IMPLEMENTATION OF THE ARBITARY LAGRANGIAN EULERIAN METHOD IN SOFT BODY PROJECTILE IMPACTS AGAINST COMPOSITE PLATES

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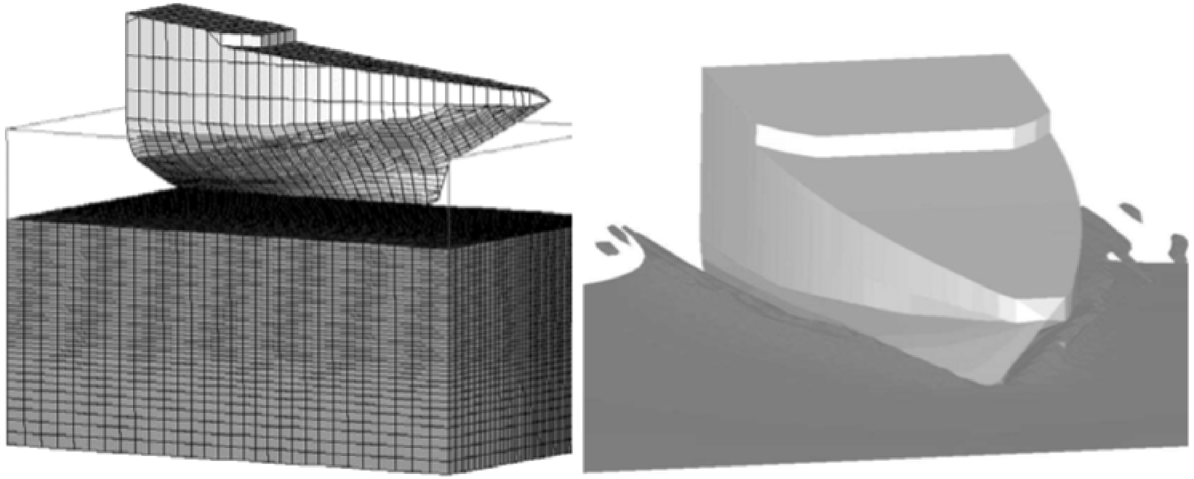
1. PROBLEMATIC

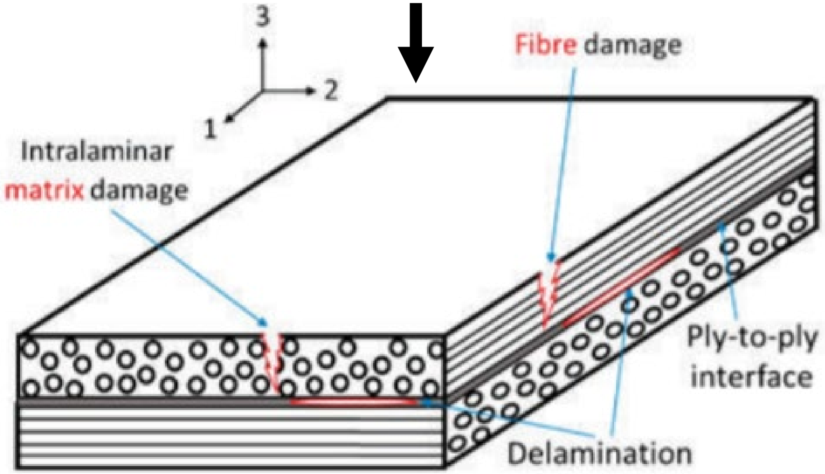
The project SUCCESS was born in France as a partnership between ICAM Engineering School, private companies and the French government, oriented to study the behavior of **composite structures** submitted to **UNDEX** and **other instantaneous loads**.

From: LS-DYNA Applications in Ship Building, Hervé Le Sourne et al



2. PROJECT CHALLENGES

One of the main challenges of the project is **<u>to include adequately the intra-laminar and inter-laminar damage mechanisms during these events</u>**, which is far more complex to the ones suffered by metallic materials.



From: Predicting the compression after impact strenght of composite laminates, Liu H et al

3. OBJECTIVES OF THE MASTER THESIS:

- To study numerically the impact of a **soft body impactor** against a **rigid plate**.

- To develop a numerical model based on an **Arbitrary Lagrangian Eulerian** approach for simulating Soft Body Impacts for rigid and elastoplastic plates.

- To extend the previous numerical model for studying the **intra-laminar damage** after impact on Fiber Reinforced Polymer plates.

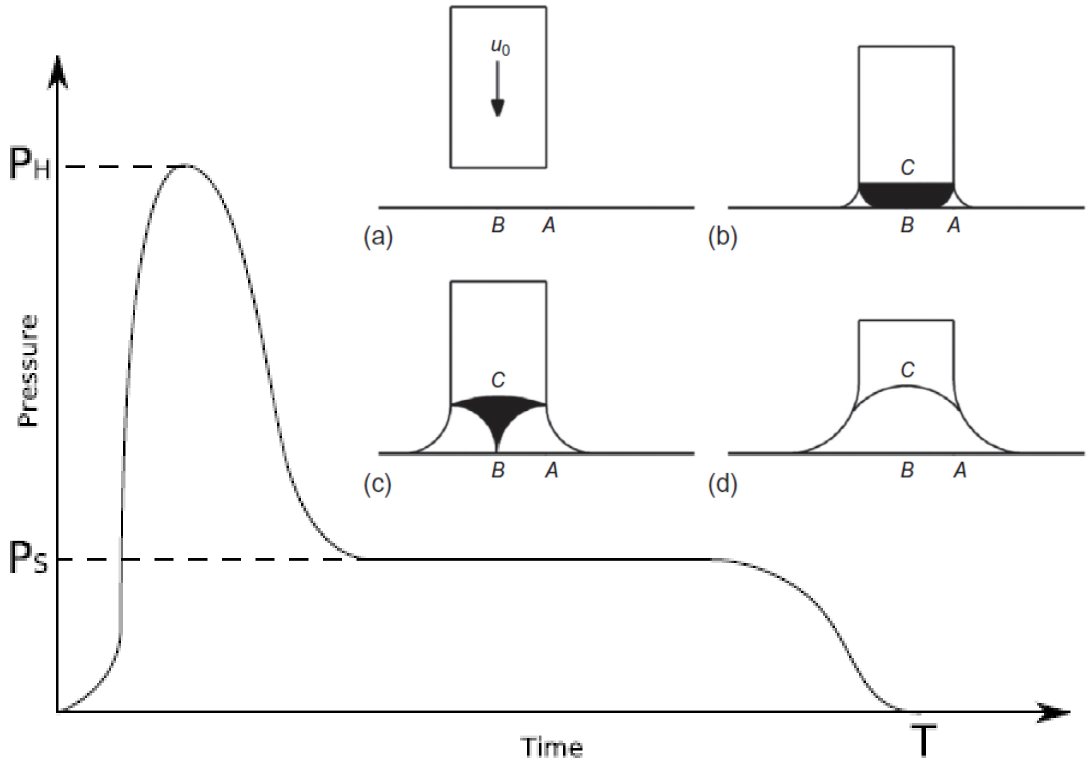
- To simulate numerically the gel-structure impact tests performed at Clement Ader institute, **contributing to prepare both pre and post experimental phases.**

4. SB IMPACT PHYSICS

1st Phase: Pressure Peak (Hugoniot)

- Material density.
- Impact velocity.
- Initial contact area.
- Non linear behavior.

- **2nd Phase: pressure stabilization (Stagnation).**
  - Material density.
  - Impact velocity.



