



# Adaptive Remeshing technique for single point incremental forming simulations using solid-shell elements

J.I.V. Sena<sup>1</sup>, C.F. Guzman<sup>2</sup>, L. Duchêne<sup>2</sup>, A.M. Habraken<sup>2,3</sup>, R.A.F.  
Valente<sup>1</sup>, R. J. Alves de Sousa<sup>1</sup>

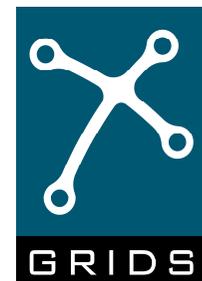
<sup>1</sup>GRIDS Research Group, TEMA Research Unity, Department of  
Mechanical Engineering, University of Aveiro, Portugal.

<sup>2</sup>Department ArGEnCo, division MS2F, Université de Liège, Belgium.

<sup>3</sup>Research Director of the Fonds de la Recherche Scientifique-FNRS



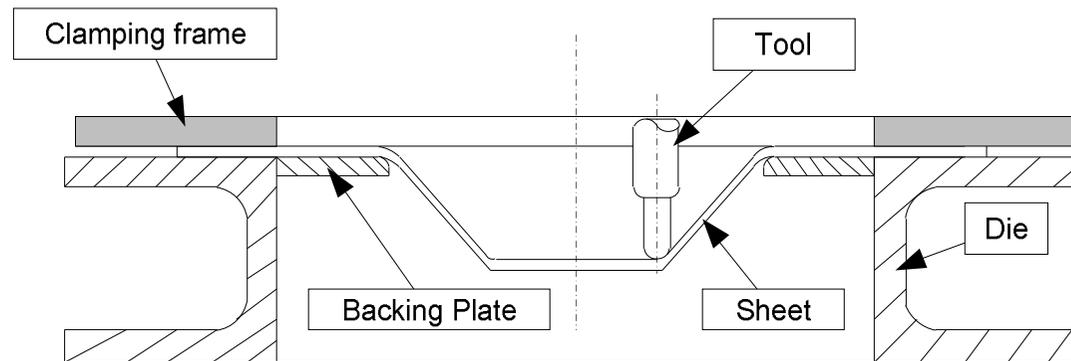
September 11th, 2013



# Contents

1. Introduction
2. SPIF Numerical simulation
3. Adaptive Remeshing
4. Benchmark example
  - 4.1. Solid-Shell Element: RESS (Reduced Enhanced Solid-Shell)
5. Final Considerations

- Single point incremental forming (SPIF) is a sheet metal forming process that is appropriate for rapid prototyping.
- In SPIF, the lower surface of the metal sheet doesn't require any dedicated dies or punches to form a complex shape.



- The tool is guided by numerical control system, which defines the trajectory where the forming tool follows and progressively deforms a clamped sheet into its desired shape
- The zone where high deformations occur is always close to the current location of the tool.

➤ PROBLEM:

- The constantly changing contact between the tool and the metal sheet during the process.
- The nonlinearities involved causes a huge computational time.

➤ In LAGAMINE was developed the Adaptive Remeshing available only for Shell finite elements\*.

➤ The Adaptive Remeshing Technique was extended to use with 8 nodes solid element.

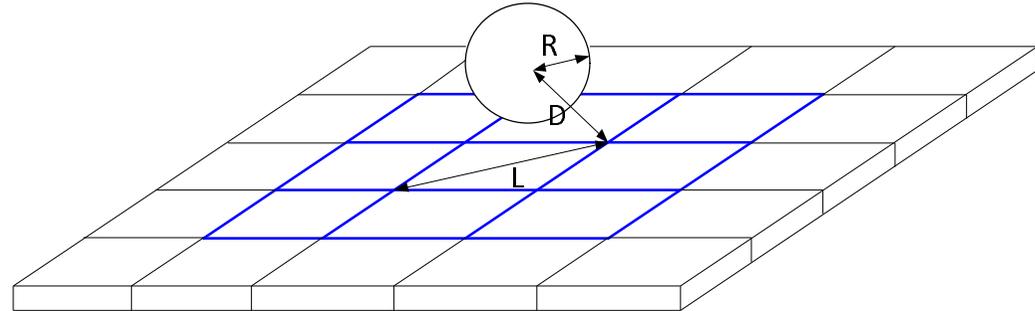
➤ Objective:

