phi'_v\, v + \tfrac{1}{2}(\Phi''_{uu}\, u^2 + 2\,\Phi''_{uv}\, uv + \Phi''_{vv}\, v^2) + o(u^2+v^2)\, e$$

- Deviation from $\Phi(u,v)$ to the tangent plane at P:

$$\tfrac{1}{2}(< v(P), \Phi''_{uu} > u^2 + 2 < v(P), \Phi''_{uv} > u\, v + < v(P), \Phi''_{vv} > v^2) + o(u^2+v^2)$$

- Size associated with a node *w* of $T(\Omega)$:

$$h_{\Phi 1}(w) = \frac{\beta}{\varepsilon(w, S(w))} \qquad \Rightarrow H_{\Phi 1}(\Omega)$$

Error based on damage

The damage is quantified by a real between 0 and

- 1 $\Rightarrow$ full damage $\Rightarrow$ minimum size
- 0 $\Rightarrow$ no damage $\Rightarrow$ maximal size
- intermediate: a linear variation can be used

$\Rightarrow H_{\Phi 2}(\Omega)$

Boundary rediscretization and domain remeshing

- Normalized length of an edge *e* = *AB*:

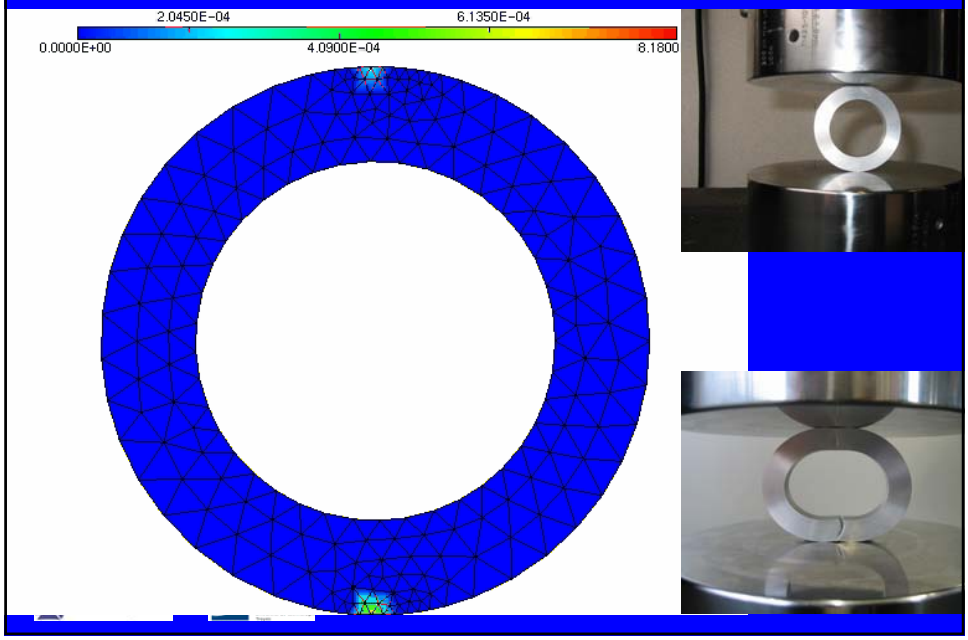
$$l_{H_g}(e) = \left\| \overrightarrow{AB} \right\| \int_0^1 \frac{1}{h(A + t\,\overrightarrow{AB})}\, dt$$

- Each edge will have a normalized length ≈ 1
- Combined advancing-front – Delaunay approach

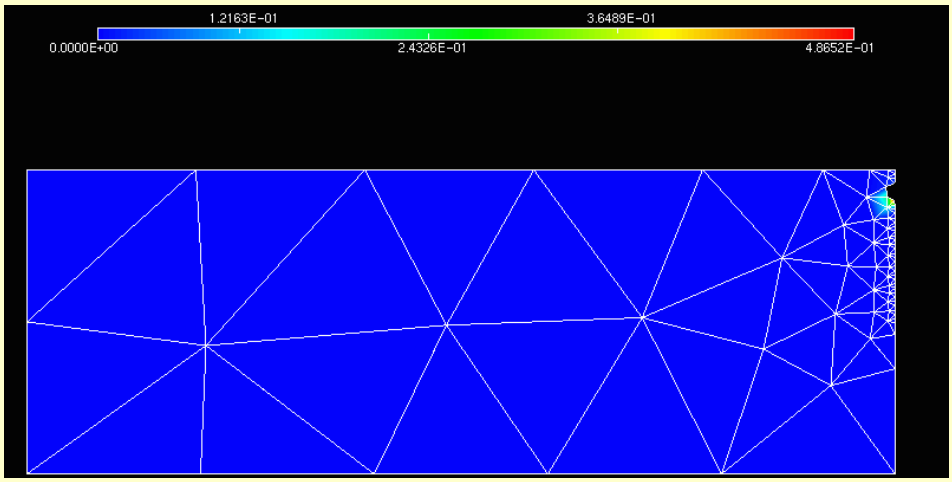
Formulation of the elastoplastic problem with damage