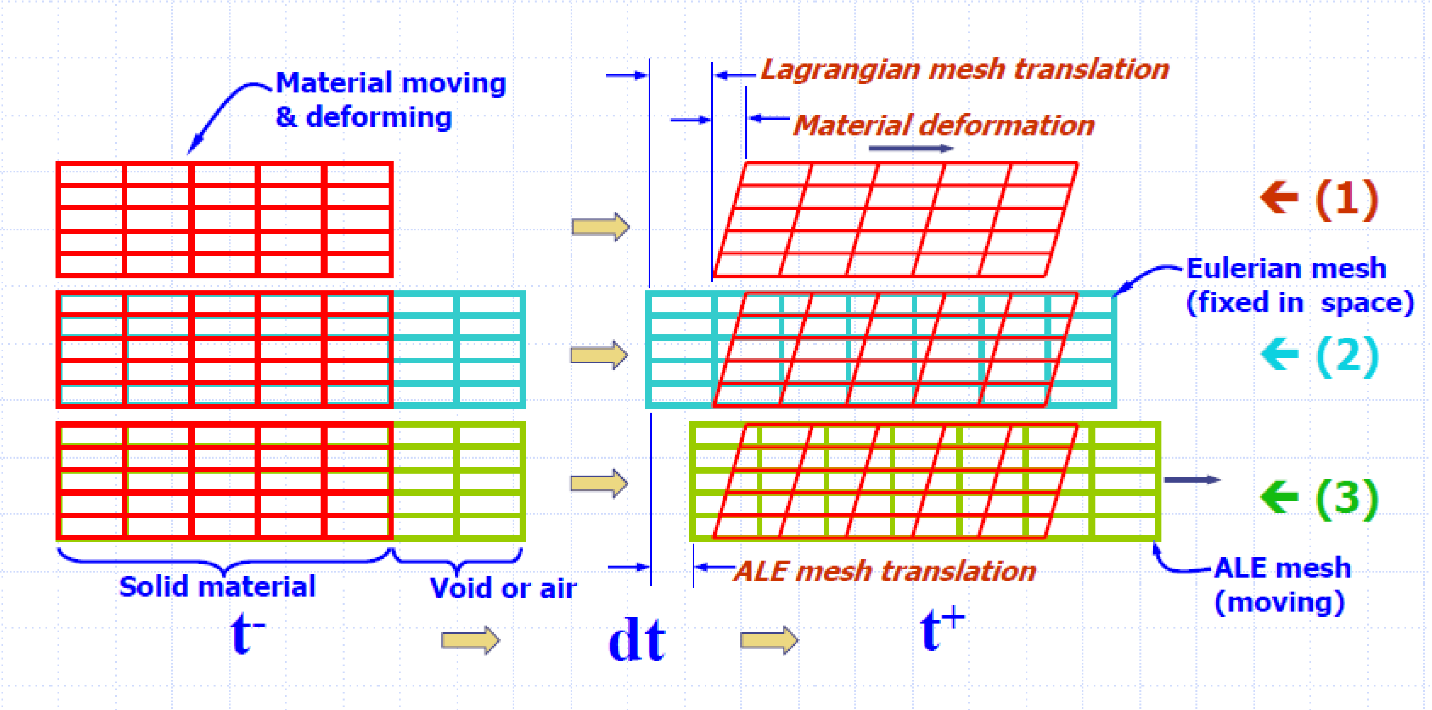
From: Aeroengine Fan Blade Design Accounting for Bird Strike. A. Blair

5. ARBITRARY LAGRANGIAN METHOD

1. Perform a Lagrangian time step.

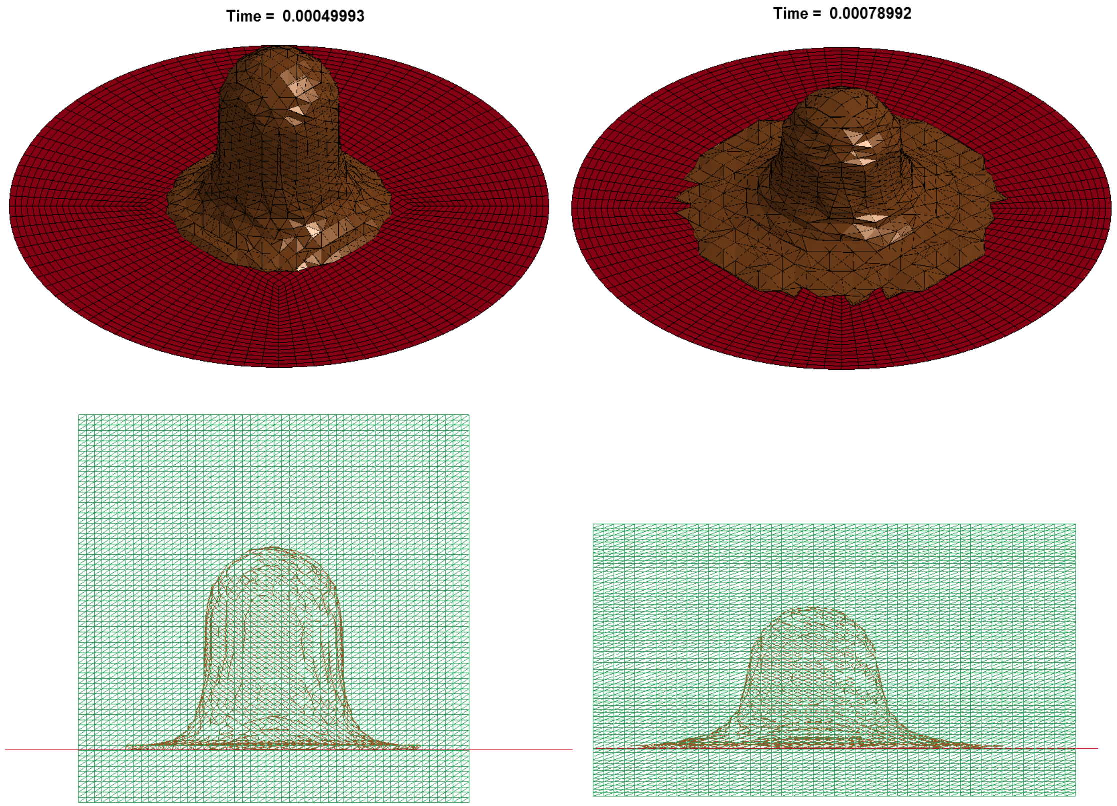
2. Perform an advection step .

a. Decide which nodes to move.
b. Move the boundary nodes.
c. Move the interior nodes.
d. Calculate the transport of the element centered variables.
e. Calculate the momentum transport and update the velocity