- Use a 3D constitutive law
- Prediction of the sheet thickness
- Avoid the initial refined mesh with 8 nodes finite element

\*see Cedric Lequesne *et al.*, Numisheet 2008, Switzerland, September 1 - 5, 2008.

## Remeshing Criterion

- Selection of a neighborhood around the position of the tool center



- Proximity condition :

$$D^2 \leq \alpha (L^2 + R^2)$$

- D: minimum distance between the tool center and the four nodes of the contact element
- L: length of the longest diagonal of the element
- R: radius of the tool
- $\alpha$ : coefficient adjusting the size of the neighborhood chosen by the user

## Derefinement Criterion

- Computation of the initial relative position:

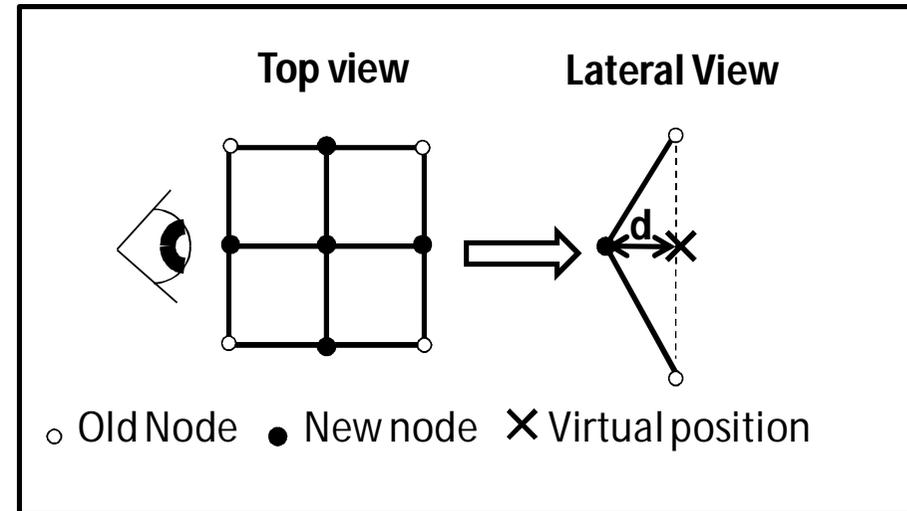
$$\underline{\mathbf{X}}_v = \sum_{i=1,4} H_i(\xi, \eta) \underline{\mathbf{X}}_i$$

- Computation of the distance

$$d = \left| \underline{\mathbf{X}}_c - \underline{\mathbf{X}}_v \right|$$

- Criterion of reaction of coarse element

$$d \leq d_{\max}$$



- $H_i$ : interpolation function
- $x, h$ : initial relative positions of the node in the coarse element
- $X_i$ : nodes positions of the coarse element
- $X_c$ : Current position of the node
- $d_{\max}$ : maximal admissible distance chosen by the user