- Equilibrium equations
- Kinematical equations with large transformations
- Relations of elastoplastic behavior with damage
- Initial conditions
- Static and geometric boundary conditions
- Unilateral contact conditions
- Coulomb friction conditions

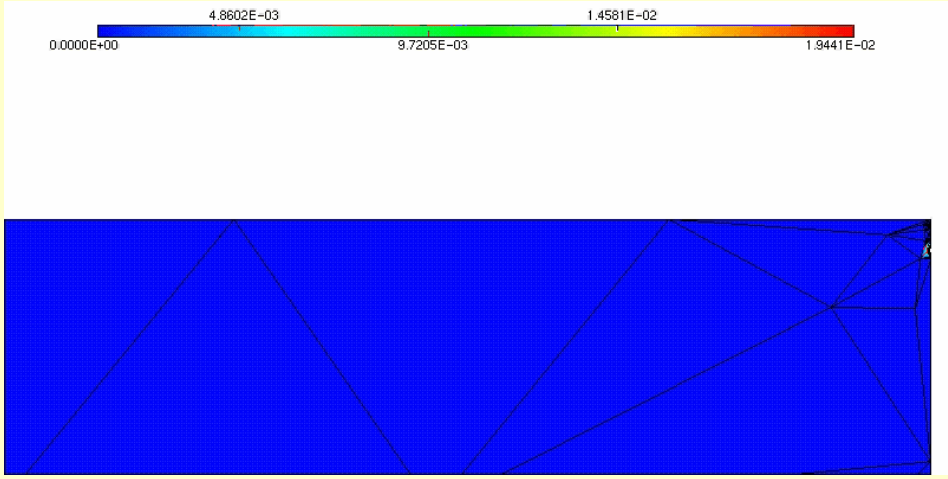
Hollow cylinder (crushing)



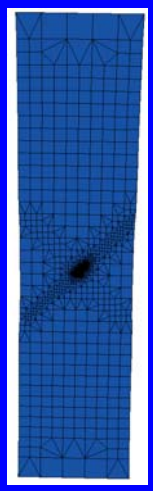
Brittle material (cutting)

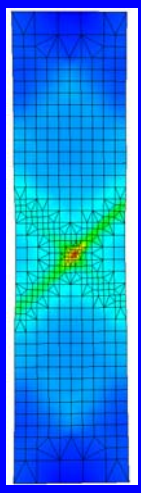


Ductile material (cutting)



Same with quads!





Outline

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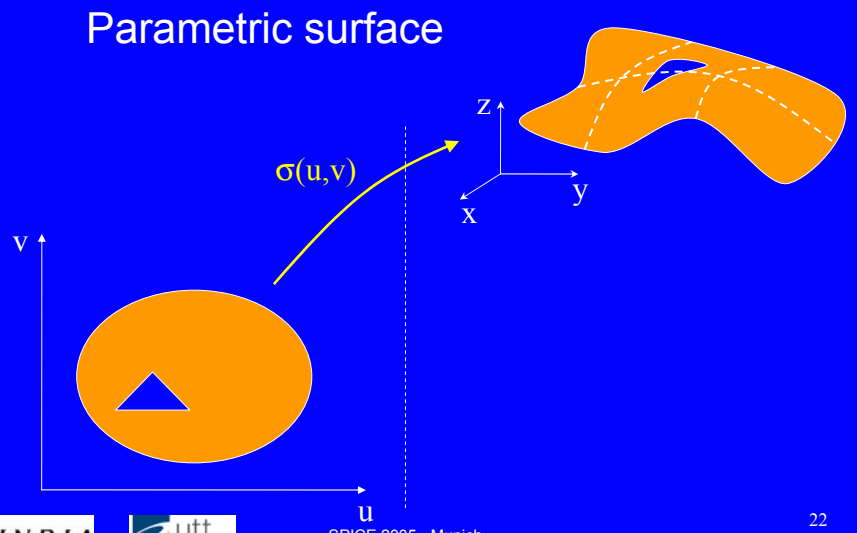
  BL2D + ABAQUS Explicit
- Surface modeling
  BLSURF + "CAD"

Surface modeling

Parametric surface



Surface repair

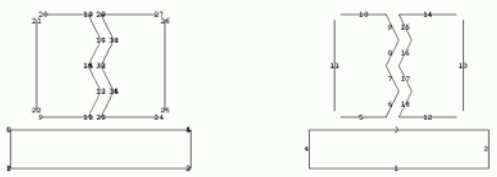


FIG. 1 – Numérotation initiale des points et des courbes.

