11th International Conference on Composites Testing and Model Identification Comptest 2023 – UDG Girona

2013-2023: TEN YEARS OF EXPERIMENTAL, NUMERICAL AND MEASUREMENT DEVELOPMENTS WITH THE VERTEX MULTIAXIAL TEST BENCH

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Multiaxial testing of Aeronautic Structures : the need

Aeronautical industry challenge:

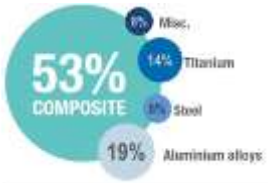
Reduction of fuel consumption ($ & CO_2)

⇒ Mass reduction of structures

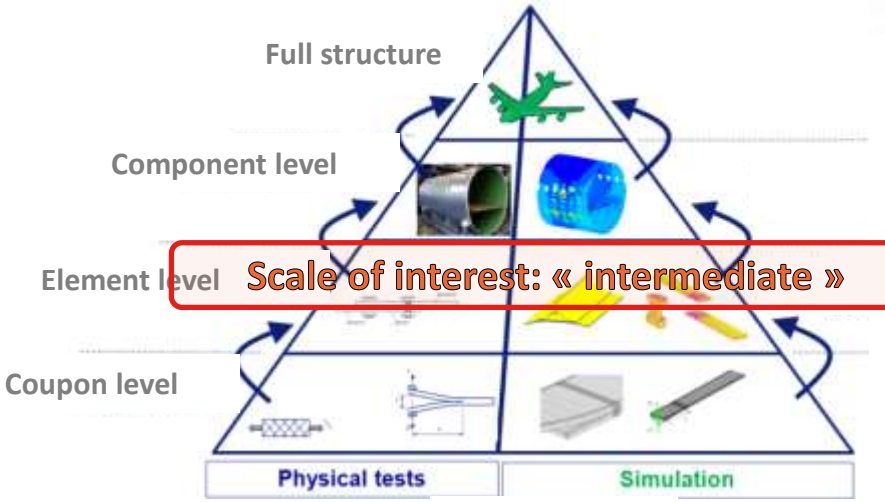
⇒ Large use of composite materials

⇒ Good stiffness/mass ratio

⇒ Complex damage behaviour

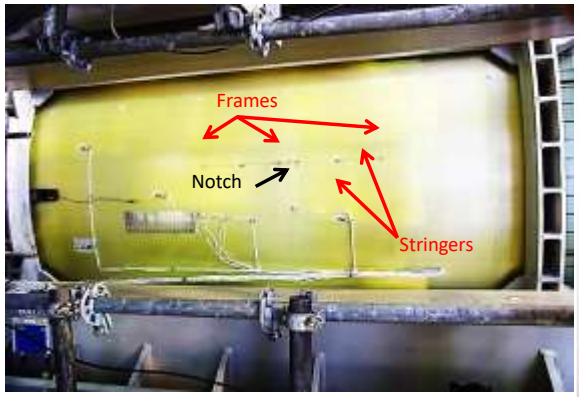


[Rouchon 1990]



Example : Problem of Large notches

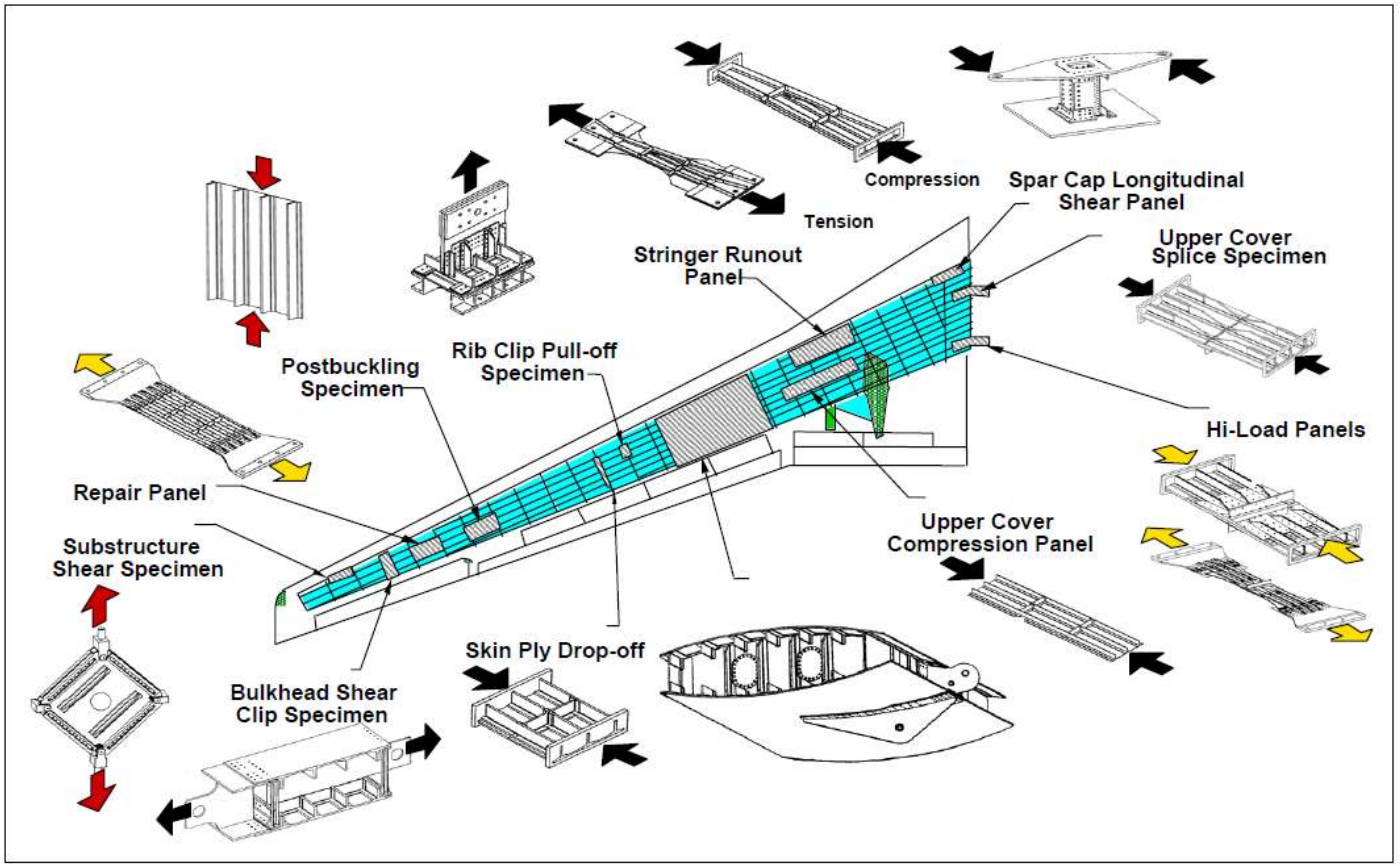
Downscaling



Only Large Scale Testing

Multiaxial testing of Aeronautic Structures : the need

Building Block Approach – Reliance on Extensive Testing

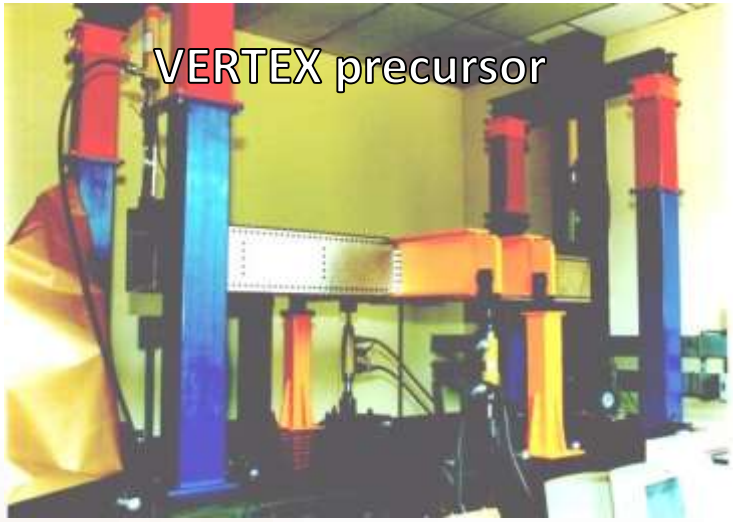


Example of tests for certification of a carbon wing box (NASA Program) : Only Uniaxial tests