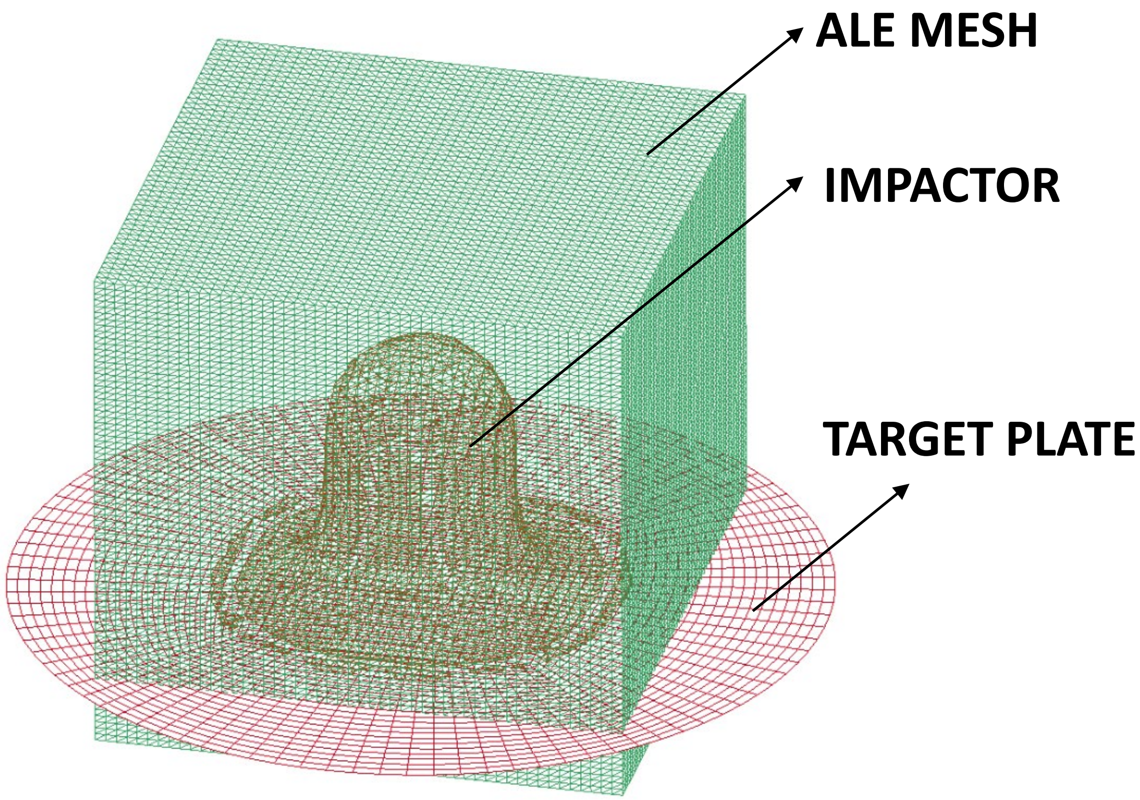


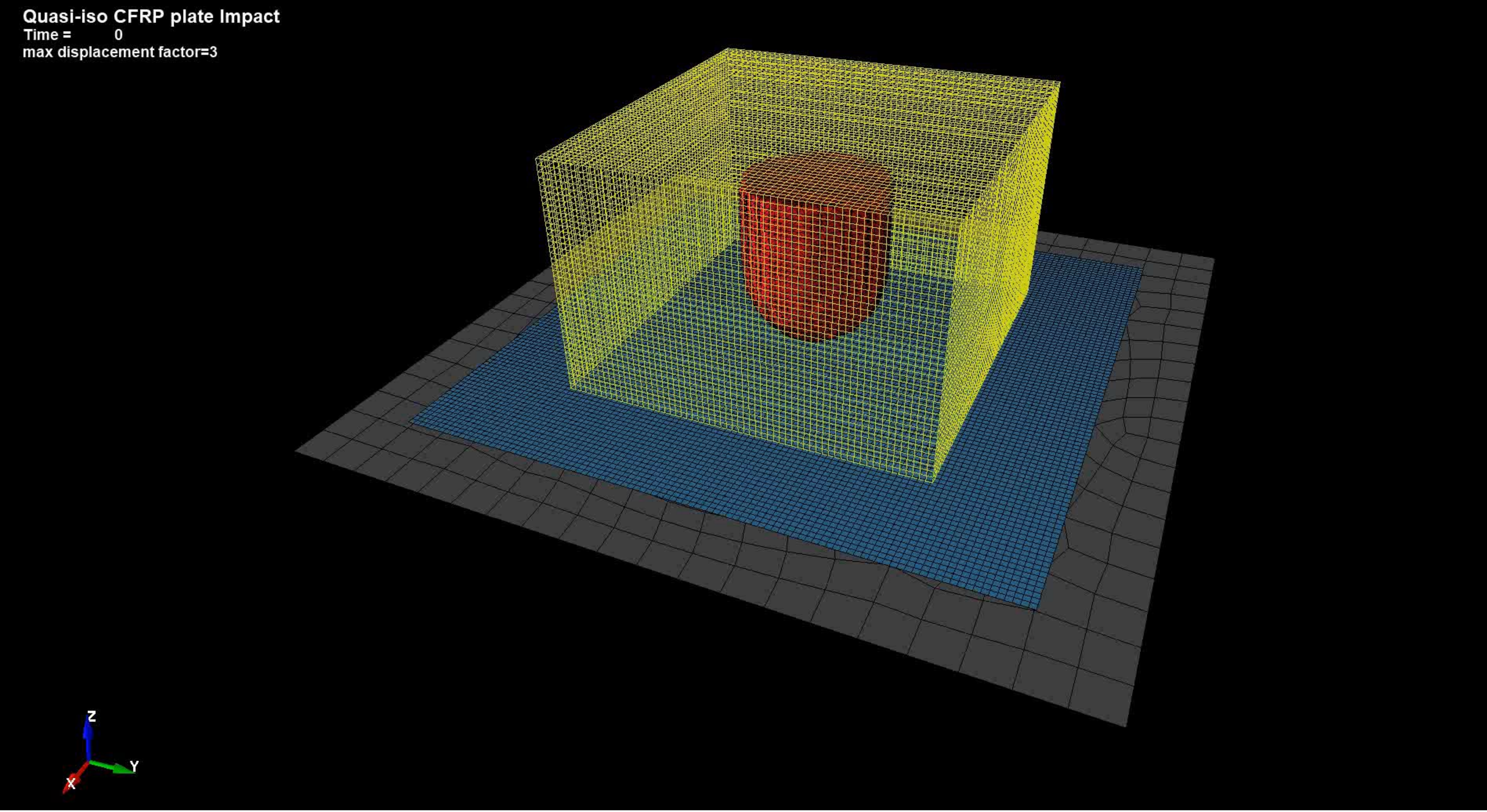
From: Overview of ALE method in LS-DYNA. Ian Do.