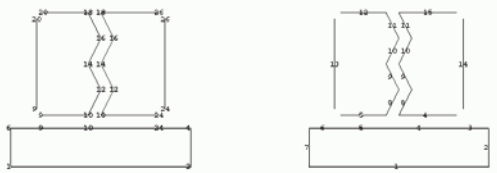
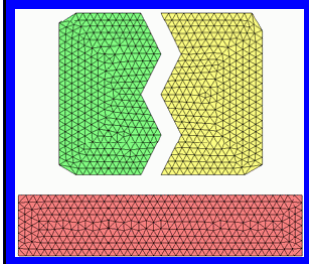
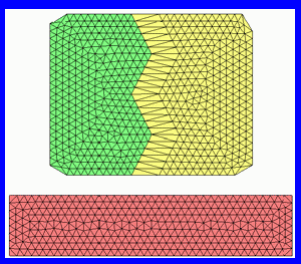
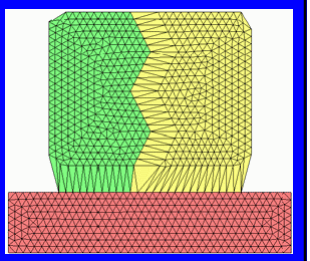


FIG. 2 – Numérotation montrant la topologie de l'assemblage conforme de carreaux.

Surface repair

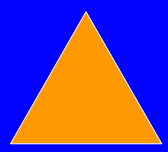






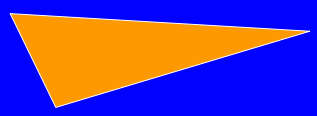
Problem to solve

- Generate a surface mesh as regular as possible



Proposed solution

- Idea: mesh the parametric domain
- Use of metrics



Integration of BLSURF

at LECTRA

in DesignConcept3D (based on TopSolid)

LECTRA company

- World leader in CAD/CAM equipment dedicated to flexible materials
- Products & solutions in: fashion, apparel, retailing, textiles, furniture & furnishings, footwear, luggage & leather goods, automotive, aerospace, marine, industrial fabrics, ….

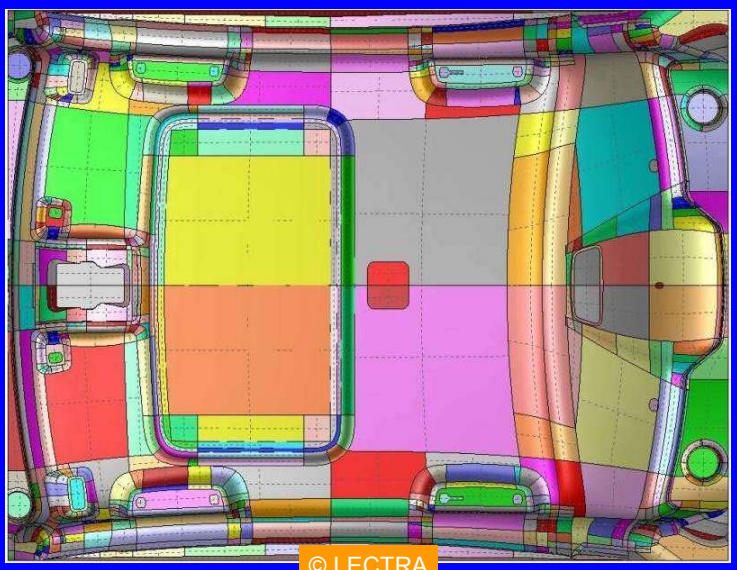
Problem to solve

Draw pattern boundaries (sewing lines) on the 3D model and then automatically flatten into 2D pattern shapes

Problem to solve

Compute pattern strain, stress, pressure, shearing, area, etc.