## Interpolation of state variables and stress

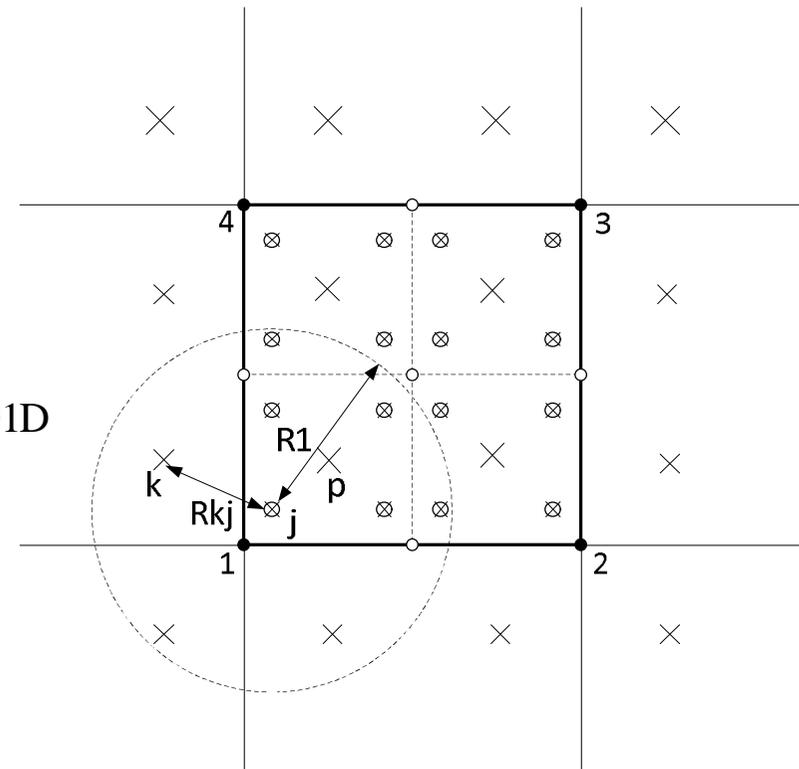
$$Z_j = \begin{cases} \frac{\sum_k \frac{Z_k}{R_{kJ}^n} + \frac{CZ_p}{R_{pj}^n}}{\sum_k \frac{1}{R_{kJ}^n} + \frac{C}{R_{pj}^n}} & \text{if } R_{pj} > R_{\min} \\ Z_p & \text{if } R_{pj} \leq R_{\min} \end{cases}$$

With :

$$R_1 = 1.5d$$

$$R_{\min} = 0.0001D$$

- j: is the index of the new integration point
- k: is the index of the integration point of another element
- p: is the index of the closest integration point
- Zi: can be the stress or variables of state components at the integration point j
- Rkj: distance between the integration point k and j

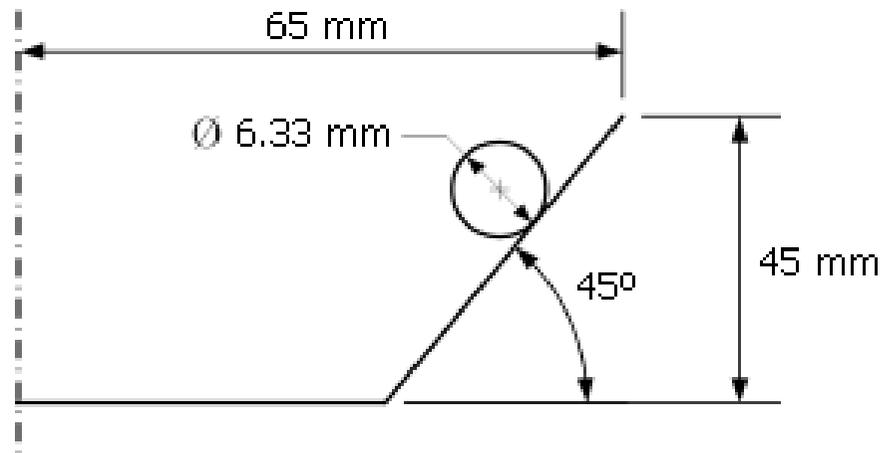


- New node
  - ⊗ New integration point
  - Old node
  - × Old integration point
- C: coefficient defined by the user
  - n: degree of interpolation
  - d: highest diagonal of the element
  - D: highest diagonal of the structure