ICA Background

2000 – PhD of Bruno Castanié

- Development of a first structural test bench
- Study of asymmetrical sandwiches



B. Castanié, JJ Barrau, JP Jaouen, S Rivallant. Combined shear/compression structural testing of asymmetric sandwich structures Experimental mechanics 44, 461-472, 2004

Boxes used for a long time in multiaxial testing : NACA TN 1750 1948

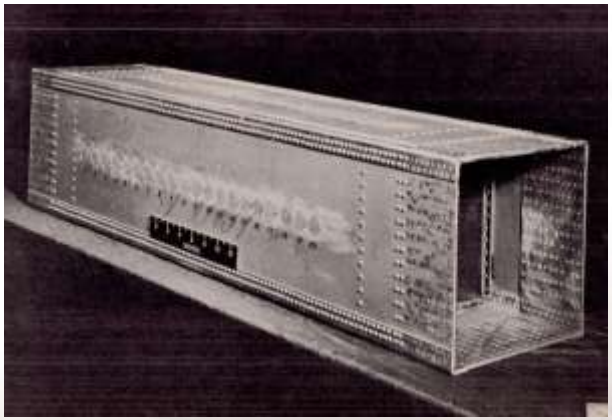

BUCKLING TESTS OF FLAT RECTANGULAR PLATES UNDER COMBINED SHEAR AND LONGITUDINAL COMPRESSION

By Roger W. Peters

Langley Aeronautical Laboratory
Langley Field, Va.

NACA

Washington
November 1948



VERTEX and VIRTUOSE project

https://websites.isae-supaero.fr/virtuose/

VERTEX

Leader: B. Castanié

Granted by ANR 2013-2017: 2800 k€

VIRTUOSE

Leader: J. Serra

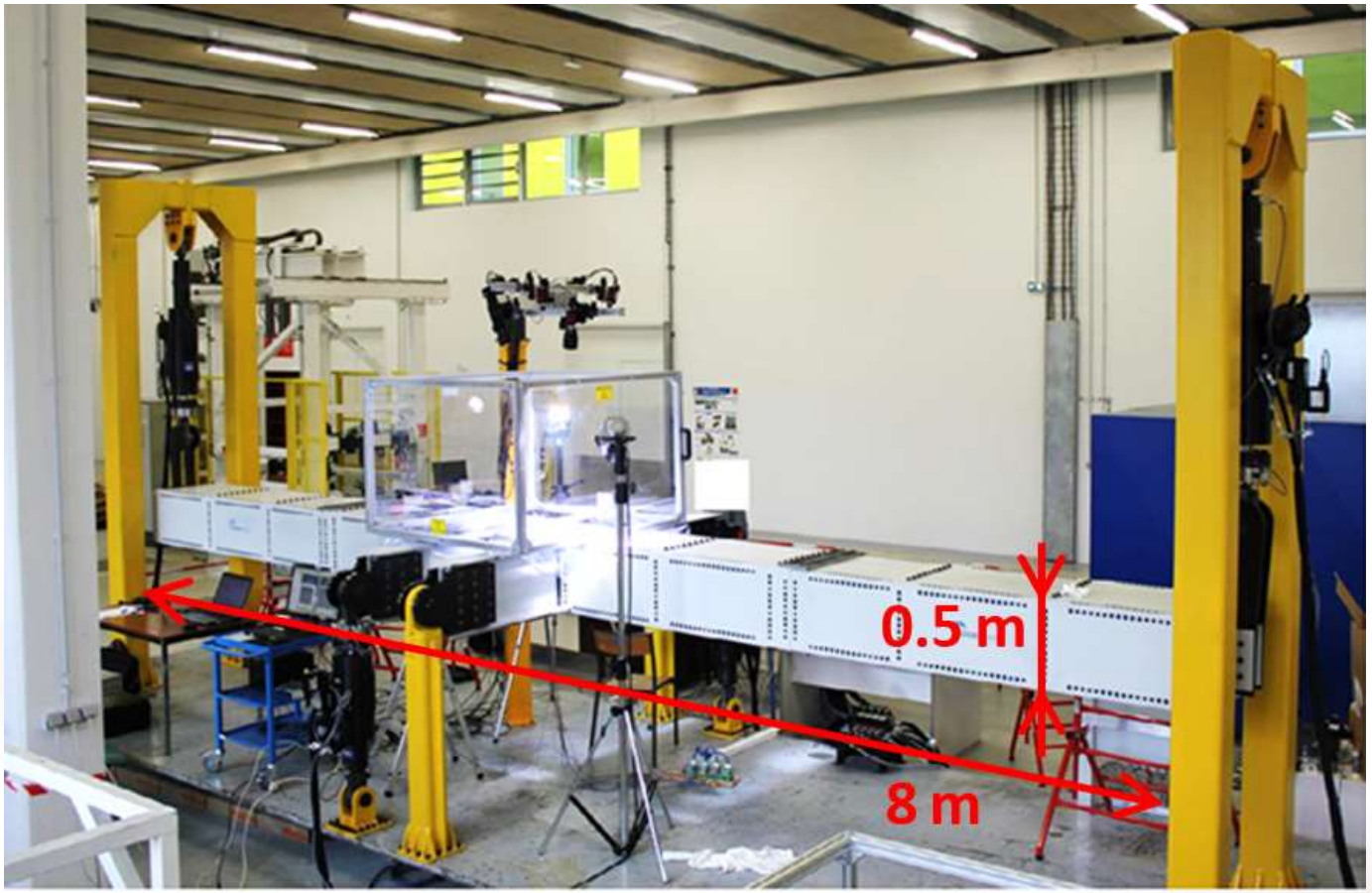
Granted by Fondation Lopez-loreta 2019-2024: 1000 k€

+ 500 k€ Funding by région midi-pyrénées to built the machine
+ 2 Phd with Elixir Aircraft and Ségula 100 k€

VERTEX bench

Intermediate-scale testing, emulating larger structural issues

[Serra 2017]