Problem to solve



Requirements

- Mesh a conforming collection of parametric patches with equilateral triangles
- Associativity
- Element size control
- Mesh respecting curvatures

Interface "CAD" / mesher

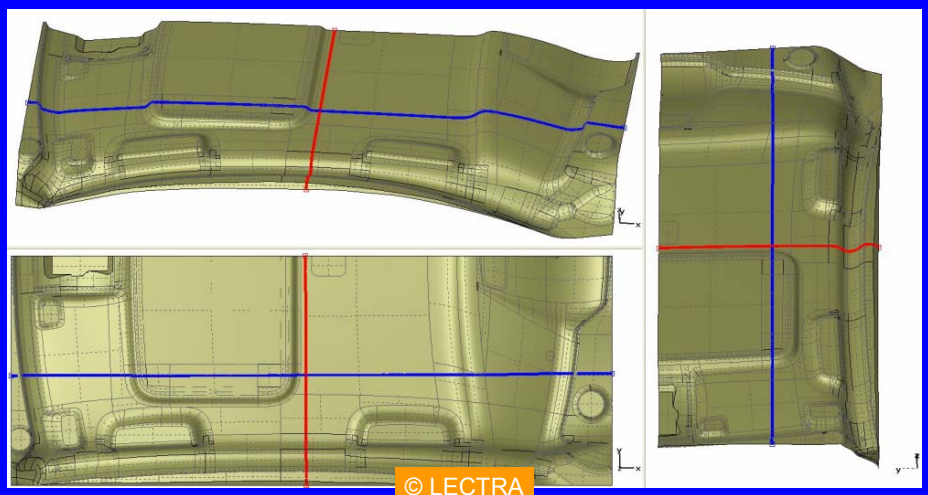
Surfaces

- Surf0(int *refs, double uv[2], double S[3]): position
- Surf1(int *refs, double uv[2], double Su[3], double Sv[3]): first derivatives
- Surf2(int *refs, double uv[2], double Suu[3], double Suv[3], double Svv[3]): second derivatives

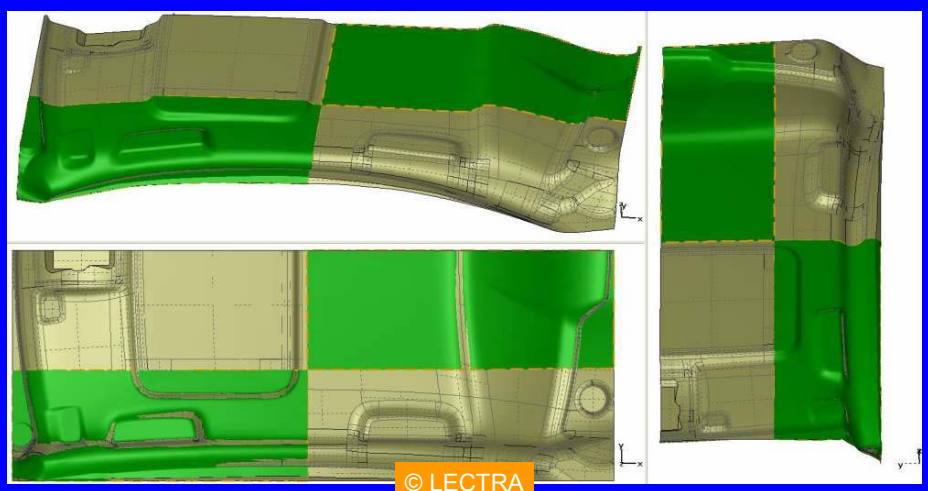
Courbes

- Curv_Int(int *refs, int *ic, double *a, double *b): interval
- Curv0(int *refs, int *ic, double *t, double C[2]): position
- Curv1(int *refs, int *ic, double *t, double Ct[2]): first derivative
- Curv2(int *refs, int *ic, double *t, double Ctt[2]): second derivative