## Conical shape simulation

- Benchmark proposal from NUMISHEET 2014 conference:



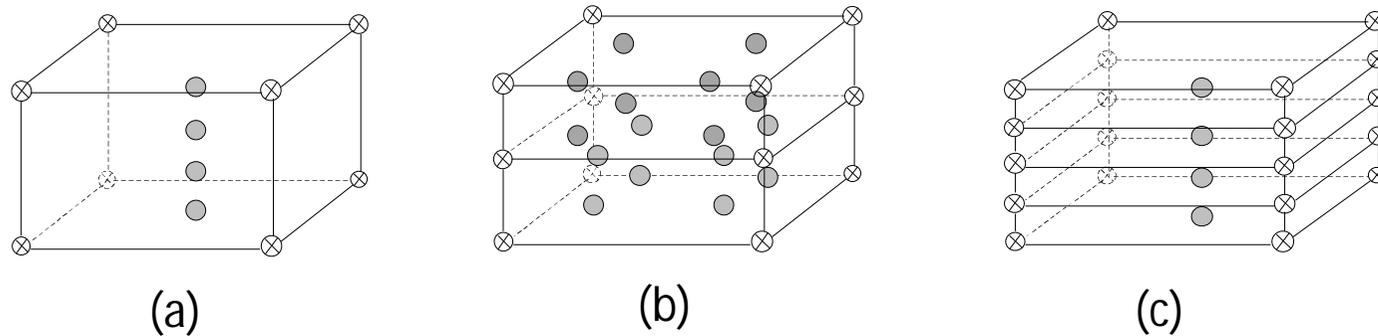
- Setup description:
  - Material : Aluminium alloy AA7075-O
  - thickness: 1.6 mm
  - spherical tool radius: 6.33 mm
  - Vertical step-down of 0.5 mm (90 contours)

## Material

- Material : An aluminium alloy AA7075-O
- The constitutive law: Hill (Isotropic behaviour law)
- Parameters:
  - Young modulus:  $E_1 = E_2 = E_3 = 72000$  MPa
  - Poisson ratio:  $\nu_1 = \nu_2 = \nu_3 = 0.33$
  - Coulomb modulus:  $G_1 = G_2 = G_3 = 27067.669$  MPa
- Hardening Swift law:  $\sigma_{eq} = K (\epsilon_0 + \epsilon_{pl})^n$  with  $K = 335.1$ ,  
 $\epsilon_0 = 0.004$ ,  
 $n = 0.157$