5. ALE SOFT BODY IMPACTOR MODEL



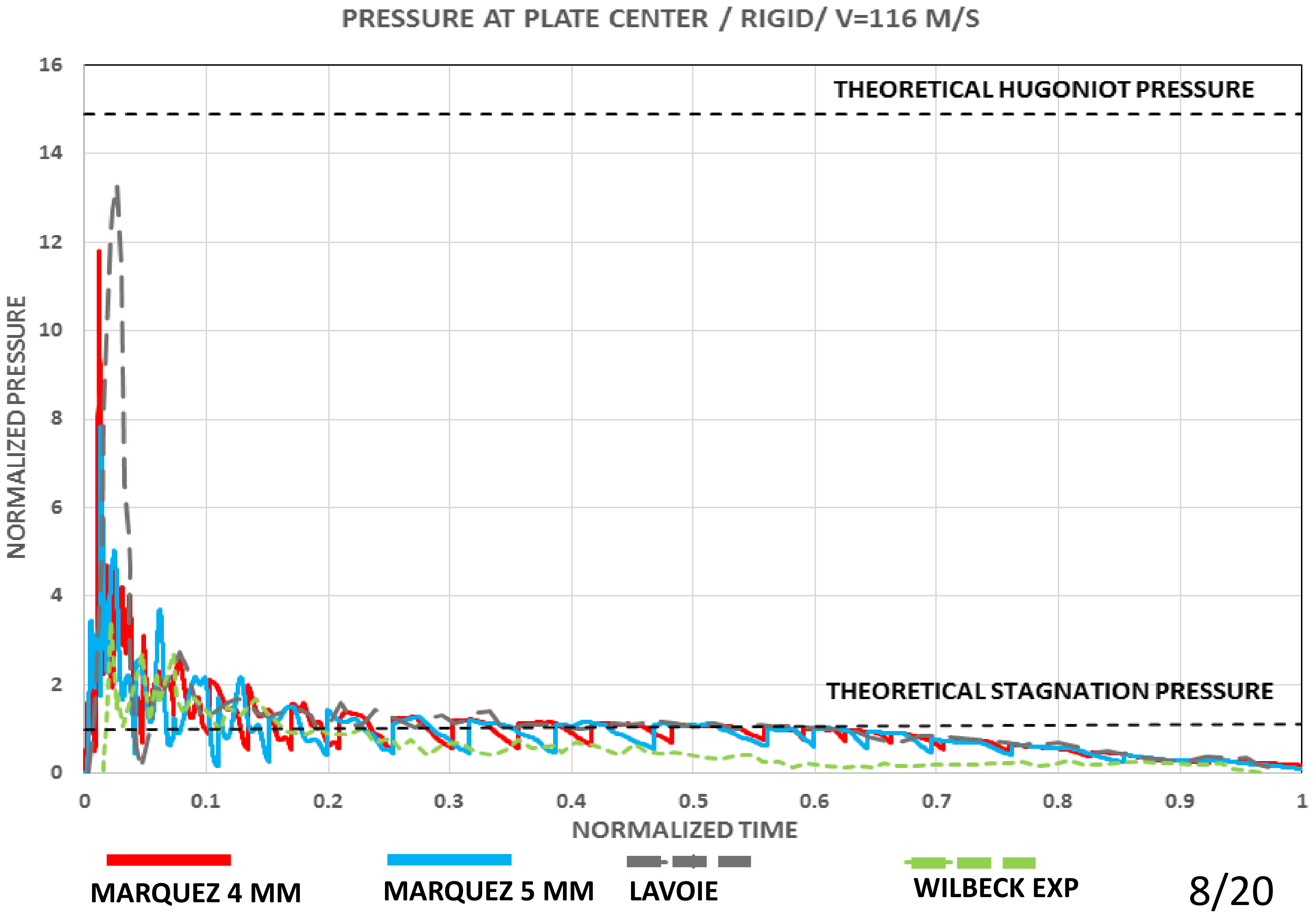
T=0.49 ms T=0.78 ms



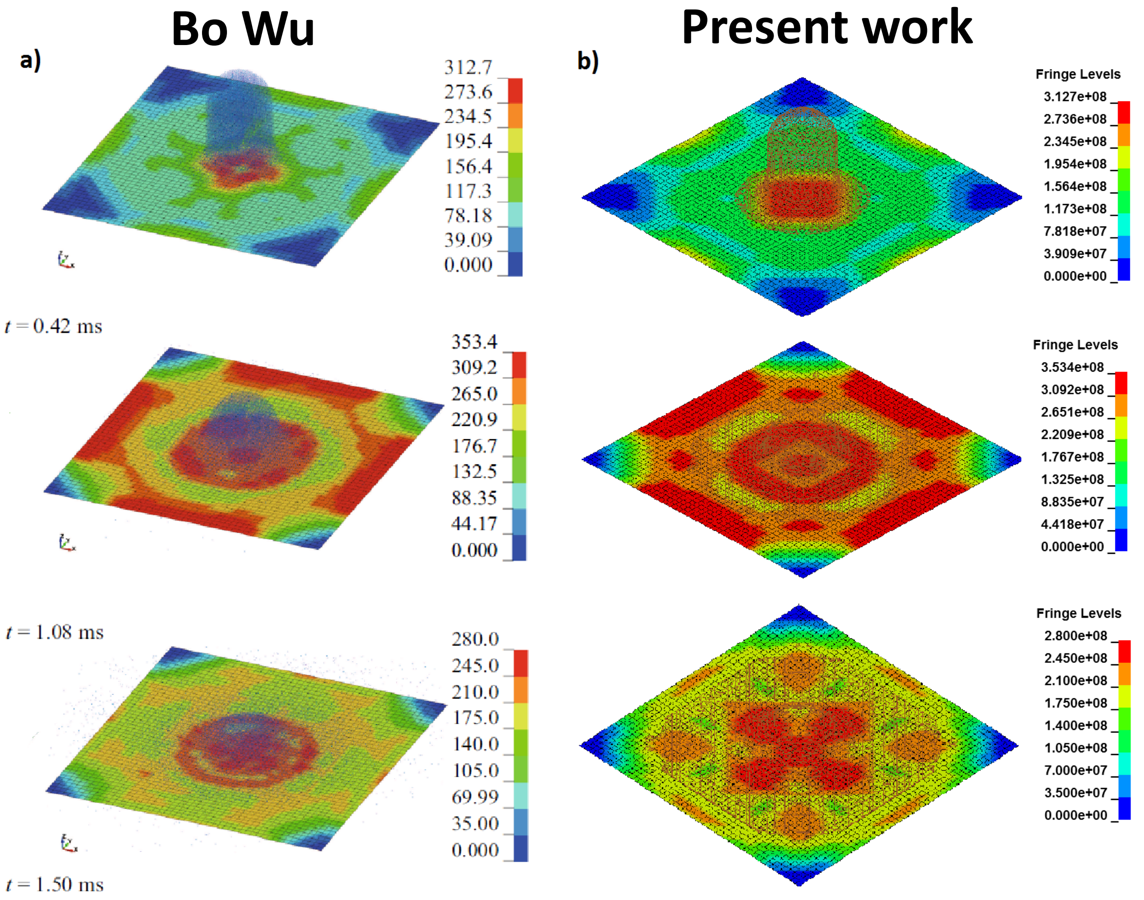

Quasi-iso CFRP plate Impact
Time = 0
max displacement factor=3
Z
Y
X

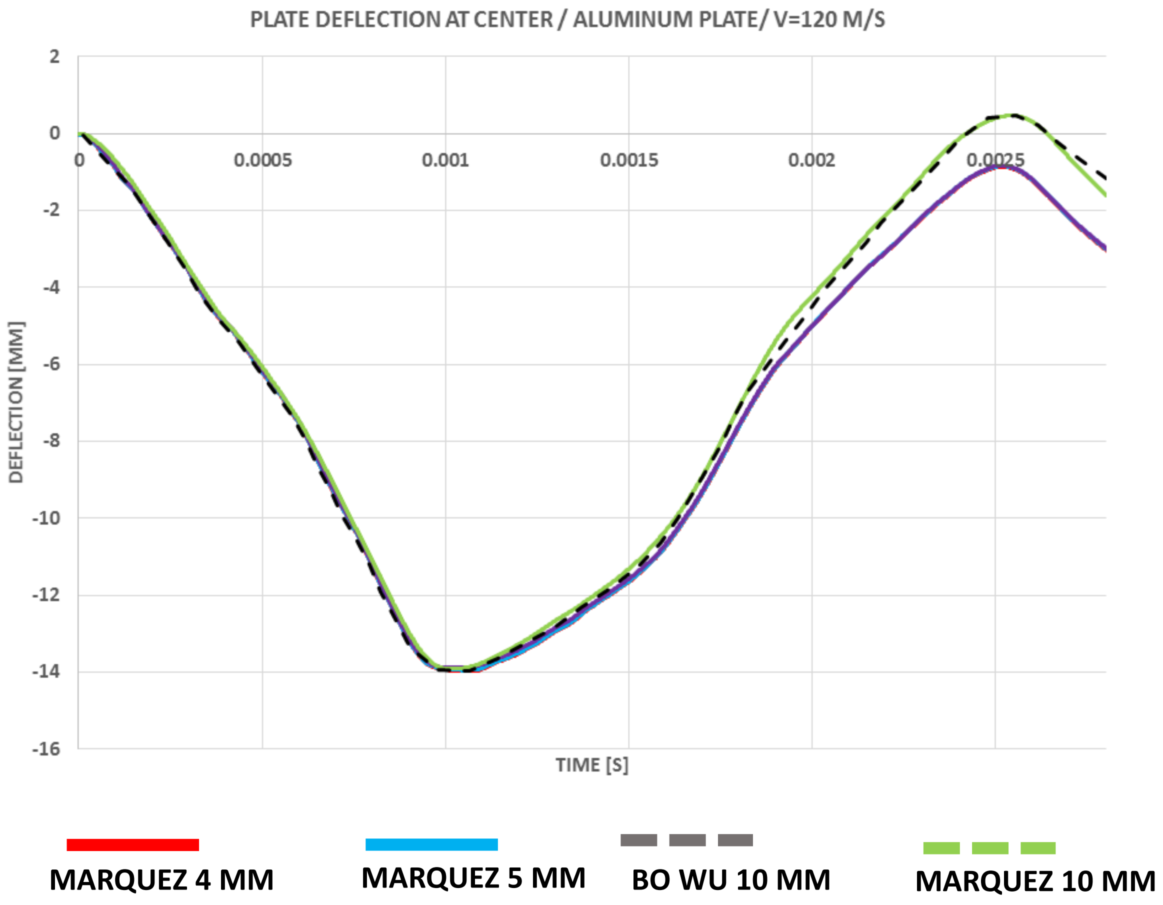
6. RIGID PLATE: PROFILE OF PRESSURE AT PLATE CENTER

PLATE DIMENSIONS			
Diameter	Φ=400	[mm]	
		[mm]	
Thickness	1.625	[mm]	
IMPACTOR DIMENSIONS			
Diameter	93	[mm]	
Length	186	[mm]	
Density	950	[Kg/m^3]	
Mass	1	[Kg]	
Impact Face	Rounded	[N/A]	
MESH PARAMETERS			
Type of Mesh	Dimensions[mm]	# Elements	Element Size
ALE Mesh	200x200x300	Variable	4-8 mm
Boundary Shell	= to Impactor	181	Variable
Plate Shell	Φ=400	2784	Variable