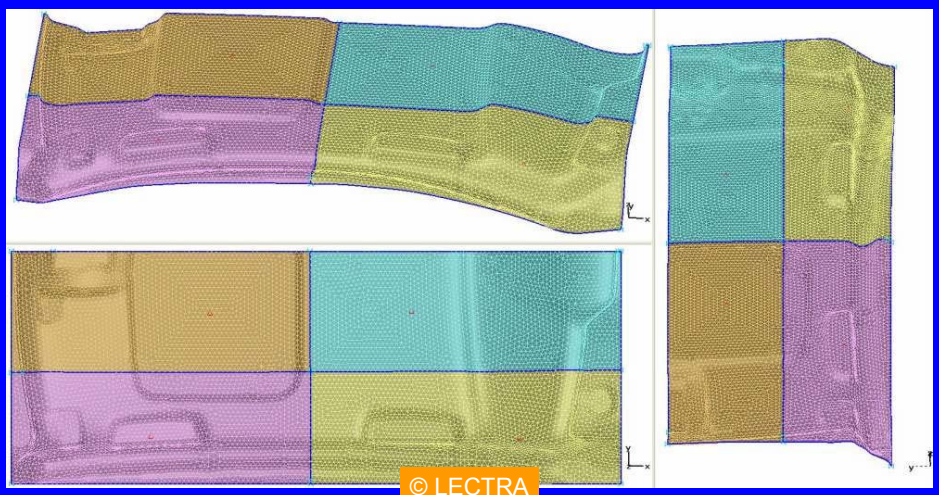
Curve conception



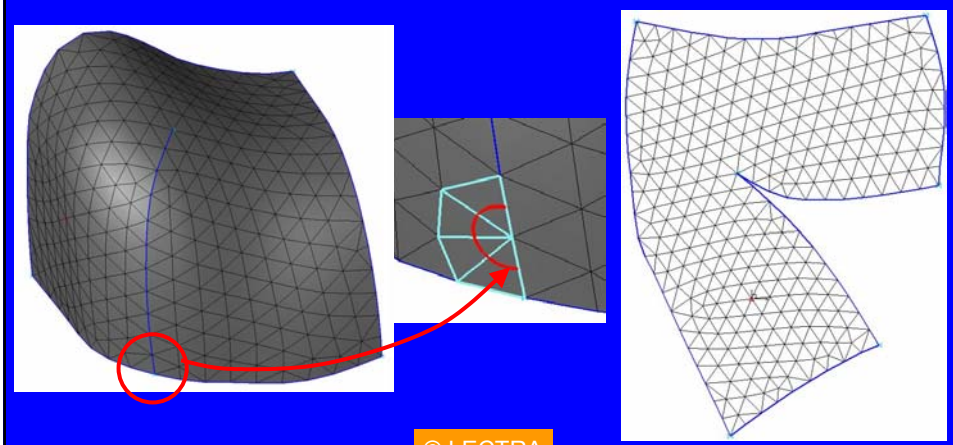
Creation of new patches



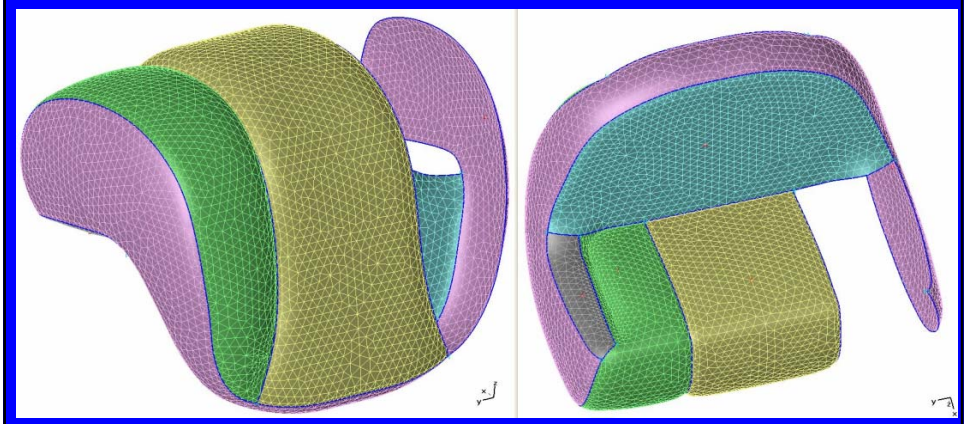
Meshing the patches



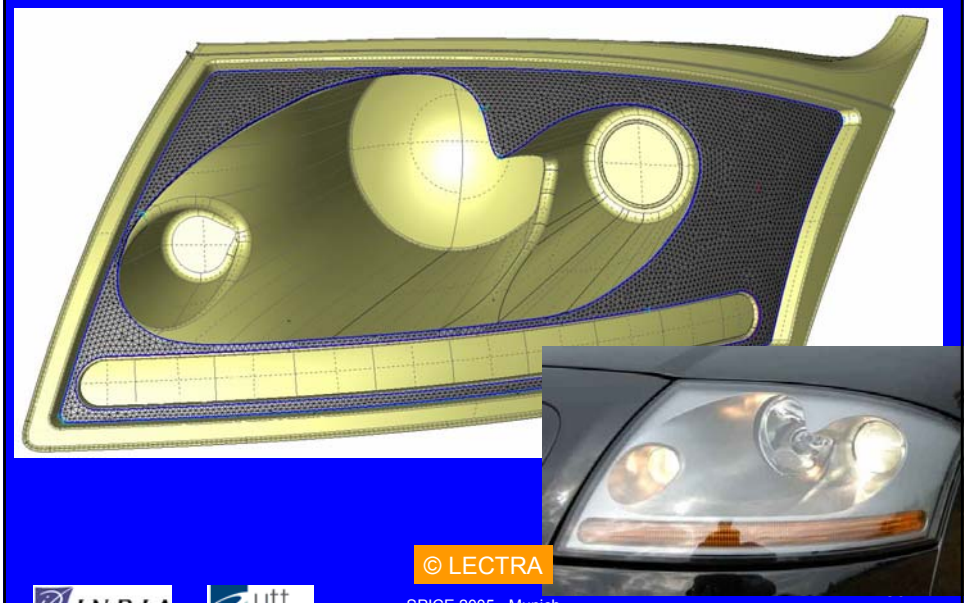
Cutting



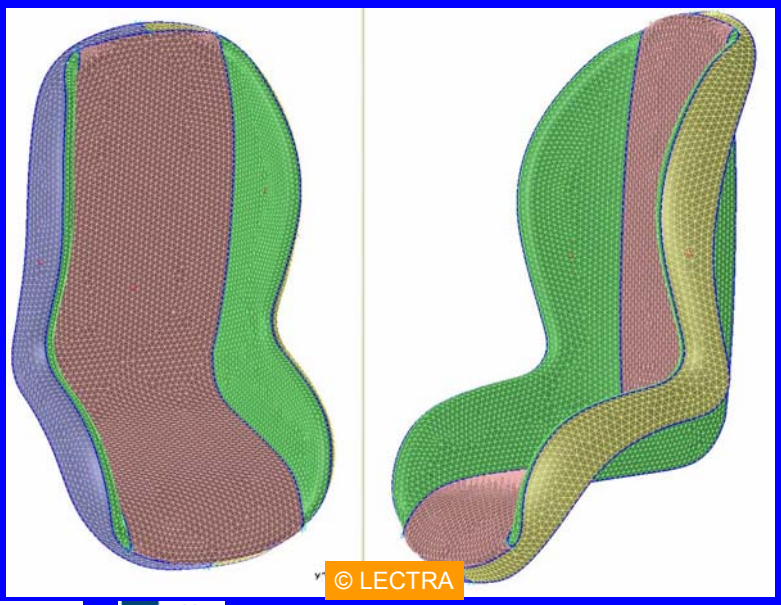
Example 1: head-rest



Example 2: Audi TT headlight



Example 3: baby seat



© LECTRA

Example 4: Peugeot 206 CC seat