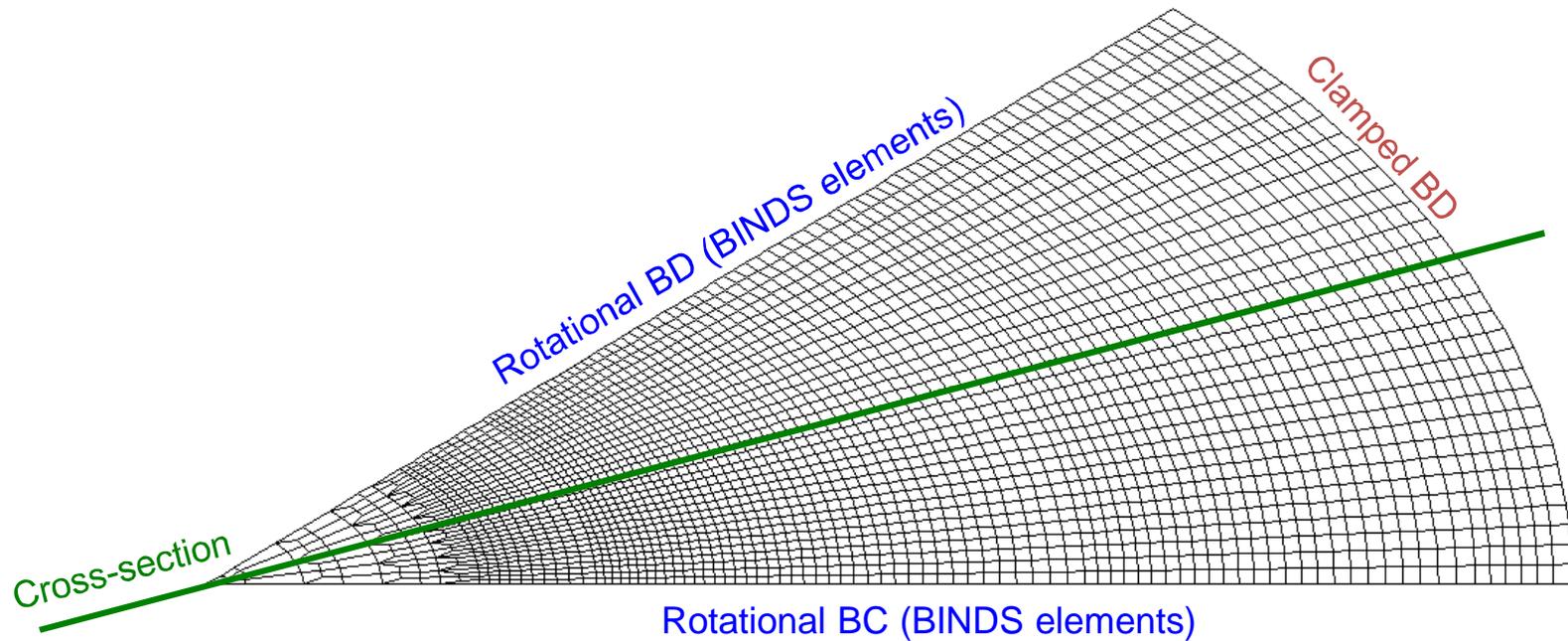
## RESS (Reduced Enhanced Solid Shell)\*

- Solid-Shell Element specially design to use in metal forming applications
- Implemented in LAGAMINE code
- Integration scheme (a) advantages:
  - Reduced integration in plane
  - Arbitrary number of integration points in one single layer in thickness direction
- Combination between displacement strain and enhanced strain components interpolated by enhanced matrix with only enhanced mode
- Stabilization technique