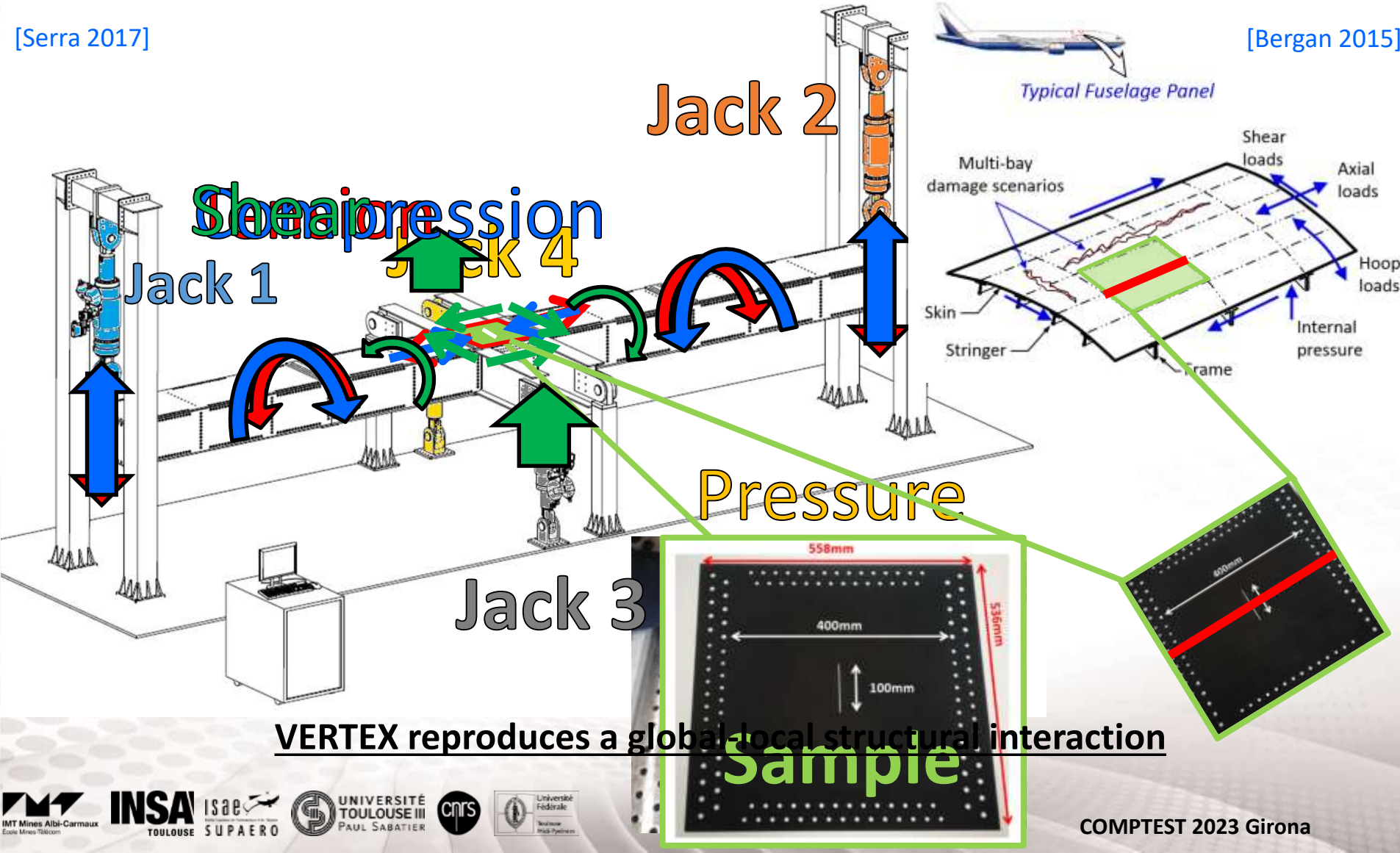
Compression 3000 N/mm, Shear 1000 N/mm, pressure 1,6 Bars

VERTEX bench

Intermediate-scale testing, emulating larger structural issues

[Serra 2017]

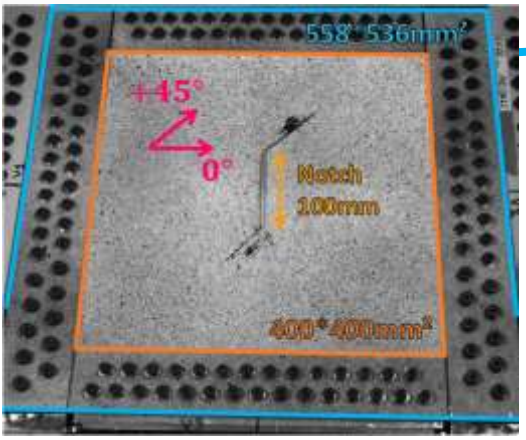
[Bergan 2015]



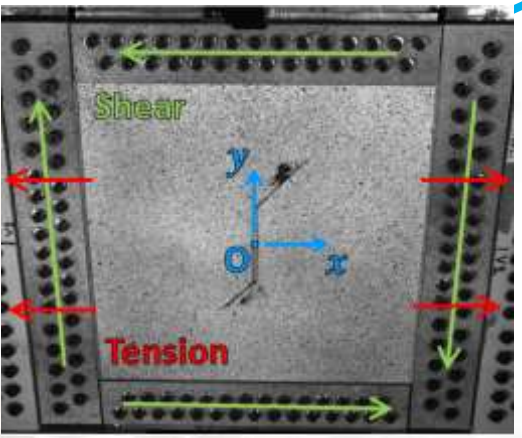
VERTEX reproduces a global-local structural interaction