7. ELASTO-PLASTIC PLATE: VM Contours and Deflection



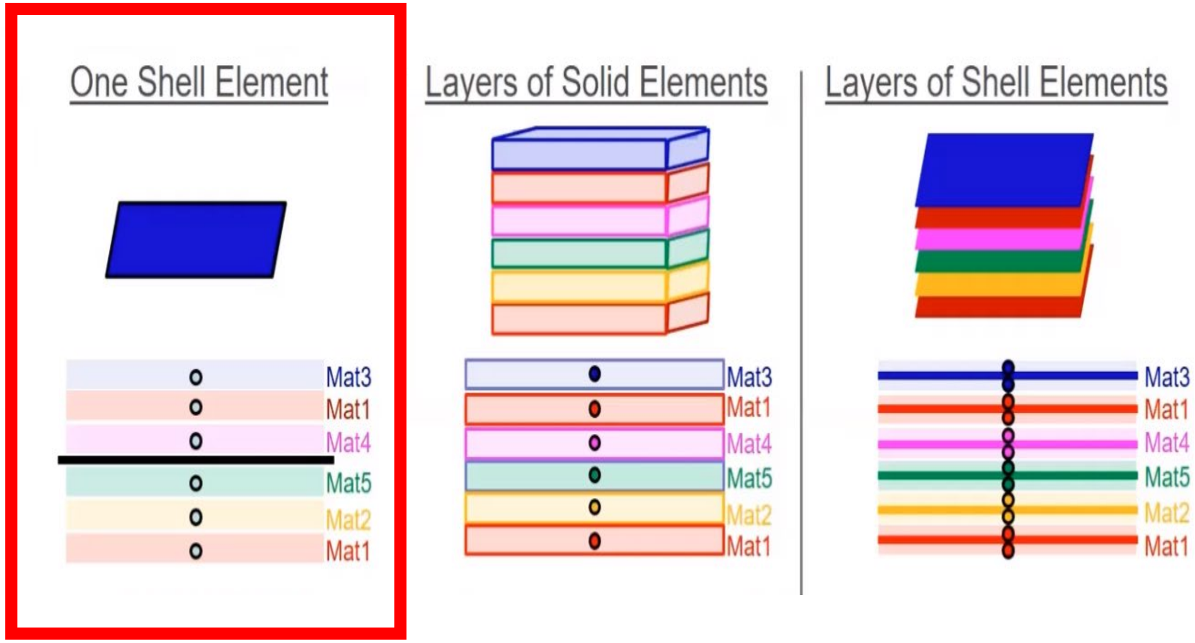


VON MISSES STRESS COMPARISSON (4MM PLATE MESH)

DEFORMATION PROFILE AT THE CENTER OF THE PLATE (DIFFERENT PLATE MESHES)

8. COMPOSITE MODELLING TECHNIQUE

- Single Shell approach along through thickness integration points.
- A stack of Shell elements (2D elements).
- A stack of Solid elements (3D elements).



From: Inter-laminar material modelling in LS-DYNA, OASYS

8. CHANG-CHANG CRITERIA

Criteria which allows to separate the failure by different modes:

- Fiber rupture (Tension or compression).
- Matrix Cracking (Tension or compression)
- Shear contribution is accounted for.

Element fails when all integration points failed in FIBER RUPTURE.

for the tensile fiber mode,

$$\sigma_{aa} > 0 \Rightarrow e_f^2 = \left(\frac{\sigma_{aa}}{X_t}\right)^2 + \beta\left(\frac{\sigma_{ab}}{S_c}\right)^2 - 1, \qquad \begin{array}{l} e_f^2 \geq 0 \Rightarrow \text{failed} \\ e_f^2 < 0 \Rightarrow \text{elastic} \end{array}$$

$$E_a = E_b = G_{ab} = \nu_{ba} = \nu_{ab} = 0$$

for the compressive fiber mode,

$$\sigma_{aa} < 0 \Rightarrow e_c^2 = \left(\frac{\sigma_{aa}}{X_c}\right)^2 - 1, \qquad \begin{array}{l} e_c^2 \geq 0 \Rightarrow \text{failed} \\ e_c^2 < 0 \Rightarrow \text{elastic} \end{array}$$

$$E_a = \nu_{ba} = \nu_{ab} = 0$$

for the tensile matrix mode,

$$\sigma_{bb} > 0 \Rightarrow e_m^2 = \left(\frac{\sigma_{bb}}{Y_t}\right)^2 + \left(\frac{\sigma_{ab}}{S_c}\right)^2 - 1, \qquad \begin{array}{l} e_m^2 \geq 0 \Rightarrow \text{failed} \\ e_m^2 < 0 \Rightarrow \text{elastic} \end{array}$$

$$E_b = \nu_{ba} = 0 \Rightarrow G_{ab} = 0,$$

and for the compressive matrix mode,

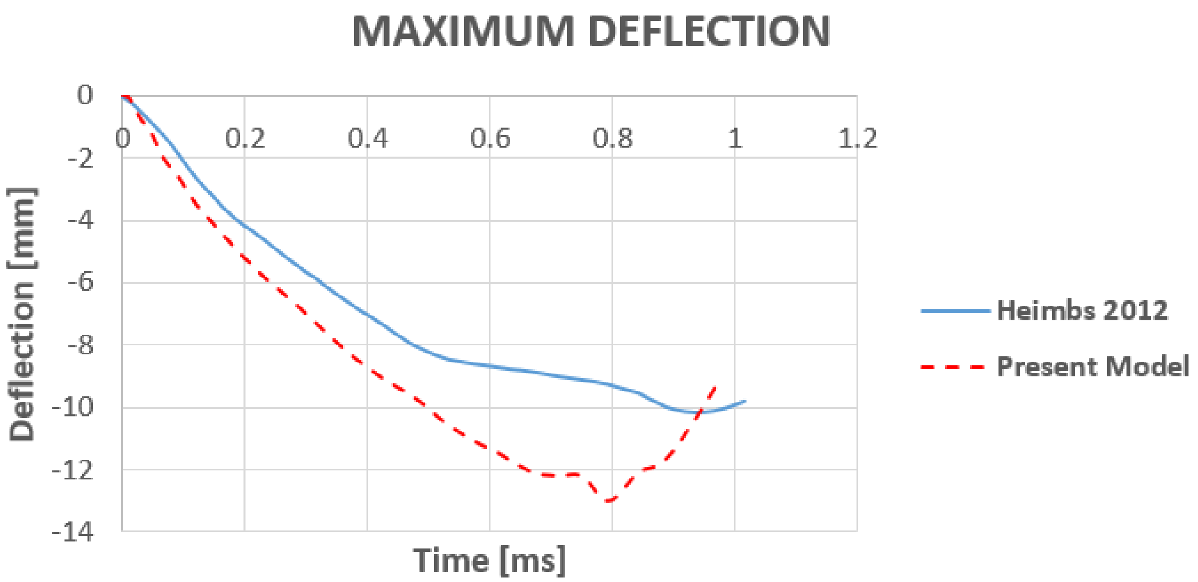
$$\sigma_{bb} < 0 \Rightarrow e_d^2 = \left(\frac{\sigma_{bb}}{2S_c}\right)^2 + \left[\left(\frac{Y_c}{2S_c}\right)^2 - 1\right]\frac{\sigma_{bb}}{Y_c} + \left(\frac{\sigma_{ab}}{S_c}\right)^2 - 1, \qquad \begin{array}{l} e_d^2 \geq 0 \Rightarrow \text{failed} \\ e_d^2 < 0 \Rightarrow \text{elastic} \end{array}$$