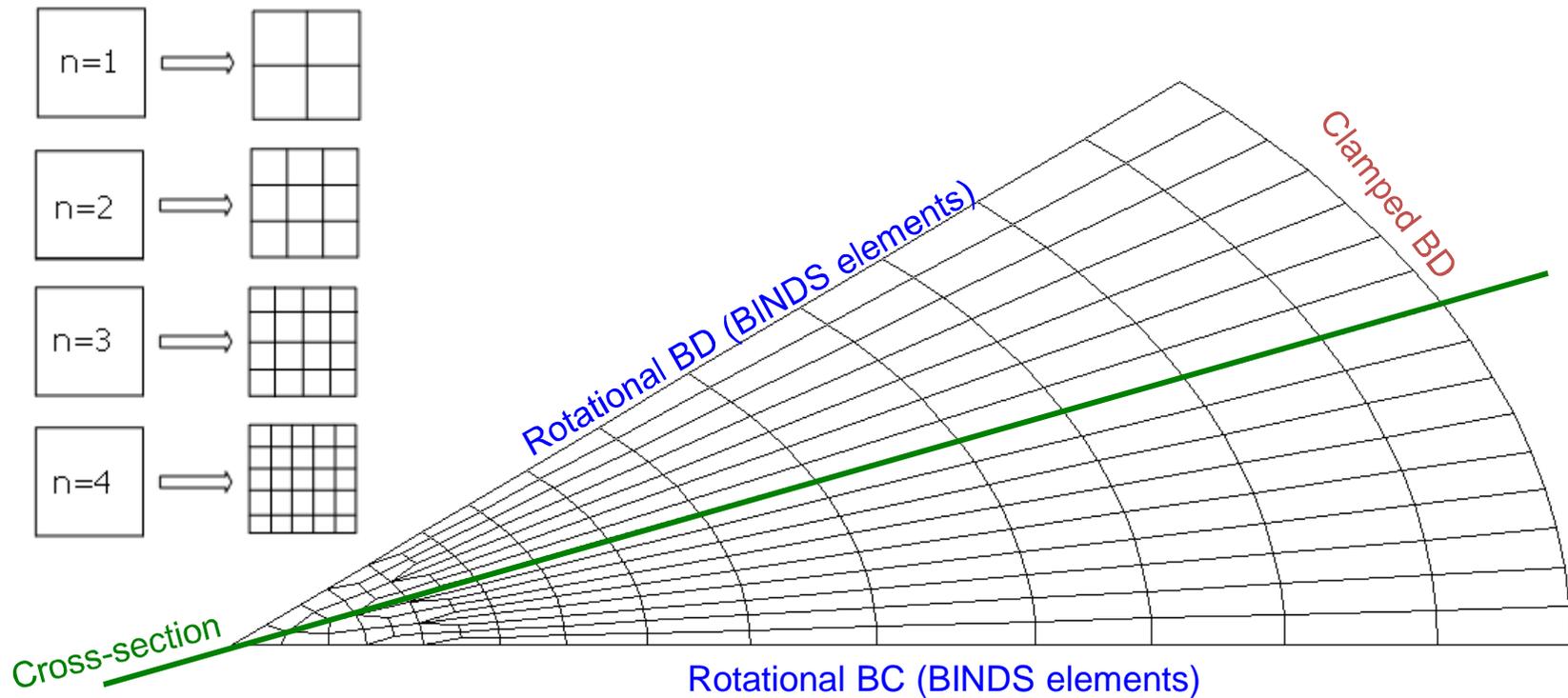
\*See in Alves de Sousa R.J. *et al.* (2007), I. J. P., Vol. 23, pp. 490-515.