Cameras

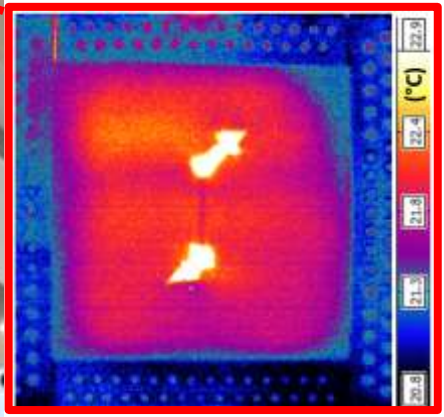
Camera A

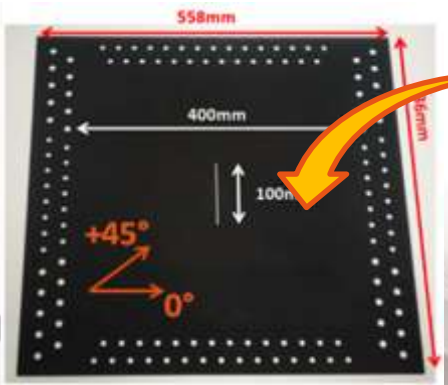


Camera B



Infrared camera

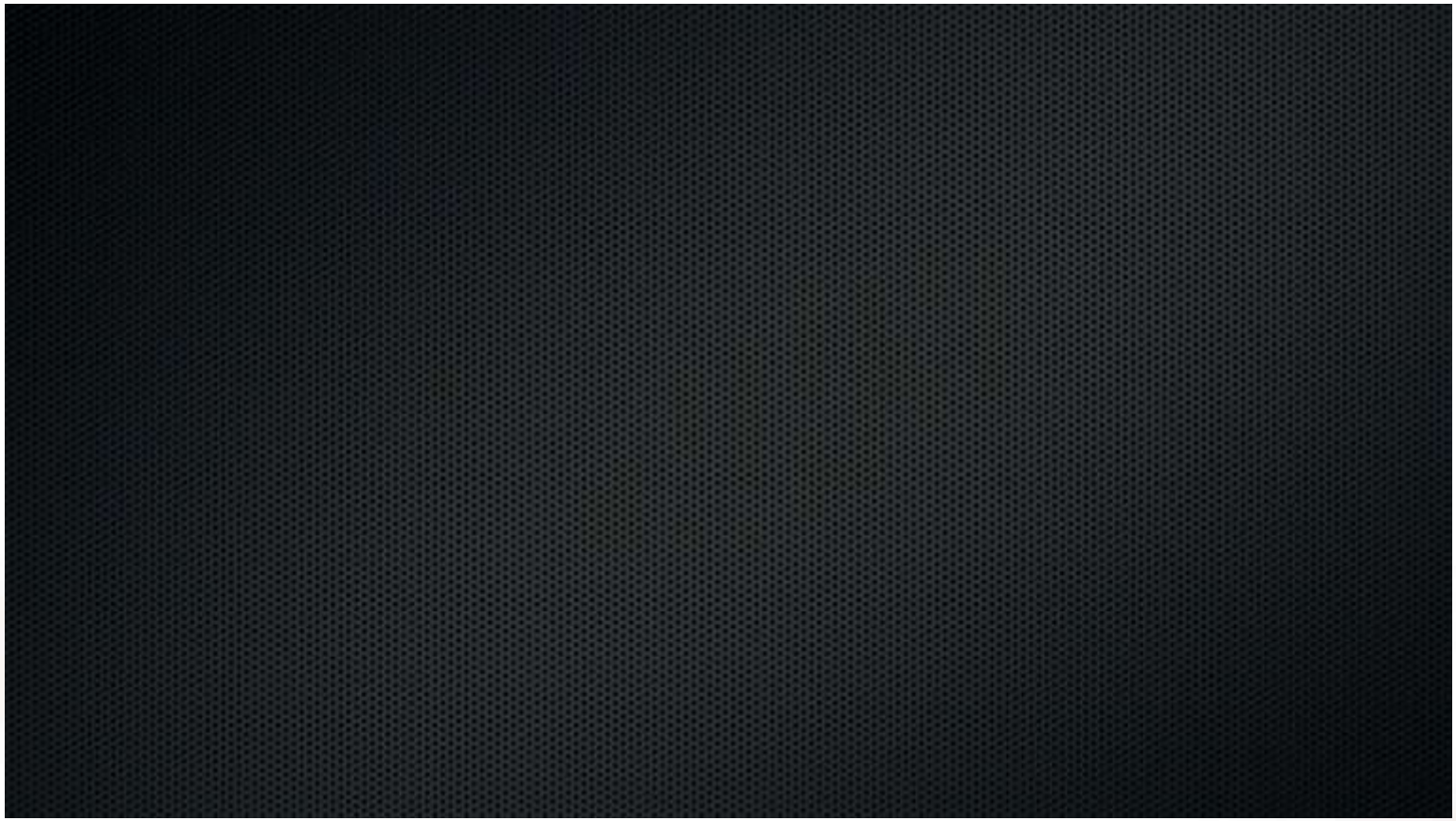




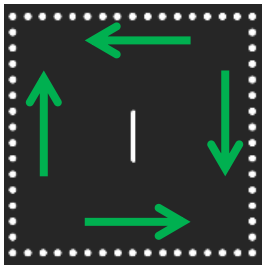
?