$$E_b = \nu_{ba} = \nu_{ab} = 0 \Rightarrow G_{ab} = 0$$

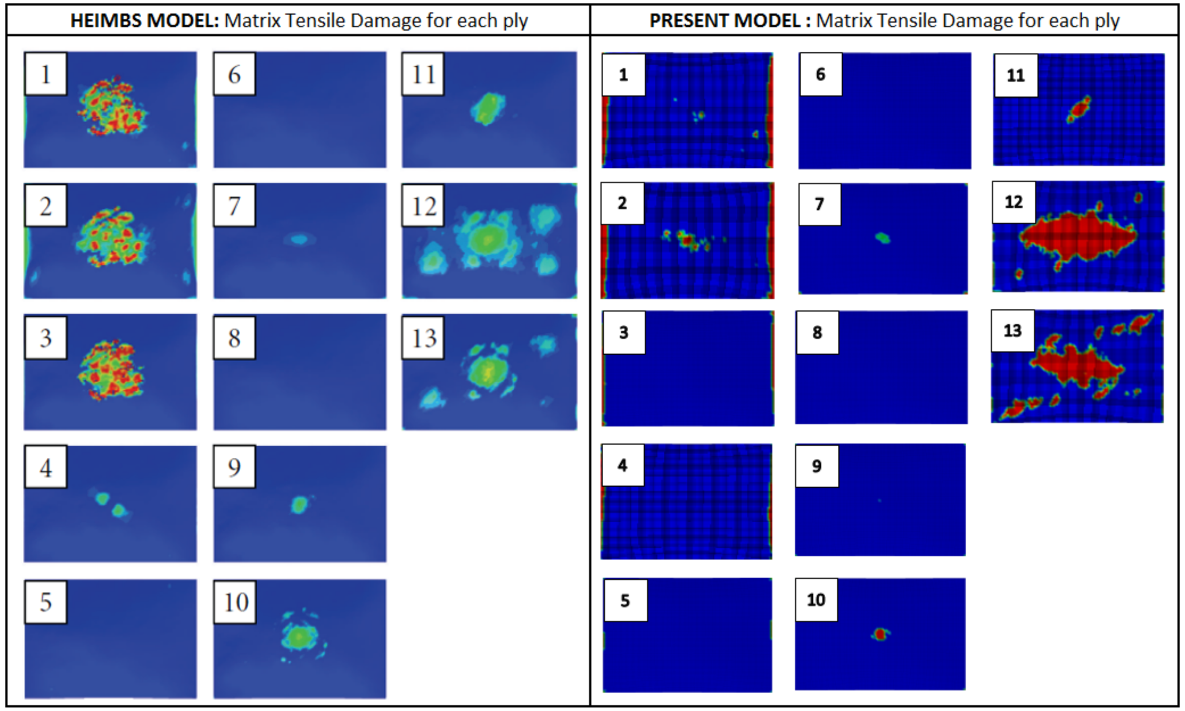
From: LS-DYNA manual , Livermore

8. HIGH VELOCITY IMPACT ON COMPOSITE PLATES, HEIMBS (2012)

100 m/s impact.
M=0,032 Kg



DEFLECTION COMPARISSON

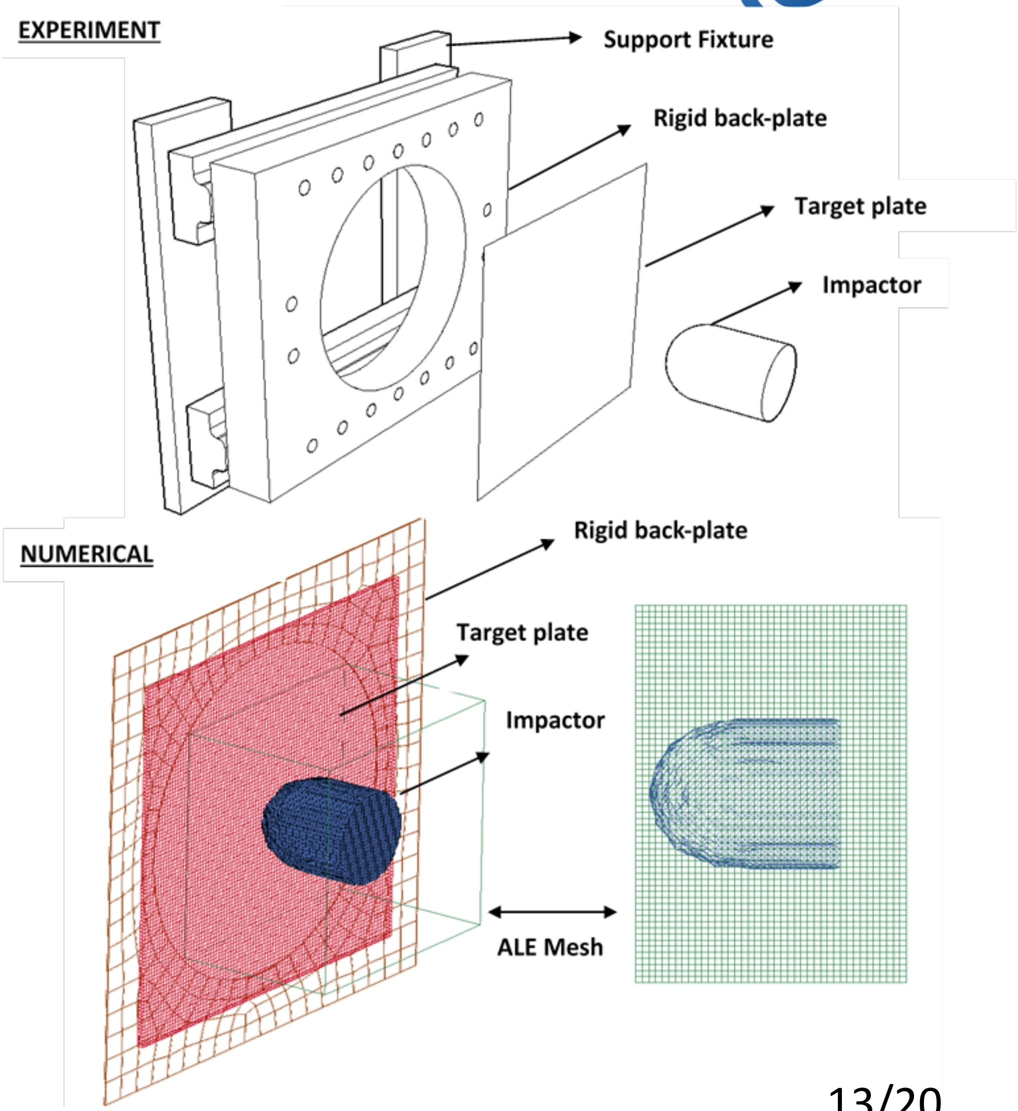


MATRIX FAILURE AT TENSION COMPARISSON

THE MODEL DEVELOPED IN MY WORK IS COMPLETELY INTRA-LAMINAR!