© LECTRA

From virtual to real!

Vector MP9 « Mass Production »

Piloté par code barre

Découpe grande vitesse
30% plus rapide que tout autre découpeur

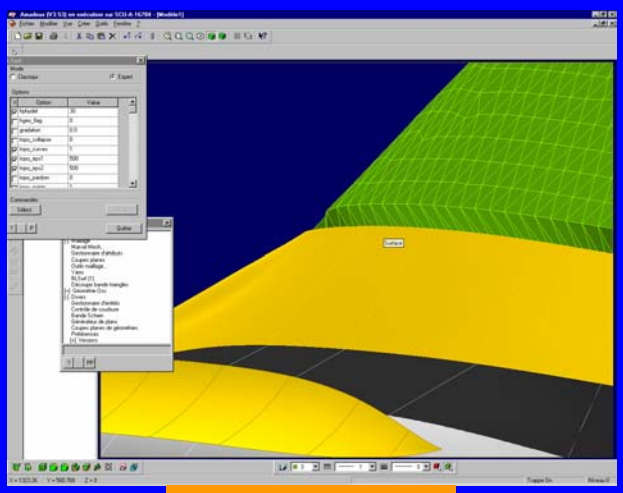
Epaisseur minimum
de 0 à 3 mm

Integration of BLSURF

at DASSAULT AVIATION

in Amadeus

BLSURF / DASSAULT AVIATION



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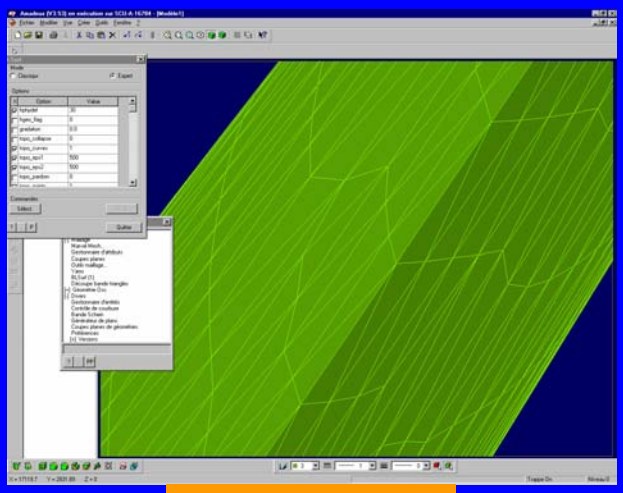