A test in real time

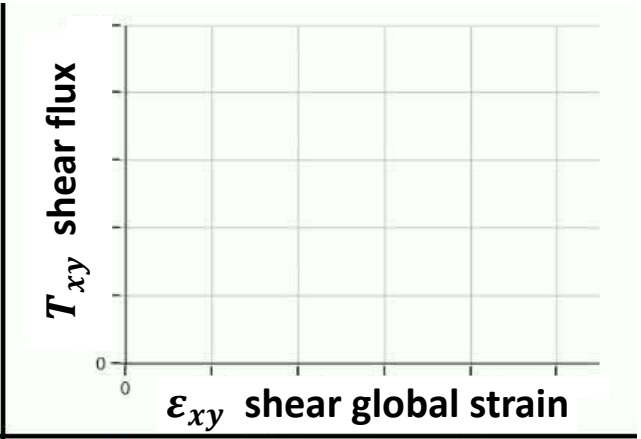
A test in real time

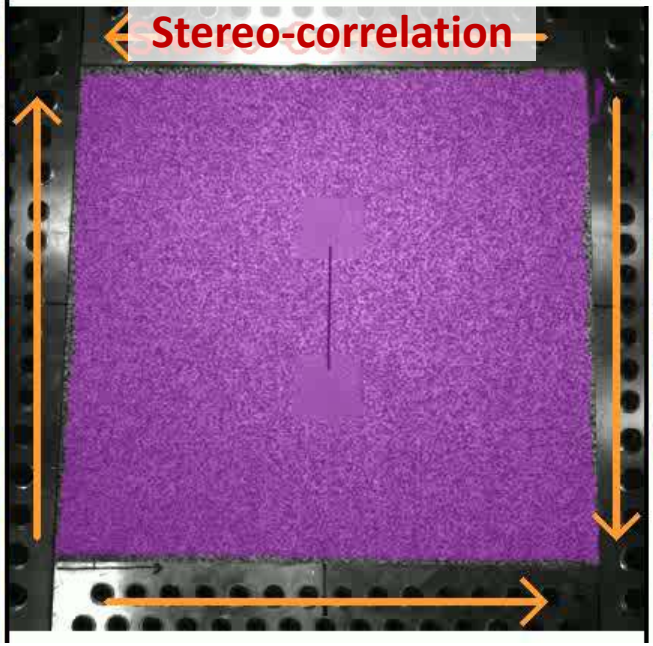


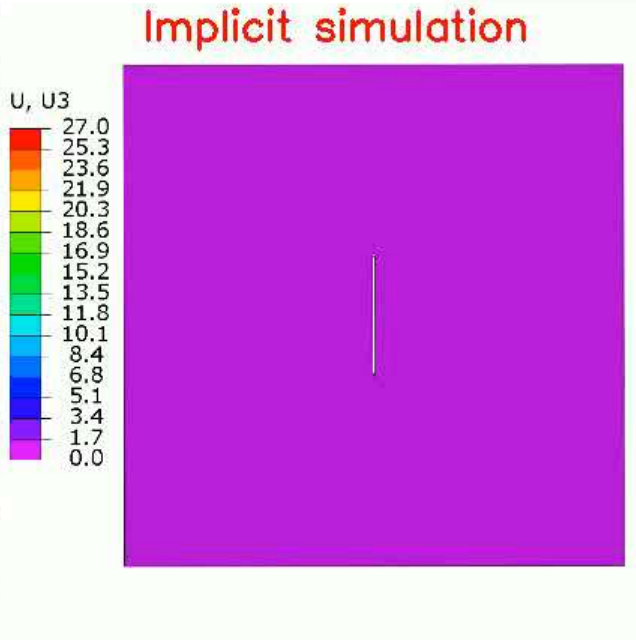
Shear + Pressure test



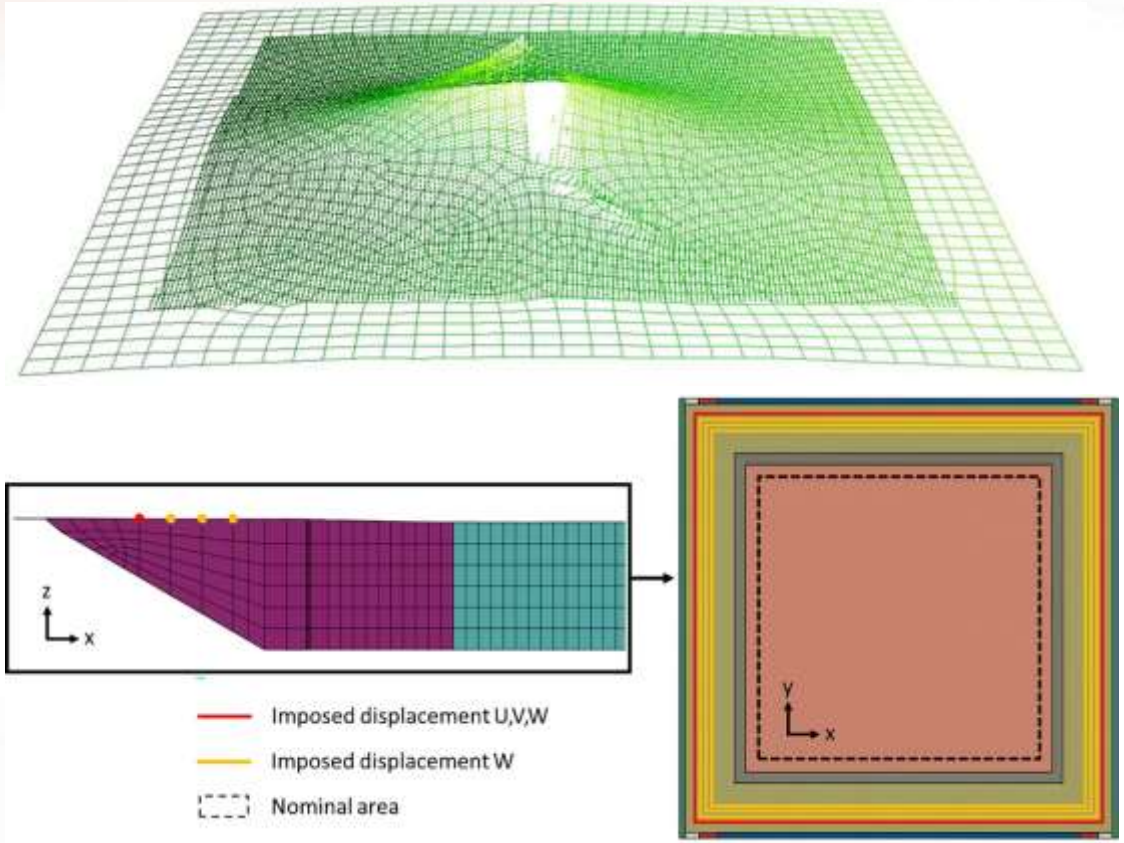
Playback speed × 3







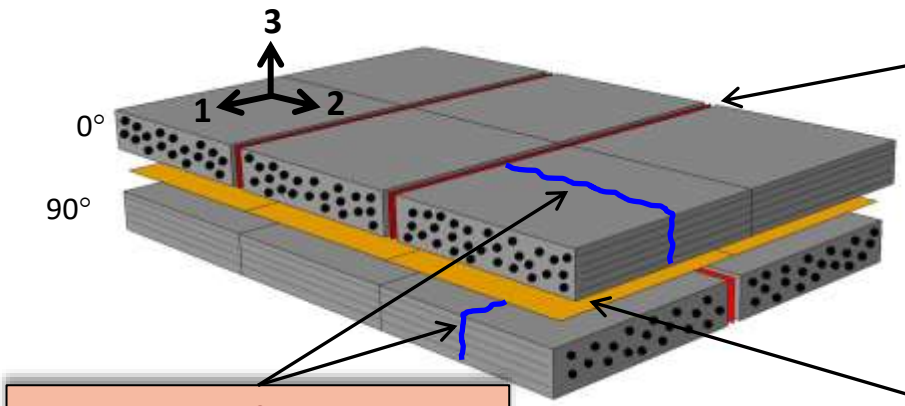
Enhanced Test/Computation dialog with FE-SDIC



Finite Element Stereo Digital Image Correlation (SDIC) data are extracted and used to apply a loading path in the numerical model. It consists of imposing the displacements (U,V,W) measured by SDIC on a rectangular frame of upper face nodes (red), plus out-of-plane displacements (W) on 3 additional rectangular frames

Using DPM for modeling

Constitutive law: 3 damage modes



Matrix cracking
(interface elements)

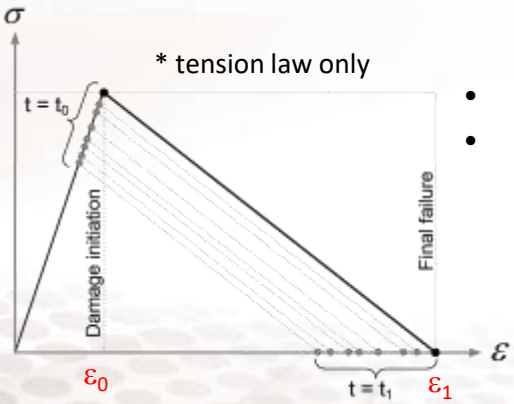
$$\left(\frac{\langle \sigma_{22} \rangle^{+}}{{\sigma_{22}}^{f}}\right)^{2} + \frac{{\tau_{12}}^{2} + {\tau_{23}}^{2}}{\left({\tau_{12}}^{f}\right)^{2}} \leq 1$$

** calculated at neighbouring volume elements

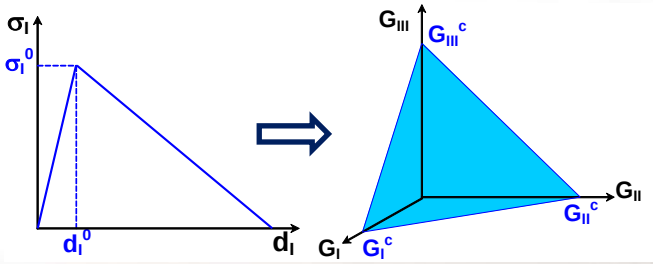
Fibre failure
(3D volume elements)

Delamination
(interface elements)

Mixed-mode progressive delamination law

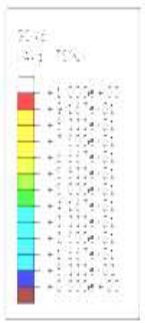


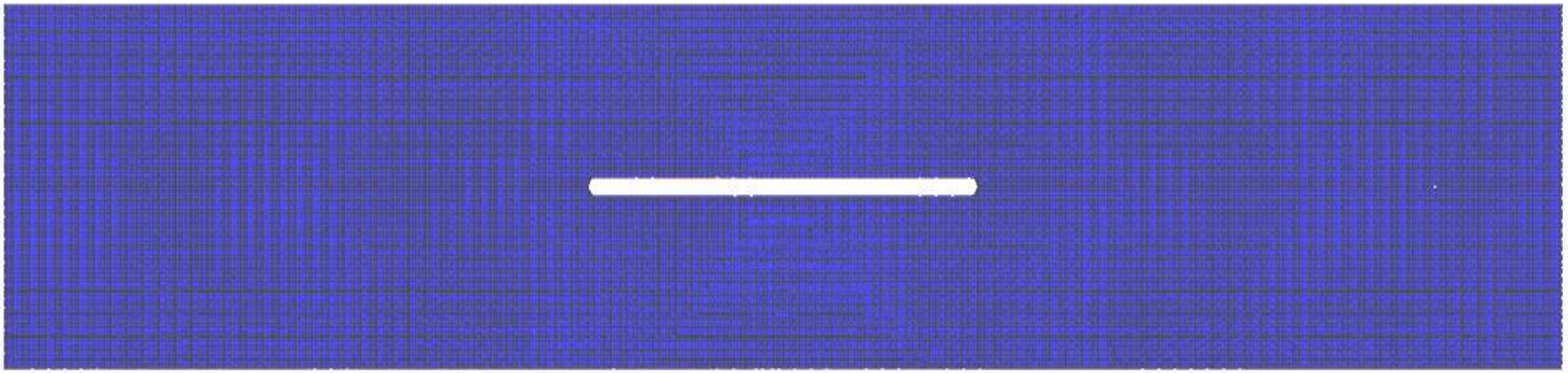
- Calculate at 8 integration points
- Energy based damage mechanics



$$\int_{V}\left(\int_{0}^{\varepsilon_1}\sigma \cdot d\varepsilon\right)\cdot dV = S \cdot G_{Ic}^{fibre}$$

Using DPM for modeling (Notches and Impact)





Metrics

Solution

Determination of 6 fields of force and moment fluxes

Averaged on edges ⇒ 6 scalar representative of the global loading intensity

Force and moment fluxes (classical plate theory)

$$\underline{\varepsilon}\big(M(x,y,z)\big) = \begin{bmatrix} \varepsilon_{0x}(x,y) \\ \varepsilon_{0y}(x,y) \\ \gamma_{0xy}(x,y) \end{bmatrix} + z * \begin{bmatrix} -\dfrac{\partial^2 w}{\partial x^2}(x,y) \\ -\dfrac{\partial^2 w}{\partial y^2}(x,y) \\ -2\dfrac{\partial^2 w}{\partial x \partial y}(x,y) \end{bmatrix}$$

curvature; half thick.