9. EXPERIMENTAL SET-UP, TOULOUSE (2018)

- Rigid plate used as back-up plate.
- Planar impactors with a mass 0.35 and 0.75 Kg at different velocities. (20-120 m/s)
- Target plate free-constrained.
- MAT 54 Enhanced composite material for target plate.
- Only Intra-laminar damage is considered.
- ALE and PLATE meshes according to previous sensitivity analysis.
- Three different laminates tested (CFRP, GFRP)



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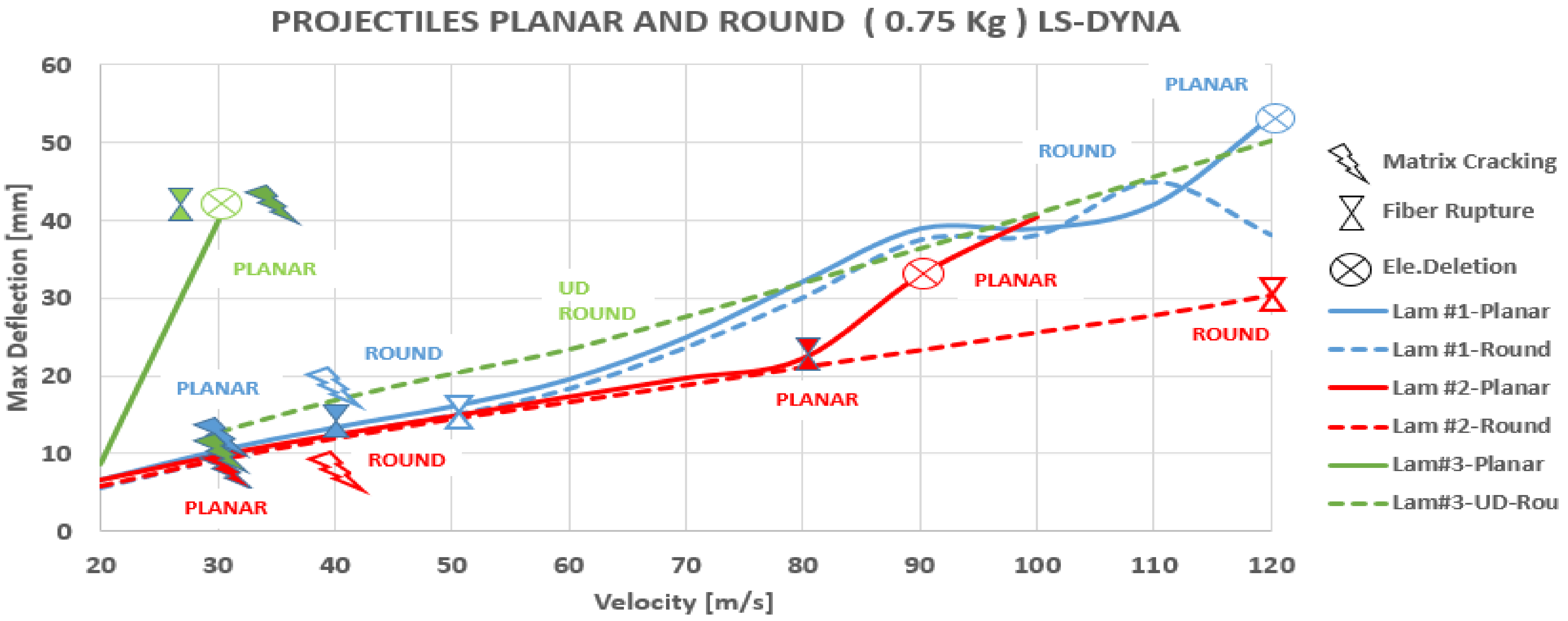

9. EXPERIMENTAL SET-UP, TOULOUSE (2018)

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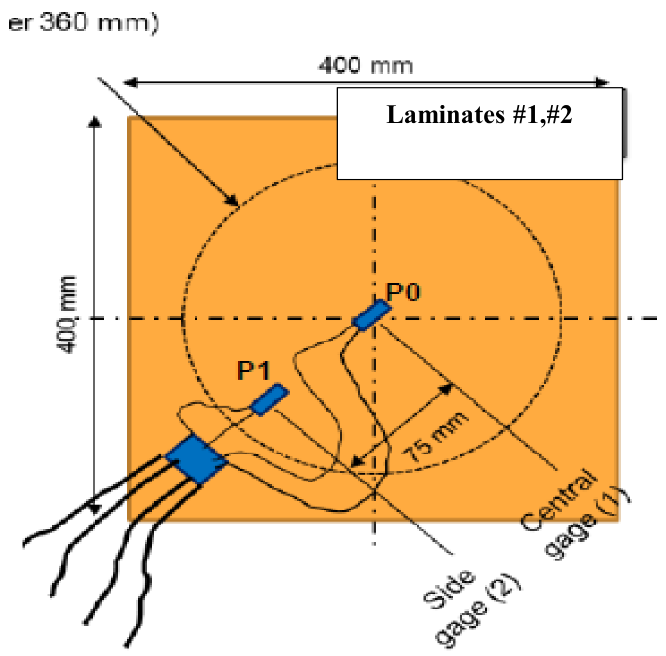
MEASURING EQUIPMENT

The strain evolution data of the laminates during impact was gathered by:

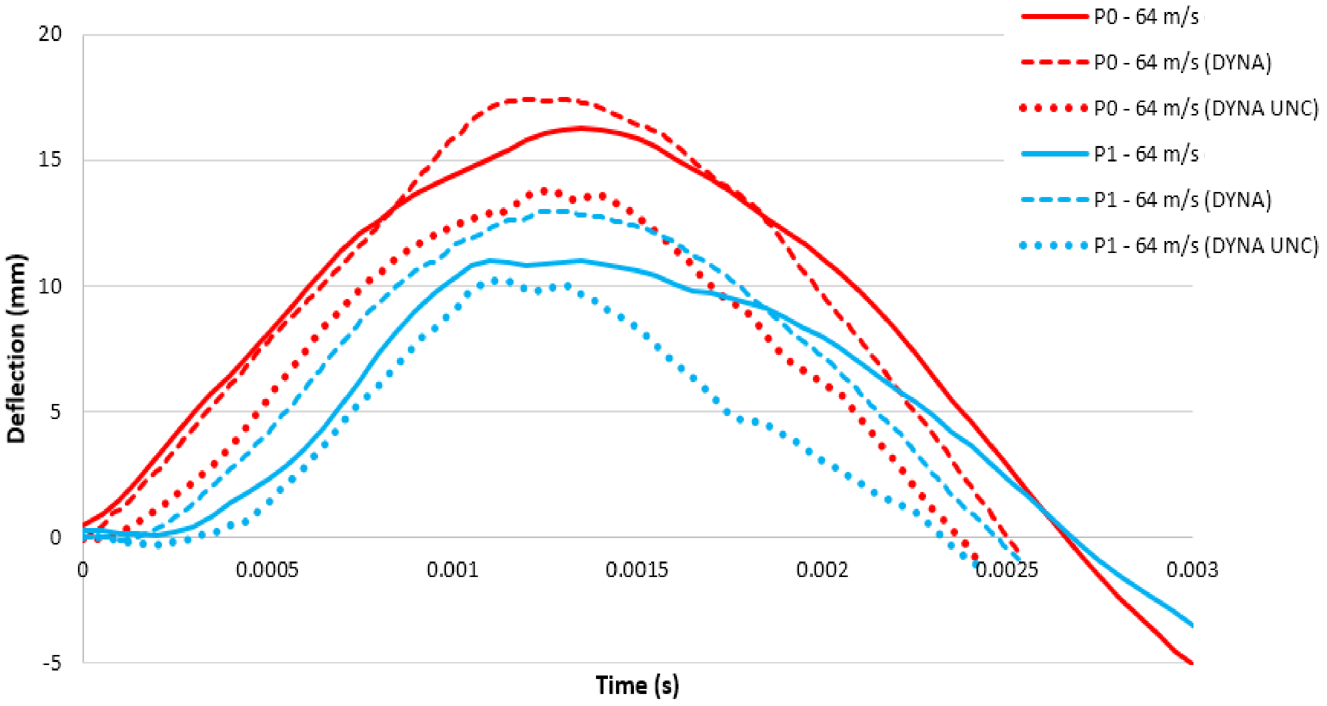
1. Using Strain gauges oriented in fiber direction