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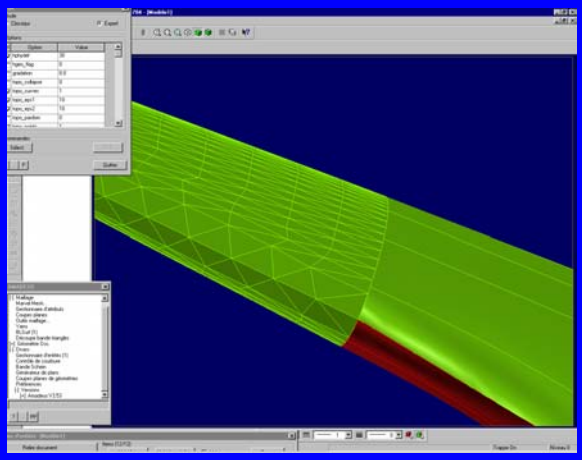

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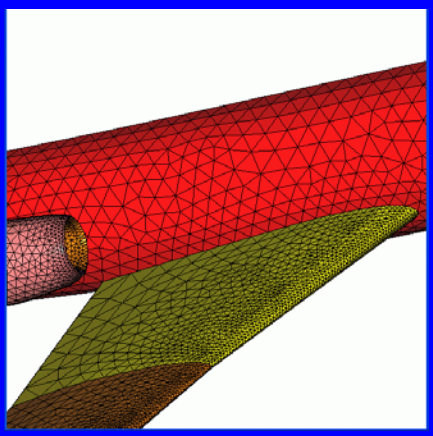

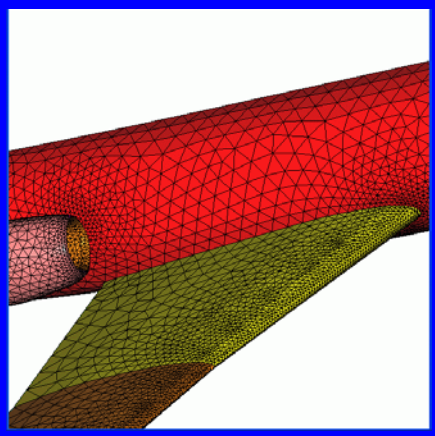

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Quality histogram

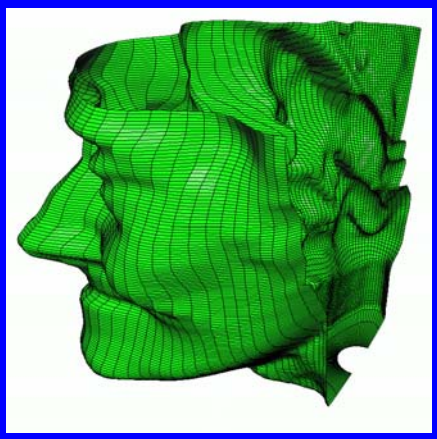
Fuselage of a Falcon business jet

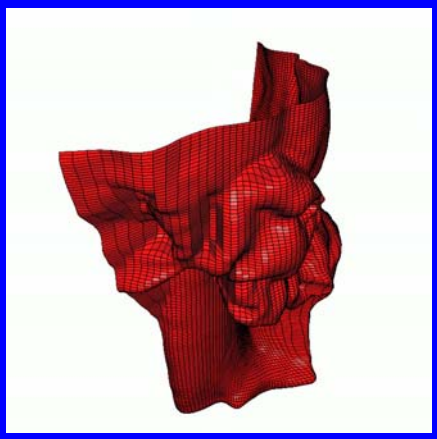
```
---------- P1 MESH QUALITY ----------
      Quality min --> 0.768544
      Quality histogram ...
       0.0 < Q < 0.1 -->          0     0.000
       0.1 < Q < 0.2 -->          0     0.000
       0.2 < Q < 0.3 -->          0     0.000
       0.3 < Q < 0.4 -->          0     0.000
       0.4 < Q < 0.5 -->          0     0.000
       0.5 < Q < 0.6 -->          0     0.000
       0.6 < Q < 0.7 -->          0     0.000
       0.7 < Q < 0.8 -->          1     0.029
       0.8 < Q < 0.9 -->         85     2.472   *
       0.9 < Q < 1.0 -->       3353    97.499
    ************************************************
```


From virtual to real!