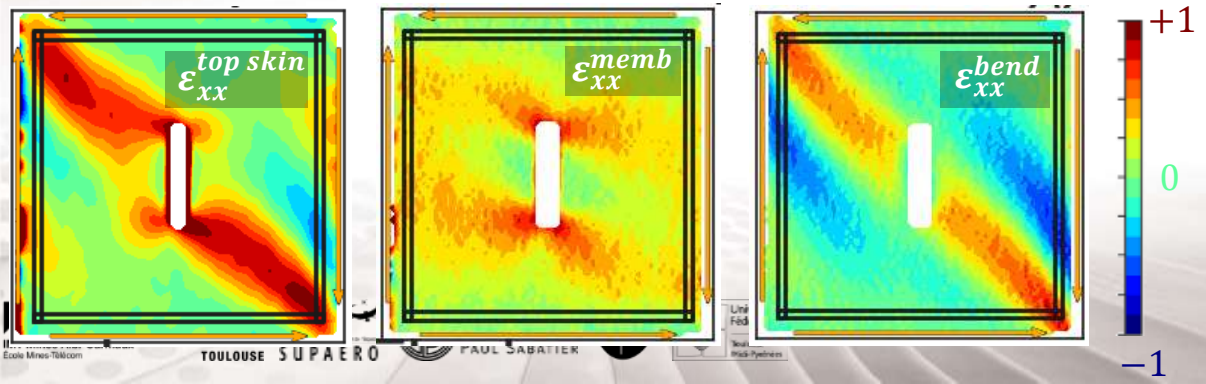
$$\begin{bmatrix} N_x \\ N_y \\ T_{xy} \\ M_x \\ M_y \\ M_{xy} \end{bmatrix} = \begin{bmatrix} \underline{\underline{A}} & \underline{\underline{B}} \\ \underline{\underline{B}} & \underline{\underline{D}} \end{bmatrix} \cdot \begin{bmatrix} \varepsilon_{0x} \\ \varepsilon_{0y} \\ \gamma_{0xy} \\ -\dfrac{\partial^2 w}{\partial x^2} \\ -\dfrac{\partial^2 w}{\partial y^2} \\ -2\dfrac{\partial^2 w}{\partial x \partial y} \end{bmatrix}$$

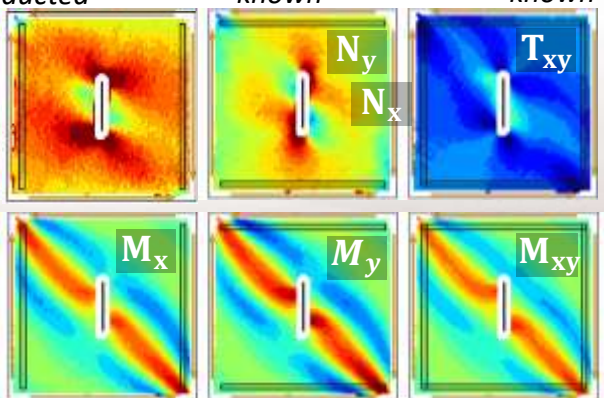
top skin = **membrane** + **bending (top skin)**

measured = *deducted* + *measured-computed*

flux = **stiffness** x **plate strain**

deducted = *known* x *known*

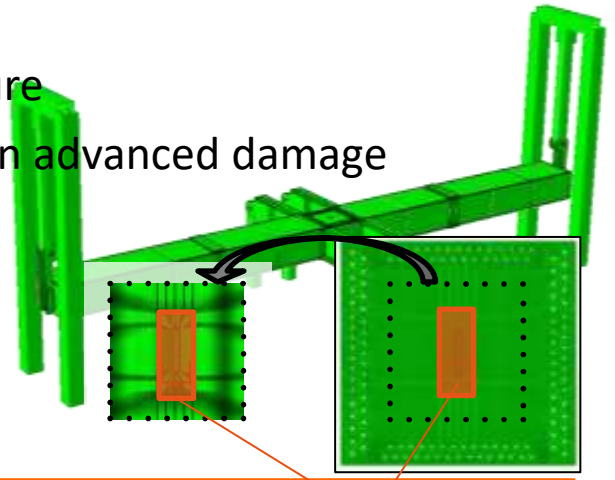




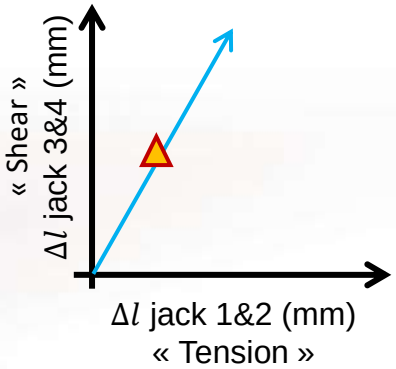
VERTEX bench FEM output

Model usage

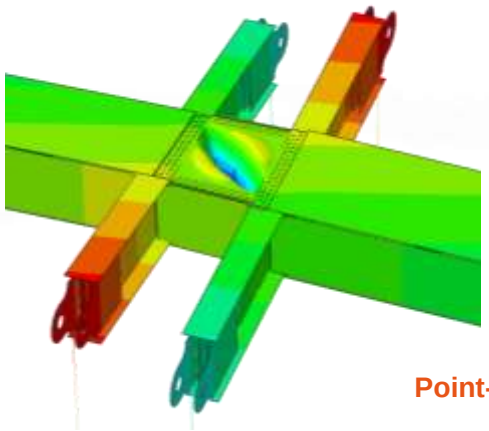
- Model input = real bench inputs = jack setpoints
- Estimate directly if a given jack displacement causes failure
- Meant to be used to generate Boundary Conditions for an advanced damage model