## Meshes



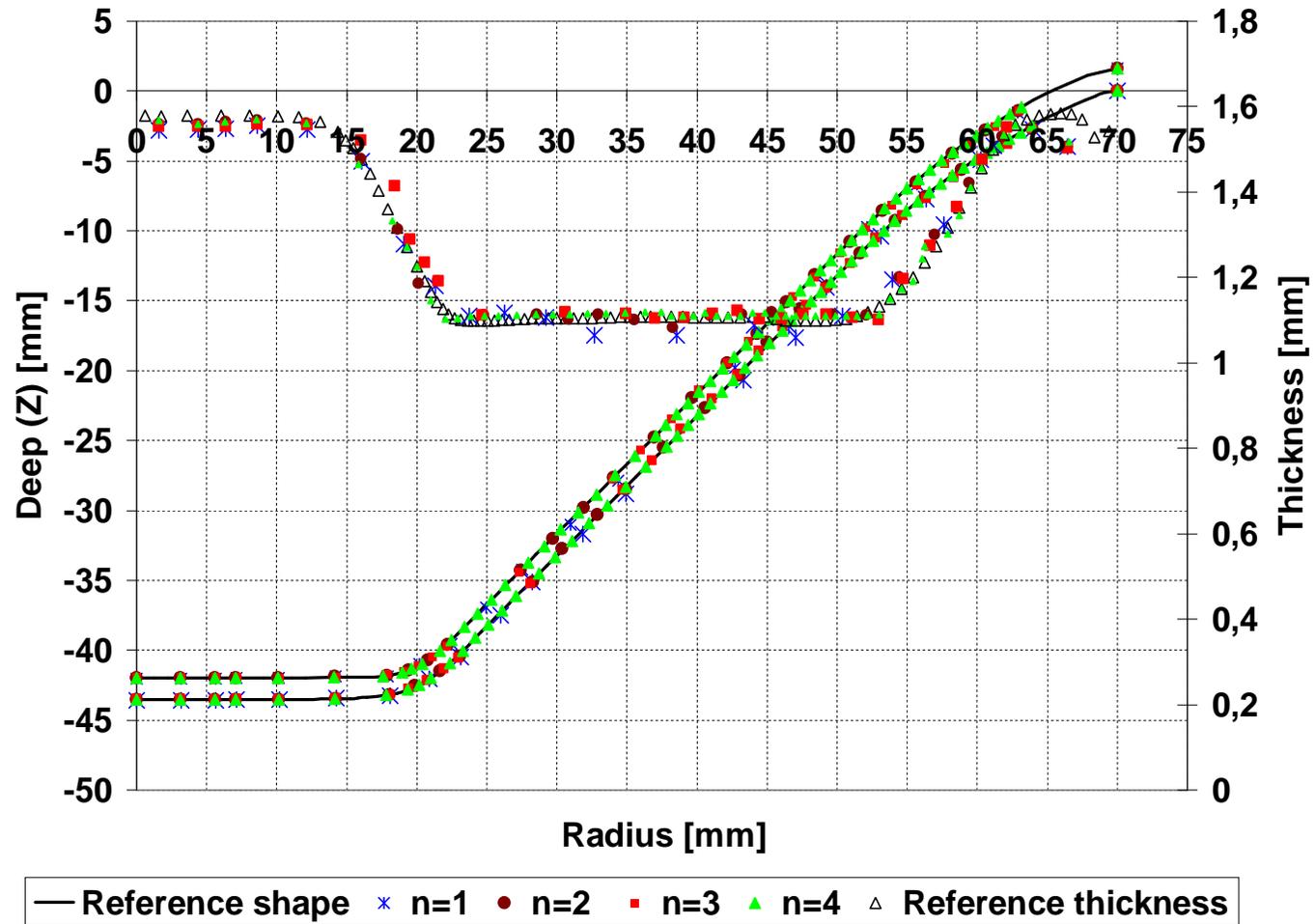
- Reference mesh without remeshing 5828 elements (RESS+CFI3D)
- One element in thickness direction
- 3 types of Elements :
  - 8 node solid-shell finite element RESS with 5GP
  - Contact element CFI3D with 4GP
  - Symmetric and rotational boundary conditions (BINDS elements)