Falcon 7X

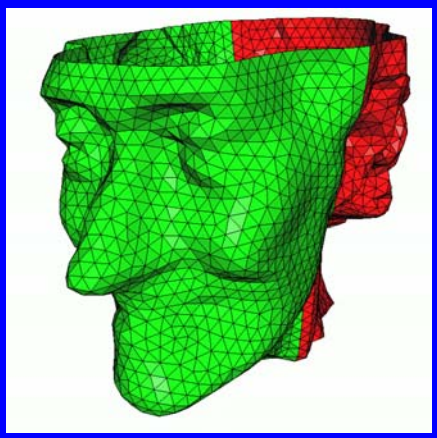
What about quads?

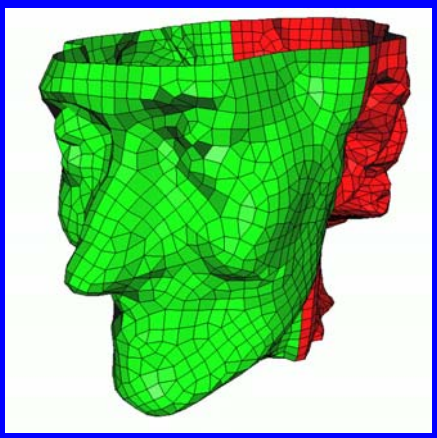




Structured grids (input)

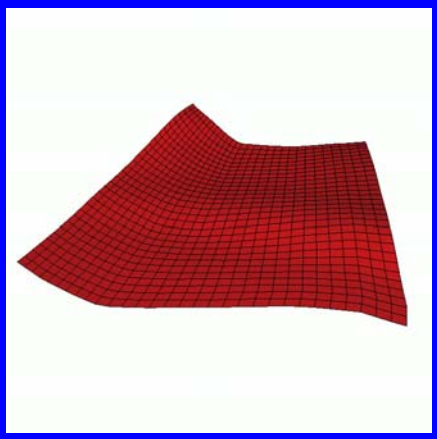
What about quads?

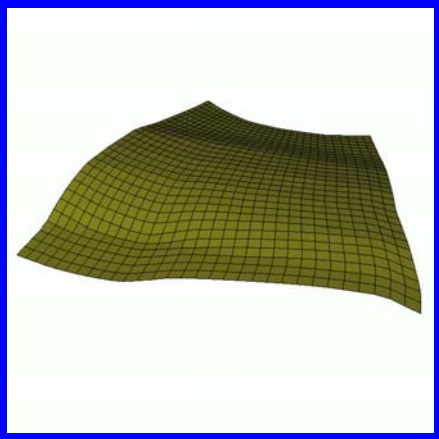




Uniform P^1 and Q^1 meshes

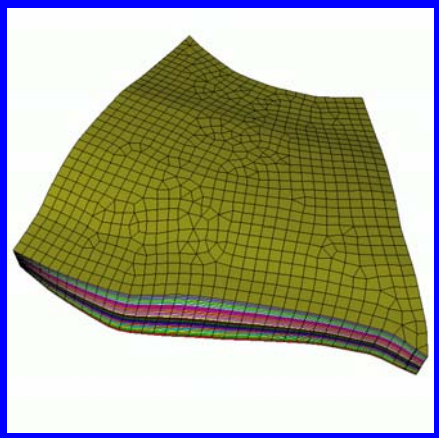
CPG reservoir





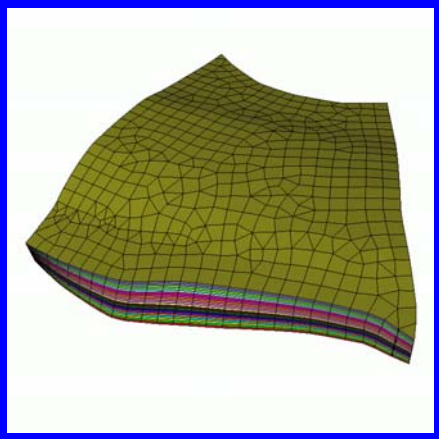
Input: $31 \times 31 \times 21$ vertices

CPG reservoir



Uniform P^1 and Q^1 meshes

CPG reservoir



Uniform (smaller) and geometric meshes

Conclusion

- Tools for automatic mesh generation
- Crack simulation
- Surface modeling
- Elements P^1, P^2, Q^1, Q^2