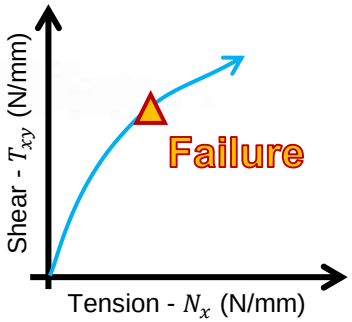


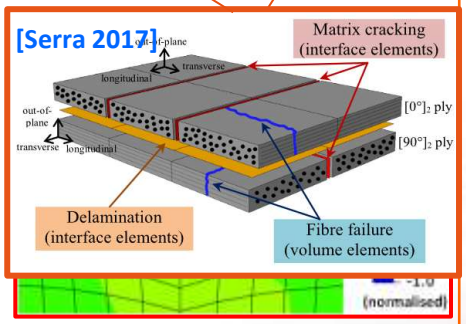
Inputs



Outputs



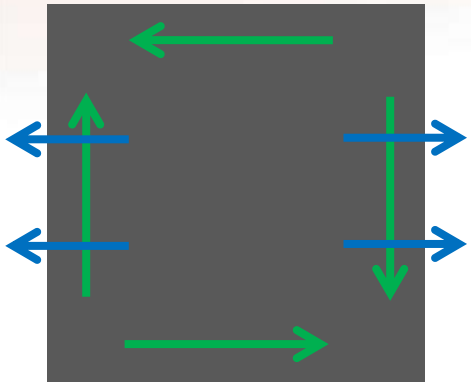


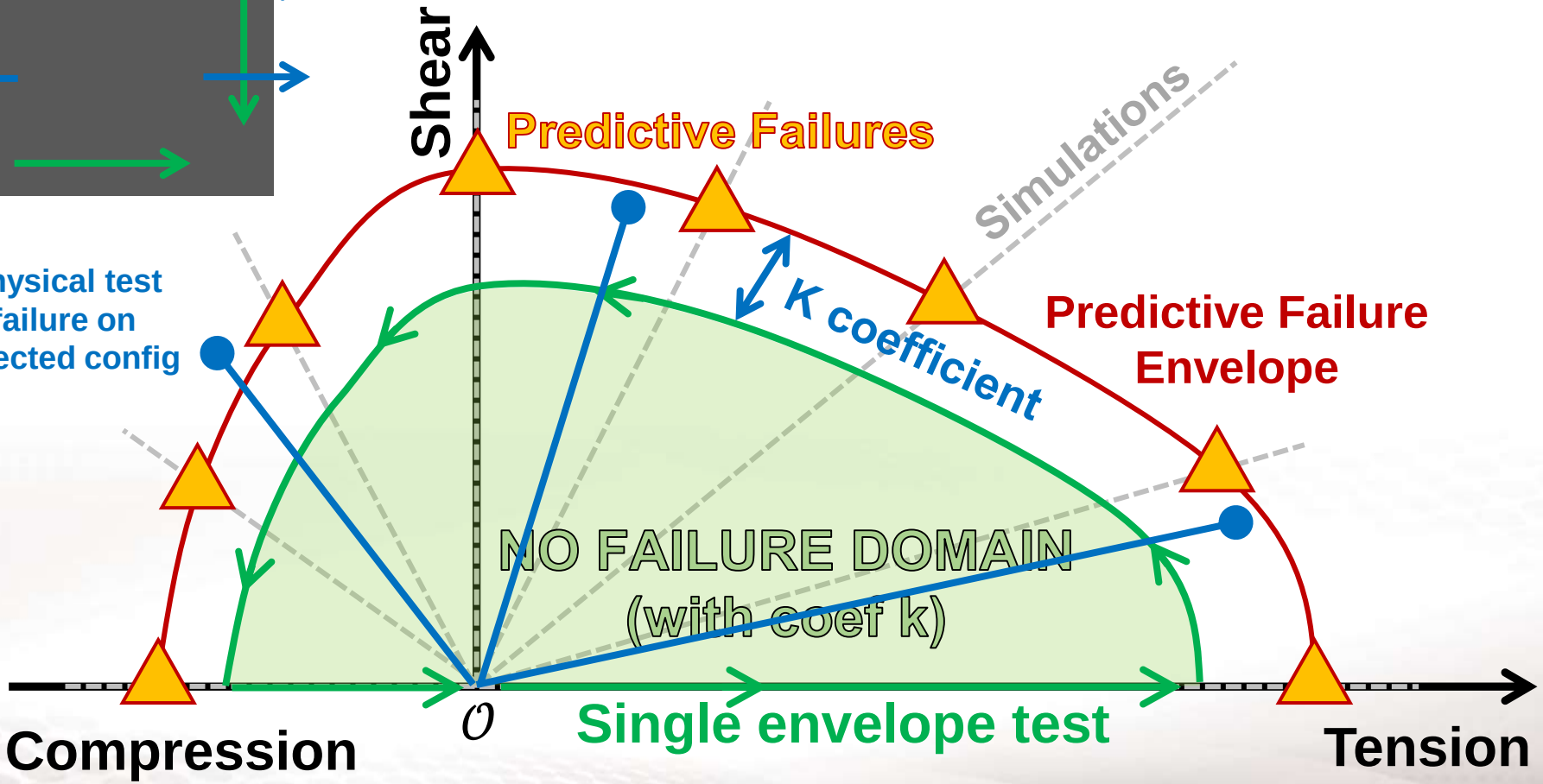


Point-stress criterion to assess first fibre failure
Identified on T_{pres}^{shear}

Envelope Validation method

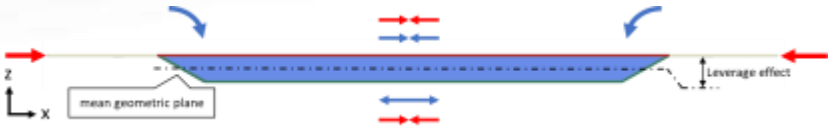
Multi-loading and multi-failure modes at element level



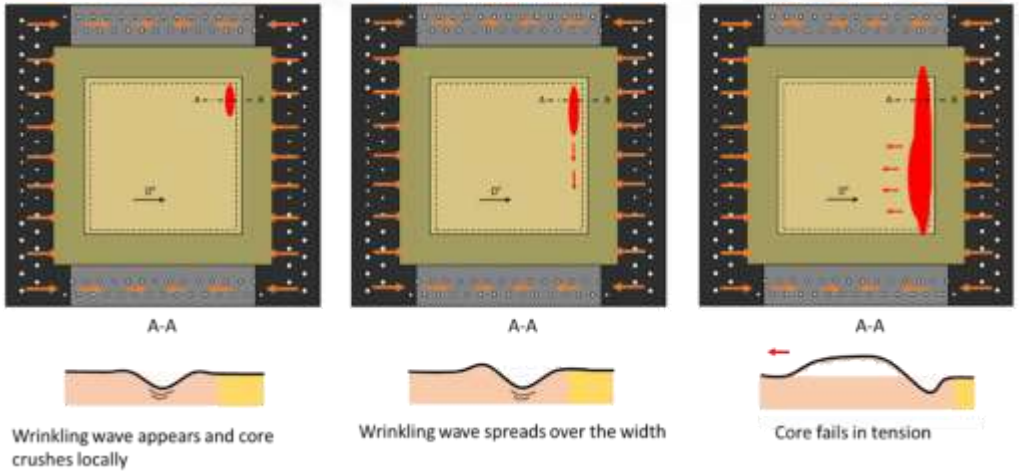


Structures under multiaxial loadings

Sandwich panels (with Elixir Aircraft)



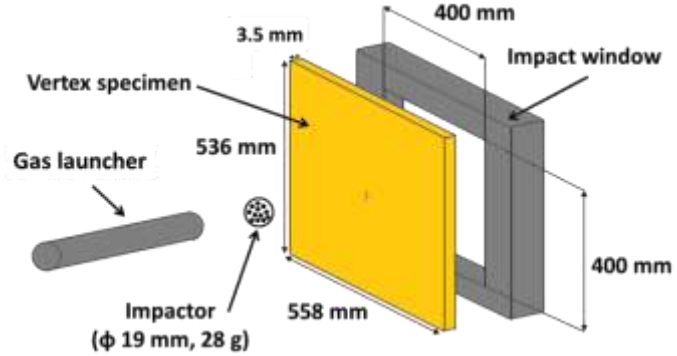
[Ginot 2023a] [Ginot 2023b]