2. Using a Digital Image Correlation equipment.

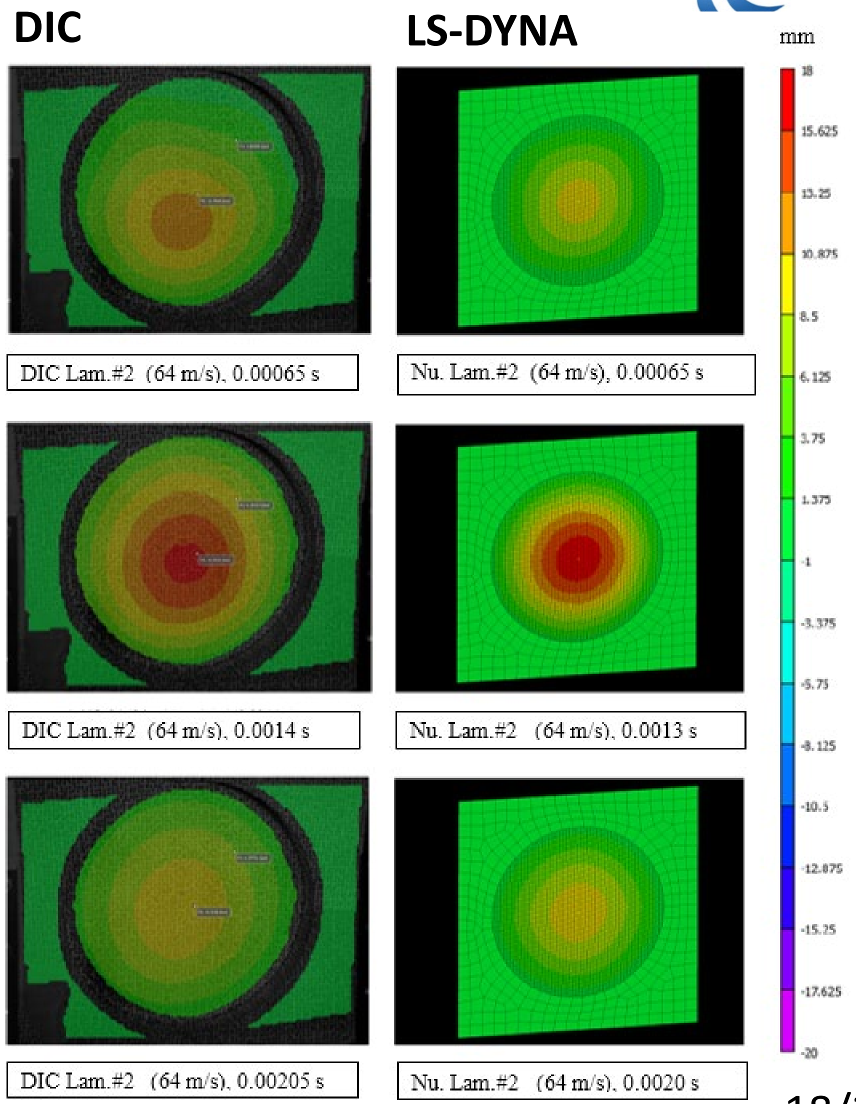


From: Guillaume Barlow, ICAM.

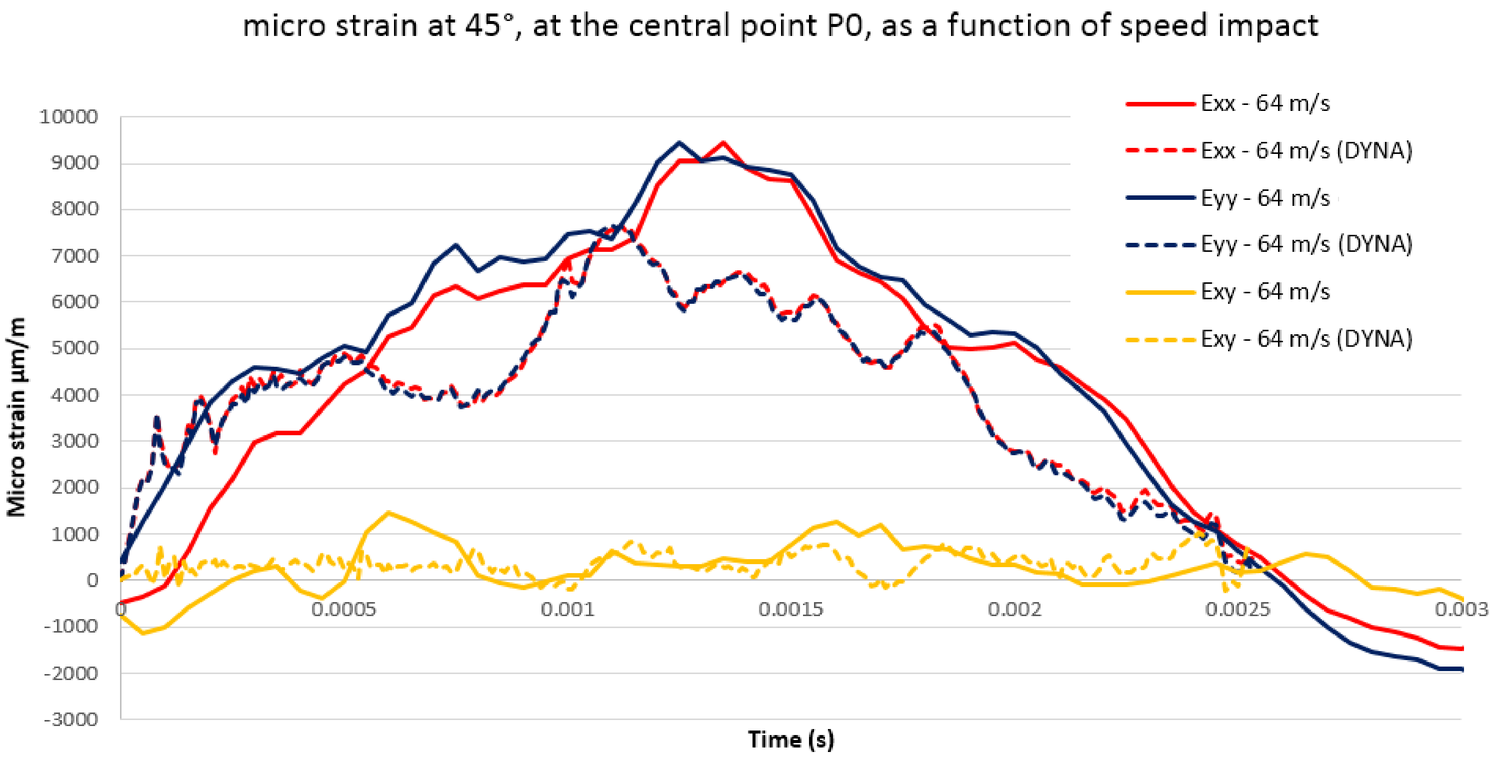
DEFLECTION HISTORY AND CONTOURS LAMINATE #2 (CFRP)



Experimental and numerical deflection history at 64 m/s for Lam. #2 (CFRP).



STRAINS HISTORY IN X, Y AND XY AT PLATE CENTER (LAMINATE #2-CFRP)



Experimental and numerical strains history in the fiber direction at center for Lam.#2 (CFRP) at 64 m/s.

10. CONCLUSIONS

- A numerical model for studying soft body impacts against plates was developed successfully, modelling both elastoplastic metallic plates and Intra-laminar damage in composite plates.

- Model validated against numerical studies and experimental tests.

- The numerical model developed for composite materials seems to be more conservative than the numerical models that include inter-laminar damage, as well as against experimental tests.

- More work needs to be performed for estimating the fabric strengths, which is hard due its weave nature.

- The Hugoniot pressure highly influence both MC and FR thresholds. For the same mass, but different impact geometry, it was observed that this pressure gets reduced almost by the half. Additionally, this pressure is highly dependent of the ALE mesh size.

THANKS FOR YOUR ATTENTION!