## Meshes (continuation)

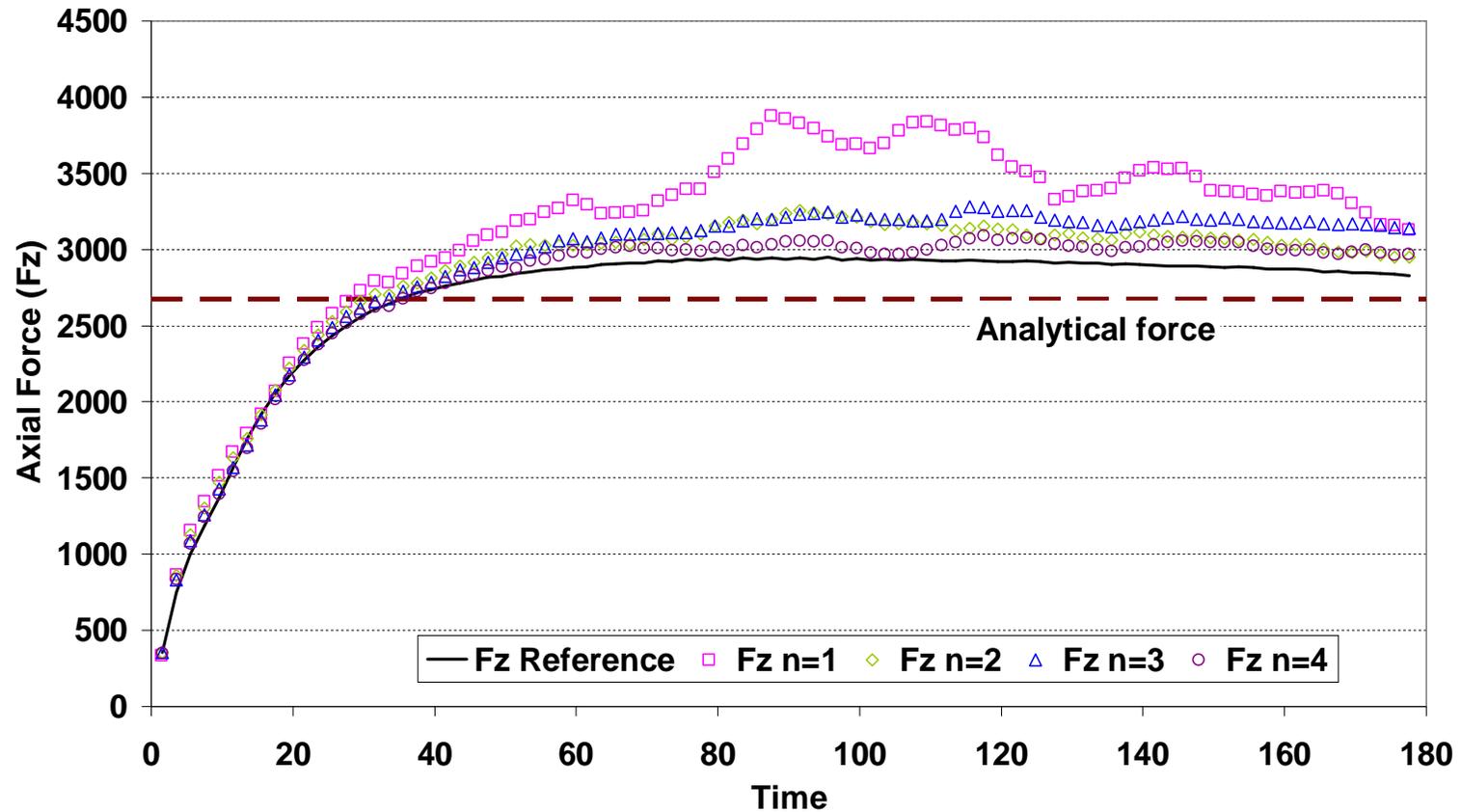


- Coarse mesh with adaptive remeshing, 410 elements (RESS+CFI3D)
- One element in thickness direction
- 3 types of Elements :
  - 8 node solid-shell finite element RESS with 5GP
  - Contact element CFI3D with 4GP
  - Binds elements

## Shape and thickness in a cross-section



## Evolution of force prediction



- Adaptive remeshing influence in the axial force prediction at different levels of refinement

## Comparisons between time performance

- Comparison between different level of refinement:

<b>N° of nodes per edge (n)</b>	<b>CPU time</b>	<b>Ratio</b>	<b>N° of Steps</b>	<b>N° of iterations</b>	<b>Initial n° of elements</b>	<b>Final n° of elements</b>
1	59m:46s	0.06	2072	9509	410	1106
2	2h:32m:25s	0.16	2290	9689	410	2228
3	7h:4m:43s	0.45	2296	9606	410	3610
4	9h:35m:55s	0.61	2297	9642	410	5860
Reference	15h:39m:1s	1	5263	22443	5828	5828

- The major interest of the present work is the 3D analysis of single point incremental forming process.
- The current work in progress is the application of adaptive remeshing using RESS finite element in an efficient and accurate simulation framework of SPIF processes for general 3D analysis.
- Avoid the memory leaks due to the dynamic allocation and deallocation of variables.



First International Workshop on the Finite  
Element Code LAGAMINE

LAGASHOP 2013



Thank you for your  
attention