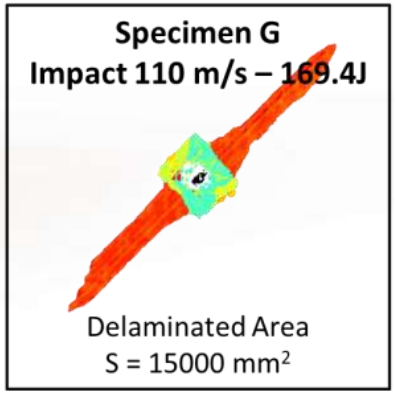


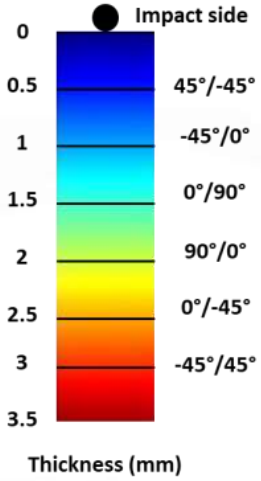
To come Wood-Based Sandwich panels (with Avion Mauboussin)

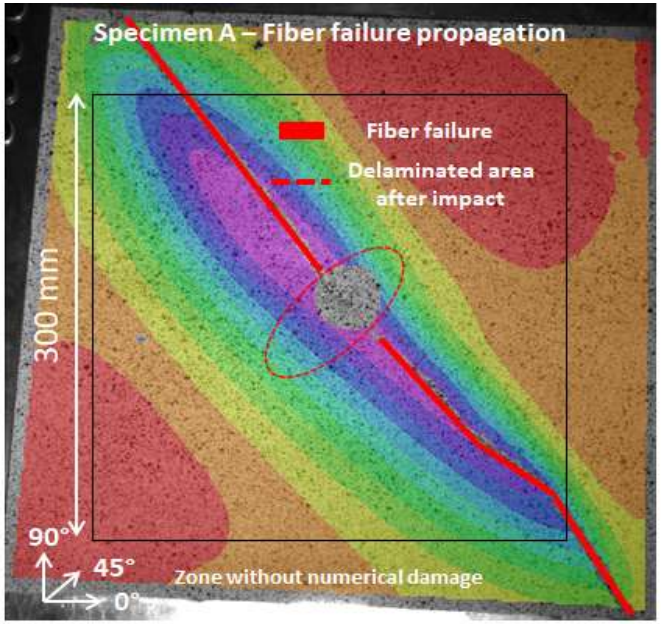
Structures under multiaxial loadings

Impacted panels





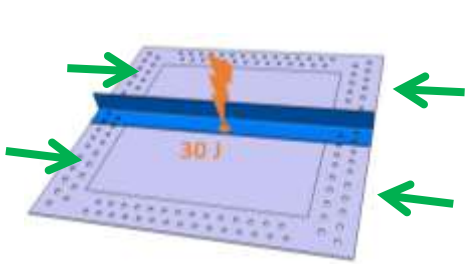


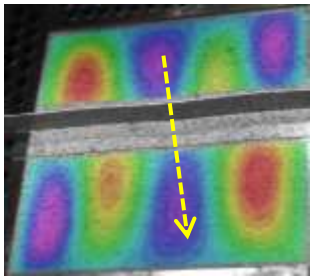


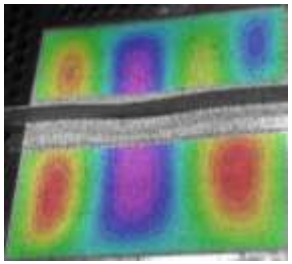
[Trellu 2020] [Trellu 2021]

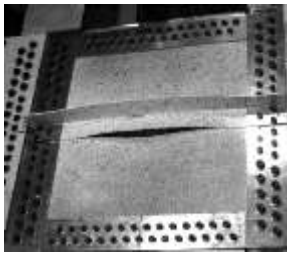
Structures under multiaxial loadings

Impacted stiffened panels



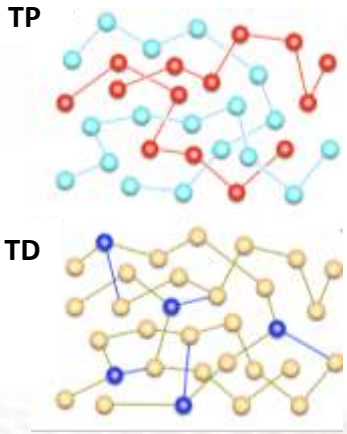


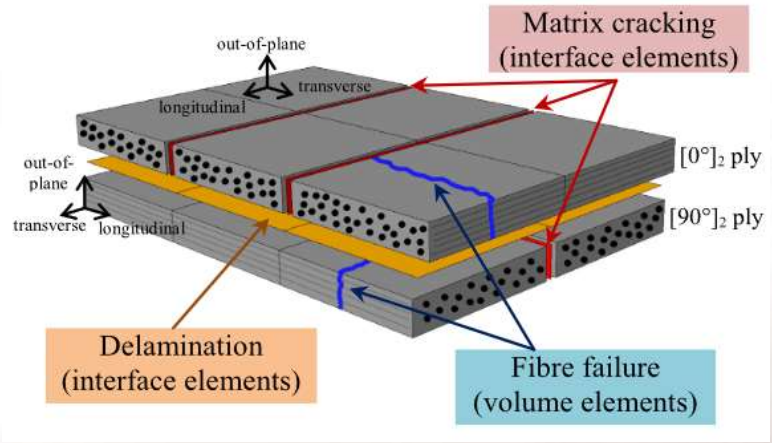




[Grotto 2023]

Notched panels: TP vs. TD (on going)





Conclusions

Moving from Coupon to Intermediate scale testing : the next step

Much complex but much informations at the early stage of design at lower prize

Less conservative (CAI)

Strong links with measurement methods and enhanced test/computation dialog

Teamwork

- Researchers


J. SERRA


C. BOUVET


B. CASTANIE


J-.N. PERIE


J.-C. PASSIEUX

- Research engineers, Phd Student and Research associates


F. GROTTO


R. LALANNE


J-. E. DUFOUR


G. COLANTONIO


Q. BAUSIERE

Some Papers

- *F. Grotto, C. Bouvet, B. Castanié, J. Serra « Design and Testing of Impacted Stiffened CFRP Panels under Compression with the VERTEX Test Rig », **Aerospace**, Vol. 10 (4), **2023***
- *M. Ginot, C. Bouvet, B. Castanié, M. D'Ottavio, J. Serra, N. Mahuet, « Local buckling on large sandwich panels applied to light aviation: Experimental and computation dialogue », **International Journal of Solids and Structures**, doi.org/10.1016/j.ijsolstr.2023.112170, **2023***
- *F. Grotto, C. Bouvet, B. Castanié, J. Serra « Experimental behaviour of aeronautical notched carbon fibre reinforced thermoplastic panels under combined tension-shear-pressure loadings », **Engineering Failure Analysis**, Vol. 146, **2023***
- *J. Serra, A. Trellu, C. Bouvet, S. Rivallant, B. Castanié, L. Ratsifandrihana « Combined loadings after medium velocity impact on large CFRP laminated plates: Discrete ply model simulations », **Composites Part C**, Vol. 6, N° 100203, **2021***
- *A. Trellu, G. Pichon, C. Bouvet, S. Rivallant, B. Castanié, J. Serra, L. Ratsifandrihana « Combined Loadings After Medium Velocity Impact on Large CFRP Laminate Plates: Tests and enhanced computation/testing dialogue », **Composites Science and Technology**, Vol. 196, N° 108194, **2020***
- *Pierré, J.-E. , Passieux, J.-C., Périé, J.-N. Finite Element Stereo Digital Image Correlation: Framework and Mechanical Regularization **Experimental Mechanics,** 57(3), pp. 443–456, **2017***
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Thank you for your attention